



# **Book of Abstracts**



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## MO1BC — Opening Plenary Special, COLLIDER, LAMEAR, HEHAC

### Why Accelerators?

M. S. Turner (University of Chicago)

This talk will highlight the relevance of laboratory based particle accelerators to answer fundamental science questions.

### Status of the Tevatron Run II

V. A. Lebedev (Fermilab)

Steady growth of luminosity has been demonstrated during the entire Tevatron Run II culminating in a record Tevatron performance. During last two years the major contributions came from improvements in antiproton stacking and cooling as well as from numerous improvements in the Tevatron. The talk will describe these improvements as well as other unexpected problems which were encountered and resolved on the road to this success.

### Status of LHC Commissioning

J. Wenninger (CERN)

Beam commissioning of the LHC started with injection tests in August 2008, and a circulating beam was obtained in little over 3 days in September 2008. Unfortunately a powering incident in one the eight LHC sectors set an abrupt end to the beam commissioning in 2008. This talk will review the LHC beam commissioning achievements. It will describe the repair the LHC sector affected by the incident and present the measures that have been taken to avoid similar incidents in the future. The commissioning steps foreseen for the 2009 run and towards LHC design performance will be outlined.

## MO2BC — Plenary Special, LAMEAR, HEHAC

### Probing the Origins of the Cosmos

What do we know about our early (<10 microseconds) universe? A talk on the achievements, goals and future prospects of "big" science for discovery of the origins of our cosmos. The talk should be accessible to a wide audience, and avoid being overly theoretical.

**J. Khoury** (PI)

### Radioactive Beams for Astrophysics

Since the 1980s the nuclear physics community has pursued the development of intense and exotic radioactive ion beams for many areas of study including astrophysics. The myriad of radionuclides that exist fleetingly inside explosive stellar scenarios are involved in nuclear reactions which are extremely difficult to model from theory, and in these cases experimental data is crucial. The measurement problems of astrophysics often require not only the most sensitive detectors and most intense radioactive beams, but also the right combination of experimental facilities, accelerators and detectors. The community has tackled these problems in a variety of different ways, with many labs already active or coming online with new aggressive accelerator, isotope production and measurement technology ready to target the big astrophysics questions. This talk gives an overview of some experimental methods and facilities used to derive astrophysically-relevant nuclear properties and highlights the places in the world that perform these studies.

**A. C. Shotter** (Edinburgh University) **A. C. Shotter** (TRIUMF)

### Status of J-PARC

The Japan Proton Accelerator Research Complex (J-PARC) is a multi-purpose facility making full use of secondary particles like neutrons, muons, Kaons, and neutrinos produced by the MW-class proton accelerators. The J-PARC accelerator scheme inserts a 3-GeV Rapid-Cycling Synchrotron (RCS) in between a 400-MeV injector linac (at present 181 MeV) and a several-ten GeV Main Ring (MR). The RCS has already demonstrated extraction of one pulse of  $2.6 \cdot 10^{13}$  protons at 3 GeV, which corresponds to 315 kW if operated at 25 Hz, with a beam loss less than one percent, and a beam power of 210 kW for a period of 70 sec in September. The beam circulation and RF capture in MR have been done in May. Also, the neutron production target was beam-commissioned, providing high-resolution, high-efficiency neutrons. The RCS users' run and the 30-GeV MR acceleration are planned in December. Rationale for the J-PARC accelerator scheme will be resumed on the basis of the results and difficulties encountered during the development, the construction and the commissioning. The upgrade plan, and, hopefully, some experimental results will be presented.

**Y. Yamazaki** (J-PARC, KEK & JAEA)

## MO3RA — Parallel Oral COLLIDER

### Recent Highlights from KEKB

K. Oide (KEK)

KEKB B-Factory is the world's highest luminosity collider and is the first operating machine with crab cavities used during routine running. The talk will summarize the running experience with KEKB with an update of the performance of the crab crossing system. The upgrade plan, SuperKEKB, will be also reported with improved design of the interaction region to achieve high luminosity with relatively longer bunch length than before.

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### Second-Generation B-Factory Proposals and Lessons from B-Factory Operation

J. Seeman (SLAC)

Second-generation B-Factory proposals are being considered both by KEK in Japan (Super KEKB) and by an INFN Frascati/SLAC/CalTech collaboration in Italy (Super-B). Novel collision schemes like crab waist with crab-sextupoles and also crab cavities are being proposed to mitigate the beam-beam effects of a large crossing angle. The talk will present concepts from both proposals in the context of the experience with the present PEP-II and KEKB B-Factories, which have been successful far beyond the initial performance goals.

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### Construction and Commissioning of BEPCII

C. Zhang, L. Ma, J. Q. Wang (IHEP Beijing)

BEPCII is the upgrade project of Beijing Electron Positron Collider (BEPC). Same as BEPC, BEPCII remains dual purpose machine for both high energy physics experiment and synchrotron radiation light source. As an  $e^+e^-$  collider, BEPCII will operate in the beam energy region of 1-2.1 GeV with design luminosity of  $1 \times 10^{33} \text{cm}^{-2}\text{s}^{-1}$  at 1.89 GeV. The construction of BEPCII started in January 2004 and completed in early November 2006 except the cryogenics of the superconducting insertion magnets (SIM's) in the interaction region (IR). The phase one commissioning of BEPCII storage rings started in Nov. 2006 with conventional magnets in the IR. (SIM). After the SIM's was installed into the interaction region, the second phase of beam commissioning began in Oct. 2007. The luminosity reached to  $1 \times 10^{32} \text{cm}^{-2}\text{s}^{-1}$  with about 1/3 of design beam current. The third phase of beam commissioning started in June 2008 after the detector moved into the on-line position. The maximum luminosity reached to  $2.3 \times 10^{32} \text{cm}^{-2}\text{s}^{-1}$ . The collider has been put in high energy physics operation at psi(2S) since early February 2009. This paper describes the construction and commissioning of BEPCII.

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\* On behalf of the BEPCII Team

### SuperB Project Status and Perspectives

The SuperB project aims at the construction of an asymmetric (4x7 GeV), very high luminosity, B-Factory on the Roma II (Italy) University campus. The luminosity goal of  $10^{36}$   $\text{cm}^{-2} \text{s}^{-1}$  can be reached with a new collision scheme with large Piwinski angle and the use of “crab” sextupoles. A crab-waist IR has been successfully tested at the DAPHNE Phi-Factory at LNF-Frascati (Italy) in 2008. The crab waist together with very low beta\* will allow for operation with relatively low beam currents and reasonable bunch length, comparable to those of PEP-II and KEKB. In the High Energy Ring, two spin rotators permit bringing longitudinally polarized beams into collision at the IP. The lattice has been designed with a very low intrinsic emittance and is quite compact, less than 2 km long. The tight focusing requires a sophisticated Interaction Region with quadrupoles very close to the IP. A Conceptual Design Report was published in March 2007, and beam dynamics and collective effects R&D studies are in progress in order to publish a Technical Design Report by the end of 2010. A status of the design and simulations is presented in this paper.

**M. E. Biagini**, R. Boni, M. Boscolo, T. Demma, A. Drago, S. Guiducci, P. Raimondi, S. Tomassini, M. Zobov (INFN/LNF) K. J. Bertsche, A. Novokhatski, J. Seeman, M. K. Sullivan, U. Wienands, W. Wittmer, G. Yocky (SLAC) S. Bettoni, D. Quattraro (CERN) A. V. Bogomyagkov, I. Koop, E. B. Levichev, S. A. Nikitin, P. A. Piminov, D. N. Shatilov (BINP SB RAS) G. Marchiori (INFN-Pisa) K. Ohmi (KEK) E. Paoloni (University of Pisa and INFN) A. Wolski (Cockcroft Institute)

### Dynamical Beta Effects in the Measurement of Horizontal Beam Sizes

It is well known that the beam-beam interaction has a focusing effect and therefore causes a dynamical beating of beta function around the rings. This effect becomes greatly enhanced when a collider, such as KEKB, is operated near half integer. The beating makes it difficult to interpret the measurement of horizontal beam size. We derived two coupled nonlinear equations and solved them analytically to obtain the beam sizes at the interaction points, taking into account of dynamical beta and emittance. It has been demonstrated its effectiveness using actual measured data at the synchrotron light monitors. It is expected that it will be implemented in the control room.

**K. Ohmi**, J. W. Flanagan, Y. Funakoshi, K. Oide (KEK) Y. Cai (SLAC)

## MO3PB — Parallel Oral LSAFEL

### Possible Upgrade of the Advanced Photon Source with an Energy Recovery Linac

M. Borland (ANL)

The Advanced Photon Source (APS) is a third-generation storage-ring-based x-ray source that has been operating for more than 11 years and is enjoying a long period of stable, reliable operation. While APS is presently providing state-of-the-art performance to its large user community, we must clearly plan for improvements and upgrades to stay at the forefront scientifically. Significant improvements should be possible through upgrades of beamline optics, detectors, and end-station equipment, along with local, evolutionary changes to the storage ring itself. However, major accelerator upgrades are also being investigated. One very promising option that has been the subject of considerable research is the use of an energy recovery linac. In this option, APS would transition from a source based on a stored electron beam to one based on a continuously generated high-brightness electron beam from a linac. Such a source promises dramatically improved brightness and transverse coherence compared to third-generation storage rings, as well as distinctly different temporal properties.

The Advanced Photon Source (APS) is a third-generation storage-ring-based x-ray source that has been operating for more

### Accelerator Physics Challenges for the NSLS-II Project

S. Krinsky (BNL)

The NSLS-II is an ultra-bright synchrotron light source based upon a storage ring with a 30-cell double-bend-achromat lattice with damping wigglers used to lower the emittance below 1 nm. In this talk we discuss the accelerator physics challenges for the design including: optimization of dynamic aperture; estimation of Touschek lifetime; achievement of required orbit stability; and analysis of ring impedance and collective effects.

The NSLS-II is an ultra-bright synchrotron light source based upon a storage ring with a 30-cell double-bend-achromat lattice with

### State of Beam Stability and Control in Synchrotron Light Sources

C. Steier (LBNL)

Beam stability is one of the most important properties for the users of a synchrotron light source. Beam stability includes the stability of orbit, beamsize, current (lifetime), energy, and energy spread. As light sources are generating higher brightnesses, adding fast switching variable polarization devices, and producing smaller source sizes, there is a necessity for continuous improvements in beam stability. In this talk an overview of the state of the art in beam stabilization and remaining challenges for beam stability are presented.

Beam stability is one of the most important properties for the users of a synchrotron light source. Beam stability includes

### Commissioning of the Shanghai Light Source

Z. T. Zhao, H. G. Xu (SINAP)

The Shanghai Synchrotron Radiation Facility (SSRF) is an intermediate energy, third generation light source. In December 2007, electron beam was stored and accumulated in the SSRF storage ring. Since then the accelerator commissioning and beam line installation have continued toward the scheduled user operation from May 2009 onwards. This paper presents an overview of the SSRF status and preparations for user operations.

The Shanghai Synchrotron Radiation Facility (SSRF) is an intermediate energy, third generation light source. In December 2007,



## MO3GR — Parallel Oral LAMEAR

### Operating Experience with the RIKEN Radioactive Isotope Beam Factory

The RIKEN RI Beam Factory (RIBF) is pushing the limits of energy for heavy ion cyclotrons. The first experiment of the RIBF has successfully finished with the discovery of new isotopes  $^{125}\text{Pd}$  and  $^{126}\text{Pd}^*$  in June 2007 with a 345-MeV/nucleon uranium beam. However, the total transmission efficiency was limited to be less than 1%. In addition, a carry-over of oil was found in the refrigerator of the Superconducting Ring Cyclotron (SRC), which was the main accelerator of the RIBF. To solve these problems, we have improved beam monitors, upgraded the oil remover system of the compressor of the liquid helium cryogenic plant at SRC and made a series of acceleration tests. As a result, 0.3 pA of a 345-MeV/nucleon uranium beam was stably delivered to RIBF users in November 2008 and a 345-MeV/nucleon  $^{48}\text{Ca}$  beam with the intensity of 170 pA was obtained in December 2008. In the PAC09 presentation, we will summarize our operating experience with the SRC and developments of RIBF accelerators in addition to most up-to-date performance of the RIBF accelerator complex.

\*T. Ohnishi et al., J. Phys. Soc. Jpn. 77 (2008) 083201

N. Fukunishi, T. Dantsuka, M. K. Fujimaki, A. Goto, H. Hasebe, Y. Higurashi, E. Ikezawa, T. Kageyama, O. Kamigaito, M. Kase, M. Kidera, M. Komiyama, H. Kuboki, K. Kumagai, T. Maie, M. Nagase, T. Nakagawa, J. Ohnishi, H. Okuno, N. S. Sakamoto, Y. Sato, K. Sekiguchi, K. Suda, H. Suzuki, M. Wakasugi, T. Watanabe, Y. Watanabe, K. Yamada, Y. Yano, S. Yokouchi (RIKEN Nishina Center)

MO3GRI01

### Neutron-Rich Beams from $^{252}\text{Cf}$ Fission at ATLAS - The CARIBU Project

Construction of the DOE Californium Rare Ion Breeder Upgrade (CARIBU) for the ATLAS facility is expected to be completed by the end of 2008 and commissioning should be well along by the time of the conference. The facility will use fission fragments from a 1 Ci  $^{252}\text{Cf}$  source, thermalized and collected into a low-energy particle beam by a helium gas catcher, mass analyzed by an isobar separator, and charge breed to higher charge states for acceleration in ATLAS. In addition, unaccelerated beams will be available for trap and laser probe studies. Expected yields of accelerated beams are up to  $\sim 5 \times 10^5$  ( $10^7$  to traps) far-from-stability ions per second on target. The facility design and first results of beam acceleration using a weaker 80 mCi source will be presented in this paper and plans for installation of the 1 Ci source will be discussed.

R. C. Pardo, S. I. Baker, C. N. Davids, D. R. Phillips, G. Savard, R. C. Vondrasek, G. P. Zinkann (ANL)

MO3GRI02

### FRIB: A New Accelerator Facility for the Production of Radioactive Beams

The 2007 Long Range Plan for Nuclear Science had as one of its highest recommendations the "construction of a Facility for Rare Isotope Beams (FRIB) a world-leading facility for the study of nuclear structure, reactions, and astrophysics. Experiments with the new isotopes produced at FRIB will lead to a comprehensive description of nuclei, elucidate the origin of the elements in the cosmos, provide an understanding of matter in the crust of neutron stars, and establish the scientific foundation for innovative applications of nuclear science to society." A heavy-ion driver linac will be used to provide stable beams of  $>200$  MeV/u at beam powers up to 400 kW that will be used to produce rare

R. C. York (NSCL)

MO3GRI03

isotopes. Experiments can be done with rare isotope beams at velocities similar to the driver linac beam, at near zero velocities after stopping in a gas cell, or at intermediate (0.3 to 10 MeV/u) velocities through reacceleration. An overview of the design proposed for implementation on the campus of Michigan State University leveraging the existing infrastructure will be presented.

## High Power RFQs

A. Pisent (INFN/LNL)

The speaker will have expertise in the design, construction and operation of RFQs, both normal and superconducting. This talk

will focus mostly on recent developments in RFQs for high power proton and deuteron beams, for both scientific and diverse purposes (e.g. Radioactive Nuclear Beam facilities, long-term irradiation tests of materials for Thermonuclear Fusion Reactors). The experience of the group at LNL in the field of cw RFQs originates from the realization of the PLAVE RFQ (superconducting 585 keV/u, heavy ion  $A/q < 8.5$ ) and the construction of the TRASCO RFQ (5 MeV, 30 mA protons). More recently within the collaboration between Europe and Japan for the construction of IFMIF-EVEDA in Rokkasho, the group at LNL is in charge of the design and construction of the RFQ (130 mA deuteron, 5 MeV). The physics design and the first construction test results will be ready for the PAC conference in 2009. In the same talk, the design approaches and experimental results of cw RFQs under development (for lower beam power) by other groups in Europe could be reviewed.

## MO4RA — Parallel Oral COLLIDER

### Experience with DAFNE Upgrade Including Crab Waist

In 2007 DAFNE was upgraded to operate in a regime of large Piwinski angle, with a novel IR optics, reduced vertical beta at the

**C. Milardi** (INFN/LNF)

interaction point, and additional sextupoles providing for crab waist collisions. The specific luminosity was boosted by more than a factor of four, and the peak luminosity was more than doubled with respect to the maximum value obtained with the original collider configuration. The DAFNE commissioning as well as the first experience with large Piwinski angle and crab waist collisions scheme will be reported.

MO4RAI01

### Status of LHC Crab Cavity Beam Studies and Simulations

The LHC crab cavity program is advancing rapidly towards a first prototype which is anticipated to be tested during the early stages of the LHC phase I upgrade and commissioning. Some aspects related to crab optics, collimation, aperture constraints, impedances, noise effects, beam transparency and machine protection critical for a safe and robust operation of LHC beams with crab cavities are addressed here.

**R. Calaga**, R. de Maria (BNL) R. W. Assmann, J. Barranco, F. Caspers, E. Ciapala, J.-P. Koutchouk, T. P.R. Linnekar, E. Métral, Y. Sun, R. Tomas, J. Tuckmantel, Th. Weiler, F. Zimmermann (CERN) A. Morita, Y. Morita (KEK) J. Qiang (LBNL)

MO4RAC02

### Optimization of Integrated Luminosity of the Tevatron

We present the strategy which has been used recently to optimize integrated luminosity at the Fermilab Tevatron proton-antiproton collider. We use a relatively simple model where we keep the proton intensity fixed, use parameters from fits to the luminosity decay of recent stores as a function of initial antiproton intensity (stash size), and vary the stash size to optimize the integrated luminosity per week. The model assumes a fixed rate of antiproton production, that a store is terminated as soon as the target stash size for the next store is reached, and that the only downtime is due to store turn-around time. An optimal range of stash size is predicted. Since the start of Tevatron operations based on this procedure we have seen an improvement of approximately 35% in integrated luminosity. Other recent operational improvements have been achieved by decreasing the shot setup time and by reducing beam-beam effects by making the proton and antiproton brightnesses more compatible, for example by scraping protons to smaller emittances.

**C. Gattuso**, M. E. Convery, M. J. Syphers (Fermilab)

MO4RAC03

**First Polarized Proton Collision at a Beam Energy of 250 GeV in RHIC**

M. Bai, L. Ahrens, J. G. Alessi, A. Bazilevsky, J. Beebe-Wang, M. Blaskiewicz, J. M. Brennan, D. Bruno, J. J. Butler, R. Calaga, T. D'Ottavio, K. A. Drees, A. V. Fedotov, W. Fischer, G. Ganetis, C. J. Gardner, J. W. Glenn, H. Hahn, Y. Hao, T. Hayes, H. Huang, P. F. Ingrassia, A. Kayran, J. S. Laster, R. C. Lee, V. Litvinenko, A. U. Luccio, Y. Luo, W. W. MacKay, Y. Makdisi, G. J. Marr, A. Marusic, G. T. McIntyre, R. J. Michnoff, M. G. Minty, C. Montag, J. Morris, P. Oddo, B. Oerter, F. C. Pilat, E. Pozdeyev, V. Ptitsyn, G. Robert-Demolaize, T. Roser, T. Russo, T. Satogata, V. Schoefer, K. Smith, S. Tepikian, D. Trbojevic, N. Tsoupas, J. E. Tuozzolo, M. Wilinski, A. Zaltsman, A. Zelenski, K. Zeno, S. Y. Zhang, R. de Maria (BNL) I. G. Alekseev, D. Svirida (ITEP)

After having provided collisions of polarized protons at a beam energy of 100 GeV since 2001, the Relativistic Heavy Ion Collider (RHIC) at BNL reached its design energy of polarized proton collision at 250 GeV. With the help of the two full Siberian snakes in each ring as well as careful orbit correction and working point control, polarization was preserved during acceleration from injection to 250 GeV. During the course of the Physics data taking, the spin rotators on either side of the experiments of STAR and PHENIX were set up to provide collisions with longitudinal polarization at

both experiments. Various techniques to increase luminosity like further beta star squeeze and RF system upgrades as well as gymnastics to shorten the bunch length at store were also explored during the run. This paper reports the performance of the run as well as the plan for future performance improvement in RHIC.

**Weak-Strong Simulation of Head-On Beam-Beam Compensation in the RHIC**

Y. Luo, N. P. Abreu, J. Beebe-Wang, W. Fischer, C. Montag, G. Robert-Demolaize (BNL) E. McIntosh (CERN)

In the Relativistic Heavy Ion Collider (RHIC) beams collide in the two interaction points IP6 and IP8. An increase of the bunch intensity above  $2 \cdot 10^{11}$  in polarized proton

operation appears difficult due to the large beam-beam tune spread generated by the two collisions. A low energy electron beam or electron lens has been proposed to mitigate the head on beam-beam effect. In RHIC such a device could be located near IP10. We summarize multi-particle weak-strong beam-beam simulations of head-on beam-beam compensation with an electron lens. The proton beam's lifetime and emittance are calculated and compared for situations with and without an electron lens. Parameters such as the proton bunch intensity, the electron beam intensity and the betatron phase advances between IP8 and IP10 are scanned in the simulations.

## MO4PB — Parallel Oral LSAFEL

### Current Status and Future Perspectives of Energy Recovery Linacs

Energy Recovery Linacs (ERL) have been successfully operated in three high-power FEL facilities, Jefferson Laboratory (JLAB)

**R. Hajima** (JAEA/ERL)

IR FEL Upgrade, Japan Atomic Energy Agency (JAEA) FEL and Budker Institute of Nuclear Physics (BINP) THz FEL. The ERLs are now considered a promising candidate for uses as high-power FELs, synchrotron radiation sources, electron cooling devices, electron-ion colliders and Compton X/gamma-ray sources. All these applications are based on the excellent feature of the ERL that is simultaneous attainment of multiple beam parameters: small emittance, short bunch duration and high-average current. In order to overcome technological challenges and realize the above future ERL applications, several R&D efforts have been launched in the world. In this paper, we overview the current status of these R&D programs and envision the future of ERLs.

### Commissioning Results with Multi-Pass ERL

The first stage of Novosibirsk high power free electron laser (FEL) is in operation since 2003. Now the FEL provides average power up to 500 W in the wavelength range 120 - 240 micron. One orbit for 11-MeV energy with terahertz FEL lies in vertical plane. Other four orbits lie in the horizontal plane. The beam is directed to these orbits

**N. Vinokurov**, E. N. Dementyev, B. A. Dovzhenko, N. Gavrilov, B. A. Knyazev, E. I. Kolobanov, V. V. Kubarev, G. N. Kulipanov, A. N. Matveenko, L. E. Medvedev, S. V. Miginsky, L. A. Mironenko, V. K. Ovchar, V. M. Popik, T. V. Salikova, M. A. Scheglov, S. S. Serebnyakov, O. A. Shevchenko, A. N. Skrinisky, V. G. Tcheskidov, Y. Tokarev, P. Vobly (BINP SB RAS)

by switching on of two round magnets. In this case electrons pass four times through accelerating RF cavities, obtaining 40-MeV energy. Then, (at fourth orbit) the beam is used in FEL, and then is decelerated four times. At the second orbit (20 MeV) we have bypass with third FEL. When magnets of bypass are switched on, the beam passes through this FEL. The length of bypass is chosen to provide the delay, which necessary to have deceleration instead of acceleration at the third passage through accelerating cavities. Now two of four horizontal orbits are assembled and commissioned. The electron beam was accelerated twice and then decelerated down to low injection energy. Project average current 9 mA was achieved. First multi-orbit ERL operation was demonstrated successfully.

### Developments for Cornell's X-Ray ERL

Cornell University is planning to build an Energy-Recovery Linac (ERL) X-ray facility. In this ERL design, a 5 GeV superconducting linear accelerator extends the CESR ring which is currently used for the Cornell High Energy Synchrotron Source (CHESS). Here we describe some of the recent developments for this ERL, including linear and nonlinear optics, tracking studies, vacuum system design, gas and intra beam scattering computations, and collimator and radiation shielding calculations

**J. A. Crittenden**, I. V. Bazarov, S. A. Belomestnykh, M. G. Billing, E. P. Chojnacki, B. M. Dunham, M. P. Ehrlichman, M. J. Forster, G. H. Hoffstaetter, Y. Li, M. Liepe, C. E. Mayes, A. A. Mikhailichenko, H. Padamsee, S. B. Peck, D. Sagan, V. D. Shemelin, A. B. Temnykh, M. Tigner, V. Veshcherevich (CLASSE) D. H. Bilderback, J. D. Brock, S. M. Gruner (CHESS) C. Johnstone (Fermilab)

based on this optics, undulator developments, optimization of X-ray beams by electron beam manipulation, technical design of ERL cavities and cryomodules, and preparation of the accelerator site.

### The Wisconsin Free Electron Laser Initiative

**K. Jacobs**, J. Bisognano, M. Bissen, R. A. Bosch, M. A. Green, H. Hoehst, K. J. Kleman, R. A. Legg, R. Reininger, R. Wehlitz (UW-Madison/SRC) W. Graves, F. X. Kaertner, D. E. Moncton (MIT)

The University of Wisconsin-Madison/Synchrotron Radiation Center and MIT are developing a design for a seeded VUV/soft X-ray Free Electron Laser serving multiple simultaneous users. The present design uses

an L-band CW superconducting 2.2 GeV electron linac to deliver 200 pC bunches to multiple FELs operating at repetition rates from kHz to MHz. The FEL output will be fully coherent both longitudinally and transversely, with tunable pulse energy, cover the 5-900 eV photon range, and have variable polarization. We have proposed a program of R&D to address the most critical aspects of the project. The five components of the R&D program are:

1. Prototyping of a CW superconducting RF photoinjector operating in the self-inflating bunch mode.
2. Development of conventional laser systems for MHz seeding of the FEL, and femtosecond timing and synchronization.
3. Address thermal distortion and surface contamination issues on the photon optics.
4. Investigate advanced undulator concepts to help reduce facility cost and/or extend performance.
5. Perform detailed modeling of all aspects of the FEL, as part of production of a Conceptual Design Report for the FEL facility.

## MO4GR — Parallel Oral ACCTECH

### High Power Fast Ramping Power Supplies

Hundred megawatt level fast ramping power converters to drive proton and heavy ion machines are under research and development at accelerator facilities in the world.

This is a leading edge technology. There are several topologies to achieve this power level. Their advantages and related issues will be discussed.

**I. Marnieris**, E. M. Bajon, R. Bonati, T. Roser, J. Sandberg, N. Tsoupas (BNL)

MO4GRI01

### Developments in Solid-State Modulator Technology towards High Availability

Solid-state based high-power modulators utilize new technology, yet must meet the operational needs of a high reliability facility.

This modulator technology is in use at SNS, and is under consideration and development for future machines, such as the ILC and PEPF. Through operational experience and a sustained development effort, a number of improvements have been deployed in the SNS modulator system to meet the high availability demands of operating facilities. The operating experience and development effort of the world-wide community will also be reviewed.

**D. E. Anderson** (ORNL)

MO4GRI02

### Laser Systems for Next Generation Light Sources

Particle accelerator and laser technologies are effectively combining with each other in the development of next generation light sources, with the latter being one of the key

factors determining the ultimate performance of these machines. VUV and X-FEL facilities take advantage of laser technology at many strategic points: creation of the electron bunch (photo-injector laser), acceleration (laser heater), undulators (seed laser), beam diagnostics (electro-optic sampling lasers), user experiments (pump-probe lasers). The talk will discuss the main requirements and challenges (photoinjector and seed lasers in particular) for the laser systems and will illustrate proposed solutions and obtained results. Recent laser achievements that are likely to have impact on important developments like high average power injectors, different guns, tunable short wavelength FEL seeding will also be addressed.

**M. B. Danailov**, A. A. Demidovich, R. Ivanov, Yu. V. Loiko, I. Nikolov, P. Sigalotti (ELETTRA)

MO4GRI03

## TU1RA — Parallel Oral MAGNET

### Special Magnet Designs and Requirements for Next Generation Light Sources

R. C. Gupta, A. K. Jain, M. Rehak, J. Skaritka, C. J. Spataro, F. J. Willeke (BNL)

This paper will describe the requirements, the design and the prototype test results of the magnets for the new synchrotron radiation source NSLS-II now under construction

at BNL. Several innovations have been incorporated in the design, in manufacturing and in the alignment procedures of the magnets. Prototypes of these magnets have been built in industry. A dipole design has been developed with a maximized magnetic length which is longer than the mechanical length. The quadrupole and sextupole magnets of NSLS-II must be aligned and positioned to better than 30 microns, a level never achieved before in such accelerators. The paper will present a brief status of the progress made in the techniques developed to measure and achieve these demanding requirements. Another concern has been the distortion of field quality due to the small (150 mm) axial spacing between the iron-yoke of two adjacent magnets. Calculations (in 3-D) and the result of systematic measurements of the field quality in the presence of other magnets and other machine components in close proximity will be presented.

### Non-Scaling FFAG Magnet Design Challenges

N. Marks (STFC/DL/ASTeC)

The latest initiatives to design and build non-scaling FFAGs have encountered novel technical challenges; the required DC combined function magnets (normal and superconducting) and fast pulsed magnets for injection and extraction present new problems. The talk will report on progress in meeting these challenges for the non-scaling machines, EMMA and PAMELA and will provide details of their current design status. With the main EMMA ring magnets now being delivered and the injection and extraction magnets being assembled in-house, practical engineering features of these systems will be presented.

### Performance of the LHC Magnet System

L. Rossi (CERN)

The LHC magnet system has been largely commissioned in 2007-08: all sectors up to 7 kA (4 TeV proton beam energy); six (out

of eight) sectors were commissioned up 9.3 kA (5.5 TeV) and one to 11.5 kA (6.9 TeV). For more than one week, both beams have been injected, circulated and captured in the RF bucket, thus assessing the optics at injection energy. The incident in sector 3-4, originated by a serious defect of a high-current joint between magnets with large collateral damage, has changed the plans: magnets in the damaged zone (about 50) are being substituted or repaired meanwhile a campaign of consolidation is under way. During commissioning, the training of the main dipoles was longer than expected on the basis of reception tests of individual magnets, thus pointing to a partial loss of quench memory. The thermal performance is within heat losses estimates and the spectacular easiness of the first injection test on 10th September has demonstrated the very good field quality, precise understanding of magnetic characteristics, quality of the elaborate field modeling and the very good shape of the magnets with proper alignment of the machine.



**Nb3Sn Magnets for the LHC Upgrade**

Insertion quadrupoles with large aperture and high gradient are required to achieve the luminosity upgrade goal of  $10^{35} \text{ cm}^{-2} \text{ s}^{-1}$

G. L. Sabbi (LBNL)

at the Large Hadron Collider (LHC). In 2004, the US Department of Energy established the LHC Accelerator Research Program (LARP) to develop a technology base for the upgrade. The focus of the magnet program, which is a collaboration of three US laboratories, BNL, FNAL and LBNL, is on development of high gradient quadrupoles using Nb3Sn in order to operate at high field and with sufficient temperature margin. Program components address technology issues regarding coil and structure fabrication, quench performance, field quality and alignment, length scale-up, quench protection, radiation hardness, conductor and cable. This paper reports the current status of model quadrupole development and outlines the long-term goals of the program.

## TU1PB — Parallel Oral BDEMF

### Fully 3D Multiple Beam Dynamics Processes Simulation for the Tevatron

E. G. Stern, J. F. Amundson, P. Spentzouris, A. Valishev (Fermilab)

Extensive work has been done to create an accurate model of beam dynamics at the Fermilab Tevatron. This talk will present validation and results from the development of a simulation of the machine including multiple beam dynamics effects. The essential features of the simulation include a fully 3D strong-strong beam-beam particle-in-cell Poisson solver, interactions among multiple bunches and both head-on and long-range beam-beam collisions, coupled linear optics and helical trajectory consistent with beam orbit measurements, chromaticity and resistive wall impedance. The individual physical processes are validated against measured data where possible, and analytic calculations elsewhere. The simulation result discussion will focus on the effects of increasing beam intensity with single and multiple bunches on the impedance of the beams.

### Simulating Electron-Ion Dynamics in Relativistic Electron Coolers

D. L. Bruhwiler (Tech-X)

Novel electron-ion collider (EIC) concepts are a high priority for the long-term plans of the international nuclear physics community. Orders of magnitude higher luminosity will be required for the relativistic ion beams in such accelerators. Electron cooling is a promising approach to achieve the necessary luminosity. The coherent electron cooling (CEC) concept proposes to combine the best features of electron cooling and stochastic cooling, via free-electron laser technology, to cool high-energy hadron beams on orders-of-magnitude shorter time scales\*. In a standard electron cooler, the key physical process is dynamical friction on the ions. The modulator section of a coherent cooler would be very similar to a standard cooler, but in this case dynamical friction becomes irrelevant and the key physics is the shape of the density wake imprinted on the electron distribution by each ion. We will present results using the massively parallel VORPAL framework for both particle-in-cell (PIC) and molecular dynamics (MD) simulations of electron-ion collisions in relativistic coolers and CEC modulators.

\* V. N. Litvinenko, I. Ben-Zvi, M. Blaskiewicz, Y. Hao, D. Kayran, E. Pozdeyev, G. Wang, G. I. Bell, D. L. Bruhwiler, A. V. Sobol et al., FEL Conf. Proc. (2008), in press.

### A Vlasov-Maxwell Solver to Study Microbunching Instability in the FERMI@Elettra First Bunch Compressor System

G. Bassi (Cockcroft Institute) G. Bassi (The University of Liverpool) J. A. Ellison, K. A. Heinemann (UNM) R. L. Warnock (SLAC)

Microbunching can cause an instability which degrades beam quality. This is a major concern for free electron lasers where very bright electron beams are required. A basic theoretical framework for understanding this instability is the 3D Vlasov-Maxwell system. However, the numerical integration of this system is computationally intensive. Investigations to date have used simplified analytical models or numerical solvers based on simple 1D models. We have developed an accurate and reliable 2D Vlasov-Maxwell solver which we believe improves existing codes. This solver has been successfully tested against the Zeuthen benchmark bunch compressors. Here we apply our self-consistent, parallel solver to study the microbunching instability in the first bunch compressor system of FERMI@Elettra.

## Application of the Reduction of Scale Range in a Lorentz Boosted Frame to the Numerical Simulation of Particle Acceleration Devices

It has been shown\* that the ratio of longest to shortest space and time scales of a system of two or more components crossing at rel-

J.-L. Vay (LBNL)

ativistic velocities is not invariant under Lorentz transformation. This implies the existence of a frame of reference minimizing an aggregate measure of the ratio of space and time scales. It was demonstrated that this translated into a reduction by orders of magnitude in computer simulation run times, using methods based on first principles (e.g., Particle-In-Cell), for particle acceleration devices and for problems such as: free electron laser, laser-plasma accelerator, and particle beams interacting with electron clouds. Since then, speed-ups ranging from 75 to more than four orders of magnitude have been reported for the simulation of either scaled or reduced models of the above-cited problems. In \*\* it was shown that to achieve full benefits of the calculation in a boosted frame, some of the standard numerical techniques needed to be revised. The theory behind the speed-up of numerical simulation in a boosted frame, latest developments of numerical methods, and example applications with new opportunities that they offer are all presented.

\* J.-L. Vay, Phys. Rev. Lett. 98, 130405 (2007).

\*\*J.-L. Vay, Phys. of Plasmas 14, 1 (2008).

## TU1GR — Parallel Oral LEAC

TU1GRI01

### Road to a Plasma Wakefield Accelerator Based Linear Collider

M. J. Hogan, I. Blumenfeld, N. A. Kirby, S. Pei, T. O. Raubenheimer, A. Seryi, P. Tenenbaum (SLAC) C. Huang, C. Joshi, W. Lu, W. B. Mori (UCLA) T. C. Katsouleas (Duke University) P. Muggli (USC)

Recent progress in generating gradients in the 10's of GV/m range with beam driven plasmas has renewed interest in developing a linear collider based on this technology. This talk will explore possible configurations of such a machine, discuss the key

demonstrations and the facilities needed to advance this effort and highlight possible alternative uses of this technology.

TU1GRI02

### R&D toward a Neutrino Factory and Muon Collider

M. S. Zisman (LBNL)

Review experimental results from MU-COOL, MICE and MERIT and discuss the extent to which they provide proof of principle

demonstrations of the key technologies required for a neutrino factory or muon collider. Also discuss progress in constructing MICE, including the coupling coils and cavities, and the future tests planned at MUCOOL.

TU1GRI03

### Progress toward a Muon Collider

R. B. Palmer (BNL)

In the past few years, there have been a number of advances in the design and supporting R&D for a machine to cool, accelerate and collide TeV muon beams. This talk will review progress and discuss how such a machine might evolve from programs to build high intensity proton sources and neutrino factories.

TU1GRC04

### FFAG Designs for the International Design Study for the Neutrino Factory

J. S. Berg (BNL) S. Machida (STFC/RAL/ASTeC)

The International Design Study for the Neutrino Factory (IDS-NF) aims to produce a design report for a neutrino factory. One

component of that design is a linear non-scaling fixed-field alternating gradient accelerator (FFAG) that will accelerate to the final energy of 25 GeV. An FFAG is used to reduce the machine cost by maximizing the number of passes made through the rf cavities. We present some design options for this FFAG, individually optimized for cost (including a "cost" for lost muons). We compute the optimal beam distribution for these FFAGs, and show how that distribution evolves under tracking.

**Muon Capture and Bunching in the International Design Study for a Neutrino Factory**

We have developed a new method for capture, bunching and phase-energy rotation of secondary beams from a proton source, using high-frequency rf systems. The method is the baseline for muon capture in the International scoping study for a neutrino factory. In this method, a proton bunch on a target creates secondaries that drift into a capture transport channel. A sequence of rf cavities forms the resulting muon beams into strings of bunches of differing energies, aligns the bunches to (nearly) equal central energies, and initiates ionization cooling. For the International Design Study the method must be optimized for performance and cost, and variations will be explored. In this paper we present results of optimization and variation studies toward obtaining the maximum number of muons for a neutrino factory, as well as for a future muon collider.

**D. V. Neuffer** (Fermilab) C. Y. Yoshikawa (Muons, Inc)

## TU2RA — Parallel Oral APAC

### Development of the IFMIF/EVEDA Accelerator

A. Mosnier (CEA)

With the aim of producing an intense flux of 14 MeV neutrons, the International Fusion Materials Irradiation Facility (IFMIF) relies on two high power CW accelerator drivers, each delivering a 125 mA deuteron beam at 40 MeV to a common lithium target. The Engineering Validation and Engineering Design Activities (EVEDA) phase of IFMIF, which has been launched in the middle of 2007, has two major objectives: to produce the detailed design of the entire IFMIF facility and to build and test the key systems, in particular the prototype of a high-intensity CW deuteron accelerator (125 mA @ 9 MeV). The design of the IFMIF accelerator, as well as the design of the prototype to be installed in Rokkasho (Japan) are presented.

### Accelerator R&D for the European ADS Demonstrator

J.-L. Biarrotte, F. Bouly, T. Junquera, A. C. Mueller (IPN) S. Barbanotti, P. Pierini (INFN/LASA) R. Gobin, M. Luong, D. Uriot (CEA) H. Klein, H. Podlech (IAP)

An Accelerator Driven System (ADS) for transmutation of nuclear waste typically requires a 600 MeV - 1 GeV accelerator delivering a proton flux of a few mA for demonstrators, and a few tens of mA for large industrial systems. Such a machine belongs to the category of the high-power proton accelerators, with an additional requirement for exceptional "reliability": because of the induced thermal stress to the subcritical core, the number of unwanted "beam-trips" should not exceed a few per year, a specification that is far above usual performance. This paper describes the reference solution adopted for such a machine, based on a so-called "fault-tolerant" linear superconducting accelerator, and presents the status of the associated R&D. This work is performed within the 6th Framework Program EC project "EUROTRANS".

## TU2PB — Parallel Oral BDEMF

### Space-Charge Simulations of Non-Scaling FFAGs Using PTC

Non-scaling FFAGs are sensitive to a slew of resonances during the acceleration ramp. An important consideration - because it affects the amount of rf power required - will

be the speed at which resonances must be crossed. We present simulations of possible non-scaling FFAGs, focusing especially on the effects of space charge, using newly developed capabilities in the code PTC\*.

\* E. Forest, Y. Nogiwa, F. Schmidt, "The FPP and PTC Libraries", ICAP'2006.

D. T. Abell, G. I. Bell, A. V. Sobol (Tech-X) E. Forest (KEK) A. G. Ruggiero, D. Trbojevic (BNL)

TU2PBC01

### Recent Improvements to CHEF, A Framework for Accelerator Computations

CHEF is body of software dedicated to accelerator beam dynamics and optics computations. It consists in a hierarchical set of libraries and a standalone application based on the latter. The code makes extensive use of templates and modern idioms such as smart pointers and generalized function objects. CHEF has been described in contributions at past conferences. In this paper, we document and discuss the implementation of recent improvements including:

1. use of embedded SQL database technology to store, organize and retrieve lattice function data,  
 2. a general approach to "knobs" based on generalized function objects,  
 3. an improved architecture to support runtime plug-in propagation physics,  
 4. a basic space-charge kick element,  
 5. a facility to record particle loss on aperture boundaries and  
 6. support for the MADX input format.

J.-F. Ostiguy, L. Michelotti (Fermilab)

TU2PBC02

### Theory and Applications of Lattice with Negative Momentum Compaction Factor

A possible solution to avoid the transition energy crossing is the lattice with a negative momentum compaction factor. The developed lattice is based on the resonantly correlated curvature and gradient modulations in arcs with integer tunes in horizontal or both planes, and it called the "resonant" lattice\*. This method was adopted for the TRIUMF and Moscow Kaon Factories. It was then applied in the SSC Low Energy Booster, the CERN Neutrino Factory, and in the Main Ring of the Japan Proton Accelerator Research Complex facility. For the superconducting option of High Energy Storage Ring lattice of the FAIR project, the same idea was also accepted, and at last it is one of the candidates for PS2 in CERN as well. Due to special features the idea of "resonant" lattice can be applied for the lattice with the stochastic cooling where the different arcs have the different mixing factors with conservation of the dynamic aperture for whole machine. The "resonant" lattice is appeared to be useful for electron machines where the minimum momentum-compaction factor and the minimum modulation of the dispersion function are both required simultaneously to have a small horizontal emittance.

\*Yu. Senichev and A. Chechenin, Journal of Experimental and Theoretical Physics, 2007, v. 105, No. 6, p. 1141

Y. Senichev (FZJ)

TU2PBC03

**Transport of Ultra-Short Electron Bunches in a Free-Electron Laser Driven by a Laser-Plasma Wakefield Accelerator**

M. P. Anania, R. C. Issac, D. A. Jaroszynski, A. J. W. Reitsma, S. M. Wiggins (USTRAT/SUPA) M. J. de Loos, S. B. van der Geer (Pulsar Physics)

The Advanced Laser-Plasma High-Energy Accelerators towards X-rays (ALPHA-X) programme\* is developing laser-plasma accelerators for the production of ultra-short electron bunches as drivers of incoherent

and coherent radiation sources from plasma and magnetic undulators. Focusing of ultra-short electron bunches from a laser-plasma wakefield accelerator into an undulator requires that particular attention be paid to the electron beam quality. We will discuss the design and implementation of an upgraded focusing system for the ALPHA-X beam line, which currently consists of a triplet of electromagnet quadrupoles. The upgrade will comprise the installation of additional compact permanent quadrupoles\*\* very close to the accelerator exit. This will improve the matching of the beam into the undulator. The design has been carried out using the General Particle Tracer (GPT) code\*\*\* and TRANSPORT code, which consider space charge effects and allow a realistic estimate of electron beam properties inside the undulator to be obtained. We will present a study of the influence of beam transport on free-electron laser action in the undulator, paying particular attention to bunch dispersion.

\* D. Jaroszynski et al., *Phil. Trans. R. Soc. A* 364, 689-710 (2006)

\*\* T. Eichner et al., *Phys. Rev. ST Accel. Beams* 10, 082401 (2007)

\*\*\* S. B. Geer, M. J. Loos, Ph. D. thesis, TU/e, Eindhoven (2001)



## TU2GR — Parallel Oral SAI

### Initial Beam Results from the Cornell High-Current ERL Injector Prototype

Cornell University has built a high average current electron injector for use with an Energy Recovery Linac. The injector is capable of up to 100 mA average current at 5 MeV (33 mA at 15 MeV) and is expected to produce the ultra low emittances needed for an ERL. This talk will give an overview of the initial performance of this injector and summarize a spectrum of beam physics experiments undertaken to demonstrate low emittance, high average current operation.

**I. V. Bazarov** (CLASSE)

TU2GRI01

### Femtosecond Photocathode Electron Gun for Time-Resolved Electron Diffraction

Ultrafast time-resolved electron diffraction based on a photocathode rf electron gun is being developed in Osaka University to reveal the hidden dynamics of intricate molecular and atomic processes in materials. The photocathode rf gun generates a femtosecond-bunch electron beam by femtosecond laser driving. The transverse emittance, bunch length and energy spread were measured. The growths of the emittance, bunch length and energy spread due to the rf and the space charge effects in the rf gun were investigated by changing the laser injection phase, the laser pulse width and the bunch charge. The demonstration of the electron diffraction measurement will be reported.

**J. Yang**, K. Kan, T. Kondoh, K. Tanimura, Y. Yoshida (ISIR) J. Urakawa (KEK)

TU2GRC02

### First Observation of an Electron Beam Emitted from a Diamond Amplified Photocathode

Electron beam emission from a Diamond Amplified Photocathode (DAP) was observed for the first time on a phosphor screen. The DAP is a device based on the generation of a large number of electron-hole pair in diamond and the emission of the electrons through a negative-affinity face of the diamond generated by hydrogenation. This achievement follows new understanding of the hydrogenated surface of the diamond. The gain of the primary electron and the current density were measured. The DAP was demonstrated to be very robust.

**X. Chang**, I. Ben-Zvi, A. Burrill, J. Kewisch, T. Rao, J. Smedley, Y. C. Wang, Q. Wu (BNL)

TU2GRC03

## TU3RA — Parallel Oral RFSYS

TU3RAI01

### SRF Experience with the Cornell High-Current ERL Injector Prototype

M. Liepe (Cornell University) S. A. Belomestnykh, E. P. Chojnacki, Z. A. Conway, V. Medjidzade, H. Padamsee, P. Quigley, J. Sears, V. D. Shemelin, V. Veshcherevich (CLASSE)

Cornell University has developed and fabricated a SRF injector cryomodule for the acceleration of the high current (100 mA) beam in the Cornell ERL injector prototype.

The injector cryomodule is based on superconducting rf technology with five 2-cell rf cavities operated in cw mode. To support the acceleration of a low energy, ultra low emittance, high current beam, the beam tubes on one side of the cavities have been enlarged to propagate Higher-Order-Mode power from the cavities to broadband rf absorbers located at 80 K between the cavities. The axial symmetry of these absorbers, together with two symmetrically placed input couplers per cavity, avoids transverse on-axis fields, which would cause emittance growth. Each cavity is surrounded by a LHe vessel and equipped with a frequency tuner including fast piezo-driven fine tuners for fast frequency control. The cryomodule provides the support and precise alignment for the cavity string, the 80 K cooling of the ferrite loads, and the 2 K LHe cryogenic system for the high cw heat load of the cavities. In this paper results of the commissioning phase of this injector cryomodule will be reported.

TU3RAI02

### Recent Developments in Low and Medium Beta SRF Cavities

M. P. Kelly (ANL)

Several high power proton and ion linac projects based on superconducting accelerating technology are currently under study

and drive an important worldwide R&D effort on superconducting cavities, especially for low and medium energy linacs. Multi-cell elliptical cavities, single or multi-spoke cavities, half-wave and quarter-wave superconducting cavities have been developed at many laboratories and institutions and continue to extend the state-of-the-art for this class of cavities. This talk reviews recent developments and results for SC cavity performance along with a brief overview of associated components such as mechanical slow tuning systems, fast tuners and rf power couplers.

TU3RAI03

### Progress on Improving SC Cavity Performance for ILC

R. L. Geng (JLAB)

A major portion of the ILC R&D effort is focused on increasing the sustainable gradients in the baseline TESLA-shape SC cavities.

This is a world-wide effort with major contributions from DESY (in parallel with their XFEL program), JLAB, FNAL and KEK. During the past year, the work in the US and Japan has ramped up considerably, and PAC09 is an opportune time to review the contributions from the groups in these regions, as well as at DESY.

**Cryomodule Tests of Four Tesla-like Cavities in the STF Phas-10<sup>-1.0</sup> for ILC**

A 6-m cryomodule, which includes four Tesla-like 9-cell cavities, was assembled and installed in the STF tunnel in April, 2008. After cooldown of the cryomodule, high power tests of four cavities had been carried out at 2 K from September to December, 2008. A cavity package consists of a 9-cell niobium cavity with two HOM couplers, an input coupler with a cold and a warm rf window, and a frequency tuning system with a mechanical and a piezo tuner. The performance as a total sc cavity system was checked in the cryomodule test with high rf power. One of the cavities was achieved a stable pulsed operation at 32 MV/m higher than the specific operating gradient (31.5 MV/m) in ILC. The maximum accelerating gradients (E<sub>acc,max</sub>) obtained in the vertical cw tests was maintained or slightly improved in the cryomodule tests with a pulsed operation of 1.5 msec and 5 Hz. Compensation of Lorentz force detuning at 31 MV/m was successfully demonstrated by using piezo tuner and pre-detuning.

E. Kako, H. Hayano, S. Noguchi, N. Ohuchi, M. Satoh, T. Shishido, K. Watanabe, Y. Yamamoto (KEK)

## TU3PB — Parallel Oral BDEMF

### Beam Dynamics and Low Loss Operation of the J-PARC Main Ring

A. Y. Molodozhentsev (J-PARC, KEK & JAEA)

For operation of the JPARC Main Ring, low loss of the high-intensity bunches during the injection and acceleration processes is crucial to avoid radiation damage of the machine. This requires identification and correction the most dangerous resonances, which should be done in combination with the collective effects, in particular, the low energy space charge effects. In frame of this talk we review the status of the Main Ring commissioning process and compare it with the simulation results for the low intensity beam. For the future operation of the Main Ring with the moderate beam power we review the status of the simulation work and discuss the budget of the beam losses.

### Linac Code Benchmarking with High-Intensity Experiments at UNILAC

L. Groening, W. Barth, W. B. Bayer, G. Clemente, L. A. Dahl, P. Forck, P. Gerhard, I. Hofmann, M. Kaiser, M. T. Maier, S. Mickat, T. Milosic, H. Vormann, S. Yaramyshev (GSI) D.-O. Jeon (ORNL) R. Tiede (IAP) D. Uriot (CEA)

Beam dynamics experiments with high intensity beams have been conducted at the GSI UNILAC in 2006-2008 with the goal of benchmarking four major simulation codes, i.e. DYNAMION, PARMILA, TraceWin/PARTRAN and LORASR with respect to transverse emittance growth along a DTL. The experiments comprised measurements of transverse phase space distributions in front of as well as behind the DTL. Additional longitudinal bunch length measurements at the DTL entrance allowed for estimate and control of mismatch in all three planes. Measured effects of mismatch and of theoretically predicted space charge resonances (equipartitioning and others) are compared with simulations for a wide range of transverse phase advance along the DTL. This contribution is the first report on the successful measurement of a space charge driven fourth order resonance in a linear accelerator.

### Transverse Schottky Noise with Space Charge

O. Boine-Frankenheim, V. Kornilov, S. Paret (GSI)

The effect of space charge on the transverse Schottky spectrum of coasting and bunched beams is studied using measurements and simulations together with analytic models. The measurements of transverse Schottky bands from heavy ion beams are performed in the SIS-18 synchrotron at GSI. In addition we analyze the noise spectrum from a particle tracking code with self-consistent space charge. Both results are compared to analytic models for coasting and for bunched beams with space charge. For coasting beams an analytic model based on the transverse dispersion relation with linear space and chromaticity reproduces the characteristic deformation of Schottky bands with increasing space charge, observed in both measurement and simulation. For bunched beams we find good agreement between the observed shifts of synchrotron satellites and a simplified model for head-tail modes with space charge. The relevance of the results for the analysis of transverse beam stability in the presence of space charge is emphasized.

**Circularly Inclined Solenoid Channel for 6D Ionization Cooling of Muons**

Ionization cooling is essential for realization of Muon Collider, muons beam based neutrino factories and other experiments involving muons. The simplest structure - absorber(s) immersed in alternating solenoidal magnetic field - provides only transverse cooling since the longitudinal motion in the most suitable momentum range (2-300MeV/c) is naturally antidamped. To overcome this difficulty it is proposed to periodically tilt solenoids so that a rotating transverse magnetic field was created. By choosing the phase advance per period above a multiple of  $2\pi$  it is possible to ensure that muons with higher momentum make a longer path in the absorber (whether distributed or localized) thus providing longitudinal damping. Basic theory of such channel and results of tracking simulations are presented.

Y. Alexahin (Fermilab)

TU3PBC04

**Simulation of Space Charge Effects in High Intensity Cyclotrons Using OPAL-CYCL**

In high intensity cyclotrons with small turn separation, both the space charge effects of single bunch and the interaction of radially neighbouring bunches play important roles.

A PIC-based three-dimensional parallel code, OPAL-CYCL, is newly developed under OPAL framework which self-consistently covers these two collective effects. In this paper we also present the simulation results from the compact cyclotron CYCIAE-100 in the light of the ongoing upgrade program of BRIF at CIAE, with the goal of 100 MeV, 200  $\mu$ A CW proton beam on target.

J. J. Yang, Y. J. Bi, Y. Lin (TUB) A. Adelman (PSI) S. An, S. M. Wei, J. J. Yang, T. J. Zhang (CIAE)

TU3PBC05

**Recent Developments at the NSCL Small Isochronous Ring**

The Small Isochronous Ring (SIR) at the NSCL/MSU was built to study space charge effects in the isochronous regime. Results of experimental studies of the longitudinal beam dynamics in the ring showed a remarkable agreement with results of numerical simulations. Recently, we have designed and built an energy analyzer to accurately measure the beam energy spread. We will present results of energy spread measurements as well as simulations of the beam behavior based on the Vlasov formalism.

Y. Li, F. Marti, T. P. Wangler (NSCL) E. Pozdeyev (BNL)

TU3PBC06

## TU3GR — Parallel Oral INSTRUM

TU3GRI01

### Longitudinal Diagnostics for Short Electron Beam Bunches

H. Loos (SLAC)

Single-pass free electron lasers require high peak currents from ultra-short electron bunches to reach saturation and an accurate measurement of bunch length and longitudinal bunch profile is necessary to control the bunch compression process from low to high beam energy. The various state-of-the-art diagnostics methods from ps to fs time scales using coherent radiation detection and RF deflection techniques are presented.

Single-pass free electron lasers require high peak currents from ultra-short electron bunches to reach saturation and an accurate

TU3GRI02

### Recent Developments in Optical Transition Radiation Beam Diagnostics

R. B. Fiorito (UMD)

Recent theoretical and experimental results advancing the state of the art in OTR diagnostics are presented. In particular, new facilities are beginning to operate in regimes where coherent effects are being seen in OTR diagnostics. The state of the art in theory and beam diagnostic data are reviewed and implications for next-generation diagnostic opportunities are presented.

Recent theoretical and experimental results advancing the state of the art in OTR diagnostics are presented. In particular, new

TU3GRI03

### NSLS-II Beam Diagnostics Overview

O. Singh, R. Alforque, B. Bacha, A. Blednykh, P. Cameron, W. X. Cheng, L. R. Dalesio, A. J. Della Penna, L. Doom, G. Ganetis, R. Heese, H.-C. Hseuh, E. D. Johnson, B. N. Kosciuk, S. L. Kramer, S. Krinsky, S. Ozaki, I. Pinayev, V. Ravindranath, J. Rose, T. V. Shaftan, S. Sharma, J. Skaritka, T. Tanabe, F. J. Willeke, L.-H. Yu (BNL)

In this paper, we present an overview of all planned instrumentation systems, results from research & development activities; and then focus on other challenging aspects.

A new 3rd generation light source (NSLS-II project) is in the early stage of construction at Brookhaven National Laboratory. The NSLS-II facility will provide ultra high brightness and flux with exceptional beam stability. It presents several challenges in the diagnostics and instrumentation, related to the extremely small emittance. In

TU3GRC04

### Bunch Length Detector Based on X-Ray Produced Photoelectrons

P. N. Ostroumov, A. Barcikowski, S. A. Kondrashev (ANL) A. Delannoy (GANIL)

We have developed and tested an X-ray based Bunch Length Detector (XBLD) for application in ion accelerators. X-rays produced as a result of ion beam interactions with matter are used to generate photoelectrons. The photoelectrons are analyzed by an rf deflector synchronized with the master oscillator, similar to the BLDs based on secondary electrons. The expected time resolution is several picoseconds. The proposed XBLD is particularly useful for the measurement of cw heavy-ion beams passing through a stripper foil or film in a high-power driver accelerator. The results of the XBLD commissioning and beam bunch profile measurements at the ANL heavy-ion cw ATLAS accelerator will be presented.

We have developed and tested an X-ray based Bunch Length Detector (XBLD) for application in ion accelerators. X-rays produced as a result of ion beam interactions

**Commissioning and Performance of the LCLS Cavity BPM System**

We present the performance of the cavity beam position monitor (BPM) system for the LCLS undulator. The construction and installation phase of 34 BPMs for the undulator and 2 for the transport line have been completed. The X-band cavity BPM employs a TM<sub>010</sub> monopole reference cavity and a TM<sub>110</sub> dipole cavity designed to operate at a center frequency of 11.384 GHz. The signal processing electronics features a low-noise single-stage three-channel heterodyne receiver that has selectable gain and a phase locking local oscillator. The approximately 40 MHz IF is digitized by a 120M sample/second four-channel 16-bit digitizer. System requirements include sub-micron position resolution for a single-bunch beam charge of 200 pC. We discuss the system specifications and commissioning results.

**S. R. Smith**, S. Hoobler, R. G. Johnson, T. Straumann, A. Young (SLAC) R. M. Lill, L. H. Morrison, W. E. Norum, N. Sereno, G. J. Waldschmidt, D. R. Walters (ANL)

## TU4RA — Parallel Oral RFSYS

### Solid State RF Amplifiers for Accelerator Applications

M. Di Giacomo (GANIL)

capabilities extend from a few kW to several hundred kW, and from less than 100 MHz to above 1 GHz, for operation both in the linear and saturated regime. This talk will review the state of the art and future prospects of rf power amplifiers for accelerator applications.

Solid state rf amplifiers are being considered for an increasing number of accelerator applications, both circular and linear. Their

### Development of a 10 MW Sheet Beam Klystron for the ILC

D. W. Sprehn, A. Jensen, E. N. Jongewaard (SLAC)

to the ILC baseline 10 MW, Multiple-Beam Klystron. By PAC09, a beam tester will have been constructed, tested, and beam quality measurements made of the 130 A, 40-to-1 aspect ratio beam after transport through a periodic magnet focusing system. General theory of operation, design trade-offs, and manufacturing considerations of both the beam tester and klystron will be discussed, and the results from operation will be presented.

SLAC is developing a 10 MW, 5 Hz, 1.6 ms, L-band (1.3 GHz) Sheet-Beam Klystron as a less expensive and more compact alternative

### Modeling and Design of High-Power Inductive Output Tubes

E. L. Wright (Beam-Wave Research, Inc.) S. J. Cooke, B. Levush (NRL) J. F. DeFord, B. Held (STAR, Inc.) J. J. Petillo (SAIC)

funded by the Office of Naval Research and Naval Research Laboratory, are investigating the physics of the beam-wave interaction of the IOT. The time-domain electrostatic PIC code MICHELLE, in conjunction with the Analyst® suite of electromagnetic codes, were used to model the cathode-grid-anode structure that comprise the input cavity. Our investigation has led to the discovery of a delay mechanism responsible for intra-bunch charge formation, as evidenced by IOT X-ray generation with energies significantly higher than the cathode accelerating potential, increasing with RF output power. Time-domain PIC results of this effect will be shown. We will also present simulation results of the large-signal beam wave interaction in the output cavity using the code TESLA. Examples of single beam and multiple-beam IOTs will also be shown.

The accelerator community is making the transition to IOT technology for a number of high-power UHF and L-band applications as a result their inherent benefits. Scientists,



**Proton Beam Acceleration with MA Loaded RF Systems in J-PARC RCS and MR Synchrotrons**

J-PARC is a unique accelerator, because magnetic alloy (MA) loaded cavities are employed for the first time in the rf systems of high intensity proton synchrotrons. High field gradients of more than 20 kV/m are achieved covering the frequency range from

0.9 MHz to 3.4 MHz. The peak voltage of 45 kV per cavity is obtained by driving with two 600 kW tetrodes in push-pull. The first high intensity beam acceleration was successfully initiated at J-PARC RCS. Although RCS beam commissioning started with 10 rf systems, instead of 11 as designed, RCS succeeded in the acceleration of an intense proton beam, which is equivalent to 300 kW when operated at 25 Hz. The longitudinal painting based on the simulation with superimposed second harmonics and with phase and momentum manipulations was the key of success. In December 2008, the J-PARC MR beam is scheduled for its first acceleration up to 30 GeV, and the Material and Life Science facilities start the user operations. During the development stage of the MA cavities, some serious problems such as electrical breakdown on core surfaces occurred. The problems were solved in a short term, and all rf systems were completed on schedule.

**M. Yoshii**, K. Takata (KEK) E. Ezura, K. Hara, K. Hasegawa, M. Nomura, C. Ohmori, A. Schnase, T. Shimada, H. Suzuki, A. Takagi, F. Tamura, M. Toda, M. Yamamoto (KEK/JAEA) K. Horino (Nippon Advanced Technology Co. Ltd.)

## TU4PB — Parallel Oral BDEMF, RFSYS

### Emittance Exchange Experimental Results

R. P. Fliller (Fermilab) T. W. Koeth (Rutgers University, The State University of New Jersey)

The promise of next-generation light sources depends on the availability of ultra-low emittance electron sources. One method of producing low transverse emittance beams is to generate a low longitudinal emittance beam and exchange it with a large transverse emittance. Experiments are underway at Fermilab's A0 Photoinjector and ANL's Argonne Wakefield Accelerator using the exchange scheme of Kim and Sessler. Experiments at the A0 photoinjector exchange a large longitudinal emittance with a small transverse emittance. AWA expects to exchange a large transverse emittance with a small longitudinal emittance. In this paper we discuss recent results at A0 and AWA and future plans for these experiments.

### Aberration Correction and Electron Optics for Microscopes and Streak Cameras

W. Wan (LBNL)

Electron microscopes and streak cameras are "mini accelerators". Advanced techniques in electron optics have been successfully applied to the design and optimization of electron microscopes and streak cameras. This talk is an overview of the status and unique designs that have arisen, with emphasis on the theoretical aspects.

### Performance Comparison of the Large Grain Cavities Treated by EP and CP

J. Gao, Z. G. Zong (IHEP Beijing) K. Saito (KEK)

.3 GHz single cell large grain (LG) cavities have been studied in our research programs on the superconducting cavity for the International Linear Collider (ILC) in the last three years and five LG cavities were fabricated at IHEP and KEK. Three cavities were dealt with by surface treatments based on electro polishing (EP) and the maximum gradient of 47.90 MV/m was achieved. The other two cavities were treated based on chemical polishing (CP) and both reached the accelerating gradients higher than 35 MV/m with the maximum gradient of 40.27 MV/m. In this paper, the performance comparison of the large grain cavities will be presented and discussed.

### Production and Testing Results of Superconducting Cavities for ISAC-II High Beta Section

V. Zvyagintsev, R. J. Dawson, K. Fong, A. Grassellino, P. R. Harmer, R. E. Laxdal, M. Marchetto, A. K. Mitra, T. C. Ries, B. Waraich, Q. Zheng (TRIUMF) R. Edinger (PAVAC)

The ISAC-II heavy ion linear accelerator has been in operation at TRIUMF since 2006. The high beta section of the accelerator, consisting of twenty cavities with  $\beta=0.11$ , is currently under development and is scheduled for completion in 2009. The cavities are superconducting bulk Niobium two-gap quarter-wave resonators at frequency 141 MHz, providing as a design goal, a voltage gain of 1.08 MV at 7 W power dissipation. Production of the cavities is started by a Canadian company, PAVAC Industries of Richmond, B. C. after two prototype cavities were developed, produced and successfully tested. Cavity production details and test results will be presented and discussed.

## TU4GR — Parallel Oral ACCTECH

### Operational Experience with the LHC Collimation System

A first stage collimation system has been installed for the 2008 first beam commissioning of the LHC. It consists of 88 collimators distributed around the ring and the two injection lines. Each collimator has two jaws for which positions and angles must be controlled and monitored with high precision. The LHC collimation system was put into operation from July to October 2008. The installed system is described and the first results from system operation without and with beam are presented. In particular, it is shown that the LHC collimation system achieved the specified accuracy and reproducibility of jaw positioning. The next steps in collimation commissioning and the expected system evolution are described. Planned system upgrades for high LHC beam intensities are outlined.

**R. W. Assmann** (CERN)

### Megawatt Class Spallation Target Development

There are three spallation neutron source facilities in the world with the potential of operating in the one megawatt proton beam power range. The SINQ facility at the Paul Scherrer Institut has already operated in this power range for several years with various water-cooled solid targets, and used a liquid metal (lead-bismuth) target for a period of four months in conducting its successful MEGAPIE project in 2006. The Spallation Neutron Source (SNS) facility at Oak Ridge National Laboratory began operation in 2006 and is approaching the one megawatt level using a liquid mercury target. The Japan Proton Accelerator Research Complex (J-PARC), which also has a mercury target, began beam-on-target operations in 2008 and is on its way to ramping-up its power level to one megawatt over the next few years. This paper will summarize the operating experience and planned improvements for the spallation targets at these megawatt class facilities.

**J. R. Haines** (ORNL) **M. Futakawa** (JAEA/J-PARC) **W. Wagner** (Paul Scherrer Institute, Spallation Source Division, ASQ)

### The MERIT High-Power Target Experiment at the CERN PS

The MERIT (MERcury Intense Target) experiment was run in the fall of 2007 using 14 and 24 GeV intense proton beams from the CERN PS. It is a proof-of-principle experiment designed to validate a target concept for producing an intense muon source for a future muon collider or neutrino factory. The experiment successfully demonstrated a target technique for multi-MW proton beams that utilizes a free-flowing liquid metal jet within the confines of a high-field solenoid. We describe the experimental strategy and parameters, as well as the results obtained and their implications for future muon-based accelerator facilities.

**K. T. McDonald** (PU)

## WE1RA — Parallel Oral CONTOPS

### New User Interface Capabilities for Control Systems

K.-U. Kasemir (ORNL)

Latest technologies promise new control systems user interface features and greater interoperability of applications. New developments using Java and Eclipse aim to unify diverse control systems and make communication between applications seamless. Web based user interfaces can improve portability and remote access. Modern programming tool improve efficiency, support testing and facilitate shared code. This talk will discuss new developments aimed at improving control system interfaces and their development environment.

### Securing Control Systems against Cyber Attacks

S. Lueders (CERN)

Virtually all modern accelerator control systems are nowadays based on commercial-off-the-shelf products (VME crates, PLCs, SCADA systems, etc.), on Windows or Linux PCs, and on communication infrastructures using Ethernet and TCP/IP. Despite the benefits coming with this (r)evolution, these "modern" control systems and infrastructures usually completely lack adequate levels of robustness, resilience and security. Even worse, new threats are inherited, too: Worms and viruses spread within seconds via the Ethernet cable, and attackers are becoming interested in breaking into control systems. This talk will discuss the initial security risks, what precautions are needed to protect control systems against cyber threats and how to provide a secure environment without sacrificing operability.

### Designing and Running for High Accelerator Availability

F. J. Willeke (BNL)

Overview of the main factors determining machine availability. Comparison of availability issues and strategy for high energy colliders and accelerators, synchrotron light sources, and spallation neutron sources. Description of how machines can be designed for high availability and systems for high reliability.

### Longevity of Accelerator Control Systems Middleware

K. Zagar (Cosylab)

Accelerators are designed to be in operation for several decades, and frequently even their construction alone takes a decade or more. Given the rapid rate of obsolescence of information technologies, it becomes a challenge how to choose the technologies that would stand the test of time, or at least make long-term support manageable. In this article, we focus on middleware: the glue that keeps inherently heterogeneous control system platforms able to interoperate with each another. Modern and less-modern middlewares, such as Internet Communication Environment (ICE), Common Object Request Broker Architecture (CORBA), Microsoft Windows Communications Foundation (WCF) are presented, and contrasted with more domain-specific middleware, such as the Experimental Physics and Industrial Control System (EPICS). We argue that whichever middleware technology is used, it is advisable to abstract it

with simple, domain-specific APIs, whose implementation can change as the evolving performance requirements push the initial middleware choice beyond its limits of applicability.

### Automated Operation of the MLS Electron Storage Ring

The Metrology Light Source (MLS) is in user operation since April 2008 working at energies ranging from  $10^{-5}$  MeV up to 630 MeV, operating currents from a single electron up to 200 mA and different values for the momentum compaction factor. In parallel to machine commissioning, an automated finite state machine has been developed. This code knows, controls and coordinates a broad manifold of machine states and meanwhile has been evolved to an automated operator acting by itself on demand of a few high level commands. Actions range from plain device I/O to complex transactions including filesystem operations and multiple device I/O. The aim is to always keep machine and control system in a well-defined state. We describe the program and report on the experience with the automated operation using this application.

**T. Birke**, B. Franksen, M. V. Hartrott, G. Wuestefeld (BESSY GmbH) M. Abo-Bakr, J. Feikes (Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Elektronen-Speicherring BESSY II)

## WE1PB — Parallel Oral BDEMF

### Detailed Electron-Cloud Modeling with CMAD

M. T.F. Pivi (SLAC)

CMAD is a new code modeling the electron cloud effect driven instability by applying an electron-beam interaction at every element of a beam line, reading a MAD description of the accelerator optics as input. CMAD is parallelized and optimized for speed. It is especially suited for the modeling of incoherent electron-cloud effects for which the spatial distribution of electrons is particularly important. This talk will review the physics, describe the design concept, the present status, benchmarking exercises, and example applications.

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### Interactions of Microwaves and Electron Clouds

F. Caspers (CERN)

The modification of microwave signals passing through an electron cloud can be used as a diagnostic tool for detecting its presence and as a measure for its effective density. This observation method was demonstrated in pioneering measurements at the CERN SPS in 2003 with protons and at PEP-II in 2006 with positron beams in the particle accelerator field. Results and applications of this technique are discussed as well as limitations and possible difficulties. A strong enhancement of the electron related signals due to cyclotron resonance is theoretically predicted and has been observed in different machines. The application of this method can also be extended for space applications and plasma physics where microwave diagnostics is known and used since many years. The question whether suitably chosen microwaves might also be employed for electron-cloud suppression will be addressed. An electron cloud may also emit microwaves itself and the intensity of this emission depends on external parameters such as the electrical bias field and resonator frequencies related to trapped mode resonances in a beam-pipe.

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### Cyclotron Resonances in Electron Cloud Dynamics

C. M. Celata, M. A. Furman, J.-L. Vay (LBNL) D. P. Grote (LLNL)  
J. S.T. Ng, M. T.F. Pivi, L. Wang (SLAC)

A new set of resonances for electron cloud dynamics in the presence of a magnetic field has been found. For short beam bunch lengths and low magnetic fields where  $l_b \ll 2\pi\omega_c$  ( $l_b$  = bunch duration,  $\omega_c$  = non-relativistic cyclotron frequency) resonances between the bunch frequency and harmonics of the cyclotron frequency cause an increase in the electron cloud density in narrow ranges of magnetic field near the resonances. For ILC parameters the increase in the density is up to a factor of approximately 3, and the spatial distribution of the electrons is broader near resonances, lacking the well-defined density "stripes" of multipactoring found for non-resonant cases. Simulations with the 2D computer code POSINST, as well as a single-particle tracking code, were used to elucidate the physics of the dynamics. The resonances are expected to affect the electron cloud dynamics in the fringe fields of conventional lattice magnets and in wigglers, where the magnetic fields are low. Results of the simulations, the reason for the bunch-length dependence, and details of the dynamics will be discussed.

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C. M. Celata is presently also a visitor in Physics, Mathematics, and Astronomy at California Institute of Technology.

### The New RF Deflectors for the CTF3 Combiner Ring

To suppress the vertical beam instability in the CTF3 Combiner Ring caused by vertical trapped modes in the rf deflectors, two new devices have been constructed. In the new structures special antennas absorb the power released by the beam to the modes. They have been realized in aluminium to reduce the costs and delivery time and have been successfully installed in the ring. In the paper we illustrate the electromagnetic design, the realization procedures, the rf measurement and high power test results.

**D. Alesini**, A. Ghigo, F. Marcellini (INFN/LNF) G. McMonagle (CERN)

WE1PBC04

### Development of an Ultra-High Repetition Rate S-Band RF Gun for the SPARX Project

We present here the design, including RF modelling, cooling, and thermal stress and frequency detuning, of an S-band RF gun capable of running near 500 Hz, for application to FEL and inverse Compton scattering

sources. The RF design philosophy incorporates many elements in common with the LCLS gun, but the approach to managing cooling and mechanical stress diverges significantly. We examine the new proprietary approach of RadiaBeam Technologies for fabricating copper structures with intricate internal cooling geometries. We find that this approach may enable very high repetition rate, well in excess of the nominal project this design is directed for, the SPARX FEL. The measurements of the main electromagnetic parameters of the RF gun are also presented.

\*C. Limborg et al., "RF Design of the LCLS Gun", LCLS Technical Note LCLS-TN-05-3

\*\*P. Frigola et al., "A Novel Fabrication Technique for the Production of RF Photoinjectors", published in EPAC08.

**L. Faillace**, L. Palumbo (Rome University La Sapienza) P. Frigola (RadiaBeam) A. Fukasawa, B. D. O'Shea, J. B. Rosenzweig (UCLA) B. Spataro (INFN/LNF)

WE1PBC05

## WE1GR — Parallel Oral HEHAC, ACCTECH

### Progress with MW-Class Operation of the SNS

J. Galambos (ORNL)

The Spallation Neutron Source (SNS) has operated at beam powers over 650 kW, and is expecting to approach 1 MW operation by the summer of 2009. Challenges in operating a proton accelerator at these power levels is reducing the uncontrolled beam loss to levels approaching  $10^{-6}$ /meter, and ensuring machine protection. Experience with beam tuning and safely handling the high power will be presented. Also the progress in beam loss reduction over the course of the power ramp-up will be reviewed.

On behalf of the SNS Team

### Commissioning of Main Ring for J-PARC

H. Kobayashi (KEK)

The J-PARC accelerator comprises a 400 MeV linac, a 3-GeV Rapid Cycling Synchrotron (RCS) and a Main Ring (MR). In the linac, an  $H^{-}$  ion beam was successfully accelerated to 181 MeV, the design target for the first step in Phase I, on January 24, 2007. Subsequently, full beam energy of 3 GeV was achieved in the RCS on October 31, 2007. The first beam commissioning of the MR was carried out in May and June 2008. Injection, circulation with rf capture and extraction to the injection beam dump were successfully performed. Some other basic tunings such as COD correction and chromaticity correction were also done well. In the MR, there are two extraction sections. One is for the Hadron Experimental Facility for which slow extraction will be mainly used and the other for neutrino experiment, which requires fast beam extraction. After confirming the basic performance of beam injection and beam circulation with rf capture, we have installed all devices for these two extraction sections and have progressed fine-tuning of ramp-up patterns of power supplies. Beam acceleration will start from December 2008. The first result of beam acceleration and extraction will be reported.

### Design Optimization of PS2

M. Benedikt (CERN)

Extensive design optimization is presently ongoing with the aim of starting the PS2 construction around 2011 and delivering beams for physics in 2017. The talk describes the various PS2 design constraints, the optimization steps, and the path towards the final design.

### The Potential of Fluidised Powder Target Technology in High Power Accelerator Facilities

C. J. Densham, O. Caretta (STFC/RAL)

This paper describes the potential of fluidised powdered material for use as a particle production target in high power particle accelerator based facilities. In such facilities a multi-MW proton beam is required to interact with a dense target



material in order to produce sub-atomic particles, e.g. neutrons for a neutron source or pions for a so-called conventional neutrino beam, a neutrino factory or a muon collider. Experience indicates that thermal transport, shock wave and radiation damage will limit the efficiency and reliability of facilities utilising solid targets at around 1 MW beam power. Consequently liquid mercury has been adopted as the target technology for the latest neutron facilities SNS and J-SNS at ORNL and Tokai respectively, and is the baseline for a neutrino factory and muon collider. However mercury introduces new problems such as Cavitation Damage Erosion. This paper discusses how a fluidised powder target may combine many of the advantages of a liquid metal with those of a solid, and describes an experimental programme at RAL currently underway to implement this technology.

### Crystal Collimation Studies at the Tevatron (T-980)

Bent-crystal channeling is a technique with a potential to increase the beam-halo collimation efficiency at high-energy colliders. First measurements at the Tevatron in 2005 have shown that using a 5-mm silicon crystal to deflect the proton beam halo onto a secondary collimator improves the system performance by reducing the machine impedance, beam losses in the collider detectors and irradiation of the superconducting magnets, all in agreement with simulations.

Recent results, obtained with substantially improved goniometer and enhanced beam diagnostics, are reported showing channeling collimation of the ~1-TeV circulating proton beam halo at the Tevatron collider. Comprehensive results of computer modeling are presented which allow further developments of the T-980 experiment towards a robust system compatible with requirements to high-efficient collimation at the Tevatron and LHC hadron colliders.

N. V. Mokhov, G. Annala, A. Apyan, R. A. Carrigan, A. I. Drozhdin, T. R. Johnson, A. M. Legan, R. E. Reilly, V. D. Shiltsev, D. A. Still, R. Tesarek, J. R. Zagel (Fermilab) R. W. Assmann, V. P. Previtali, S. Redaelli, W. Scandale (CERN) Y. A. Chesnokov, I. A. Yazynin (IHEP Protvino) V. Guidi (INFN-Ferrara) Yu. M. Ivanov (PNPI) S. Peggs (BNL) M. Prest (Universita dell'Insubria & INFN Milano Bicocca) S. Shiraishi (Enrico Fermi Institute, University of Chicago)

## WE2RA — Parallel Oral MAGNET

### The Superconducting Undulator for the ILC Positron Source

J. Rochford (STFC/RAL/ASTeC)

The ILC positron source relies upon a ~200 m long superconducting helical undulator in order to generate the huge flux of gamma photons required. The period is only 11.5 mm but the field strength is ~1 T. The UK is building and testing a full scale 4 m long ILC cryomodule at the moment. It will be completed in 2008 and the results used to demonstrate the feasibility of the full (200 m long) system.

### Status of Cryogenic Permanent Magnet Undulator Development

T. Tanaka (RIKEN/SPring-8)

Several labs are pursuing the concept of cooling permanent magnet undulators down to cryogenic temperatures in order to increase the remnant field of the material and so the on-axis field strength. This talk will review the progress made in this field, experimental magnet field data will be available to show the real performance of such a device and show whether they can be built and shimmed at room temperature and operated at cryotemperatures.

## WE2PB — Parallel Oral BDEMF

### Local Chromaticity Measurement Using the Response Matrix Fit at APS

The response matrix fit is routinely used at APS for linear optics correction. The high accuracy of the method enables us to measure the variation of betatron phase advance around the ring with rf frequency. This variation can be used to calculate local chromaticity. Such measurements were first performed at the APS at the moment when a sextupole was mistakenly connected with the wrong polarity. Local chromaticity calculations clearly pointed to the location of the sextupole error. Results and details of the measurements are reported and discussed.

V. Sajaev (ANL)

WE2PBC01

### A New Mode for Operation with Insertion Devices at UVX

The UVX is a 1.37 GeV electron storage ring at the Brazilian Synchrotron Light Laboratory. The ring has 6 long straight sections, 4 of which are available for insertion devices. The first device, a 2.0 T hybrid multipolar wiggler, was installed in the ring in the beginning of 2005 with a reduced chamber aperture. The second device, an EPU, was installed 2 years later, also with a reduced aperture. To minimize the impact of these devices on the beam lifetime we established operation modes with low vertical b-function in the straight sections where the devices were installed. These modes had the same tunes as the standard mode allowing for migration between these modes without losing the beam. With the perspective of installing the third device, a superconducting wiggler, in the end of 2009, and a fourth device soon, we implemented a new mode with low vertical b-function in all six straight sections, restoring the 6-fold symmetry of the ring. This mode has a much larger vertical tune and cannot be reached by migrating the beam from the standard mode. A new commissioning of the injection and energy ramping conditions had to be performed and are described in this report.

L. Liu, R. H.A. Farias, X. R. Resende, P. F. Tavares (LNLS)

WE2PBC02

### Investigation of Beam - RF Interactions in Twisted Waveguide Accelerating Structures Using Beam Tracking Codes

Investigations of the rf properties of certain twisted waveguide structures show that they support favorable accelerating fields. This makes them potential candidates for accelerating cavities. Using the particle tracking code, ORBIT, we examine the beam - rf interaction in the twisted cavity structures to understand their beam transport and acceleration properties. The results will show the distinctive properties of these new structures for particle transport and acceleration, which have not been previously analyzed.

J. A. Holmes, Y. W. Kang, J. L. Wilson, Y. Zhang (ORNL) M. H. Awida (University of Tennessee)

WE2PBC03

**RF Coupler Kicks in the 3.9 GHz 3rd Harmonic Cavity for the XFEL**

E. Gjonaj, W. Ackermann, T. Lau, T. Weiland (TEMF, TU Darmstadt)

In the XFEL third harmonic cavities\* are applied in the injector stage to compensate nonlinear distortion of the longitudinal phase space. In this paper we investigate the rf-induced transverse kicks resulting from the asymmetry of the fundamental mode (FM) and higher order mode (HOM) couplers\*\* in a 3.9 GHz third harmonic cavity. For this purpose, the fundamental field is computed numerically within a whole cavity using a parallel eigenvalue solver. Using these data, the relative contributions of each of the FM and HOM couplers as well as the total rf coupler kicks are evaluated.

\* P. Pierini, "Third Harmonic Superconducting Cavity Prototypes for the XFEL", LINAC08.

\*\* T. Khabiboulline, "New HOM Coupler Design For 3.9 Ghz Superconducting Cavities At FNAL", PAC07.

## WE2GR — Parallel Oral SAI

### ECR Ion Sources: A Brief History and a Look into the Next Generation

Significant progress has been achieved since first ECR ion source was developed more than three decades ago and it became one of the best ion sources for heavy ion accelerators in the world. Such progress has been mainly due to utilization of higher microwave frequency and stronger magnetic confinement, technical innovations, and understanding of the production mechanisms of highly charged heavy ions in ECR plasma. Especially, in the last decade, the progress is strongly dependent on advances in the superconducting magnet technology and understanding of the Physics of ECR plasma. Very recently, as the interest in the radioactive beam for research in various fields grows, the need for more intense beam of highly charged heavy ions to inject into the accelerator requires new innovation to improve the ECR ion source performance. In this contribution, I will present the progress of the technology and physics of ECR ion sources. Based on these results, the concepts for next generation ECR ion source for meet the requirements will be presented.

**T. Nakagawa** (RIKEN Nishina Center)

WE2GRI01

### Doubling the SNS H<sup>-</sup> Beam Current with the Baseline LBNL Ion Source

Over the past year the performance of the LBNL H<sup>-</sup> source has been improved to routinely produce 36 mA when averaged over 0.7 ms long pulses at 60 Hz, measured at the RFQ output of the Spallation Neutron Source accelerator. This is up from 25-30 mA during early 2008, and up from 10-20 mA during 2007. Some of the recent gain was achieved with refined conditioning and cesiation procedures, which now yield peak performance within 8 hours of starting a source change. The ~10 mg released Cs is sufficient for 3 weeks of operation without significant degradation. Another recent gain comes from the elevated Cs collar temperature, which was gradually implemented to probe its impact on the performance lifetime. In addition, load resistors improve the voltage stability of the electron dump and the lenses, which now can be more finely tuned. The achieved gain allowed for lowering the RF power to ~50 kW for improved reliability. A beam current of 38 mA is required at SNS for producing neutrons with a proton beam power of 1.4 MW. In one case, after 12 days of 4% duty factor operation, 56 mA were demonstrated with 60 kW of RF power. This is close to the 59 mA required for 3 MW operations.

**B. Han**, D. J. Newland (ORNL RAD) S. N. Murray, T. R. Pennisi, M. Santana, M. P. Stockli, R. F. Welton (ORNL)

WE2GRC02

### Acceleration of Charge Bred Radioactive Ions at TRIUMF

Most ion sources at ISOL (isotope separation on-line) facilities can produce only singly charged ions but efficient post acceleration requires high charge states. For light ions this can be achieved by stripping after a first moderate acceleration but with heavy ions this is no longer possible and charge state breeding is necessary. The breeder should be able to work at a high efficiency for the required charge state and especially for short-lived radioactive isotopes the process should be fast. For the ISAC facility at TRIUMF an ECRIS charge breeder (14 GHz PHOENIX from Panttechnik) has been chosen as it is well adapted to the continuous mode operation of the accelerator and for radioactive ions there is practically no limit for the beam

**F. Ames**, R. A. Baartman, P. G. Bricault, K. Jayamanna, M. McDonald, P. Schmor (TRIUMF) T. Lamy (LPSC)

WE2GRC03

intensity. After off-line optimization on a test bench the source has been moved on-line to the ISAC facility. Mass separated beams of radioactive ions from the on-line ion sources can be directed into the source. During a first test in fall 2008 a beam of  $^{80}\text{Rb}^{14+}$  was successfully created from  $^{80}\text{Rb}^{1+}$  and accelerated by the ISAC post accelerator. A summary of the results from the test bench and from the on-line commissioning will be presented.

## WE3RA — Parallel Oral RFSYS

### Progress in High Gradient Accelerator Structure Research for Future Linear Colliders

This talk will summarize progress towards high-gradient accelerator structures for a future multi-TeV linear collider. The research summarized will include the US high gradient research collaboration and the CLIC research program, and will include recent experimental results of testing a variety of accelerator structures with different frequencies, geometries and materials, and features that allow for wake field damping. The talk also presents the results of specialized material studies geared towards the understanding of surface fatigue limits due to high magnetic fields, and progress on the theory of rf breakdown in high vacuum structures and multipactoring in dielectric loaded structures.

**S. G. Tantawi** (SLAC)

WE3RAI01

### High-Power Testing of X-Band CLIC Power Generating Structures

A fundamental element of the CLIC concept is two-beam acceleration, where rf power is extracted from a high-current and low-energy beam in order to accelerate the low-current main beam to high energy. The power extraction occurs in special X-band Power Extraction and Transfer Structures (PETS). The structures are large aperture, high-group velocity and overmoded periodic structures. Following the substantial changes of the CLIC baseline parameters in 2006, the PETS design has been thoroughly updated along with the fabrication methods and corresponding rf components. Two PETS prototypes have been fabricated and high power tested. Test results and future plans are presented.

**I. Syratchev** (CERN)

WE3RAC02

### High-Power Test Results of a 10 MW, High Efficiency, L-Band Multiple Beam Klystron

CPI has designed and is currently in the process of building a prototype of a horizontally oriented multiple beam klystron (MBK) required to provide at least 10 MW peak rf output and 65% efficiency at 1300 MHz and 1.5% rf duty. The klystron was ordered by DESY for the European XFEL. In our design six off-axis electron beams go through seven ring resonators operating in the fundamental-mode. This ensures sufficient beam separation for longer cathode life while keeping the overall diameter of the device small. The MBK was designed using state-of-the-art multi-dimensional design codes which showed that it was exceeding all performance requirements. First rf hot test data at reduced duty produced 11.2 MW peak saturated rf output and 74% efficiency, which was however accompanied by high beam interception. Initial optimization of the electromagnet resulted in a 70% reduction of the rf body current, but at the expense of rf output power, efficiency (down to 67%) and gain. The magnetic field balance has to be further optimized for low body current and high efficiency at all required operating conditions. Complete test data after optimization and tuning will be presented at the conference.

**T. W. Habermann**, A. Balkcum, R. Begum, H. P. Bohlen, M. Cattelino, E. Cesca, L. Cox, E. L. Eisen, S. Forrest, D. Gajaria, T. Kimura, J. L. Ramirez-Aldana, A. Staprans, B. Stockwell, L. Zitelli (CPI)

WE3RAC03

### Applications of General-Purpose Reconfigurable LLRF Processing Architectures

L. R. Doolittle (LBNL)

Traditional rf processing systems have involved heterodyned rf processing based on mixing a Local Oscillator to up and down convert rf signals through a baseband I/Q or Mag/Phase processing channel. These systems were traditionally custom engineered for each accelerator application. Recent technical developments in rf processing and the development of sufficiently fast reprogrammable digital processing functions lead to development of general-purpose rf processing functions which can incorporate a mix of heterodyned and direct digital down/up-converted processing ("software radio"). This general-purpose approach allows one design of hardware to be applicable to many rf processing tasks, where the firmware and software in the programmable functions define the application. An example design, with applications to linac LLRF control loops and electro-optic timing reference stabilization is presented.

Traditional rf processing systems have involved heterodyned rf processing based on mixing a Local Oscillator to up and down

### Modeling the LLRF Control of a Multi-Cavity RF Station for Project X

J. Branlard, B. Chase (Fermilab)

Fermilab's High Intensity Neutrino Source (HINS), the 325 MHz low energy section of Project X consists of an RFQ, 18 copper cavities and a section of superconducting spoke resonator cavities, all driven by a single 2.5 MW klystron. Each cavity has a high power ferrite vector modulator which provides individual RF power control. This paper proposes a scheme that optimizes RF drive and vector modulator control. The different gradients, acceleration phase angles, unloaded Q's and beam loading are taken into account to optimize the cavities detuning angles, forward power, and loaded Q's. This scheme makes an efficient use of the klystron's high bandwidth ability to modulate the forward power, hence minimizing the burden on the high power vector modulator during the RF pulse. The proposed method is explained in details, a parameter sensitivity analysis is performed and the impact on the total power consumption for the RF station is calculated.

Fermilab's High Intensity Neutrino Source (HINS), the 325 MHz low energy section of Project X consists of an RFQ, 18 copper

### Development of the Model of a Self-Excited Loop

G. Joshi (BARC) V. Agarwal, G. Kumar (Indian Institute of Technology Bombay) R. G. Pillay (TIFR)

As a first step towards its development in digital domain, a computer model of a self excited loop (SEL) has been created using MATLAB/SIMULINK. The behaviour of resonator and power amplifier combination has been approximated using two first-order differential equations. The square of the amplitude of the RF field in the resonator acts as the driving force for the motion of mechanical modes of the resonator which are, individually, represented as second order systems. The loop phase shifter has been modeled as a co-ordinate rotation matrix operating on the in-phase and quadrature (I, Q) components of the input. The limiter has been modeled as a feedback loop, which keeps the output amplitude constant by multiplying a number to both I and Q components of the input phasor. To build oscillations in the SEL, a pulse has to be injected at the start-up. To study the field stabilization, proportional amplitude and phase feedback loops have been appended to the model of the SEL. The model has been created in the I-Q domain for computational efficiency and close correspondence with actual implementation. In this paper, we discuss the details of the model and the results obtained with it.

As a first step towards its development in digital domain, a computer model of a self excited loop (SEL) has been created using MATLAB/SIMULINK. The behaviour of



## WE3PB — Parallel Oral BDEMF

### Head-Tail Modes for Strong Space Charge

Head-tail modes are described when the space charge tune shift significantly exceeds the synchrotron tune. Spatial shape of the modes, their frequencies, coherent growth rates and Landau damping rates are found.

A. V. Burov (Fermilab)

### Study of Beam Dynamics during the Crossing of Resonances in the VEPP-4M Storage Ring

The influence of resonances on the beam dynamics in storage rings is of substantial interest to accelerator physics. For example, a fast crossing of resonances occurs in the damping rings of future linear colliders during the beam damping (due to the incoherent shift) can result in a loss of particles. We have studied experimentally the crossing of resonances of different power near the working point of the VEPP-4M storage ring. Observation of the beam sizes and particle losses was performed with a single-turn time resolution. Comparison with the numerical simulation has been made and will be presented alongside the experimental results.

P. A. Piminov (BINP SB RAS)

### LHC Beam-Beam Compensation Studies at RHIC

Long-range and head-on beam-beam effects are expected to limit the LHC performance with design parameters. To mitigate long-range effects current carrying wires parallel to the beam were proposed. Two such wires are installed in RHIC where they allow studying the effect of strong long-range beam-beam effects, as well as the compensation of a single long-range interaction. The tests provide benchmark data for simulations and analytical treatments. To reduce the head-on beam-beam effect electron lenses were proposed for both the LHC and RHIC. We present the experimental long-range beam-beam program and report on head-on compensations studies at RHIC, which are primarily based on simulations.

W. Fischer, N. P. Abreu, R. Calaga, Y. Luo, C. Montag, G. Robert-Demolaize (BNL)

### Nonlinear Dynamics Study of Storage Rings with Super Periods

Many modern light source storage rings use a basic magnetic lattice structure consisting of a number of repetitive periodic lattice block, the super periods. The study of one super-period can reveal the dynamical proprieties of the storage ring. Unlike the traditional approach of studying the one-turn map of the storage ring, the work focuses on the study of a super-period lattice, which allows us to gain new insight into the storage ring dynamics using a simpler magnetic structure. In this paper, both analytical and numerical techniques, including Lie Algebra and Normal Form, and particle tracking and frequency analysis, are used to study the nonlinear dynamics of one super-period of a standard double-bend achromat (DBA) and

H. Hao, X. Q. Wang (USTC/NSRL) Y. K. Wu (FEL/Duke University)

triple-bend achromat (TBA) with two or more nonlinear elements (e.g. sextupoles). The relationship between the super-period dynamics and storage ring dynamics is explored in terms of the global lattice tuning and local lattice selection for straight sections.

H. Hao is currently working as a visiting scholar at Duke University Free Electron Laser Laboratory.

### Advanced Simulation and Optimization Tools for Dynamic Aperture of Non-Scaling FFAGs and Related Accelerators including Modern User Interfaces

C. Johnstone (Fermilab) M. Berz, K. Makino (MSU) P. Snopok (St. Petersburg State University)

Innovations in computer techniques in combination with increased sophistication in modeling are required to accurately understand, design and predict high-energy, and,

in particular, the new generation of frontier accelerators for HEP and other applications. A recently identified problem lies in the simulation and optimization of FFAGs and related devices, for which currently available tools provide only approximate and inefficient simulation. For this purpose new tools are being developed within the advanced accelerator code COSY INFINITY to address complex, specific electromagnetic fields, including high-order fringe fields, out of plane fields, edge effects, and general field profiles; tools linked to modern global optimization techniques that can further accommodate the ultra-large emittances of proposed beams to allow efficient probing of very high dimensional parameter space. This new set of tools based on modern techniques and simulation approaches will be furnished with modern GUI-based user interfaces.

## WE3GR — Parallel Oral INSTRUM

### Stochastic Cooling in RHIC

After the success of longitudinal stochastic cooling of bunched heavy ion beam in RHIC, transverse stochastic cooling was installed and commissioned with proton beam. The talk presents the status of this effort and gives an estimate, based on simulation, of the RHIC luminosity with stochastic cooling in all planes.

**J. M. Brennan**, M. Blaskiewicz, F. Severino (BNL)

WE3GRI01

### State of the Art in High-Stability Timing, Phase Reference Distribution and Synchronization Systems

Recent advances in high-stability electronic and electro-optic timing and synchronization systems are presented. These systems have been proposed for several new FEL facilities, and are in development at several labs. Several basic technical implementations are in development, some based on pulsed mode-locked laser technology, others using CW systems. There are numerous technical choices with regard to the stability, synchronizability, capability of multi-drop operation, availability of inherent diagnostic information, complexity of transmitters vs. receivers, use of commercial vs. custom-designed components, etc. This talk presents an overview of the basic timing and synchronization requirements in accelerator systems, and reviews the state of the art. Contrasts are made between the CW and pulsed optical distribution approaches. The technology in development to distribute a 38 GHz phase coherent LO at the ALMA radiotelescope is highlighted as a related technical system in development.

**M. Ferianis** (ELETTRA)

WE3GRI02

### Development of CW Laser Wire in Storage Ring and Pulsed Laser Wire

Future accelerators require a high resolution beam profile monitor that measures the beam non-destructively and works at high beam intensity. Laser based beam monitors can be the solution. It uses a focused laser beam to scan the electron beam while detecting the Compton scattered photon. Accelerator Test Facility at KEK has been developing various types of Laser Wire monitors. CW laser wire with build-up optical cavity has been used to measure the small emittance beam at the damping ring. Pulsed laser wire has been developed to measure a small focused beam at the extraction line. Performance of these systems will be presented.

**Y. Honda** (KEK)

WE3GRI03

### 3-Dimensional Beam Profile Monitor Based on Pulse Storage in an Optical Cavity for Multi-Bunch Electron Beams

We have been developing a pulsed-laser storage technique in a super-cavity for compact X-ray sources. The pulsed-laser super-cavity enables to make high peak power and small waist laser at the collision point with

**K. Sakaue**, M. Washio (RISE) S. Araki, M. K. Fukuda, Y. Higashi, Y. Honda, T. Taniguchi, N. Terunuma, J. Urakawa (KEK) N. Sasao (Kyoto University)

WE3GRC04

the electron beam. Recently, using 357 MHz mode-locked Nd:VAN laser pulses which stacked in a super-cavity scattered off a multi-bunch electron beam, we obtained multi-pulse X-rays through laser-Compton scattering. Detecting an X-ray pulse-by-pulse using a high-speed detector makes it possible to measure the 3-dimensional beam size with bunch-by-bunch scanning the laserwire target position and pulse timing. This technique provides not only the non-destructive beam profile monitoring but also the measuring of bunch length and/or bunch spacing shifting. In our multi-bunch electron linac, the bunch spacing narrowing due to the electron velocity difference in the train at the output of rf-gun cavity was observed. The principle of the 3-dimensional laserwire monitor and the experimental results of multi-bunch electron beam measurements will be presented at the conference.

### Time-Dependent Phase-Space Mapping of Space-Charge-Dominated Particle Beams

D. Stratakis (BNL) R. B. Fiorito, I. Haber, R. A. Kishek, P. G. O'Shea, M. Reiser, J. C.T. Thangaraj (UMD) K. Tian (JLAB)

In this paper we report on a proof of principle experiment for demonstrating the possibility of reconstructing the time resolved-phase-space distribution of a space-charge

dominated beam by a tomographic technique which provides us with far more information than a time-sliced emittance. We emphasize that this work describes and demonstrates a new methodology which can be applicable to any beam pulse using imaging methods with the appropriate time resolution for the pulse duration. The combination of a high precision tomographic diagnostic with fast imaging screens and a gated camera are used to produce phase space maps of two beams: one with a parabolic current profile and another with a short perturbation atop a rectangular pulse. The correlations between longitudinal and transverse phase spaces are apparent and their impact on the dynamics is discussed.

## WE4RA — Parallel Oral ACCTECH

### Optimal Design and Operation of Helium Refrigeration Systems

Helium refrigerators are of keen interest to present and future particle physics programs utilizing superconducting magnet or radio frequency (RF) technology. They typically utilize helium refrigeration at and below 4.5-Kelvin (K) temperatures and are very energy intensive. After an overview of the quality of energy, basic processes used for cryogenics, the Carnot step (as defined by the author) and cycle design theory, the concept of overall process optimization is presented. In particular the question of 'what is an optimum system' will be discussed. In this regard, the Ganni cycle and floating pressure control philosophy will be examined with respect to a more traditional approach as a solution to an optimum system for new designs and existing systems.

V. Ganni (JLAB)

WE4RAI01

### The CERN LHC - World's Largest Vacuum Systems

With the successful circulation of beams in the Large Hadron Collider (LHC), its vacuum system becomes the World's largest vacuum system under operation. This system is composed of 54 km of UHV vacuum for the two circulating beams and about 50 km of insulation vacuum around the cryogenic magnets and the liquid helium transfer lines. The LHC complex is completed by 7 km of high vacuum transfer lines for the injection of beams from the SPS and their dumping. Over the 54 km of UHV beam vacuum, 48 km are at cryogenic temperature (1.9 K), the remaining 6 km are at ambient temperature and use extensively non-evaporable getter (NEG) coatings, a technology that was born and industrialised at CERN. The cryogenic insulation vacuums, less demanding technically, impress by their size and volume: 50 km and 15000 m<sup>3</sup>. Once cooled at 1.9 K, the cryopumping allows reaching pressure in the 10<sup>-4</sup> Pa range. This paper describes the LHC vacuum system, its behaviour in presence of beams as well as the detailed actions undertaken to recover its integrity after the electrical short which happened in a quadrupole busbar on 19th of September 2008.

J. M. Jimenez (CERN)

WE4RAI02

### Fifteen Years Operation Experiences of TLS Vacuum System

The Taiwan Light Source (TLS), a third generation accelerator, has been operated successfully since 1993. It has been upgraded to increase the beam energy from 1.3 GeV to 1.5 GeV and the consequent capability of full energy injection afterwards. While the beam current has been increased from 200 mA to 300 mA after replacement of RF cavities with superconducting one. The vacuum pressure tends to decrease continuously after installations of 3 undulators and 4 wigglers as well as the new front ends. The accumulated beam dose increased faster up to > 14500 Ah after the routine operational top-up mode since 2006 with average pressure has been maintained below 0.13 nPa/mA. The beam life time of 6 hours at 300 mA has been kept with a limitation of Touschek life time at a stable beam with variation of photon flux < 0.05%. However, the photon absorbers of front ends have been replaced with new ones for subjecting the higher irradiation power after upgrading. The good dynamic pressure reflects the effective pumping performance. The experiences of components failures will be summarized in this paper.

G.-Y. Hsiung, C. K. Chan, C.-C. Chang, C. L. Chen, S-N. Hsu, C. Y. Yang (NSRRC) J.-R. Chen (National Tsing Hua University)

WE4RAC03

**The Power Supply System for the SESAME Booster****S. Varnasseri (SESAME)**

The SESAME booster, with a circumference of 38 m, has several bending magnets, focussing quadrupoles and defocussing quadrupoles and also the injection and extraction septums and kickers. There will be one ramping power converter which supplies a series of 12 dipole magnets. Also 12 focussing magnets family and 6 defocussing magnets family are supplied separately with two ramping power converters. Technical issues of all the ramping and pulsed power supplies needed for the SESAME booster are discussed in this paper.

## WE4PB — Parallel Oral LAMEAR

### EMMA, the World's First Non-Scaling FFAG Accelerator

EMMA, the Electron Model with Many Applications, was originally conceived as a model of a GeV-scale muon accelerator. The non-scaling (NS) properties of resonance crossing, small apertures, parabolic ToF and serpentine acceleration are novel, unproven accelerator physics and require "proof of principle". EMMA has metamorphosed from a simple "demonstration" objective to a sophisticated instrument for accelerator physics investigation with operational demands far in excess of the muon application that lead to technological challenges in magnet design, rf optimisation, injection and extraction, and beam diagnostics. Machine components procured in 2008 will be installed February-May 2009 leading to full system tests June-August and commissioning with electrons beginning September 2009.

**S. L. Smith** (STFC/DL/ASTeC)

WE4PBI01

### SNS Ring Operational Experience and Power Ramp Up Status

The SNS Ring has now been operating for about 2.5 years, and our march continues to increase the beam power to the design value of 1.4 MW. The Ring is a loss-limited machine, and in general the radioactivation levels are good, but there are some unanticipated hot spots that we are working to relieve. Beam optics functions have been measured using the model independent and orbit response matrix methods, and our results will be compared to the ideal model. High-intensity beam profiles measurements show space-charge effects, and these will be compared to model calculations. We will also discuss the status of equipment upgrades that are now in progress in the high-energy beam transport momentum dump, the injection-dump beam line, and in the ring-to-target beam line.

**M. A. Plum** (ORNL)

WE4PBC02

### A High-Duty Factor Radio-Frequency Quadrupole Accelerator for ADS Study in China

A high-duty factor proton RFQ accelerator has been constructed at IHEP, Beijing for the basic study of Accelerator Driven Subcritical System. The ADS basic study is supported by a national program for nuclear waste transmutation which is regarded essential for the rapid development of nuclear power plants in China. In the initial commissioning of the 3.5MeV RFQ with an ECR ion source showed a nice performance with a transmission rate about 93% with an output beam of 46mA. The 352MHz RFQ is design for CW operation with the RF power source from LEP-II of CERN. This paper presents the beam commissioning and recent progress in high-duty factor operation from 7% to 15%.

**H. F. Ouyang**, S. Fu, K. Y. Gong, T. Huang, J. Li, J. M. Qiao, T. G. Xu, X. A. Xu, Y. Yao, H. S. Zhang, Z. H. Zhang, F. X. Zhao (IHEP Beijing) J. X. Fang, Z. Y. Guo (PKU/IHIP) X. L. Guan (CIAE)

WE4PBC03

### An Electron Linac Photo-Fission Driver for the Rare Isotope Program at TRIUMF

I. V. Bylinskii, F. Ames, R. A. Baartman, P. G. Bricault, S. R. Koscielniak, R. E. Laxdal, M. Marchetto, L. Merminga, A. K. Mitra, I. Sekachev, V. A. Verzilov (TRIUMF)

A 0.5 megawatt electron linear accelerator is being designed at TRIUMF in support of its expanding rare isotope program, which targets nuclear structure and astrophysics studies as well as material science. The first

stage of the project, a 25 MeV, 5 mA, cw linac matching the isotope production target power-handling capability in the next five-year plan, is planned to be completed in 2013. The injector cryomodule development, which is being fast tracked, is the subject of a scientific collaboration between TRIUMF and the VECC laboratory in Kolkata, India. The paper gives an overview of the accelerator design progress.

### The HITRAP Decelerator Linac at GSI

F. Herfurth, W. Barth, L. A. Dahl, P. Gerhard, M. Kaiser, H. J. Kluge, C. Kozhuharov, W. Quint, T. Stoehlker, G. Vorobjev (GSI) O. K. Kester (NSCL) J. Pfister, U. Ratzinger, A. C. Sauer, A. Schempp (IAP)

Deceleration of heavy, highly charged ions from the ion storage ring ESR of the GSI accelerator facility with an rf-linear decelerator will provide ions up to bare uranium almost at rest for cutting edge experiments in atomic and nuclear physics. For this unique

approach the beam has to be prepared well by electron cooling in the ESR to account for a 26 time increase of the transverse emittance during the following deceleration. An interdigital H-type (IH) structure and a radio-frequency quadrupole (RFQ) structure are operated in inverse to decelerate first from 4 MeV/u to 0.5 MeV/u and then to 6 keV/u. The quasi-continuous beam from the ESR is adapted, by using a double drift buncher, to match the longitudinal acceptance of the IH. Downstream from the IH-structure the 0.5 MeV/u beam is then fit with a spiral re-buncher to the RFQ, which finally decelerates the ions to 6 keV/u. First commissioning beam times have shown that the bunching works well and ions have been decelerated to 0.5 MeV/u in the IH structure. Extensive measurements of transversal emittance before and after deceleration can now be compared to beam dynamics calculations.



## WE4GR — Parallel Oral INSTRUM, CONTOPS

### MR Beam Diagnostics at the First Beam Commissioning of the J-PARC MR

Beam commissioning of the J-PARC MR has been going on from May 2008. The beam was one bunch of  $4 \cdot 10^{11}$  protons, nearly one hundredth of the design value. Here describe performances of the beam diagnostic devices: DCCT's, BPM's, BLM's, profile monitors and tune meters. Diagnostic design for the design intensity will be also included.

**T. Toyama**, D. A. Arakawa, A. Arinaga, Y. Hashimoto, S. Hiramatsu, S. Igarashi, S. Lee, H. Matsumoto, J.-I. Odagiri, M. Tejima, M. Tobiyama (KEK) S. H. Hatakeyama (MELCO SC) N. Hayashi, K. Yamamoto (JAEA/J-PARC) K. Satou (J-PARC, KEK & JAEA)

WE4GRC01

### Measurement of Electron Cloud Development in the Fermilab Main Injector Using Microwave Transmission

The production of an Electron Cloud poses stability issues for future high intensity running of the Fermilab Main Injector. Recent experiments have shown the presence of the electron cloud can be detected by the phase shift of a TE wave propagated along the beam pipe. This technique has been employed to provide very sensitive measurements of the electron cloud development in the Fermilab Main Injector.

**N. Eddy**, J. L. Crisp, I. Kourbanis, K. Seiya, R. M. Zwaska (Fermilab) S. De Santis (LBNL)

WE4GRC02

### First Results from the LHC Beam Instrumentation Systems

During the 2008 LHC injection synchronisation tests and the subsequent days with circulating beam, the majority of the LHC beam instrumentation systems were capable of measuring their first beam parameters. This includes the two large, distributed, beam position and beam loss systems, as well as the scintillating and OTR screen systems, the fast and DC beam current transformer systems, the tune measurement system and the wire scanner system. The fast timing system was also extensively used to synchronise most of this instrumentation. This paper will comment on the results to date, some of the problems observed and improvements to be implemented before the next LHC run.

**E. Bravin** (CERN)

WE4GRC03

### The Alignment of the LHC

The Large Hadron Collider (LHC) has been aligned using classical and non-standard techniques. The results have been seen on September 10th, 2008, the day when the beam made several turns in the machine with very few correctors activated. The paper will present the different steps of the alignment, from the metrological measurements done during the phase of the magnets assembly to the alignment itself in the tunnel as well as the techniques used to obtain the accuracy required by the physicists. The correlation of the results of this alignment with the position of the beam seen on the BPMs by the operation team during the days the beam has circulated will be presented.

**D. P. Missiaen**, J.-P. Quesnel, R. J. Steinhagen (CERN)

WE4GRC04

### Machine Protection for the Experiments of the LHC

R. Appleby, D. Macina (CERN)

The LHC stored beam contains 362 MJ of energy at the top beam energy of 7 TeV, presenting a significant risk to the components of the machine and the detectors. In response to this threat, a sophisticated system of machine protection has been developed to minimize the danger, and detect potentially dangerous situations. In this paper, the protection of the experiments in the LHC from the machine is considered, focusing on pilot beam strikes on the experiments during injection and on the dynamics of hardware failure with a circulating beam, with detailed time-domain calculations performed for LHC ring power converter failures and magnet quenches. The prospects for further integration of the machine protection and experimental protection systems are considered, along with the risk to near-beam detectors from closed local bumps.

### ALS Top-Off Mode Beam Interlock System

K. M. Baptiste, M. O. Balagot, W. Barry, P. W. Casey, H. K. Chen, R. S. Mueller, D. Robin, C. Steier, J. M. Weber (LBNL)

ALS has been upgraded by adding Top-Off Mode, a new mode of operation to the existing modes of Fill and Stored Beam. The Top-Off Mode permits injection of 1.9 GeV electron beam into the Storage Ring, with the safety shutters open, once certain strict conditions are met and maintained. Top-Off Mode enables User operation without an interruption caused by mode switching between the Stored Beam Mode when safety shutters are open, to the Fill Mode with the safety shutters closed and back. The conditions necessary to permit Top-Off Mode are; stored beam is present, the energies are matched between the injector and storage ring, a select set of storage ring lattice magnets are operating at the correct current levels, and radiation losses are minimized. If certain combinations of these conditions are not met, a potentially dangerous condition of injecting electrons down a users beam line can exist. Therefore a system of mode control, energy match, lattice match and stored beam interlocks are needed to control the injected beam prohibiting potentially dangerous conditions. In this paper we will present the Top-Off Mode Beam Interlock system requirements, design, and operational parameters.

## TH1GR — Parallel Oral LAMEAR / Asian Focus

### HIRFL-CSR Facility

CSR is a new ion cooler-storage-ring system in China IMP, it consists of a main ring (CSRm) and an experimental ring (CSRe).

J. W. Xia, Y. Liu, Y. J. Yuan (IMP)

The two existing cyclotrons of the Heavy Ion Research Facility in Lanzhou (HIRFL) are used as its injector system. The heavy ion beams from the cyclotrons are injected first into CSRm for accumulation with e-cooling and acceleration, finally extracted fast to CSRe for internal-target experiments and mass measurements of radioactive ion beams (RIBs), or extracted slowly for external-target experiments or cancer therapy. In 2005 the CSR construction was completed and the commissioning finished in the past three years. It includes stripping injection (STI), electron-cooling with hollow electron beam, C-beam stacking with the combination of STI and e-cooling, wide energy-range acceleration from 7 MeV/u to  $>10^4$  MeV/u with the RF harmonic-number changing, multiple multi-turn injection (MMI) and beam accumulation with MMI and e-cooling for heavy-ion beams of Ar, Kr and Xe, fast and slow extraction from CSRm, the commissioning of CSRe with two lattice modes, and a RIB mass-spectrometer test with the isochronous mode in CSRe by the time-of-flight method.

### Status of the China Spallation Neutron Source Project

CSNS accelerator mainly consists of an  $H^-$  linac and a proton rapid cycling synchrotron. It is designed to accelerate proton beam pulses to 1.6 GeV kinetic energy at 25 Hz repetition rate, striking a solid metal target to produce spallation neutrons. The accelerator is designed to deliver a beam power of 120 kW with the upgrade capability up to 500 kW, The CSNS accelerator is the first large-scale, high-power accelerator project to be constructed in China and thus we are facing a lot of challenges in some key technologies. A series of R&D for major prototypes have been conducted since 2006, including an  $H^-$  ion source, DTL tank, RF power supply for the linac, injection/extraction magnets and its pulse power supplies, dipole and quadrupole prototype magnets in the ring and its power supplies, ferrite-loaded RF prototype cavity, ceramic vacuum chamber, control and some beam diagnostics. This paper will briefly introduce the design and R&D status of the CSNS accelerator.

S. Fu, H. Chen, Y. W. Chen, Y. L. Chi, C. D. Deng, H. Dong, W. He, K. X. Huang, W. Kang, J. Li, H. F. Ouyang, H. Qu, C. Shi, H. Sun, J. Tang, S. Wang, J. Wei, T. G. Xu, Z. X. Xu, X. Yin, J. Zhang, Z. H. Zhang (IHEP Beijing)

### Particle Accelerators in Korea

Recently the Korean government successfully completed a large-scale facility, called the KSTAR, a fully superconducting tokamak after joining in the ITER project. It made renewed interests in large-scale scientific facilities to promote basic and applied research capabilities. The next projects include a space project and particle accelerators. The immediate one in accelerator program is the PLS-upgrade, and its budget is now in the congress for FY2009. The others are in the middle of consensus making process: a heavy ion accelerator for rare isotopes and a new synchrotron light source other than the PLS-upgrade and the ongoing proton linac program. This paper will give an overview

W. Namkung (POSTECH)

of the status and prospects of major particle accelerator initiatives in Korea. The paper will also include descriptions of the significant contributions undertaken by Korea through collaborations with major international facilities using particle accelerators. Finally, the paper will outline how industry, government and universities in Korea are collaborating on particle accelerator R&D.

## Overview of the Accelerator Programs at the Indian Laboratories

V. C. Sahni (RRCAT)

Particle accelerator programs being pursued by the Indian labs cover a broad range, encompassing accelerators for nuclear physics research (NPR) (in the low and intermediate energy range), construction of synchrotron radiation sources (SRS) as well as participation in international accelerator projects, especially those related to high energy physics. Machines for NPR include 14MV Pelletrons, augmented by home built superconducting linac boosters to enhance the energy & mass range of the ion beams, and a superconducting cyclotron which is currently undergoing commissioning at Kolkata. Two SRS, namely, a 450 MeV ring Indus-1 and 2.5 GeV booster cum light source, Indus-2, have been indigenously constructed and set up at Indore. A program is also on to develop a high current proton accelerator that will eventually be used for R&D linked to ADS. Regarding our international collaborations, Indian labs have contributed to setting up of LHC at CERN, are associated with the CLIC Test Facility 3 & Linac-4 and the FAIR project at Hamburg besides working with Fermilab on ILC/Project-X R&D. The talk will give an overview of some of the recent developments related to these activities.

## TH1PB — Special Forum APAC

### Applications of Accelerators to Environmental Protection at the Idaho Accelerator Center

This talk will focus on linear accelerators as the source for photon activation analysis (PAA) of environmental samples for climate change analysis (of particular interest), waste analysis (looking for toxic or recyclable metals before they go into a landfill), etc. Where relevant, US agencies and programs will be used as examples beyond the Idaho Accelerator Center to give a broad perspective of activities and opportunities in this field.

D. Wells (IAC)

TH1PB101

### Accelerators for Security Applications

Accelerators are increasingly being deployed for security applications at ports, borders and other sensitive locations. The requirements and economic drivers for these systems will be described as will the present marketplace, players and projected growth. The presently deployed technology and future evolution based on developing requirements will be discussed.

A. V. Mishin (AS&)

TH1PB102

### Management Concepts and Strategies for the Construction of the European XFEL

The European XFEL is a truly international accelerator project, as there are likely several more to come in the future. Many partners far-scattered even outside Europe will contribute to the project to a large extent collaboratively at all phases, i.e. to the conceptual design, engineering, fabrication, installation and exploitation. While the technologies are meanwhile basically mature, it is actually the extent of decentralisation, quite unusual for accelerator projects so far, which imposes now the highest demands on the management. Multitude and extent of managerial structures required for such large accelerator projects are easily underestimated in the early project stages. The European XFEL is very aware of those demands and risks and is consequently working hard to implement the necessary means. This talk will explain the project structures with their associated needs and present the management concepts and strategies, which have been developed to conquer the challenges. These concepts and strategies might be well be the ones for future accelerator projects.

T. H. Hott (DESY)

TH1PB103

### Techniques for Successful Project Management - Lessons from ORNL SNS

There are many planned or nascent particle-accelerator-based projects world-wide. Often these are large and complex projects that can benefit from strong project management. Following the premise that it is better to learn from the community's successes rather than its mistakes, this talk will draw on successful experiences from the Oak Ridge SNS project in elaborating strategies and techniques for successful project management.

S. A. Herron (ORNL)

TH1PB104

## TH2PB — Louis Costrell Honorary Session

### Plasma Wakefield Accelerators Using Multiple Electron Bunches

E. Kallos (QMUL) E. Kallos (USC)

For 70 years particle acceleration schemes have been based on the same technology which places particles onto rf electric fields inside metallic cavities. However, since the accelerating gradients cannot be increased arbitrarily due to limiting effects such as wall breakdown, in order to reach higher energies today's accelerators require km-long structures that have become very expensive to build, and therefore novel accelerating techniques are needed to push the energy frontier further. Plasmas do not suffer from those limitations since they are gases that are already broken down into electrons and ions. In addition, the collective behavior of the particles in plasmas allows for generated accelerating electric fields that are orders of magnitude larger than those available in conventional accelerators. As plasma acceleration technologies mature, one of the main future challenges is to monoenergetically accelerate a second trailing bunch by multiplying its energy in an efficient manner, so that it can potentially be used in a future particle collider. The work presented here analyzes the use of multiple electron bunches in order to enhance certain plasma acceleration schemes.

For 70 years particle acceleration schemes have been based on the same technology which places particles onto rf electric fields

### Nonlinear Dynamics Studies in the Fermilab Tevatron Using an AC Dipole

R. Miyamoto (BNL) A. Jansson, M. J. Syphers (Fermilab) S. E. Kopp (The University of Texas at Austin)

particles circulating in a synchrotron. Observation of such oscillations with beam-position-monitors allows direct measurements of a synchrotron's nonlinear parameters. This paper presents experimental studies to measure effects of sextupole and octupole fields, such as tune dependence on amplitude and resonance driving terms, performed in the Fermilab Tevatron using an AC dipole.

An AC dipole magnet produces a sinusoidally oscillating dipole field with frequency close to betatron frequency and excites large sustained oscillations of beam

### 2009 APS Robert R. Wilson Prize

S. Ozaki (BNL)

for fundamental science on two continents, and his promotion of international collaboration.

For his outstanding contribution to the design and construction of accelerators that has led to the realization of major machines

## TH3GA — Parallel Oral PPHIB

### Electron Beam Dynamics in the Long-Pulse, High-Current DARHT-II Linear Induction Accelerator

The DARHT-II linear induction accelerator (LIA) now accelerates 2-kA electron beams to more than 17 MeV. This LIA is unique in that the accelerated current pulse width is greater than 2 microseconds. This pulse has a flat-top region where the final electron kinetic energy varies by less than 1% for more than 1.5 microseconds. The long rise-time of the 6-cell injector current pulse is 0.5 microsecond, which can be scraped off in a beam-head cleanup zone (BCUZ) before entering the 68-cell main accelerator. We discuss our experience with tuning this novel accelerator; and we will present data for the resulting beam transport and dynamics. We will also present beam stability data, and relate these to previous stability experiments at lower current and energy\*.

\* "Long-pulse beam stability experiments on the DARHT-II linear induction accelerator," Carl Ekdahl, et al., IEEE Trans. Plasma. Sci. Vol. 34, 2006, pp. 460-466

C. Ekdahl, E. O. Abeyta, P. Aragon, R. D. Archuleta, G. V. Cook, D. Dalmas, K. Esquibel, R. J. Gallegos, R. W. Garnett, J. F. Harrison, E. B. Jacquez, J. B. Johnson, B. T. McCuistian, N. Montoya, S. Nath, K. Nielsen, D. Oro, L. J. Rowton, M. Sanchez, R. D. Scarpetti, M. Schauer, G. J. Seitz, H. V. Smith, R. Temple (LANL) R. Anaya, G. J. Caporaso, F. W. Chambers, Y.-J. Chen, S. Falabella, G. Guethlein, B. A. Raymond, R. A. Richardson, J. A. Watson, J. T. Weir (LLNL) H. Bender, W. Broste, C. Carlson, D. Frayer, D. Johnson, C.-Y. Tom, C. P. Trainham, J. T. Williams (NSTec) T. C. Genoni, T. P. Hughes, C. H. Thoma (Voss Scientific) B. A. Prichard, M. E. Schulze (SAIC)

TH3GAI01

### Status of the Dielectric Wall Accelerator

The dielectric wall accelerator\* (DWA) system being developed at the Lawrence Livermore National Laboratory (LLNL) uses fast switched high voltage transmission lines to generate pulsed electric fields on the inside of a high gradient insulating (HGI) acceleration tube. High electric field gradients are achieved by the use of alternating insulators and conductors and short pulse times. The system is capable of accelerating any charge to mass ratio particle. Applications of high gradient proton and electron versions of this accelerator will be discussed. The status of the developmental new technologies that make the compact system possible will be reviewed. These include high gradient vacuum insulators, solid dielectric materials, photoconductive switches and compact proton sources.

\*Patents pending.

G. J. Caporaso, D. T. Blackfield, Y.-J. Chen, S. Falabella, G. Guethlein, J. R. Harris, S. A. Hawkins, L. Holmes, S. D. Nelson, A. Paul, B. R. Poole, M. A. Rhodes, R. A. Richardson, S. Sampayan, M. Sanders, S. Sullivan, L. Wang, J. A. Watson (LLNL) D. W. Pearson (TomoTherapy) J. T. Weir (CPAC)

TH3GAI02

### Designing Neutralized Drift Compression for Focusing of Intense Beam Pulses in a Background Plasma

I. Kaganovich, R. C. Davidson, M. Dorf, E. Startsev (PPPL) A. B. Sefkow (Sandia National Laboratories)

Neutralized drift compression offers an effective means for particle beam focusing and current amplification. In neutralized drift compression, a linear radial and longitudinal

velocity drift is applied to a beam pulse, so that the beam pulse compresses as it drifts in the focusing section. The beam intensity can increase more than a factor of 100 in both the radial and longitudinal directions, totaling to more than a 10,000 times increase in the beam density during this process. The optimal configuration of focusing elements to mitigate the time-dependent focal plane is discussed in this paper. The self-electric and self-magnetic fields can prevent tight ballistic focusing and have to be neutralized by supplying neutralizing electrons. This paper presents a survey of the present numerical modeling techniques and theoretical understanding of plasma neutralization of intense particle beams. Investigations of intense beam pulse interaction with a background plasma have identified the operating regimes for stable and neutralized propagation of intense charged particle beams.

### Progress in Beam Focusing and Compression for Target Heating and Warm Dense Matter Experiments

P. A. Seidl, A. Anders, F. M. Bieniosek, J. E. Coleman, J.-Y. Jung, M. Leitner, S. M. Lidia, B. G. Logan, P. N. Ni, D. Ogata, P. K. Roy, W. L. Waldron (LBNL) J. J. Barnard, R. H. Cohen, D. P. Grote (LLNL) E. P. Gilson (PPPL) D. R. Welch (Voss Scientific)

The Heavy-Ion Fusion Sciences Virtual National Laboratory is pursuing an approach to target heating experiments in the warm dense matter regime, using space-charge-dominated ion beams that are simultaneously longitudinally bunched and trans-

versely focused. Longitudinal beam compression by large factors has been demonstrated in the Neutralized Drift Compression Experiment (NDCX) with controlled ramps and forced neutralization. Using an injected 30 mA K<sup>+</sup> ion beam with initial kinetic energy 0.3 MeV, axial compression leading to ~100X current amplification and simultaneous radial focusing to a few mm have led to encouraging energy deposition approaching the intensities required for eV-range target heating experiments. We discuss the status of several improvements to NDCX to reach the necessary higher beam intensities, including:

1. greater axial compression via a longer velocity ramp;
2. beam steering dipoles to mitigate aberrations in the bunching module;
3. time-dependent focusing elements to correct considerable chromatic aberrations; and
4. plasma injection improvements to establish a plasma density always greater than the beam density, expected to be  $>10^{13} \text{ cm}^{-3}$ .



## TH3GB — Parallel Oral ADVCON

### Two Beam Linear Colliders / Special Issues

The path towards a multi-TeV  $e^+e^-$  linear collider proposed by the CLIC study is based on the Two Beam Acceleration scheme. Such a scheme is promising in term of efficiency, reliability and cost. The rationale behind the two-beam scheme is discussed in the paper, together with the special issues related to this technology and the R&D needed to demonstrate its feasibility.

**R. Corsini** (CERN)

TH3GBI01

### Longitudinal Shaping of Electron Bunches with Applications to the Plasma Wakefield Accelerator

The first successful attempt to generate ultrashort (1-10 picosecond) relativistic electron bunches characterized by a ramped current profile that rises linearly from head to tail and then falls sharply to zero was recently reported.\* Bunches with this type of longitudinal shape may be applied to plasma-based accelerator schemes as an optimized drive beam, and to free electron lasers as a means of reducing asymmetry in microbunching due to slippage. We will review the technique used to generate these bunches, which utilizes a sextupole-corrected dogleg compressor to manipulate the longitudinal phase space of the beam, and examine its potential application in a realistic plasma wakefield accelerator scenario, the proposed FACET project at SLAC.

**R. J. England, M. J. Hogan** (SLAC) **J. B. Rosenzweig, G. Travish** (UCLA)

TH3GBI02

\* R. J. England, J. B. Rosenzweig, G. Travish, Phys. Rev. Lett. 100, 214802 (2008).

### Generation of Trains of Subpicosecond Electron Bunches

Trains of subpicosecond electron bunches are essential to reach high transformer ratio and high efficiency in compact, beam-driven, plasma-based accelerators. These trains with a correlated energy chirp can also be used in pump-probe experiments driven by FELs. We demonstrate experimentally for the first time that such trains with controllable bunch-to-bunch spacing, bunch length, and charge can be produced using a mask technique. With this simple mask technique, the stability of the bunch train in energy and time is guaranteed by the beam feedback system.

**V. Yakimenko** (BNL)

TH3GBI03

### Positron Transport, Focusing and Acceleration Using Plasma Techniques

Preservation of the incoming beam emittance is a key characteristic needed for any accelerating system, including the beam-driven, plasma-based accelerator or plasma wakefield accelerator (PWFA). Electron beams with a density larger than the plasma density propagate in a pure and uniform plasma ion column that acts as a focusing element free of geometric aberrations, and the beam emittance is preserved. On the contrary, positron beams attract plasma

**P. Muggli** (USC)

TH3GBI04

electrons that flow through the beam and create a non-uniform charge density inside the beam that can exceed the beam density. The resulting plasma focusing force is non-uniform and non-linear. Experimentally, we observe the formation of a beam halo on a screen placed downstream from the plasma. Analysis of the beam images as a function of the plasma density show that the transverse beam size at the screen is strongly reduced in the high emittance plane, and that in the low emittance plane charge is transferred from the beam core to the halo. Numerical simulations of the experiments show the same behavior and indicate that there is emittance growth in both planes. Experimental and simulations will be presented.

## TH3PB — Parallel Oral LSAFEL

### Commissioning Status of the LCLS X-Ray FEL

The Linac Coherent Light Source (LCLS) is a SASE x-ray Free-Electron Laser (FEL) project at SLAC presently in an advanced phase of machine commissioning. The injector, linac, and new bunch compressors were commissioned in 2007 and 2008, establishing the necessary electron beam brightness at 14 GeV. The final phase of accelerator commissioning, including the FEL undulator and the long transport line from the linac, began in November 2008, with first light expected in July 2009. We report on the first results of FEL operation, although still prior to the availability of the full x-ray diagnostics suite, which will not be ready until late May of 2009.

**P. Emma** (SLAC)

### Progress of the SCSS Test Accelerator for XFEL/SPring-8

The SPring-8 compact SASE source (SCSS) test accelerator was constructed in FY2005 to demonstrate a new concept for X-ray free electron lasers composed of a low-emittance thermionic electron injector, a high-gradient normal conducting C-band accelerator, and a short-period in-vacuum undulator. With a 250 MeV electron beam, continuous SASE saturation can generate intense and stable FEL beams at the wavelength range from 50 to 60 nm with the maximum pulse energy of 30 micro-J and the intensity fluctuation of ~10%. Analysis of the SASE saturation data with a 3D-FEL simulation code suggests negligible degradation of the electron beam emittance during the high bunch compression process. We also succeeded in operating the C-band accelerator with a high accelerating gradient of 37 MV/m and a repetition rate of 60 pps. Now, the FEL beam is routinely delivered for user experiments. At this conference we will present the machine performance and recent progress of the SCSS test accelerator together with the anticipated performance of the 8 GeV XFEL under construction.

**K. Togawa**, T. Fukui, T. Hara, T. Hasegawa, A. Higashiya, N. Hosoda, T. Inagaki, S. I. Inoue, T. Ishikawa, H. Kitamura, M. K. Kitamura, H. Maesaka, M. Nagasono, T. Ohshima, Y. Otake, T. Sakurai, T. Shintake, K. Shirasawa, H. Tanaka, T. Tanaka, M. Yabashi (RIKEN/SPring-8) T. Asaka, H. Ohashi, S. Takahashi, S. Tanaka (JASRI/SPring-8)

### Progress at the Jefferson Lab FEL

As the only currently operating free electron laser (FEL) based on a CW superconducting energy recovering linac (ERL), the Jefferson Laboratory FEL Upgrade remains unique as an FEL driver. The present system represents the culmination of years of effort in the areas of SRF technology, ERL operation, lattice design, high power optics and DC photocathode gun technology. In 2001 the FEL Demo generated 2.1 kW of laser power. Following extensive upgrades, in 2006 the FEL Upgrade generated 14.3 kW of laser power breaking the previous world record. The FEL Upgrade remains a valuable testbed for studying a variety of collective effects, such as the beam breakup instability, longitudinal space charge and coherent synchrotron radiation. Additionally, there has been exploration of operation with lower injection energy and higher bunch charge. Recent progress and achievements in these areas will be presented, and two recent milestones – installation of a UV FEL and establishment of a DC gun test stand – will be discussed.

**C. Tennant** (JLAB)

Additionally, a review of the longitudinal matching scheme and the use of incomplete energy and its implications will be presented.

### FLASH Operation as an FEL User Facility

S. Schreiber, B. Faatz, J. Feldhaus, K. Honkavaara, R. Treusch (DESY)

The free-electron laser facility FLASH at DESY, Germany is the world-wide unique SASE-FEL operating in the VUV and the soft X-ray wavelengths range. Since Summer 2005, FLASH operates as a user facility providing fully coherent 10 to 50 femtosecond long laser radiation in the wavelength range from 47 nm to 6.5 nm and with an unprecedented brilliance - many orders of magnitude higher than any other facility. The SASE radiation contains also higher harmonics. Several experiments have successfully used the third and fifth harmonics, in the latter case with a wavelength down to 1.59 nm. In addition, FLASH serves as a pilot facility for the European XFEL. Part of the beam time is reserved for general accelerator studies which also includes ILC related studies.

### Demonstration of Efficient Electron-Radiation Interaction in a 7th Harmonic IFEL Experiment

S. Tochitsky, A. M. Cook, D. J. Haberberger, C. Joshi, P. Musumeci, J. B. Rosenzweig, C. Sung, O. Williams (UCLA)

Many proposals and ongoing national projects exist worldwide to build a single-pass X-ray FEL amplifier in which a high-brightness, multi-GeV electron beam has a resonant energy exchange with radiation in an undulator. Because of the practical limit on the undulator period, the electron beam energy represents one of constraints on the shortest reachable wavelength. Recently the high-order harmonic FEL/IFEL interactions were considered theoretically as a technique that would allow the reduction of the beam energy without corresponding decrease in the undulator period and the magnetic field strength. We demonstrate microbunching of the 12.3 MeV electrons in a 7th order IFEL interaction, where the seed radiation frequency is seven times higher than the fundamental frequency. Strong longitudinal modulation of the beam is inferred from the observation of the first, second and third harmonics of the seed radiation in a Coherent Transition Radiation spectrum. The level of seed power is comparable to that required for microbunching at the fundamental frequency of the ten-period-long undulator. The implications of these results for the next generation of FELs will be explored.

## TH4GA — Parallel Oral APAC

### Commissioning of Hadrontherapy Synchrotrons: HIT and CNAO

The Heidelberg Ion Therapy facility (HIT) is the first dedicated proton and carbon therapy facility in Europe. HIT will start treating the first patients by the end of 2008. The talk presents the commissioning experience and reports on the quality of machine operations in the clinical environment including initial treatment results. The commissioning of the Italian facility Centro Nazionale di Adroterapia Oncologica (CNAO) is also discussed.

**Th. Haberer** (HIT)

TH4GAI01

### Recent Progress on HIMAC for Carbon Therapy

Based on more than ten years of experience of the carbon cancer therapy with HIMAC, we have proposed a new treatment facility for the further development of the therapy with HIMAC. This facility will consist of three treatment rooms: two rooms equipped with horizontal and vertical beam-delivery systems and one room with a rotating gantry. For the beam-delivery system of the new treatment facility, a 3D hybrid raster-scanning method with gated irradiation with patient's respiration has been proposed. A R&D study has been carried out toward the practical use of the proposed method, although this method was verified by a simulation study. In the R&D study, we have improved the beam control of the size, the position and the time structure for the proposed scanning method with the irradiation gated with patient's respiration. Further, owing to the intensity upgrade of the synchrotron, we can successfully extend the flattop duration, which can complete one fractional irradiation with one operation period and can increase the treatment efficiency of the gated irradiation. We will report the recent progress on HIMAC for carbon therapy.

**K. Noda** (NIRS)

TH4GAI02

### PAMELA Overview: Design Goals and Principles

The PAMELA (Particle Accelerator for Medical Applications) project is to design an accelerator for proton and light ion therapy using non-scaling Fixed Field Alternating Gradient (FFAG) accelerators, as part of the CONFORM project, which is also constructing the EMMA electron model of a non-scaling FFAG at Daresbury. This paper presents an overview of the PAMELA design, and a discussion of the design goals and the principles used to arrive at a preliminary specification of the accelerator.

**K. J. Peach**, J. H. Cobb, S. L. Sheehy, H. Witte, T. Yokoi (JAI) M. Aslaninejad, M. J. Easton, J. Pasternak (Imperial College of Science and Technology, Department of Physics) R. J. Barlow, H. L. Owen, S. C. Tygier (UMAN) C. D. Beard, P. A. McIntosh, S. L. Smith, S. I. Tzenov (STFC/DL/ASTeC) N. Bliss (STFC/DL) T. R. Edgecock, J. K. Pozimski, J. Rochford (STFC/RAL) R. J.L. Fenning, A. Khan (Brunel University) C. Johnstone (Fermilab) B. Jones, B. Vojnovic (Gray Institute for Radiation Oncology and Biology) D. J. Kelliher, S. Machida, C. T. Rogers (STFC/RAL/ASTeC) R. Seviour (Cockcroft Institute, Lancaster University)

TH4GAC03

**Neutron Source with Emittance Recovery Internal Target****Y. Mori (KURRI)**

Accelerator based neutron source with an internal target (ERIT-emittance recovery internal target) placed into the proton storage ring has been developed. In this scheme, the beam and energy degradation caused by the target are cured by ionization cooling and the thermal and epi-thermal neutron flux of more than  $1 \times 10^9$  n/cm<sup>2</sup>/sec can be obtained. The experimental results will be given in the conference.

## TH4GB — Parallel Oral ADVCON

### Recent Results on Acceleration Mechanisms and Beam Optimization of Laser-Driven Proton Beams

Beam optimization of laser-accelerated protons is a crucial point for the development of applications in various areas. Several directions need to be pursued, namely (i) optimization of the high-energy end of the spectrum e.g. for dense plasma radiography,

and (ii) enhancement of laser-to-protons conversion efficiency and reduction of divergence e.g. for fast ignition. We will present recent experimental results and simulations on these topics. We will show that high-energy protons in the TNSA regime could be enhanced using low-density plasmas [2] or reduced mass solid targets [3]. The laser-to-protons conversion efficiency is equally sensitive to laser and target parameters and can be increased using ultrathin targets [4] or reduced mass solid targets [3]. In addition, we will present some results in exploring radiation-pressure acceleration of ions using circularly polarized laser pulses.

[3] S. Buffechoux et al., "Enhanced laser acceleration of protons from reduced mass targets", in preparation

[4] P. Antici, J. Fuchs et al., IEEE Trans. On Plasma Sci. 36, 1817 - 1820 (2008).

**S. F. Buffechoux**, P. Antici, P. Audebert, J. Fuchs (LULI) M. Amin (ILPP) M. Borghesi, G. Sarri (Queen's University of Belfast) T. Burris-Mog, T. Cowan, K. Zeil (FZD) S. Fourmaux, J. C. Kieffer (INRS-EMT) T. Motonobu (ISIR)

### Stable, Monoenergetic 50-400 MeV Electron Beams with a Matched Laser Wakefield Accelerator

High-power, ultrashort laser pulses have been shown to generate quasi-monoenergetic electron beams from underdense plasmas. Several groups have reported generating high-energy electron beams using either supersonic nozzles\* or a capillary based system\*\*.

Many issues still remain, with respect to pointing and energy stability of the beam, charge in the monoenergetic component, energy spread, and robustness. We demonstrate for the first time the generation of 300-400 MeV electron beams with 600 pC of charge, using self-guided laser pulses and a stable, high-quality laser pulse. Matching the laser to the plasma is crucial for stable operation since there is minimal nonlinear evolution of the pulse. The beam is highly reproducible in terms of pointing stability and energy -- with parameters superior to those previously obtained using optical injection\*\*\*. The stability and compactness of this accelerator make it possible to conceive of mobile applications in non-destructive testing, or long-standoff detection of shielded special nuclear materials. Scaling laws indicate that with a longer plasma and higher laser powers it should be possible to obtain stable, GeV class electron beams.

\* S. P.D. Mangles et al., Nature 431, 535-538 (2004).

\*\* W. P. Leemans et al., Nature Physics 2, 696-699 (2006).

\*\*\* J. Faure et al., Nature 444, 737-739 (2007).

**S. Banerjee**, N. D. Powers, V. Ramanathan, D. P. Umstadter (UNL)

### Injection of Electrons into a Laser Wakefield Accelerator Driven in a Capillary Discharge Waveguide Using an Embedded Gas Jet

A. J. Gonsalves, E. Esarey, C. G.R. Geddes, W. Leemans, C. Lin, K. Nakamura, D. Panasenko, C. B. Schroeder, C. Toth (LBNL)

A key issue in laser wakefield accelerators (LWFAs) is injection of electrons into the accelerating region of the wake. Typically electron beams have been self-injected into

the wake in a highly non-linear process, and at a higher plasma density than that for an optimized guiding and accelerating structure. This in turn limits the electron beam energy and quality that can be achieved. In this talk it is shown that this coupling of injection and acceleration can be addressed for LWFA in a capillary discharge waveguide with the use of a gas jet embedded into the capillary to longitudinally tailor the electron density profile. Previous experiments without a gas jet have shown self-trapping and acceleration of electrons with energy up to 1 GeV [Leemans et al., Nature Phys. Vol. 2, 696, 2006]. By adding a gas jet in the capillary it has been shown that electrons can be trapped and accelerated to high-energy using plasma densities in the capillary lower than in previous experiments, and that use of this technique improved electron beam properties.

### Towards a Compact XUV Free-Electron Laser: Characterising the Improving Beam Quality of Electron Beams Generated in a Laser Wakefield Accelerator

S. M. Wiggins, M. P. Anania, E. Brunetti, S. Cipiccia, B. Ersfeld, M. R. Islam, R. C. Issac, D. A. Jaroszynski, G. Raj, R. P. Shanks, G. Vieux, G. H. Welsh (USTRAT/SUPA) W. A. Gillespie (University of Dundee) A. MacLeod (UAD)

The Advanced Laser-Plasma High-Energy Accelerators towards X-rays (ALPHA-X) programme\* is developing laser-plasma accelerators for the production of ultra-short electron beams as drivers of incoherent and coherent radiation sources from plasma and

magnetic undulators\*\*. Initial quantitative measurements of the electron beam properties have been made. A high power (20 TW) femtosecond laser pulse is focused into a gas jet (length 2 mm) and electrons from the laser-induced plasma are self-injected into the accelerating potential of the plasma density wake behind the laser pulse. The electron beam pointing as it exits the gas jet is as large as 10 mrad. Understanding the pointing stability is an essential step for reproducible beam transport and we present a theoretical model to account for this behaviour. The beam divergence is as low as 2 mrad, which is consistent with a normalised emittance of the order of 1 pi mm mrad. The maximum central energy of the beam is ~90 MeV with r.m.s. relative energy spread as low as 0.8%. An analysis of this unexpectedly high beam quality is presented and its impact on the viability of a free-electron laser\*\*\* driven by such a beam is examined.

\* D. A. Jaroszynski et al., Phil. Trans. R. Soc. A 364, 689 (2006).

\*\* H.-P. Schlenvoigt et al., Nature Phys. 4, 130 (2008).

\*\*\* B. Shepherd and J. Clarke, Proc. EPAC 2006, 3580 (2006).

### Boosted Frame PIC Simulations of LWFA: Towards the Energy Frontier

S. F. Martins, S. Fonseca, L. O. Silva (Instituto Superior Tecnico) W. Lu, W. B. Mori (UCLA)

We address full particle-in-cell simulations of the next generation of Laser Wakefield Accelerators with energy gains > 10 GeV. The distances involved in these numerical

experiments are very demanding in terms of computational resources and are not yet possible to (easily) accomplish. Following the work on simulations of particle beam-plasma interaction scenarios in optimized Lorentz



frames by J.-L. Vay\*, the Lorentz transformation for a boosted frame was implemented in OSIRIS\*\*, leading to a dramatic change in the computational resources required to model LWFA. The critical implementation details will be presented, and the main difficulties discussed. Quantitative comparisons between lab/boost frame results with OSIRIS, QuickPIC\*\*\*, and experiment will be given. Finally, the results of a three-dimensional PIC simulation of a > 10 GeV accelerator stage will be presented, including a discussion on radiation emission.

\* J.-L. Vay, PRL 98, 130405 (2007)

\*\* R. A. Fonseca et al., LNCS 2329, III-342 (Springer-Verlag, 2002)

\*\*\* C. Huang, et al., JCP 217, Issue 2, 20 (2006)

### X-Band Photonic Bandgap (PBG) Breakdown Structure Experiment

A photonic bandgap (PBG) structure is designed to obtain first results on both electric and magnetic field effects in PBG structures at realistic operating conditions: high power, high rep rate, reasonable aperture. To provide a baseline comparison, the PBG structure has been designed to interface with SLAC mode launchers for a single cell breakdown test. Design, fabrication and cold test are presented for the 1C-SW-A5.65-T4.6-Cu-PBG structure. Breakdown results for this structure are compared with results for single cell breakdown tests of pillbox copper (1C-SW-A5.65-T4.6-Cu) structures.

**R. A. Marsh**, M. A. Shapiro, R. J. Temkin (MIT/PSFC) V. A. Dolgashev, S. G. Tantawi (SLAC)

## TH4PB — Parallel Oral LSAFEL

### LNLS-2: A New High Performance Synchrotron Radiation Source for Brazil

P. F. Tavares, R. H.A. Farias, L. Liu, X. R. Resende (LNLS)

We present an overview of a new synchrotron radiation source currently being designed at the Brazilian Synchrotron Light Laboratory (LNLS) in Campinas. The LNLS-1 light source, based on a 1.37 GeV storage ring, has been in routine operation since 1997. The LNLS-2 light source will consist of an injector system and a low emittance 2.5 GeV electron storage ring capable of delivering undulator radiation with average brightness in excess of  $10^{20}$  photons/sec/0.1%/mm<sup>2</sup>/mrad<sup>2</sup> in the few hundred eV to several tens of keV photon energy range. High flux radiation up to 100 keV will also be available with the use of superconducting wigglers. In this work, we present the basic design considerations and parameters for a proposed magnetic lattice for LNLS-2, with special attention to providing solutions for the realization of low emittance which are cost effective regarding both the construction investment as well as the operation of the facility. In particular, the possibility of the large scale use of permanent magnet technology for the storage ring lattice magnets is discussed.

### Recent Developments at Diamond Light Source

R. P. Walker (Diamond)

Diamond Light Source, the UK's 3rd generation synchrotron light facility, became operational in 2007. We report here on a number of important recent developments, aimed at increasing its operational performance. In particular, we present our initial experience with regular top-up injection, which began at the end of October 2008, including its reliability and effect on beam stability. We also discuss the issues that have been faced in increasing the beam current to its design value of 300 mA. Diamond currently operates with 10 in-vacuum undulators with a specified initial minimum operating gap of 7 mm. We report on our efforts to understand and control the distribution of beam losses in the ring, in order to allow operation with gaps as small as the target value of 5 mm. On behalf of the Diamond Machine Staff

### Major Upgrade Activity of the PLS in PAL: PLS-II

S. H. Nam (PAL)

The Pohang Accelerator Laboratory (PAL) celebrated its 20th anniversary this year. After the completion of the Pohang Light Source (PLS) construction in 1994, the PLS started user service with two beamlines in 1995. The PLS energy was 2.0 GeV. The first major upgrade of the PLS had been done from 2000 to 2002, in which operation energy of the PLS was increased from 2.0 GeV to 2.5 GeV. The number of beamlines has been steadily increased since the start of user service. The number of beamlines currently in service is 28. Three beamlines are under construction. Number of users and performed experiments in 2007 were respectively 2553 and 837. Average impact factor of published papers is over 3.0, which is one of the best among Korean research institutes. Based on such success, the PAL is pursuing the second upgrade plan, called the PLS-II. The PLS will be upgraded its energy from 2.5 GeV to 3.0 GeV. With the upgrade, it will be possible to construct ten more insertion devices. The brightness of the PLS-II will be more than a order higher compared to the current PLS. In this presentation, details of the PLS-II project will be introduced.

This work was supported by the MEST (Ministry of Education, Science and Technology) and the POSCO (POhang iron and Steel making COmpany) in Korea.

### Study of Emittance Degradation of Sources in Presence of Transverse RF Deflectors in QBA Lattice of Perfect TPS Machine

Since use of such deflecting structures leads to growth in vertical amplitude and slope of electrons, non-zero momentum compaction factor, nonlinearities and coupling of the elements between the deflectors affect the tilted electrons even in perfect machine and change their amplitude and slope at second deflecting cavity. It causes the second deflector cannot cancel the first kick perfectly and leads to increase of transverse emittance. We have studied simulation and detail analyses of effects of non-zero momentum compaction factor and sextupoles between the deflecting structures, as sources of emittance degradation in TPS and evaluate how much emittance growths due to the effects. We also contrast the statuses of interior sextupoles and elucidate them.

H. Ghasem, G.-H. Luo (NSRRC)

TH4PBC04

### Recent Results of the SPARC FEL Experiments

The SPARC project foresees the realization of a high brightness photo-injector to produce a 150-200 MeV electron beam to drive 500 nm FEL experiments in SASE, Seeding and Single Spike configurations. The SPARC photoinjector is also the test facility for the recently approved VUV FEL project named SPARX. The second stage of the commissioning, that is currently underway, foresees a detailed analysis of the beam matching with the linac in order to confirm the theoretical prediction of emittance compensation based on the “invariant envelope” matching, the demonstration of the “velocity bunching” technique in the linac and the characterisation of the spontaneous and stimulated radiation in the SPARC undulators. In this paper we report the experimental results obtained so far. The possible future energy upgrade of the SPARC facility to produce UV radiation and its possible applications will also be discussed.

M. Ferrario, D. Alesini, M. Bellaveglia, R. Boni, M. Boscolo, M. Castellano, E. Chiadroni, A. Clozza, L. Cultrera, G. Di Pirro, A. Drago, A. Esposito, L. Ficcadenti, D. Filippetto, V. Fusco, A. Gallo, G. Gatti, A. Ghigo, C. Marrelli, M. Migliorati, A. Mostacci, E. Pace, L. Palumbo, L. Pellegrino, R. Ricci, B. Spataro, F. Tazzioli, S. Tomassini, C. Vaccarezza, M. Vescovi, C. Vicario (INFN/LNF) G. Andonian, G. Marcus, J. B. Rosenzweig (UCLA) A. Bacci, I. Boscolo, F. Castelli, S. Cialdi, D. Giove, C. Maroli, V. Petrillo, A. R. Rossi, L. Serafini (Istituto Nazionale di Fisica Nucleare) L. Catani, A. Cianchi, B. Marchetti (INFN-Roma II) F. Ciocci, G. Dattoli, A. Dipace, A. Doria, G. P. Gallerano, L. Giannessi, E. Giovenale, G. L. Orlandi, S. Pagnutti, A. Petralia, M. Quattromini, C. Ronsivalle, E. Sabia, I. P. Spassovsky, V. Surrenti (ENEA C. R. Frascati) M. Mattioli, M. Serluca (INFN-Roma)

TH4PBC05

### Performance and Capabilities of Upgraded High Intensity Gamma-ray Source at Duke University

Since 2008, the upgraded High Intensity Gamma-ray Source (HIGS) at the Duke FEL Lab has provided users with gamma beams of unprecedented quality for scientific research. The recently completed accelerator

Y. K. Wu, M. D. Busch, M. Emamian, J. F. Faircloth, S. M. Hartman, J. Li, S. F. Mikhailov, V. Popov, G. Swift, P. W. Wallace, P. Wang (FEL/Duke University) C. R. Howell (TUNL)

TH4PBC06

upgrades include a HOM-damped RF cavity, a full-energy top-off booster injector, redesigned storage ring straight sections, and two new FELs. The HIGS facility is now capable of producing a high intensity gamma beam in a wide energy range (1 - 100 MeV) using commercial FEL mirrors. It has achieved an exceptionally high flux, up to  $\sim 1 \cdot 10^{10}$  g/s total (< 20 MeV), making it the world's most powerful Compton gamma source. It produces almost 100% polarized gammas, either linear or circular. At the HIGS, the gamma energy can be changed rapidly within a factor of three in minutes. Operated by Triangle Universities Nuclear Laboratory since summer 2008, the HIGS is a dedicated Compton gamma source, capable of producing more than 2,000 h of gamma beam time per year with a five-day, two-shift schedule. Future development at the HIGS includes higher energy gamma beams toward the pion threshold and a rapid switch of circular polarization.

## FR1RA — Parallel Oral LEAC

### CLIC Project Overview

The CLIC study is exploring the scheme for an electron-positron collider with a centre-of-mass energy of 3 TeV in order to make the multi-TeV range accessible for physics. The current goal of the project is to demonstrate the feasibility of the technology by the year 2010. Recently, important progress has been made concerning the high-gradient accelerating structure tests and the experiments with beam in the CLIC test facility, CTF3. On the organizational side, the CLIC international collaborations have significantly gained momentum considerably boosting the CLIC study.

**R. Tomas** (CERN)

### The Conversion and Operation of the Cornell Electron Storage Ring as a Test Accelerator (CesrTA) for Damping Rings Research and Development

In March of 2008, the Cornell Electron Storage Ring (CESR) concluded twenty eight years of colliding beam operations for the CLEO high energy physics experiment. We have reconfigured CESR as an ultra low emittance damping ring for use as a test accelerator (CesrTA) for International Linear Collider (ILC) damping ring R&D. The primary goals of the CesrTA program are to achieve a beam emittance approaching that of the ILC Damping Rings with a positron beam, to investigate the interaction of the electron cloud with both low emittance positron and electron beams, to explore methods to suppress the electron cloud, and to develop suitable advanced instrumentation required for these experimental studies (in particular a fast x-ray beam size monitor capable of single pass measurements of individual bunches). We report on progress with the CESR conversion activities, the status and schedule for the experimental program, and the first experimental results that have been obtained.

**M. A. Palmer**, J. P. Alexander, M. G. Billing, J. R. Calvey, S. S. Chapman, G. W. Codner, J. A. Crittenden, J. Dobbins, G. Dugan, M. J. Forster, R. E. Gallagher, S. W. Gray, S. Greenwald, D. L. Hartill, W. H. Hopkins, D. L. Kreinick, Y. Li, X. Liu, J. A. Livezey, V. Medjidzade, R. Meller, S. B. Peck, D. P. Peterson, M. C. Rendina, D. H. Rice, N. T. Rider, D. L. Rubin, D. Sagan, J. W. Sexton, J. P. Shanks, J. P. Sikora, E. N. Smith, K. W. Smolenski, C. R. Strohman, A. B. Temnykh, M. Tigner, S. Vishniakou, W. S. Whitney, T. Wilksen, H. A. Williams (CLASSE) J. M. Byrd, C. M. Celata, J. N. Corlett, S. De Santis, M. A. Furman, A. Jackson, R. Kraft, D. V. Munson, G. Penn, D. W. Plate, A. W. Rawlins, M. Venturini, M. S. Zisman (LBNL) J. W. Flanagan, P. Jain, K. Kanazawa, K. Ohmi, Y. Suetsugu (KEK) K. C. Harkay (ANL) Y. He, M. C. Ross, C.-Y. Tan, R. M. Zwaska (Fermilab) R. Holtzapple (CalPoly) J. K. Jones (STFC/DL/ASTeC) J. Kandaswamy (Cornell University, Department of Physics) D. Kharakh, M. T.F. Pivi, L. Wang (SLAC) A. Wolski (Cockcroft Institute)

### ATF2 Commissioning

A. Seryi, J. W. Amann, P. Bellomo, B. Lam, D. J. McCormick, S. Molloy, J. Nelson, J. M. Paterson, M. T.F. Pivi, T. O. Raubenheimer, C. M. Spencer, G. R. White, M. Woodley, Y. T. Yan, F. Zhou (SLAC) D. Angal-Kalinin (STFC/DL/ASTeC) R. Apsimon, A. S. Aryshev, G. A. Blair, B. Constance, V. Karataev, C. Perry, J. Resta-López, C. Swinson (JAI) S. Araki, H. Hayano, Y. Honda, K. Kubo, T. Kume, S. Kuroda, M. Masuzawa, T. Naito, T. Okugi, R. Sugahara, T. Tauchi, N. Terunuma, J. Urakawa, K. Yokoya (KEK) S. Bai, J. Gao (IHEP Beijing) P. Bambade, Y. Renier, C. Rimbault (LAL) B. Bolzon, N. Geffroy, A. Jeremie (IN2P3-LAPP) S. T. Boogert (Royal Holloway, University of London) P. Burrows (OXFORDphysics) G. B. Christ-ian (ATOMKI) J.-P. Delahaye, R. Tomas, F. Zimmermann (CERN) E. Elsen (DESY) E. Gianfelice-Wendt, M. C. Ross, M. Wendt (Fermilab) A. Heo, E.-S. Kim, H.-S. Kim (Kyungpook National University) Y. Iwashita, T. Sugimoto (Kyoto ICR) Y. Kamiya (ICEPP) S. Komamiya, M. Orouku, T. S. Suehara, T. Yamanaka (University of Tokyo) A. Lyapin (UCL) B. Parker (BNL) T. Sanuki (Department of Physics, Graduate School of Science, Tohoku University) A. Scarfe (UMAN) T. Takahashi (Hiroshima University, Graduate School of Science) A. Wolski (Cockcroft Institute)

ATF2 is a final-focus test beam line that attempts to focus the low-emittance beam from the ATF damping ring to a beam size of about 37 nm, and at the same time to demonstrate nm beam stability, using numerous advanced beam diagnostics and feedback tools. The construction is well advanced and beam commissioning of ATF2 has started in the second half of 2008. ATF2 is constructed and commissioned by ATF international collaborations with strong US, Asian and European participation.

### Achievements in CTF3 and Commissioning Status

S. Bettoni, R. Corsini, A. E. Dabrowski, S. Doebert, D. Manglunki, P. K. Skowronski, F. Tecker (CERN)

The aim of the last CLIC test facility CTF3, built at CERN by an international collaboration, is to prove the main feasibility issues of the CLIC two-beam acceleration technology.

The main points which CTF3 should demonstrate by 2010 are the generation of a very high current drive beam and its use to efficiently produce and transfer RF power to high-gradient accelerating structures. To prove the first point a delay loop and a combiner ring have been built, following a linac, in order to multiply the current by a factor two and four, respectively. The power generation and transfer and the high gradient acceleration are instead demonstrated in the CLIC experimental area (CLEX), where the drive beam is decelerated in special power extraction structures (PETS). In this paper we describe the results of the combination in the ring, properly working after the cure of the vertical instability which limited high current operation, and the commissioning of the new beam lines installed in the second half of 2008, including response matrix analysis and dispersion measurements used to validate the optics model. The results of the energy transfer will be also briefly described.

### Update on Optics Modeling for the ATF Damping Ring at KEK

K. Kubo, S. Kuroda, T. Okugi (KEK) K. G. Panagiotidis, A. Wolski (The University of Liverpool) M. Woodley (SLAC)

One of the goals of the Accelerator Test Facility (ATF) at KEK is to demonstrate ultra-low vertical emittance for linear colliders. Highly precise correction of the vertical dispersion and betatron coupling will be needed to achieve the target of 2 pm (which will be required for ILC). Optics

correction and tuning must be supported by an accurate model, which can be developed from a variety of beam measurements, including orbit response to dipole kicks, beta functions at the quadrupoles, etc. Here, we report experimental data and the status of the model and low-emittance tuning.

## FR1PB — Parallel Oral COLLIDER

### RHIC Progress and Future

C. Montag (BNL)

The talk reviews the RHIC performance, including the unprecedented manipulations of polarized beams and the recent low energy operations. Achievements and limiting factors of RHIC operation are discussed, e.g. intrabeam scattering, electron cloud, beam-beam effects, magnet vibrations, and the efficiency of novel countermeasures such as bunched beam stochastic cooling, beam conditioning and chamber coatings. The future upgrade plans and the pertinent R&D program will also be presented.

### Electron-Ion Collider Initiatives

R. Milner (MIT)

There are presently three initiatives for a hadron-lepton collider in the world: eRHIC at BNL, ELIC at JLab (both part of the EIC collaboration), and LHeC at CERN. This talk presents the status of these initiatives and compares their different thrusts in physics research as well as in their approach to the facility design, pointing out the strengths and limits of each particular proposal.

### LHC Upgrade Scenarios

J.-P. Koutchouk, F. Zimmermann (CERN)

An LHC high-luminosity upgrade has been studied by various European and international collaborations since about 2001. Ingredients of such an LHC upgrade include the optimization of the IR layout, new high-field or large-aperture triplet quadrupoles, chromatic correction, possibly detector-integrated slim magnets, crab cavities, beam-beam compensators, operation in a regime of large Piwinski angle, luminosity leveling for reduced detector pile up, heat-load, background, and radiation damage due to the collision debris, and a renovation of the injector complex. Scenarios, decision paths, and present R&D efforts will be presented.

### Recent Tevatron Operational Experience

A. Valishev, G. Annala, D. S. Bollinger, B. M. Hanna, R. S. Moore, D. A. Still, C.-Y. Tan, X. Zhang (Fermilab)

Over the past year Tevatron has been routinely operating at initial luminosity over  $3 \cdot 10^{32}$ . The high luminosity regime highlighted several issues that became the focus for operational improvements. In this report we summarize the experience in such areas as mitigation of particle losses, maintaining orbit and optics stability, and identification of aperture restrictions.



**The Large Hadron-electron Collider (LHeC) at the LHC**

Sub-atomic physics at the energy frontier probes the structure of the fundamental quanta of the Universe. The Large Hadron Collider (LHC) at CERN opens for the first time the “terascale” (TeV energy scale) to experimental scrutiny, exposing the physics of the Universe at the sub-attometric ( $\sim 10^{-19}$  m,  $10^{-10}$  as) scale. The LHC will also take the science of nuclear matter to hitherto unparalleled energy densities (low-x physics). The hadron beams, protons or ions, in the LHC underpin this horizon, and also offer new experimental possibilities at this energy scale. A Large Hadron electron Collider, LHeC, in which an electron (positron) beam of energy (70 to 140 GeV) is in collision with one of the LHC hadron beams, makes possible terascale lepton-hadron physics. The LHeC is presently being evaluated in the form of two options, “ring-ring” and “linac-ring”, either of which operate simultaneously with pp or ion-ion collisions in other LHC interaction regions. Each option takes advantage of recent advances in radio-frequency, in linear acceleration, and in other associated technologies, to achieve ep luminosity as large as  $10^{33}$  cm<sup>-2</sup>s<sup>-1</sup>.

**F. Zimmermann**, F. Bordry, H.-H. Braun, O. S. Brüning, H. Burkhardt, R. Garoby, E. B. Holzer, J. M. Jowett, T. P.R. Linnecar, K. H. Mess, J. A. Osborne, L. Rinolfi, D. Schulte, R. Tomas, J. Tuckmantel, A. de Roeck (CERN) H. Aksakal (N. U) S. Chattopadhyay, J. B. Dainton (Cockcroft Institute) A. K. Ciftci (Ankara University, Faculty of Sciences) A. L. Eide (EPFL) M. Klein (The University of Liverpool) S. Sultansoy (TOBB ETU) A. Vivoli (LAL) F. J. Willeke (BNL)

## FR1GR — Parallel Oral HEHAC

### Coherent Electron Cooling

V. Litvinenko (BNL)

Cooling intense high-energy hadron beams remains a major challenge in modern accelerator physics. Synchrotron radiation is still too feeble, while the efficiency of two other cooling methods, stochastic and electron, falls rapidly either at high bunch intensities (i.e. stochastic of protons) or at high energies (e-cooling). In this talk a specific scheme of a unique cooling technique, Coherent Electron Cooling, will be discussed. The idea of coherent electron cooling using electron beam instabilities was suggested by Derbenev in the early 1980s, but the scheme presented in this talk, with cooling times under an hour for 7 TeV protons in the LHC, would be possible only with present-day accelerator technology. This talk will discuss the principles and the main limitations of the Coherent Electron Cooling process. The talk will describe the main system components, based on a high-gain free electron laser driven by an energy recovery linac, and will present some numerical examples for ions and protons in RHIC and the LHC and for electron-hadron options for these colliders. BNL plans a demonstration of the idea in the near future.

### Project X at Fermilab

S. D. Holmes (Fermilab)

As the Fermilab Collider program draws to a close, a vision has emerged of an experimental program built around the high intensity frontier. The centerpiece of this program will be a new 8 GeV superconducting  $H^+ - H^-$  linac which will support world leading programs in long baseline neutrino experimentation and the study of rare processes. Based on technology shared with the International Linear Collider, Project X will support the generation of multi-MW beams at 60-120 GeV from the Main Injector, simultaneous with several hundred kilowatts at 8 GeV from the Recycler. Project X will also open the possibility of a future energy frontier facility based on the utilization as the front end of a muon storage ring based facility.

### Advanced Design of the FAIR Storage Ring Complex

F. Steck (GSI)

The FAIR storage ring complex comprises three storage rings with a magnetic rigidity of 13 m. Each of the rings, CR, RESR, and NESR, serves specific tasks in the preparation of secondary beams, rare isotopes and antiprotons, or for experiments with heavy ion beams. The CR is optimized for fast stochastic pre-cooling of secondary beams. The RESR design includes optimization of antiproton accumulation. The design of the NESR for experiments with heavy ions, deceleration of ions or antiprotons for a subsequent low energy facility, and the accumulation of rare isotope beams is proceeding. This report summarizes various new concepts conceived in the design process of this new storage ring facility.

### Polarized Proton Performance of AGS in Run-9 Operation

After installation of two partial snakes in the Brookhaven Alternating Gradient Synchrotron (AGS), a polarized proton beam with  $1.5 \cdot 10^{11}$  intensity and 65% polarization has been achieved. There are residual polarization losses due to horizontal resonances over the whole energy ramp and some polarization loss due to vertical intrinsic resonances. Many efforts have been put in to reduce the emittances coming into the AGS and to consequently reduce polarization loss. This paper presents the accelerator setup and preliminary results from run-9 operations.

**H. Huang**, L. Ahrens, M. Bai, K. A. Brown, C. J. Gardner, J. W. Glenn, F. Lin, A. U. Luccio, W. W. MacKay, T. Roser, S. Tepikian, N. Tsoupas, K. Yip, K. Zeno (BNL)

### The LHC Injection Tests

A series of LHC injection tests was performed in August and September 2008. The first saw beam injected into sector 23; the second into sectors 78 and 23; the third into sectors 78-67 and sectors 23-34-45. The fourth, into sectors 23-34-45, was performed the evening before the extended injection test on the 10th September which saw both beams brought around the full circumference of the LHC. The tests enabled the testing and debugging of a number of critical control and hardware systems; testing and validation of instrumentation with beam for the first time; deployment, and validation of a number of measurement procedures. Beam based measurements revealed a number of machine configuration issues that were rapidly resolved. The tests were undoubtedly an essential precursor to the successful start of LHC beam commissioning. This paper provides an outline of preparation for the tests, the machine configuration and summarizes the measurements made and individual system performance.

**M. Lamont**, R. Alemany-Fernandez, R. Bailey, P. Collier, B. Goddard, V. Kain, A. Macpherson, L. Ponce, S. Redaelli, W. Venturini Delsolaro, J. Wenninger (CERN)

## FR2RA — Parallel Oral PPHIB

### R&D for Linear Induction Accelerators in China

J. Deng (CAEP/IFP)

It has been three decades since the research and development of key technologies and components started at the Institute of Fluid Physics, CAEP, for the linear induction accelerator (LIA). The first LIA was built in 1989 with beam parameters of 1.5 MeV, 3 kA and pulse width of 90 ns. Later the SG-I LIA (3.3 MeV, 2 kA, 90 ns) was developed for FEL in 1991. The first Linear Induction Accelerator X-Ray Facility (LIAXF, 10 MeV, 2 kA, 90 ns, spot size about 6 mm in diameter) was built in 1993 and upgraded to 12 MeV with higher performance (LIAXFU, 12 MeV, 2.5 kA, 90 ns, spot size about 4 mm in diameter) in 1995. The Dragon-I LIA with the best quality (20 MeV, 2.5 kA, 80 ns, spot size about 1 mm in diameter) in the world was finished in 2003. The smallest LIA with double pulses separated by 300 ns (MiniLIA, 200 keV, 1 A, 80 ns) was developed in 2007 for beam physics studies.

### Measurement and Analysis of SPS Kicker Magnet Heating and Outgassing with Different Bunch Spacing

M. J. Barnes, K. Cornelis, L. Ducimetiere, E. Mahner, G. Papotti, G. Rumolo, V. Senaj, E. N. Shaposhnikova (CERN)

Fast kicker magnets are used to inject beam into and eject beam out of the CERN SPS accelerator ring. These kickers are generally ferrite loaded transmission line type magnets with a rectangular shaped aperture through which the beam passes. Unless special precautions are taken the impedance of the ferrite yoke can provoke significant beam induced heating, over several hours, even above the Curie temperature of the ferrite. At present the nominal bunch spacing in the SPS is 25 ns, however for an early stage of LHC operation it is preferable to have 50 ns bunch spacing. Machine Development (MD) studies have been carried out with an inter-bunch spacing of 25 ns, 50 ns or 75 ns. For some of the SPS kicker magnets the 75 ns bunch spacing resulted in considerable beam induced heating. In addition the MDs showed that 50 ns bunch spacing could result in a very rapid pressure rise in the kicker magnet and thus cause an interlock. This paper discusses the MD observations of the SPS kickers and analyses the available data to provide explanations for the phenomena: possible remedies are also discussed.

### A Fast Kicker Using A Rectangular Dielectric Wakefield Accelerator Structure

J. L. Hirshfield (Omega-P, Inc.) T. C. Marshall (Columbia University) S. V. Shchelkunov (Yale University, Beam Physics Laboratory) G. V. Sotnikov (NSC/KIPT)

A rectangular two-beam dielectric wakefield accelerator (DWA) module is described which, when energized by a 14 MeV, 50 nC drive bunch moving in one channel, is shown to deflect a test bunch which originates from an independent source moving in a parallel channel. We show that such a module, 30 cm in length, can deflect transversely a 1 GeV electron by  $\sim 1$  mrad in 1 ns, after which a following bunch can pass undeflected. Apparatus required to accomplish this task consists of a laser-cathode RF gun and an optional linac to generate the drive bunch. The associated DWA components could be used for kicker applications in a storage ring or a more energetic electron linear accelerator. An example we describe is tailored to a DWA demonstration project underway at the Argonne Wakefield Accelerator, but the design can be altered to allow for changes including a lower-energy but still relativistic drive bunch. The kicker, through appropriate design, can deflect one out of several bunches in a storage ring, leaving the remaining bunches essentially unaffected by the structure.

## FR2PB — Parallel Oral BDEMF

### Advances in Impedance Theory

A remarkable progress over the last decade in development of computer codes significantly advanced our capabilities in calculation of wakefields and impedances for accelerators.

**G. V. Stupakov (SLAC)**

There are however a number of practical problems that, when approached numerically, require a huge mesh, and hence memory, or an extraordinary CPU power, or both. One class of such problems is related to wakes of ultra short bunches, typical for many next generation electron/positron accelerators and photon sources. Another class is represented by long shallow collimators and tapers, often with non round cross sections. The numerical difficulties with these problems can be traced to a small parameter in the system, such as, e.g., a ratio of the bunch length to the length of a taper. It is remarkably, however, that the same small parameter often allows developing approximate analytical methods that provide a simplified solution to the impedance problem. In this paper, we review recent results in the analytical theory of wakefields, which include calculation of the wakes of very short bunches, long transitions and some special cases of the resistive wall impedance.

### Gravitational Instability of a Nonrotating Galaxy

Gravitational instability of a star distribution in a galaxy is a well-known phenomenon in astrophysics. This problem can be

**A. Chao (SLAC)**

analyzed using the standard tools developed in accelerator physics for analyzing the onset of beam instability and loss of Landau damping. An attempt is made here for a nonrotating galaxy. Predictions for the maximum stable galaxy size are in remarkable agreement with observations.

## FR2GR — Parallel Oral APAC

FR2GRI01

### USPAS and Its Role in Educating the Next Generation of Accelerator Scientists and Engineers

W. A. Barletta (MIT)

Accelerators are essential engines of discovery in fundamental physics, biology, and chemistry. Particle beam based instruments in medicine, industry and national security constitute a multi-billion dollar per year industry. More than 55,000 peer-reviewed papers having accelerator as a keyword are available on the Web. Yet only a handful of universities offer any formal training in accelerator science. The United States Particle Accelerator School (USPAS) is a National Graduate Educational Program that has developed a highly successful educational paradigm that, over the past twenty years, has granted more university credit in accelerator / beam science and technology than any university in the world. The USPAS offers a responsive and balanced curriculum of science, engineering, computational and hands-on courses. Sessions are held twice annually, hosted by major US research universities that approve course credit, certify the USPAS faculty, and grant course credit. Somewhat different approaches to accelerator education are offered by other programs in Europe and Asia such as the CERN Accelerator School, JUAS, and the KEK school.

Accelerators are essential engines of discovery in fundamental physics, biology, and chemistry. Particle beam based instruments

FR2GRI02

### The SPIRAL 2 Superconducting Linac

R. Ferdinand (GANIL)

The SPIRAL 2 superconducting linac is currently under construction. This talk describes the collaboration effort with industrial partners to fabricate the two cryomodule families: the low beta Cryomodule A, and the high beta Cryomodule B. The low beta family is composed of 12 single cavity cryomodules. The high energy section is composed of 7 cryomodules hosting 2 cavities each. The design goal for the accelerating field Eacc of the SPIRAL 2 QWRs is 6.5 MV/m.

The SPIRAL 2 superconducting linac is currently under construction. This talk describes the collaboration effort with industrial

## FR3RB — Closing Plenary LSAFEL, HEHAC, LEAC

## Single Particle Diffraction at FLASH

Radiation damage limits the resolution of structural information obtained by X-ray diffraction. We are developing coherent diffractive imaging of biological specimens beyond conventional radiation damage resolution limits.

The soft X-ray free-electron-laser (FEL) in Hamburg, FLASH\*, was used to generate high-resolution low-noise coherent diffraction patterns from nanostructured non-periodic objects before they turned into a plasma and exploded during single -10--30 fs long X-ray pulses\*\*,\*\*\*. Iterative phase retrieval algorithms were used to reconstruct images of the objects\*\*\*\*. Recent single particle diffraction experiments at FLASH, achieved in part due to the bunch train time pattern available from this superconducting linear accelerator, will be described. Data from single nanoparticles, their clusters and single cells will be discussed. Extending this approach to hard X-ray FELs, such as the Linac Coherent Light Source (LCLS) at the SLAC National Accelerator Laboratory, is anticipated to facilitate near atomic resolution imaging of nm-to-um-sized objects without the need for crystallization\*\*\*\*\*.

\* Ayvazyan et al Eur Phys J D 2006 37 297

\*\* Chapman et al Nat Phys 2006 2 839

\*\*\* Bogan et al Nano Lett 2008 8 310

\*\*\*\* Marchesini Rev Sci Instr 2007 78 011301

\*\*\*\*\* Neutze et al Nature 2000 406 752

**M. J. Bogan** (SLAC) H. Chapman (DESY) J. Hajdu (Uppsala University, Biomedical Centre)

FR3RBI01

## Science and Techniques of Ultra-Fast Electron and Photon Sources

The author will review the remarkable world-wide field and activities of ultra-fast and exotic electron and photon sources and

the science that can be accomplished through their use, as well as several specialized new sources of accelerated electrons. The areas to be covered include: the generation, manipulation and measurement of few-fs to sub-fs ultra-high phase space density electron bunches (10-1000 MeV) with ultra-intense waveform-controlled few-cycle light; the generation and measurement of few-fs to sub-fs hard X-ray pulses from the interaction of high-density electron bunches with periodic structures; laser wakefield accelerators and other exotic emerging sources; the use of these devices for science, including control and real-time observation of electron dynamics on atomic & sub-atomic scales.

**S. Karsch** (MPQ) **S. Karsch** (LMU)

FR3RBI02

## The New Generation of Neutron Sources

Powerful new tools for neutron-based research are coming on line throughout the world. After summarizing developments

that have permitted spallation neutron sources to reach the megawatt threshold, the speaker will describe opportunities to improve performance, both by delivering higher power and by making more effective use of available power. In discussing the new science that is being or will be produced by this new generation of neutron sources,

**T. E. Mason** (ORNL)

FR3RBI03

the speaker will highlight recent results from the Spallation Neutron Source and review progress on current projects in Europe and Asia.

### The Neutrino Factory - The Final Frontier in Neutrino Physics?

A. D. Bross (Fermilab)

This talk will present arguments that the Neutrino Factory - an extremely intense source of flavor-tagged neutrinos from muon decays in a storage ring - gives the best physics reach for CP violation, as well as virtually all parameters in the neutrino oscillation parameter space. It will describe the physics capabilities of a baseline Neutrino Factory as compared to other possible future facilities (beta-beam and super-beam facilities), give an overview of the accelerator complex, describe the current international R&D program and present a potential time line for the design and construction of the facility. Although the baseline study focuses on a facility with muon energy of 25 GeV, a concept for a Low-Energy ( $\sim 4$  GeV) Neutrino Factory has also been developed and its physics reach will also be discussed. Finally, it will be shown that a facility of this type is unique in that it can present a physics program that can be staged, addressing exciting new physics at each step. Eventually it can lead to an energy-frontier muon collider. A muon accelerator facility is a natural extension that can exploit the high intensity potential at FNAL starting with Project X.

### Progress Toward the International Linear Collider

N. J. Walker (DESY)

With a now extended plan to 2012, the ILC Global Design Effort Technical Design Phase focuses on key R&D to verify performance goals and to reduce both technical risk and cost. This talk will review the progress during the last two years, and plans for the future.



## MO6PF — Afternoon Poster MAGNET

### Design of Permanent Magnet Dipoles for the LNLS2 Electron Storage Ring

We present several alternative designs of hybrid bending magnets based on the use of ferrite blocks with steel pole pieces to be used in the new Brazilian storage ring - LNLS2. Their main magnetic and mechanical characteristics are presented. Such models are compared to electromagnet magnets, and some advantages and disadvantages are listed, as well as a cost estimate.

G. Tosin, R. Basilio, J. F. Citadini (LNLS)

### System Based on Homogeneous Dipolar Field Magnet and a Reference Search Coil for Calibration of Magnetic Field Sensors

The calibration of magnetic sensors is recognized as being of fundamental importance, especially for characterization of Undulators. For them, the field profile determines

the intensities of the photon fluxes, their energies of emission and the orbit distortion. A simple system built to calibrate magnetic sensors is presented. This system consists in a very homogeneous magnetic field generated by an electromagnet dipole. The accurate field measurement is performed by a coil, named reference coil, with well determined dimensions. Sources of errors are analyzed and the system accuracy and precision are found.

J. F. Citadini, M. Potye, G. Tosin (LNLS)

### Specifications and R&D Program on Magnet Alignment Tolerances for NSLS-II

The NSLS-II light source is a proposed 3 GeV storage ring, with the potential for ultra-low emittance\*. Despite the reduced emittance goal for the bare lattice, the closed orbit amplification factors are on average >50 in both planes, for random quadrupole alignment errors. The high chromaticity will also require strong sextupoles and the low 3 GeV energy will require large dynamic and momentum aperture to insure adequate lifetime. This will require tight alignment tolerances (~30microns) on the multipole magnets during installation. By specifying tight alignment tolerances of the magnets on the support girders, the random alignment tolerances of the girders in the tunnel can be significantly relaxed. Using beam based alignment to find the golden orbit through the quadrupole centers, the closed orbit offsets in the multipole magnets will then be reduced to essentially the alignment errors of the magnets, restoring much of the DA and lifetime of the bare lattice. Our R&D program to achieve these tight alignment tolerances of the magnets on the girders using a vibrating wire technique\*\*, will be discussed and initial results presented.

\*Work presented on behalf of the NSLS-II Design Team, CDR(2006) and CD2(2007).

\*\*A. Jain, et al, International Workshop on Accelerator Alignment, Tsukuba, Japan, Feb.11-15, 2008.

S. L. Kramer, A. K. Jain (BNL)

MO6PFP001

MO6PFP002

MO6PFP003

MO6PFP004

### Small Gap Magnets and Vacuum Chambers for eRHIC

W. Meng, Y. Hao, A. K. Jain, V. Litvinenko, G. J. Mahler, J. E. Tuozzolo (BNL)

eRHIC, a future high luminosity electron-ion collider at BNL, will add polarized electrons to the list of colliding species in RHIC. A 10-to-30 GeV electron energy recovery linac will require up to six passes around the RHIC 3.8 km circumference. We are developing and testing small (3-to-5 mm gap) dipole and quadrupole magnets and vacuum chambers for cost-effective eRHIC passes. We are also studying the sensitivity of eRHIC pass optics to magnet and alignment errors in such a small-magnet structure. We present the magnetic and mechanical designs of the small gap eRHIC components and prototyping test results.

eRHIC, a future high luminosity electron-ion collider at BNL, will add polarized electrons to the list of colliding species in RHIC. A 10-to-30 GeV electron energy recovery

MO6PFP005

### Steering Magnet Design for a Limited Space

M. Okamura, J. M. Fite, V. Lo Destro, D. Raparia (BNL)

A steering magnet is not a major component in a beam line, however it is usually needed in any real set up. Also it is hard to estimate the required field strength before the beam line construction, since the strength needed is determined by misalignment errors of other devices. Sometimes it is difficult to find enough space to install steering magnets because of other constraints on the length of the beamline. We compare two extreme designs of steering magnets. The first one is very thin steering magnet design which occupies only 6 mm in length and can be additionally installed as needed. The other is realized by applying extra coil windings to a quadrupole magnet and does not consume any length. We will present both designs in details and will discuss pros and cons.

A steering magnet is not a major component in a beam line, however it is usually needed in any real set up. Also it is hard to estimate

MO6PFP006

### Design of the NSLS-II High Order Multipoles

J. W. Jackson, J. Bengtsson, G. Danby, M. Rehak, J. Skaritka, C. J. Spataro (BNL)

The "figure eight" quadrupole concept has been generalized to high order multipoles: sextupole, octupole and decapole in a feasibility study. In order to avoid interference with the vacuum vessel, the yoke is interrupted, leaving gaps in a symmetric pattern. Moreover, significant space savings can be achieved while keeping adequate field quality.

The "figure eight" quadrupole concept has been generalized to high order multipoles: sextupole, octupole and decapole in a feasibility study. In order to avoid interference

MO6PFP007

### Design and Measurement of the NSLS-II Quadrupoles

M. Rehak, A. K. Jain, J. Skaritka, C. J. Spataro (BNL)

The quadrupole magnets for the National Synchrotron Light Source (NSLS-II) have stringent performance requirements. These magnets are relatively short compared to their aperture thus the pole profiles have been optimized in 3D using the new Optimizer module from VECTOR FIELDS in what may be one of the first such application of this module. A geometry lending itself to parameterization was developed while minimizing allowed harmonics serving as the objective functions. Prototypes were measured and have confirmed the design field quality.

The quadrupole magnets for the National Synchrotron Light Source (NSLS-II) have stringent performance requirements. These

### Design and Construction of NSLS-II Magnets

NSLS-II is a new state-of-the-art medium energy synchrotron light source designed to deliver world leading brightness and flux with top-off operation for constant output. Design and engineering of NSLS-II began

in 2005 and the beginning of construction and operations are expected to start in 2009 and 2015, respectively. The energy of the machine is 3Gev and the circumference 792 m. The chosen lattice requires tight on magnetic field tolerances for the ring magnets. These magnets have been designed with 3D Opera software. The required multipole field quality and alignment preclude the use of multifunctional sextupoles, leading to discrete corrector magnets in the storage ring. The corrector magnets are multifunctional and will provide horizontal and vertical steering as well as skew quadrupole. This paper describes the dipoles, quadrupoles, sextupoles, and corrector magnets design and prototyping status of the NSLS-II.

**J. Skaritka, J. Bengtsson, W. Guo, R. C. Gupta, J. W. Jackson, A. K. Jain, S. L. Kramer, S. Krinsky, Y. Li, B. Nash, S. Ozaki, M. Rehak, S. Sharma, C. J. Spataro, T. Tanabe, F. J. Willeke (BNL)**

MO6PFFP008

### Design and Measurement of the NSLS-II Correctors

Discrete corrector magnets are used for the 230 horizontal and vertical steering magnets in the NSLS-II storage ring. A unique design incorporates both dipole and skew quad correctors for(DC) steering in the same magnet. Separate AC (orbit feedback) correctors have also been designed. Comparison with alternate designs are presented as well as prototype measurements

**G. Danby, J. W. Jackson, A. K. Jain, M. Rehak, O. Singh, J. Skaritka, C. J. Spataro (BNL)**

MO6PFFP009

### Design and Measurement of the NSLS-II Sextupoles

The Sextupole magnets for the National Synchrotron Light Source (NSLS-II) have stringent performance requirements. These magnets have a faceted pole profile departing from the classic shape due to constraint imposed by the vacuum tube. Three different geometric features were used as parameters to minimize unallowed harmonics. Prototypes were measured and have confirmed the good field quality.

**C. J. Spataro, A. K. Jain, M. Rehak, J. Skaritka (BNL)**

MO6PFFP010

### Imperfection Investigation for the Main Magnet Construction for Compact Cyclotron

CYCIAE-100 is a 100 MeV, 200  $\mu\text{A}$   $\text{H}^{-1}$  cyclotron being constructed at CIAE. The tolerance of the magnetic field is as tight as 1.2 Gauss for isochronous field and 2 Gauss for first harmonics. Due to the absence of coil adjusting in this machine, a measure that helps to achieve a more compact structure (435 ton for the main magnet), the imperfection hence becomes a much more critical factor in our consideration. The effects by the various kinds of imperfection are investigated numerically and the imperfection fields are predicted for beam dynamics simulation, serving as a basic guidance in the magnet construction for CYCIAE-100. Some of the important results will be reported in this paper, including

**T. J. Zhang, Y. L. Lu, C. Wang, S. M. Wei, J. J. Yang, H. J. Yao, J. Q. Zhong (CIAE)**

1. the deformation of the main magnet by the gravity itself, 480 ton EM force and 120 ton vacuum pressure,  
2. segregation, inclusion and contraction cavity induced by the casting procedure,

MO6PFFP011

3. fabrication and assembling tolerance, and
4. thermal deformation.

### Correction Coil System for Compact High Intensity Cyclotron

T. J. Zhang, C. J. Chu, G. F. Song, S. M. Wei, J. Q. Zhong (CIAE)  
J. J. Yang (TUB)

CYCIAE-100, a high intensity compact cyclotron selected as a driving accelerator for BRIF, has 4 straight sectors. It is expected that only few correction coils are needed for

this compact machine. To limit the cost for the main magnet construction, the cast steel is used for the top/bottom yoke and return yoke. The imperfection may not be ignored and the harmonic coils on the return yokes will enable the field to reach the requirements easier during the shimming. The thermal deformation and the vacuum pressure may change the field distribution and then, we have to use trim coils to adjust the field during the machine operation. In this paper, the effect of correction coils (centering coils on the hills in the center region, trim coils in the valleys, harmonic coils on the return yokes) was investigated and will be presented. At least 2 sets of centering coils, about 8 sets of trim coils and 1 set of harmonic coils are required. The detail configuration of the correction coils will be introduced in the paper as well. Some experience for the coils inside the high vacuum tank is tested and the results will be given too.

### Field Interference Studies Between Bump Magnets with Different Coil Structures

J. Tang, Y. Chen (IHEP Beijing)

For magnets arranged so closely that the distance between them is comparable to the magnet apertures, the field interference be-

comes important. This is the case in the injection region at the China Spallation Neutron Source (CSNS) where several bump magnets are used to create fixed and dynamic local orbit bumps for the beam injection using the Hstripping and the phase space painting method. The reduction in the field integral due to the field interference will cause an orbit distortion, and the orbit bumps will be no longer localized. It is found that the end coil structure plays an important role in reducing the fringe field of a magnet. This has been analyzed by using both the image current method and three-dimensional magnetic field calculations. The saddle end coil instead of the compact end coil has been adopted at the CSNS. The relative reduction in the field integration after the optimization can meet the design requirement of about 1% or less.

### ALBA Synchrotron Quadrupoles and Sextupoles Manufacturing and Measurements

S. M. Gurov, A. M. Batrakov, M. F. Blinov, A. E. Levichev, E. B. Levichev, P. Martyshkin, I. N. Okunev, V. V. Petrov, S. I. Ruvinsky, T. V. Rybitskaya, A. V. Semenov, A. V. Sukhanov, P. Vobly (BINP SB RAS) E. Boter, D. Einfeld, M. Pont (ALBA)

BINP manufactured and measured the 243 multipoles of 9 types for ALBA storage ring. Magnets had severe requirements on the manufacturing tolerances and the alignment of their magnetic axis. The quadrupole magnets had 1mm laminated yoke with

bore diameter of 61mm. The sextupoles magnets had 0.5mm laminated yoke with bore diameter of 76mm. A rotating coils and Hall probes were used for magnetic measurements. The features of manufacturing and results of magnetic measurements are discussed.

### Fabrication and Production Test Results of Multi-Element Corrector Magnets for the Fermilab Booster Synchrotron

The fabrication of the multi-element corrector magnets for the Fermilab Booster synchrotron has just been completed. These water-cooled packages include six different corrector types - normal and skews oriented dipole, quadrupole and sextupole elements.

They will provide full orbit control, tune and chromaticity of the beam over the whole range of Booster energies, from 0.4 GeV to 8 GeV. During production, a set of quality assurance measurements were performed, including special thermal tests. This paper summarizes the results from these measurements as well as discussing some specific steps of the magnet fabrication process.

**G. Velev**, J. DiMarco, C. C. Drennan, D. J. Harding, V. S. Kashikhin, S. Kotelnikov, J. R. Lackey, A. V. Makarov, A. Makulski, R. Nehring, D. F. Orris, W. Pellico, E. Prebys, P. Schlabach, D. G.C. Walbridge (Fermilab)

MO6PFP015

### Magnetic Field Calculations for the Magnets of the High-Energy Storage Ring (HESR) at FAIR

Forschungszentrum Jülich has taken the leadership of a consortium responsible for the design, installation and commissioning of the High-Energy Storage Ring (HESR) for antiprotons as part of the FAIR project at GSI in Darmstadt, Germany.

Since a normal-conducting design of the ring has now been favored over the previously envisioned superconducting option, new calculations have been performed in order to assess the magnetic field characteristics of the normal-conducting dipole, quadrupole, and sextupole magnets of the HESR. This paper presents the physical features of the magnets and the results of the 3D calculations with emphasis on the various multipole contributions at the ends of the magnets.

**H. Soltner**, U. Bechstedt, R. Tolle (FZJ) J. G. De Villiers (iThemba LABS)

MO6PFP016

### Magnetic Field Control in Synchrotrons

The use of hadron beams delivered by normal conducting synchrotrons is highly attractive in various fundamental research applications as well as in the field of particle therapy. These applications require fast synchrotron operation modes with pulse-to-pulse energy variation and magnetic field slopes up to 10 T/s. The aims are to optimize the duty-cycle or to minimize treatment times for the patients as well as to provide extremely stable properties of the extracted beams, i.e. position and spill structure. Studies performed at the SIS18 synchrotron at GSI showed that not only the dipoles but the quadrupoles as well significantly contribute to the underlying time constants of the slowly extracted beam. An attempt has been made to measure the magnetic fields in synchrotron magnets with high precision and speed comparable to the current measurement with a DCCT. Additional magnetic field monitoring includes the retarding effects into the current control feedback loop neglecting the unfavourable dynamic effects from hysteresis and eddy currents. The presentation describes this controls approach, the results obtained at the HIT synchrotron and the SIS18 at GSI will be discussed.

**A. Peters**, E. Feldmeier, R. Steiner (HIT) H. Eickhoff, T. Knapp, C. P. Welsch (GSI) C. Schömers (MPI-K)

MO6PFP017

### The Pulsed Magnet System for the Simultaneous Injection of KEK-PF and KEKB Ring

T. Mimashi, K. Furukawa, N. Iida, K. Kakihara, M. Kikuchi, T. Miyajima, S. Nagahashi, M. Sato, M. Tawada, A. Ueda (KEK) T. Kudo (MELCO SC) H. Mori (Nichicon (Kusatsu) Corporation)

The KEK Linac delivers the beam to KEK-Photon factory storage ring, KEKB ring and the advanced ring for photon factory. In order to deliver the beam to the KEK-photon factory and KEKB ring simultaneously, the

pulsed bending magnet was installed at the end of KEKB Linac. The pulsed bending magnet extract 2.5GeV electron beam to the PF beam transfer line. The deflection angle of the magnet is 0.114 radians and the field strength is almost 1.22T. The peak current stability is better than 0.1% at 24kA operation. The maximum repetition rate is 25Hz. The 1.2m long ceramic chamber is inserted into the 1m long magnet. This system makes possible the top up operation of PF ring.

### Development of Pulsed Bending Magnet for Simultaneous Top-Up Injection to KEKB and PF

M. Tawada, M. Kikuchi, T. Mimashi, A. Ueda (KEK)

KEKB linac is a 600 m long electron linac and is used to deliver beam to four rings, KEKB HER ring (electron, 8 GeV), KEKB

LER ring (positron, 3.5 GeV), PF ring (electron, 2.5 GeV) and PF-AR ring (electron, 6.5 GeV). KEKB rings are operated under top-up injection mode and have occupied the current linac operation mostly. Simultaneous injection to three rings (KEKB HER and KEKB LER and PF) is required due to the top-up injection to PF ring is required recently. We have developed the pulsed bending magnet for this. This magnet produces 114 mrad deflection angle for 2.5 GeV PF beam. The fast switching between KEKB and PF can be performed up to 25 Hz. We will describe this magnet system in detail.

### Design Study of Superconducting Final Focus Quadrupoles for the Super KEKB Interaction Region

M. Tawada, Y. Funakoshi, H. Koiso, N. Ohuchi, K. Oide, K. Tsuchiya (KEK)

KEK is studying the design of the superconducting final focus quadrupoles for the Super KEKB. The system consists of quadrupole-doublet cooled at 1.9 K. The vertical fo-

cusings quadrupole has the maximum magnetic field more than 8 T in the superconducting coils. The field gradient at the magnet center is more than 80 T/m and the effective magnetic length is 0.25 m. The horizontal focusing quadrupole is designed with the field gradient of 9.5 T/m and the effective magnetic length of 1.0 m. These magnet parameters will be iterated in the process of optimizing the beam optics. In this paper, the conceptual design of final focusing system and magnets will be reported.

### Field Measurement System for CYCHU-10

A 10MeV  $H^+ - H^-$  compact cyclotron (CYCHU-10) is under construction in Huazhong University of Science and Technology. This paper presents a field measurement system for

measuring the cyclotron magnet. A Hall probe and a precision granite x-y stage are adopted in the project. The Cartesian mapping will replace traditional polar system. The motion control and data acquisition system for the magnet field measurement system consists of a Teslameter and Hall probe, servomotors, motion control card, optical grating rulers and IPC. The magnet field will be automatically scanned by this apparatus, and a flying mode will be the main running mode to reduce measure time.

**J. Yang**, L. Cao, T. Hu, D. Li, K. F. Liu, B. Qin, J. Xiong, Y. Q. Xiong, T. Yu (HUST) C. J. Chu (CIAE)

MO6PFFP021

### Main Magnet and Central Region Design for a 10 MeV PET Cyclotron

Low energy compact cyclotrons applied in Positron Emission Tomography (PET) have foreseeable prospects with the growing demands in medical applications. HUST proposed to develop a 10MeV PET cyclotron with internal PIG ion source. The main magnet employs small valley gap (SVG) scheme that achieves high average magnetic field. The axial focusing is recovered and optimized by some design considerations. Now the magnet is in the process of machining and the field mapping system is almost accomplished. Without beam manipulation provided by external beam injection line, the central region is carefully designed to obtain good centering and maximum RF phase acceptance. OPERA3D/TOSCA code was used for modeling/simulation of the main magnet and the central region. A code for beam simulation in the central region was developed and tested.

Low energy compact cyclotrons applied in Positron Emission Tomography (PET) have foreseeable prospects with the growing demands in medical applications. HUST proposed to develop a 10MeV PET cyclotron with internal PIG ion source. The main magnet employs small valley gap (SVG) scheme that achieves high average magnetic field. The axial focusing is recovered and optimized by some design considerations. Now the magnet is in the process of machining and the field mapping system is almost accomplished. Without beam manipulation provided by external beam injection line, the central region is carefully designed to obtain good centering and maximum RF phase acceptance. OPERA3D/TOSCA code was used for modeling/simulation of the main magnet and the central region. A code for beam simulation in the central region was developed and tested.

**B. Qin**, M. Fan, D. Li, K. F. Liu, Y. Q. Xiong, J. Yang (HUST) C. J. Chu (CIAE)

MO6PFFP022

### Development of a Feedback Control System for Resonant Power Supplies in J-PARC 3-GeV Synchrotron

In the J-PARC 3-GeV Synchrotron, dipole magnets and 7 families of quadrupole magnets are excited with a DC-biased 25Hz sinusoidal waveforms using a individual resonant circuits. This paper proposed a feedback system to improve the amplitude and phase stability, specially against variation of capacitance caused by temperature characteristics in resonant circuits. The control system has been successfully demonstrated and achieved amplitude and phase stability under  $\pm 0.005\%$  and  $\pm 1\mu S$ , respectively.

**Y. Watanabe** (JAEA/J-PARC)

MO6PFFP023

### Permanent Magnet Final Focus Doublet R&D for ILC at ATF2

Although the base line technology of the Final Focus Doublet for ILC is superconducting magnet, which is supposed to be conventional, the slender structure may be suffered from its vibration. The permanent magnets, however, do not have any vibration source in it at the steady state. The five-ring-singlet configuration, proposed by R. L. Gluckstern adds 100% strength adjustability to permanent magnet quadrupole (PMQ) lens. A prototype of this lens is fabricated and under evaluation. It was originally

**Y. Iwashita**, T. Sugimoto (Kyoto ICR) M. Masuzawa, T. Tauchi, K. Yokoya (KEK)

MO6PFFP024

designed for ILC that also has the extra hole for the outgoing beam. In order to realize the beam test at ATF2, the inner bore is enlarged from D20mm to D50mm to clear the background photons from Shintake-Monitor. The magnet is described.

### Effect of Errors of Manufacture on the Magnetic Field of Quadrupole Lenses

O. V. Ryezayev (NSC/KIPT)

The results of simulation of quadrupole lenses for the X-ray generator Nestor are presented. The errors, which appear upon manufacture of quadrupole lenses, are explored. Their affect on characteristics of a magnetic field is investigated.

### Design Considerations for the TPS Pulsed Magnets System

C.-H. Chang, C. K. Chan, J.-R. Chen, C.-S. Fann, C.-S. Hwang, Y.-H. Liu, C.-S. Yang (NSRRC)

The highly stable pulsed magnets are designed for injection and extraction the electron beams operation in Taiwan Photon Source. The injection to the booster at 0.15 GeV is performed with septum and kicker devices as well as the extraction from the booster at 3 GeV. There are 5 in-vacuum septum and kicker magnets used for booster injection and extraction processes. For the storage ring, an injection of the electron beam into the storage ring is performed with a septum magnet and four identical kicker magnets. All pulsed magnets are designed for injection into the 3-GeV storage ring. The kicker magnet is excited with a 4.8- $\mu$ s half-sine current waveform. A prototype of kicker magnet with 0.6 m of length is made and tested for examining the field errors. The field performances of the kicker magnet are presented. All pulsed magnets are fed with special current waveform. Both pulsed magnets are considered with the goal to achieve reliable work.

### Study of Eddy Current Effect on a Laminated Iron Design of a Booster-Ring Sextupole Magnet

J. C. Huang, C.-S. Hwang (NSRRC)

A 3 GeV electron storage ring with low-emittance was designed for the Taiwan Photon Source (TPS) which will offer one of the world's brightest synchrotron x-ray sources. Sextupole magnets for a booster ring (BR) are used to correct chromatic of beam particles. A.C. power supply is generally used in a booster ring to ramp up beam particles to a required energy. As a result, 3Hz A. C. power supply is used to charge the sextupole magnet and it would induce eddy current on a vacuum chamber which produces multpole errors in the magnetic field. In the aspect of magnet design, chamber geometry needs to be considered in order to reduce the eddy current effect on magnetic field homogeneity. The paper shows the effect of eddy current and hysteresis loss on magnetic field homogeneity when different types of vaccum chamber in use. Magnetic circuit design with different lamination iron and conductor design of booster-ring sextupole magnet are also presented. Multipole error analysis and mechanical deformation caused by the magnetic forces were included to assure the accuracy of magnetic circuit design.



### Status of Accelerator Lattice Magnets Design of TPS Project

The accelerator lattice magnets of the Taiwan Photon Source (TPS) with energy 3 GeV have been designed for the storage and booster ring. The magnetic computation

codes of TOSCA and RADIA software packages were used to design the magnet circuits of the accelerator magnets. Meanwhile, the design of a magnet circuit must take into account both the requirements of accelerator physics and practical engineering constraints. The criterion of magnet design is to keep a rise of coil temperature within 100 C and a safety margin greater than 15 %. We apply pole edge shims and end magnet chamfers to enhance the field homogeneity and to decrease multipole components, respectively. The edge shim involves a smaller magnet dimension but maintains the same quality of the field. Use of an end magnet chamfer avoids field saturation. The mechanical engineering design of the storage ring magnets has been completed and the booster ring magnets have started to be designed. The 3D Solidworks package was used to draw and design the mechanical engineering. The prototype magnets of the storage ring have been contracted out to the local company in Taiwan and will be finished before the end of 2009.

C.-S. Hwang, C.-H. Chang, H.-H. Chen, M.-H. Huang, J. C. Jan, C. Y. Kuo, F.-Y. Lin, C.-S. Yang (NSRRC)

### Precise Rotating Coil System for Characterizing the TPS Magnets

Lots of multipole magnets will be fabricated for the accelerator lattice magnets of Taiwan Photon Source (TPS) that include the storage

ring magnets, booster ring magnets, and the transfer line magnets. Therefore, several precise rotating-coil measurement systems (RCS) with high speed measurement are developed to characterize the magnetic field of quadrupole (QM) and sextupole (SM) magnets. Printed circuit coil including normal-coil and bucking-coil, are applied to measure the absolute and relative values of multipole components, respectively. Normal-coils with three turns (single-layer-coil) has been previously discussed and found to have good reproducibility. Moreover, a 12-turn multi-layer-coil has been designed to characterize the booster ring multipole magnets of TPS. This study, compares the compensatory characteristics of two bucking-coils with 75/150 turns and 150/300 turns with those of normal-coil. A continuously-winding-method for bucking-coil is presented in the paper. A precision testing bench was used to test the performance of this system. This work describes the measurement system design and fabrication, and discusses the system precision and accuracy.

J. C. Jan, C.-H. Chang, C.-S. Hwang, F.-Y. Lin (NSRRC)

### Development of Combined Function Magnets for the Taiwan Photon Source

Bending magnets, quadrupole magnets, and sextupole magnets are the most essential magnetic elements in the synchrotron accel-

erator facility or in the high energy accelerator collider ring. Generally, one uses separate bending magnets, quadrupoles or sextupoles magnets for individual function. However, a lattice design for a limited space accelerator ring or a compact ring, the combined function magnet is selected to reduce the numbers of magnet and to fit into the limited space. Therefore, one designs a single magnet with multi-function tasks simultaneously. These are the so called combined function magnets, which use one single magnet instead of two or three separate ones. The main advantage of a combined function magnet is the economy in the available space and the magnet price will cost down in the accelerator facility. In this paper, a method of designing pole profiles of bending magnet with magnet field strength of the dipole, quadrupole, and sextupole components in the combined function bending

C. Y. Kuo, C.-S. Hwang (NSRRC)

magnets is presented. In addition, a pole profile of a quadrupole magnet with the components of gradient field and sextupole field are also discussed herein.

### 3D Field Quality Studies of SNS Ring Extraction Lambertson Septum Magnet

J. G. Wang (ORNL)

3D computer simulations are performed to study magnetic field qualities in the SNS ring extraction Lambertson septum magnet.

This work is motivated by the existence of a significant skew quad term in the magnet that has been identified as the source of causing a beam profile distortion on the target. The skew quad term is computed with different methods in simulations and is compared to measurement data. The origin of the large skew quad term is thoroughly investigated. The remedy for minimizing the skew quad term by modifying the magnet is also proposed. Particle tracking has been performed to verify the beam profile evolution through the existing and modified septum. The magnetic interference to the septum performance from an adjacent quadrupole is also assessed. This paper reports our simulation techniques and major results.

### Magnet System for PLS Upgrade Project

D. E. Kim, H. S. Han, H.-G. Lee, K.-H. Park, H. S. Suh, Y. G. Young-Gyu (PAL)

Pohang Accelerator Laboratory (PAL) is planning to upgrade the Pohang Light Source (PLS) which is a 3rd generation light source operating since 1995. The key fea-

tures of the upgrade are, decrease of the beam emittance to 5.6 nm, increasing the beam energy to 3.0 GeV, additional shorter straight sections for more insertion devices. Because the PLSII should use practically same circumference preserving the shielding wall structure of the existing PLS, the lattice space is squeezed to the limit to secure the additional space for the insertion devices. This requirements forces heavy use of the combined function magnet. All dipoles are replaced to gradient magnet, and all sextupoles have horizontal corrector winding, vertical corrector winding, skew quadrupole windings. In this report, the design features and engineering efforts for the PLSII magnet systems are reported.

### Magnet Design for Proton and Carbon Ion Synchrotron for Cancer Therapy

H. S. Suh, H.-S. Kang, Y. G. Young-Gyu (PAL)

The magnets for a medical synchrotron were designed. The synchrotron is for cancer therapy with proton and carbon-iron beams.

The magnets for the injection include a septum magnet and an electrostatic septum magnet. And the magnets for the extraction include a resonance sextupole magnet, an electrostatic septum magnet, a thin septum magnet, and a thick septum magnet. The design achieved good field uniformity and acceptable leakage field level. We used 3D code for the electromagnetic simulation and the optimization of magnetic structures. In this paper, the basic design process for the injection and extraction magnets will be presented.

### Field Distribution of the 90 Degree Bending Magnets of the IFUSP Microtron

The IFUSP Microtron transport line guides the 5 MeV electron beam from the booster to the main microtron, where it can be accelerated up to 38 MeV in steps of 0.9 MeV.

A few meters after leaving the main microtron, the beam is guided to the experimental hall, which is located 2.7 m below the accelerator room. The beam leveling is made by two 90° bending magnets. In the experimental hall there is a switching magnet to drive the beam to two different experimental lines. Each of these lines has another 90° bending magnet. These magnets were designed, constructed and characterized. In this work we present the analysis of the field distribution of these 90° bending magnets. Comparison between field simulation and data from field mapping is presented. We also present a reproducibility analysis where the field distributions of two twin magnets are presented.

C. Jahnke, A. A. Malafronte, M. N. Martins, T. F. Silva, V. R. Vanin (USP/LAL)

MO6PFP034

### Magnetic Measurements of the Booster Dipole Magnets for the ALBA Synchrotron

The paper presents the magnetic measurements of the 32 long dipoles and 8 short dipoles magnet manufactured by Sigmaphi

for the ALBA synchrotron booster based in Spain. An extensive set of measurements based on search coils was made by Sigmaphi to characterize the magnetic field at different currents. This paper describes the magnetic measurements results. The measurements show the maximum field integral deviation between the magnets is within  $\pm 3.10^{-3}$  as expected.

F. Forest (Sigmaphi)

MO6PFP035

### The "SF" System of Sextupoles for the JLAB 10 KW Free Electron Laser Upgrade

The characteristics of the system of "SF" Sextupoles for the infrared Free Electron Laser Upgrade at the Thomas Jefferson National Accelerator Facility (JLab) are described.

These eleven sextupoles possess a large field integral (2.15 T/m) with  $\pm 0.01\%$  field quality over a 150 mm width within a very short effective length (150 mm pole length) and have field clamps for fast field roll-off. The field integrals reproduce extremely well with good absolute resolution ( $\pm 0.1\%$ ). The simple, two-dimensional shape pole tips (directly from the original 3-D RADIA magnetic model) of these "all ends" magnets include the correction for end fields. Magnetic measurements are compared to the model. The system's hysteresis protocol and power supplies were also used for the measurement process to enhance reproducibility in service, a recent initiative at JLab. The intricacies of magnetic measurement using the JLab field probe based Stepper Stand are described. The challenges of developing the in-house design power supplies for these magnets, based on use of a low quality supply brought to 0.001% current regulation by a CAN-Bus control are described.

G. H. Biallas, K. S. Baggett, D. Douglas (JLAB) A. Smirnov, D. Yu (DULY Research Inc.)

MO6PFP036

### Fabrication and Measurement of 12 GeV Prototype Quadrupoles at Thomas Jefferson National Accelerator Facility

Jefferson Lab's Continuous Electron Beam Accelerator Facility (CEBAF) currently has maximum beam energy of 6 GeV. The 12

T. Hiatt (JLAB)

MO6PFP037

GeV Upgrade Project will double the existing energy and is currently scheduled for completion in 2014. This doubling of energy requires modifications to the beam transport system which includes the addition of several new magnet designs and modifications to many existing designs. Prototyping efforts have been concluded for two different designs of quadrupole magnets required for the upgrade. The design, fabrication and measurement will be discussed.

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### Magnetic and Structural Analysis of SESAME Storage Ring Magnets

H. Tarawneh, M. M. Shehab (SESAME)

The paper contains the revised design of a dipole magnet for SESAME. All design aspects and manufacturing related issues such as mechanical tolerances and manufacturing techniques are presented, 3D Magnetic analysis and optimization for the dipole end chamfer as well as the electromagnetic forces effects on the dipole mechanical design is presented. The paper also contains the mechanical interactions of the dipole magnet, girder system and vacuum chamber as well as the structural analysis for the assembly

### The Design of Combined Quadrupole and Sextupole Magnet

X. Zhao, G. Feng, L. Wang, H. Xu (USTC/NSRL)

HALS(Hefei Advanced Light Source) is the electron storage ring of ultra-low emittance in process of design. Under this design, the quadrupole magnet with sextupole component must be mounted on which the  $\beta\eta$  is much bigger, to use enough the effect of compensation chromaticity of sextupole magnet field and to use sparingly the space in the same time. So the combined quadrupole and sextupole magnet must be designed, and have more strong sextupole component and restrain the production of high harmonic field. In this paper, the choice of design scheme is discussed, and the calculation of combined quadrupole and sextupole magnet design is given.

### Double-Helix Magnets --Technology, Application and Analysis

R. B. Meinke, M. Ball, C. Goodzeit (Advanced Magnet Lab., Inc)

Winding configurations with sinusoidal modulations of solenoid windings offer significant advantages for normal and superconducting magnets. Such Double-Helix coils generate almost pure multipole fields, various combined function magnets, bent dipoles, and twisted and funnel-shaped coils. Double-helix coils can be done cost effectively on standard machining centers, resulting in small random field errors. The technology is applicable to different conductor shapes, including round, square and rectangular wires and cables, as well as HTS tape conductors. Brittle conductors like Nb<sub>3</sub>Sn and HTS materials benefit from the intrinsic large bending radii of the coil configuration. In a novel implementation of the technology, the conductors and coils are "directly" fabricated from conductive cylinders, which lead to a significant reduction in resistance. With the possibility of highly effective conductor cooling in these coils, current densities in normal conducting coils become possible that are unachievable with conventional wire-based conductors. A general overview of the Double-Helix technology will be presented together with its applications.

### Bent Superconducting Dipole Magnets

A helical coil formed by the sinusoidal modulation in the axial direction of the turns of a solenoid produces both transverse and axial field components. A concentric pair of two such coils having opposite modulation amplitudes produces a cancellation of the axial field while the transverse field component is doubled. This configuration is called the “double-helix” coil. It is shown how a superposition of amplitude frequencies of the conductor path can produce magnets that contain pure multipoles of the desired order and thus enable pure multipole magnets or combined function magnets. An example of the application is shown for the case of a 4.5 T bent dipole with a bend radius of 718 mm and an aperture of 100 mm considered for future rare isotope accelerators (i.e. AEBL and RIA). The manufacturing technology, design features and first test results will be presented.

**R. B. Meinke**, M. Ball, C. Goodzeit (Advanced Magnet Lab., Inc)

MO6PFFP042

### Fabrication of a Prototype Fast Cycling Superferric Dipole Magnet

GSI had manufactured a prototype of a fast cycling superconducting dipole magnet at Babcock Noell GmbH. This is the first full size magnet for the SIS100 synchrotron at the future Facility for Antiproton and Ion Research (FAIR) in Darmstadt / Germany. In close collaboration with GSI, the magnet was technologically developed, manufactured and assembled by Babcock Noell. The system was successfully tested at GSI reaching the nominal cycling performance, including the high ramping rate of 4 T/s and the maximum field of 2.1 T. Especially the superconducting cable, the coils and the iron yoke are subject to strong mechanical and thermal stresses. Here we describe the details on the fabrication of these components and give an outlook on possible improvements of the manufacturing technologies, applicable to future prototypes and series magnets for SIS100.

**G. Sikler**, W. Gaertner, A. Wessner (BNG) E. S. Fischer, E. Floch, D. Krämer, P. Schnizer (GSI)

MO6PFFP043

### Superconducting Magnets for a Final Focus Upgrade of ATF2

The Accelerator Test Facility (ATF2) at KEK is a scaled down version of the final focus design proposed for the future linear colliders (LC) and aims to experimentally verify the final focus (FF) technology needed to obtain very small, stable beam spots at a LC interaction point. Initially the ATF2 FF is made using conventional (warm) quadrupole and sextupole magnets; however, we propose to upgrade the FF by replacing some of the conventional magnets with new superconducting magnets constructed with the same technology as those of the International Linear Collider baseline FF magnets\*. With the superconducting magnet upgrade we can look to achieve smaller interaction point beta-functions and to study superconducting magnet vibration stability in an accelerator environment. Therefore for the ATF2 R&D magnet we endeavor to incorporate cryostat design features that facilitate monitoring of the cold mass movement via interferometric techniques. The design status of the ATF2 superconducting upgrade magnets is reported in this paper.

**B. Parker**, M. Anerella, J. Escallier, P. He, A. K. Jain, A. Marone (BNL) B. Bolzon, A. Jeremie (IN2P3-LAPP) C. Hauviller (CERN) A. Seryi (SLAC) T. Tauchi, K. Tsuchiya, J. Urakawa (KEK) D. Urner (OXFORDphysics)

MO6PFFP044

\*International Linear Collider Reference Design Report, ILC-REPORT-2007-001, August 2007.

### Magnetic Design Studies for the Final Focus Quadrupoles of the SuperB Large Crossing Angle Collision Scheme

E. Paoloni (University of Pisa and INFN) S. Bettoni (CERN) M. E. Biagini, P. Raimondi (INFN/LNF) M. K. Sullivan (SLAC)

We present an improved design of the focusing elements close to the interaction point of the SuperB accelerator. These magnets have to provide pure quadrupolar fields on each

of the two beams to decrease the background rate in the detector which would be produced by the over-bend of the off-energy particles if a dipolar component were present. Very good field quality is also required to preserve the dynamic aperture of the rings. Because of the small separation of the two beams (only few centimeters) and the high gradient required by the SuperB final focus, neither a permanent magnet design nor a multi-layer configuration are viable solutions. A novel design, based on 'helical-type' windings, has therefore been investigated. In this paper we will present the improved magnetic design and its performances evaluated with a three dimensional finite element analysis.

### First Field Test of FiDeL, the Magnetic Field Description for the LHC

L. Bottura, L. Deniau, P. Hagen, N. J. Sammut, E. Todesco, R. Wolf (CERN)

The start-up of the LHC has provided the first field test for the concept, functionality and accuracy of FiDeL, the Field Description for the LHC. FiDeL is primarily a parametric

model of the transfer function of the main field integrals generated by the series of magnets in the LHC powering circuits, from main optical elements to high-order harmonic correctors, both superconducting and normal-conducting magnets. In addition, the same framework is used to predict harmonic errors of both static and dynamic nature, and forecast appropriate corrections. In this paper we give a description of the level of detail achieved in the model and the rationale adopted for the LHC start-up. Beam-based measurements have been used for an assessment of the first-shot accuracy in the prediction of the current setting for the main arc magnets\*.

\*The work reported has been performed by the authors and the FiDeL Team

### Upgrade of the Protection System for Superconducting Circuits in the LHC

R. Denz, K. Dahlerup-Petersen, L. Walckiers (CERN)

Prior to the re-start of the Large Hadron Collider LHC in 2009 the protection system for superconducting magnets and bus bars QPS

will be submitted to a substantial upgrade. The foreseen modifications will enhance the capability of the system in detecting problems related to the electrical interconnections between superconducting magnets as well as the detection of so-called symmetric quenches in the LHC main magnets. The paper will describe the design and implementation of the new protection layers and report as well on the commissioning of the system and first operational results.

### A Method to Detect Faulty Splices in the Superconducting Magnet System of the LHC

The incident of 19 September 2008 at the LHC was apparently caused by a faulty inter-magnet splice of about 200 nOhm resistance. Cryogenic and electrical techniques have been developed to detect other abnormal splices, either between or inside the magnets. The quench protection system is used in a special mode to measure the voltage across each magnet with an accuracy better than 0.1 mV, allowing internal splices with  $R > 10$  nOhm to be detected. Since this system does not cover the bus between magnets, the cryogenic system is used in a special configuration\* to measure the rate of temperature rise due to ohmic heating. Accuracy of a few mK/h, corresponding to a few Watts, has been achieved. This allows detection of excess resistance of more than a few tens of nOhms in a cryogenic sub-sector (2 optical cells). Follow-up measurements, using an ad-hoc system of high-accuracy voltmeters, are made in regions identified by the cryogenic system. These techniques have detected two abnormal internal magnet splices of 100 nOhms and 50 nOhms respectively. In 2009, this ad-hoc system will be replaced with a permanent one which will monitor all splices at the nOhm level.

**M. Koratzinos**, R. Bailey, B. Bellesia, N. Catalan-Lasheras, Z. Charifoulline, S. D. Claudet, K. Dahlerup-Petersen, R. Denz, C. Fernandez-Robles, M. Pojer, L. Ponce, R. I. Saban, R. Schmidt, A. P. Siemko, M. Solfaroli Camillocci, L. J. Tavian, H. Thiesen, A. Vergara-Fernández (CERN) M. Bednarek, E. Gornicki, P. Jurkiewicz, P. J. Kapusta (HNINP) R. H. Flora, J. Strait (Fermilab)

\*L. Tavian, Helium II Calorimetry for the Detection of Abnormal Resistive Zones in LHC Sectors, this conference.

### Hysteresis Effects of MCBX Magnets on the LHC Operation in Collision

The Large Hadron Collider beams are brought into collision by superconducting orbit corrector magnets which generate the parallel separation and crossing angles at the interaction points during the different cycle phases. Unfortunately, the magnetic field errors that result from hysteresis effects in the operation region of these magnets lead to unwanted orbit perturbations. In a previous paper, it has been shown that these effects are within the perturbations coming from beam-beam interactions for the MCBC and the MCBY magnets but are significant in the case of the MCBX magnets. This paper presents a refined model of their field in the frame of the Field Description for the LHC (FiDeL), the results obtained from new magnetic measurements in cold conditions to test the model, the powering mechanism employed to maximize their field reproducibility, and the impact the modeling error is predicted to have on the LHC orbit.

**N. J. Sammut**, C. Giloux, M. Lamont, W. Venturini Delsolaro, S. M. White (CERN)

### Earth Current Monitoring Circuit for Inductive Loads

The search for higher magnetic fields in particle accelerators increasingly demands the use of superconducting magnets. This mag-

**V. Montabonnet**, S. Pittet, Y. Thurel (CERN)

net technology has a large amount of magnetic energy storage during operation at relatively high currents. As such, many monitoring and protection systems are required to safely operate the magnet, including the monitoring of any leakage of current to earth in the superconducting magnet that indicates a failure of the insulation to earth. At low amplitude, the earth leakage current affects the magnetic field precision. At a higher level, the earth leakage current can additionally generate local losses which may definitively damage the magnet or its instrumentation. This paper presents an active earth fault current monitoring circuit, widely deployed in the CERN-LHC converters for the superconducting magnets. The circuit allows the detection of earth faults before energising the circuit as

well as limiting any eventual earth fault current. The electrical stress on each circuit component is analyzed and advice is given for a totally safe component selection in relation to a given load.

### Electrical Behaviour of the LHC Main Dipole Circuits during Quenches and Fast Energy Discharges

A. P. Siemko, N. Catalan-Lasheras, K. Dahlerup-Petersen, R. Denz, G. Kirby, S. L.N. Le Naour, M. Modena, R. I. Saban, R. Schmidt, H. Thiesen, A. P. Verweij, R. Wolf (CERN) R. H. Flora (Fermilab)

A string of 154 LHC main superconducting dipole magnets connected in series forms one main dipole circuit of a sector, one eighth of the LHC machine. The LHC architecture allows powering of each sector in-

dependently. In order to avoid high temperatures in the magnets and high voltages between coils and ground appearing in case of a magnet quench, an active magnet protection system is implemented. The dipole magnets are by-passed by passive protection diodes which are located in the cold masses. In case of a quench most of the stored magnetic energy is dissipated in the resistive parts of the magnet coil. The energy stored in magnets that did not quench is extracted and dissipated in external dump resistors. The commissioning procedures require powering in a number of steps with increasing current level. Several steps involve either heater provoked or natural quenches. This paper describes the electrodynamic behaviour of the LHC main dipole circuit during a fast discharge after a quench. An evaluation of the parameters which cannot directly be measured, such as the current sharing between magnets and diodes and the sharing of dissipated energy, will be presented and discussed.

### Study of a Less Invasive LHC Early Separation Scheme

G. Sterbini, J.-P. Koutchouk (CERN)

The LHC Early Separation Scheme consists in a four 5-10 Tm dipole scheme (D0s) installed close to the two LHC high luminos-

ity experiments. Its aim, in the framework of LHC Phase II Upgrade, is to improve the luminosity by reducing the crossing angle between the two colliding beams, mitigating and controlling at the same time their parasitic interactions. We investigate a less invasive implementation in the detectors (D0 at 14 from the IP) with respect to those already presented (D0 at 7 m from the IP). The luminosity performances are discussed and a tentative analysis on beam-beam effect impact is given. For the new D0 position, preliminary dipole design and power deposition results are shown.

### Pre-Cycle Selection for the Superconducting Main Magnets of the Large Hadron Collider

A. P. Verweij, N. J. Sammut, W. Venturini Delsolaro, R. Wolf (CERN)

Pre-cycles for setting up the main magnets of the Large Hadron Collider are necessary for ensuring field reproducibility and low field-decay rates at injection. In this paper

we propose standard pre-cycles for the main magnets of the LHC. We study the influence of the pre-cycle parameters on the field decay at injection by two different models. One already proven model is semi-empirical based on magnetic measurements of the magnets. The other is a new network based model of a Rutherford cable which directly calculates the current redistribution and associated magnetization change in the cable strands. The pre-cycle to be used may depend on the history of the machine or may have to be changed because of unforeseen phenomena in the machine. The choice of a new pre-cycle on the basis of magnetic measurements alone is a



lengthy process. We confirm the usefulness of the network based model as a tool for selecting new pre-cycles, including decay-blocking degaussing pre-cycles, and compare with magnetic measurements.

### AC Dipole Magnet for Mu2e Experiment

The AC Dipole magnet for Mu2e experiment should generate alternating dipole field with the frequency of 300 kHz in the 10 mm high and 50 mm wide aperture. The main issue is that the magnet continuously powered by a sine wave resulting in large power dissipations in the ferrite yoke and driving conductor. The choice of materials is strongly coupled with the magnet design and performance. Besides that, there is a high voltage applied to the conductor and the electrical insulation reliability should be taken into account. Paper describes the magnet design, 3D AC field simulations, test results of driving conductor assembly and MnZn ferrite laminations.

V. S. Kashikhin, D. J. Harding, V. Kashikhin, A. V. Makarov (Fermilab)

### Electromagnetic SCRF Tuner

A novel prototype of SCRF cavity tuner is being designed at Fermilab. This is a superconducting C-type iron dominated magnet having 10 mm air gap and field 1 Tesla. Inside the gap is a superconducting coil which is capable of moving  $\pm 1$  mm and producing a longitudinal force of  $\pm 1500$  N. This static force applied to the SCRF cavity flanges provides long term cavity geometry tuning to normal frequency. The same coil powered by AC 1 kHz current waveform provides moving for fast cavity tuning for compensation of RF Lorentz detuning and microphonic effects. Special superconducting bucking coils substantially reduce the magnet system fringing field up to acceptable for SCRF cavity operation level.

V. S. Kashikhin, G. W. Foster, Y. M. Pischalnikov (Fermilab)

### 120-mm Superconducting Quadrupole for Interaction Regions of Hadron Colliders

Magnetic and mechanical designs of compact superconducting quadrupole magnets with 120-mm aperture suitable for interaction regions of hadron collides are presented. The quadrupole mechanical structure is based on a thick stainless steel skin and aluminum clamps. Magnet parameters including maximum field gradient, field quality and temperature margin for NbTi or Nb3Sn coils at the operating temperatures of 1.9 K and 4.5 K are reported. Coil prestress at room and operating temperatures and at the nominal field gradient is reported and discussed. Electrical, thermal and mechanical aspects of magnet quench protection are presented.

V. Kashikhin, I. Novitski, A. V. Zlobin (Fermilab)

### Operating Margin of Large-Aperture Nb3Sn IR Quadrupoles with Respect to Radiation Heat Depositions

Large-aperture Nb3Sn quadrupoles is an attractive option for high-luminosity interaction regions of hadron colliders due to high temperature and field margins of Nb3Sn superconductor. Operating margins of Nb3Sn quadrupole magnets under

V. Kashikhin, N. V. Mokhov, A. V. Zlobin (Fermilab)

the radiation heat depositions in the coils are discussed. Effects of operating temperature and critical current margin, coil material properties and cooling conditions are presented. Results are compared with NbTi IR quadrupoles.

### Four-Coil Superconducting Helical Solenoid Model for MANX

M. J. Lamm, N. Andreev, V. Kashikhin, V. S. Kashikhin, A. V. Makarov, K. Yonehara, M. Yu, A. V. Zlobin (Fermilab) R. P. Johnson, S. A. Kahn (Muons, Inc)

The magnet for MANX has to generate longitudinal solenoid and transverse helical dipole and helical quadrupole fields. This paper discusses the 0.6 m diameter 4-coil Helical Solenoid model design, manufacturing,

and testing that has been done to verify the design concept, fabrication technology, and the magnet system performance. Details of magnetic and mechanical designs, including the 3D analysis by TOSCA and ANSYS will be presented and compared to measurements. The model quench performance in the test setup in the FNAL Vertical Magnet Test Facility cryostat will be discussed. Projected performance and cost will also be presented for the full length MANX magnet.

### Studies of the High-Field Section for a Muon Helical Cooling Channel

M. L. Lopes, V. S. Kashikhin, A. V. Zlobin (Fermilab) R. P. Johnson, S. A. Kahn (Muons, Inc)

The Helical Cooling Channel (HCC) is a new technique proposed for 6D cooling of muon beams required for muon collider and some other applications. HCC uses a continuous absorber inside superconducting magnets which produce solenoidal field superimposed with transverse helical dipole and helical gradient fields. HCC is usually divided into several sections each with progressively stronger fields, smaller aperture and shorter helix period to achieve the optimal muon cooling rate. This paper presents the results of designs studies of the HCC high field section in terms of magnet aperture limitations, tunability of field component and field correction. The maximum field in the coil and the conductor options are also discussed.

continuous absorber inside superconducting magnets which produce solenoidal field superimposed with transverse helical dipole and helical gradient fields. HCC is usually divided into several sections each with progressively stronger fields, smaller aperture and shorter helix period to achieve the optimal muon cooling rate. This paper presents the results of designs studies of the HCC high field section in terms of magnet aperture limitations, tunability of field component and field correction. The maximum field in the coil and the conductor options are also discussed.

### Solenoid Focusing Lenses for the R&D Proton Linac at Fermilab

M. A. Tartaglia, J. DiMarco, Y. Huang, D. F. Orris, T. M. Page, R. Rabehl, I. Terechkine, J. C. Tompkins (Fermilab)

An R&D proton linac is under construction at FNAL and it will use solenoid lenses in the beam transport line. Because the needed focusing field is on the level of 6 Tesla,

superconducting systems are used. In the low energy part of the linac, which uses room temperature accelerating structures, the lenses are placed in stand-alone cryostats. Production of the lenses and cryostats for the low energy section is under way. In the superconducting accelerating sections, the lenses are mounted inside RF cryomodules. Although focusing solenoids for the high energy sections have been designed and prototypes tested, R&D is still ongoing to address magnetic shielding and alignment issues. This report summarizes the performance of lenses for the low-energy part of the linac and presents the status of ongoing R&D.

### Magnets for Muon 6D Helical Cooling Channels

The Helical Cooling Channel (HCC), a new technique for six-dimensional (6D) cooling of muon beams using a continuous absorber inside superconducting magnets, has shown considerable promise based on analytic and simulation studies. The implementation of this method of muon cooling requires high field superconducting magnets that provide superimposed solenoid, helical dipole, and helical quadrupole fields. Novel magnet design concepts are being developed to provide HCC magnet systems with the desired fields for 6D muon beam cooling. The Helical Solenoid (HS) features a simple coil configuration that produces these complex fields with the required characteristics, where new high field conductor materials are particularly advantageous. Correction coil schemes to allow larger coil radius for given HCC parameters are being developed to make room for required mechanical structures, including RF cavities for practical HCC designs. Numerical simulations are being used to optimize and verify the muon cooling behavior of the HCC designs.

**K. Yonehara**, V. S. Kashikhin, A. V. Zlobin (Fermilab) R. P. Johnson, S. A. Kahn, M. Turenne (Muons, Inc)

MO6PFP062

### Modeling of the High Field Section of a Muon Helical Cooling Channel

This presentation will describe conceptual designs of short HTS and Nb<sub>3</sub>Sn models of Helical Cooling Channel high-field section which are being built and tested, their parameters, structural materials and conductor choices, fabrication technologies, and other engineering challenges.

**A. V. Zlobin**, E. Z. Barzi, V. S. Kashikhin, M. J. Lamm, M. L. Lopes, M. Yu (Fermilab) R. P. Johnson, S. A. Kahn (Muons, Inc)

MO6PFP063

### Development of High-Field Superconducting Solenoids for Muon Beam Cooling

The final stage of muon beam cooling channel of a future muon collider uses a string of 1-m long superconducting solenoids with an aperture of ~50 mm and a field of 40-50 T. The magnet performance and cost can significantly benefit from a hybrid coil design with the high-temperature superconductors (HTS) in the coil inner layers and the low temperature superconductors (LTS) in the coil outer layers. A feasibility study of high-field solenoids based on the HTS/LTS materials was performed for several optimization criteria and the results were reported earlier. This paper updates the solenoid designs based on the recent progress in the development of HTS materials including BSCCO-2212 wires and YBCO tapes. The main magnet parameters will be reported along with the mechanical and technological considerations. The small coil R&D program, started at Fermilab to develop the key technologies for the HTS-based accelerator magnets, and the first results of the short sample and small coil tests will be also presented and discussed.

**A. V. Zlobin**, E. Z. Barzi, V. Kashikhin, M. J. Lamm, V. Lombardo, G. Norcia, D. Turrioni (Fermilab)

MO6PFP064

### Fast Ramped Superferric Prototype Magnets of the FAIR Project: First Test Results and Design Update

The 100 Tm synchrotron SIS 100 is the core component of the international Facility of Antiproton and Ion Research (FAIR) to be built in Darmstadt. An intensive R&D period was conducted to design 3m long 2T dipoles providing a stable ramp rate of 4 T/s within an usable aperture

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MO6PFP065

of 115mm x 60mm with minimum AC losses, high field quality and good long term operation stability. Three full size dipole - and one quadrupole magnets were built. Recently the first dipole magnet, produced by Babcock Noell, was intensively tested at the GSI cryogenic test facility. We present the measured characteristic parameters: training behaviour, the field quality along the load line for DC operation as well as on the ramp, AC losses, and the cryogenic operation limits. We compare them to the calculated results as well as to the requested design performance. Based on the obtained results we discuss adjustments for the final design.

### Design and Construction of a 15 T, 120 mm Bore IR Quadrupole Magnet for LARP

S. Caspi, D. W. Cheng, D. R. Dietderich, H. Felice, P. Ferracin, R. R. Hafalia, R. Hannaford, G. L. Sabbi (LBNL) G. Ambrosio, R. Bossert, V. Kashikhin, D. Pasholk, A. V. Zlobin (Fermilab) M. Anerella, A. K. Ghosh, J. Schmalzle, P. Wanderer (BNL)

Pushing accelerator magnets beyond 10 T holds a promise of future upgrades to machines like the Large Hadron Collider (LHC) at CERN. Nb<sub>3</sub>Sn conductor is at the present time the only practical superconductor capable of generating fields beyond 10 T. In

support of the LHC Phase-II upgrade, the US LHC Accelerator Research Program (LARP) is developing a large bore (120mm) IR quadrupole (HQ) capable of reaching 15 T at its conductor peak field. The 1 m long two-layer coil, based on the design of the LARP TQ quadrupole series that achieved 230 T/m in a 90 mm bore, will demonstrate additional features such as alignment and accelerator field quality while exploring the magnet performance limits in terms of gradient, forces and stresses. In this paper we summarize the design and report on the magnet construction progress.

### Magnetic Field Measurements of HD2, a High Field Nb<sub>3</sub>Sn Dipole Magnet

X. Wang, S. Caspi, D. W. Cheng, H. Felice, P. Ferracin, R. R. Hafalia, J. M. Joseph, A. F. Lietzke, J. Lizarazo, A. D. McInturff, G. L. Sabbi (LBNL) K. Sasaki (KEK)

The Superconducting Magnet Program at Lawrence Berkeley National Laboratory has designed and tested HD2, a 1 m long Nb<sub>3</sub>Sn accelerator-type dipole with a 42 mm clear bore. HD2 is based on a simple block-type

coil geometry with flared ends, and represents a step towards the development of cost-effective accelerator quality magnets operating in the range of 13-15 T. The design was optimized to minimize geometric harmonics and to address iron saturation and conductor magnetization effects. Field quality was measured during recent cold tests. The measured harmonics are presented and compared to the design values.

### Design and Analysis of a Nb<sub>3</sub>Sn Superconducting Magnet for a 56 GHz ECR Ion Source

P. Ferracin, S. Caspi, D. Leitner, C. M. Lyneis, S. Prestemon, G. L. Sabbi, D. S. Todd, F. Trillaud (LBNL)

Third generation electron cyclotron resonance (ECR) ion sources operate at rf frequencies between 20 and 30 GHz and implement NbTi superconducting magnets with a

conductor peak field of 6-7 T. A significant gain in performance can be achieved by using Nb<sub>3</sub>Sn superconducting solenoids and sextupole coils capable of reaching a field of 15 T in the windings. In this paper we describe the design of a Nb<sub>3</sub>Sn superconducting magnet for a fourth generation ECR source operating at a rf frequency of 56 GHz. The magnet design features a configuration with an internal sextupole magnet surrounded by three solenoids, and adopts a support structure based on an external aluminum shell pre-tensioned with pressurized bladders. The structural concept, developed for high-field accelerator magnets, allows a precise control of the coil

pre-stress and minimizes conductor motion during excitation. A finite element magnetic and mechanical model has been used to investigate conductor peak fields and coil stresses during assembly, cool-down and operation. Results of the numerical analysis are presented and discussed.

### Progress on the MuCOOL and MICE Coupling Coils

The superconducting coupling solenoid for MuCOOL and MICE will have an inside radius of 750 mm, and a coil length of 285 mm. The MuCOOL coupling coil is identical to the MICE coupling coils. The MICE coupling magnet will have a self inductance of 592 H. When operated at its maximum design current of 210 A (the highest momentum operation of MICE), the magnet stored energy will be about 13 MJ. These magnets will be kept cold using a pair of pulse tube cryocoolers that deliver 1.5 W at 4.2 K and 55 W at 60 K. This report describes the progress on the MuCOOL and MICE coupling magnet design and engineering. The progress on the construction of the first coupling coil will also be presented.

**M. A. Green**, D. Li, S. P. Virostek, M. S. Zisman (LBNL) A. B. Chen, X. L. Guo, X. K. Liu, H. Pan, L. Wang, H. Wu, F. Y. Xu, S. X. Zheng (ICST) D. J. Summers (UMiss)

### Progress on the Fabrication and Testing of the MICE Spectrometer Solenoids

The Muon Ionization Cooling Experiment (MICE) is an international collaboration that will demonstrate ionization cooling in a section of a realistic cooling channel using a muon beam at Rutherford Appleton Laboratory (RAL) in the UK. At each end of the cooling channel a spectrometer solenoid magnet consisting of five superconducting coils will provide a 4 tesla uniform field region. The scintillating fiber tracker within the magnet bore tubes will measure the emittance of the muon beam as it enters and exits the cooling channel. The 400 mm diameter warm bore, 3 meter long magnets incorporate a cold mass consisting of two coil sections wound on a single aluminum mandrel: a three-coil spectrometer magnet and a two-coil section that matches the solenoid uniform field into the MICE cooling channel. The fabrication of the spectrometer solenoids has been completed, and preliminary testing and field mapping of the magnets is nearly complete. The key design features of the spectrometer solenoid magnets are presented along with a summary of the progress on the testing and magnetic measurements.

**S. P. Virostek**, M. A. Green, D. Li, M. S. Zisman (LBNL)

### HTS Development for 30-50 T Final Muon Cooling Solenoids

High temperature superconductors (HTS) have been shown to carry significant current density in the presence of extremely high magnetic fields when operated at low temperature. The successful design of magnets needed for high energy physics applications using such high field super-conductor (HFS) depends critically on the detailed wire or tape parameters which are still under development and not yet well-defined. HFS is being developed for accelerator use by concentrating on the design of an innovative magnet that will have a useful role in muon beam cooling. A conceptual design of a high field solenoid using YBCO HFS conductor is being analyzed. Mechanical properties of HFS conductors will be measured along with the maximum engineering current density ( $J_e$ ) as a function of temperature and strain to extend the HFS specifications to conditions needed for low temperature applications. HFS quench properties will be measured and quench protection schemes developed for the solenoid.

**S. A. Kahn**, R. P. Johnson, M. Turenne (Muons, Inc) F. Hunte, J. Schwartz (NHMFL)

### Multi-Purpose Fiber Optic Sensors for HTS Magnets

M. Turenne, R. P. Johnson (Muons, Inc) J. Schwartz (NHMFL)

Magnets using new high temperature superconductor (HTS) materials are showing great promise for high magnetic field and/or radiation environment applications such as particle accelerators, NMR, and the plasma-confinement systems for fusion reactors. The development and operation of these magnets is limited, however, because appropriate sensors and diagnostic systems are not yet available to monitor the manufacturing and operational processes that dictate success. Optical fibers will be imbedded within the HTS magnets to monitor strain, temperature and irradiation, and to detect quenches. In the case of Bi2212, the fiber will be used as a heat treatment process monitor to ensure that the entire magnet has reached thermal equilibrium. Real-time measurements will aid the development of high-field magnets that are subject to large Lorentz forces and allow the effective detection of quenches so that the stored energy of operating magnets can be extracted and/or dissipated without damaging the magnet.

### PAMELA Magnets - Design and Performance

H. Witte, J. H. Cobb, T. Yokoi (OXFORDphysics) K. J. Peach, S. L. Sheehy (JAI)

PAMELA is a design study of a non-scaling FFAG for hadron therapy aiming to deliver 250 MeV protons and 400 MeV/u carbon ions. This paper outlines the general magnet design required for the 250 MeV proton case. The magnet design is challenging because of the combination of required field strength (up to 4T), geometric constraints (the magnets need to be short) and large beam aperture (up to 160 mm). All magnets are combined function magnets with dipole, quadrupole, sextupole and octupole field components of good field quality.

### Stress Computation in the C400 Superconducting Coil Using the Opera-2d Stress Analysis Module

W. Beeckman (Sigmaphi) J. Simkin (Vector Fields Ltd.) M. Wilson (Oxford Instruments, Accelerator Technology Group)

A tender for the study and construction of a large superconducting split solenoid for the C400 carbon therapy cyclotron was issued by IBA in March 2008 and awarded to Sigmaphi. Although the current density is moderate, the large radius and average field imply quite a high level of hoop stress. Simple formulas range between 140 and 180 MPa and, with such large values and uncertainties, it was felt necessary to perform a finite element analysis of the structure. Average fields in a cyclotron are very well modeled using an axially symmetrical structure and the stress was therefore studied using the stress module of the Vector Fields Opera2d suite. Different models were tried with different levels of details. A comparison is made between them as well as with the analytical results.

### A New Generation of an In-Vacuum, Cryogenic Elliptical-Polarization Undulator (Cryo-EPU)

D. J. Waterman, A. Deyhim, J. D. Kulesza (Advanced Design Consulting, Inc) K. I. Blomqvist (MAX-lab)

This publication describes an Apple/EPU type Cryogenically-Cooled Permanent Magnet Undulator. It has been recently discovered that magnetic materials like NdFeB

have about 25% stronger remanent fields and 3-5-fold higher coercivity as the temperature is lowered. Higher coercivity usually means lower remanence, so the best types of NdFeB can not be used for in-vacuum undulators due to degradation in radiation and at UHV bakeout temperatures. Cooling the magnets to increase coercivity allows higher remanence grades of NdFeB to be used, and then it makes the fields stronger in addition. For the exotic materials PrFeB, this effect takes place at liquid nitrogen temperature. To make use of this effect, undulators must be cooled to cryogenic temperatures and in the cooled down state, magnetic measurements and adjustments of the PM must be performed.

### Spectral Performance of Circular Polarizing Quasi-Periodic Undulators for Soft X-Rays at the Advanced Photon Source

In the selection of a new insertion device optimized for producing intense soft x-rays at the Advanced Photon Source, two different types of circular polarizing quasi-periodic undulators were studied. The magnetic structure of the undulators consists of pure permanent magnets for one of the undulators (an APPLE-II style undulator) and of electromagnets and pole pieces for the other type. The undulator period lengths were chosen so that the first harmonic energy occurs at 200 eV in linear horizontal polarization mode and at 400 eV in both linear vertical and circular polarization modes. Calculations of on-axis brilliance and on-axis flux spectra for both types of undulators and reductions of the spectral harmonics due to quasi-periodicity are presented. The introduction of quasi-periodicity of the magnetic fields shifts the higher spectral harmonics to a lower energy, hence reducing the so-called higher-order contamination dramatically. At the same time however, it reduces the first harmonic intensity by 20 -- 40%. The non-sinusoidal shape of the horizontal and vertical magnetic fields of the electromagnetic undulator at high K values enhances the intensity of the first harmonic.

R. J. Dejus, M. S. Jaski (ANL) S. Sasaki (HSRC)

### Magnetic Simulation of a Superconducting Undulator for the Advanced Photon Source

A superconducting planar undulator is under development at the Advanced Photon Source (APS). The initial R&D phase of the project includes intensive magnetic modeling performed with the Opera 2d and 3d software packages. This simulation addresses questions of magnetic design of the undulator including calculation of peak field on the undulator axis and maximum field in the conductor, superconductor load line optimization, and design of the undulator ends and correction coils. Results of the magnetic simulation are presented in the paper.

Y. Ivanyushenkov (ANL)

### Status of R&D on a Superconducting Undulator for the APS

An extensive R&D program is underway at the Advanced Photon Source (APS) with the aim of developing a technology capable of building a 2.4-m-long superconducting planar undulator for APS users. The initial phase of the project concentrates on using a NbTi superconductor and includes magnetic modeling, development of manufacturing techniques for the undulator magnet, and design and test of short prototypes. The current status of the R&D phase of the project is described in this paper.

Y. Ivanyushenkov, T. W. Buffington, C. Doose, Q. B. Hasse, M. S. Jaski, S. H. Kim, R. Kustom, E. R. Moog, E. Trakhtenberg, I. Vasserman (ANL)

### A Concept for a Quasi-Periodic Planar Superconducting Undulator

Y. Ivanyushenkov, E. Trakhtenberg (ANL) S. Sasaki (HSRC)

A request from the light source user community for insertion devices that provide only monochromatic light has led to development of quasi-periodic undulators (QPUs). These devices generate shifted harmonics in the photon energy spectrum, thus allowing suppression of higher harmonics by optical monochromator systems. Until now such undulators have been technically realized with pure permanent magnets or with hybrid structures. A concept for a superconducting quasi-periodic undulator (SCQPU) is suggested and described in this paper.

### Circular Polarizing Quasi-Periodic Undulator

M. S. Jaski, E. R. Moog (ANL) S. Sasaki (HSRC)

Investigation into a circular polarizing quasi-periodic undulator is presented here. Electromagnets are used to generate the vertical field. Permanent magnets are used to generate the horizontal field. Calculated maximum effective vertical and horizontal magnetic fields on the undulator axis higher than 8.5 kGauss are achieved at a 10.5-mm gap for a 9-cm-period undulator. Fields of this magnitude are difficult to achieve in purely electromagnetic devices. Switching the sign of the current for the vertical field electromagnets allows for right- or left-handed circular polarization. A laminated core can be introduced to allow for fast helicity switching in order to utilize lock-in detection techniques. Quasi-periodicity can be introduced in the vertical electromagnet field by reducing the current at the quasi-periodic poles and can be turned on, off, or somewhere in between. Quasi-periodicity can be introduced in the horizontal permanent magnet field by inserting weakened magnets at the quasi-periodic poles. Since it is built into the magnet structure, this quasi-periodicity cannot be turned off.

### Magnetic Field Measurement System for Superconducting Helical Undulators

S. H. Kim, C. Doose, Y. Ivanyushenkov (ANL)

The baseline configuration of the proposed International Linear Collider includes superconducting helical undulators as a scheme to produce positrons. This paper presents a conceptual design of the magnetic field measurement system for helical undulators with the undulator axis in a horizontal direction at liquid helium temperature. The system consists of a cryomodule and a linear stage unit with a travel length of approximately 3.5 m. The linear stage unit provides the motion control for the Hall probe housing, which is connected to a small-diameter carbon fiber rod inside bellows-flange connections. Stainless steel bellows are at the same vacuum pressure as the cold mass in the cryomodule. A linear encoder is used for motion control of the stage, but precise position measurement of the Hall probe relies on the laser interferometer system.

### SC Quadrupole for Cryomodule for ERL/ILC

A. A. Mikhailichenko (Cornell University, Department of Physics)

We are considering SC quadrupole where the field formed not only by current distributions, but with poles at the same time. This delivers a good field field in all aperture allowing compact and inexpensive design. This type of quadrupole designed for Cornell ERL could be recommended for ILC also.



### SC Undulator with the Possibility to Change Its Strength and Polarization

We describe design of optimized undulator with SC windings able to generate magnetic field of opposite helicities, including elliptic and a linear ones oriented as desired. For undulator period 25mm and aperture 8mm, K factor could be changed from zero up to 1.5 by changing the feeding current. Polarization changed by changing currents in additional helical windings.

**A. A. Mikhailichenko** (Cornell University, Department of Physics)

MO6PFFP083

### Undulator Magnet for Cornell Energy Recovery Linac

The paper describes the design as well as short prototype and the prototype test result of undulator magnet planned for use in Cornell Energy Recovery Linac. The prototype has pure permanent magnet (PPM) structure with 24mm period, 5mm diameter round gap and is 30cm long. In comparison with conventional undulator magnets it has: a) full X-ray polarization control; b) 40% stronger magnetic field in linear and approximately 2 times stronger in circular polarization modes; c) compactness. These advantages were achieved through a number of non-conventional approaches. Among them is control of the magnetic field strength via longitudinal motion of the magnet arrays. The moving mechanism is also used for x-ray polarization control. The compactness is achieved using a recently developed permanent magnet soldering technique for fastening PM blocks. We call this device a "Delta" undulator after the shape of its PM blocks.

**A. B. Temnykh** (Cornell University, Department of Physics)

MO6PFFP084

### Simulation of NdFeB Permanent Magnets at Low Temperature

Cryogenic Permanent Magnet Undulators (CPMU) are currently being developed in some Synchrotron Light Sources. Low Temperature NdFeB Permanent Magnets are used to achieve both a high remanence and a high coercive field. Low temperature magnetization hysteresis curves cannot be obtained by a simple transformation of ambient temperature curves; this requires a specific simulation tool. A Monte-Carlo based Permanent Magnet Simulator has been developed at the ESRF. In this simulator, the magnets can be described as a set of several magnetic grains. The model inputs are physical parameters such as anisotropy constants, easy-axis distribution and coercive field. The orientation of magnetic moments are calculated for each grain according to an analytical model and optimization methods are used for fast computations. Magnetization versus external field curves is calculated in a few seconds. This fits with low temperature NdFeB magnetization measurements. These curves have been efficiently used to obtain Radia material parameters for CPMU design.

**G. Lebec, J. Chavanne** (ESRF)

MO6PFFP085

### Spectrum of the Low Energy Electrons Bombarding the Wall in the ANKA Storage Ring

Recent investigations with the cold bore superconducting undulator installed at ANKA indicate that the main contribution to the beam heat load is caused by electron bombardment. For a quantitative understanding of the problem a cold vacuum chamber for

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diagnostics has been designed. Among other important parameters

MO6PFFP086

(heat load, pressure, etc) this device shall monitor the spectrum of the low energy electrons bombarding the wall. In this contribution we report on the measurements of the spectrum of the low energy electrons bombarding the wall of the cold vacuum chamber in a room temperature region of the ANKA storage ring performed using a in house developed retarding field analyzer (RFA). The calibration of the RFA performed at the national laboratories of Frascati is also described.

### Troubleshooting Status for the ALS In Vacuum Insertion Device

A. Madur, S. Marks, S. Prestemon, D. Schlueter (LBNL)

Advanced Light Source (ALS) of Lawrence Berkeley National Laboratory. Since then the IVID has been demonstrating unexpected behaviors especially at small gaps (minimum gap = 5.5mm). The main observations related to these issues are partial or total beam losses as well as sudden pressure increases while operating the IVID gap. This paper is reporting these observations and describes the investigations and the repair attempt performed on this insertion device.

In 2006, the 30mm period In-Vacuum Insertion Device (IVID) was operational for the femtosecond phenomena beamline at the

### LCLS Undulator System Tuning and Magnetic Measurements

Z. R. Wolf, S. D. Anderson, V. Kaplounenko, Yu. I. Levashov, A. W. Weidemann (SLAC)

quadrupoles between the undulators must be accurately fiducialized. A description of the quadrupole magnetic measurements and fiducialization is also presented.

The LCLS project at SLAC requires 40 undulators be tuned, fiducialized, and a final data set taken. The techniques used to do this work are presented. In addition, the

### Test of the Superconducting Undulator Short Prototype for the ANKA Synchrotron Light Source

E. M. Mashkina (University Erlangen-Nurnberg, Institute of Condensed Matter Physics) C. Boffo, M. Borlein, W. Walter (BNG) S. Casalbuoni, A. W. Grau, M. Hagelstein, D. Saez de Jauregui (FZK) N. Vassiljev (University Erlangen-Nuernberg, Institute of Condensed Matter Physics)

has been fabricated. The prototype has been tested in vertical configuration and liquid helium at 4.2K in the CASPER facility at ANKA. The magnetic field has been measured along the beam axis direction by Hall probes with a positioning precision of 3  $\mu\text{m}$ . We report here on the field shimming scheme and the resulting performance of the coils.

A new 15 mm period, 1.5 m long planar undulator is being fabricated by Babcock Noell GmbH (BNG) for the ANKA synchrotron light source. In order to qualify the production process and to optimize both the quench protection scheme and the magnetic field correction system, a short prototype

**Phase Shifter Prototype with Laminated Permalloy Yokes for a Polarization-Controlled Undulator**

A 27-m polarization-controlled undulator that consists of four horizontal and four vertical  $10^{-8}$  undulator segments and seven phase shifters will be installed at SPring-8 as the most highly brilliant soft x-ray

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source for the material science beamline of the University of Tokyo. Each phase shifter controls the radiation phase between undulator segments by giving a bump orbit to the electron beam with its magnetic field to generate horizontal, vertical and circular polarization states. High reproducibility and stability of the phase control and fast helicity switching of the circular polarization radiation are required for the phase shifter. We designed and fabricated a phase shifter prototype to satisfy these requirements. The phase shifter prototype consists of three H-type dipole magnets and the yokes are made of 0.1-mm-thick permalloy laminations united and insulated by varnish. Various field measurements of the prototype were performed to evaluate the performance. In this paper, we will present the phase shifter prototype for the 27-m polarization-controlled undulator and its performance.

## MO6RF — Afternoon Poster ACTECH T14, SAI

### Enhancing RHIC Luminosity Capabilities with In-situ Beam Pipe Coating

A. Hershcovitch, M. Blaskiewicz, W. Fischer (BNL) H. J. Poole (PVI)

Electron clouds have been observed in many accelerators, including RHIC at BNL. They can limit the machine performance through pressure degradation, beam instabilities or incoherent emittance growth. The formation of electron clouds can be suppressed with beam pipe surfaces that have low secondary electron yield. Also, high wall resistivity in accelerators can result in unacceptably high ohmic heating levels for superconducting magnets. These are concerns RHIC, as its vacuum chamber in the superconducting dipoles is made from relatively high resistivity 316LN stainless steel. The high resistivity can be addressed with a copper (Cu) coating; a reduction in the secondary electron yield can be achieved with a titanium nitride (TiN) or amorphous carbon (a-C) coating. Applying such coatings in an already constructed machine is rather challenging. We started developing a robotic plasma deposition technique for in-situ coating of long, small diameter tubes. The technique entails fabricating a device comprising of staged magnetrons and/or cathodic arcs mounted on a mobile mole for deposition of about 5  $\mu\text{m}$  (a few skin depths) of Cu followed by about 0.1  $\mu\text{m}$  of TiN (or a-C).

### Status of NSLS-II Storage Ring Vacuum Systems

H.-C. Hseuh, L. Doom, M. J. Ferreira, C. Longo, V. Ravindranath, P. Settepani, S. Sharma, K. Wilson (BNL)

National Synchrotron Light Source II is a 3-GeV, 792-meter circumference, high-flux and high-brightness synchrotron radiation facility being constructed at Brookhaven National Laboratory. The storage ring vacuum chambers are made of extruded aluminium and the bending magnet photons are intercepted at discrete photon absorbers. The design of the storage ring vacuum system will be presented, with emphasis on vacuum chamber design and fabrication, pumping arrangements, photon beam tracking and absorber positioning, and interface with other accelerator systems. The evaluation of the aluminium chamber prototypes and RF shielded bellows will also be described.

### The Vacuum System of HIRFL

X. T. Yang, D. Z. Guo, C. Y. Hao, S. J. Hou, Z. J. Hu, Y. S. Jia, M. L. Lou, S. M. Lv, X. L. Ma, J. Meng, Z. S. Nie, Z. W. Niu, W. S. Yang, Z. M. You, J. H. Zhang, Y. G. Zhao (IMP)

The vacuum system of HIRFL is a large and complex system. HIRFL consists of two ECR ion sources, a sector focus cyclotron (SFC), a separate sector cyclotron (SSC) and a multi-purpose cooling storage ring system which has a main ring (CSRm) and an experiment ring (CSRe). Several beam lines connect these accelerators together and transmit various heavy ion beams to more than 10 experiment terminals. According to the requirements of the ion acceleration and ion lifetime, the working pressure in each accelerator is different. SFC is nearly 50 years old. After upgrade, the working pressure in SFC is improved from  $10\text{E-6mbar}$  to  $10\text{E-8mbar}$ . The pressure in SSC which was built in 1980s reaches the same level. The cooling storage ring system with a length of 500m came into operation in 2007. The average pressure in CSRm and CSRe is  $5\text{E-12mbar}$  and  $8\text{E-12mbar}$  respectively. Different designs were adopted for vacuum system of dozens beam lines to meet various experiment terminals requirement.

For instance, some shockproof measures have to be taken for the heavy ion microbeam facility. A clean and large throughput differential pumping system was built for the Gas-filled Recoil Separator and so on.

### The Status of the Vacuum System of ALBA Synchrotron

The vacuum system of CELLS is in the production stage of its subsystems and installation for part of it. The booster vacuum chambers are being assembled and baked out in a provisional lab in the ALBA building and will be ready for the installation by the beginning of 2009. more than 60% of the storage ring vacuum chambers have been delivered, and the delivery will finish by the end of February 2009, several chambers were tested at CELLS (tests include vacuum tests, dimensional check, magnetic permeability tests...etc). All the tools needed for the assembly of the storage ring vacuum chambers have been delivered and tested at CELLS to validate the assembly procedure. Concerning the standard vacuum components; all the gauges and residual gas analysers were delivered, almost all the ion pumps and all the controllers are at CELLS, the NEG pumps and the UHV valves were delivered too.

E. Al-Dmour, D. Einfeld, R. Martin (ALBA)

### CesrTA Vacuum System Modifications

In concert with the ILC global design effort, the CESR is being converted into ILC Damping Ring Test Accelerator. The vacuum system is undergoing staged reconfigurations to support both the CesrTA physics goals and the CHSS X-ray sources. Six superconducting wigglers were moved to a sector with zero-dispersion. The sector is densely populated with beam instrumentation and diagnostic devices. A new photon stop chamber will be used to handle the high synchrotron radiation power generated from the SCWs at high positron beam energy. A 12-m long gate-valve isolated straight sector was created in a second location, where many electron-cloud diagnostic chambers will be installed and tested. We also configured two very short sections in the arcs, with additional gate valves, to provide flexibility of exchanging various meter-long test chambers with minimum impact to the operations. Many retarding field analyzers were integrated into the vacuum modifications in SCWs, dipoles, and drifts to study EC growth and suppression techniques. Creating environments where both local and collaborator provided equipment can be easily installed has been a major objective in the modifications.

Y. Li (Cornell University, Department of Physics) X. Liu, V. Medjizade, M. A. Palmer, D. H. Rice, D. L. Rubin (CLASSE) J. J. Savino (CHSS)

### Neon Venting of Activated NEG Beam Pipes in the CERN LHC Long Straight Sections without Losing Vacuum Performance

In the CERN Large Hadron Collider, about 6 km of the UHV beam pipe are at ambient temperature and serve as experimental or utility insertions. The vacuum of these sectors rely on TiZrV non-evaporable getter (NEG) coating to achieve very low pressure. In the case of venting to atmosphere, the use of NEG coatings implies the bake-out of the vacuum sector to recover the low pressure and reactivate the NEG coatings. A new method to vent a vacuum sector to atmosphere allows performing short interventions without losing completely the performance of the already activated NEG coating. The principle is to over-pressurize the vacuum sector with neon gas which is not pumped by the NEG coatings, remove the faulty component and then pump down the sector again. The injection of such a gas in the vacuum sector aims at preserving the saturation of the NEG coatings during the exchange of the

G. Bregliozzi (CERN)

component. A detailed description of this new venting system will be presented and discussed. Preliminary results obtained from a laboratory venting system and its evaluation in the LHC tunnel to replace existing components will be presented.

### Design and Vacuum Tests of the CLIC Quadrupole Vacuum Chambers

C. Garion, H. Kos (CERN)

The Compact Linear Collider, under study, requires vacuum chambers with a very small aperture, of the order of 8 mm in diameter, and with a length up to around 2 m for the main beam quadrupoles. To keep the very tight geometrical tolerances on the quadrupoles, no bake out is allowed. The main issue is to reach UHV conditions (typically  $10^{-9}$  mbar static pressure) in a system where the vacuum performance is driven by water outgassing. For this application, a thin-walled stainless steel vacuum chamber with two ante chambers equipped with NEG strips, is proposed. The mechanical design, especially the stability analysis, is shown. The key technologies of the prototype fabrication are given. Vacuum tests have been carried out on the prototypes. The test set-up as well as the performance of the pumping system are presented and compared with predictions.

### Experimental Studies of Carbon Coatings as Possible Means of Suppressing Beam Induced Electron Multipacting in the CERN SPS

E. N. Shaposhnikova, G. Arduini, J. Axensalva, E. Benedetto, S. Calatroni, P. Chiggiato, K. Cornelis, P. Costa Pinto, B. Henrist, J. M. Jimenez, E. Mahner, G. Rumolo, M. Tadorelli, C. Yin Vallgren (CERN)

Electron cloud build-up is a major limitation for the operation of the SPS with LHC beam above nominal intensity. These beams are envisaged in the frame of the LHC luminosity upgrade and will be available from the new injectors LPSPL and PS2. A series of studies have been conducted in order to identify possible means to suppress electron multipacting by coating the existing SPS vacuum chambers with thin films of amorphous carbon. After a description of the experimental apparatus installed in the SPS, the results of the tests performed with beam in 2008 will be presented.

### The ATLAS Beam Vacuum System

R. Veness (CERN)

The LHC collider has recently started-up at CERN. It will provide colliding beams to four experiments installed in large underground caverns. A specially designed and constructed sector of the LHC beam vacuum system transports the beams through each of these collision regions, forming a primary interface between machine and experiment. ATLAS is the largest of the four LHC colliding beam experiments, being some 40 m long and 22 m in diameter. Physics performance, geometry and access imposed a large number of constraints on the design of the beam vacuum system. This paper describes the geometry and layout of the ATLAS beam vacuum system. Specific technologies developed for ATLAS, and for the alignment and installation of the vacuum chambers are described as well as the issues related to the physical interfaces with the experiment.

### Installation and Commissioning of Vacuum Systems for the LHC Particle Detectors

The LHC collider has recently completed commissioning at CERN. At four points around the 27 km ring, the beams are put into collision in the centre of the experiments

**R. Veness**, S. Blanchard, P. Lepeule, D. Ramos, A. Rossi, G. Schneider (CERN)

ALICE, ATLAS, CMS and LHCb which are installed in large underground caverns. The 'experimental vacuum systems' which transport the beams through these caverns and collision points are a primary interface between machine and experiment and were developed and installed as one project at CERN. Each system has a different geometry and materials as required by the experiment. However, they all have common requirements from the machine, and use many common technologies developed for the project. In this paper we give an overview of the four systems stressing the similarities between them. We explain the technologies that were developed and applied for the installation, test, bakeout and subsequent closure of the experimental vacuum systems. We also discuss lessons learnt from the project.

MO6RFP010

### Status of the ESRF Vacuum System from an Operational Point of View

This paper outlines the present status and configuration of the ESRF vacuum system and its performance over the last years. A

**R. Kersevan**, M. Hahn, I. Parat, D. Schmied (ESRF)

short overview of the installed vacuum devices is given as well as an outlook of future developments towards the planned ESRF upgrade. The storage ring down times caused by vacuum accidents have been dramatically improved due to a systematical survey using advanced vacuum diagnostic tools. Their use and drawbacks will also be discussed in this paper.

MO6RFP011

### Vacuum Behavior of Longer Insertion Device Straight Sections for the Upgrade Program of the ESRF Storage Ring

The ESRF is working on an upgrade program which includes new beamlines and improvements of the accelerator complex.

**R. Kersevan**, M. Hahn (ESRF)

The available length for insertion devices will be increased from five to six and later seven meters. The new vacuum chambers will use non evaporable getter coatings on aluminium, stainless steel and copper substrates. This paper presents MOLFLOW+ simulations of the new six meter ID chamber placed between new quadrupole vacuum chambers without lumped pumping, and a prototype high-power crotch absorber. Scenarios concerning the dynamic vacuum behavior of the NEG coated sections are derived from ten years of experience with NEG coatings for insertion device and other vacuum chambers at ESRF.

MO6RFP012

### Photodesorption Measurements on Thin-Film Coatings at the ESRF

At the ESRF, since 1998 a dedicated photodesorption beamline, D31, is in operation. A number of interesting measurements on

**R. Kersevan**, G. Debut (ESRF) P. Chiggiato, P. Costa Pinto (CERN)

photodesorption yields of various materials have been carried out, namely the first ones on non-evaporable getters (NEGs) on stainless steel, aluminium, and copper. The success of these measurements started the development of NEG coatings on accelerators, a technology which has been implemented on many accelerators worldwide. At the

MO6RFP013

same time, the requirement for coatings which possess a very low secondary electron yield for the mitigation of the formation of electron clouds, has been started. This paper deals with the first measurement of a different type of coating, amorphous carbon (a-C), on a stainless steel chamber. We discuss measurements of its photodesorption yield and compare it to that of chambers with the same geometry and different materials or coatings.

### Thin Film Coating for the Upgrade of the Heavy Ion Synchrotron SIS18 at GSI

M. C. Bellachioma, H. Kollmus, A. Kraemer, J. Kurdal, H. Reich-Sprenger, St. Wilfert (GSI) M. Bender (LMU)

For the future FAIR facility intensities up to  $10^{12}$   $U^{28+}$  ions per second are required. For this purpose the existing heavy ion synchrotron SIS18, which will serve as injector, has

to be upgraded. Since the required base pressure is  $10^{-10}$  Pa, among the different measures undertaken to improve the existing UHV system, the installation of NEG coated magnet chambers is foreseen. Two magnetron sputtering facilities were designed and commissioned at GSI to perform the coating. The characterization of the thin films has been carried out by RBS and XPS. Considering that the vacuum chambers mounted in accelerators undergo several venting-activation cycles, a deep investigation on the NEG aging was performed by ERDA. Fourteen dipole and one quadrupole chambers were coated and installed in the SIS 18, and the replacement of the remaining magnet pipes will follow in the next years. Additionally to overcome the dynamic vacuum instability a collimation system equipped with thin film coated absorbers was successfully tested in 2008. The coating facilities, their operating mode, the results achieved on the thin film characterization, and the ones obtained in the SIS 18 are presented.

### Gas Desorption from TiN-Coated Copper Beam Duct

K. Shibata, H. Hisamatsu, K. Kanazawa, M. Shirai, Y. Suetsugu (KEK)

The titanium nitride (TiN) coating inside a beam duct has been recently attracting attention as a measure to mitigate the electron cloud effect in positron/proton rings. Here

studied is the gas desorption from the TiN-coated copper beam duct, which will be adopted in the upgrade of KEK B-factory (KEKB). In the experiment, the pressure in a TiN-coated duct was measured and compared with that in a non-coated one. The TiN film (200 nm thick) was coated by DC magnetron sputtering at KEK. After an air exposure for the previously-determined period, the duct was evacuated by a turbo-molecular pump (300 l/s). At 50 hours after evacuation, the pressure was about 4 times larger than that for the case of the non-coated one. The residual gas was mainly water. In order to find the minimum baking temperature to decrease the gas desorption from the TiN coating, the pressures were measured after the baking by changing the temperatures in the practical range, from 50 to 150 degrees. The pressure after the baking at 80 degrees was finally found to be comparable to that for the non-coated one. This paper describes these results in detail including the measurements of gas desorption rates.

### Vacuum Status during the Beam Operation of RCS in J-PARC

J. Kamiya, Y. Hikichi, K. Kanazawa, K. Mio, N. Ogiwara, Y. Takiyama (JAEA/J-PARC)

Since the start of the beam commissioning on October 2007, we have succeeded to increase the beam power of the Rapid Cycling Synchrotron (RCS) in the Japan Proton Ac-

celerator Research Complex (J-PARC). The effect of the high power beam on the vacuum had become visible above the beam power of 50 kW. When the high power beam was operated at 25 Hz, the vacuum pressure became higher.



Especially the vacuum of the injection area became worse than other areas. The residual gas analyzer was installed in order to investigate which kinds of outgassing were desorbed by the high power beam. The carbon compound mainly increased with the high power beam in the area. The source of the outgassing is thought to be carbon foils for charge exchange and/or a electron catcher which was installed in order to collect the stripped electron by the carbon foil. After this, the RCS forwards into the stage where the high power beam is continuously operated during a few weeks. We will report the results of the conditioning effect on the vacuum by the beam itself.

### Large Scale Ti Bellows

At the 3-GeV RCS in J-PARC, pure Ti has been adopted as the material for bellows because of its small residual radioactivity. Large scale bellows are necessary to adjust

the gap between the ceramic ducts. However, the space for the bellows is so narrow that their requirements are strict. The typical free length and inner diameter of the bellows were 100 mm and 400 mm respectively; nevertheless, a spring rate of less than 100 N/mm was needed in order to avoid damage to the ceramic ducts. Therefore, we decided to make the flexible hydro-formed bellows. To realize the bellows, it is essential to bend the Ti plates and to make sure of close contact. There were 2 tasks: lack of elongation and spring-back effect. Repetition of the combination of the bending process with annealing enables us to ensure close contact of Ti plates. Finally, the production process for the bellows was established after confirming the above effects of annealing experimentally, and we succeeded in developing a hydro-formed bellows with the same flexibility as a welded one.

**N. Ogiwara**, J. Kamiya, M. Kinsho, K. Suganuma (JAEA/J-PARC)  
O. Koizumi (Osaka Rasenkan Kogyo Co.,LTD.)

MO6RFP017

### TPS Vacuum System

The Taiwan Photon Source (TPS) vacuum system has been designed for a 3 GeV electron storage ring of 24DBA lattice, 518.4 m circumference, 24 unit cells and 24 long straight sections of 6 in 12 m and 18 in 7 m.

The vacuum ducts for each cell made from thick aluminum plates and extruded aluminum beam pipes will be precisely machined and welded for obtaining a low impedance with small quantity of flanges and bellows. The beam ducts in long straight sections will be flat extruded aluminum pipes of 10 mm vertical height inside which will be ready for installation of the undulators without breaking the vacuum. The BPMs, 2 in each straight sections and 5 in each cells, will be fixed on the ground or on the girder rigidly through the strong supports maintaining a displacement of < 0.1 micron against the stress force of 10 kg from the beam ducts. The small aperture of 10 mm inside the aluminum bending chamber rejects the PSD outgas from the crotch absorbers backfilled to the beam channel, while the surface of bending chamber will be cleaned with ozonated water to reach lower thermal outgassing rate that maintains a much lower averaged pressure below 100 nPa inside the beam ducts.

**G.-Y. Hsiung**, C. K. Chan, C.-C. Chang, C. L. Chen, S-N. Hsu, H. P. Hsueh, A. Sheng, C. Y. Yang, R. Yb (NSRRC) J.-R. Chen (National Tsing Hua University)

MO6RFP018

### TPS Front End Design in NSRRC

National Synchrotron Radiation Research Center (NSRRC) will build a new 3GeV, 400mA synchrotron accelerator machine.

Several different IDs have been proposed and the corresponding front ends are designed. Beam lines of IU20, IU28, SW48 and EPU70 will be the phase I requirement. Due to different power load and density flux, fixed

**A. Sheng** (NSRRC)

MO6RFP019

masks, photon absorber, slits, photon absorber and photon beam position monitor will all be customized to meet the beam line user requirements as well as the thermomechanical limits. Overall front end layout, analysis results of the high heat load components are illustrated; experiments of photon beam position monitor, front end pressure distribution due to thermal and photon stimulated desorption outgassing analysis, are also presented in this paper.

### The Pressure Distribution of the TPS FE Vacuum System

C. Y. Yang, C. K. Chan, J.-R. Chen, G.-Y. Hsiung, C. K. Kuan, A. Sheng (NSRRC)

Front End (FE) is the first area shapes radiation power to suit the need not only for protection but also for the beam line uses. About 14m long FE vacuum system will connect the ultra high vacuum (UHV) storage ring and beam line in Taiwan Photon Source (TPS). The Fixed mask (FM), photon absorber (PAB) and slit are the major high gas load components, especially in insertion Devices (ID) front ends, because of the synchrotron radiation. From the  $P(\text{pressure})=Q(\text{outgas})/S(\text{pump})$  formula, there are some issues will be concerned to get lower vacuum pressure: The low outgassing rate of the vacuum chamber ( $Q_{\text{thermal}}$ ), the localization of the the pumps (IP and NEG) to pump down the outgassing of the photon simulated desorption( $Q_{\text{psd}}$ ), and the arrangement of the aperture and gas load . The basic pressure distribution of the bending magnet (BM) and ID front ends will be discussed.

Front End (FE) is the first area shapes radiation power to suit the need not only for protection but also for the beam line uses. About 14m long FE vacuum system will

### TRIUMF Cyclotron Vacuum System Upgrade and Operational Experience

I. Sekachev, I. V. Bylinskii, A. Koveshnikov, D. Yosifov (TRIUMF)

The replacement of the 30-year-old Philips cryogenerator with a modern LINDE-1630 helium refrigerator is an important component of TRIUMF's ongoing 500 MeV cyclotron refurbishing program. Two 10.7 m long cryopanel are cooled with liquid helium rather than with 17K helium gas, as was the case with the cryogenerator. This has increased the pumping speed and, respectively, improved the ~100 m<sup>3</sup> cyclotron tank vacuum. Additionally, the thermal shield, previously cooled with helium gas, is now cooled with liquid nitrogen. These changes have resulted in increased reliability of the cyclotron vacuum system and, consequently, longer operation periods without maintenance. The new refrigeration unit was commissioned in September 2007. The results from over one year of operational experience are discussed. Also, data on hydrogen cryopumping is presented.

The replacement of the 30-year-old Philips cryogenerator with a modern LINDE-1630 helium refrigerator is an important component of TRIUMF's ongoing 500 MeV cyclotron refurbishing program.

### The Design and Test of Plug-In Cryopumps

G. F. Pan, Z. G. Li, J. C. Qin, J. S. Xing, S. P. Zhang, T. J. Zhang (CIAE) I. Sekachev (TRIUMF)

The design and cryo-test system of a plug-in cryopump used in CYCIAE-100 is introduced. The plug-in cryopump consists of two cryopanel, a baffle, a half-opened shield, and two GM refrigerators (CGR411,,CVI) which power is 83W/80K at the first stage and 7.5W/20K at the second stage, its designed pumping speed is 15000L/s. Cryo-test system of plug-in cryopump employs the flux method to test pumping speed, cool-down time, ultimate pressure, temperature distribution on cryopanel and capacity at the pressure of 10<sup>-6</sup>Pa to 1Pa. The heat load calculation of cryopanel and shield including baffle is conducted in succession. In the end a comparison between design parameters and test results is drawn.

The design and cryo-test system of a plug-in cryopump used in CYCIAE-100 is introduced. The plug-in cryopump consists of two cryopanel, a baffle, a half-opened shield, and two GM refrigerators (CGR411,,CVI) which power is 83W/80K at the first stage and 7.5W/20K at the second stage,

**Experimental Study of Stainless Steel Vacuum Chamber with TiN Film Coating**

TiN coating has been widely applied in surface treatments of particle accelerator vacuum chambers because of its characteristics such as good electrical conductivity, stability of performance, ability to block hydrogen permeation, low SEY, etc. With DC sputtering, TiN film has been coated on the inner face of a stainless steel pipe vacuum chamber, 86 mm in diameter and 2300 mm in length. The vacuum performances testing of the coated chamber has also been done, including thermal outgassing rate measurement, PSD measurement, and SEY measurement of samples. Compared with those of uncoated stainless steel chamber, the results show that coating TiN film is a very effective method of the treatment of particle accelerator vacuum chamber.

**Y. Wang** (USTC/NSRL)

MO6RFP023

**Experimental Study of Stainless Steel Pipes with TiZrV Film Coating**

Titanium-zirconium-vanadium film, which can be fully activated after 4 h heating at 200°C, has been applied in many accelerators owing to the outstanding vacuum performance. In this paper, TiZrV films were deposited onto the inner face of stainless steel pipes via DC sputtering using argon gas as the sputtering gas. After coating, samples were investigated by Scanning Electron Microscopy (SEM) and X-ray Photoelectron Spectrum (XPS) to obtain the information of the film thickness and composition. Pumping performance of the coated pipe and Second Electron Yields (SEY) of samples were measured.

**Y. Wang, B. Zhang** (USTC/NSRL)

MO6RFP024

**Construction of the BNL EBIS Preinjector**

A new heavy ion preinjector, consisting of an Electron Beam Ion Source (EBIS), an RFQ, and IH Linac, is under construction at Brookhaven National Laboratory. This preinjector will provide ions of any species at an energy of 2 MeV/u, resulting in increased capabilities for the Relativistic Heavy Ion Collider, and the NASA Space Radiation Laboratory programs. Initial operation of the EBIS and RFQ will be reported on, along with the status of the construction and installation of the remainder of the preinjector.

**J. G. Alessi, D. S. Barton, E. N. Beebe, S. Bellavia, O. Gould, A. Kponou, R. F. Lambiase, E. T. Lessard, V. LoDestro, R. Lockey, M. Mapes, D. R. McCafferty, A. McNerney, M. Okamura, A. Pendzick, D. Phillips, A. I. Pikin, D. Raparia, J. Ritter, J. Scaduto, L. Snydstrup, M. Wilinski, A. Zaltsman** (BNL) **T. Kanesue** (Kyushu University) **U. Ratzinger, A. Schempp** (IAP) **J. Tamura** (Department of Energy Sciences, Tokyo Institute of Technology)

MO6RFP025

**Metal Ion Beam Acceleration with DPIS**

We have studied a laser ion source in Brookhaven National Laboratory since 2006. In November 2008, we had first beam through an RFQ and the measured current reached about 50 mA with carbon beam. The RFQ and ion source were originally commissioned in Japan and moved to BNL in 2006. We will report various acceleration test results at the conference.

**M. Okamura** (BNL) **T. Kanesue** (Kyushu University, Department of Applied Quantum Physics and Nuclear Engineering) **J. Tamura** (Department of Energy Sciences, Tokyo Institute of Technology)

MO6RFP026

### Results of LEBT/MEBT Upgrade at BNL 200 MeV Linac

D. Raparia (BNL)

The low energy (35 keV) and medium energy (750 keV) transport lines for (un)polarized  $H^{\pm}$  have been reconfigured to reduce beam losses and the beam emittance out of the 200 MeV Linac. The medium energy line in the original layout was 7 m long, and had ten quadrupoles, two beam choppers, and three bunchers. The bunchers were necessary to keep the beam bunched at the entrance of the Linac. About 35% beam loss occurred, and the emittance growth was several fold. In the new layout, the 750 keV line is only 0.7 m long, with three quads and one buncher. To preserve beam polarization in the 35 keV line, the solenoid in front of the RFQ (35 keV to 750 keV) was replaced with an Einzel lens. To reduce the spin-precession in the LEBT, which may cause the depolarization, a 47.4 degree bend was removed and focusing solenoid in front of RFQ was replaced with an Einzel lens. We will present the experimental result of the upgrade.

### Highly Charged Ion Beam Production at SECRAL Superconducting ECR Ion Source

H. W. Zhao (IMP)

An advanced superconducting ECR ion source named as SECRAL was successfully built to produce intense beams of highly charged ions for HIRFL accelerator in Lanzhou. What is different from traditional superconducting ECR ion source for SECRAL is that the three axial solenoid coils are located inside of the sextupole bore with a cold iron structure, which can produce peak mirror fields on axis 3.6 Tesla at injection and a radial sextupole field of 2.0 Tesla at plasma chamber wall. During the commissioning phase at 18 GHz, tests with various gases and some metals have been conducted with two 18GHz rf generators. Record beam intensities have been produced, for instance, 505  $e\mu A$  of  $Xe^{20+}$ , 305  $e\mu A$  of  $Xe^{27+}$  and so on. Recently SECRAL is being tested using double frequency heating 18GHz +14.5 GHz with an aluminium chamber, some new record beam intensities of highly charged ions have been produced. Dependences of the rf power, the magnetic field configuration on the ion source performance and beam emittance have been studied experimentally. SECRAL has been put into operation for HIRFL accelerator since May 2007. Operation status will be presented.

### Injection Layout for PAMELA

M. J. Easton, M. Aslaninejad, J. Pasternak, J. K. Pozimski (Imperial College of Science and Technology, Department of Physics) K. J. Peach (JAI) T. Yokoi (OXFORDphysics)

For PAMELA project, the injection lay out for both protons as well as carbon 6+ ions is discussed. Injection system would consist of a 30 MeV cyclotron for protons and a chain of elements for carbon ions such as ECR ion source, bending magnets and focusing solenoids; RFQ, IH/CH structures and a striping foils. The charge particle simulation for different protons as well as carbon ions passing through the elements has been carried out with General Particle Tracer (GPT), software.

### The MISHA Ion Source for Hadron Therapy Facilities

During the last 10 years it was demonstrated that slight variations of microwave frequency used in ECRIS strongly influence their performances either for extracted current and for beam brightness and stability. Theoretical investigations put in evidence that such frequency tuning is linked to the electromagnetic field structure inside the resonant cavity. On this basis, we carried out PIC simulations, showing that the frequency tuning has a global influence on plasma properties and on beam brightness. Such analysis allowed the design of the optimum setup for plasma chamber dimensions and microwave injection, to achieve higher currents and better emittances. The magnetic field is based on the use of steep gradient but the cryogenics issues are simplified; the extraction system is designed to minimize the aberrations. The overall dimensions of the MISHA source (Multicharged Ion Source for HAdrontherapy) have been chosen as a compromise between the ideal size for microwave to plasma interaction, the need to get long ion confinement time and the request of getting a compact ECRIS. The description of the source design will be given, along with the expected performances.

**S. Gammino**, L. Celona, G. Ciavola, F. Maimone, D. Mascali (INFN/LNS)

MO6RFP030

### A New Approach to the Modelling of the Plasma Dynamics in ECR Ion Sources

The trend of ECRIS to higher frequencies and magnetic fields is driven by the need to have higher beam currents and higher charge states for nuclear physics accelerators. Anyway, because of the limits imposed by the magnets' and microwaves generator's technology, any further increase of performances requires a detailed investigation of the plasma dynamics. The experiments have shown that the current, the charge states and even the beam shape change by slightly varying the microwave frequency (frequency tuning effect - FTE). Moreover, for last generation ECRIS, electron energies up to 2 MeV have been detected, depending mainly on the magnetic field structure and gradient distribution over the ECR surface. The plasma dynamics have been studied by means of single particle and PIC simulations: they explain the FTE in terms of the wave field distribution over the ECR surface and the existence of high energy electrons due to diffusion in the velocity space above the stochastic barrier. Other methods used to improve the ECRIS performances, e.g. the two frequency heating with an adequate phase relation between the two waves, can be exploited by means of the simulations.

**D. Mascali**, L. Celona, G. Ciavola, S. Gammino, F. Maimone (INFN/LNS)

MO6RFP031

### Development of Very Small ECR H<sup>+</sup> Ion Source with Pulse Gas Valve

We are aiming to develop a compact accelerator based neutron source using Li(p,n) reaction. The first target is a small and high current H<sup>+</sup> ion source as an injector of the neutron source. The demands are not only being small and high current but also longer MTBF and large ratio of H<sup>+</sup> to molecular ions such as H<sup>2</sup> or H<sup>3</sup>. Therefore, the ECR ion source with permanent magnets is selected as such an ion source. Because ECR ion sources don't have hot cathodes, longer MTBF is expected. Furthermore, they can provide high H<sup>+</sup> ratio because of their high electron temperature. Using permanent magnets makes the ion source small and running cost low. Up to now, we have measured ion beam current on the first model of the ECR ion source, and fabricated the redesigned model. The data measured of the second model will be presented.

**M. Ichikawa**, H. Fujisawa, Y. Iwashita, T. Sugimoto, H. Tongu, M. Yamada (Kyoto ICR)

MO6RFP032

### Development of a Li<sup>+</sup> Alumino-Silicate Ion Source

P. K. Roy, A. Anders, W. G. Greenway, J. W. Kwan, S. M. Lidia, P. A. Seidl, W. L. Waldron (LBNL)

To uniformly heat targets to electron-volt temperatures for the study of warm dense matter, one strategy is to deposit most of the ion energy at the peak of energy loss (dE/dx) with a low ( $E < 5$  MeV) kinetic energy beam and a thin target\*. Lower mass ions have a peak dE/dx at a lower kinetic energy. To this end, a small lithium (Li<sup>+</sup>) alumino-silicate source has been fabricated, and its emission limit has been measured. These surface ionization sources are heated to -10-00-1150 C where they preferentially emit singly ionized alkali ions. Alumino-silicates sources of K<sup>+</sup> and Cs<sup>+</sup> have been used extensively in beam experiments, but there are additional challenges for the preparation of high-quality Li<sup>+</sup> sources: There are tighter tolerances in preparing and sintering the alumino-silicate to the substrate to produce an emitter that gives uniform ion emission, sufficient current density and low beam emittance. We report on recent measurements of high (up to 35 mA/cm<sup>2</sup>) current density from a Li<sup>+</sup> source. Ion species identification of possible contaminants is being verified with a Wien (E x B) filter, and via time-of-flight.

\*J. J. Barnard et al., Nuclear Instruments and Methods in Physics Research A 577 (2007) 275–283.

### The EBIT Charge State Booster for Exotic Beam Reacceleration at MSU

O. K. Kester, G. Bollen, S. Chouhan, M. J. Johnson, J. Ottarson, M. Portillo, S. Schwarz, C. Wilson (NSCL)

The National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University (MSU) is implementing a system to reaccelerate rare isotope beams from projectile fragmentation to energies of about 3 MeV/u. The reacceleration of stopped radioactive beams from projectile fragmentation at the NSCL/MSU makes use of charge state breeding in an Electron Beam Ion Trap (EBIT) to provide a compact and cost efficient system layout of MSU's ReA3. The MSU EBIT breeder device will provide a high electron beam current density of about 10<sup>4</sup> A/cm<sup>2</sup> making it well suited to rapidly increase the charge state of short-lived isotopes within tens of milliseconds or less. In addition, the breeder is optimized to provide a high storage capacity, a high beam acceptance and uses a continuous injection and beam accumulation scheme explicitly, which makes it unique. To match the beam of singly charged rare isotope ions into the acceptance of the EBIT and to analyze and purify the EBIT beams, a sophisticated beam line and diagnostic system is required. The present paper will present an overview and the status of the ReA3 EBIT.

### Performance Investigation of the NSCL 18 GHz Superconducting ECR Ion Source SUSI

G. Machicoane, C. Benatti, D. Cole, M. Doleans, O. K. Kester, F. Marti, X. Wu, P. A. Zavodszky (NSCL)

The construction of the Superconducting Source for Ions (SUSI), a 3rd generation Superconducting ECR ion source for the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University has been completed and commissioning of the source is ongoing. SUSI operates primarily at 18GHz and is scheduled to replace the 6.4 GHz SC-ECR for injection in the coupled cyclotron later this year. Excellent performances during commissioning have been obtained with SUSI for the production of highly charged ions for both metallic and gas elements and will be presented. A set of six solenoid coils gives SUSI the capability to modify the length and the position of the resonant zone and also to adjust the gradient of the axial magnetic field near the resonance. The impact of this flexible magnetic field profile on the ion beam production and the charge state distribution is actively studied and will be discussed. Emittance measurements of the ion beam extracted from SUSI have been performed and will also be presented.

## H<sup>-</sup> Ion Sources for High Intensity Proton Drivers

Spallation neutron source user facilities require reliable, intense beams of protons. The technique of H<sup>-</sup> charge exchange injection into a storage ring or synchrotron can provide the needed beam currents, but it is limited by the ion sources that have currents and reliability that do not meet future requirements and emittances that are too large for efficient acceleration. In this project we are developing an H<sup>-</sup> source which will synthesize the most important developments in the field of negative ion sources to provide high current, small emittance, good lifetime, high reliability, and power efficiency. We describe planned modifications to the present external antenna source at SNS that involve: 1) replacing the present 2 MHz plasma-forming solenoid antenna with a 60 MHz saddle-type antenna and 2) replacing the permanent multicusp magnet with a weaker electromagnet, in order to increase the plasma density near the output aperture. The SNS test stand will then be used to verify simulations of this approach that indicate significant improvements in H<sup>-</sup> output current and efficiency, where lower RF power will allow higher duty factor, longer source lifetime, and/or better reliability.

**V. G. Dudnikov**, G. Dudnikova, R. P. Johnson (Muons, Inc) M. P. Stockli, R. F. Welton (ORNL)

## The SNS External Antenna H<sup>-</sup> Ion Source

The U. S. Spallation Neutron Source (SNS) is an accelerator-based, pulsed neutron-scattering facility, currently in the process of ramping up neutron production. In order to insure that we will meet our operational commitments as well as provide for future facility upgrades with high reliability, we have developed an RF-driven, H<sup>-</sup> ion source based on a ceramic aluminum nitride (AlN) plasma chamber\*. This source is expected to enter service as the SNS neutron production source starting in 2009. This report details the design of the production source which features an AlN plasma chamber, 2-layer external antenna, cooled-multicusp magnet array, Cs<sub>2</sub>CrO<sub>4</sub> cesium system and a Molybdenum plasma ignition gun. Performance of the production source both on the SNS accelerator and SNS test stand is reported. The source has also been designed to accommodate an elemental Cs system with an external reservoir which has demonstrated unanalyzed beam currents up to ~100mA (60Hz, 1ms) on the SNS ion source test stand.

**R. F. Welton**, J. R. Carmichael, D. W. Crisp, R. H. Goulding, S. N. Murray, T. R. Pennisi, M. Santana, M. P. Stockli (ORNL) B. Han (ORNL RAD)

\*R. F. Welton, et al., "Next Generation Ion Sources for the SNS", Proceedings of the 1st Conference on Negative Ion Beams and Sources, Aix-en-Provence, France, 2008

## The ORNL Helicon H<sup>-</sup> Ion Source

Plasmas produced by helicon wave excitation typically develop higher densities, particularly near the radial plasma core, at lower operating pressures and RF powers than plasmas produced using traditional inductive RF coupling methods. Approximately two years ago we received funding to develop an H<sup>-</sup> ion source based on helicon wave coupling. Our approach was to combine an existing high-density, hydrogen helicon plasma generator developed at ORNL for the Variable Specific Impulse Magnetoplasma Rocket (VASIMR) project with the SNS external antenna H<sup>-</sup> source. To date we have achieved plasma densities >10<sup>13</sup> e/cm<sup>3</sup> inside the ion source

**R. F. Welton**, J. R. Carmichael, D. W. Crisp, S. C. Forrester, R. H. Goulding, S. N. Murray, D. O. Sparks, M. P. Stockli (ORNL) O. A. Tarvainen (LANL)

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using <10kW of RF power and <5 SCCM of H<sub>2</sub> gas flow. This report discusses the first cesiated H<sup>-</sup> beam current extraction measurements from the source.

### Calculation of Charge-Changing Cross Sections of Ions or Atoms Colliding with Fast Ions Using the Classical Trajectory Method

I. Kaganovich, R. C. Davidson (PPPL) H. E. Mebane (HCL) A. Shnidman (PU)

The evaluation of ion-atom charge-changing cross sections is needed for many accelerator applications. A classical trajectory Monte Carlo (CTMC) simulation has been used to calculate ionization and charge exchange cross sections. For benchmarking purposes, an extensive study has been performed for the simple case of hydrogen and helium targets in collisions with various ions. Despite the fact that the simulations only account for classical mechanics effects, the calculated values are comparable to the experimental results for projectile velocities in the region corresponding to the maximum cross section. Shortcomings of the CTMC method for multi-electron target atoms are also discussed.

The evaluation of ion-atom charge-changing cross sections is needed for many accelerator applications. A classical trajectory Monte Carlo (CTMC) simulation has been used to

### Initial Results from the Front End Test Stand High Performance H Ion Source at RAL

D. C. Faircloth, M. H. Bates, S. R. Lawrie, A. P. Letchford, M. Perkins, M. Whitehead, P. Wise, T. Wood (STFC/RAL/ISIS) C. Gabor (STFC/RAL/ASTeC) D. A. Lee, P. Savage (Imperial College of Science and Technology, Department of Physics) J. K. Pozimski (STFC/RAL)

have many applications including drivers for spallation neutron sources, neutrino factories, waste transmuters and tritium production facilities. The aim of the FETS project is to demonstrate that chopped low energy beams of high quality can be produced and is intended to allow generic experiments exploring a variety of operational conditions. This paper details the first results from the initial operation of the ion source.

The RAL Front End Test Stand (FETS) is being constructed to demonstrate a chopped H<sup>-</sup> beam of up to 60 mA at 3 MeV with 50 pps and sufficiently high beam quality for future high-power proton accelerators (HP-PA). High power proton accelerators with beam powers in the several megawatt range

### Mechanical Engineering for the Front End Test Stand

P. Wise, M. H. Bates, D. C. Faircloth, S. R. Lawrie, A. P. Letchford, M. Perkins, M. Whitehead, T. Wood (STFC/RAL/ISIS) C. Gabor (STFC/RAL/ASTeC) J. K. Pozimski, P. Savage (Imperial College of Science and Technology, Department of Physics)

neering components manufactured so far and the challenges which need to be meet in the near future.

The RAL Front End Test Stand (FETS) is being constructed to demonstrate a chopped H<sup>-</sup> beam of up to 60 mA at 3 MeV with 50 pps and sufficiently high beam quality for future high-power proton accelerators (HP-PA). This paper details the mechanical engi-



### A Highly Flexible Low Energy Ion Injector at KACST

At the National Centre for Mathematics and Physics (NCMP), at the King Abdulaziz City for Science and Technology (KACST), Saudi Arabia, a multi-purpose low-energy experimental platform is presently being developed in collaboration with the QUASAR group. The aim of this project is to enable a multitude of low-energy experiments with most different kinds of ions both in single pass setups, but also with ions stored in a low-energy electrostatic storage ring. In this contribution, the injector of this complex is presented. It was designed to provide beams with energies of up to 30 kV/q and will allow for switching between different ion sources from e.g. duoplasmatron to electrospray ion sources and to thus provide the users with a wide range of different beams. We present the overall layout of the injector with a focus on its mechanical and ion optical design.

M. O.A. El Ghazaly (KUK) M. H. Al-Malki, M. O.A. El Ghazaly (KACST) A. I. Papash (MPI-K) C. P. Welsch (Cockcroft Institute)

MO6RFP042

### Design of an SRF Gun for Polarized Electron Beams

The use of an RF electron gun with a magnetized cathode in place of a DC gun for ILC may reduce the requirements for emittance damping rings. Maintaining adequate lifetime of the necessary cathode material requires vacuum levels in the  $10^{-11}$  torr range. While vacuum levels around the  $10^{-9}$  torr range are common in a normal conducting RF gun, the cryogenic pumping of the cavity walls of a superconducting RF (SRF) gun may maintain vacuum in the range needed for GaAs cathode longevity. Advanced Energy Systems, Inc. is collaborating with Brookhaven National Laboratory to investigate the generation of polarized electron beams using a SRF photocathode gun. The team is developing an experiment to study the quantum lifetime of a GaAs cathode in a SRF cavity and investigate long term cavity performance while integrated with a cesiated GaAs cathode\*. In addition to the experimental investigation, a design is being developed that is compatible with the production of high aspect ratio polarized electron beams. The mechanical and physics aspects of this design will be discussed.

H. Bluem, D. Holmes, T. Schultheiss (AES) I. Ben-Zvi, A. Burrill, J. Kewisch, D. Pate, T. Rao, R. J. Todd, E. Wang, Q. Wu (BNL)

\*J. Kewisch, et. al., Presentation at PAC09.

MO6RFP043

### An Optimization of a DC Injector with Merger for the Energy Recovery Linac Upgrade to the APS

An energy recovery linac (ERL) is a potential candidate for the Advanced Photon Source (APS) upgrade at Argonne National Laboratory.

X. W. Dong, M. Borland, Y.-C. Chae (ANL)

A high-DC-voltage photocathode-gun-based electron injector\* was investigated to meet the requirement for ultra-low emittance. Recently the DC photoinjector was remodeled using the fully three-dimensional tracking simulation code IMPACT-T to integrate a Zigzag-type merger into the simulation. A multiobjective numerical optimization is performed with the goal of delivering a 10-MeV, 19-pC bunch with a normalized transverse emittance less than  $0.1 \mu\text{m}$  at the entrance of the linac. In this paper we present the optimum machine parameters.

\*Y.-E. Sun et al., "Optimization of a DC Injector for an Energy Recovery Linac Upgrade to the Advanced Photon Source", Proc. of LINAC 2008, TUP100, to be published on <http://www.jacow.org>.

MO6RFP044

### Photocathode Studies for Ultra-Low Emittance Electron Sources

K. C. Harkay, K. Nemeth, M. White (ANL) L. K. Spentzouris (Illinois Institute of Technology)

Future x-ray light sources such as FELs and ERLs impose requirements on emittance and bunch repetition rate that are very demanding on the electron source. Even if perfect compensation of space-charge effects could be attained, the fundamental cathode emission properties determine a lower bound on achievable source emittance. Development of ultra-low-emittance sources is a rapidly evolving area of R&D with exciting new results measured for low bunch charge, but it is very difficult to compare different results and quantify what works. The study of photocathodes, with the goal of optimizing for low emittance, is limited in scope. In this paper, we describe an R&D effort to systematically measure and design the fundamental properties of photocathodes suitable for an FEL or ERL. We plan to apply surface analysis lab techniques to characterize photoemission, and then correlate material properties with emittance. On the theory side, we plan to calculate electron band structure for crystal surfaces, correlate with lattice parameters and work function, and then estimate the transverse momentum using the three-step model. The status and results to date of this effort will be reported.

Future x-ray light sources such as FELs and ERLs impose requirements on emittance and bunch repetition rate that are very demanding on the electron source. Even if

### Optimized Design of an Ultra-Low Emittance Injector for Future X-Ray FEL Oscillator

P. N. Ostroumov, K.-J. Kim, B. Mustapha (ANL) P. Piot (Northern Illinois University)

The concept of an ultra-low transverse emittance injector operating in CW mode for an XFEL\* was discussed at LINAC-08\*\*. Here we will report the design optimization of the injector, which includes a 100 MHz RF-gun with thermionic cathode, an energy filter to produce short bunches (~0.5 nsec), a velocity bunching section, higher harmonic cavities to minimize longitudinal emittance, two bunch compressors and accelerating sections operating at 400 MHz and 1300 MHz to obtain 540 MeV electrons. The proposed design is capable of producing 40 pC bunches with 0.5 psec rms time width and 0.7 MeV rms energy spread. Most significantly, the transverse rms emittance is kept below  $0.11 \pi \mu\text{m}$ . The longitudinal emittance and bunch time width can be substantially reduced for low-charge bunches of several pC.

The concept of an ultra-low transverse emittance injector operating in CW mode for an XFEL\* was discussed at LINAC-08\*\*. Here we will report the design optimization of the

\*K.-J. Kim, Y. Shvyd'ko, and S. Reiche, Phys. Rev. Lett., 100 244802 (2008).

\*\*P. N. Ostroumov, K.-J. Kim, Ph. Piot, Proceedings of the Linac-2008.

### High Frequency Bunch Train Generation from an RF Photoinjector at the AWA

J. G. Power (ANL) C.-J. Jing (Euclid TechLabs, LLC)

An exploratory study for the generation of high frequency bunch trains is underway at the Argonne Wakefield Accelerator (AWA) facility. High frequency bunch trains have numerous applications ranging from advanced acceleration methods to THz radiation sources. Recent studies have shown that such trains can be generated when an intensity modulated laser pulse is incident on the photocathode in the gun. Using the recently developed technique of temporal pulse stacking with UV birefringent crystals\* the modulation wavelength obtainable is primarily limited by the UV pulse length. For the AWA photoinjector laser system this limit is about 200  $\mu\text{m}$  (rms=670 fs); although using commercially available laser systems this can be as short as 10  $\mu\text{m}$ . We present measurements of the intensity modulated laser pulse created with an alpha-BBO crystal array, TStep simulations of the electron beam dynamics, and experimental plans to measure the bunch train using an L-band deflecting mode cavity.

An exploratory study for the generation of high frequency bunch trains is underway at the Argonne Wakefield Accelerator (AWA)

\*J. G. Power et al., in Proc. 2008 Advanced Accelerator Concepts, Santa Cruz, Ca., AIP Press, editors C. Schroeder and K. Girardi

**Simulation Study of a Normal-Conducting CW Photoinjector for ERL X-Ray Sources**

Low-frequency normal-conducting photoinjectors have the potential to generate CW beam due to low frequency and relatively

**C.-x. Wang** (ANL)

low field. They can provide a much higher accelerating field at the cathode than envisioned DC injectors but without the complexity involved in superconducting rf injectors. Low frequency allows a relatively long bunch near the cathode to reduce space-charge effects, which is detrimental for generating demandingly high-brightness beams. However, low frequency means higher bunch charge for a given average current, counteracting the potential benefits of low-frequency rf injectors. Furthermore, significant bunch length reduction in the injectors is often needed, which may degrade transverse brightness. To explore the potential of a normal-conducting injector for the envisioned ERL upgrade of the Advanced Photon Source, we made a preliminary design and searched for a suitable solution using genetic optimization. Simulation results are presented.

MO6RFP048

**An Experiment to Test the Viability of a GaAs Cathode in a SRF Electron Gun**

Gallium arsenide cathodes are used in electron guns for the production of polarized electrons. In order to have a sufficient quantum efficiency lifetime of the cathode the

**J. Kewisch, I. Ben-Zvi, A. Burrill, D. Pate, T. Rao, R. J. Todd, E. Wang, Q. Wu** (BNL) **H. Bluem, D. Holmes, T. Schultheiss** (AES)

vacuum in the gun must be  $10^{-11}$  torr or better, so that the cathode is not destroyed by ion back bombardment. All successful polarized guns are DC guns, because such vacuum levels can not be obtained in normal conducting RF guns. A superconductive RF gun may provide a sufficient vacuum level due to cryo-pumping of the cavity walls. We report on the progress of our experiment to test such a gun.

MO6RFP049

**Ion Bombardment in RF Photoguns**

A linac-ring eRHIC design requires a high-intensity CW source of polarized electrons. An SRF gun is viable option that can deliver

**E. Pozdeyev, A. Kayran, V. Litvinenko** (BNL)

the required beam. Numerical simulations presented elsewhere have shown that ion bombardment can occur in an RF gun, possibly limiting lifetime of a NEA GaAs cathode. In this paper, we analytically solve the equations of motion of ions in an RF gun using the ponderomotive potential of the RF field. We apply the method to the BNL 1/2-cell SRF photogun and demonstrate that a significant portion of ions produced in the gun can reach the cathode if no special precautions are taken. Also, the paper discusses possible mitigation techniques that can reduce the rate of ion bombardment.

MO6RFP050

**Ultra-Short High-Brightness Electron Beam Characterization at the NSLS SDL**

There is a growing interest in optimizing the electron beam for an X-ray Free Electron Laser (FEL) in the low charge (10 to 200 pC) and femto-seconds regimes. We have exper-

**X. J. Wang, Y. Hidaka, J. B. Murphy, B. Podobedov, H. J. Qian, S. Seletskiy, Y. Shen, X. Yang** (BNL) **C.-X. Tang** (TUB)

imentally demonstrated sub-picosecond high-brightness electron beam for a 40 pC charge with ballistic bunch compression and a reduced laser spot size\*. Simulation studies showed the feasibility of generating 10 femto-seconds kilo-ampere electron beam with a 20 pC charge\*\*. This paper reports the progress of experimental demonstration

MO6RFP051

of a femto-seconds kilo-ampere electron beam at the NSLS Source Development Lab (SDL). The femto-seconds kilo-ampere electron beam will be used to drive a self-amplified spontaneous emission (SASE) FEL, and SASE FEL spectra and pulse length will be used to measure the electron beam bunch length. The transverse properties of the electron beam will also be experimentally characterized.

\*X. J. Wang, et al, Phys. Rev. E , 54, No.4, R3121 -3124 (1996).

\*\*X. J. Wang and X. Y. Chang, Nuclear Instruments and Methods in Physics Research A 507, 310-313 (2003)

### Scheme for Polarized Positron Production by Polarized Electrons at ILC

A. A. Mikhailichenko (Cornell University, Department of Physics)  
E. G. Bessonov (LPI)

ing in an ILC damping ring. The rate might be satisfying for ILC.

We analyze the possibility for polarized positron generation for ILC by conversion of polarized electrons from ILC electron source into polarized positrons with positron stack-

### A Continuous Wave, Normal Conducting, L-Band PWT Photoelectron Gun

D. Yu, Y. Luo (DULY Research Inc.) M. Poelker (JLAB)

for example, in the Continuous Electron Beam Accelerator Facility (CEBAF) at the Thomas Jefferson National Accelerator Facility. DULY Research is developing a normal-conducting, L-band photoelectron gun in an ultra high vacuum accelerating structure called the Plane-Wave-Transformer (PWT) integrated with an activated, strained-lattice GaAs photocathode, as a continuous wave polarized electron source. We compare two designs (1-cell and  $\frac{1}{2}$  cell) of an L-Band PWT photoelectron gun in this paper. This RF gun will simplify the CEBAF photoinjector design by replacing the direct current (DC) gun, buncher cavities and the capture section. The new compact design provides a stiffer beam that is less subject to space charge blowup. In addition, a higher field gradient at the photocathode would mitigate electron and ion backbombardment problems. Cooling for a CW PWT gun is challenging but manageable.

A Gallium Arsenide (GaAs) photocathode RF electron gun is useful if high polarization (>85%) and low emittance are required as,

### XPS Investigations on Cs<sub>2</sub>Te Photocathodes of FLASH and PITZ

S. Lederer, S. Schreiber (DESY) P. M. Michelato, L. Monaco, C. Pagni, D. Sertore (INFN/LASA) R. Ovsyannikov, M. Sperling, A. Vollmer (BESSY GmbH) F. Stephan (DESY Zeuthen)

A rapid unexpected decrease of the initial QE, from 10% to values below 0.5% in only a few weeks of operation, was observed. In XPS measurements we identify a peak of Fluorine possibly originating from Teflon. After identification and removal of this specific contaminant, the life time of the cathodes increased to several months. In addition we have investigated the response of fully functional photocathodes to extensive usage, bad vacuum conditions, and oxidation by means of XPS measurements. The experiments - carried out at the ISIS and the PM3 beam lines at the synchrotron facility BESSY -- compare the chemical composition and electronic structure of freshly prepared, contaminated, used, and oxidised Cs<sub>2</sub>Te cathodes.

Caesium telluride (Cs<sub>2</sub>Te) photocathodes are used as sources for electron beams because of their high quantum efficiency (QE) and their ability to release high peak current electron bunches in a high gradient RF-gun.

**Investigations on the Increased Life Time of Photocathodes at FLASH and PITZ**

Caesium telluride photocathodes are used as laser driven electron sources at FLASH and PITZ. FLASH is operated as user facility as well as for accelerator related studies and therefore has a constant and moderate usage

of the cathodes. In contrary, PITZ is an injector R&D facility with a stronger usage of cathodes including gradients in the RF-gun of up to 60 MV/m. In the past, one concern of operating RF-guns with Cs<sub>2</sub>Te cathodes was the degradation of the quantum efficiency in a few weeks at FLASH and a couple of days at PITZ. Improved vacuum conditions and removing contaminants in both accelerators yielded an increased life time of several months. In this contribution we report on routinely performed QE measurements, investigations on the homogeneity of the electron emission, and dark current issues for both facilities.

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MO6RFP055

**Cryogenic Test of the Nb-Pb SRF Photoinjector Cavities**

In this contribution, we report progress on the development of a hybrid lead/niobium superconducting RF (SRF) photoinjector. The goal of this effort is to build a Nb injector with the superconducting cathode made of lead, which demonstrated in the past superior quantum efficiency (QE) compared to Nb Three prototype hybrid devices, consisting of an all-niobium cavity with an arc-deposited spot of lead in the cathode region, have been constructed and tested. We present the cold test results of these cavities with and without lead.

**J. S. Sekutowicz**, A. Muhs (DESY) P. Kneisel (JLAB) R. Nietubyc (The Andrzej Soltan Institute for Nuclear Studies, Centre Swierk)

MO6RFP056

**Recent Electron Beam Measurements at PITZ with a New Photocathode Laser System**

The Photo Injector Test facility at DESY, Zeuthen site, (PITZ\*) aims to develop and optimize electron sources for frontiers linac

based FELs such as FLASH and the European XFEL. A new laser system has been commissioned at PITZ in autumn 2008. It is capable to deliver laser pulses with challenging temporal shape: a flat-top profile with ~20 ps FWHM and rise and fall times of  $\leq 2$  ps. This laser system, being a significant step towards the European XFEL photo injector specifications, has been used in a 1.6-cell L-band rf gun with ~60MV/m electric field at the cathode to produce high brightness electron beams. A major part of the PITZ measurement program is the optimizing of the transverse phase space. Recent electron beam measurements at PITZ will be presented.

\*for the PITZ team

**M. Krasilnikov** (DESY Zeuthen)

MO6RFP057

**Design of an Ultrafast Relativistic Electron Diffraction System with a Photocathode RF Gun**

To investigate ultrafast dynamics of physical or chemical systems, ultrashort X-rays or electron beams may be used. Compared to

X-rays, electron beams are less destructive to material and the scattering cross section is larger, however it is difficult to decrease the electron beam pulse length due to space charge forces. One way of overcoming this difficulty is

**J. H. Han** (Diamond)

MO6RFP058

by means of a photocathode RF gun, which allows the beam energy to be rapidly increased immediately after the electron emission from the photocathode, minimizing therefore the pulse lengthening due to space charge forces. For time-resolved observation of atomic processes electron beams shorter than 100 fs (fwhm) with small divergence are required. In this paper, a conceptual design of a gun system is proposed with beam parameters optimized for relativistic electron diffraction experiments.

### Design of a Normal Conducting L-Band Photoinjector

J. H. Han (Diamond)

For the successful operation of an X-ray free electron laser the injector must be robust and able to provide a high quality beam.

In this paper we present the design of a normal conducting L-band photoinjector which is based on the successful DESY/PITZ gun, but with improved cavity geometry. The result of beam dynamics simulations predicts that a beam with a normalized transverse emittance of less than 0.7 mm mrad at 1 nC can be produced. With an expected repetition rate of at least 1 kHz this gun meets the requirements of the first stage injector for the UK's New Light Source project.

### Numerical Study of the Thermal Behavior of a Photocathode RF Gun

J. H. Han, H. C. Huang (Diamond)

To precisely control the electron beam parameters from a photocathode RF gun, the RF field distribution during real RF operation

must be known. During RF operation, the RF field induces local RF heating on the cavity surface. This non-uniform temperature distribution may deform the cavity and affect the output beam parameters. Here, we model a copper RF gun cavity and calculate the temperature distribution and the stress over the cavity surface. Then, the beam parameter change caused by the cavity deformation is simulated.

### Positron Source Target Survivability Studies

S. Hesselbach, G. A. Moortgat-Pick (Durham University) I. R. Bailey (Cockcroft Institute) J.-L. Fernandez-Hernando (STFC/DL/ASTeC) S. Riemann, A. Schaelicke, A. Ushakov (DESY Zeuthen) L. Zang (The University of Liverpool)

The energy deposition in the conversion targets of positron sources for future linear colliders leads to thermal shock waves which could possibly destroy the targets. For the International Linear Collider baseline source, we have studied the energy de-

position in a target taking the higher harmonics of the undulator radiation fully into account and applying hydrodynamical models for the resulting heat flow to determine the thermal stress in the target and to assess its survivability. We consider the applicability of these results to other positron source configurations.

### Microbunching Studies for SPARX Photoinjector

The SPARX X-FEL accelerator will be the first FEL facility to operate with a hybrid (RF plus magnetic chicane) compression scheme. Detailed numerical studies of propagation of beam density modulations stemming from various sources (photogun laser, cathode surface, shot noise ... ) through the photoinjector operating under velocity bunching conditions have been carried out. Comparisons with analytical models are also reported when possible. Finally, related experiments in the SPARC facility, currently in operation at Frascati, are discussed.

**C. Ronsivalle** (ENEA C. R. Frascati) M. Ferrario, C. Vaccarezza (INFN/LNF) M. Migliorati (Rome University La Sapienza) M. Venturini (LBNL)

Installation of the new photo-injector for the CTF3 drive beam (PHIN) has been completed on a stand-alone test bench. The photoinjector operates with a 2.5 cell RF gun at 3 GHz, using a Cs<sub>2</sub>Te photocathode illuminated by a UV laser beam. The test bench is equipped with different beam monitoring devices as well as a 90-degree spectrometer. A grid of 200 micrometer wide slits can be inserted for emittance measurements. The laser used to trigger the photo-emission process is a Nd:YLF system consisting of an oscillator and a preamplifier operating at 1.5 GHz and two powerful amplifier stages. The infrared radiation produced is frequency quadrupled in two stages to obtain the UV. A Pockels cell allows adjusting the length of the pulse train between 50 nanoseconds and 50 microseconds. The nominal train length for CTF3 is 1.272 microseconds (1908 bunches). The first electron beam in PHIN was produced in November 2008. In this paper, results concerning the operation of the laser system and measurements performed to characterize the electron beam are presented.

### First Results from Commissioning of the PHIN Photo-Injector for CTF3

Installation of the new photo-injector for the CTF3 drive beam (PHIN) has been completed on a stand-alone test bench. The photoinjector operates with a 2.5 cell RF gun at 3 GHz, using a Cs<sub>2</sub>Te photocathode illuminated by a UV laser beam. The test bench is equipped with different beam monitoring devices as well as a 90-degree spectrometer.

**M. Petrarca**, H.-H. Braun, N. Champault, E. Chevally, R. Corsini, S. Doebert, K. Elsener, V. Fedosseev, G. Geschonke, R. Losito, A. Masi, O. Mete, L. Rinolfi (CERN) G. Bienvenu, M. Jore, B. M. Mercier, C. Prevost, R. Roux (LAL) M. Divall (STFC/RAL) C. Vicario (INFN/LNF)

A grid of 200 micrometer wide slits can be inserted for emittance measurements. The laser used to trigger the photo-emission process is a Nd:YLF system consisting of an oscillator and a preamplifier operating at 1.5 GHz and two powerful amplifier stages. The infrared radiation produced is frequency quadrupled in two stages to obtain the UV. A Pockels cell allows adjusting the length of the pulse train between 50 nanoseconds and 50 microseconds. The nominal train length for CTF3 is 1.272 microseconds (1908 bunches). The first electron beam in PHIN was produced in November 2008. In this paper, results concerning the operation of the laser system and measurements performed to characterize the electron beam are presented.

### Stacking Simulations for Compton Positron Sources of Future Linear Colliders

The Compton positron source of a future linear collider must obtain the target bunch population by accumulating a large number of positron packets, arriving either in a number of bursts from a "Compton ring", with intermediate damping of the scattering electron beam, or quasi-continually from a "Compton energy recovery linac". We present simulation results for the longitudinal stacking of Compton positrons in the ILC damping ring and the CLIC pre-damping ring, reporting parameter optimization, stacking efficiency, possible further improvements, and outstanding questions.

**F. Zimmermann**, Y. Papaphilippou, L. Rinolfi (CERN) F. Antoniou (National Technical University of Athens) R. Chehab (IN2P3 IPNL) M. Kuriki (HU/AdSM) T. Omori, J. Urakawa (KEK) A. Variola, A. Vivoli (LAL) V. Yakimenko (BNL)

### Simulations of Mode Separated RF Photo Cathode Gun

A. Deshpande (GUAS/AS) S. Araki, M. K. Fukuda, N. Terunuma, J. Urakawa (KEK) K. Sakaue, M. Washio (RISE) N. Sasao (Kyoto University)

At Accelerator Test Facility (ATF), we have developed and successfully used RF Photocathode gun as the source of electrons. We have also used a similar gun in the Laser Undulator Compact X-ray source facility (LUCX), KEK (High Energy Accelerator Research Organization) for performing experiments to generate X-rays by inverse Compton scattering. Both the existing guns have mode separation of 4 MHz. We designed a new RF Gun with high mode separation of around 9 MHz and high Q value to achieve a low emittance beam of good quality. We are also modifying the power delivery scheme to the accelerator at LUCX to achieve the acceleration of 200 nC in 100 bunches with low emittance. This will help to increase the intensity of X-rays by the inverse Compton scattering.

### Operational Performance of Positron Production from Tungsten Single-Crystal Target at the KEKB Injector Linac

T. Suwada, K. Furukawa (KEK)

The first operation of the positron production with a tungsten single-crystal target has been performed at the positron source of the KEKB injector linac for the KEK B-factory (KEKB) from September 2006 to June 2007 (~10 months). Previously we carried out the systematic studies on the positron-production efficiencies with tungsten crystals having various thickness using 4- and 8-GeV electron beams at the test beam line during the term of 2000-2005. Finally, we optimized the thickness of the tungsten crystal at 4 GeV and developed both the target fabrication technique and the crystal-axis alignment technique in 2006. After the systematic studies, we installed a tungsten crystal target at the KEKB positron source without any significant modifications for the positron source. The data on the positron production, especially, the positron-production efficiencies and stabilities in terms of the primary electron and positron beams, were obtained during the nominal KEKB operation in this term. We summarize the long-term operational performance on the positron production with the tungsten crystal target at the KEKB injector linac in this report.

### Beam Dynamics Simulation for the Compact ERL Injector

T. Miyajima, Y. Honda, Y. Kobayashi, T. M. Mitsunashi, T. Muto, S. Sakanaka (KEK) R. Hajima (JAEA/ERL)

The compact ERL, cERL, is a project to test an energy recovery linac (ERL) with 60 MeV and 100 mA electron beam to generate synchrotron radiation with smaller emittance and shorter pulse length. The design work of the cERL injector has been carried out using a space charge simulation code. The injector consists of 500 kV photo cathode DC gun, two solenoid magnets, buncher cavity, three super conducting RF cavities and merger section to return pass. It generates an electron beam with -77 pC bunch charge and 1.3 GHz repetition rate. Our target value of emittance is less than 1 mm mrad with the bunch length of 1 mm at the exit of the injector. The parameter optimization of the injector using the multi objected method has been carried out to obtain the minimum emittance. The simulation results will be presented in detail.



**ERL Scheme for Compton Polarised Positron Sources**

One of the main challenges for the future linear colliders projects (ILC and CLIC) is to design an efficient positron source taking into account the constraints imposed by the target heating. At present, different schemes

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have been analysed to produce high energy gammas and to convert them in an amorphous target. One of them considers the possibility to boost the energy of the backscattered photons of a laser pulse by Compton effect. This method is very attractive since the source is independent from the main Linac and since the photon helicity is conserved in Compton scattering and subsequently transferred to the produced pairs. This allows the physics experiments disposing of both positron and electron polarised sources. Different schemes have been proposed to provide the electron beam for the Compton collisions. taking into account the constraint imposed by the low value of the Thomson cross section. One of the explored possibilities is to design an ERL with relatively low repetition frequency, high charge per pulse and then to stack the produced positrons in an accumulation ring. Different considerations on this scheme will be illustrated and the main constraints discussed.

MO6RFP068

**A Study of Life Time of GaAs Photocathode for High Brightness Electron Source**

High brightness electron source is a key technology for future projects based on advanced accelerators. Although GaAs photocathode is very attractive because it can generate highly polarized and extremely high

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brightness electron beam, the limited operational life time is a technical issue. In Hiroshima University, a photocathode test bench is implemented for various studies of GaAs photo-cathode. Super high vacuum,  $9E-9Pa$ , was achieved and the cathode was successfully activated by processes of heat cleaning technique and the alternate evaporation of Cs and oxygen. The quantum efficiency and its lifetime were investigated as a function of cathode temperature, simulating temperature rise by the high power cathode drive laser. Wavelength dependence was also investigated.

MO6RFP069

**Optical Injector Based on Particle Acceleration by Stimulated Emission of Radiation in a Penning-Trap**

We present results of an analysis demonstrating that electrons oscillating in a Penning trap may drain the energy stored in an adjacent active medium. For this process to happen, the electrons must become bunched and the energy imparted to the electrons allows them to leave the trap resulting into a train of bunches. Their angular frequency corresponds to medium's resonance.

**L. Schächter** (Technion)

MO6RFP070

### Velocity Bunching Experiments at SPARC

M. Ferrario, D. Alesini, M. Bellaveglia, R. Boni, M. Boscolo, M. Castellano, E. Chiadroni, L. Cultrera, G. Di Pirro, L. Ficcadenti, D. Filippetto, V. Fusco, A. Gallo, G. Gatti, C. Marrelli, E. Pace, L. Palumbo, B. Spataro, C. Vaccarezza, C. Vicario (INFN/LNF) G. Andonian, G. Marcus, J. B. Rosenzweig (UCLA) A. Bacci, D. Giove, V. Petrillo, A. R. Rossi, L. Serafini (Istituto Nazionale di Fisica Nucleare) A. Cianchi, B. Marchetti (INFN-Roma II) L. Giannessi, G. L. Orlandi, M. Quattromini, C. Ronsivalle (ENEA C. R. Frascati) M. Migliorati, A. Mostacci (Rome University La Sapienza)

One of the main goals of the SPARC high brightness photoinjector is the experimental demonstration of the emittance compensation process while compressing the beam with the velocity bunching technique, also named RF compressor. For this reason, the first two S-band travelling wave accelerating structures downstream of the RF gun are embedded in a long solenoid, in order to control the space charge induced emittance oscillations during the compression process.

An RF deflecting cavity placed at the exit of the third accelerating structure allows bunch length measurements with a resolution of 50  $\mu\text{m}$ . During the current SPARC run a parametric experimental study of the velocity bunching technique has been performed. The beam bunch length and projected emittance have been measured at 120 MeV as a function of the injection phase in the first linac, and for different solenoid field values. In this paper we describe the experimental layout and the results obtained thus far. Comparisons with simulations are also reported.

### On-Line Diagnostic of Cs<sub>2</sub>Te Photocathodes during their Growth

L. Monaco, P. M. Michelato, C. Pagani, D. Sertore (INFN/LASA)

Since '90s our laboratory is in charge of producing Cs<sub>2</sub>Te photocathodes employed as laser driven electron sources in the high

brightness photoinjectors of the FLASH and PITZ facilities. The production recipe has been developed and standardized during years, fulfilling the requests for photocathode operation in the photoinjectors. Nevertheless, the growing process of the film is still not totally understood, mainly respect to the final material properties. In this paper, reflectivity and spectral response measurements, at different wavelengths, measured during the photocathode growth are presented and compared with the corresponding photocurrent behavior. The new information, together with results obtained with standard diagnostic tools, will help to improve the understanding of the growing process, of the compounds formation with different Cs/Te ratio and of the reproducibility of the Cs<sub>2</sub>Te film structure.

### Status of the SPARC Photocathode Drive Laser

C. Vicario, D. Filippetto, G. Gatti, A. Ghigo (INFN/LNF) M. Petrarca (CERN)

In this paper we report the status of the SPARC photocathode drive laser system. In the high brightness photoinjector the properties of the electron beam are directly related

to the drive laser features. In fact the 3-D distribution of the electron beam and the time of emission are determined by the incoming laser pulse. The SPARC laser is a 10 Hz frequency-tripled TW-class Ti:Sa commercial system. A dedicated activity on the shape of the laser pulse has been performed in order to produce high energy UV flat top and multi-peaks time profile. To achieve the required flat top shape we perform a manipulation of the laser spectrum at the fundamental wavelength and directly at the third harmonic. The production of multi peaks laser pulse have been studied and tested. Finally we present the key laser performances recorded for the SPARC FEL experiment.

**Design and Fabrication of a 500-kV Photocathode DC Gun for ERL Light Sources**

A 500-kV, 10-mA photocathode DC gun has been designed and is now under fabrication by the collaboration efforts of JAEA, KEK, Hiroshima Univ. and Nagoya Univ. The Cockcroft-Walton generator and the ceramic insulator are installed upright in the SF<sub>6</sub> tank. We have adopted a multiple-stacked cylindrical ceramic insulator, because this type of ceramic insulator has shown good stability and robustness at the 200-kV Nagoya polarized gun and the 250-kV JAEA FEL gun. All the vacuum chambers are made of titanium alloy with very low out-gassing. The Cockcroft-Walton generator, the ceramic insulator, the vacuum chambers will be fabricated by April 2009 and a high-voltage test will be started soon later. Up-to-date status of the gun development will be presented in detail.

**R. Hajima** (JAEA/FEL) Y. Honda, T. Miyajima, T. Muto (KEK) H. Iijima, R. Nagai, N. Nishimori (JAEA/ERL) M. Kuriki (HU/AdSM) T. Nakanishi, S. Okumi, M. Yamamoto (Nagoya University)

MO6RFP074

**Development of a 250-kV Photocathode Electron Gun at JAEA**

A 250-kV, 50-mA electron gun has been developed at JAEA for establishing fundamental technologies to generate and evaluate a ultra-small emittance beam, which is required for future ERLs such as a coherent X-ray source and a high-flux gamma-ray source. The gun has been assembled and the first photo-current was obtained from a cathode of NEA-GaAs. Apparatuses for beam measurements has been installed. We plan to measure the transverse emittance by a double-slit configuration and the temporal profile with a deflecting cavity.

**R. Nagai**, R. Hajima, H. Iijima, N. Nishimori (JAEA/ERL) Y. Honda, T. Miyajima, T. Muto (KEK)

MO6RFP075

**Optimization Studies for the Advanced Photoinjector Experiment (APEX)**

The Advanced Photoinjector Experiment (APEX) seeks to validate the design of a proposed high-brightness, normal conducting RF photoinjector gun and bunching cavity feeding a superconducting RF linac to produce nC-scale electron bunches with sub-micron normalized emittances at MHz-scale repetition rates. The beamline design seeks to optimize the slice-averaged 6D brightness of the beam prior to injection into a high gradient linac for further manipulation and delivery to an FEL undulator. Details of the proposed beamline layout and electron beam dynamics studies are presented.

**S. M. Lidia** (LBNL)

MO6RFP076

**Status of the LBNL Normal Conductive CW VHF Photo-Injector**

A high-brightness high-repetition rate photo-injector based on a normal conducting 187 MHz RF cavity design capable of CW operation is under construction at the Lawrence Berkeley National Laboratory. A cathode field of ~20 MV/m accelerates electron bunches to 750 keV with peak current, energy spread and transverse emittance suitable for FEL and ERL applications. A vacuum load-lock mechanism is included and a 10 picoTorr range vacuum capability allows most types of photocathodes to operate at a MHz repetition rate with present laser technology. The status of the project is presented.

**F. Sannibale**, K. M. Baptiste, J. N. Corlett, S. Kwiatkowski, D. Li, J. Qiang, J. W. Staples, R. P. Wells, L. Yang, A. Zholents (LBNL) T. M. Huang (Institute of High Energy Physics, CAS)

MO6RFP077

### Upgrades to the Injector Cathode and Supporting Structure of the DARHT Second Axis Accelerator

R. R. Mitchell, B. A. Gardner, T. Ilg (LANL) M. Leitner (LBNL)  
B. A. Prichard (SAIC)

The Dual-Axis Radiographic Hydrodynamic Test Facility (DARHT) at Los Alamos National Laboratory (LANL) consists of two linear induction accelerators oriented at right angles to each other. The DARHT First Axis has been successfully operated since 1999 and produces a 60 ns pulse with beam energy of 20 MeV and beam current of 1.9 kA. The DARHT Second Axis was successfully commissioned in May 2008 and produces a 1600 ns pulse with beam energy of 17.5 MeV and beam current of 2.1 kA. The Second Axis Injector uses a 16.5 cm diameter thermionic cathode with a 10 A/cm<sup>2</sup> required current density to emit electrons into the accelerator. During the early Second Axis commissioning activities in 2006, deficiencies in the DARHT Second Axis Injector were found that prevented the injector cathode from meeting the required 10 A/cm<sup>2</sup> current density. A comprehensive campaign was initiated to solve the injector cathode performance issues. This paper describes the deficiencies found and the solutions used to enable the DARHT Second Axis Injector to meet its requirements.

The Dual-Axis Radiographic Hydrodynamic Test Facility (DARHT) at Los Alamos National Laboratory (LANL) consists of two linear induction accelerators oriented at

### Improved DC Gun Insulator

R. Sah, K. B. Beard, M. L. Neubauer (Muons, Inc) C. Hernandez-Garcia, G. Neil (JLAB)

Many user facilities such as synchrotron light sources and free electron lasers require accelerating structures that support electric fields of 10-100 MV/m, especially at the start of the accelerator chain where ceramic insulators are used for very high gradient DC guns. These insulators are difficult to manufacture, require long commissioning times, and have poor reliability, in part because energetic electrons bury themselves in the ceramic, creating a buildup of charge and causing eventual puncture. A novel ceramic manufacturing process is proposed. It will incorporate bulk resistivity in the region where it is needed to bleed off accumulated charge caused by highly energetic electrons. This process will be optimized to provide an appropriate gradient in bulk resistivity from the vacuum side to the air side of the HV standoff ceramic cylinder. A computer model will be used to determine the optimum cylinder dimensions and required resistivity gradient for an example RF gun application. A ceramic material example with resistivity gradient appropriate for use as a DC gun insulator will be fabricated by glazing using doping compounds and tested.

Many user facilities such as synchrotron light sources and free electron lasers require accelerating structures that support electric fields of 10-100 MV/m, especially at the

### Intense Stopping Muon Beams

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Intense stopping muon beams are useful for basic and applied physics research. However, the stopping flux is limited by the pion production dynamics and, in past designs, by processes that occur in the material used to slow the muons. This paper discusses the application of novel pion/muon capture techniques, recent six-dimensional beam cooling inventions, particularly Helical Cooling Channels, and new simulation tools to develop designs for low-energy beam lines to stop many muons in small target volumes. A particular motivation is to develop methods to improve the sensitivity of Mu2e, an experiment to detect the coherent conversion of muons to electrons in the field of a nucleus, in order to take full advantage of the increased proton intensity that will become available in the Project X era at FNAL. A new concept for reducing the energy spread of the secondary pion beam

Intense stopping muon beams are useful for basic and applied physics research. However, the stopping flux is limited by the pion production dynamics and, in past designs, by processes that occur in the material used

has been invented and is under development to provide better protection from many sources of background that could limit the sensitivity of the experiment; it also provides the possibility of highly polarized stopping muon beams for various applications.

### Status of the Photo-Injector Development at NSRRC

A high brightness photo-injector for light source research applications is being built at NSRRC. This injector consists of a laser driven RF gun with an emittance compensation solenoid and linac sections that booster the beam energy up to 150 MeV. A 266 nm pico-second UV laser system which generates a 300 uJ laser pulse with pulse which can be varied by a UV stretcher from 1 to 15 ps have been installed and laser shaping techniques will be developed to reduce the emittance growth. The RF gun is a 1.6 cell cavity operating at pi mode and the solenoid used to compensate the emittance growth due to the space charge effect will be set up in the spring of 2009. Beam dynamics study is performed by PARMELA and simulation results show that a normalized rms transverse emittance of 0.7 mm-mrad with a 10 ps flattop pulse at 1 nC charge can be achieved. Measurements of characteristics of the RF gun and the solenoid will be presented.

A. P. Lee, J. H. Chen, C. S. Chou, J.-Y. Hwang, W. K. Lau, C. C. Liang (NSRRC) C. H. Chen, N. Y. Huang, W. K. Luo (NTHU)

MO6RFP081

### Theory and Modeling of Electron Emission from Cesium Semiconductor Surfaces

Laser switched photocathodes are now the electron source of choice for short wavelength Free Electron Lasers. The photocathode requirements are profound: ideally, capabilities such as high peak and average current, high quantum efficiency (QE) in the visible, long lifetime in an rf injector and the ability to be repaired in situ are desired. We are pursuing cathodes with self-rejuvenating surfaces based on cesium dispenser cathode technology<sup>\*,\*\*</sup>, in which the physics of recession, evaporation, diffusion, and evolution of the surface coating and the QE are the metrics of performance. Here, we present predictive theoretical models of surface evolution and QE in a manner appropriate for inclusion in beam simulation codes, wherein emission non-uniformity and dark current affect emittance, beam halo, and dynamic evolution of bunched electron beams<sup>\*\*\*</sup>. The emission models focus on bulk transport issues (including scattering processes) and surface conditions (including diffusion in the presence of random, non-uniform sub-monolayer coverage), and relate these factors to recent experimental characterizations of the surface evolution.

K. L. Jensen, J. L. Shaw, J. E. Yater (NRL) D. W. Feldman, E. J. Montgomery, P. G. O'Shea, P. Z. Pan (UMD) N. A. Moody (LANL) J. J. Petillo (SAIC)

\*Jensen, et al., JAP-10-2, 074902 ; Moody, et al., APL90, 11410<sup>8</sup>.

\*\*E. Montgomery, et al., (this conference)

\*\*\*Petillo, et al., Proc IEEE PAC (2007); Jensen, et al., PRST-AB 11, 0810<sup>01</sup>.

MO6RFP082

### Fabrication and Recession of Alkali Antimonide Photocathodes

High performance FELs require photocathodes with quantum efficiencies of several percent at green wavelengths, kWhr lifetime, kA/cm<sup>2</sup> peak and A/cm<sup>2</sup> average current, and ps response. Such cathodes are challenged to maintain requisite high quantum efficiency while in harsh accelerator vacuum conditions. Delicate surface coatings are often cesium-based, and therefore are reactive with

E. J. Montgomery, D. W. Feldman, P. G. O'Shea, P. Z. Pan (UMD) K. L. Jensen (NRL) N. A. Moody (LANL)

MO6RFP083

contaminant gases. The dispenser photocathode architecture resupplies the cesium coating from a subsurface reservoir through a porous substrate, thereby extending lifetime\*. Recession has been shown to rejuvenate Cs:Ag cathodes from O<sub>2</sub>, CO<sub>2</sub>, and N<sub>2</sub>O contamination\*\*, and theory of dispenser photocathodes is advancing\*\*\*. We here investigate the fabrication, contamination, and external recession of alkali antimonides with high quantum efficiency, in support of the dispenser photocathode design.

\*Moody et al., APL90, 11410<sup>8</sup>.

\*\*Montgomery et al., Proc. AACW 2008 (submitted for publication).

\*\*\*K. Jensen et al., (this conference).

### Control of the Incident Light to the Photocathode RF Gun Using the Digital $\mu$ Mirror Device for Radiation Therapy

T. Kondoh, K. Kan, H. Kashima, K. Norizawa, A. Ogata, S. Tagawa, J. Yang, Y. Yoshida (ISIR)

The radiation therapy of cancer is developing to un-uniform irradiation, for concentrating dose to a tumor and reducing dose to normal tissue. For the un-uniform irradiation,

optical modulation of electron beam using the Digital $\mu$ Mirror Device was studied on a photocathode RF gun. The optical modulation of electron beam and dynamic control succeeded by a digital $\mu$ mirror device. Fundamental data such as the spatial resolution and the contrast of the optical modulated electron beam was measured. It will be reported that the relations between the intensity distribution and the emittance.

### Study of Transverse Emittance Evolution in 3.5-Cell DC-SC Photo-Injector

W. Xu, S. W. Quan, K. Zhao, J. Zhuang (PKU/IHIP)

High quality electron beam with low transverse emittance in 3.5-cell DC-SC photo-injector is crucial significance for PKU-

ERL-FEL facility. In this paper, we analyse the emittance evolution in the 3.5-cell DC-SC photo-injector by simply model with consideration of DC acceleration, RF acceleration and space charge effect. The results are compared with Astra simulation. The matching condition of DC-gun and Superconducting cavity, which is critical for the final emittance at the exit of the injector, is also presented.

### Design, Construction and Operation of the Dutch rf-Photoguns

S. B. van der Geer (Pulsar Physics) G. J.H. Brussaard, O. J. Luiten, W. P.E. M. Op 't Root, M. J. de Loos, W. van Dijk, W. J. van Hemmen, S. B. van der Geer (TUE) W. Knulst (Delft University of Technology, Opto-electronic Section)

Three different S-band rf-photoguns have been constructed by Eindhoven University of Technology in the Netherlands: A 1.5-cell, a 100 Hz 1.6-cell, and a 2.6-cell. They share a design concept that differs from the 'standard' BNL-gun in many aspects: Individual cells are clamped and not brazed saving valuable manufacturing time and allowing damaged parts to be replaced individually. The inner geometry employs axial incoupling, inspired by DESY, to eliminate any non-cylindrically symmetric modes. Elliptical irises, identical to a 2.6-cell design of Strathclyde University, reduce the maximum field on the irises and thereby reduce electrical breakdown problems. The manufacturing process uses single-point diamond turning based on a micrometer-precise design. The overall precision is such that the clamped cavities are spot-on resonance and have near-perfect field balance without the need for any post-production tuning. Operational performance of the three Dutch rf-photoguns will be presented.

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### Thermionic Cathode Grid Assembly Simulations for RF Guns

The projected electron RF gun of Novosibirsk Microtron-Recuperator injector employs an industrial thermionic cathode grid assembly with 0.08 mm gap that usually used in metal-ceramic RF tubes. Three-dimensional (3D) computer simulations have been performed that use the mesh refinement capability of the both Microwave Studio and 2D SAM codes to examine the full region of the real cathode grid assembly in static fields in order to illustrate the beam quality that can result from such a gridded structure. These simulations have been found to reproduce the beam current behaviors versus of applied potentials that are observed experimentally. Based on it ASTRA RF beam simulations also predict a complicated time-dependent response to the waveform applied to the grid during the current turn-on, calculation of the dissipated power by electrons at the grid, and particle tracking downstream of the grid into RF gun cavity and farther on. These simulations may be representative in other sources, such as some L-band RF injectors for industrial applications.

**V. Volkov**, E. Kenjebulatov, S. A. Krutikhin, G. Y. Kurkin, V. M. Petrov, E. Rotov, N. Vinokurov (BINP SB RAS)

MO6RFP087

### Operating a Tungsten Dispenser Cathode in Photoemission Mode

The Stanford Synchrotron Radiation Laboratory operates a thermionic radio-frequency gun as part of its injector for the SPEAR 3 storage ring. In order to generate the high bunch charge required for top-off injection, it may be advantageous to operate the thermionic cathode as a photoemitter. In this note we report on measurements of the wavelength dependence of the quantum efficiency of a tungsten dispenser cathode in a low-field environment, and on high-power tests of the injector in photoemission mode.

**S. M. Gierman**, P. R. Bolton, W. J. Corbett, G. R. Hays, R. E. Kirby, J. F. Schmerge, J. J. Sebek (SLAC)

MO6RFP088

### Recent Polarized Photocathode Developments for Future Linear Colliders at SLAC

SLAC has worldwide unique dedicated test facilities, cathode test system and dc-gun test lab, to completely characterize polarized photocathodes. Recent systematic measurements on strained AlInGaAs/AlGaAs cathode at the facilities show that 87% of polarization and 0.3% of QE is achieved. After atomic hydrogen cleaning the QE can be increased to ~1.0%. The limit of surface charge at very low current intensity and the dependence of the polarization on the surface charge are observed. The QE lifetime impacted by the ion back-bombardment onto the cathode is also measured and analyzed. Our ongoing/upcoming exciting programs to improve polarized photocathodes for linear colliders are introduced.

**F. Zhou**, A. Brachmann, T. V.M. Maruyama, J. Sheppard (SLAC)

MO6RFP089

### The TRIUMF/VECC Collaboration on a 10MeV/50kW Electron Injector

R. E. Laxdal, F. Ames, R. A. Baartman, S. R. Koscielniak, M. Marchetto, L. Merminga, A. K. Mitra, I. Sekachev, V. A. Verzilov, F. Yan (TRIUMF) A. Bandyopadhyay, A. Chakrabarti, V. Naik (DAE/VECC)

TRIUMF (Canada) and VECC (India) are planning to each build a 1.3GHz 50MeV/500kW superconducting electron linac as a driver for producing radioactive ion beams through photo-fission. The two institutes have launched a collaboration with the initial

goal to design, build and test a 5-10MeV superconducting injector cryomodule capable of accelerating up to 10mA. A testing area is being set-up at TRIUMF to house the electron gun, rf buncher, injector cryomodule, diagnostic station and beam-dump for beam studies. The project will test all critical elements of the final linac; beam halo generation, HOM excitation, LLRF and rf beam loading and cavity and cryomodule design/performance. The scope and status of the project will be described.

### A Laser-Cooled Electron Source for Ultrafast Electron Diffraction

S. B. van der Geer, B. Fleskens, O. J. Luiten, M. P. Reijnders, G. Taban, E. J.D. Vredendregt (TUE) S. B. van der Geer (Pulsar Physics)

Ultrafast electron diffraction (UED) enables single-shot studies of structural dynamics at atomic length and time scales, i.e. 0.1 nm and 0.1 ps. At present UED experiments are based on femtosecond laser photoemission

from solid state cathodes. We propose a new type of electron source, based on near-threshold photoionization of a laser-cooled and trapped atomic gas. The electron temperature of these sources can be as low as 10 K. This implies an increase in brightness by orders of magnitude and enables single-shot studies of, e.g., biomolecular samples. In this contribution we numerically investigate the performance of a laser-cooled electron source by GPT tracking simulations with realistic fields and all pairwise Coulomb interactions.

### Undulator-Based Positron Source for CLIC

L. Zang (The University of Liverpool) I. R. Bailey, A. Wolski (Cockcroft Institute)

A model has been created in Geant4 to simulate the key elements of an undulator-based positron source for CLIC: the goal is to consider such a source as an alternative

to the present baseline concept. The parameters of the undulator and capture device have been optimized for a range of operating scenarios. In each case we have calculated the rate of positron production, positron polarization, activation of the target, and capture efficiency. We discuss the strengths and weaknesses of the undulator scheme in CLIC.

### High Power Photon Collimators for the ILC

L. Zang (The University of Liverpool) I. R. Bailey, A. Wolski (Cockcroft Institute)

An undulator-based source has been chosen as a part of the baseline configuration for the International Linear Collider (ILC) to generate an intense beam of polarised positrons.

A photon collimator placed between the undulator and the target can be used to adjust the size, intensity and



polarisation of the photon beam impacting the target, and can also protect the target station and limit the activation of downstream components. In this paper, we calculate quantities such as the energy deposition, temperature change, activation and dose rate for different designs of the photon collimator, and consider the advantages and disadvantages for each case.

### Optimization of Applied Electric Field of Multi-Alkali Photocathode S-Band RF Gun to Reduce Dark Current and Designing a New RF Gun

Multi-Alkali photocathode has the good possibility as a electron source which has high quantum efficiency and low workfunction.

**K. Miyoshi** (The University of Tokyo, Nuclear Professional School)

However the surface of the cathode is sensitive over the electric field of 100[MV/m] in a RFGun, the amount of dark current is not negligible. In order to reduce such a dark current, we consider the valance of the electric field between half-cell and full-cell of BNL-IV RF gun by numerical simulation using GPT code. In this work we will show that high quality electron beam can be transported on the condition that appled electric field in half and full cell is about 50[MV/m] and 150[MV/m] respectively.

MO6RFP094

### The MeV Ultra-Fast Electron Diffraction Experiment at Tsinghua University

Time-resolved MeV ultra-fast electron diffraction (UED) is a promising tool for studying of structural dynamics on the fundamental temporal and spatial scales of atomic motion. To reach the desired temporal and spatial resolutions, precise control and measurement of ultra-short, low emittance electron pulses are required. A MeV UED system based on an S-band photocathode RF gun is built and optimized at Tsinghua University. We present the experiment results here.

**R. K. Li, H. Chen, C. Cheng, Q. Du, Du. Taibin. Du, Y.-C. Du, W.-H. Huang, Y. Lin, J. Shi, C.-X. Tang, L. X. Yan** (TUB)

MO6RFP095

### Beam Slice Characterization at SPARC High Brightness Photoinjector

The SPARC photoinjector drives a SASE FEL to perform several experiments both for the production of high brightness electron beam and for testing new scheme of SASE radiation generation. The control of the beam properties, in particular at the level of the slice dimension, is crucial in order to optimize the FEL process. We report the different measurements performed in order to characterize the slice properties of the electron beam.

**A. Cianchi** (Universita di Roma II Tor Vergata) **M. Bellaveglia, E. Chiadroni, L. Cultrera, G. Di Pirro, M. Ferrario, D. Filippetto, G. Gatti, E. Pace, C. Vaccarezza, C. Vicario** (INFN/LNF) **L. Ficcadenti, A. Mostacci** (Rome University La Sapienza) **B. Marchetti** (INFN-Roma II)

MO6RFP096

### Longitudinal Beam Dynamics of the Photoinjector Blowout Regime

Longitudinal Beam Dynamics of the Photoinjector blowout regime are investigated.

**J. T. Moody, M. S. Gutierrez, P. Musumeci, C. M. Scoby** (UCLA)

MO6RFP097

The beam's longitudinal phase space is measured via a deflecting cavity and dipole spectrometer. Sources of systematic error of the measurement are investigated. Longitudinal phase space is then measured as a function of beam parameters and compared to simulations done in GPT.

### Breaking the 100 Femtosecond Frontier in Relativistic Electron Diffraction

P. Musumeci, M. S. Gutierrez, J. T. Moody, C. M. Scoby (UCLA)

We report on the use of a ultrashort high brightness relativistic beam from the UCLA Pegasus laboratory RF photoinjector source for probing matter transformation at the atomic scale with sub-100 fs time resolution. The high accelerating gradient and the relativistic electron energy allow to pack more than  $10^7$  electrons in less than 100 fs bunch length, enabling the study of irreversible ultrafast phenomena by single-shot diffraction patterns. The experimental setup, and the initial results from the first ever relativistic electron diffraction time-resolved study will be discussed.

### A Single Bunch Electron Gun for the ANKA Injector

A. Hofmann, M. Fitterer, M. Klein, A.-S. Muller, K. G. Sonnad (University of Karlsruhe) G. Blokesch (PPT) E. Huttel, N. J. Smale (FZK) C. Piel (ACCEL) R. Weigel (Max-Planck Institute for Metal Research) T. Weis (DELTA)

The microtron of the ANKA injector is presently equipped with a diode-type electron gun, which produces long pulses. A new thermionic DC triode-type electron gun has been ordered and foreseen for installation in the ANKA injector. The new gun allows single bunch as well as long pulse operation, thus offering the possibility to study beam properties in single bunch operation. This is particularly of interest for the investigation of the short bunch dynamics in the generation of coherent THz radiation. Furthermore, the new gun will make time resolved measurement possible. Simulations of the gun-to-microtron transport with special emphasis on the emittance evolution e.g. due to space charge have been done. Measurements of the gun performance are presently underway and are summarised in this paper.

### Design of a Combined ITC-RF Gun with a Diode Gun for FEL

Y. J. Pei (USTC/NSRL)

Recently, great attention has been paid to short electron pulses because of requirement for FEL project. To get such beams, we advanced an independently tunable cells (ITC) RF gun with an external injecting beam, which consists of two cavities with a diode gun to compress short beam pulses. The microwave power and their phase in the two cells can be adjusted independently, therefore the beam with excellent characteristics can be obtained by choosing appropriate combination of feeding power and phase into the cells. This paper describes the design of such an ITC-gun with external injecting diode gun which is named a DC-ITC-RF gun. We found that the external injecting structure can increase beam current and decrease energy spread. At the same time, it cancels the BB effect near completely. Our simulation results showed that the RF gun would get good beam performance: pulse current of 20A, 0.7~4.5ps, energy spread of 0.2% and so on.

### Development of High Brightness Injector at NSRL

A photocathode injector system is developing at NSRL. A BNL type S-band photocathode RF gun has been built. The emittance will be compensated by a Solenoid. The driving laser is a high-Q product. It will be reformed into uniform distribution in the transverse distribution, but will not in the longitudinal direction. The whole system will be tested soon.

S. C. Zhang (USTC/NSRL)

MO6RFP101

### Present Status of a Multi-Bunch Electron Beam Linac Based on Cs-Te Photo-Cathode RF-Gun at Waseda University

At Waseda University, we have been developing a high quality electron source based on photo-cathode rf-gun and its application experiments. To produce a high current electron beam, we installed a Cs-Te cathode which has higher quantum efficiency and improved the structure of the rf cavity. By adopting a Cs-Te cathode, it is expected that the production of the higher charged single bunch electron beam with a low emittance can be achieved. Moreover, the generation of high quality multi-bunch electron beam is also expected to be possible due to the high quantum efficiency of Cs-Te. For understanding of a Cs-Te cathode and higher quantum efficiency operation, we have performed the fundamental studies by single bunch beam. On the other hand, we have also developed a multi-pulse UV laser for generating the multi-bunch electron beam. Our laser system is composed by all-solid-state Nd:YLF for the stable operation, and the specification of this laser is expected to generate a 100bunch/train with the bunch charge of 800pC/bunch. In this conference, the experimental results of Cs-Te and new laser system and the recent progress of multi-bunch electron beam generation will be reported.

T. Suzuki (RISE)

MO6RFP102

### The Effects of Field Curvature on Bunch Formation in RF Electron Guns

For many years it has been speculated that uniformly filled ellipsoidal electron bunches, with their linear fields, would be ideal to produce high charge density with low emittance beams. This may be particularly advantageous with bunch compression schemes required for operation of an FEL. The "blow-out" mode is a method of producing the desired electron bunch distribution: an initial charge pancake is produced at the cathode and allowed to expand to an ellipsoidal shape under the influence of its own space charge. In earlier studies a constant, DC electric field has been assumed in the production of ellipsoidal bunch distributions using "blow-out" mode. In this paper we look at the effects of a time varying, non-constant electric field on the development of the electron bunches as they are emitted from the photocathode and travel through an accelerating RF cavity. We present the effects of frequency in the cavity, field strength of the cavity,, as well as the phase of the electron bunch. These three variables change the spatial curvature and the temporal slope of the electric field as observed by the electron bunch. This results in changes in bunch development and formation.

M. M. Allen (Xavier University of Louisiana) J. Bisognano, R. A. Legg (UW-Madison/SRC)

MO6RFP103

## TU5PF — Morning Poster RFSYS T06, T07, T08

### Modeling RF Breakdown Arcs

J. Norem, Z. Insepov (ANL) A. Hassanein (Purdue University) D. Huang (IIT) S. Mahalingam, P. Stoltz, S. A. Veitzer (Tech-X)

We are modeling breakdown arcs in rf structures with Particle in Cell, (OOPIC Pro and VORPAL), Molecular Dynamics (HyDyn, LAMMPS), and an integrated radiation-magnetohydrodynamic package (HEIGHTS) to evaluate the basic parameters and mechanisms of rf discharges. We are evaluating the size, density, species temperature, radiation levels and other properties, to determine how the breakdown trigger works, what the growth times of the discharge are, effects of strong magnetic fields and what happens to both the arc and cavity energy. The goal is to have a complete picture of the plasma and its interaction with the wall. While we expect that these calculations will help guide further experimental studies, we have recently benchmarked model predictions against available experimental data on rise times of x ray pulses, and found a reasonable agreement.

We are modeling breakdown arcs in rf structures with Particle in Cell, (OOPIC Pro and VORPAL), Molecular Dynamics (HyDyn, LAMMPS), and an integrated radiation-

### Recent Results from Tests of Atomic Layer Deposition (ALD) for Superconducting RF

J. Norem, J. W. Elam, M. J. Pellin (ANL) L. Cooley (Fermilab) A. V. Gurevich (NHMFL) Y. Ha, Th. Proslir, J. Zasadzinski (IIT) P. Kneisel, R. A. Rimmer (JLAB)

those obtained from bulk niobium, The ALD process offers the possibility of conformally coating complex cavity shapes with precise layered structures with tightly constrained morphology and chemical properties. Our program looks both at the metallurgy and superconducting properties of these coatings, and also their performance in working structures. Initial results include: 1) evidence from point contact tunneling showing magnetic oxides can be a significant limitation to high gradient operation, 2) experimental results showing the production sharp niobium/oxide interfaces from a high temperature bake of ALD coated Al<sub>2</sub>O<sub>3</sub> on niobium surfaces, 3) results from ALD coated structures.

We have begun using Atomic Layer Deposition (ALD) to synthesize a variety of surface coatings on coupons and cavities as part of an effort to produce rf structures with significantly better performance and yield than

### A New SLED Test Stand in the APS Injector Linac

S. J. Pasky, T. Berenc, D. J. Bromberek, A. R. Cours, J. E. Hoyt, D. A. Meyer, A. Pietryla, N. Sereno, T. L. Smith, J. H. Vacca, W. D. Wright (ANL)

Recently, a new SLED test stand located in the Advanced Photon Source linac klystron gallery was developed using a spare modulator-klystron system and a recently developed prototype water station. The new test stand will be used to condition, tune and perform rf measurements on spare SLEDs without interfering with normal daily linac operations. This will allow technical groups to replace a low-performance SLED from one of the operational linac sectors with a fully conditioned SLED. The pre-conditioned SLED is expected to require less conditioning time after being put into operation compared to an unconditioned SLED. As an additional benefit, the prototype water station system developed to replace aging linac water systems can be tested under realistic conditions. In this paper, we describe the test stand design, prototype water station system, and first results using it to condition SLEDs and perform SLED rf measurements.

Recently, a new SLED test stand located in the Advanced Photon Source linac klystron gallery was developed using a spare modulator-klystron system and a recently developed prototype water station. The new test

### Effects of External Magnetic Fields on RF Cavity Operation

Beam cooling for a future neutrino factory or muon collider requires high gradient rf cavities in the presence of strong magnetic fields. Experimental measurements suggested that the maximum accelerating gradient drops as the axial magnetic field increases. Little is known about the explicit dependence of the gradient on the strength of the magnetic field. The experimental observation of dark currents arising from local regions with enhanced surface field intensities under external magnetic fields however, suggests a new possible mechanism of breakdown based on electron field emission. A model of magnetic field breakdown is proposed. We illustrate that the field emitted electrons are focused by the external fields into small spots on the other side of the cavity and estimate the energy density they deliver to the wall. We show that this energy increases with the magnetic field, and this may lead to melting of the cavity surface. The influence of local fields at the emitter side is discussed and the extent to which space-charge affects this process is investigated. Results of our model are compared with recent experimental data from the 201 MHz and 805 MHz cavities.

**D. Stratakis**, J. S. Berg, R. C. Fernow, J. C. Gallardo, R. B. Palmer (BNL)

TU5PFP004

### Transfer Matrix Method Used in RF Tuning on DTL for CSNS

In the conventional 324 MHz DTL designed for China Spallation Neutron Source (CSNS) accelerating  $H^{-}$  ion from 3MeV to 132MeV, there are 7 tanks and currently the R&D of tank-1 is under proceeding, which has 29 cells and 29 quadrupoles. In design, the Tank-1 has a tilt field distributed partially in order to obtain most effective energy gain and low Kilpatrick parameter. In order to decrease the difficulty of tuning the partial tilt field distribution, a new analysis named transfer matrix method is introduced. Verifying of the calculation and simulation of the transfer matrix has been finished with MDTFISH code, picking parameters from CSNS and SNS. Checking the method on the model tank in CSNS will be operated.

**Z. R. Sun**, S. Fu, J. Peng (IHEP Beijing)

TU5PFP005

### Wakefield Damping for the CLIC Crab Cavity

A crab cavity is required in the CLIC to allow effective head-on collision of bunches at the IP. A high operating frequency (X-band) for the crab cavity is preferred as the deflection voltage required and the RF phase tolerance are inversely proportional to the operating frequency. However, the strong inter-bunch wakefields deteriorate the quality of the colliding bunches. The short bunch spacing of the CLIC scheme and the crab cavity's high sensitivity to dipole kicks demands very high damping of the inter-bunch wakes. A crab cavity requires special attention to the damper design as its wakefield spectrum is entirely different from that of an accelerating cavity. In addition to the higher-order modes, the orthogonally polarised dipole mode (same order mode) and the fundamental monopole mode (lower order mode) also need to be damped, however their resonant frequencies make damping these modes complicated. The same order mode suppression requires the use of an azimuthally asymmetric damper. This paper investigates the nature of the wakefields in the CLIC crab cavity and the possibility of using choke-mode damping and various types of waveguide damping to suppress them effectively.

**P. K. Ambattu**, G. Burt, R. G. Carter, A. C. Dexter (Cockcroft Institute, Lancaster University) V. A. Dolgashev (SLAC) R. M. Jones, V. F. Khan (UMAN)

TU5PFP006

## A Damped Detuned Structure for the Main Accelerating Structures of Compact Linear Collider

V. F. Khan, R. M. Jones (UMAN)

Here we present initial results on an alternate design for CLIC main accelerating linacs which is moderately damped and detuned structure. In order to suppress the wake-fields, we detune the lowest dipole modes as they have significant impact on the beam emittance compared to the other multipoles. In order to mitigate the reappearance of the wake-field of a detuned accelerator structure, we provide moderate damping by coupling cells to manifolds which run parallel to each accelerator structure. The manifolds are designed such that they are non-propagating at the acceleration mode frequency. The cell parameters are optimised by considering the r.f. breakdown, pulse surface heating and beam dynamics constraints.

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## RF Measurements on Variations of the 500 MHz ALBA Dampy Cavity

M. L. Langlois, M. Cornelis, D. Einfeld, F. Perez (ALBA)

The Dampy cavity, operating at 500 MHz and up to 160 kW, normal conducting HOM damped, will be used in the ALBA storage ring. The pre-series has shown two problems. First, the HOM damping is very efficient but for one mode. The longitudinal impedance of the E011 mode was found to be around 11 k $\Omega$ , slightly above ALBA stability threshold. Second, overheating close to the dampers flanges induces a vacuum leak after several thermal cyclings. The maximum achieved operational dissipated power is 40 kW, if power is further increased a leak opens at one of the dampers flanges. In order to alleviate this latter drawback, two modifications have been implemented in two different cavities. The pre-series has been provided with short-circuits bridging waveguide ridges and cavity body. These are supposed to decrease the current in the area of the flanges. The first production cavity features a reduced thermal impedance between the water cooling channels and the area of overheating by replacing stainless steel by copper in the critical area. Both these cavities are currently under test and this paper will show the results.

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## Ferroelectric Based High Power Components for L-Band Accelerator Applications

A. Kanareykin (Euclid TechLabs, LLC) S. Kazakov (KEK) E. Nenashева (Ceramics Ltd.) A. Tagantsev (EPFL) V. P. Yakovlev (Fermilab)

Euclid TechLabs LLC is developing BST based ferroelectric elements designed to be used as the basis for new advanced accelerator components operating in the 1.3 GHz frequency range and intended for Project X and ILC applications. These new ferroelectric elements are designed for the fast active tuner for SC cavities that can operate in air at low biasing DC fields in the range of 15 kV/cm. The BST(M) material (BST ferroelectric with Mg-based additives) allows fast switching and tuning in vacuum and in air both; switching time of material samples < 10 ns has been demonstrated. The overall goal of the program was to design an L-band externally-controlled fast ferroelectric tuner for controlling the coupling of superconducting RF cavities for the future linear colliders. The tuner prototype has been built; a time response of <30 ns, or 1 deg. in 0.5 ns has been reached. . The following problems are addressed: (i) lowering the losses in the ferroelectric material; (ii) improving the technique of the ferroelectric element metallization and brazing; and (iii) improvement breakdown threshold at high voltage bias.

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### Multipactor in Dielectric Loaded Accelerating Structures

The development of high gradient rf driven dielectric accelerating structures is in part limited by the problem of multipactor. The first high power experiments with an 11.424

-GHz rf driven alumina accelerating structure exhibited single surface multipactor. Unlike the well understood multipactor problem for dielectric rf windows, where the rf electric field is tangential and the rf power flow is normal to the dielectric surface, strong normal and tangential rf electric fields are present from the TM<sub>01</sub> accelerating mode in the DLA and the power flow is parallel to the surface at the dielectric-beam channel boundary. While a number of approaches have been developed, no one technology for MP mitigation is able to completely solve the problem. In this paper we report on numerical calculations of the evolution of the MP discharge, and give particular attention to MP dependence on the rf power ramp profile and the use of engineered surface features on the beam channel wall to interrupt the evolution of the multipactor discharge.

**P. Schoessow**, C.-J. Jing, A. Kanareykin (Euclid TechLabs, LLC)  
W. Gai, J. G. Power (ANL) O. V. Sinitsyn (UMD)

### A Novel Technique for Mitigating Multipactor by Means of Magnetic Surface Roughness

Multipactor phenomena which are closely linked to the SEY (secondary electron yield) can be mitigated by many different methods including grooves in the metal surface as well as using electric or magnetic bias fields.

However frequently the application of global magnetic or electric bias field is not practicable considering the weight and power limitations on-board satellites. Additionally, surface grooves may degrade the RF performance. Here we present a novel technique which is based on a magnetostatic field pattern on the metallic surface with fast spatial modulation in the order of 30 micron. This field pattern is produced by proper magnetization of an underlying ferromagnetic layer such as nickel. Simulations and preliminary experimental results will be shown and a number of applications, both for particle accelerators and satellite microwave payloads are discussed.

**F. Caspers**, E. Montesinos (CERN) V. E. Boria (DCOM-iTEAM-UPV) W. Bruns (WBFB) L. Galan (UAM) B. Gimeno (UVEG) I. Montero (CSIC) D. Raboso (ESA-ESTEC) C. Vicente (aurorasat)

### Statistical Modeling of DC Spark

The understanding of electrical breakdowns has a critical role in the design of the RF accelerating cavities for the CLIC linear collider. In this context a new statistical model of the conditioning process and breakdown rate evolution is presented for a DC spark system with tip-plane electrode geometry charged from a capacitance.

The approach requires a small amount of assumptions, but can still make several interesting predictions. Electrode gap distance dependence on the saturated breakdown field and spittfest (grouped breakdowns) are among the phenomena that could be explained from this simple model.

**Y. I. Levinsen**, S. Calatroni, A. Descoedres, M. Taborelli, W. Wuensch (CERN)

### Quantitative Outgassing Studies in DC Electrical Breakdown

Y. I. Levinsen, S. Calatroni, A. Descoedres, M. Taborelli, W. Wuensch (CERN)

Electrical breakdown in the accelerating cavities set a potential limit to the performance of the CLIC linear collider. Vacuum degradation and beam instability are possible outcomes from a breakdown if too much gas is released from the cavity surface. Quantitative data of gas release are provided for copper electrodes (milled Cu-OFE, as-received and heat-treated), and molybdenum electrodes. These data are produced from a controlled DC spark environment with capacitance charged anode at fixed energy.

### Novel Acceleration Structure Using Slot-Resonance Coupling

N. Barov, J. S. Kim, D. J. Newsham (Far-Tech, Inc.) R. H. Miller (SLAC)

We describe a novel acceleration structure for acceleration of electron and ion beams where the cell-to-cell coupling is provided by slot resonances in the wall of adjacent accelerator cells. As with the side-coupled linac, the concept allows for the operation of a standing-wave structure in a phase and amplitude stabilized  $\pi/2$  mode. We explore the applications of such a structure to electron and ion accelerators.

### A Compact, Low-Voltage Multi-Beam Klystron for 1300 MHz Cryomodules

N. Barov, J. S. Kim, D. J. Newsham (Far-Tech, Inc.)

We describe the design and construction status of a compact, 830 kW multi-beam klystron (MBK) for driving 1300 MHz cryomodules. The applications for this tube range from ILC and ILC test facilities to Project X. The use of low gun voltage (36 kV) simplifies the modulator and gun socket requirements. A high efficiency, predicted to be  $> 65\%$ , will allow the klystron to be used in applications requiring low overall site power and high wallplug efficiency.

### Rapidly Tunable RF Cavity for FFAG Accelerators

D. J. Newsham, N. Barov, J. S. Kim (Far-Tech, Inc.)

The fixed-field alternate gradient (FFAG) synchrotron offers an attractive solution for systems that require rapid acceleration over a wide range of energies. The ability to rapidly tune the frequency of the accelerating cavity in the “non-scaling” variety of an FFAG synchrotron represents a fundamental barrier to their implementation in a wide variety of applications for proton, ion and muon acceleration. Initial results of the rapidly tunable cavity design for specific application to proton and light ion medical FFAG accelerators are presented.

### Dielectric Loaded RF Cavities

M. Popovic, A. Moretti (Fermilab) M. L. Neubauer (Muons, Inc)

Alternative cavity fabrication techniques at low frequencies are needed to improve manufacturability. RF cavities below 800 MHz are large, increase the cost of installation, are difficult to manufacture, require significant lead times and are expensive. Novel dielectric loaded RF cavities will allow smaller diameter cavities to be designed; changing the



frequency of a cavity design would be as simple as changing the dielectric cylinder insert material or inner radius of the dielectric in the cavity. A cavity designed for 800 MHz fitted with a ceramic cylinder, high power tested and compared to an 800 MHz cavity without ceramic is described. High power tests at 800 MHz with a ceramic cylinder insert inside of a pill box cavity designed for high pressure hydrogen gas is compared to the breakdown studies in a hydrogen filled 800 MHz cavity operated without a ceramic insert. Assembly processes are investigated to determine the tolerance requirements for ceramic inserts in RF pillbox cavities.

### Compact, Tunable RF Cavities

New developments in the design of fixed-field alternating gradient (FFAG) synchrotrons have sparked interest in their use as rapid-cycling, high intensity accelerators of ions, protons, muons, and electrons. Compact RF cavities that tune rapidly over various frequency ranges are needed to provide the acceleration in FFAG lattices. An innovative design of a compact RF cavity that uses orthogonally biased ferrite or garnet materials for fast frequency tuning and liquid dielectric to reduce the overall cavity size will be developed using computer models, prototyped, and tested. The ferrite and garnet test cavity and the model cavity that were built in an earlier project will be exploited to determine the range of possibilities for FFAG and other applications. A working prototype cavity will be designed to provide a second-harmonic RF cavity for the Fermilab Booster to improve the capture of protons from the Linac. The same concept, using different magnetic and dielectric materials will be evaluated for FFAG machines, the PS2 upgrade of CERN's Large Hadron Collider, and Fermilab's Main Injector proton driver.

**M. Popovic**, A. Moretti (Fermilab) M. Alsharo'a, R. P. Johnson, M. L. Neubauer (Muons, Inc)

TU5PFP018

### Phase and Frequency Locked Magnetrons for SRF Sources

Typically, high power sources for accelerator applications are many megawatt microwave tubes that may be combined together to form ultra high-power localized power stations. The RF power is then distributed to multiple strings of cavities through high power waveguide systems, which are expensive to produce and to operate because of reduced efficiency and lower reliability. Magnetrons are the lowest cost microwave source in \$/kW with the highest efficiency, typically greater than 85%, but the frequency and phase stability of magnetrons has been a problem when used as power sources for accelerators. Novel variable frequency cavity techniques have been developed which will be utilized to phase and frequency lock magnetrons, allowing their use for either individual cavities, or cavity strings. Economies of scale will further reduce magnetron costs, in addition to removing the capital, efficiency, and reliability costs of combining and/or distributing power.

**M. Popovic**, A. Moretti (Fermilab) M. L. Neubauer (Muons, Inc)

TU5PFP019

### Hydrogen-Filled RF Cavities for Muon Beam Cooling

Ionization cooling requires low-Z energy absorbers immersed in a strong magnetic field and high-gradient, large-aperture RF cavities to be able to cool a muon beam as quickly as the short muon lifetime requires. RF cavities that are pressurized with dense hydrogen gas are being developed that use the same real estate to provide the energy absorber and the RF acceleration needed for ionization cooling, where the absorption of dark currents

**K. Yonehara**, M. Chung, M. Hu, A. Jansson, A. Moretti, M. Popovic, A. V. Tollestrup (Fermilab) M. Alsharo'a, R. P. Johnson (Muons, Inc) D. Rose (Voss Scientific)

TU5PFP020

by the dense gas will allow the cavities to operate in strong magnetic fields. Systematic measurements of the operation of a hydrogen-filled cavity are made as functions of external magnetic field and charged particle beam intensity and compared with models to understand the limitations of this technology and to develop mitigating strategies to overcome them. A pressurized RF cavity is being tested that will be used to extend measurements of maximum stable gradient in strong magnetic fields and in the presence of ionizing radiation.

### Traveling Wave RF System for Muon Colliders

K. Yonehara, A. Moretti, M. Popovic, G. V. Romanov (Fermilab)  
R. P. Johnson, M. L. Neubauer (Muons, Inc) L. Thorndahl (CERN)

The great advantage in the helical ionization cooling channel (HCC) is its compact structure that enables the fast cooling of the muon beam 6-dimensional phase space.

This compact aspect requires a high average RF gradient, with few places that do not have cavities. Also, the muon beam is diffuse and requires an RF system with large transverse and longitudinal acceptance. A traveling wave system can address these requirements. First, the number of RF power coupling ports can be significantly reduced, which saves space in longitudinal direction. Second, by adding a nose on the cavity, the transverse size of the cavity can be smaller than a conventional pill box type cell. We discuss the design and simulations of the cooling performance of a traveling wave RF system in a HCC, including the optimization of the cavity shape, to reduce its size, and the design of the RF power couplers needed to transfer power into and out of the cavity.

### COSY as Ideal Test Facility for HESR RF and Stochastic Cooling Hardware

R. Stassen, F. J. Etzkorn, R. Maier, D. Prasuhn, H. Stockhorst (FZJ)

The COoler SYnchrotron COSY at the Forschungszentrum Jülich is operating now since 1992. Up to  $5 \cdot 10^{10}$  protons can be de-

livered over a momentum range of 600 MeV/c to 3.6 GeV/c. The prototype of the HESR barrier bucket cavity was installed into COSY and many measurements have been performed. Especially the co-operation of barrier bucket with stochastic cooling has been studied. During the measurements the internal WASA Pellet target was available which is similar to the PANDA target at the HESR. A 1.2m long cryo-tank has been designed and installed to measure the sensitivities of new pickup structures for the HESR stochastic cooling system. Tank design and structures arrangement correspond to the projected HESR stochastic cooling layout. The recent results will be presented.

### Bunch Compression for FAIR

P. Hülsmann (GSI)

To feed the production targets of FAIR with very short bunches (pulse durations of not more than 50 ns are envisaged) demanding

rf-systems for bunch compression are required in SIS18 and SIS100. But also the opposite process, namely debunching, is required in the collector ring CR. Bunch compression as well as debunching will be done by fast bunch rotation. Due to space restrictions both rf-systems must be able to generate a very high field gradient of 50 kV/m at very low frequencies. Such high field gradients can be realised only using magnetic alloy (MA) cavities, since their saturation field strength is about ten times higher compared to NiZn-ferrites. For SIS18 a MA bunch compressor unit, which generates the required 50 kV/m at 800- and 1200 kHz, has already been realized as a forerunner for the required FAIR-systems.

### Design of an MA Based RF System for the Collector Ring at FAIR

The 'Facility of Antiproton and Ion Research' (FAIR) project will be realized at the 'GSI Helmholtzzentrum für Schwerionenforschung GmbH' (Darmstadt, Germany) in the scope of a large international collaboration. One of the FAIR storage rings is the collector ring (CR) whose main purpose is to allow a fast cooling of secondary beams (rare isotopes and antiprotons). The RF system of the collector ring has to allow pulsed operation (40kV, duty cycle  $5e-4$ ) as well as continuous operation (2kV) in the frequency range of 1.2 to 1.4MHz. The detailed conceptual design of this RF system is introduced here. It will be based (similar to the existing RF system 'SIS18 bunch compressor' which will also be presented at PAC09) on two inductively loaded quarter wavelength coaxial resonators operating on a common ceramic gap. The resonator will be loaded with twelve ring cores (rout=313mm, rin=145mm, h=25mm) of a cobalt based amorphous magnetic alloy (VitroVac6030F); it will be cooled by forced air. The cavity will be driven by a push-pull amplifier operated in class A consisting of two tetrodes (TH555A) that will be coupled inductively to the cavity.

U. Laier, P. Hülsmann, K.-P. Ningel, G. Schreiber (GSI)

TU5PF024

### The New cw RFQ Prototype

A short RFQ prototype was built for tests of high power RFQ structures. We will study thermal effects and determine critical points of the design. Simulations with CST Microwave Studio and first measurements were done. First results and the status of the project will be presented.

U. Bartz, A. Bechtold, N. Mueller, A. Schempp (IAP)

TU5PF025

### RF System for RACCAM FFAG

This paper presents the RF systems of RACCAM FFAG for medical applications. Design of the RF system was updated to fit short and curved straight section of the spiral FFAG in view of preserving the compactness of the spiral lattice.

C. Ohmori (KEK) F. Meot (CEA) J. Pasternak (LPSC)

TU5PF026

### Design of a New J-PARC RF Cavity for Muon Short Bunch

J-PARC RCS accelerates a high intensity beam using 11 sets of Magnetic Alloy loaded cavities. It supplies the proton beam to the MLF (Material Life Science Facility) for the neutron and muon experiments. For very high resolution muon experiments, a short proton beam bunch of few ten ns is necessary. To reduce the bunch width to several ten ns, a bunch rotation scheme before extraction will be useful. For the bunch width of few ten ns, a much higher RF voltage is also required. Based on a new magnetic alloy core technology, a design of a new RF cavity to increase the maximum RF voltage by a factor of two will be described in this paper.

C. Ohmori, E. Ezura, K. Hara, A. Takagi, M. Toda, M. Yoshii (KEK)  
K. Hasegawa, M. Nomura, A. Schnase, T. Shimada, H. Suzuki, F. Tamura, M. Yamamoto (JAEA/J-PARC)

TU5PF027

### High-Gradient RF Breakdown Studies with Narrow Waveguide

K. Yokoyama, S. Fukuda, Y. Higashi, T. Higo, N. Kudoh, S. Matsumoto, Y. Watanabe (KEK)

High-gradient RF breakdown studies have been in progress at Nextef (New X-band Test Facility at KEK) since 2006. To study the characteristics of different materials on high-field RF breakdown, we have performed high-gradient experiments by using narrow waveguides that has a field of around 140 MV/m at 50 MW power. Breakdown rates of stainless-steel and copper cases were measured and the results are described in this paper.

High-gradient RF breakdown studies have been in progress at Nextef (New X-band Test Facility at KEK) since 2006. To study the characteristics of different materials on high

### Preliminary Design of RF Cavities for the Cyclotron CYCHU-10

L. Cao, M. Fan, T. Hu, J. Huang, D. Li, W. Xiao (HUST)

At Huazhong University of Science and Technology (HUST), the design study of a 10 MeV compact negative hydrogen cyclotron (CYCHU-10) for Positron Emission Tomography (PET) has been developed since 2007. This paper describes the recent status of RF cavities including numerical simulation results of resonant cavities, the construction and cold test of 1:1 scale prototype. The shape and size design of the fixed inductive coupling loop and its performance of matching with the 10KW RF power generator are also presented.

At Huazhong University of Science and Technology (HUST), the design study of a 10 MeV compact negative hydrogen cyclotron

### Design and Test of 10kW RF Amplifier Based on Direct Digital Synthesizer

D. Li, L. Cao, T. Hu, J. Huang, B. Qin, J. Yang (HUST)

In order to reduce the cost of the signal generator comprising a high performance direct digital synthesizer (DDS), the method of picking up a desired aliased signal of DDS output is adopted in the study. The chip AD9850 is used to synthesize RF signal in the system, and the amplitude modulation of the system is achieved by altering the external connection resistance of the chip. The output frequency is tunable from 99.5 to 101MHz. The principle and the test results of the signal synthesizer will be presented. The amplifier based on tetrode technology can deliver the 10kW RF power in a continuous wave (CW) mode of operation. The driver amplifier consists of two solid-state modules, and it can provide the tetrode with up to 300W input power. The tetrode operates in the grounded cathode configuration. The conceptual design of the final stage amplifier will also be demonstrated in this paper.

In order to reduce the cost of the signal generator comprising a high performance direct digital synthesizer (DDS), the method

### Computational Study of Multipactor Discharge

S. Ahmed, D. M. Kaplan (Illinois Institute of Technology) A. Moretti (Fermilab)

Multipactor discharge is a most commonly observed phenomenon in high power microwave devices, radio-frequency (RF) accelerators and space based communication systems. This occurs due to surfaces exposed to intense time-varying electric fields. It is worth analyzing the surface properties of various materials under the effects of RF frequency, field intensity and the angle of applied field. The response to applied RF fields of isotropic, anisotropic and multi-layer dielectric substrates has been analyzed in terms of material relaxation time ( $\epsilon/\sigma$ ). These simulations have been done using the finite-difference time-domain method. Results will also involve 1D particle-in-cell (PIC) simulations.

Multipactor discharge is a most commonly observed phenomenon in high power microwave devices, radio-frequency (RF) accelerators and space based communication systems.

### RF Studies at Fermilab MuCool Test Area

The accelerating gradient in an RF cavity is a function of many factors, such as the surface material properties, RF frequency, the external magnetic field and the gas pressure inside the cavity. In the MuCool Program, RF cavities are studied with the aim of understanding the basic mechanisms of breakdown and thus improving their maximum stable gradient. Our cavities are prototypes of those that might eventually find application in a muon ionization cooling channel for a Neutrino Factory or Muon Collider. We report studies using the 805 MHz and 201 MHz RF cavities in the MuCool Test Area (MTA) at Fermilab. Some new results include data from several buttons of different materials mounted in the 805 MHz cavity, study of the accelerating gradient in the 201 MHz cavity and x-ray background radiation from the cavities due to electron Bremsstrahlung. The 201 MHz cavity has been shown to be stable at 19 MV/m, well in excess of its design gradient. We will also discuss results from the 201 MHz cavity studies in high magnetic field and introduce the study of E, B effects with the 805 MHz cavity and the testing of the new proton beamline for the MTA.

**D. Huang**, Y. Torun (IIT) A. D. Bross, A. Moretti, Z. Qian (Fermilab) D. Li, M. S. Zisman (LBNL) J. Norem (ANL) R. A. Rimmer (JLAB)

### BNL 703 MHz SRF Cryomodule Demonstration

This paper will present the preliminary results of the testing of the 703 MHz SRF cryomodule designed for use in the ampere class ERL under construction at Brookhaven National Laboratory. The preliminary VTA cavity testing, carried out at Jefferson Laboratory, demonstrated cavity performance of 20 MV/m with a  $Q_0$  of  $1 \times 10^{10}$ , results we expect to reproduce in the horizontal configuration. This test of the entire string assembly will allow us to evaluate all of the additional cryomodule components not previously tested in the VTA and will prepare us for our next milestone test which will be delivery of electrons from our injector through the cryomodule to the beam dump. This will also be the first demonstration of an accelerating cavity designed for use in an ampere class ERL, a key development which holds great promise for future machines.

**A. Burrill**, I. Ben-Zvi (BNL)

### LHC Crab Cavity Cryostat and Infrastructure

The complex LHC crab cavity design and the beam-line configuration pose very tight constraints for the cryostat design. An initial assessment of the LHC main RF cryostat points to a new design both from the RF and engineering point of view. The cavity and tunnel constraints are discussed in detail and an initial cryostat design along with the cryogenic circuit is presented.

**R. Calaga** (BNL) O. Brunner, E. Ciapala, T. P.R. Linnecar, J. Tuckmantel, W. Weingarten (CERN) T. J. Peterson, N. Solyak, V. P. Yakovlev (Fermilab)

**A Proof-of-Principle Experiment of the Ferroelectric Tuner for a 1.3 GHz Cavity**

H. Hahn, E. M. Choi (BNL) J. L. Hirshfield (Yale University, Physics Department) S. Kazakov, S. V. Shchelkunov (Omega-P, Inc.)

A novel tuner has been developed by the Omega-P company to achieve fast control of the accelerator RF cavity frequency. The tuner is based on the ferroelectric property which has a variable dielectric constant as function of applied voltage. Tests using a Brookhaven National Laboratory (BNL) 1.3 GHz RF cavity have been carried out for a proof-of-principle experiment of the ferroelectric tuner. Two different methods were used to determine the frequency change achieved with the ferroelectric tuner. The first method is based on a S11 measurement at the tuner port to find the reactive impedance change when the voltage is applied. The reactive impedance change then is used to estimate the cavity frequency shift. The second method is a direct S21 measurement of the frequency shift in the cavity with the tuner connected. The estimated frequency change from the reactive impedance measurement due to 5 kV is in the range between 3.2 kHz and 14 kHz, while 9 kHz is the result from the direct measurement. The two methods are in reasonable agreement. The detail description of the experiment and the analysis will be discussed in the paper.

**Design of the Fundamental Mode Damper and the HOM Dampers for the 56 MHz SRF Cavity**

H. Hahn, S. Bellavia, I. Ben-Zvi, E. M. Choi (BNL)

A 56 MHz Superconducting RF cavity is developed for the luminosity enhancement of the Relativistic Heavy Ion Collider (RHIC). The 56 MHz SRF cavity enables to adiabatically rebucket the beam from the 28 MHz accelerating cavities, which with shorter bunch lengths will enhance the luminosity significantly. The 56 MHz SRF cavity fundamental mode must be damped during injection and acceleration by a fundamental mode damper (FD), which is physically withdrawn at store for operation. The cavity frequency changes from the withdrawing motion but is kept below the beam frequency at store by a judicious axial placement of the FD. Physics studies by numerical simulations, tests of the FD in the prototype cavity, and the challenging engineering issues are here addressed. In addition, higher-order mode (HOM) dampers are necessary for the stable operation of the 56 MHz SRF cavity. The HOM's are identified and the external Q factors are obtained from tests of the prototype cavity and are compared to simulations with the CST MWS program. The HOM damper blocks the fundamental mode by a 5 element high pass filter. The HOM stability criteria of the cavity are satisfied with four HOM dampers.

**Ripple Structure in 56 MHz Quarter Wave Resonator for Multipacting Suppression**

D. Naik, I. Ben-Zvi (BNL)

A beam excited 56 MHz RF Niobium Quarter Wave Resonator has been proposed to enhance RHIC beam luminosity and bunching. As multipacting is expected, an extensive study was carried out with the Multipac 2.1 code, looking for a way to suppress it. Multipacting bands were found. Discharge occurred at cavity's top corner above beam gap and on outer conductor up to more than half its length, moving towards the end of the cavity. We find single-point multipacting, with emission from the outer conductor, as well as two-point multipacting involving both inner and outer conductor. We found a geometric approach to suppressing multipacting. The most promising method was ripples in outer conductor. Ripples' depth, width and gap were optimized. In shallow depth of 1 cm, electrons multiply, drift further, however they are stopped by 2 cm ripples. Width of 1 and 3 cm didn't work as in 1 cm electrons

emerge out of it, whereas, in 3 cm, they resonate and trap inside. A 2 cm wide was found good. Likewise, 2 cm gap was valuable. Finally, we find that ripples of 2 cm deep, 2 cm wide spaced by 2 cm completely suppressed multipacting, and were adopted for fabrication.

### 1.3 GHz Superconducting RF Accelerator Unit and the Horizontal Test Stand R&D

With the aim to master 1.3 GHz superconducting accelerator technology in the frame of ILC collaboration, IHEP has proved a program to build a Superconducting RF Accelerator Unit, which includes a 9-cell 1.3 GHz superconducting cavity, high power input coupler, tuner, cryomodule, low level rf, 1.3 GHz high power source, etc. At the same time, this program includes IHEP superconducting accelerator laboratory upgrade which permits this accelerator unit to be built and tested at IHEP. We will make use of this unit as a horizontal test stand for 9-cell cavity and the auxiliaries in the future, as existed in Europe and North America. In this paper, we report the recent R&D status of the program.

**J. Gao**, Y. L. Chi, J. P. Dai, J. Gu, M. Hou, S. P. Li, Z. Q. Li, W. M. Pan, J. Yu, J. Y. Zhai (IHEP Beijing) J. Z. Chen (HJL) L. Q. Liu (Technical Institute of Physics and Chemistry) W. P. Xie (OTIC) Q. Z. Xing (TUB) H. Yuan (BIAM) T. X. Zhao (TIPC)

TU5PFP038

### HOM Simulations with HFSS Using the TESLA 9-Cell Cavity Model

This paper describes the development of HOM simulation routines for HFSS to be used for the Superconducting Proton Linac

(SPL) at CERN. The SPL is a study for a multi-megawatt superconducting, high current  $H^{1-1}$  accelerator at CERN. The analysis of High Order Modes (HOMs) is a crucial step in the design of the superconducting cavities and will help to decide whether HOM couplers are necessary for stable operation of the linac. Both cavity simulation and parameter calculations are performed with HFSS. The existing TESLA 9-cell cavity geometry data is used to construct the models in HFSS. This cavity has been chosen, because it is well documented and thus ideally suited as a benchmark for the simulations. Monopole, dipole and quadrupole modes are obtained by applying different boundary conditions on various cavity models. The HFSS scripts used to automatically calculate the parameters of modes have been written and run successfully with the geometry of the TESLA cavity. These scripts can also be used for other cavities with different geometries and sizes and will be used to study the cavity shapes of the SPL.

**R. H. Zeng** (IHEP Beijing) M. Schuh (CERN)

TU5PFP039

### Novel Geometries for the LHC Crab Cavity

In 2017 the LHC is envisioned to increase its luminosity via an upgrade. This upgrade is likely to require a large crossing angle hence a crab cavity is required to align the bunches prior to collision. There are two possible

schemes for crab cavity implementation, global and local. In a global crab cavity the crab cavity is far from the IP and the bunch rotates back and forward as it traverses around the accelerator in a closed orbit. For this scheme a two cell elliptical squashed cavity at 800 MHz is preferred. To avoid any potential beam instabilities all the modes of the cavities must be damped strongly, however crab cavities have lower order and same order modes in addition to the usual higher order modes and hence a novel damping scheme must be used to provide sufficient damping of these modes. In the local scheme two crab cavities are placed at each side of the IP two start and stop rotation of the bunches. This would require crab cavities much smaller transversely than in the global scheme but

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TU5PFP040

the frequency cannot be increased any higher due to the long bunch length of the LHC beam. This will require a novel compact crab cavity design.

### Tests Status of the SPIRAL 2 Low Beta Cryomodules

P.-E. Bernaudin, P. Bosland, J. Giraud, A. Perolat, C. G. Thomas-Madec (CEA) R. Ferdinand (GANIL)

The Spiral2 project at Ganil aims at producing exotic ion beams for Nuclear Physics. The accelerator of the primary beam is a superconducting LINAC designed to provide 5mA deuteron beams at 40MeV. It will also allow accelerating stable ions of different Q/A values ranging from protons to Q/A=1/6 heavy ions. The accelerator should be commissioned by the end of 2011, first beam in 2012; the first tests aiming to produce exotic beams are planned one year later. The superconducting LINAC consists of 12 low beta (0.07) quarter wave (88MHz) superconducting (SC) cavities and 24 beta (0,14) SC cavities integrated in their cryomodule. The status of the low beta cryomodules, supplied by the CEA Saclay Irfu institute, is reported in this paper. The RF full power tests were performed at the end of 2008 on the qualifying cryomodule, and the tests of the first series cavity in vertical cryostat were performed during spring 2009.

### Electromagnetic and Mechanical Properties of the Cornell ERL Injector Cryomodule

Z. A. Conway, M. Liepe (CLASSE)

This paper reports results of cold measurements characterizing the electro-mechanical properties of the Cornell ERL injector cryomodule, which houses five superconducting niobium elliptical 2-cell cavities developed for a high-current (100 mA) low-emittance electron beam. Each cavity is equipped with a blade tuner. The Cornell ERL blade tuner is a modified version of the INFN-Milano design, and incorporates 4 piezoelectric actuators and accelerometers enabling concurrent slow/fast cw RF frequency control and mechanical vibration measurements. Cavity microphonics and fast tuner electro-mechanical transfer functions for all of the cavities have been measured and show the feasibility of stable feedback control at microphonic noise frequencies below ~100 Hz.

### Fast Piezoelectric Actuator Control of Microphonics in the CW Cornell ERL Injector Cryomodule

Z. A. Conway, M. Liepe (CLASSE)

The RF power required to phase-stabilize the Cornell University ERL main linac cavities is expected to be driven by microphonic noise. To reduce the required RF power we are exploring the possibility of active compensation of cavity microphonic noise with the cavities in the Cornell ERL injector cryomodule. The Cornell ERL injector cryomodule houses five elliptical 2-cell SRF cavities developed for the acceleration of a high current (100mA) ultra-low emittance beam and is currently undergoing extensive testing and commissioning. Each of the five cavities is equipped with a blade tuner; each blade tuner integrates 4 piezoelectric actuators and vibration sensors for the active compensation of cavity detuning. This paper presents first results of active frequency-stabilization experiments performed with the Cornell ERL injector cryomodule cavities and their integral blade/piezoelectric fast tuners.



### Defect Location in Superconducting Cavities Cooled with He-II Using Oscillating Superleak Transducers

Superconducting RF cavity quench detection is presently a cumbersome procedure requiring two or more expensive cold tests.

Z. A. Conway, D. L. Hartill, H. Padamsee, E. N. Smith (CLASSE)

One cold test identifies the cell-pair involved via quench field measurements in several 1.3 GHz TM010 pass-band modes. A second test follows with numerous fixed thermometers attached to the culprit cell-pair to identify the particular cell. A third measurement with many localized thermometers is necessary to zoom in on the quench spot. We report here on a far more efficient alternative method which utilizes a few (e.g. 8) oscillating superleak transducers (OST) to detect the He-II second sound wave driven by the defect induced quench. Results characterizing defect location with He-II second sound wave OST detection, powering multiple modes of the 1.3GHz TM010 passband to locate multiple defects, and corroborating measurements with carbon thermometers will be presented.

### Status of Niowave ILC Vendor Qualification Tests at Cornell

To build the ~14,000 cavities required for the ILC each of the three world regions must have a sizable industrial base of qualified companies to draw cavities from. One of these companies, Niowave Inc., recently manufactured six 1.3 GHz single-cell cavities for qualification purposes. All six cavities achieved gradients above 25 MV/m before they were limited by the available RF power (Q-slope) or quenched. This paper will report the results of cold tests for all six cavities and on the causes of quench determined by 2nd sound detection and optical inspection.

Z. A. Conway, E. P. Chojnacki, D. L. Hartill, M. Liepe, H. Padamsee, J. Sears (CLASSE) M. S. Champion, G. Wu (Fermilab)

### ILC Nine-Cell Testing Program at Cornell University

Cornell University's superconducting niobium nine-elliptical-cell cavity testing and repair program is one contributor to the collaborative effort on critical SRF R&D for the ILC. The Cornell University program benefits from several unique features which provide for the rapid testing and, if necessary, repair of ILC nine-cell cavities: a continuous vertical electropolish procedure, superfluid helium second sound defect location, and tumble polishing.

Z. A. Conway, E. P. Chojnacki, D. L. Hartill, M. Liepe, H. Padamsee, J. Sears (CLASSE)

First, we report on the cavity 2K RF performance and the effect of micro-EP preceding the cavity test. Single-cell results at KEK have shown that micro-EP as a final surface treatment reduces the spread in gradients, but micro-EP has not yet been tried with multi-cell cavities. Secondly, we report on the highly efficient method of detecting defects using a few He-II second sound wave detectors and powering several modes of the 1.3GHz TM010 passband.

### Multi-Cell Reentrant Cavity Development and Testing At Cornell

An innovative reentrant cavity design investigated the initial, highly successful, superconducting niobium reentrant-single-cell cavity tests at Cornell and KEK. Prompted by the success of the single cell program a joint effort of Cornell University and Advanced Energy Systems (AES)

Z. A. Conway, E. P. Chojnacki, D. L. Hartill, M. Liepe, D. Meidlinger, H. Padamsee, J. Sears (CLASSE) J. Rathke (AES)

fabricated two multiple-cell reentrant cavities: a three-cell and a nine-cell cavity. This paper reports the development status of these two cavities. First, the results of cold tests, superfluid helium defect location and repair work on the reentrant nine-cell cavity will be presented. Second, the results of cold tests, including defect location and repair efforts of the reentrant three-cell cavity will be presented.

### Robustness of the Superconducting Multicell Cavity Design for the Cornell Energy Recovery Linac

M. Liepe (Cornell University) G. Q. Stedman, N. R.A. Valles (CLASSE)

Cornell University is developing an Energy-Recovery-Linac driven x-ray light source. One of the major components of this accelerator will be its 5 GeV superconducting main

linac. The design of the superconducting RF cavities in this main linac has been optimized primarily for two objectives: (1) low RF losses from the accelerating mode to minimize refrigeration cost and (2) strong Higher-Order-Mode damping to preserve low emittance and prevent beam break-up at high beam current (100 mA). In this paper we study the robustness of this optimized cavity design with respect to small cell shape fluctuations from fabrication errors.

### Vertical Test Results for Vertically Electropolished 1.3GHz 5-Cell Superconducting Cavities

D. Meidlinger, E. P. Chojnacki, J. J. Kaufman, H. Padamsee, A. J. Windsor (CLASSE)

Diagnosing field-limiting behavior in multi-cell superconducting cavities can be difficult due to the lack of direct local measurements of cavity surface properties. The results of

multiple vertical tests on several 5-cell vertically electropolished 1.3GHz superconducting cavities with measurements of cavity surface properties are presented. A combination of oscillating superleak transducer and resistive thermometry data for various accelerating passband modes are used to infer the field-limiting mechanism for several cells of each multi-cell cavity.

### A Procedure for Electropolishing Vertically Oriented Muticell Niobium Radiofrequency Cavities

A. C. Crawford (JLAB) H. Padamsee (CLASSE)

We report the vertical electropolish of a nine-cell International Linear Collider cavity along with details of the method and technology.

The cavity was then electropolished using the conventional horizontal technique. RF test results for both cases are presented.

### Superconducting Multicell Cavity Design for the Energy Recovery Linac at Cornell

V. D. Shemelin, M. Liepe (CLASSE)

The first phase of the Cornell Energy Recovery Linac was the high current, low emittance injector. At present the injector is under commissioning.

The next phase calls for the development of multicell cavity for the main linac. The cavities need to have low RF losses to minimize refrigeration and strong HOM damping to preserve low emittance and

prevent beam break-up at high current (100 mA). Here we present the RF design of the cavity meeting these requirements.

### Exploring the Maximum Superheating Magnetic Fields of Niobium

The superheating magnetic field of a superconducting niobium 1.3 GHz reentrant cavity was measured at several points in the temperature range from (1.7 to 4.4) K. This experimental data is used to discriminate between two competing theoretical models for the temperature dependent behavior of the RF superheating field. Measurements were made with <250 ns high power pulses (HPP, ~1MW) to avoid defect initiated thermal breakdown from contaminating the data. Our test incorporated oscillating superleak transducers to determine the cavity quench locations and characterize changes and the migrations of the quench locations during processing. This information provides insight into the factors which limit the ultimate achievable RF surface magnetic field.

N. R.A. Valles, Z. A. Conway, M. Liepe (CLASSE)

### Cryogenic Test of a Coaxial Coupling Scheme for Fundamental and Higher Order Modes in Superconducting Cavities

A coaxial coupling device located in the beam pipe of the TESLA type superconducting cavities provides for better propagation of Higher Order Modes (HOMs) and their strong damping in appropriate HOM couplers. Additionally, it also provides efficient coupling for fundamental mode RF power into the superconducting cavity. The whole coupling device can be designed as a detachable system. If appropriately dimensioned, the magnetic field can be minimized to a negligible level at the flange position. This scheme, presented previously\*, provides for several advantages: strong HOM damping, flangeable solution, exchangeability of the HOM damping device on a cavity, less complexity of the superconducting cavity, possible cost advantages. This contribution will describe the results of the first cryogenic test.

J. S. Sekutowicz (DESY) P. Kneisel (JLAB)

\*J. Sekutowicz et al., Proceedings LINAC08, Victoria, Canada, 2008.

### Development of Large Grain Superconducting Resonators for the European XFEL

A test program of 1.3 GHz TESLA shape 9-cell large grain (LG) resonators for the European XFEL project was started at DESY. The main aim is to find out whether or not the choice of LG material could be an option for the fabrication of approx. 800 XFEL resonators. Several aspects are under investigation and will be compared with the conventional polycrystalline material option. One of the aspects is the material issue: could the required amount of LG niobium be produced at industry in a cost effective and reliable manner? The second issue is the fabrication of cavities: could the series production of resonators be done on the level of required accuracy and costs? The third one is the performance issue: what is the appropriate treatment for reproducibly achieving the specified XFEL accelerating gradients? Development of the LG disc production was done within the framework of the R&D program of DESY and W. C. HERAEUS. Eleven resonators are produced at the company ACCEL. Up to now three resonators are RF-tested vertically. The He-vessel was welded onto one

W. Singer, J. Iversen, G. Kreps, L. Lilje, A. Matheisen, X. Singer, H. Weise (DESY) M. Pekeler, J. Sch. Schwellenbach (ACCEL) F. Schoelz (W. C. Heraeus GmbH COPY, Materials Technology Dept.) B. Spaniol, E. Stiedl (W. C. Heraeus GmbH, Materials Technology Dept.)

of the resonators which passed the horizontal RF-test. The data and perspectives of the LG cavity application are discussed.

### Hydroforming of Multi-Cell Niobium and NbCu-Clad Cavities

X. Singer, I. Jelezov, A. Matheisen, W. Singer (DESY) G. Ciovati, P. Kneisel, M. Morrone (JLAB)

Technological aspects of seamless tube fabrication and multi-cell cavity production by hydroforming will be discussed. Problems related to the fabrication of seamless cavities from bulk niobium are mainly solved. Several two cell- and three cell- niobium cavities have been produced by hydroforming at DESY. A 9-cell cavity of the TESLA shape has been completed from three sub-sections at company ZANON. The cavity was treated by electropolishing (EP) and successfully RF-tested. Two 3-cell units equipped with niobium beam pipes are being RF-tested after BCP surface treatment. The temperature mapping method with Jlab's two-cell thermometry system is applied for performance analysis. It is of particular interest to compare the seamless cavity quench locations to those from standard cavities. The cryogenic test results and the T-mapping findings will be discussed. Of special interest is the combination of the seamless technique with NbCu cladding, i.e. the fabrication of cavity from bimetallic clad NbCu tube by hydroforming. Fabrication of single-cell and multi-cell NbCu clad cavities by hydroforming from bimetallic tubes is proven. Some test results will be presented.

### Control System Design for Automatic Cavity Tuning Machines

R. H. Carcagno, T. N. Khabiboulline, S. Kotelnikov, A. Makulski, R. Nehring, J. M. Nogiec (Fermilab) A. Goessel, G. Kreps, C. Mueller, J. H. Thie (DESY)

A series of four automatic tuning machines for 9-cell TESLA-type cavities are being developed and fabricated through a collaboration between DESY, FNAL and KEK. These machines are intended to support high-throughput cavity fabrication for construction of large SRF-based accelerator projects. Two of these machines will be delivered to cavity vendors for the tuning of XFEL cavities. The control system for these machines must support a high level of automation adequate for industrial use by non-expert operators. This paper describes the control system hardware and software designs, and shows preliminary results obtained with a tuning machine prototype.

### Analyses of Defects in the Heat Affected Zone of Welded Niobium Coupons

L. Cooley, D. Burk, M. H. Foley, D. T. Hicks, R. Schuessler, C. Thompson, G. Wu (Fermilab)

Combined temperature mapping and optical inspection of SRF cavities has revealed defects near the edge of the heat affected zone (HAZ) of numerous welds. We have re-created similar defects on welded coupons that were electropolished in the lab and characterized by a variety of tools. Several features that may have bearing on the origin of these defects are discussed, such as their location relative to grain boundaries, the strain state of the niobium prior to welding and etching, the electropolishing parameters, and so forth. Since coupons are useful for distribution to academic researchers, we also describe other detailed characterizations.

### Construction of a 3.9 GHz Superconducting RF Cavity Module at Fermilab

Fermilab is in a collaboration with DESY to provide a cryomodule containing 4-3.9 GHz superconducting RF cavities to be placed in TTF/FLASH. The purpose of this 'Third Harmonic' module is to linearize the non-linear beam energy-time profile produced by the 1.3 GHz accelerating gradient. The completed module has now been shipped to DESY and is awaiting cold, powered testing and installation into FLASH later this year. We report on experience with fabricating, testing, assembling, and shipping the module and its components with a focus on cavity test results.

**H. T. Edwards**, T. T. Arkan, M. H. Foley, M. Ge, E. R. Harms, A. Hocker, T. N. Khabiboulline, M. W. McGee, D. V. Mitchell, D. R. Olis, A. M. Rowe, N. Solyak (Fermilab)

TU5PFP058

### Vibrational Stability of SRF Accelerator Test Facility at Fermilab

Recently developed, the Superconducting Radio Frequency (SRF) Accelerator Test Facilities at Fermilab supports the International Linear Collider (ILC), High Intensity Neutrino Source (HINS), a new high intensity injector (Project X) and other future machines. These facilities; Meson Detector Building and New Muon Lab (NML) have very different foundations, structures, relative elevations with respect to grade level and surrounding soil composition. Also, there are differences in the operating equipment and their proximity to the primary machine. All the future machines have stringent operational stability requirements. The present study examines both near-field and ambient vibration in order to develop an understanding of the potential contribution of near-field sources (e.g. compressors, ultra-high and standard vacuum equipment, klystrons, modulators, utility fans and pumps) and distant noise sources to the overall system displacements. Facility vibration measurement results and methods of possible isolation from noise sources are presented and discussed.

**M. W. McGee**, J. T. Volk (Fermilab)

TU5PFP059

### Development of 325 MHz Single Spoke Resonators and Helium Vessels at Fermilab for HINS

The Fermilab High Intensity Neutrino Source (HINS) Linac R&D program is building a 60 MeV superconducting  $H^-$  linac. The Linac incorporates SC solenoids, high power RF vector modulators for independent control of multiple cavities powered from a single klystron, and SC spoke-type accelerating cavities starting at 10 MeV. This will be the first application and demonstration of any of these technologies in a low-energy, high-intensity proton/ $H^-$  linear accelerator. The HINS effort is relevant to a high intensity, superconducting  $H^-$  linac that might serve the next generation of neutrino physics and muon storage ring/collider experiments. Three types of superconducting resonators are used in the front end section of the linac. Single Spoke Resonators  $\text{typ}\cdot 10^{-1}$  (SSR1) at  $\text{Beta}=0.2$ , Single Spoke Resonators  $\text{typ}\cdot 10^{-2}$  (SSR2) at  $\text{Beta}=0.4$  and Triple Spoke Resonators (TSR) at  $\text{Beta}=0.6$ . This paper describes the status of fabrication, chemical processing and cold testing of SSR1 resonators. The design of the helium vessel was completed and the first resonator was dressed with a helium vessel. The Buffer Chemical Polishing (BCP) setup was redesigned to improve the flow of the acid mixture.

**L. Ristori**, G. Apollinari, I. G. Gonin, T. N. Khabiboulline, A. Mukherjee, J. P. Ozelis, V. Poloubotko, D. A. Sergatskov, R. L. Wagner, R. C. Webber (Fermilab) G. Lanfranco (ELETTRA)

TU5PFP060

### Improved Input and HOM Couplers for a SC Acceleration Structure

V. P. Yakovlev, I. G. Gonin, A. Lunin, N. Solyak (Fermilab)

Different couplers are described that allow the reduction of both transverse wake potential and RF kick in the SC acceleration structure of ILC. A simple rotation of the couplers reducing the RF kick and transverse wake kick is discussed for both the main linac and bunch compressors, along with possible limitations of this method. Designs of a coupler unit are presented which preserve axial symmetry of the structure, and provide reduced both the RF kick and transverse wake field.

### Excitation of Traveling Wave in a Superconducting Structure with Feedback

V. P. Yakovlev, A. Lunin, N. Solyak (Fermilab) P. V. Avrakhov, A. Kanareykin (Euclid TechLabs, LLC) S. Kazakov (KEK)

The accelerating gradient required for the ILC project exceeds 30 MeV/m. With current technology the maximum acceleration gradient in SC structures is determined mainly by the value of the surface RF magnetic field. In order to increase the gradient, the RF magnetic field is distributed homogeneously over the cavity surface (low-loss structure), and coupling to the beam is improved by introducing aperture "noses" (re-entrant structure). These features allow gradients in excess of 50 MeV/m to be obtained for a single-cell cavity. Further improvement of the coupling to the beam may be achieved by using a TW SC structure with small phase advance per cell. We have demonstrated that an additional gradient increase by up to 46% may be possible if a  $\pi/2$  TW SC structure is employed. However, a TW SC structure requires a SC feedback waveguide to return the few GW of circulating RF power from the structure output back to the structure input. Advantages and limitations of different techniques of exciting the traveling wave in this structure are considered, including an analysis of mechanical tolerances. We also report on investigations of transient processes in the SC TW structure.

### Low-Beta Structure for High Energy Part of Project X

V. P. Yakovlev, I. G. Gonin, A. Lunin, N. Solyak (Fermilab) I. K. Drozdov, N. Perunov (MIPT)

Long 11-cell,  $\beta=0.81$  L-band structure is considered as an initial stage of the high-energy part of the Project-X in order to accommodate to a standard CM4 cryomodule. The cavity shape is optimized for maximal energy gain providing the same time field flatness along the structure not worse than for ILC  $\beta=1$  cavity, and the same ratio of surface magnetic field to electric field. The results of spectrum analysis for monopole and dipole HOMs is presented as well as the HOM damper design.

### SC Crab Cavity with Reduced Transverse Size for the LHC Upgrade

V. P. Yakovlev, I. G. Gonin, T. N. Khabiboulline, N. Solyak (Fermilab)

In the paper the Crab Cavity is described for local Crab schemes for LHC that demand reduced transverse cavity dimensions small enough to fit limited space necessary for the beams separation. The results of the configuration cavity optimization are presented that include (a) the surface field minimization; (b) parasitic monopole and dipole spectrum optimization and dumping, (c) the input and the

parasitic mode damping couplers design. The results of multipacting simulations, which were performed in order to understand the possible gradient limitations, are discussed also.

### FZJ HIPPI SC Triple-Spoke Cavity

The paper describes the design, fabrication and first test results of the triple-spoke cavity (resonant frequency 352 MHz,  $\beta=0.48$ ) developed at Forschungszentrum Juelich in the frame of High Intensity Pulsed Proton

Injector project. The cavity has 5 cm diameter beam aperture, a transverse radius of 21.7 cm and the whole length of 78 cm. An initial wall thickness of niobium sheets used for cavity fabrication was around 4 mm. The RF cavity design has been adapted to two main goals - the simplest technology of cavity manufacture and for the prime goal of the project to achieve the best possible structural parameters (Lorenz force frequency shift and a resonant frequency pressure dependence). Intense cavity structural analyses have been conducted and the further prospectives on cavity developments are also presented. Construction of the niobium cavity prototype has been completed, the cavity has been chemically processed. Results of initial cold test are discussed.

**E. N. Zaplatin**, R. Maier, M. Pap, R. Stassen, R. Tolle (FZJ) W. Behr, H. Glueckler, W. Guenther, J. Wolters (Forschungszentrum Juelich GmbH, Institut für Nuklearchemie (INC))

### IFMIF Superconducting $\beta=0.094$ Half-Wave Resonator Design

The driver of the International Fusion Material Irradiation Facility (IFMIF) consists of two 125 mA, 40 MeV cw deuteron accelerators. A superconducting option for the 5 to

40 MeV linac is based on Half-Wave Resonators (HWR) has been chosen. The first cryomodule should contain 8 HWR's with resonant frequency of 175 MHz and  $\beta=v/c=0.094$ . The paper describes RF design of half-wave length resonator. The requirements on high power coupler define its installation in the cavity central region. Few options of cavity tune were investigated, the capacitive tuner installed opposite to the coupler port have been accepted. The cavity structural analyses have been conducted and cavity stiffening has been worked out.

**E. N. Zaplatin** (FZJ) P. Bosland, P. Bredy, N. Grouas, P. Hardy, A. Mosnier, F. Orsini, J. Plouin (CEA)

### Development of Surface Analysis System for Superconducting RF Cavity

An XHV surface analysis system with capability of sample coupon transfer in UHV from surface treatment systems of niobium cavities was developed. The analysis system

is equipped with XPS/AES with ion etching capability and SIMS. Sample coupons up to six just after some surface treatment are put into a small UHV suitcase with motion drives and an ion pump and so on, which allows us to transfer the coupons to the analysis system keeping UHV. In this paper, the system performance is described in the detail.

**S. Kato**, H. Hayano, M. Nishiwaki, T. Saeki (KEK) T. Noguchi (KAKEN Inc.)

### Transient Analysis of Dynamic Lorentz Force Deformation and Detuning

Y. Morozumi (KEK)

The main linacs of the International Linear Collider are supposed to consist of tens of thousands of superconducting accelerator structures. The structures are made of a few mm thick niobium shells and are subject to a small deformation by Lorentz forces but to a subsequent significant frequency detuning because of their large Q factors of typically  $10^{10}$ . Transient behaviors of the structure deformation and detuning will be presented.

### Surface Study Using Niobium Sample Coupons for Super Conducting RF Cavity

M. Nishiwaki, H. Hayano, S. Kato, T. Saeki, M. Sawabe. (KEK)  
P. V. Tyagi (GUAS/AS)

In order to achieve higher and more stable performance of super conducting radio-frequency (SRF) cavities, extensive effort in development and application has being done for surface treatment and conditioning methods such as mechanical grinding, buffered chemical polishing (BCP), electro-polishing (EP), ultrasonic ultra pure water (UPW) rinse, alcohol rinse, degreaser rinse, hydrogen peroxide rinse, high pressure water rinse (HPR), baking and so on. Those methods have been evaluated with vertical tests showing lots of remarkable results in cavity performance. However it cannot be well understood yet how surface treatment or conditioning contributed to the results and which step of process in the treatment or conditioning affected the results. In this article, we describe our try to understand those questions focusing on the surface analyses with SEM (scanning electron microscope) and XPS (x-ray photoelectron spectroscopy) for a series of niobium sample coupons treated with different methods and processes to upgrade the yield of SRF cavity treatments at KEK.

### Development of 2-Cell SC Cavity System for ERL Injector Linac at KEK

S. Noguchi, E. Kako, M. Satoh, T. Shishido, K. Watanabe, Y. Yamamoto (KEK)

A cryomodule including three 2-cell sc cavities was designed for the ERL injector Linac, which is operated at the beam energy of 10 MeV and the beam current of 100 mA. A prototype 2-cell cavity with two input coupler ports and four HOM couplers was fabricated. The double input couplers is to reduce the power per coupler and to keep a symmetric filed configuration around the coupler port. Required rf power in the input couplers is about 200 kW in the cw operation. First vertical test of the 2-cell cavity will be carried out in March.

### R&D for the Sponge Cleaning of Superconducting RF Cavity

T. Saeki, Y. Funahashi, H. Hayano, S. Kato, M. Nishiwaki, M. Sawabe., K. Ueno, K. Watanabe (KEK)

The Electro-polishing process is the best candidate of final surface treatment for the production of ILC cavities. Nevertheless, the broad distribution of the gradient caused by field emitters in cavities is still a serious problem for the EP process. Ethanol- and degreaser-rinse processes after the EP process were found to be effective to decrease the field emitter in recent studies, however, these are not perfect yet. We tried to test the sponge cleaning as the post EP process to remove the field emitter



inside the cavity. This article describes the results of series tests with a proto-type sponge-cleaning tool for single-cell cavity at KEK.

### Recent Results of the Cavity Inspection for the Superconducting Cavities at KEK-STF

The inspections of the superconducting RF cavities seem essential in achieving high accelerating gradient. The Kyoto camera system is a good tool to survey a defect location

**K. Watanabe**, H. Hayano, E. Kako, S. Noguchi, T. Shishido, Y. Yamamoto (KEK) Y. Iwashita (Kyoto ICR)

and to be analysis a defect shape in the inner surface of the superconducting rf cavities. The cavity inspections of the AES, ACCEL, ZANON and STF Baseline cavities were inspected to study relations between a defect shape and a heating gradient of the superconducting rf cavities. The STF Baseline #5 and #6 cavities with each surface treatment (as received, after Pre-EP, after EP-1, and after vertical test with EP-2) were inspected to trace a changing spots shape. The full inspection of the EBW seam, the HAZ (heat affected zone) and hot spots region were carried out before EP-2 process and a vertical test then the shape analysis of a discovered spots was done. The vertical tests of these cavities with T-map of fixed 9-cell type were measured at STF from September 2008. The inspection and shape analysis of these cavities were made after vertical tests for based on T-map data. The result of vertical tests and changing a shape of a discovered spots with EP-2 process will be presented.

### Recent Results of the Vertical Test for 1.3 GHz Superconducting 9-Cell Cavities at KEK-STF

A new vertical test facility for L-band multi-cell cavities has been completed in support of development efforts of ILC (International Linear Collider) and ERL (Energy Recovery Linac) projects at STF (Superconducting rf

**Y. Yamamoto**, H. Hayano, E. Kako, S. Noguchi, M. Satoh, T. Shishido, K. Umemori, K. Watanabe (KEK) H. Sakai (ISSP/SRL) T. X. Zhao (TIPC)

Test Facility) of KEK. The facility possesses a clean booth for pre-tuning the cavities, four cavity stands to prepare the cavities prior to vertical testing, a half-underground pit which accommodates up to two vertical cryostats which can be pumped and operated separately under a movable iron shield. Vertical testing of the cavities, with a 400 W high-power amplifier and with a temperature-mapping (T-mapping) and additional monitoring systems, is supervised from a control room which overlooks the entire facility. This paper describes the specific details of the facility and results from its initial pilot operation that was conducted in Summer-Fall of 2008.

### Observation and Numerical Calculation of Lorentz-Detuning for the Cryo-Module Test of STF Baseline Cavities at KEK-STF

A pulsed RF operation of four units of 9-cell L-band (1.3 GHz) cavities in a horizontal cryostat (cryo-module) was conducted in 2008 as part of R&D efforts at STF at KEK for ILC. A series of compensation experiments

**Y. Yamamoto**, H. Hayano, E. Kako, T. Matsumoto, S. Michizono, T. Miura, S. Noguchi, M. Satoh, T. Shishido, K. Watanabe (KEK) T. X. Zhao (TIPC)

were conducted for Lorentz-detuning effects, which are critically important for pulsed RF operation of high-gradient linacs based on superconducting cavity technologies. The experiments were done at a repetition rate of 5 Hz with RF pulses of a width of 1.5 msec, and the typical accelerating gradient within the cavities was 20 -- 32 MV/m. Two types of compensation techniques have been tested. In a "feed-forward" method, piezo actuators on

individual cavity tuners are activated to mechanically control the tuning of the cavity in synchronization with the RF pulses. In a “feed-back” method, the low-level RF system is driven so as to maintain the average of “I” and “Q” components of the cavities as constant. This paper reports the experimental results using the various parameters of the piezo control to compensate the effect of Lorentz-detuning. These results are consistent with the numerical calculation postulating that two mechanical modes mainly contribute to the effect.

### A New Cavity Diagnostic System for the Vertical Test of 1.3 GHz Superconducting 9-Cell Cavities at KEK-STF

Y. Yamamoto, H. Hayano, E. Kako, S. Noguchi, M. Satoh, T. Shishido, K. Umemori, K. Watanabe (KEK) H. Sakai (ISSP/SRL) T. X. Zhao (TIPC)

A new cavity diagnostic system has been introduced for vertical testing of nine-cell L-band superconducting cavities at KEK-STF. The present system is based on approximately 300 carbon resistors for temperature-

mapping (T-mapping), and approximately 40 PIN photo diodes for detecting emission of X-rays. The system can accommodate up to total 600 sensors in needed in the future. While most of the sensors are attached to the cavity exterior in a pre-determined regular pattern, some sensors can be strategically placed at non-regular positions so as to watch the areas which are considered “suspicious” as per the surface inspection done prior to vertical testing. Data from the sensors can be collected every 100 msec. The data can be graphically displayed online and are stored for offline analysis. This paper describes the details of this system, together with results from its initial pilot operation which was done with a nine-cell cavity on loan from FNAL (AES#001). Effectiveness of the combined use of T-mapping and PIN photo diodes in operation of the pi-mode and other pass-band modes in conjunction with surface inspection is discussed.

### Improvements to RF Cavity Input Couplers at the Advanced Photon Source

D. Horan, D. J. Bromberek, L. H. Morrison, G. J. Waldschmidt (ANL)

Work is underway to improve the reliability and power handling capability of input couplers used in the Advanced Photon Source single-cell and five-cell cavities. Coupler

performance during conditioning in a test cavity suggests that ceramic material defects and field enhancement caused by a mechanical gap in the coupler design may be responsible for past coupler failures at high power. Simulation results and high-power test data will be discussed.

### 352-MHz Solid State RF Power System Development at the Advanced Photon Source

D. Horan, B. Brajuskovic, J. T. Collins, L. H. Morrison, G. J. Waldschmidt (ANL)

An investigation into development of a 200-kW CW solid state rf power system design to replace the existing klystron-based 352-MHz rf systems at the Advanced Photon

Source has been started. The baseline 352-MHz solid state system design will consist of multiple 1-kW CW modules combined to produce a total output capability of 200-kW CW, sufficient to drive one single-cell storage ring cavity. A description of the 1-kW CW module building block of the solid state power system will be presented, along with results from hardware evaluation tests at the 1-kW CW level.

### A Status Report on the Advanced Photon Source 2-MW DC Resistive Load

The redesign, construction, and high-power testing of a 95-kV DC, 2MW water-cooled resistive load has been completed. This load was built and installed to test and troubleshoot the Advanced Photon Source (APS) 352-MHz high-voltage klystron power supplies. The original resistive load<sup>\*</sup>,<sup>\*\*</sup> was modified to enhance and improve the load performance. In this paper, we describe the redesign of the DC load, report on the recent test results, and discuss its performance improvements.

G. Trento, D. Horan, E. Swetin, G. J. Waldschmidt (ANL)

<sup>\*</sup>D. Horan et al., "A 2-Megawatt Load for Testing High Voltage DC Power Supplies".

<sup>\*\*</sup> D. Horan et al., "Performance of a 2-Megawatt High Voltage test Load".

### Design, Construction, System Integration, and Test Results of the 1 MW CW RF System for the E-Gun Cavity in the Energy Recovery Linac at Brookhaven National Laboratory

Brookhaven's ERL (Energy Recovery LINAC) requires a 1 MW CW RF system for the superconducting electron gun cavity. The system consists primarily of klystron tube, transmitter, and High-Voltage Power Supply (HVPS). The 703.75 MHz klystron made by CPI, Inc. provides RF power of 1 MW CW with efficiency of 65%. It has a single output window, diode-type electron gun, and collector capable of dissipating the entire beam power. It was fully factory tested including 24-hour heat run at 1.1 MW CW. The solid state HVPS designed by Continental Electronics provides up to 100 kV at low ripple and 2.1 MW CW with over 95% efficiency. With minimal stored energy and a fast shut down mode no crowbar circuit is needed. Continental's transmitter includes PLC based user interface and monitoring, RF pre-amplifier, magnet and Vac-Ion pump supplies, cooling water instrumentation, and integral safety interlock system. BNL installed the klystron, HVPS, and transmitter along with other items, such as circulator, water load, and waveguide components. The collaboration of BNL, CPI, and Continental in the design, installation, and testing was essential to the successful operation of the 1 MW system.

A. Zaltsman, R. F. Lambiase (BNL) D. L. Dickey, J. Sainz, P. F. Utay (Continental Electronics Corp.) E. L. Eisen, S. Lenci (CPI)

### Modular High Power Solid State RF Amplifiers for Particle Accelerators

The modular architecture of high power solid state rf amplifiers for the frequency range of 72 to 3000MHz is described. The characteristic features of the modular components are presented, focusing on the multi transistor amplifier modules delivering a power in the 0.5 to 1.5 kW range, the transmission line combiner system combining up to 150 amplifier modules, the monitoring of the rf power flow in the system and other relevant performance parameters, as well as the heat exchanger concept and the digital amplifier control system.

H. Piel, B. A. Aminov, A. Borisov, M. Getta, S. Kolesov, N. Pupeter (CRE)

### Commissioning of the Modulator Test Facility at DESY

H. Leich, U. Gensch, M. Grimberg, L. Jachmann, W. Koehler, M. Penno, R. W. Wenndorff (DESY Zeuthen) S. Choroba, H.-J. Eckoldt, T. Grevsmuehl (DESY)

The European XFEL, an X-ray free electron laser, is planned as an European project with a strong connection to the DESY research center in Hamburg. The LINAC of the XFEL incorporates 27 RF stations, which supply the RF power required by the superconducting cavities. In order to generate the RF power (1.3 GHz, 10MW pulses) HV pulse modulators are required. Each modulator has to supply 12kV pulses at 1.6kA for 1.5ms pulse duration and at 10Hz nominal repetition rate. The repetition rate can be increased to 30Hz at shorter pulse duration. Although extensive experience exists from the test facilities FLASH and PITZ (DESY Hamburg and Zeuthen sites) a dedicated modulator test stand has been setup to test and investigate additional new modulator prototypes developed by different companies. The results of these tests and the experience gained with the RF-stations at PITZ and FLASH will be an important criterium for the decision on the final layout and choice of vendor. An overview of the Modulator Test Facility at DESY will be presented. The first of two prototypes was delivered in July 2008 and started its operation in October. First test results of this prototype will be presented.

### Modular Multi-Purpose Amplifier

I. Roth, M. P.J. Gaudreau, M. K. Kempkes, J. Kinross-Wright (Diversified Technologies, Inc.)

Constructing and supporting a wide range of RF amplifiers for research accelerators at is costly at present. This is because amplifiers to date have been designed for a single application, and have little commonality in their design and control interfaces. Diversified Technologies, Inc. (DTI) is developing a modular RF amplifier design for a wide range of amplifier requirements. Amplifiers built on this model have common design, controls, and spares, independent of frequency or power. The amplifier design combines a solid-state RF driver, power conditioning, and controls with a high-power vacuum electronic device, giving high performance at a low cost. In this paper, DTI will describe results of the first implementation of the amplifier, which delivers 20 kW CW at 704 MHz.

### Multi-MW K-Band 7th Harmonic Multiplier for High-Gradient Accelerator R&D

N. Solyak, V. P. Yakovlev (Fermilab) A. Didenko, J. L. Hirshfield (Omega-P, Inc.)

A preliminary design is presented for a two-cavity 7th harmonic multiplier, intended as a high-power RF source for use in experiments aimed at developing high-gradient structures for a future collider. The harmonic multiplier is to produce power in K-band using as an RF driver an XK-5 S-band klystron (2.856 GHz). The device is to be built with a TE111 rotating mode input cavity and interchangeable output cavities, a principal example of which is a TE711 mode cavity running at 19.992 GHz. Design of the harmonic multiplier is described that uses a 250 kV, 20 A injected laminar electron beam. With 10 MW of S-band drive power, 4.7 MW of 20-GHz output power is predicted. Details are described of the gun beam optics, beam dynamics in the RF system, and of the magnetic circuit. The theory of an azimuthally distributed coupler for the output cavity is presented, as well as the conceptual design of the entire RF circuit.

### A High Power Dual Resonant Ring System for High Gradient Testing of 11.424 GHz Linear Accelerator Structures

The salient features and design parameters of a dual resonant ring system configured for evaluating the high gradient performance of 11.424 GHz TW linear accelerator structures are presented; and the inherent rapid protection mechanism that automatically curtails energy deposition during breakdown of the structure, and minimizes RF source reflections, is discussed. The diagnostic characteristics of the RF bridge load monitors and their unique capability of detecting the power imbalance caused by a feedback loop phase change of less than 2 parts in 10000, representing a 2 to 3 degree phase change of the linac structure, is described. The transient and steady-state power apportionment within the ring system is analyzed; and, in considering initial high power tests using an 18-cavity CLIC/KEK/SLAC structure, the results indicate that the demonstration of a 120 MV/m average accelerating gradient will require a 32 MW power source.

J. Haimson, B. A. Ishii, B. L. Mecklenburg, G. A. Stowell (HRC)

The super-conducting RF test facility (STF) at KEK has been functional since 2005, and the STF phase-I, which involves the testing of a cryomodule with four superconducting cavities, was performed at the end of 2008. In this test, intense study of the power distribution system for the possible linear collider scheme was performed. Linear power distribution and tree-like distribution were compared and also the effects of eliminating circulator are studied. Current status of RF source of KEK STF are reported.

### Status of RF Sources in Super-Conducting RF Test Facility (STF) at KEK

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S. Fukuda, M. Akemoto, H. Hayano, H. Honma, H. Katagiri, S. Kazakov, S. Matsumoto, T. Matsumoto, H. Matsushita, S. Michizono, T. Miura, H. Nakajima, K. Nakao, T. Shidara, T. Takenaka, Y. Yano, M. Yoshida (KEK)

### Renewal of a Klystron Power Supply for the Photon Factory Storage Ring at KEK

Four klystron power supplies that can provide a typical voltage of 40kV (current 8A) are used for the PF storage ring at High Energy Accelerator Research Organization (KEK). The original power supplies were fabricated during 1979-1987. Although the power supplies have been operated well, we anticipate some difficulty in maintaining them in future. Then, we planned to renew them by stages. As the first step, we renewed one of the power supplies in 2003. The renewed power supply have been operated well without any trouble. As the second step, we updated another power supply in the summer of 2008. The renewed power supply is equipped with a solid-state high-voltage (HV) switch that is made of insulated gate bipolar transistors (IGBT) for klystron protection. The renewed power supply have been operated well from September, 2008. We report the performance of the new power supply.

T. Takahashi, M. Izawa, S. Sakanaka, K. Umemori (KEK)

Four klystron power supplies that can provide a typical voltage of 40kV (current 8A) are used for the PF storage ring at High Energy Accelerator Research Organization (KEK). The original power supplies were fabricated during 1979-1987. Although the power supplies have been operated well, we anticipate some difficulty in maintaining them in future. Then, we planned to renew them by stages. As the first step, we renewed one of the power supplies in 2003. The renewed power supply have been operated well without any trouble. As the second step, we updated another power supply in the summer of 2008. The renewed power supply is equipped with a solid-state high-voltage (HV) switch that is made of insulated gate bipolar transistors (IGBT) for klystron protection. The renewed power supply have been operated well from September, 2008. We report the performance of the new power supply.

### Integrating a Traveling Wave Tube into an AECR Ion Source

M. Kireeff Covo, J. Y. Benitez, D. Leitner, C. M. Lyneis, A. Ratti (LBNL) J. L. Vujic (UCB)

A RF system of 500W - 10.75 to 12.75 GHz was designed and integrated into the Advanced Electron Cyclotron Resonance (AECR) ion source of the 88-inch Cyclotron at Lawrence Berkeley National Laboratory. The AECR produces ion beams for the Cyclotron giving large flexibility of ion species and charge states. The broadband frequency of a Traveling Wave Tube (TWT) allows modifying the shape of the annular ellipsoidal-shaped volume that couples and heats the plasma. Details of the RF source and Automatic Gain Control Unit designs for the TWT and integration with the AECR source are provided.

### Dissolved Gas-in-Oil Analysis to Assess the Health of the LANSCE High Voltage Systems

K. A. Young, G. O. Bolme, J. T.M. Lyles, D. Rees, A. M. Velasquez (LANL)

The LANSCE linac RF system consists of four 201.25 MHz RF stations that supply RF power to the drift tube linac (DTL), and forty-four 805 MHz RF stations, that supply RF power to the coupled-cavity linac (CCL). There are four large high voltage power supplies for the DTL RF systems. Seven high voltage power supplies provide the power for the 805 MHz klystrons. All power supplies consist of a transformer/rectifier, Inductrol Voltage Regulator (IVR) and a capacitor bank with crowbar protection. After 39 years of operation, some components are approaching the end of life and will be refurbished through the LANSCE-R project to ensure the reliability of the machine until 2025. An analysis of the oil in the high voltage power supply units was done to assess their health to determine if units need to be replaced or repaired as part of LANSCE-R. Since 1998 the oil in each unit has been sampled and tested annually, and reprocessed when required. Gas-in-oil data for these units from 1998 to present was analyzed. The levels of each gas component, trends in the data and the significance of the each dissolved gas are discussed. The health of the units is assessed.

### Solid State High Power RF System for Superconducting Cavities

A. A. Zavadtsev, S. V. Kutsaev, D. A. Zavadtsev (Nano) L. V. Kravchuk (RAS/INR)

Solid State High Power RF System is proposed for XFEL and ILC. It includes individual RF power supply for each SC cavity and common control system. Each RF power supply includes Solid State Generator, circulator and Q-tuner. Triggering, synchronization, output power and phase of each Solid State Generator are controlled from the common control system through fiber-optic lines. Main parameters of Solid State Generator are: frequency 1.3 GHz, peak power 128 kW, pulse length 1.4 msec, repetition rate 10 Hz, average power 1.8 kW, CW power 2.5 kW. Advantages of Solid State High Power RF System are: simple triggering, synchronization, output power and phase adjustment for all cavities separately, operation both in pulse and in CW modes, unlimited lifetime, no high voltage, no oil-tank, compactness.

### Status of the SNS RF Systems

The SNS has been operational and delivering beam to the target for 3 years. Over this time period we have increased the beam power delivered to the target to 700 kW, 50% of the design goal. The RF Group has acquired a fair amount of experience in the operation and maintenance of our RF systems during the power ramp up process. This paper reviews the design and layout of the various SNS RF systems, documents the present state and performance of the systems and covers, in a broad sense, issues raised during operation and improvements we have undertaken as well as future RF system requirements.

**T. W. Hardek**, M. T. Crofford, Y. W. Kang, M. P. McCarthy, M. F. Piller, A. V. Vassioutchenko (ORNL) M. E. Middendorf (ORNL RAD)

### Status and Upgrade Plan of High Power RF System for the PLS Storage Ring

The RF system for the Pohang Light Source (PLS) storage ring is operating at total maximum RF power of 300kW with four 75kW klystron amplifiers and four PF-type normal conductivity(NC) RF cavities for 190mA at 2.5GeV. The PLS will be upgraded from 2.5GeV/200mA to 3.0GeV/400mA in the near future. Therefore the RF system should be greatly upgraded to supply total 627kW beam power. We are investigated the some upgrade ways with adding NC cavities or new super conductivity(SC) RF cavities. According to the cavity type, the high power RF system will be adjusted the total RF power, and source type and quantity such as klystron or IOT. This paper describes the present operation status and several optional ways of high power RF system for the upgrade project of PLS storage ring

**M.-H. Chun**, M. H. Jung, I. S. Park, Y. U. Sohn, I. H. Yu (PAL)

### Low Beam Voltage, 10 MW, L-Band Cluster Klystron

Conceptual design of a multi-beam klystron (MBK) for ILC and Project X application is presented. The chief distinction between the MBK design and existing 10-MW MBK's is the low operating voltage of 60 kV. There are at least four compelling reasons that justify development of a low-voltage MBK, namely (i) no pulse transformer would be required; (ii) no oil tank would be required for the tube socket; (iii) modulator would be a compact 60-kV IGBT switching circuit. The proposed klystron consists of four clusters that contain six beams each. The tube has common input and output cavities for all 24 beams, and individual gain cavities for each cluster. A closely related optional configuration for a 10 MW tube would involve a design having four totally independent cavity clusters and four 2.5 MW output ports, all within a common magnetic circuit. This option has appeal because the output waveguides would not require a controlled atmosphere and because it would be easier to achieve phase and amplitude stability as required in individual SC cavities.

**V. E. Teryaev** (BINP SB RAS) J. L. Hirshfield (Yale University, Physics Department) S. Kazakov (KEK) V. P. Yakovlev (Fermilab)

### High Power RF Testing of the EMMA RF System

EMMA is a prototype non-scaling FFAG that requires a demanding RF system. Production for the final RF system is due for completion in Spring 09 and testing of the combined hardware has taken place. This paper describes the high power verification tests of the IOT transmitter, waveguide distribution, RF cavity and LLRF control system.

**C. D. Beard** (STFC/DL/ASTeC)

### MICE RF System

A. J. Moss, J. F. Orrett (STFC/DL/ASTeC)

The Muon Ionisation Cooling Experiment (MICE) at the Rutherford Appleton Laboratory uses normal conducting copper cavities to re-accelerate a muon beam after it has been retarded by liquid hydrogen absorbers. Each cavity operates at 200MHz and requires 1MW of RF power in a 1ms pulse at a repetition rate of 1Hz. In order to provide this power, a Thales TH116 triode, driven by a Burle 4616 tetrode is used, with each amplifier chain providing ~2.5MW. This power is then split between 2 cavities. The complete MICE RF system is described, including details of the low level RF, the power amplifiers and the coaxial power distribution system. Testing of the amplifier chain, power supplies and low level RF is described.

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### Operational Experience of the Super-Conducting RF System on ALICE at Daresbury Laboratory

A. E. Wheelhouse, S. R. Buckley, P. A. McIntosh, A. J. Moss, J. F. Orrett (STFC/DL/ASTeC)

ALICE (Accelerators and Lasers in Combined Experiments) incorporates two super-conducting radio frequency (SCRf) cryomodules each with two identical 9-cell cavities that are powered by 5 inductive output tubes (IOTs) from 3 different commercial suppliers. During the commissioning of the ALICE rf system numerous problems were encountered with the operation of the high voltage power supply and the auxiliary power supplies, which had to be resolved before the beam commissioning of the accelerator could commence. The issues encountered and measures taken to improve the operation of the rf system are described within this paper.

ALICE (Accelerators and Lasers in Combined Experiments) incorporates two super-conducting radio frequency (SCRf) cryomodules each with two identical 9-cell cavities that are powered by 5 inductive output tubes (IOTs) from 3 different commercial suppliers. During the commissioning of the ALICE rf system numerous problems were encountered with the operation of the high voltage power supply and the auxiliary power supplies, which had to be resolved before the beam commissioning of the accelerator could commence. The issues encountered and measures taken to improve the operation of the rf system are described within this paper.

### Design Progress of the RF System for EMMA at Daresbury Laboratory

A. E. Wheelhouse, C. D. Beard, P. A. McIntosh, A. J. Moss, J. F. Orrett (STFC/DL/ASTeC)

EMMA (Electron Model for Many Applications) is a non-scaling Fixed Field Accelerating Gradient (NS-FFAG) accelerator presently in the process of being built at Daresbury Laboratory as a proof of principle demonstrator for proton/carbon therapy application. Its aim is to take an injected beam from ALICE (Accelerators and Lasers in Combined Experiments) at 10MeV and accelerate it to 20MeV, so that the characteristics of NS-FFAGs can be studied. The beam is to be accelerated by 19 identical 1.3GHz RF cavities, which each need to provide the same accelerating voltage to the beam. The initial design stage of the RF system design has been completed, utilising three commercial suppliers of the major RF sub-system components.

EMMA (Electron Model for Many Applications) is a non-scaling Fixed Field Accelerating Gradient (NS-FFAG) accelerator presently in the process of being built at Daresbury Laboratory as a proof of principle demonstrator for proton/carbon therapy application. Its aim is to take an injected beam from ALICE (Accelerators and Lasers in Combined Experiments) at 10MeV and accelerate it to 20MeV, so that the characteristics of NS-FFAGs can be studied. The beam is to be accelerated by 19 identical 1.3GHz RF cavities, which each need to provide the same accelerating voltage to the beam. The initial design stage of the RF system design has been completed, utilising three commercial suppliers of the major RF sub-system components.

### The Elettra Radiofrequency System Status and Developments

C. Pasotti, M. Boccia, L. Bortolossi, A. Fabris, M. Ottobretti, M. Rinaldi (ELETTRA)

The full energy injection is now the standard procedure for the Elettra synchrotron radiation light source. The four RF storage ring plants have been benefited by this procedure in terms of reliability and stability of operation. The injector booster RF plant is running well. A new High Order Mode (HOM) diagnostic board has been implemented using the radiofrequency (RF) cavity's signal to

The full energy injection is now the standard procedure for the Elettra synchrotron radiation light source. The four RF storage ring plants have been benefited by this procedure in terms of reliability and stability of operation. The injector booster RF plant is running well. A new High Order Mode (HOM) diagnostic board has been implemented using the radiofrequency (RF) cavity's signal to



improve the HOM's detection. The analysis and the performances of the new Inductive Output Tube (IOT)based RF power transmitter are presented.

### Phase-Modulation SLED Mode on BTW Sections at Elettra

The former linac sections used in the injector system of the Elettra Laboratory storage ring will be upgraded for use on the FERMI@elettra project, a free-electron laser user facility operating down to 3 nm. These seven accelerating sections are  $3\pi/4$  mode backward-travelling wave (BTW) constant-impedance structures, powered by 45 MW TH2132A klystrons couple to what was called a PEN -- power enhancement network, or more commonly referred to as a SLED system. Due to breakdown problems inside the sections, that was the result of high peak fields generated during conventional SLED operation, the sections experienced difficulties in reaching the design gradients. To lower the peak field and make the compressed pulse "flatter", phase-modulation of the SLED drive power option is investigated. This paper presents the results of this investigations and includes a detailed mathematical analysis.

D. Wang, G. D'Auria, P. Delgiusto, A. Fabris, M. M. Milloch, A. Rohlev, C. Serpico (ELETTRA)

### High Power rf Test on the C-Band rf Components of 8 GeV Accelerator for XFEL/SPring-8

We report the high power rf test results of C-band accelerator system for X-ray free electron laser (XFEL) in SPring-8. The C-band accelerator system is composed of two C-band accelerator of Choke-mode-type HOM damping structure, the rf pulse compressor, the 50 MW klystron, oil-filled modulator and solid state switching high voltage charger. It is designed to operate at rather high accelerating gradient as high as 35 MV/m, therefore it is crucial to evaluate high gradient performance and reject some component with defect or poor performance. In the 8 GeV main accelerator, 64 C-band systems will be used in total, whose components are under mass production at several industries in Japan. Some of these systems have been installed and tested in high-power test bunker since July 2008. We report on statistics of the high voltage breakdown, and related measurement; such as power calibration of klystron 50 MW, gain measurement on rf pulse compressor.

T. Sakurai, T. Inagaki, C. Kondo, T. Shintake, K. Shirasawa (RIKEN/SPring-8) S. Suzuki (JASRI/SPring-8)

### A New Prototype Modulator for the European XFEL Project in Pulse Step Modulator Technology

The European XFEL project at DESY in Germany requires 27 RF stations capable of 10 MW RF power each. Each RF station needs one high voltage modulator that generates pulses up to 12 kV and 2 kA with a duration of 1.7 ms and a nominal repetition rate of 10 Hz. DESY decided to investigate new modulator prototypes and Thomson has been awarded to design and build one of these prototype modulators. The Thomson modulator is based on the pulse step modulator (PSM) principle. This technology allows the regulation of the pulse voltage during the pulses and by this achieving a good flatness. In addition to the common PSM technology this modulator design includes additional features. The first one is a constant power regulation system in order to prevent a 10 Hz loading of the mains. The second one

J. Alex, M. Bader, M. Iten, D. Reimann, J. Troxler (Thomson Broadcast & Multimedia AG) S. Choroba, H.-J. Eckoldt, T. Grevsmuehl (DESY) U. Gensch, M. Grimberg, L. Jachmann, W. Koehler, H. Leich, M. Penno, R. W. Wenndorff (DESY Zeuthen)

is the extension of a part of the system to allow 2-quadrant mode in order to demagnetise the core of the pulse transformer between the pulses. The modulator has been delivered to DESY in July 2008 and is under testing at the modulator test facility in Zeuthen. The paper will give a detailed overview on the system and shows the results of the factory testing and of the testing at DESY.

## RF System for SESAME

A. Kaftoosian, D. S. Foudeh, A. Nadji (SESAME)

The SESAME (Synchrotron light source for Experimental Science and Applications in the Middle-East) accelerator consists of a 22MeV Microtron, an 800MeV booster synchrotron and a 2.5GeV storage ring. Each accelerator has its own RF system. The Microtron RF frequency is 3GHz generated by a 2MW pulsed Magnetron while the booster and storage ring have a common 500MHz CW RF source. The Booster RF system consists of a DORIS cavity fed by a 2kW CW solid-state RF amplifier but the storage ring (SR) RF system has been designed based on four 500 MHz plants, each comprising a normal conducting (NC) single-cell cavity, powered with 140 kW (CW) by two combined 80kW IOTs to have maximum possible RF power in the cavity via a WR1800 waveguide line. In the initial phase, it has been decided to start with two ELETTRA type cavities and in final phase, four cavities will be accommodated in one straight section in the storage ring to have nominal energy and current in the machine. This paper presents status of installed Microtron RF system and modified booster RF system from BESSY I, as well as designed SESAME storage ring high power RF system and low level electronics.

## TU5RF — Morning Poster LSAFEL A05, A06, A16

### A Study of Lattice Structure and Insertion Devices at the Positron Ring of the TAC Project

The Turkish Accelerator Complex (TAC) is a project for accelerator based fundamental and applied researches supported by Turkish State Planning Organization (DPT). The proposed complex is consisted of 1 GeV electron linac and 3.56 GeV positron ring for a charm factory and a few GeV proton linac. Apart from the particle factory, it is also planned to produce synchrotron radiation from positron ring. In this study the lattice structure design of the positron storage ring is made to produce the third generation synchrotron light. The parameters of complementary undulators and wigglers are determined. It is shown that the insertion devices with the proposed parameter sets produce maximal spectral brightness to cover 10 eV - 100 keV photon energy range.

**K. Zengin**, A. K. Ciftci, R. Ciftci (Ankara University, Faculty of Sciences)

TU5RFP001

### Alternate Hybrid Mode Bunch Patterns for the Advanced Photon Source

The Advanced Photon Source is filled for five weeks per year in a special bunch (hybrid) pattern of one large 16-mA (74-nC) bunch in a gap of 3 microseconds, and the remaining 86 mA in 8 trains of 7 consecutive bunches, forming a 500-microsecond-long bunch train. We are developing variations of this bunch pattern, which might have 3 large bunches equally spaced in the 3-microsecond gap in a 4-mA, 16-mA, and 8-mA distribution. The 500-microsecond-long bunch train could be changed to 2 or 3 bunch trains of 7 bunches. We report on the difficulties in bringing these into future operations: impedance-driven injection losses, sextupoles in injection section, lifetime and topup injection limit, and beam diagnostics responses to the patterns.

**L. Emery**, K. C. Harkay, V. Sajaev (ANL)

TU5RFP002

### Superconducting Multi-Cell Deflecting Cavity for Short-Pulse X-Ray Generation at the Advanced Photon Source

A superconducting multi-cell cavity for the production of short x-ray pulses at the Advanced Photon Source (APS) has been explored as an alternative to a single-cell cavity design in order to improve the packing factor and potentially reduce the number of high-power RF systems and low-level RF controls required. The cavity will operate at 2815 MHz in the APS storage ring and will require heavy damping of parasitic modes to maintain stable beam operation. Novel on-cell dampers, attached directly to the cavity body, have been utilized by taking advantage of the magnetic field null on the equatorial plane in order to enhance damping. Design issues and simulation results will be discussed.

**G. J. Waldschmidt**, L. H. Morrison, A. Nassiri (ANL) R. A. Rimmer, K. Tian, H. Wang (JLAB)

TU5RFP003

### Observation of Ion Induced Effects and their Impact on the Performance of the MLS Electron Storage Ring

J. Feikes, M. V. Hartrott, G. Wuestefeld (BESSY GmbH) A. Hoehl, R. Klein, R. Muller, G. Ulm (PTB)

The Metrology Light Source (MLS)\* is in user operation since April 2008 at operating energies ranging from 105 MeV up to 630 MeV and with multi bunch currents up

to 200 mA. At the injection energy of 105 MeV as soon as the beam current exceeds a few mA the beam is strongly blown up in all three spatial dimensions and strong oscillations at very different spectral frequencies can be observed. These effects are caused by the interaction of beam charge with ions present and their strength and characteristic time scales depend on beam energy, beam current, transversal orbit, transversal coupling, clearing voltage, beam shaking frequency and amplitude. As ion effects can strongly deteriorate the performance of the MLS we studied them systematically and report on these investigations.

\*G. Brandt et al., Nucl. Instr. Meth. B 258, 445 (2007)

### Low Alpha Operation of the MLS Electron Storage Ring

G. Wuestefeld, J. Feikes, M. V. Hartrott (BESSY GmbH) A. Hoehl, R. Klein, R. Muller, G. Ulm (PTB)

The Metrology Light Source (MLS)\* is in user operation since April 1st, 2008. It is the first storage ring designed and built for operation in the low  $\alpha$  mode, which relies on

the control of higher order terms of the momentum compaction factor  $\alpha$  with respect to the momentum deviation  $dp/p$ ,  $\alpha = a_0 + a_1 * dp/p + a_2 * (dp/p)^2$ . The  $a_0$  term is controlled by quadrupoles,  $a_1$  by 3 families of sextupoles for controlling the chromaticity in the transverse and longitudinal planes, the  $a_2$  term is controlled by an octupole family. The  $a_0$  value can be varied by more than a factor of -10-00. The low  $\alpha$  mode is also called 'isochronous' operation, it is used for short bunch operation, where intense signals of coherent sub-THz radiation are produced. We report on operation experience of this scheme.

\*R. Klein et al., 'Operation of the Metrology Light Source as a primary radiation source standard', PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS 11, 110701 (2008).

### Beam Transport and Diagnostics for the NSLS II Injection System

R. P. Filler, R. Alforque, R. Heese, R. Meier, J. Rose, T. V. Shaftan, O. Singh, N. Tsoupas (BNL)

The NSLS II is a state of the art 3 GeV synchrotron light source being developed at BNL. The injection system will consist of a 200 MeV linac and a 3 GeV booster synchro-

tron. The transport lines between the linac and booster (LtB) and the booster and storage ring (BtS) must satisfy a number of requirements. In addition to transporting the beam while maintaining the beam emittance, these lines must allow for commissioning, provide appropriate diagnostics, allow for the appropriate safety devices and in the case of the BtS line, provide for a stable beam for top off injection. Appropriate diagnostics are also necessary in the linac and booster to complement the measurements in the transfer lines. In this paper we discuss the design of the transfer lines for the NSLSII along with the incorporated diagnostics and safety systems. Necessary diagnostics in the linac and booster are also discussed.

### NSLS II Booster Acceptance Studies

The NSLS II is a state of the art 3 GeV synchrotron light source being developed at BNL. The injection system will consist of a

R. P. Fliller, W. Guo, R. Heese, Y. Li, T. V. Shaftan (BNL)

200 MeV linac and a 3GeV booster synchrotron. The injection system must supply 7.3nC every minute to satisfy the top off requirements. A large booster acceptance is necessary to have a high booster injection efficiency and alleviate the requirements on linac gun. We also anticipate transverse stacking of bunches in the booster to increase the amount of charge that can be delivered. We present studies of the anticipated booster stay clear including lattice errors and the ramifications for injection efficiency and transverse stacking.

### New Approaches in Lattice Design and Optimization with Insertion Devices

NSLS-II, the third generation light source which will be built at BNL is designed and optimized for 3 GeV energy, ultra small emittance and high intensity of 500 mA. It

W. Guo, J. Bengtsson, S. L. Kramer, S. Krinsky, Y. Li, B. Nash, T. V. Shaftan (BNL)

will provide very bright synchrotron radiation over a large spectral range from IR to hard X-rays. Damping wigglers (DWs) are deployed to reduce the emittance of 2 nm by factors of 2-4 times, as well as for intense radiation sources for users. The normal approach to add insertion devices (IDs) to a third generation light source is two fold: Minimizing the linear and nonlinear fields by careful design and fabrication and correcting the residual effects during installation and operation. NSLS-II design philosophy is emphasizing the radiation effect of the DWs, and including them as part of the magnetic lattice of the accelerator. The linear and nonlinear effects induced by the DWs are integrated into the lattice design and optimization. In this paper, we discuss the linear compensation schemes, the usage of chromatic sextupoles, and other design considerations that maintain good dynamic aperture in presence of the DWs. Our approaches could be applied to the other light sources with strong insertion devices.

### NSLS-II Pulsed Magnet Design and Tolerances

NSLS-II injection system contains 13 pulsed magnets and their power supplies for injection in and extraction from the booster and injection in the storage ring. Requirement of having injection process transparent for the NSLS-II users translates into challenging specifications for the pulsed magnet design. To keep the beam jitter within 10% of radiation source size, relative kicker mismatch must be kept on  $10^{-5}$  level and residual vertical field must be below few gauss in amplitude. In this paper we discuss specifications for the pulsed magnets, their preliminary design and parameters' tolerances.

R. Heese, R. P. Fliller, M. Rehak, T. V. Shaftan (BNL)

### Flexibility in the Design of the NSLS-II Lattice

The NSLS-II light source is a proposed 3 GeV storage ring, with the potential for ultra-low emittance\*. The lattice design uses

S. L. Kramer, W. Guo (BNL)

a 30 cell DBA structure with a periodicity of 15, for alternating long and short straight sections. All cells are tuned achromatic to maximize the emittance reduction achieved as damping wigglers are added to the ring. Recent optimization of the lattice consisted of increasing the number of possible hard X-ray beam ports using three pole

wigglers, reducing the number of magnets (quadrupoles and sextupoles) and shifting the magnets to allow easier extraction of the photon beams. The impact of the reduction of magnets on the lattice flexibility will be presented in terms of the tuning range possible for the lattice parameters: tune, emittance, and chromaticity, beta function matching to user insertion devices (IDs) and for compensating for ID induced distortions to these parameters. This flexibility is important for optimizing the lattice linear and nonlinear properties, the dynamic aperture, and its impact on beam lifetime, as well as matching the user source requirements and for value engineering of magnets and power supplies.

\*Work presented on behalf of the NSLS-II Design Team, CDR(2006), CD2(2007) and CD3(2008).

### Top-Off Safety Analysis for NSLS-II

Y. Li, W. R. Casey, R. Heese, H.-C. Hseuh, P. K. Job, S. Krinsky, B. Parker, T. V. Shaftan, S. Sharma (BNL)

studies for possible machine fault scenarios are required. We compare two available simulation methods, backward (H. Nishimura-LBL) and forward tracking (A. Terebilo-SLAC). We also discuss the tracking settings, fault scenarios, apertures and interlocks considered in our analysis.

Top-off injection will be adopted in NSLS-II. To ensure no injected beam can pass into experimental beamlines with open photon shutters during top-off injection, simulation

### Alternative Designs of the NSLS-II Injection Straight Section

T. V. Shaftan, R. P. Filler, R. Heese, R. Meier, M. Rehak, F. J. Willeke (BNL) E. Weihreter (BESSY GmbH)

currently fits a conventional injection set-up that consists of four kickers producing a closed bump together with a DC septum and a pulsed septum. In this paper we analyze alternative options based on: a) injection via a pulsed sextupole and b) injection with a Lambertson septum. We discuss dynamics of the injected and stored beams and, consequently, magnet specifications and tolerances. In conclusion we summarize advantages and drawbacks of each injection scheme.

The NSLS-II is a state of the art 3 GeV synchrotron light source that is being developed at BNL. The 9.3 meter long injection straight section of NSLS-II storage ring currently

### Dynamic Response and Filtering Effects of a Light Source Accelerator Ring Structure

N. Simos, M. Fallier (BNL)

at high brightness and extremely small photon beam sizes is paramount. Movement of the magnetic elements of the accelerator lattice, and in particular when uncorrelated, will induce jitter in the beam and degrade the machine performance. The accelerator lattice response is coupled with the ring structure which in turn interacts with the site and the ground vibration field that characterizes it. Therefore, understanding this dynamic coupling between the accelerator ring structure and the site and the "filtering" effect of the interaction on both the amplitude and the spectral characteristics of the ground vibration is central towards establishing the response of the lattice. In this study, the site-ring dynamic interaction is evaluated based on the NSLS II design and site conditions using a state-of-the-art 3-D wave propagation and scattering analysis model. The study is augmented with an extensive array of measurements at the selected site as well as field studies at similar operating light source facilities.

Vibration stability in third generation light sources such as the 3 GeV NSLS II under construction at BNL and which are aiming

### Numerical Treatment of Moving Loads Affecting the Stability of NSLS2 Light Source Accelerator

Cultural noise generated within or in the proximity of a light source facility aiming to achieve stability levels of just tens of

N. Simos, M. Fallier (BNL) H. Amick (Colin Gordon, Associates)

nanometers in the electron beam and extremely small photon beams in special experimental lines could be a limiting factor towards achieving the performance goals. While operating systems within the facility are more readily identifiable as sources of vibration and cause of instabilities and they tend to be of deterministic nature so appropriate action can be taken to minimize their impact, moving-type loads such as traffic in the general vicinity or within the bounds of the accelerator facility are more of a stochastic nature and require a different approach in assessing its impact on the synchrotron facility. In this study the effect of such loads which poses both stochastic elements and a complex spectrum on the stability performance goals of the NSLS II synchrotron and its vibration-sensitive experimental lines is addressed prior to the construction of the facility. This is achieved through the synergy of a comprehensive numerical model and an array of recorded field data.

### Model of NSLS II Lattice Response to Random, Stationary Vibrations

The extremely small photon beam dimensions of NSLS II impose challenging requirements on the e-beam orbital stability in the

N. Simos, F. J. Willeke (BNL)

6-D phase space. The electron beam orbit at the photon source locations must remain within a few hundred nanometer window for a wide frequency band. The beam orbit movement is coupled to the movement of the magnetic elements in the lattice which are itself coupled to the ring-building structure. While the vibration exciting the ring structure consists of deterministic and stochastic noise, it is the high frequency random, uncorrelated part that has the largest impact on the residual beam orbit movement as it is most difficult to control by fast orbit feedback. In this study, an analytical model is employed to quantify lattice displacement and beam orbit jitter for the expected conditions of NSLS II. The dynamic interaction of the ring supporting the lattice with the stationary ground vibration is addressed using a 3-D model of wave-structure interaction. Cross transfer functions linking ground vibration with the ring and magnetic lattice for various stochastic parameters are deduced leading to a multi-degree of freedom cross-spectral density of the lattice.

### Achieving Extreme Stability at NSLS II Beamlines

A major goal of the next generation synchrotron light sources, such as the currently under construction NSLS II, is to achieve photon

N. Simos, Y. Q. Cai, D. S. Coburn, M. Fallier, Q. Shen (BNL)

beam parameters that enable probing with extremely high sensitivity in both positional and energy spaces. Stability, however, at the probe location, is influenced by several dynamically coupled factors stemming from the global vibration environment, the path to the probe support structure and the dynamic response of the probe. In this study, the quantification of the complex relationship between the vibration environment anticipated to exist once the NSLS II accelerator is realized and the vibration-sensitive experimental lines is sought. Numerical models are employed allowing (a) for vibration characterization at the experiment locations, for both structurally independent and integrated with the experimental floor beamlines, and (b) for probe design optimization to achieve desired stabilization. Field studies focusing on the dynamic response and stabilization features of designs adopted to-date at other light source facilities and experiments are augmenting the analytical study to effectively influence and help optimize the NSLS2 beamline design.

## Coherent Synchrotron Radiation Production at the Canadian Light Source

L. O. Dallin, M. S. de Jong (CLS)

Coherent Synchrotron Radiation (CSR) is produced when short bunch lengths are set up in the Canadian Light Source storage ring. To achieve short bunches large negative dispersion is introduced into the straight regions of the lattice such that the momentum compaction can be made to approach zero. In this way CSR has been observed using a few single bunches with currents up to 10 mA per bunch at the nominal operating energy of 2.9 GeV. Attempts produce CSR with low bunch currents in many bunches were unsuccessful at 2.9 GeV. At 1.5 GeV, however, it is possible to achieve CSR with a total of 5 mA stored in over 70 bunches. CSR production is enhanced by operating at a horizontal tune where the chromaticity can be kept near zero. Tracking simulations in longitudinal phase space indicate enhanced stability at tunes lower than the nominal tune. The optimum tune does not depend on the fractional tune but rather there is a tune "window" at the center of which stable longitudinal motion can be maximized.

## Orbit Improvements at the Canadian Light Source

T. Summers, D. Chabot, L. O. Dallin (CLS)

Upgrades to the orbit control system at the Canadian Light Source (CLS) have resulted in increased beam stability and reproducibility. These upgrades include improving position information from the beam position monitors (BPMs) by modifying the data acquisition algorithm and switching to a real-time operating system. Beam motion has been reduced to an RMS deviation of less than 1 micron in both planes. Limiting the maximum corrector step has allowed the use of all singular values when inverting the BPM response matrix, resulting in much better orbit reproducibility. As well, improved lookup tables have been developed to compensate for the effects of changing undulator gaps and polarizations. Presently, work is underway to develop fast orbit correction with rates up to 100 Hz. Fast orbit correction will further reduce the residual perturbations caused by undulator activity and will allow fast ramping of superconducting wigglers.

## Design and Optimization of the BEPCII Synchrotron Radiation Mode

Q. Qin, L. M. Chen, D. Wang, J. Q. Wang, X. H. Wang, Y. Wei, X. M. Wen, J. Xing, G. Xu, C. H. Yu, C. Zhang, Y. Zhang (IHEP Beijing)

The upgraded project of the Beijing Electron-Positron Collider (BEPCII) can be operated not only for high energy physics experiments as a charm factory, but for synchrotron radiation users as a first generation light source. The design of the synchrotron radiation (SR) mode of the BEPCII storage ring keeps all the original beam lines of the BEPC. The lattice based on the layout of the collider can meet all the requirements of the SR users, and the emittance is minimized. Optimization of the SR mode focuses on reducing the effects from wigglers around the ring. Some results from the operations of the SR mode are also given.



### Status of the ALBA Light Source

ALBA is the first 3rd generation synchrotron light source to be build in Spain. The project is in the process of installation, with the LINAC already commissioned, and the Booster and Storage Ring in the installation phase, and the building already completed. The Booster synchrotron is expected to be finish and commission by the end of summer 2009, and the storage ring commissioning should take place in spring 2010. Most of the major components are already delivered and tested in-house, among those the vacuum system, the magnets, the RF cavities, etc. In this paper, the status of the project and of the most relevant components is reviewed.

**D. Einfeld** (ALBA)

TU5RFP020

### Exploiting Linac Flexibility to Produce a Superior X-Ray Beam

X-ray beam production from a linac beam is investigated, especially emphasizing the optical matching flexibility that is possible with an external beam but not with a storage ring. Compared to existing storage ring light sources, a high energy linac (with or without recirculation) can produce monochromatic hard x-ray beams having comparable flux density, and far higher brilliance, than are available with existing storage rings. Full coherence and the possibility of diffraction limited focusing are preserved by avoiding the need for x-ray focusing mirrors.

**R. M. Talman** (CLASSE)

TU5RFP021

### A Proposed New Light Source Facility for the UK

The New Light Source (NLS) project was launched in April 2008 by the UK Science and Technology Facilities Council (STFC) to consider the scientific case and develop a conceptual design for a possible next generation light source based on a combination of advanced conventional laser and free-electron laser sources. Following a series of workshops and a period of scientific consultation, the science case was approved in October 2008 and the go-ahead given to continue the project to the design stage. In November the decision was taken that the facility will be based on cw superconducting technology in order to provide the best match to the scientific objectives. In this paper we present the source requirements, both for baseline operation and with possible upgrades, and the current status of the design of the accelerator driver and free-electron laser sources to meet those requirements.

**R. P. Walker**, R. Bartolini, C. Christou, J. H. Han, J. Kay, I. P.S. Martin, G. Rehm (Diamond) D. Angal-Kalinin, M. A. Bowler, J. A. Clarke, D. J. Dunning, B. D. Fell, A. R. Goulden, S. P. Jamison, K. B. Marinov, P. A. McIntosh, J. W. McKenzie, B. L. Militsyn, B. D. Muratori, S. M. Pattalwar, M. W. Poole, R. J. Smith, S. L. Smith, N. Thompson, P. H. Williams (STFC/DL/ASTeC) N. Bliss, G. P. Diakun, M. D. Roper (STFC/DL) G. J. Hirst (STFC/RAL) J. P. Marangos (Imperial College of Science and Technology, Department of Physics) B. W.J. McNeil (USTRAT/SUPA) H. L. Owen (UMAN)

TU5RFP022

### Future Plans for DELTA

DELTA is a 1.5-GeV synchrotron radiation source at the TU Dortmund University (Germany) comprising a superconducting wiggler and a storage-ring FEL. Among other activities, it is planned to generate ultrashort and coherent VUV pulses

**S. Khan** (DELTA)

TU5RFP023

by seeding the FEL in an optical-clystron configuration with femtosecond laser pulses and by producing higher harmonics. In addition to enabling laser-pump/VUV-probe experiments in material sciences with unprecedented time resolution, the seeding process gives rise to coherent and short radiation pulses in the THz regime. The paper reviews the status of DELTA and describes its new projects.

### Radiation Dose Depending on the Operating Conditions of a Superconducting In-Vacuum Undulator at ANKA

I. Birkel, E. Huttel, A.-S. Muller (FZK)

Gamma and neutron radiation dose from the operation of the ANKA storage ring at various beam energies were measured by an online radiation monitoring system. Special machine shifts were dedicated to the systematic investigation of the impact of the operating conditions of a superconducting in-vacuum undulator on beam lifetime and radiation dose.

### Full-Energy-Injector for ANKA

E. Huttel, I. Birkel, A.-S. Muller, N. J. Smale, K. G. Sonnad, P. Wesolowski (FZK)

The ANKA storage ring is filled at 0.5 GeV and then ramped to 2.5 GeV for regular user operation. A full-energy injection of the ANKA storage ring would have several advantages. The damping at a beam energy of 2.5 GeV is stronger, which will more efficiently fight instabilities during the injection, therefore allowing higher beam currents. With constant magnet settings, the orbit stability would improve significantly. The injection time would be reduced and topping- up operation would become possible. As a consequence, the optical elements of the user beamlines would see a constant power as a function of time which further enhances the overall stability. In this paper, a design for a full energy injector is proposed. The injector will be located inside the storage ring tunnel, similar to the SLS and ALBA design. The focusing is mainly provided by combined function magnets. The full energy injector has a design emittance of 40 nmrad and a circumference of 94.8 m. A modification of the existing storage ring is foreseen to house the necessary more powerful injection elements.

### Electro-Optical Sampling of Coherent Terahertz Radiation Emitted by Short Bunches in the ANKA Storage Ring

A. Plech, S. Casalbuoni, E. Huttel, Y.-L. Mathis, A.-S. Muller, K. G. Sonnad (FZK) A. Bartels (CAP Konstanz) R. Weigel (Max-Planck Institute for Metal Research)

In a synchrotron radiation source coherent synchrotron radiation is emitted when the bunch length is comparable to the wavelength of the emitted radiation. To generate coherent THz (far IR) radiation, the ANKA storage ring is operated regularly with a dedicated low-alpha optics. Typical effective pulse lengths are of the order of 1 ps and below. In order to characterize the THz emission and beam oscillations in this mode a femtosecond laser system has been set up. This allows resolving the Terahertz electrical field by electro-optical sampling in a ZnTe crystal. The laser system consists of a 500 MHz repetition rate oscillator that can be phase locked to the repetition rate of the synchrotron. First results are presented. In contrast to previous approaches the high repetition rate is used in conjunction with a high frequency detection scheme in order to significantly increase the sensitivity of the detection. The discussion will concentrate on the limits in synchronization by locking the laser to either the

bunch clock, a stripline signal in the ring or the visible light emission co-propagating with the THz radiation. The observations are compared to calculated pulse shapes.

### Observations of Coherent THz Radiation from the ANKA and MLS Storage Rings with a Hot Electron Bolometer

In synchrotron radiation sources coherent radiation is emitted when the bunch length is comparable to or shorter than the wavelength of the emitted radiation. A detector system based on a superconducting NbN ultra-fast bolometer with an intrinsic response time of about 100 ps jointly developed by the University of Karlsruhe (Institute of micro- and nanoelectronic systems) and German Aerospace Center (Berlin) was used to resolve the radiation emitted from single bunches. This paper reports the observations made during measurements at the MLS and ANKA storage rings.

**A.-S. Muller**, I. Birkel, E. Huttel, Y.-L. Mathis, N. J. Smale (FZK) E. Bruendermann (Ruhr-Universität Bochum) T. Bueckle, M. Fitterer, S. Hillenbrand, N. Hiller, A. Hofmann, M. Klein, S. Marsching, K. G. Sonnad (University of Karlsruhe) H. W. Huebers, A. Semenov (DLR) R. Muller (PTB) G. Wuestefeld (BESSY GmbH)

### TBONE: Ultra-fast High-Power Coherent THz to Mid-IR Radiation Facility

A linac based coherent radiation source in the THz to mid-IR range is proposed. The TBONE machine will deliver pulses of radiation as short as a few fs in the frequency range from 0.1 to 150 THz with up to MW peak power. This combination of parameters will open up unprecedented opportunities in THz and infrared applications, such as e.g. microscopy or spectroscopy. This paper presents the main parameters and design considerations. Special emphasis is put on the study of suitable bunch compression and beam transport schemes.

**A.-S. Muller**, T. Baumbach, S. Casalbuoni, B. Gasharova, M. Hagelstein, E. Huttel, Y.-L. Mathis, D. A. Moss, A. Plech, R. Rossmannith (FZK) E. Bruendermann, M. Havenith (Ruhr-Universität Bochum) S. Hillenbrand, K. G. Sonnad (University of Karlsruhe)

### Detection of Particle Losses at the MLS Using Cherenkov Fibers

The 0.6 GeV storage ring Metrology Light Source (MLS) is in operation since April 2008. Recently, Cherenkov glass fibers have been installed for a temporal and spatial detection of electron beam losses. Based on this information the loss mechanisms can be studied in detail and the performance of the machine can be optimized. First experiments with this diagnostic tool will be presented.

**J. Bahrdt**, J. Feikes, W. Frentrup, A. Gaupp, M. V. Hartrott, M. Scheer, G. Wuestefeld (Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Elektronen-Speicherring BESSY II) R. Klein, G. Ulm (PTB)

**Universal Mode Operation of the BESSY II UE112 APPLE Undulator**

J. Bahrtdt, W. Frentrup, A. Gaupp, M. Scheer (Helmholtz-Zentrum Berlin für Materialien und Energie GmbH)

The UE112 APPLE undulator operated at BESSY II covers the low photon energies down to the visible regime. Below 100eV the state of polarization is significantly modified by the optical components of the beamline. Moving independently three magnet rows of the APPLE undulator (universal mode) any state of polarization can be produced which permits the compensation of the beamline effects. Thus, circularly polarized light can be provided at the experiment. The dynamic multipoles of the universal mode can be compensated with flat wires which are glued onto the vacuum chamber. Simulations and first experiments with the electron beam related to the dynamic multipoles and their compensation are presented.

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**Recent Progress of the Operation at PF-Ring and PF-AR**

Y. Kobayashi, T. Aoto, S. Asaoka, K. Ebihara, K. Haga, K. Harada, T. Honda, T. Ieiri, M. Izawa, T. Kageyama, T. Kasuga, M. Kikuchi, K. Kudo, H. Maezawa, K. Marutsuka, A. Mishina, T. M. Mitsuhashi, T. Miyajima, H. Miyauchi, S. Nagahashi, T. T. Nakamura, T. Nogami, T. Obina, K. Oide, M. Ono, T. Ozaki, C. O. Pak, H. Sakai, Y. Sakamoto, S. Sakanaka, H. Sasaki, Y. Sato, M. Shimada, T. Shioya, M. Tadano, T. Tahara, T. Takahashi, R. Takai, S. Takasaki, Y. Tanimoto, M. Tejima, K. Tsuchiya, T. Uchiyama, A. Ueda, K. Umemori, S. Yamamoto, Ma. Yoshida, S. I. Yoshimoto (KEK)

Two synchrotron light sources of the Photon Factory storage ring (PF-ring) and the Photon Factory advanced ring (PF-AR) have been stably operated at KEK. PF-ring covers the photon-energy range from VUV to hard X-ray using a 2.5 GeV (sometimes 3.0 GeV) electron beam. PF-AR is mostly operated in a single-bunch mode of 6.5GeV to provide pulsed hard X-rays. Recently, the operation has progressed to realize a so-called top-up injection at PF-ring. In a single-bunch mode, the continuous injection to preserve a constant beam current of 51 mA has been carried out since February 2007. In addition, the injection with continuing the experiments has been successfully operated in a multi-bunch mode since October 2008. At PF-AR, sputter ion pumps have been extensively reinforced to prolong the beam lifetime and to reduce the frequency of sudden lifetime drops by substituting for distributed ion pumps, which are considered as one of the dust sources. In this conference, we present the recent progress of the operation at PF-ring and PF-AR including machine developments.

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**Top-Up Operation of the Photon Factory**

T. M. Mitsuhashi, T. Aoto, S. Asaoka, A. Enomoto, K. Haga, K. Harada, T. Honda, K. Hurukawa, N. Iida, M. Ikeda, M. Isawa, K. Kakihara, T. Kasuga, M. Kikuchi, Y. Kobayashi, H. Maezawa, T. Mimashi, A. Mishina, T. Miyajima, H. Miyauchi, S. Nagahashi, T. Nogami, T. Obina, Y. Ogawa, Y. Ohnishi, S. Ohsawa, C. O. Pak, S. Sakanaka, H. Sasaki, M. Sato, Y. Sato, T. Shioya, A. Shirakawa, T. Sugimura, T. Suwada, M. Tadano, T. Tahara, T. Takahashi, R. Takai, Y. Tanimoto, M. Tawada, K. Tsuchiya, T. Uchiyama, A. Ueda, K. Umemori, S. Yamamoto, Y. Yano, K. Yokoyama, M. Yoshida (KEK)

The operation of the storage ring by top-up or continuous injection is now very important in the SR facility. This operation of the storage ring provides us keeping the constant intensity of SR for the users. In the KEK, a linac upgrade project is now in progress. This project involves realizing a pulse by pulse multi-energy acceleration of the beam in one linac (8GeV for HER of B-factory, 3.5GeV for LER of B-factory, and 2.5GeV for PF). Using this scheme, we can inject the beam into both B-factory and Photon factory simultaneously, we plan to operate the PF storage ring by a top-up injection mode. Since 2007, we investigate some issues such as injection pulse bump errors, suppression

The operation of the storage ring by top-up or continuous injection is now very important in the SR facility. This operation of the storage ring provides us keeping the constant intensity of SR for the users. In the KEK, a linac upgrade project is now in progress. This project involves realizing a pulse by pulse multi-energy acceleration of the beam in one linac (8GeV for HER of B-factory, 3.5GeV for LER of B-factory, and 2.5GeV for PF). Using this scheme, we can inject the beam into both B-factory and Photon factory simultaneously, we plan to operate the PF storage ring by a top-up injection mode. Since 2007, we investigate some issues such as injection pulse bump errors, suppression

of beam instabilities by feedback system, radiation safety issues, etc. After these investigations, we successfully started test user operation with the top-up injection in the single-bunch user operations from 2007. The pulse by pulse switching operation of Linac will be started in Autumn run 2009, and the full time top-up operation of the PF planed to start in the same time.

### Design Study of a Dedicated Beamline for THz Radiation Generation at the SPARC Linac

A feasibility study for a dedicated beamline for a THz radiation source at SPARC is discussed. A radiofrequency electron gun followed by a compressor can generate trains of THz sub-picosecond electron pulses by illuminating the photocathode with a comb laser pulse. This structure of the beam can be used to produce coherent radiation. The quality of the coherent spectrum emitted by a comb beam is tightly connected to the electron micro-bunches lengths and to micro-pulses inter-distance. Beam dynamics studies are summarized here and compared to a conventional single bunch case, optimized for the THz radiation generation. The dynamics is studied within the SPARC system with the PARMELA code and with the RETAR code for the evaluation of the radiation.

**M. Boscolo**, M. Castellano, E. Chiadroni, M. Ferrario (INFN/LNF)  
 P. Calvani, S. Lupi, A. Nucara (Universita di Roma I La Sapienza)  
 B. Marchetti (INFN-Roma II) V. Petrillo (Universita' degli Studi di Milano) A. R. Rossi (Istituto Nazionale di Fisica Nucleare)

TU5RFP034

### Development of Kicker Magnet for Generation of Short Pulse Synchrotron Radiation in the SPring-8 Storage Ring

We have developed a kicker magnet system including a compact power supply to generate short pulse synchrotron radiation in the SPring-8 storage ring. One method to generate the short pulse synchrotron radiation is cutting out a synchrotron radiation coming from an tilted electron bunch with a slit. For this purpose, we induced a head-tail oscillation of an electron bunch due to non-zero vertical chromaticity excited by using a pulsed magnetic field. By using this scheme, the required specification to the magnet system is relaxed which leads to reduction of construction cost. Developed kicker magnet system can generate a short pulsed vertical field of about 3.6 mT within the 3 us to an electron bunch at 1 Hz repeat. With the kicker magnet system, we successfully observed a bunch profile which leans about 2 mm between head and tail position by a streak camera. We will report the detail setup of the kicker magnet system including compact power supply and the measurement system of beam profile, then discuss the comparisons between real beam motion and simulation results.

**C. Mitsuda**, K. Fukami, A. Mochihashi, T. Ohshima, M. Oishi, J. Schimizu, Y. Shimosaki, M. Shoji, K. Soutome, K. Tamura, H. Yonehara (JASRI/SPring-8) K. Kobayashi, T. Nakanishi (SES)

TU5RFP035

### Bunch Length in Low Alpha Operation at the SPring-8 Storage Ring

Various operations aiming at generating short pulse synchrotron radiation have been demonstrated at the SPring-8 storage ring. One of them is low alpha operation. We have measured the bunch lengths in low alpha operation with a streak camera and achieved the short bunch of about 3ps (rms). We will present the performance of the streak camera operated at the SPring-8 storage ring and show results of bunch length measurements in low alpha operation together with those obtained in normal operation mode.

**K. Tamura**, M. Masaki, A. Mochihashi, T. Nakamura, J. Schimizu, Y. Shimosaki, K. Soutome, M. Takao (JASRI/SPring-8)

TU5RFP036

**Ultra-Low Emittance Light Source Storage Ring with Four Long Straight Sections**

K. Tsumaki (JASRI/SPring-8)

An ultra-low emittance storage ring with an energy of 6 GeV was proposed as a next generation synchrotron radiation source\*. The storage ring has the same circumference as that of SPring-8 storage ring so as to be able to replace the existing storage ring, but has not four long straight sections. Accordingly, the storage ring beam line is slightly different from that of SPring-8 and the positions of photon beam lines are also different from the existing one. To avoid this, a storage ring with four long straight sections has been designed. The beam line position of the new storage ring is the same as the existing one. The storage ring consists of twenty ten-bend achromat cells, four five-bend achromat cells and four long straight sections. The long straight section length is 34.0 m and the short one is 6.6 m. The natural emittance is less than 100 pm-rad. In the paper, the dynamic aperture problem is discussed and the other ring characteristics are presented.

\*K. Tsumaki and N. Kumagai, EPAC'06, 3362.

An ultra-low emittance storage ring with an energy of 6 GeV was proposed as a next generation synchrotron radiation source\*. The storage ring has the same circumference as that of SPring-8 storage ring so as to be able to replace the existing storage ring, but has not four long straight sections. Accordingly, the storage ring beam line is slightly different from that of SPring-8 and the positions of photon beam lines are also different from the existing one. To avoid this, a storage ring with four long straight sections has been designed. The beam line position of the new storage ring is the same as the existing one. The storage ring consists of twenty ten-bend achromat cells, four five-bend achromat cells and four long straight sections. The long straight section length is 34.0 m and the short one is 6.6 m. The natural emittance is less than 100 pm-rad. In the paper, the dynamic aperture problem is discussed and the other ring characteristics are presented.

**Performance Requirements and Metrics for Future X-Ray Sources**

J. N. Corlett (LBNL) R. O. Hettel (SLAC)

LBNL--SLAC study group\*. As identified by this group, essential x-ray capabilities for light sources in the future (but not necessarily from any single source) include: 1) x-ray pulses with Fourier-transform-limit time structure from the picosecond to attosecond regime, synchronized with conventional lasers, and with control of longitudinal pulse shape, amplitude and phase; 2) full transverse coherence; 3) high average flux and brightness; 4) energy tunability in soft and hard x-ray regimes, and polarization control. Metrics characterizing source properties include not only average and peak spectral brightness but also the photons per pulse and repetition rate as a function of pulse length, and the proximity to transform-limited dimensions in six dimensional phase space. We compare the projected performance of various advanced x-ray source types, with respect to these metrics and discuss their advantages and disadvantages. We briefly discuss the technology challenges for future sources and the areas of R&D required to address them.

\*R. Falcone, J. Stohr et al., "Scientific Needs for Future X-Ray Sources in the U. S. - A White Paper", SLAC-R-910, LBNL-1090E, October 2008.

The future directions of x-ray science and the photon beam properties required to pursue them were recently evaluated by a joint

**Using Synchrotron Resonances to Generate a Crabbed Beam at the ALS**

C. T. Hliang, D. Robin, F. Sannibale, W. Wan (LBNL)

Several years ago experiments at the APS demonstrated the possibility of creating crabbed beam through vertically kicking the beam and letting it oscillate for a half of a synchrotron period. Such a crabbed beam would allow the possibility of creating a few ps x-rays. At the ALS we have repeated these experiments. In this paper we will present the results obtained and compare them to theoretical predictions.

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### Pseudo Single Bunch at the ALS: First Experiment Results

Typically storage ring light sources operate with the maximum number of bunches as possible with a gap for ion clearing. The

**G. J. Portmann**, P. Fischer, M. P. Hertlein (LBNL)

Advanced Light Source (ALS) has 2 nanoseconds between the bunches and typically operates with 276 bunches out of a possible 328. For experimenters doing timing experiment this bunch separation is too small and would prefer to see only one or two bunches in the ring. In order to provide more flexible operations and substantially increase the amount of operating time for time-of-flight experimenters, a stripline magnet was installed to kick one bunch on a different vertical closed orbit. By spatially separating the light from this bunch from the main bunch train in the beamline, one can create a pseudo-single bunch operation during regular multi-bunch operations. By putting this bunch in the middle of the ion clearing gap the required bandwidth of the kicker magnets is reduced. This paper will show the first experimental results with the ALS beamline users.

TU5RFP040

### Progress on Diagnostics Upgrades for ALS Top-Off Mode

In preparation for top-off mode at the Advanced Light Source, some old diagnostics systems are being refurbished and several

**T. Scarvie**, W. Barry, F. Sannibale (LBNL)

new ones created. This paper catalogs the progress made on these top-off related upgrades. In particular, results from our first booster-to-storage-ring transfer line synchrotron radiation monitor are shown, and progress on the future storage ring bunch-by-bunch current monitor is presented.

TU5RFP041

### Commissioning and User Operation of the ALS in Top-Off Mode

The upgrade of the Advanced Light Source to enable top-off operation has been ongoing for the last four years. Activities over the last year have centered around radiation safety aspects, culminating in a systematic proof that top-off operation is equally safe as decaying beam operation, followed by commissioning and full user operations. Top-off operation at the ALS provides a very large increase in time-averaged brightness to ALS users (by about a factor of 10) as well as improvements in beam stability. The presentation will provide an overview of the radiation safety rationale, commissioning results, as well as experience in user operations.

**C. Steier**, K. M. Baptiste, W. Barry, R. J. Donahue, H. Nishimura, D. Robin, S. L. Rossi, F. Sannibale, T. Warwick (LBNL)

TU5RFP042

### Design of a 250 MeV, X-Band Photoinjector Linac for a Precision Compton-Scattering Based Gamma-Ray Source

We present a compact, X-band, high-brightness accelerator design suitable for driving a precision gamma-ray source. Future applications of gamma-rays generated by Compton-scattering of laser and relativistic electron beams place stringent demands on the brightness and stability of the incident electron beam. This design identifies the beam parameters required for gamma-ray production, including position, and pointing stability. The design uses an emittance compensated, 11.4 GHz photo-gun and linac to generate 400 pC, 1-2 mm-mrad electron

**S. G. Anderson**, F. Albert, C. P.J. Barty, D. J. Gibson, F. V. Hartemann, D. P. McNabb, M. J. Messerly, B. Rusnak, M. Shverdin, C. Siders (LLNL) S. G. Tantawi, A. E. Vlieks (SLAC)

TU5RFP043

bunches at up to 250 MeV and 120 Hz repetition rate. The effects of jitter in the photo-cathode laser and RF power system are analyzed as well as structure and optic misalignments and wakefields. Finally, strategies for the mitigation of on-axis bremsstrahlung noise are discussed.

### An Optic with Small Vertical Beta Function for the CAMD Light Source

V. P. Suller, P. Jines, D. J. Launey, T. A. Miller, Y. Wang (LSU/CAMD) S. Wang (CAEP/IFP)

At the CAMD Light Source a new optic has been developed for the lattice having small vertical beta function in each of the 4 long straight sections. This optic will be necessary to operate the multipole wigglers with small vertical aperture which are planned to be installed in the near future. Results are presented of the tests which have been made with this optic, particularly in the critical area of injection, which is made low energy. The lattice functions have been characterized using LOCO software and the reduced vertical aperture confirmed with an adjustable scraper.

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### Skew Quadrupoles for the CAMD Light Source

V. P. Suller, A. J. Crappell, P. Jines, D. J. Launey, T. A. Miller, Y. Wang (LSU/CAMD)

To control the emittance coupling in the CAMD Light Source, new power supplies have been constructed which adjust the currents in the individual coils of the normal lattice sextupoles, thereby creating skew quadrupole fields. The new power supplies add or subtract current through the pre-energized coils. Performance contributing factors include a summing network with a temperature coefficient less than 1ppm/°C, a water cooled resistive shunt, and linear optical signal isolation. High density & modularity control boards and water cooled power cards are mounted as pull-out units in a 19" rack. Active limiters and fault indicators can provide reliability and portability to higher power designs. The use of these skew quadrupoles in controlling and minimizing the emittance coupling is presented.

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### Accelerator Design of the MIT Compact X-Ray Source Project

W. Graves, J. Brown, D. E. Moncton (MIT) J. R. Delayen, G. A. Krafft (JLAB) T. L. Grimm (Niowave, Inc.) R. A. Legg (UW-Madison/SRC) J. W. Lewellen (NPS) P. Piot (Northern Illinois University)

The design of the accelerator components and beamline layout for a compact source\* of hard x-rays based on inverse Compton scattering (ICS) are described. The main accelerator components are the photoinjector and short linac. Both of these components are based on CW superconducting RF cavities operating at 4 Kelvin. They are designed to produce a high-brightness electron beam consisting of a stream of ultrashort 10 pC pulses at 100 MHz repetition rate for a 1 mA average beam current at energy up to 40 MeV. Efficient x-ray production requires very low electron emittance, short pulses, and high average current. The design of the accelerator and its beamline components are presented, along with discussion of optimum electron beam properties and start-to-end simulations.

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\*W. S. Graves, W. Brown, F. X. Kaertner, D. E. Moncton, "MIT Inverse Compton Source Concept", proceedings of ICFA Workshop on Compton Sources for X/Gamma Rays, Sardinia, Italy (2008), to appear in NIM-A



### Proposal for a Synchrotron Radiation Source for Romania

Synchrotron Radiation (SR) shows great advantages in multiple and simultaneous applications due to the fact that it is generated by the relativistic electron motion along a trajectory which is closed in a source called "storage ring", consisting of straight sections separated by bending magnet sections

where the electron trajectories are bent by dipole magnets. SR is generated in bending magnets and in insertion device included in the straight trajectories. Taking into account the final values for the 3 GeV beam electron energy and the 1A electron beam current, this paper presents the main parameters for the SR source based on the standard insertion device – wiggler, undulator and optical klystron, the latter being calculated in the seeded coherent harmonic generation FEL scheme. According with this project, the SR source will generate beams of wiggler radiation, undulator radiation and SR FEL for R&D purposes in physics, chemistry, biology, medical science, material sciences, environmental sciences, life science, mechanical engineering etc. The spectrum range of the obtained radiation will cover IR & UV range, inclusively.

**F. Scarlat**, E. S. Badita, G. Georgescu, R. Medianu, E. Mitru, M. Oane, A. M. Scarisoreanu (INFLPR) V. Babin, E. Carstea, I. S. Dontu, S. Miclos, C. M. Radu, E. Ristici, M. I. Rusu, D. Savastru, M. Tautan (Mustata) (INOE 2000) A. Dafinei, M. R. Leonovici (Bucharest University, Faculty of Physics)

TU5RFP047

### Design and Performance of Linac and Recirculation Optics for the X-Ray Free Electron Laser Oscillator

The X-ray Free Electron Laser Oscillator\* (XFEL-O) is a concept for a high-brightness fourth-generation x-ray source with full spatial and temporal coherence. It is based on a CW electron source and superconducting linac. In order to reduce cost and increase versatility, a recirculating linac configuration is being entertained. In this paper, we present an optics design for the four-pass linac and the three recirculation systems. The design goals are preservation of the beam emittance and energy spread, as well as minimal cost and complexity. We also present the results of tracking studies that show the expected performance.

\*K. J. Kim et al., Phys. Rev. Letters, to be published.

**M. Borland** (ANL)

TU5RFP048

### Parameter Study of an X-Ray FEL Oscillator

An x-ray radiation source based on a free-electron laser (FEL) oscillator was recently proposed as a complementary facility to those based on self-amplified spontaneous emission\*. Such a source uses narrow-bandwidth Bragg mirrors and a low-emittance, high-brightness electron beam to produce coherent, intense pulses of hard x-ray radiation. We present a study of the FEL oscillator performance and radiation characteristics at several potential wavelengths using a variety of electron beam and undulator parameters. Our simulations include realistic complex mirror reflectivities calculated from dynamical diffraction theory, and highlight additional constraints imposed by a four-mirror cavity that can provide tunable FEL radiation. We comment on how this concept may be extended to soft x-rays using dielectric multilayer mirrors.

\*K.-J. Kim, Y. Shvyd'ko, S. Reiche, Phys. Rev. Lett. 100, 244802 (2008)

**R. R. Lindberg**, K.-J. Kim (ANL)

TU5RFP049

### Electron Beam Energy Stabilization Using a Neural Network Hybrid Controller at the Australian Synchrotron Linac

E. Meier (ASCo)

This paper describes the implementation of a neural network hybrid controller for energy stabilization at the Australian Synchrotron Linac. The structure of the controller consists of a neural network (NNET) feed forward control, augmented by a conventional Proportional-Integral (PI) feedback controller to ensure stability of the system. The system is provided with past states of the machine in order to predict its future state, and therefore apply appropriate feed forward control. The NNET is able to cancel multiple frequency jitter in real-time. When it is not performing optimally due to jitter changes, the system can successfully be augmented by the PI controller to attenuate the remaining perturbations.

This paper describes the implementation of a neural network hybrid controller for energy stabilization at the Australian Synchrotron Linac.

### A Study of the Stability of FEL Resonators

S. Krishnagopal (BARC) T. Basak, S. A. Samant (CBS)

The presence of an FEL interaction perturbs the stability of an optical resonator. We use this effect, and map out the modified stability diagram in two dimensions. In particular we study the phenomenon of mode-beating, and parameterization of the FEL interaction in terms of a lens model.

The presence of an FEL interaction perturbs the stability of an optical resonator. We use the FEL oscillator code TDAOSC to study this effect, and map out the modified stability diagram in two dimensions. In particular we study the phenomenon of mode-beating, and parameterization of the FEL interaction in terms of a lens model.

### Experimental Characterization of a SASE FEL in the Exponential Gain and Saturation Regimes

X. J. Wang, Y. Hidaka, J. B. Murphy, B. Podobedov, H. J. Qian, S. Seletskiy, Y. Shen, X. Yang (BNL) B. Hafizi (Icarus Research, Inc.) J. Penano, P. Sprangle (NRL)

The NSLS Source Development Laboratory (SDL) has been a world leader in the development of laser seeded free electron lasers (FEL). Recently we initiated an experimental program to investigate a Self-Amplified Spontaneous Emission (SASE) FEL in both the exponential gain and the saturation regimes. We have experimentally demonstrated the saturation of a SASE FEL in the visible to near IR. The experimental characterization of the transverse and spectral properties of the SASE FEL along the undulator for a uniform and tapered undulator will be presented. In addition, an efficiency enhancement concept for a SASE FEL, which involves a step wiggler taper in the exponential gain regime prior to trapping, will be presented. Simulations of the SASE FEL processes will employ the GENESIS FEL code.

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### Efficiency and Spectrum Enhancement in a Tapered Free-Electron Laser Amplifier

X. J. Wang, D. A. Harder, J. B. Murphy, H. J. Qian, Y. Shen, X. Yang (BNL) H. Freund, W. H. Miner (SAIC)

We report the first experimental characterization of efficiency and spectrum enhancement in a laser-seeded free-electron laser (FEL) using a tapered undulator. Output and spectra in the fundamental and 3rd harmonic were measured versus distance for uniform and tapered undulators. With a 4% field taper over 3 m, a 300% (50%) increase in the fundamental (3rd harmonic) output was observed. A significant improvement in the spectra with the elimination of side-bands was observed for the first time using a tapered undulator. The experiment is in good agreement with predictions using the MEDUSA simulation code.

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### PSI-XFEL Sensitivity to Beam Main Parameters and Undulator Focusing

The study of radiation saturation length and saturation power sensitivity to beam main parameters (emittance, energy spread and peak current) at the entrance of the undulator section of PSI-XFEL project is presented. The comparative analysis of the SASE FEL performance with external and natural focusing in undulator section is given.

**V. G. Khachatryan**, V. Sahakyan, A. Tarloyan, V. M. Tsakanov (CANDLE) T. Garvey, S. Reiche, A. Streun (PSI)

TU5RFP054

### Design of an Intense Terahertz Source at CBS

Centre for Excellence in Basic Sciences (CBS) is proposing to build an intense terahertz source for applications in basic and applied science. This source would provide radiation tunable from 30 to 100 microns, using a 25 MeV electron beam and 2.5 m long undulator. In this paper, we present details of the design.

**T. Basak**, S. Krishnagopal, S. A. Samant (CBS)

TU5RFP055

### A High Power Terahertz Source Based on a Photoinjector

A terahertz (THz) source based on a photoelectron gun to deliver a much higher peak power than is available from other non-FEL sources at sub-mm wavelengths has been invented by DULY Research Inc. The photoelectron gun is integrated with a robust, compact and efficient radiator inside the vacuum envelope. The THz power extractor is driven by a low-energy (MeV), conventional RF photoinjector operated in a custom mode.

**D. Yu**, A. Smirnov (DULY Research Inc.)

TU5RFP056

### Coordinating Civil Construction of the European XFEL

This poster describes the organizational structures and processes which were established for coordinating civil construction at the European XFEL. Local managements supervise the different construction sites in cooperation with a central team which manages the overall effort and provides general services (e.g. coordination, communication, safety, legal). Communication processes, workflows for reviewing, approving and distributing construction drawings and formalized change management have been defined and established. Reporting, cost management and controlling procedures have been put in place, as well as procedures for maintaining good public relations. All the processes are documented in a project handbook, and they are supported and optimized by IT systems, in particular the DESY Engineering Data Management System, DESY EDMS.

**L. Hagge**, S. Eucker, J. Kreutzkamp, A. S. Schwarz (DESY)

TU5RFP057

**Inter-Disciplinary Collaborative 3D Design Processes for the European XFEL and the ILC**

L. Hagge, N. Bergel, A. Herz, J. Kreutzkamp, S. Suehl, N. Welle (DESY)

In most sub-systems of the European XFEL, more than one institute participates in the design & development activities. This is the case for e.g. the cold linac, cryogenics, bunch compressors, undulators and photon beam systems. To ensure interface compatibility and make sure components fit into their complex environments, the collaborating institutes have to create high-level 3D models of their sub-systems. These 3D models are centrally integrated into a master model, which enables identification and elimination of collisions and non-conformities prior to manufacturing. A "collaborative design process", which supports efficient, interactive and inter-disciplinary cooperation of different institutes, has been successfully developed and established at the European XFEL. It consists of design guidelines and processes definitions for information & data exchange, reviews, approvals and change management. The process is supported by the DESY Engineering Data Management System, DESY EDMS, and allows the combination of 3D models from multiple 3D CAD systems. Following the good experience at the European XFEL, the same process is now established at the Global Design Effort for the ILC.

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**FLASH Upgrade**

S. Schreiber, B. Faatz, J. Feldhaus, K. Honkavaara, R. Treusch (DESY)

FLASH provides fully coherent femtosecond laser radiation from 47 nm down to 6.5 nm and higher harmonics. Late 2009, FLASH will be upgraded with an additional superconducting TESLA type accelerating module boosting its beam energy to 1.2 GeV. This will allow lasing with a wavelength below 5 nm. In addition, a 3rd harmonic accelerating cavity will be installed. It allows to flatten and to a certain extent shape the longitudinal phase space improving the overall performance of the facility.

The free-electron laser user facility FLASH at DESY, Germany is the world-wide leading SASE-FEL operating in the VUV and the soft X-ray wavelengths range. At present,

**Impedance Budget Database for European XFEL**

O. Zagrodnova, T. Limberg (DESY)

The European XFEL contains hundreds of sources of the coupled impedances. To have an overview of them an impedance budget database is developed. It contains wake functions of the point charge (Green functions) and allows to calculate the wake potentials for arbitrary bunch shapes.

The European XFEL contains hundreds of sources of the coupled impedances. To have an overview of them an impedance budget

**A Fast Switching Mirror Unit at FLASH**

M. Sachwitz, A. Donat, U. Gensch, R. Heller, L. V. Vu (DESY Zeuthen) U. Hahn, S. Karstensen, H. Schulte-Schrepping, K. I. Tiedtke (DESY)

A first prototype of a switching mirror has been designed, built and tested. With a repetition rate of up to 2.5 Hz the mirror is used to provide different beam lines with the Laser light produced by FLASH. The repetition accuracy is in the order of 1 um whereas the yawing is about 1 arcsec.

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### Start to End Simulations of a 1 keV FEL Driven by a Superconducting Linac

Several new light source projects aim at the production of X-ray photons with high repetition rate (1kHz or above). We present here the results of the start-to-end simulations of a 2.2 GeV superconducting LINAC based on L-band SC Tesla-type RF cavities and the corresponding optimisation of the FEL dynamics at 1 keV photon energy.

**R. Bartolini**, C. Christou, J. H. Han, I. P.S. Martin (Diamond)

TU5RFP062

### Laser Heater Coherent Synchrotron Radiation: Numerical and Analytical Results

We develop some considerations allowing the possibility of deriving the conditions under which laser heater devices may suppress the Coherent Synchrotron Instability (CSRI)

**G. Dattoli** (ENEA C. R. Frascati) M. Migliorati (INFN/LNF) A. Schiavi (Rome University La Sapienza)

without creating any prejudice to the use of the beam for FEL SASE or FEL oscillator operation. We discuss the problem using either numerical and analytical methods. The analytical part is aimed at evaluating the amount of laser power, necessary to suppress the instability. We use methods already developed within the context of FEL-storage rings beam dynamics, with particular reference to the interplay between FEL and Saw Tooth Instability. The numerical method employs a procedure based on the integration of the Liouville equation, describing the coupled interaction between e-beam and wake-fields, producing the instability, and the laser producing the heating. Particular attention is devoted to the competition between instability and heating. The comparison between numerical and analytical results is discussed too and the agreement is found to be satisfactory.

TU5RFP063

### Towards A Self Sustained Free Electron Laser Device

We explore the possibility of using free-electron laser (FEL) triggered cathodes to produce high quality e-beams. We propose a scheme which foresees cathodes operating

**E. Sabia**, G. Dattoli (ENEA C. R. Frascati) A. Dipace (ENEA Portici)

either as thermionic and photo-cathodes, which can be exploited in devices using the same e-beam to drive the laser and the cathode. We discuss different modes of operation, in particular we consider oscillator FELs, in which the light from higher order harmonics, generated in the oscillator cavity, is used to light the cathode. The dynamics of the system is explored along with the technical solutions, necessary for the stability of the system. The Master Oscillator Power Amplifier FEL scheme is explored too. The use of the same e-beam, driving the photocathode and the FEL, makes the system naturally free of any synchronization problem, arising when an external laser is used. The device is a kind of regenerative amplifier in which the growth of the optical power can be controlled by using a proper detuning or misalignment of the optical cavity. Specific examples are reported. The use of this technique for an ab-initio control the Coherent Radiation Synchrotron instability is finally discussed too.

TU5RFP064

### FEL Transverse Mode Shaping Using Intra-Cavity Apertures

The storage ring based free electron laser (FEL) oscillator serves as a photon driver for the High Intensity Gamma-Ray Source (HIGS) at Duke University. The FEL cavity consists of two concave mirrors with a large radius of curvature of more than 27 m. Both cavity mirrors see very high intensity intracavity FEL power; the downstream mirror also

**J. Li**, Y. K. Wu (FEL/Duke University) S. Huang (PKU/IHIP)

TU5RFP065

receives higher harmonic spontaneous UV-VUV radiation of wigglers. The large heat load by various types of radiation can deform the mirror surface, causing FEL mode distortion. The FEL mirror can also be damaged by intense UV-VUV wiggler harmonic radiation. To mitigate these problems, a pair of water-cooled, in-vacuum apertures have been installed inside the FEL cavity. These apertures are ideal for manipulating the FEL transverse profile. This paper reports our study on the FEL transverse mode shaping using these apertures, including the characterization of the transverse mode structure of the FEL beam under a variety of operation conditions. These studies allow us to minimize the diffraction loss of the fundamental mode of the FEL while effectively reducing the impact of off-axis UV-VUV wiggler radiation on the FEL mirrors.

### Multibunch Injection Scheme for the Booster Synchrotron of the Duke FEL and HIGS Facility

S. F. Mikhailov, J. Li, V. Popov, P. W. Wallace, P. Wang, Y. K. Wu (FEL/Duke University) O. Anchugov (BINP SB RAS)

A booster-injector synchrotron has been recently built and commissioned at Duke University to provide for the top-off injection into the storage ring in the energy range of

0.24 - 1.2 GeV. Booster injection kicker was designed with a pulse length of 18 out of 19 booster separatrices, assuming a long train of electron bunches to be injected from the existing linac. Such scheme required a major linac upgrade from single bunch photo emission mode to a multibunch thermionic mode. A major disadvantage of the latter was much higher radiation levels in the facility. Since commissioning, the booster could only operate with one or two bunches limited by both long kicker pulse and single bunch injection from the linac. The consequent limitation of the injection rate restricted the capability of production of the Compton gamma rays in the loss mode, i.e. production of gammas with energy above 20-25 MeV, to about  $5 \cdot 10^8$  photons per sec. Update of the linac for the repetition rate of up to 10 Hz, and modification of the injection kicker for 15 ns pulse length allowed us to develop an alternative multibunch injection scheme with a significant increase of the injection rate into storage ring.

### Pass-by-Pass Multistage FEL Gain Measurement Technique for a Storage Ring FEL

S. F. Mikhailov, J. Li, V. Popov, Y. K. Wu (FEL/Duke University)

The paper presents a novel technique of measuring the gain of a storage ring based FEL oscillator. As opposed to the conven-

tional technique of measuring the FEL gain from its macro-pulse envelope, this new technique is based upon the measurement of pass-by-pass FEL  $\mu$ pulses. To record the growth of the optical energy in the FEL micro-pulse train, we use fast photo-diodes and photo-multiplier tubes (PMTs). PMTs are usually employed at the very beginning of the FEL lasing development, while the photodiodes are used at the latter stages when the FEL power is fully developed and saturated. This new gain measurement technique provides a powerful tool to study the details of the FEL gain process starting from spontaneous radiation to saturation. It allows us to investigate five to seven orders of magnitude of the FEL energy growth. As fast photo-detectors with a sub-nanosecond time response become available, this new technique can be adopted for many oscillator FELs, including those driven by superconducting linacs. Special attention is paid to the dynamic non-linearity issues of the photodiodes and PMTs associated with short length of FEL pulses.

### Quasi-Monochromatic High Intensity Compton Gamma Source Powered by a High Finesse Fabry-Perot Optical Cavity

The High Intensity Gamma-ray Source (HIGS), a highly polarized Compton gamma source at Duke university, uses an intense FEL beam to collide with the electron beam in the storage ring. However, in the high flux mode with a large optical power in the FEL cavity, the gamma beam energy spread of a well-collimated HIGS beam remain relatively large at a few percent. This large gamma beam energy spread is the result of the increased electron beam energy spread induced by the FEL interaction. In this work, we report a new research project at the DFELL to develop a quasi-monochromatic Compton gamma source from 1 to 20 MeV with an exceptionally high energy resolution of 0.1% to 0.5%. This new gamma-ray source will be driven by a high finesse Fabry-Perot (FP) optical cavity powered by an external laser. The high optical power built-up inside the FP cavity will be used to collide with the circulating electron beam in the storage ring. We will give an outline of this project and present the recent progress.

Y. K. Wu, M. D. Busch, B. Jia, J. Li, S. F. Mikhailov, V. Popov, C. Sun (FEL/Duke University)

TU5RFP068

### Experiments on Madey Theorem with Optical Klystron Free-Electron Laser

The Madey theorem is a valuable research tool for studying Free-Electron Lasers (FELs). The theorem relates the shape of the on-axis spontaneous radiation spectrum of FEL wigglers to the FEL gain. The theorem predicts that degradation of the spontaneous spectrum, for example as a result of the increase of the electron beam energy spread, provides a direct measure of the reduction of the FEL gain. Extensive experiments have been performed to study the validity of the Madey theorem for a storage ring base optical klystron FEL. The experimental data show that the lasing wavelength of the FEL is very close to the maximum slope of spontaneous spectra as predicted by the Madey theorem with a relative wavelength discrepancy less than 0.2%. Further analysis is underway to understand this wavelength difference. In addition, we have performed direct measurements of the start up gain of the FEL and compared it with the changing slope of the spontaneous spectra. The preliminary results show a good agreement between the measured FEL gain and the prediction by Madey theorem.

S. Huang, J. Li, Y. K. Wu (FEL/Duke University) S. Huang (PKU/IHIP)

TU5RFP069

### Accelerator Physics Research and Development Programs at Duke University

The Duke Free-Electron Laser Laboratory (DFELL) operates several accelerators as a driver for storage ring based Free-Electron Lasers (FELs) and Compton gamma-ray source, the High Intensity Gamma-ray Source (HIGS). The HIGS is the most powerful Compton gamma-ray source in the world below 100 MeV. Since completing a major upgrade of the HIGS in 2007, the Duke storage ring FEL and HIGS gamma source have been operated extensively for user research programs. In 2008, the DFELL was merged with the Triangle Universities Nuclear Laboratory (TUNL) to become a major accelerator facility of the TUNL. The accelerator physics program at the DFELL covers a wide range of activities, from nonlinear dynamics research, to the study of beam instability with advanced feedback systems, to light source research and development, in particular, the FEL research and Compton light source development. In this paper, we will report our recent progress in accelerator physics research and light source development to meet new challenges of today's and future accelerators.

Y. K. Wu (FEL/Duke University)

TU5RFP070

### Study of Storage Ring Free Electron Laser Dynamics

B. Jia, Y. K. Wu (FEL/Duke University) J. Wu (SLAC)

The storage ring Free-Electron Laser (SRFEL) has been operated in a wide range of wavelength from IR and visible to UV and VUV. SRFEL dynamics are inherently complex since the FEL system involves several physical processes of drastically different time scales from fast synchrotron oscillation, SRFEL power growth, to slow damping time. A comprehensive investigation of FEL growth from noise to saturation is critical for understanding the SRFEL dynamics. Our study implement both experimental and numerical techniques. The experiments focus on the measurements of the turn-by-turn SRFEL growth from noise to saturation with the data over several decades of growth. The simulation work focuses on building a numerical model to study the SRFEL build-up by using the existing code such as Genesis, OPC as well as software packages under development at DFEL. The goal is to match the simulation with the experimental results. After the numerical model is fully tested at a given wavelength, it will be used to study a wide range of SRFEL operation in particular for UV and VUV. This study will be crucial for High Intensity Gamma-ray Source to achieve higher than 100 MeV gamma operation.

### Status of the XUV Seeding Experiment at FLASH

J. Boedewadt, A. Azima, F. Curbis, H. Delsim-Hashemi, M. Drescher, Th. Maltezopoulos, V. Miltchev, M. Mittenzwey, J. Rossbach, S. Schulz, R. Tarkeshian, M. Wieland (Uni HH) S. Dusterer, J. Feldhaus, T. Laarmann, H. Schlarb (DESY) R. Ischebeck (PSI) S. Khan (DELTA) A. Meseck (BESSY GmbH)

A seeded free-electron laser operating in the soft X-ray (XUV) spectral range will be added to the SASE FEL facility FLASH. For this purpose, a 40 m long section upstream of the existing SASE undulator will be rebuilt during the shutdown in fall 2009. This includes the injection of the seed beam into a new 10 m variable-gap undulator, the out-coupling of the seeded FEL radiation and all diagnostics for photon- and electron beams. The XUV seed pulse is generated by high harmonics (HHG) from a near-infrared laser, optically synchronized with FLASH. After amplification within the undulators the XUV light will be guided towards diagnostic stations. Besides a proof-of-principle demonstration for seeding at short wavelength the purpose of this development is to provide future pump-probe experiments with a more stable FEL source in terms of spectral properties and timing.

### Simulation and Optimization Research of a THz Free-Electron Laser Oscillator

P. Tan, M. Fan, B. Qin, Y. Q. Xiong (HUST)

A primary design of a compact THz FEL oscillator is presented, which is consisted of an independently tunable cell thermionic rf gun (ITC-RF Gun), a rf linac, a planar undulator and an near concentric optical cavity composed of symmetrical spherical mirrors with an on-axis outcouple hole. Without  $\alpha$ -magnet and other bunch compressor, the size of this machine is decreased sharply. The effect of the electron beam parameters on THz radiation is discussed. It is found that the influence of energy spread is pronounced and the influence of emittance is neglectable. Large current is required to got saturation in several us. Then the optimized beam parameters and basic design parameters are summarized.



### Status of Thomson Source at SPARC/PLASMONX

The PLASMONX project foresees the installation at LNF of a 0.2 PW (6 J, 30 fs pulse) Ti:Sa laser system FLAME (Frascati Laser for Acceleration and Multidisciplinary Experiments) to operate in close connection with

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the existent SPARC electron photo-injector, allowing for advanced laser/e-beam interaction experiments. Among the foreseen scientific activities, a Thomson scattering experiment between the SPARC electron bunch and the high power laser will be performed and a new dedicated beamline is foreseen for such experiments. The beam lines transporting the beam to the interaction chamber with the laser have been designed, and the IP region geometry has been fixed. The electron final focusing system, featuring a quadrupole triplet and large radius solenoid magnet (ensuring an e-beam waist of -10--15 microns) as well as the whole interaction chamber layout have been defined. The optical transfer line issues: transport up to the interaction, tight focusing, diagnostics, fine positioning, have been solved within the final design. The building hosting the laser has been completed; delivering and installation of the laser, as beam lines elements are now being completed.

### Status of the SPARX-FEL Project

The SPARX-FEL project aims at producing ultra high peak brightness electron beams in the 1.5 - 2.4 GeV range with the goal of

**L. Palumbo** (INFN/LNF)

generating FEL radiation in the 0.6-40 nm range. The construction is planned in two steps, starting with a 1.5 GeV Linac. The project layout includes both RF-compression and magnetic chicane techniques, in order to provide the suitable electron beam to each one of three undulator systems which will generate VUV-EUV, Soft X-Rays and Hard X-rays radiation respectively. This will be distributed in dedicated beamlines suitable for applications in basic science and technology: time resolved X-ray diffraction with pump and probe experiments, nanolithography processes, biological proteins, nano-particles and clusters, coherent diffraction and holographic X-ray techniques, nano-imaging. The project was funded by the Italian Department of Research, MIUR, and by the local regional government, Regione Lazio; The associated test-facility, SPARC, located at LNF, has been successfully commissioned: the SPARX-FEL project foresees the construction of a user facility inside the Tor Vergata campus by a collaboration among CNR, ENEA, INFN and the Università di Tor Vergata itself.

### Mechanical Layout and Civil Infrastructures of the SPARX-FEL Complex

The SPARX-FEL project consists in an X-ray-FEL facility which aim is the generation of electron beams characterized by ultra-high peak brightness at the energy of 1.5 and 2.4 GeV. This facility will be built in the Tor Vergata

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University area in Rome. The paper describe the engineering aspects of the mechanical design of the accelerator, photo-injector, LINACs, bunch compressors, beam distribution, undulators and experimental stations. Moreover the integration of accelerator with the civil infrastructures is discussed.

### Microbunching Instability Modeling in the SPARX Configurations

C. Vaccarezza, M. Ferrario, A. Marinelli (INFN/LNF) L. Giannessi, C. Ronsivalle (ENEA C. R. Frascati) M. Migliorati (Rome University La Sapienza) M. Venturini (LBNL)

The modeling of the microbunching instability has been carried out for the SPARX FEL accelerator, two configurations have been considered and compared: hybrid compression scheme (velocity bunching plus magnetic compressor) and purely magnetic. The effectiveness of a laser heater in reducing this instability drawbacks on the electron beam quality has also been exploited. Analytical predictions and start to end simulation results are reported in this paper.

### Lasing of MIR-FEL and Construction of User Beamline at Kyoto University

M. A. Bakr, K. Higashimura, T. Kii, R. Kinjo, K. Masuda, H. Ohgaki, T. Sonobe, K. Yoshida, H. Zen (Kyoto IAE) Y. U. Jeong (KAERI)

The first laser amplification at a 12 micrometre mid-infrared free-electron laser (MIR-FEL) was observed at the Institute of Advanced Energy (IAE), Kyoto University in March 2008. A 25 MeV electron beam of 17 A peak current was used for the lasing experiment. FEL gain was estimated to be 16% from the exponential growth of the laser output signal. A beam loading compensation method with an RF amplitude control both in the thermionic RF gun and in the accelerator tube was used to extend the macropulse duration against the back bombardment effect in the gun. We also developed a feedforward RF phase control to stabilize the RF phase shifts which were originated with RF amplitude control. As a result FEL saturation was observed in May 2008. The estimated FEL gain was 33% with the electron beam of 5.5 microsecond macropulse duration by use of peak current of 33 A which was deduced from GENESIS simulation. A user beamline was designed and constructed. The laser characterization at the user station will be reported in the conference. Applications of the MIR-FEL at Kyoto University in the chemistry energy research will be presented as well.

### ERL Staging

K. C. Harkay, Y.-C. Chae (ANL)

ERL staging is a novel concept that provides a practical path to upgrading an existing synchrotron light source while minimizing disruption to the users and managing the technical risk. In the very first stage, the accelerator operating parameters are comparable to CEBAF without recirculation. Therefore, initially, energy recovery is not required and the injector is more modest. Consequently, the technical risk is significantly reduced relative to the full ERL. Using the APS as an example, the first stage is based on a full-energy, 7-GeV superconducting radiofrequency (srf) linac and an electron source that is almost off-the-shelf. The linac would initially deliver a low average current beam (<200 uA), but with a geometric emittance that is much smaller than the storage ring, the x-ray brightness can exceed the APS. Furthermore, the spatial coherence fraction would be about 100 times higher and the pulse length up to 100 times smaller than the APS. Valuable srf operating experience is attained at an early stage while allowing critical energy recovery issues to be studied. Energy recovery is commissioned in stage 2. The optics design and performance at each stage will be presented.

### Multi-Beam Injection and a Quasi-CW ERL for Future X-Ray Light Sources

The envisioned next-generation ERL-based x-ray light sources demand costly CW superconducting linacs and high-brightness high-current photoinjectors that are beyond the state of the art. To overcome the fiscal challenge of a multi-GeV CW superconducting ERL and the physical challenge of high-brightness high-current CW photoinjectors, we explore a new scheme using multi-beam injection into a quasi-CW ERL. Multi-beam injection lowers the burden on individual rf injectors at subharmonics of the linac frequency. Lower injector frequency allows higher bunch charge, which permits lower duty factor of the linac with significant reduction in construction and operation costs. Preliminary studies foresee many benefits and no obvious physical showstoppers, despite potential technical challenges. Here we provide a simulation study of a preliminary design.

C.-x. Wang (ANL)

TU5RFP080

### Status of the Energy Recovery Linac Project in Japan

Future synchrotron light source project using an energy recovery linac (ERL) is under proposal at the High Energy Accelerator Research Organization (KEK) in collaboration with several Japanese institutes such as the JAEA and the ISSP. We are on the way to develop such key technologies as the super-brilliant DC photo-injector and superconducting cavities that are suitable for both CW and high-current operations. We are also promoting the construction of the Compact ERL for demonstrating such key technologies. We report the latest status of our project, including update results from our photo-injector and from both superconducting cavities for the injector and the main linac, as well as the progress in the design and preparations for constructing the Compact ERL.

S. Sakanaka, M. Akemoto, A. Enomoto, S. Fukuda, K. Furukawa, T. Furuya, K. Haga, K. Harada, T. Honda, Y. Honda, K. Hosoyama, E. Kako, T. Kasuga, H. Kawata, M. Kikuchi, Y. Kobayashi, Y. Kojima, H. Matsushita, S. Michizono, T. M. Mitsunashi, T. Miura, T. Miyajima, T. Muto, S. Nagahashi, H. Nakai, H. Nakajima, E. Nakamura, K. Nakanishi, T. Nogami, T. Obina, S. Ohsawa, T. Ozaki, S. Sasaki, M. Satoh, T. Shidara, M. Shimada, T. Suwada, T. Takahashi, R. Takai, Y. Tanimoto, M. Tawada, M. Tobiyama, T. Uchiyama, K. Umemori, M. Yamamoto, S. Yamamoto (KEK) R. Hajima, H. Iijima, N. Kikuzawa, E. J. Minehara, R. Nagai, N. Nishimori, M. Sawamura (JAEA/ERL) H. Hanaki (JASRI/SPRING-8) A. Ishii, I. Ito, T. Kawasaki, H. Kudo, N. Nakamura, H. Sakai, S. Shibuya, K. Shinoe, T. Shiraga, H. Takaki (ISSP/SRL) M. Katoh (UVSOR) M. Kuriki (HU/AdSM) S. Matsuba (Hiroshima University, Graduate School of Science) K. Torizuka, D. Yoshitomi (AIST)

TU5RFP081

### ERL Based Light Source with Multiturn Circulation Ring

Energy recovery linac(ERL) is a candidate for next-generation light sources with its ultimate quality of the beam. In previous paper\*, we proposed a scheme to circulate an ERL beam in a storage ring several turns, with which we can reduce the average current of the ERL and the electron gun by the factor of the number of turns. The reduction of the current leads to a multi-pass ERL scheme and eases the requirement on the electron gun and the drive laser. However, radiation excitation increases the horizontal emittance and the energy spread of the circulating beam in the ring and competes with the increase of the ring average current by multiturn circulation. The scheme and the effect of the radiation excitation are discussed for an existing ring.

T. Nakamura (JASRI/SPRING-8)

\*T. Nakamura, "Multiturn circulation of an energy-recovery linac beam in a storage ring", Phys. Rev. ST Accel. Beams 11, 032803 (2008).

TU5RFP082

### Progress on the Commissioning of ALICE, the Energy Recovery Linac Based Light Source at Daresbury Laboratory

S. L. Smith, C. D. Beard, S. R. Buckley, D. J. Dunning, S. P. Jamison, J. K. Jones, L. B. Jones, P. A. McIntosh, J. W. McKenzie, K. J. Middleman, B. L. Militsyn, A. J. Moss, J. F. Orrett, Y. M. Saveliev, D. J. Scott, B. J.A. Shepherd, N. Thompson, A. E. Wheelhouse, P. H. Williams (STFC/DL/ASTeC) K. Harada (KEK) S. F. Hill (STFC/DL/SRD) D. J. Holder (Cockcroft Institute) P. J. Phillips (University of Dundee)

ALICE (Accelerators and Lasers in Combined Experiments) is a 35 MeV energy recovery linac based light source. ALICE is being developed as an experimental test-bed for a broad suite of science and technology activities that make use of electron acceleration and ultra-short pulse laser techniques. This paper reports the progress made in accelerator commissioning and includes the

results of measurement made on the commissioning beam. The steps taken to prepare the beam for short pulse operation as a driver for a Compton Back Scattered source and in preparation for the commissioning of the free electron laser are reported.

### Beam Optics Study for the Compact ERL in Japan

T. Shiraga, N. Nakamura, H. Takaki (ISSP/SRL) R. Hajima (JAEA/ERL) K. Harada, Y. Kobayashi, T. Miyajima, S. Sakanaka, M. Shimada (KEK)

A compact ERL (energy recovery linac) is planned in Japan in order to demonstrate excellent ERL performances and to test key components such as low-emittance photocathode gun and superconducting RF cavity.

We studied and optimized the compact ERL optics (except the injector part) to generate a subpico-second bunch in bunch compression mode and to preserve the beam emittance in normal and low-emittance mode. As a result, we could obtain a very short bunch of about 50 fs with a charge of 77 pC in bunch compression mode and almost keep the normalized emittance of 0.1 mm mrad with a charge of 7.7 pC in low-emittance mode. We also designed it to achieve efficient energy recovery at the superconducting RF cavities and to transport the beam to the dump section without serious loss. The design study of the compact ERL optics was carried out with the simulation code Elegant, including CSR(coherent synchrotron radiation) effects. In this paper, we will present the results of the beam optics study for the compact ERL.

## TU6PF — Afternoon Poster APAC, HEHAC, PPHIB A15

### Production of High-Purity-Niobium under Industrial Scale for Upcoming Linear Collider Projects

Sheet material made of high-purity Niobium (Nb-RRR) is the key component for future linear accelerators based on the superconducting radio-frequency technology. To be prepared for large production scale quantities, which are demanded for the upcoming projects like XFEL and ILC respectively, W. C. Heraeus (D) and Plansee SE (A) joined their competencies in the field of Nb-RRR. In 2007 the qualification procedure as material supplier for the XFEL project could be successfully finished and a complete product and technology package for products made of Nb-RRR was established. Based on the combination of the high expertise and long-term experience in electron beam melting of different Nb-RRR qualities; the knowledge and availability of various processing technologies for manufacturing of semi-finished and ready to assemble components; and the unique analytical capabilities for advanced quality control along the process chain customized product solutions can be realized for the accelerator industry. Beside a general overview about the production capabilities a strategy for installation of a Quality-Assurance-Management system for large production scale quantities are presented.

**R. Grill**, W. Simader (Plansee Metall GmbH) B. Spaniol (W. C. Heraeus GmbH, Materials Technology Dept.) U. Weitzel-Hoefler (W. C. Heraeus GmbH COPY, Materials Technology Dept.)

### Design, Construction and Tests of a 10 MeV Linac for Polymer Radiation Processing

In China, polymer radiation processing has become one of the most important processing industries. The radiation processing source may be an electron beam accelerator or a radioactive source. Physical design of an electron beam facility applied for radiation crosslinking is introduced because of its much higher dose rate and efficiency. Main parts of this facility is a 10MeV travelling wave electron linac with constant impedance accelerating structure which is the first electron beam facility designed for polymer radiation processing by NSRL. A start to end simulation concerning the linac is reported in this paper. The codes Opera-3d, Poisson-superfish and Parmela are used to describe electromagnetic elements of the accelerator and track particle distribution from the cathode to the end of the linac. After beam dynamic optimization, wave phase velocities in the structure have been chosen 0.56, 0.9 and 0.999 respectively. Physical about main elements are presented. Main parameters' measurement about the linac proves that they are in a good agreement with the design values.

**G. Feng** (USTC/NSRL)

### Application of Portable 950 keV X-Band Linac X-Ray Source to Condition Based Maintenance for Pump-Impeller

T. Yamamoto, T. Natsui (UTNL) E. Hashimoto, S. Hirai, K. Lee, M. Uesaka (The University of Tokyo, Nuclear Professional School) J. Kusano, N. Nakamura, M. Yamamoto (A) E. Tanabe (AET Japan, Inc.)

We are developing X-ray nondestructive testing (NDT) system using with portable X-band linac. This system uses 9.4 GHz X-band linac and 250 kW magnetron. Our system energy is 950 keV for Japanese regulation. Therefore we can use it on-site using

local radiation protection. We measured electron beam and X-ray. We have started X-ray imaging test. We will use this system for condition based maintenance of pump-impeller at nuclear plants. The linac based X-ray source can generate pulsed X-ray. Therefore we can get still images without stopping rotation when x-ray repetition rate synchronizes impeller's rotation rate. We are successful in proof of principle using a simple fan and a synchronized circuit. We prepare real-time imaging for conventional pump. In this paper, we will explain the detail of this system and experimental results.

### Proton LINACs for Medical Applications

Y. Kawai Parker, H. Seki (AccSys)

AccSys has been built proton LINACs for medical applications such as Proton Beam Therapy (PBT), Positron Emission Tomography (PET) radioisotope production, and Boron Neutron Capture Therapy (BNCT). We will review the systems those have been shipped: For the PBT application, 6 systems have been shipped and under operation; for PET application, 5 systems have been shipped; for BNCT research application, one system has been shipped. We will also talk about high current proton linacs desired for BNCT and PET applications.

phy (PET) radioisotope production, and Boron Neutron Capture Therapy (BNCT). We will review the systems those have been shipped: For the PBT application, 6 systems have been shipped and under operation; for PET application, 5 systems have been shipped; for BNCT research application, one system has been shipped. We will also talk about high current proton linacs desired for BNCT and PET applications.

### Status Report on the Centro Nazionale di Adroterapia Oncologica (CNAO)

E. Bressi, M. Pullia (CNAO Foundation) C. Biscari (INFN/LNF)

The Centro Nazionale di Adroterapia Oncologica (National Center for Oncological Hadrontherapy, CNAO) is the Italian center

for deep hadrontherapy. It will deliver treatments with active scanning both with proton and carbon ion beams. The accelerator complex is based on a 25 m diameter synchrotron capable to accelerate carbon ions up to 400 MeV/u and protons up to 250 MeV. Four treatment lines, in three treatment rooms, are foreseen in a first stage. In one of the three rooms a vertical and a horizontal fixed beam lines are provided, while in the other two rooms the treatment will be administered with horizontal beams only. The injection chain is positioned inside the synchrotron ring itself, to save space and to better exploit the two non-dispersive regions in the synchrotron. The injection chain is made by a 8 keV/u Low Energy Beam Transfer line (LEBT), a RFQ accelerating the beam to 400 keV/u, a LINAC to reach the injection energy of 7 MeV/u and a Medium Energy Beam Transfer line (MEBT) to transport the beam to the synchrotron. This report describes the design and the performances of the CNAO complex, and reports about the status of the commissioning of the machine.

### Conceptual Design of Carbon/Proton Synchrotron for Particle Beam Therapy

Slow cycle synchrotron system for cancer therapy is presented to realize the pencil beam scanning with carbon and proton. The designed synchrotron's circumference is 60m and the maximum beam energies are 480MeV/u for carbon and 250MeV for proton.

**F. Noda**, F. Ebina, F. Fujitaka, H. Hae, H. Hiramoto, H. Nishiuchi, K. Saito, M. Umezawa (Hitachi, Ltd., Energy and Environmental System Laboratory) H. Akiyama (Hitachi Ltd., Power & Industrial Systems)

These energies correspond to the beam range of 35cm in water. In the treatment system with the present synchrotron, the discrete spot scanning scheme for lateral irradiation is employed using fast beam ON/OFF that is characteristic of the RF driven slow beam extraction from the synchrotron. Distal dose distribution is controlled with energy stacking technique, which is superimposing various bragg peaks which are controlled with the energy of the beam accelerated by the synchrotron. Furthermore, respiratory-gated operation with high throughput will be realized by the variable flat top length and timing for the beam extraction.

### Compact and Non Expensive Transport Systems for Medical Facilities Using Ion Beams

All known ion beam transport systems for medical applications with or without GANTRY are very large, complicated and expensive.

**M. M. Kats** (ITEP)

Its cost is comparable with accelerator facility itself. It stimulates search of beam transport and distribution systems that allow reducing their cost and sizes considerably keeping treatment efficiency. Two such transport system are considered in the present paper. The first one is based on bend magnets that are rotated around their center of mass with movement of patient in horizontal position around of magnets. The second one uses stationary magnets with movement of patient in horizontal position in vertical plane. It is shown that the proposed ion transport systems provide treatment efficiency comparable with GANTRY at considerably lower sizes, mechanical complexity and cost.

### Design Features of a 300 AMeV Superconducting Cyclotron for Hadron Therapy

The new steps in the design process will be presented.

**L. A.C. Piazza**, L. Calabretta, D. Campo, L. Celona, G. Cuttone, G. Gallo, D. Garufi, R. La Rosa, M. M. Maggiore, S. Passarello (INFN/LNS)

### Design of Laser-Driven Ion Accelerator Systems for Hadron Therapy at PMRC (Photo-Medical Research Center)

The cancer treatment with hadron beams continues to be made as hadron treatment facilities are being developed around the globe with state-of-the-art accelerator technology.

**H. Sakaki** (JAEA)

The generation of energetic protons and ions from laser-plasma interactions, has made laser-driven hadron radiotherapy a subject of strong interest. Proton bunches with high peak current and ultralow emittance are typical of ultrafast laser-foil interactions. However, these bunches also exhibit large divergence and energy spread. Photo Medical Research Center (PMRC) of JAEA was recently established to address the challenge of the laser-driven ion accelerator development for hadron therapy. Our mission at PMRC is

to develop integrated, laser-driven ion accelerator systems (ILDIAS) that demonstrate desired beam characteristics for such therapy. We used the Phase and Radial Motion in Ion Linear Accelerators (PARMILA) design software which was originally developed as a numerical tool to design and simulate beam performance. This report will discuss beam specifications of laser-driven ion accelerators using PARMILA.

### Feasibility Studies on the In-Vivo Experiments at the MC-50 Cyclotron Using a Prototype LEPT System

K. R. Kim, J.-H. Jang, M. H. Jung, S.-K. Lee (KAERI) Y. M. Lee (Kyungpook National University) T. K. Yang (KIRAMS)

A prototype LEPT (Low Energy Proton Therapy) system was developed and established at the MC-50 cyclotron in 2007. Some of the users of the PEFP (Proton Engineering Frontier Project) has been requiring a irradiation system for in-vivo experiments for the beam utilization in the fields of medical and biological sciences. We are studying on the possibility of in-vivo experiments the prototype LEPT system. The LEPT system consists of collimators, range shifter, modulator for SOBP, dose measurement system, etc. The energy and current from the cyclotron was 45 MeV and a few nA. For the in-vivo experiments accurate control of dose rate and penetration depth range is essential. The other important issue is how we can control the irradiation area and depth with high uniform dose distribution. We investigated the dose rate and uniformity of dose distribution inside the sample using PMMA and water phantom. The dose was measured by using ionization chamber and GAF films. The dose rate was 0.2~1Gy/sec and the penetration depth was 10~15 mm. The further studies using small animals using this LEPT system will be done by the users.

### Preliminary Results of Sample Activation Measurement Using a HPGe Detector for the Nano Particle Fabrication by Proton Beam Irradiation

K. R. Kim, J.-H. Jang, M. H. Jung, H. O. Kim, C. W. Lee (KAERI) Chai, G.s. Chai (Samsung SDI Co. Ltd.) H. J. Kim (Kyungpook National University) M. K. Min (SAMSUNG SDI CO. LTD)

The sample activation during proton beam irradiation sometimes interrupt the measurement and investigation of the instant changes of the samples after irradiation. During the experiments for nano particle fabrications with ~35MeV and ~20uA, we found that the samples was highly activated after the proton beam irradiation. To investigate the source of the rdadiation from the samples, we measured the energy spectrum of gamma ray using HPGe spectroscopy. The results was compared to the calculated results by the MCNP code simulation. The sample was small amount of heavy metal dispersed in enthanol in the beaker made of quartz.

### Extra Dose Reduction by Optimizing RF-KO Slow-Extraction at HIMAC

K. Mizushima, T. Fujisawa, T. Furukawa, Y. Iwata, K. Noda, S. Sato, T. Shirai (NIRS) H. Uchiyama (AEC)

A 3D scanning method gated with patient's respiration has been developed for the HIMAC new treatment facility. In the scanning irradiation, the RF-KO slow-extraction method has been used, because of the quick response to beam on/off from the synchrotron. However, a small amount of beam remained just inside the separatrix is extracted just before turning on the transverse RF field, which brings the extra dose. We proposed to apply another transverse RF-frequency component matched with the betatron frequency of the particles in the vicinity of the stopband, in addition to the original transverse RF field for the RF-KO slow-extraction. Using the proposed method, the particles just inside the separatrix, which cause



the extra dose, can be selectively extracted during the irradiation; as a result, the extra dose can also be reduced. The validity of this approach has been verified by the simulation and the measurement with the non-distractive 2D beam profile monitor. We will report the result of this approach.

### Status of the Siemens Particle Therapy Accelerators

Siemens has earned two contracts to deliver Particle Therapy\* systems to be operated in Marburg and Kiel, both in Germany. The accelerator consists of an injector (7 MeV/u protons and light ions) and a compact synchrotron able to accelerate proton beams up to 250 MeV and carbon ions up to 430 MeV/u. These beams can be slowly extracted and delivered to a choice of fixed-angle horizontal, semi-vertical and vertical beam-ports. An overview of the design will be given. At the time of PAC09 installation of the first system will be nearing completion and commissioning will have started. Performance of some of the components and the status of the projects will be presented.

**H. Rohdjess**, S. Emhofer, P. Fischer, V. L. Lazarev, M. Leghissa, B. Steiner, E. Tanke, P. Urschütz (Siemens Med) M. Budde, F. Bødker, I. Jensen, S. P. Møller, S. V. Weber (Siemens DK)

\*Particle Therapy is a work in progress and requires country-specific regulatory approval prior to clinical use.

### Electron Linac Concepts for the Production of Molybdenum 99

The medical isotope Molybdenum-99 is presently used for 80-85% of all nuclear medicine procedures and is produced by irradiating highly enriched uranium U-235 targets in nuclear reactors. It has been proposed\* that an electron linac be used for the production of <sup>99</sup>Mo via photo-fission of a natural uranium target. The nominal linac parameters are 50 MeV electron energy, 100 mA beam current and 100% duty factor. This paper describes two possible superconducting RF accelerator design concepts based on the frequencies of 704 MHz and 1.3 GHz. We present design parameters, efficiency and reliability estimates, and comparisons between the two options. Finally, we describe how the proposed e-linac project at TRIUMF can be used for proof-of-principle demonstration and critical validation tests of the accelerator-based production of <sup>99</sup>Mo.

**S. R. Koscielniak**, N. S. Lockyer, L. Meringa (TRIUMF)

\*Making Medical Isotopes: Report of the Task Force on Alternatives for Medical-Isotope Production (2008)

### Compton Backscattering Concept for the Production of Molybdenum-99

The medical isotope Molybdenum-99 is presently used for 80-85% of all nuclear medicine procedures and is produced by irradiating highly enriched uranium U-235 targets in NRU reactors. It was recently proposed that an electron linac be used for the production of <sup>99</sup>Mo via photo-fission of a natural uranium target coming from the excitation of the giant dipole resonance around 15 MeV. The photons can be produced using the braking radiation ("bremsstrahlung") spectrum of an electron beam impinged on a high Z material. In this paper we present an alternate concept for the production of <sup>99</sup>Mo which is also based on photo-fission of U-238, but where the ~15 MeV gamma-rays are produced by Compton backscattering of laser photons from relativistic electrons. We assume a laser wavelength of 330 nm, resulting in 485 MeV electron beam energy, and 10 mA of average current. Because the induced energy

**L. Meringa** (TRIUMF) G. A. Krafft (JLAB)

spread on the electron beam is a few percent, one may recover most of the electron beam energy, which substantially increases the efficiency of the system. The accelerator concept, based on a three-pass recirculation system with energy recovery, is described and efficiency estimates are presented.

### Pinpoint keV X-Ray Imaging for X-Ray Drug Delivery System

M. Uesaka (The University of Tokyo, Nuclear Professional School)  
K. Mizuno, A. Mori, T. Natsui, H. Taguchi, J. D. Trono (University of Tokyo)

In X-ray Drug Delivery System, anticancer drugs containing Pt, such as cisplatin and dachplatin, and Au colloid contrast agent are surrounded by polymers (micelle, PEG (polyethylene glycol), etc.). Their sizes are

controlled to be 20-100 nm. Since holes of capillary to organ are as large as 100 nm in only cancer, those large particles can be accumulated in cancer effectively. That is called as EPR (Extended Penetration and Retention effect). We have observed the distribution of Pt of dachplatin-micelle in cancer of mouse's pancreas by X-ray fluorescence analysis using 10  $\mu$ m pinpoint 15 keV X-ray by SPring8. Further, in-vitro- and in-vivo-experiments of Au colloid PEG are under way. It is expected to be used as contrast agent for dynamic tracking treatment for moving cancer. Imaging properties for polychromatic X-rays from X-ray tube and monochromatic Compton source are numerically analyzed and discussed. We continue to analyze radiation enhancement by Auger electrons and successive characteristic X-rays and its toxic effect to cancer.

### Biomolecular Cluster Irradiation System (DIAM)

M. J. Bajard (UCBL) C. Peaucelle (IN2P3 IPNL)

DIAM is a new experimental system created for study the processes initiated by protons impact upon clusters of biomolecules espe-

cially the mechanism resulting from ionization and fragmentation in a complex molecular nanosystem. The experimental setup is designed to analyse interactions of two beams: on the one hand, protons from an ECR source are accelerated and guided into a monochromatic beam of 20 to 150 kV and 1mA. On the other hand, a cluster source is mounted on a high tension plat-form (5 to 30 kV). In order to analyse the products of protons/cluster interaction of the 2 crossing beams, we use several detection system such as Electro spray Time of Flight (ESI-TOF) or mass spectrometers.

### MeV Ultrafast Electron Diffraction System at the NSLS SDL

Y. Hidaka, C. C. Kao, J. B. Murphy, S. Pjerov, B. Podobedov, H. J. Qian, S. Seletskiy, Y. Shen, X. J. Wang, X. Yang (BNL)

Ultrafast electron diffraction (UED) is a promising technique that allows us to observe a molecular structure transition on a time scale on the order of femtoseconds.

The UED has several advantages over the competing technology, X-Ray Free Electron Laser (XFEL) in terms of its compactness, 6 orders of magnitude larger cross section, and less damaging ability to the samples being probed. Present state-of-the-art UED systems utilize subrelativistic electron bunches as the probing beam. With such low energy, however, the number of electrons in the bunch must be significantly decreased for a short bunch length (~100 fs) due to space charge effects. This limits the detection capability of such keV UED devices. To overcome this issue, a UED system using an MeV electron beam has been proposed, and designed at Source Development

Laboratory (SDL) in National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory (BNL). A detailed performance analysis of this system using the particle tracking code, GPT, from the photoinjector cathode to the detector, will be presented, as well as the status of the commissioning of our UED system.

### Magnetic Property Changes of FeMn-NiFe Thin Films by the Irradiation of Various Ion Species

The exchange biased anisotropy with unidirectional characteristics originates from the exchange interaction between ferromagnetic (FM) spins and anti-ferromagnetic (AFM) spins at their interface. Exchange bias in the interfaces of FM/AFM alloy films by Ion irradiation using various ion (H, He, N, Ar etc.) species were investigated. The VSM carried out on sputtered exchange biased films before and after Ion irradiation. Exchange bias and magnetic characteristics of NiFe/FeMn exchange coupled bilayer are extremely sensitive to the NiFe(111) texture. Ion irradiation oriented NiFe tends to provide an exchange interaction at the interface between NiFe and FeMn films and this interaction changes an exchange bias field. He ion irradiation on the NiFe-FeMn system shows an increase of exchange bias field and coercivity as He ion dose increase. But the field decrease over  $4 \times 10^{14}$  ions/cm<sup>2</sup> dose. After Critical ion dose, the exchange bias field was vanished.

Y. Noh, K. R. Kim (KAERI)

### Integration of Scanning Probes with Ion Beams with Application to Single Ion Implantation

The integration of scanning probes with ion beams enables non-destructive, nanometer scale imaging and alignment of ion beams to regions of interest in to be implanted device structures. We describe our basic approach which uses piezo-resistive force sensors and pierced cantilevers as dynamic shadow masks, integrated with low current (<1 mA), low energy (<1 MeV) ion beams from a series of ion sources (ECR and EBIT). Single ion sensing strategies based on charge transients induced in devices and detection of secondary electrons are discussed. We will show results from our studies of single ion doping of 50 nm scale transistors in tests of radiation response mapping of transistors with this technique.

T. Schenkel (LBNL)

### Dual-Energy Operations at LANSCE for Proton Induced Nuclear Cross Section Measurements

The WNR facility at LANSCE is preparing for a set of proton induced cross section measurements in support of the LANL Isotope Production Program. To determine the best way to produce particular isotopes, it is necessary to measure the production rate's energy dependence. The first measurements will use a 197-MeV proton beam, which prompted recovery of the facility's ability to transport multiple energy proton beams simultaneously to different experimental areas to ensure that an 800-MeV beam is available for Proton Radiography or Ultra-Cold Neutron experiments while a sample is irradiated with a lower energy beam for the cross section measurements. The ability to change the beam energy pulse-to-pulse was built into the original accelerator controls, but the multiple energy controls were unused for over a decade and the system was re-commissioned for this effort. These

M. S. Gulley, H. Bach, L. J. Bitteker, A. J. Couture, R. E. Gritzo, F. M. Nortier, C. Pillai, A. Seifter, D. M. Smith, J. L. Ullmann, F. O. Valdez, S. A. Wender (LANL)

experiments form part of an effort to establish a capability for the measurement of cross sections in the 197 to 800 MeV energy range. The experiments are expected to provide the needed data for activities that may develop into a unique isotope production capability to compliment the existing 100-MeV IPF facility.

### Decontamination of Antistress Food Supplement Components by Irradiation with Electron Beam

R. D. Minea, M. Dumitrascu, E. Mitru, E. Sima (INFLPR) P. Constantinescu (ISPB) E. Mazilu (Hofigal S. A.) V. Meltzer (University of Bucharest, Faculty of Chemistry)

The use of ionizing radiation for microbial decontamination of medicinal plants as well as the derived products from them is an efficient and ecological method. Regarding to achieve a new phytotherapeutic product

“food supplement with antistress properties” exclusively based on medicinal plants, we proposed to study the irradiation effects with electron beam on the most important compounds with therapeutic action correlated with necessary decontamination degree. The samples grinded very well (*Hypericum perforatum*, *Valeriana officinalis*, *Urtica dioica*, *Hippophae Rhamnoides* and *Momordica charantia*) were irradiated with doses from 0.25 up to 5 kGy. The active principles and microbial load were investigated for each sample before and after irradiation. The behaviour of active principles was analyzed by spectrophotometry, HPLC and DSC. Were tested following microbiological markers: total number of germs, coliforms bacteria, *E. coli*, *Salmonella*, yeasts and moulds. The results showed that the decontamination by irradiation with electron beam is influenced by the initial microbial load and the irradiation dose.

### Spectrocolorimetric Methods Used to Evaluate the Radioinduced Changes in Irradiated Medicinal Plants with Electron Beam in Order to Decontaminate

R. D. Minea, M. Dumitrascu, E. Mitru, E. Sima (INFLPR) E. Mazilu (Hofigal S. A.)

In this paper is presented a simple method, fast and nondestructive to evaluate the radio induced changes produced by electron beam irradiation of medicinal plants in order

to decontaminate and use them to obtain the phytotherapeutic products. Color Measurement systems are used globally for research or quality control in a series of applications: textile, paints and coatings, food and pharmaceutical industry. The solid samples grinded very well were measured with an UltraScan Pro spectrocolorimeter by reflectance, in the wavelength range 350–10-50 nm, illuminant D65/10. The irradiation doses were: 0, 0.25, 0.5, 1, 1.5, 2, 3, 4 and 5 kGy. For each sample were effectuated 20 measurements that has been mediated and processed with Easy Match QC program. The total color differences, calculated between the unirradiated and irradiated samples and the parameters variation of color depending on the dose of radiation were determined with this method.

### Swift Heavy Ion Induced Modifications at Multilayered Mo/Si System

G. Agarwal, I. P. Jain, V. K. Kulshrestha, R. Verma (UOR) D. Kabiraj (IUAC)

Swift Heavy Ion (SHI) induced modification at Metal/Si interfaces has emerged as an interesting field of research due to its large applications. In the present study we investigate

SHI induced mixed molybdenum silicide film with ion fluences. The Molybdenum and Si thin thin films were deposited on Silicon substrates using e-beam evaporation at  $10^{-8}$  torr vacuum. Thin films were irradiated with Au

ions of energy 120 MeV to form molybdenum silicide. The samples were characterized by grazing incidence X-ray diffraction (GIXRD) technique for the identification of phase formation at the interface. Rutherford backscattering spectrometry (RBS) was used to investigate the elemental distribution in the films. The mixing rate calculations were made and the diffusivity values obtained leads to a transient melt phase formation at the interface according to thermal spike model. Irradiation induced effects at surface have been observed and roughness variations at the surface were calculated using atomic force microscopy (AFM) technique.

### SHI Induced Effect on Structural, Optical and Electrical Properties of Nickel Nitride Thin Films

Binary nitrides are an interesting set of compounds that display a wide range of properties such as thermal stability or electrical conductivity. The study of their bonding properties to metals and semiconductors, for instance via swift heavy ion irradiation, is of great importance. Here, we report the ion induced effects on Ni<sub>3</sub>N/Si bilayers system. After the 100 MeV Au<sup>+8</sup> ion irradiation at higher fluence, strong mixing and formation of Ni<sub>2</sub>Si and Si<sub>3</sub>N<sub>4</sub> phases were detected at the Ni<sub>3</sub>N/Si interface. Optical properties of nickel nitride films, which were deposited onto Si (100) by ion beam sputtering at vacuum 1.2×10<sup>-4</sup> torr, were examined using Au ions. In-situ I-V measurement on Ni<sub>3</sub>N/Si samples were also under taken at room temperature. It was observed from I-V measurements that there is an increase in current with increasing fluence of Au<sup>+8</sup> ions, while as-deposited sample is almost electrically insulator.

R. Dhunna, I. P. Jain, C. Lal, V. Sisodia (UOR)

### Conceptual Design of a Helium Ion FFAG for Helium Embitterment Research

In recent years, Fixed Field Alternating Gradient (FFAG) accelerator is becoming a highlight in particle accelerator R&D area. This type of accelerator could accelerate ions with higher beam current than conventional strong focusing circular accelerator, which could be more useful for the study of radioactive material. In this paper, conceptual design of an FFAG with high Helium ion beam current and a few MeV energy which is dedicated to study the impact of Helium embitterment to fusion reactor envelope material is discussed, the periodic focusing structure model is given, following which the calculation result of magnetic field is also presented.

H. L. Luo, H. Hao, X. Q. Wang (USTC/NSRL)

### Improvement of Compact Pico-Second and Nano-Second Pulse Radiolysis Systems at Waseda University

A pulse radiolysis method is very useful in clarifying primary processes of radiation chemistry. At Waseda University, compact pico-second and nano-second pulse radiolysis systems have been developing. A pico-second system is based on pump-probe method. IR and UV pico-second laser pulses are generated from Nd:YLF mode-locked laser and used for generating of white light continuum as analyzing light and irradiating to photo-cathode RF gun, respectively. Recently, we have installed a new photo-cathode RF gun with Cs-Te cathode which has high quantum efficiency, so we have succeeded in improving optical density and S/N ratio of our pulse radiolysis system. We are now developing a new nano-second system which can get time profile with only one-shot and follow up wider time region than pico-second system. In the past, this system has been used He-Ne laser as analyzing light, but it can measure only 633nm. Instead of He-Ne laser, this

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system adopts Xe flush lamp which has broad spectrum as analyzing light. As system evaluation experiments, we tried to get time profile of some species. In this conference, present status and future plans of our pulse radiolysis systems will be reported.

### GENEPI-3C, a Versatile Neutron Generator for the GUINEVERE ADS Feasibility Studies

J.-M. De Conto, M. A. Baylac, A. Billebaud, P. Boge, D. Bondoux, J. Bouvier, T. Cabanel, Y. Carcagno, G. Dargaud, E. Froidefond, Y. Gomez-Martinez, M. Heusch, D. Marchand, R. Micoud, E. Perbet, M. Planet, D. Tourres (LPSC) P. Beaten, G. Vittiglio (SCK-CEN) G. Gaudiot, G. Heitz, P. Poussot, C. Ruescas (IPHC) J. M. Gautier, Y. Merrer (LPC) G. Granget, F. Mellier (CEA Cadarache) J. Laune, D. Reynet (IPN)

GUINEVERE, Generator-of-Uninterrupted-Intense-NEutrons-at-the-lead-VEenus-REactor, is devoted to ADS feasibility studies and to investigate on-line reactivity monitoring, sub-criticality determination and operational procedures. It will couple a versatile neutron source to the VENUS-F lead core at the SCK-CEN site in Mol (Belgium). It is based on an electrostatic accelerator

generating 14 MeV neutrons by bombarding a deuteron beam on a tritium target located in the reactor core. A new accelerator has been developed. It will produce alternatively 1  $\mu$ s 250 keV deuteron pulses with adjustable repetition rate (40 mA peak), as well as continuous beam (1 mA) with programmable interruptions. Beam will be inserted vertically into the reactor core. The accelerator is designed to enable the vertical section of the beam line to be easily lifted out the reactor bunker for maintenance operations, target changes and core loading procedures. This paper will describe the design of the accelerator and its commissioning in Grenoble (France), before its transfer to the Belgian site. This work is performed within the 6th Framework Program EC project EUROTRANS.

### Reactor Design Studies for an Accelerator Driven System

C. Bungau (Manchester University) R. J. Barlow (UMAN) R. Cywinski (University of Leeds)

Nuclear power production can benefit from the development of more comprehensive alternatives for dealing with long-term radioactive waste. One such alternative is an

accelerator-driven system which has been proposed for energy production and for burning radioactive waste. Different reactor designs have been investigated in order to improve the power distribution inside the reactor core for different spallation targets. The impact of the proton beam energy, target material and the fuel composition on the reactor performance was also examined.

### 6D Acceleration Studies in Proton Fixed Field Alternating Gradient Accelerator Lattices

S. C. Tygier (Manchester University) R. J. Barlow, H. L. Owen (UMAN)

It has been proposed to use a proton Fixed Field Alternating Gradient (FFAG) accelerator to drive an Accelerator Driven Subcritical Reactor (ADSR) as they have the potential to

provide high current beams to energies needed, 500 MeV to 1 GeV. This paper describes the results of 6D simulations of acceleration in possible lattice designs to explore longitudinal acceptance. This is needed to evaluate accelerator duty cycle and options for acceleration such as harmonic number jumping.

### Research on a Terahertz Coherent Transition Radiation Source Based on Ultrashort Electron Beam

The preliminary experiments and three-dimensional (3D) particle-in-cell (PIC) simulations of terahertz (THz) coherent transition radiation (CTR) performed at the Accelerator Laboratory of Tsinghua University are reported in this paper. THz radiation is generated from the interactions of Titanium foil with the ultrashort electron beam produced by the photocathode RF gun. The frequency and power of radiation are measured with the Martin-Pupplet interferometer and Gollay Cell detector, respectively. The radiation characteristics depending on the foil properties are preliminarily studied with the experiments and PIC simulations. On the other hand, the distribution of radiation field pattern and energy are studied by numerical calculated, and those results are in agreement with the PIC simulations.

W. Liu, Y.-C. Du, W.-H. Huang, R. K. Li, C.-X. Tang, D. Wu, L. X. Yan (TUB)

### Comparison of Excitation Function for the $^{64}\text{Cu}$ Production via Various Nuclear Reactions

Cu has a branched decay ( $\beta^-$ : 38.5 %,  $\beta^+$ : 18 %; EC: 43.5 %) that ensures the potential to serve a dual role in the development of molecular agents in PET. TALYS 1.0 code was used to calculate excitation functions for proton induced on  $^{66}\text{Zn}$ ,  $^{67}\text{Zn}$ ,  $^{68}\text{Zn}$ ,  $^{70}\text{Zn}$  and  $^{64}\text{Ni}$  deuteron induced on  $^{64}\text{Zn}$ ,  $^{66}\text{Zn}$ ,  $^{67}\text{Zn}$ ,  $^{68}\text{Zn}$ , and  $^{64}\text{Ni}$  that lead to produce  $^{64}\text{Cu}$ ; calculates was performed out up to 50 MeV. Recommended thickness of the targets according to SRIM code was premeditated. Theoretical integral yields for any reaction were computed. The code predicts that maximum yield of proton induced on  $^{66}\text{Zn}$  is 2.379 MBq/uA·h and maximum yield of deuteron induced on  $^{64}\text{Zn}$  is 2.053 MBq/uA·h with high impurity production in entire energy range. Using a target of high isotopically enriched  $^{64}\text{Ni}$ , proton energy of 3 to 12 MeV, resulted in yield as two much than the optimum previous methods (4.403 MBq/uA·h), without any impurity. Isotopic impurities via  $^{64}\text{Ni}(d,x)^{64}\text{Cu}$  is in full benefit energy range while  $^{64}\text{Cu}$  yield is 10.545 MBq/uA·h.  $^{64}\text{Ni}(d,x)^{64}\text{Cu}$  processes can be an efficient route and economic for the production of  $^{64}\text{Cu}$  with incident beam energy less 15 MeV using low energy accelerator. AJ Koning, S Hilarie and M Duijvestijn, A nuclear reaction program. TALYS 1.0. NRG - Nuclear Research and Consultancy Group. (2007)

M. Sadeghi (Agricultural, Medical & Industrial Research School) Z. Gholamzadeh, S. Seyyedi (Islamic Azad University, Faculty of Engineering)

### No-Carrier-Added $^{109}\text{Cd}$ Production from Silver on a Gold-Coated Copper Backing

Cadmium-109 (462.6 days) decays by electron capture to  $^{109m}\text{Ag}$  with the emission of a  $\gamma$ -ray of 88.03 keV (3.61%). it is use as sources to calibrate nuclear instruments. Silver electrodeposition on gold substrate carried out by the alkaline baths to production  $^{109}\text{Cd}$ . Gold was electrodeposited on copper backing initially; the bath content consisted of 17.7 gl-1 KCN, 6.6 gl-1 Au, 6.6 gl-1  $\text{K}_2\text{CO}_3$  and 3.3 gl-1  $\text{Na}_2\text{CO}_3$ , acidity=10 and 45°C temperature. Gold layer of 61  $\mu\text{m}$  thicknesses with satisfactory morphology obtained after 19 hour. Silver coated on gold substrate with 100% efficiency using bath conditioned 7.7 gl-1 KCN, 7.7 gl-1 AgCN and 3.3 gl-1  $\text{Na}_2\text{CO}_3$  at pH=10 and 40°C temperature.  $^{109}\text{Cd}$  was produced via  $^{109}\text{Ag}(p,n)^{109}\text{Cd}$  reaction, 15 MeV proton beam and current of 150 mA. Then the target was dissolved by 5 M  $\text{HNO}_3$  at 45°C.  $^{109}\text{Cd}$  separated from silver in the solution

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by 0.015M HCl precipitation with recovery of more than 99% involved silver impurity of less 1 ppm. The  $^{109}\text{Cd}$  production yields were  $1.88 \mu\text{Ci}/\mu\text{A}\cdot\text{h}$  ( $0.069 \text{ MBq}/\mu\text{A}\cdot\text{h}$ ) before and after separation.

### Design of L-Band High Power Linac for Irradiation Processing

H. C. Liu, S. Fu, G. Pei (IHEP Beijing)

A high power L-band electron accelerator is designed for irradiation applications. It is capable of producing 10 MeV electron beam with more than 30kW average power. A Thales klystron is chosen for the RF power source, with frequency of 1300MHz, pulsed power of 9MW and average power of 80kW. A traveling wave structure is designed with a quasi-constant gradient and operated with  $2\pi/3$  mode. The beam dynamics simulation shows about 90% beam transmission efficiency and an acceptable beam size. RF structure and its thermal analysis of the accelerating tube are studied. Design details are presented in this paper.

### A University-Based Accelerator Complex for Pulsed Neutron and Proton Applications, Therapy, and Accelerator-Driven Sub-Critical System Tests

J. Wei (IHEP Beijing)

During the past decades, large-scale national neutron sources are developed in Asia, Europe, and USA. Complementing such efforts, compact hadron beam complexes and neutron sources intended for universities and industrial institutes are proposed and established. Responding to the demands in China for multidisciplinary researches and applications using pulsed neutrons and protons, hadron therapy and radiography, and accelerator-driven sub-critical reactor systems (ADS) for nuclear waste transmutation, we here propose a compact yet expandable accelerator complex based on a proton source, a 3 MeV RFQ linac, and a 22 MeV DTL linac. A Be target with solid methane and room-temperature water moderators serve 6 neutron stations for imaging/radiography, irradiation, SANS, engineering powder diffraction, instrumentation, and therapy. The proton platform serves multiple stations for bio-applications, fuel cell and nano-applications, and space irradiation and detection. A rapid cycling synchrotron subsequently accelerates the beam to up to 300 MeV for proton therapy and radiography. Following the DTL linac with a superconducting RF linac and a sub-critical reactor offers an ADS test facility.

### The First Results of the SOPHI Experiment at Saclay

O. Delferriere, A. Curtoni, P. Dupré, L. Liszakay, T. Muranaka, P. Perez, J. M. Rey, N. Ruiz, Y. Sacquin (CEA)

At Saclay, a high intensity positron source, SOPHI, has been built, to provide  $10^8$  slow  $e^+/s$ , i.e. a factor  $\sim 10^0$  greater than the strongest activity Na22 based setups. The SOPHI experiment is a device based on a small 5 MeV electron linac to produce positrons via pair production on a tungsten target. The linac has been commissioned and the assembly is already finished. First positron production test are planned for the beginning of December. The experiment will be described in details and first positron production rate measurements reported. Further developments are underway like the conception of a solid Ne moderator to produce a large amount of slow positrons, or the study of a Penning-Malmberg trap that can be adapted to store and extract  $10^{10}$  to  $10^{11}$  positrons in ultra high vacuum conditions. The future of the experiment and its combination with antiprotons at CERN for the antimatter experiment will be briefly discussed.



### End-to-End Spectrum Reconstruction Method to Assist Electron Beam Parameters Determination from Compton gamma-Ray Beam

A gamma-ray beam produced by Compton scattering of a laser beam with a relativistic electron beam can be used to measure the electron beam parameters. In the past, the

electron beam energy and energy spread was directly fitted from the high energy edge of the full energy peak of the measured gamma beam spectrum. However, under some circumstances, the full energy peak could be buried in the measured gamma beam spectrum. Thus, the measured spectrum need to be unfolded before being used for the determination of the electron beam parameters. In this paper, we will present a novel end-to-end spectrum reconstruction method to unfold the gamma beam spectrum. With the assistance of this method we have accurately measured the energy and energy spread of the electron beam in Duke storage ring using a Compton gamma-ray beam from the High Intensity gamma-ray Source (HI gamma S) facility.

C. Sun, Y. K. Wu (FEL/Duke University) G. Rusev, A. Tonchev (TUNL)

### Studies of High Energy Density Matter Using Intense Ion Beams at FAIR at Darmstadt: The HEDgeHOB Collaboration

Studies of High Energy Density (HED) states in matter is one of the recently proposed important applications of intense particle beams. GSI Darmstadt is worldwide famous due to its unique accelerator facilities.

Construction of the new accelerator FAIR, will enhance these capabilities many fold. During the past years, extensive theoretical work has been carried out to propose future HED physics experiments that could be carried out at FAIR. It is expected that the new heavy ion synchrotron, SIS100, will deliver a uranium beam with  $10^{12}$  uranium ions that will be delivered in a single bunch, 50 – 100 ns long. Circular, elliptic and annular focal spots can be generated that will allow one to perform different type of HED physics experiments. This work has shown that using a special technique, named HIHEX, one may access those areas of the phase diagram that have never been accessed before. Using another experimental configuration, LAPLAS , it will be possible to generate physical conditions that are expected to exist in the interiors of the giant planets. Material properties under dynamic conditions can also be studied using a third experimental set up.

N. A. Tahir (GSI) V. E. Fortov, I. Lomonosov, A. Shutov (IPCP) D. Hoffmann (TU Darmstadt) R. Piriz (Universidad de Castilla-La Mancha)

### Material Recognition by Means of Different Bremsstrahlung Beams: Is that Really Possible?

At the Dipartimento di Fisica, Università di Messina, an X-ray source based on a 5 MeV electron linac has been designed. By means of the MCNP-4C2 code, several simulations have been performed to evaluate if the source can be used as a NDT device for material recognition purposes. In particular, being able to vary the electron beam energy for producing bremsstrahlung beams with different absorption, X-ray transmission through several materials and for different X-ray beams energy has been studied. First results have shown the capability of the system to distinguish dissimilar materials by properly choosing the X-ray beam end-point energy and processing the obtained transmission values.

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Since the uncertainties level in the material identification could be improved differentiating the response of the imaging system, a theoretical study has been performed to evaluate how X-ray beams obtained with different end-point energies, and eventually transmitted by properly chosen filters, are absorbed by different scintillators. The obtained results will be presented and discussed in order to give indications on the real chance to use the designed device for material recognition purposes.

### Ring Optics for Compact X-Ray Source

C. Bruni, Y. Fedala, J. Haissinski, M. Lacroix, R. Roux, A. Variola (LAL) P. Brunelle, A. Loulergue (SOLEIL)

The goal of X-ray sources based on Compton back scattering processes is to develop a compact device, which could produce an intense flux of monochromatic X-rays. Compton back-scattering results from collisions between laser pulses and relativistic electron bunches. Due to the relative low value of the Compton cross section, a high charge electron beam, a low emittance and a high focusing at the interaction point are required for the electron beam. In addition, the X-ray flux is related to the characteristics of the electron beam, which are themselves dynamically affected by the Compton interaction. One possible configuration is to inject frequently into a storage ring with a low emittance linear accelerator without waiting for the synchrotron equilibrium. As a consequence, the optics should be designed taking into account the characteristics of the electron beam from the linear accelerator. The accelerator ring design for a 50 MeV electron beam, aiming at producing a flux higher than  $10^{13}$  ph/s, will be presented.

### Fast Pulsing Neutron Generators for Security Application

Q. Ji, J. W. Kwan (LBNL)

Active neutron interrogation has been demonstrated to be an effective method of detecting shielded fissile material. A fast fall-time/fast pulsing neutron generator is needed primarily for differential die-away technique (DDA) interrogation systems. A compact neutron generator, currently being developed in Lawrence Berkeley National Laboratory, employs an array of 0.25-mm-dia apertures (instead of one 5-mm-dia aperture) such that gating the beamlets can be done with low voltage and a small gap to achieve sub-microsecond ion beam fall time and low background neutrons. The system will aim at both high and low beam current applications. We have designed and fabricated an array of 16 apertures (4x4) for a beam extraction experiment. Our preliminary results showed that, using a gating voltage of less than 800 V and a gap distance of 1 mm, the fall time of extracted ion beam pulses is less than 1 ms at various beam energies ranging between 200 eV to 600 eV. More experimental results with an array of 20x20 apertures will be presented.

### Dual-Energy Electron Linac for Cargo Inspection System

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In today's turbulent and unsecure world, an X-ray radiographic image and a dual-energy Z-detection mapping of a container contents are needed to provide a reasonable level of port and border security. An interlaced dual-energy electron-beam linac has been developed for the use in cargo inspection systems to meet this growing need. Electron energy of the linac is software controllable from 3 to 15 MeV. Nominal operating energy levels of 4 and 9 MeV were chosen. The 9 MeV beam energy operating point is used for generating the X-ray radiographic image

while 4 and 9 MeV beams are used for Z-detection mapping. The S-band linac has been calculated, designed, built and tested. Frequency repetition rate of alternating 4 and 9 MeV beams is 240 Hz. Pulse length is 10 usec. The beam energy in each beam pulse is over 10 J.

### Design Study of an Accelerator Mass Spectrometer Based on a Cyclotron

An accelerator mass spectrometer (AMS) based on a compact cyclotron has been studied for biomedical uses. The system will have the mass resolving power of over 4000 to analyze a few different kinds of isotopes for tracing or chronometric dating. High transmission efficiency is a major design goal to compete with a Tandem AMS. A compact magnet with high stability, a saw tooth harmonic buncher, and flat-topping rf system are the components needed to achieve the goal. The results of design study for the AMS cyclotron and its injection line will be presented as well as the results of model tests for the cavity and the buncher.

J.-W. Kim (NCC, Korea) M. Youn, C. C. Yun (SNU)

### Development of Laser Compton Scattering X-Ray and High Intense THz Sources Based on S-Band Compact Linac

We have developed the laser Compton Scattering (LCS) X-ray and high intense THz sources based on the S-band Compact Linac. In case of the LCS X-ray source, a multi-collision LCS scheme has been developed using multi-bunch electron beam and a laser cavity based on a regenerative amplification. In case of the THz source, coherent THz radiation has been obtained using an ultra-short electron bunch and the THz time domain spectroscopy (TDS) and imaging system have been developed. In this conference, we will report present statuses of these developments.

R. Kuroda, H. Ikeura-Sekiguchi, M. K. Koike, H. Ogawa, N. Sei, H. Toyokawa, K. Y. Yamada, M. Y. Yasumoto (AIST)

### Design and Test of a Low Run-Out Rotating Sample Stage for TXM at NSRRC

A low run-out rotating sample stage is under development to realize a precise resolution within 30 nm on the horizontal plane for the end-station of transmission X-ray microscope (TXM) at NSRRC. The main assembly consists of a commercial rotation stage with run-out less than 1  $\mu\text{m}$ , six capacitive sensors, one master ball, one flat and a horizontal adjusting stage. Error sources (including the profile of the master ball, run-out of the master ball in horizontal and vertical directions, flat plate) are separated from stage and the sensor readings can be down to the nanometer level. A feedback method is proposed to compensate the systematic errors and keeps the samples with little run-out and axial motion in the level of several tens nanometer. The details and tests of the rotation stage are presented in this paper.

H. S. Wang (NSRRC)

### High-Flux Inverse Compton Scattering Systems for Medical, Industrial and Security Applications

S. Boucher, P. Frigola, A. Y. Murokh (RadiaBeam) I. Jovanovic (Purdue University) J. B. Rosenzweig, G. Travish (UCLA)

Conventional X-ray sources used for medical and industrial imaging suffer from low spectral brightness, a factor which severely limits the image quality that can be obtained. X-ray sources based on Inverse Compton Scattering (ICS), in which a high-power laser scatters off a relativistic electron beam, hold promise to greatly improve the brightness of X-ray sources. While ICS sources have previously been demonstrated, and have produced high-peak brightness X-rays, so far experiments have produced low average flux, which limits their use for certain important commercial applications (e.g. medical imaging). RadiaBeam Technologies is currently developing a high peak- and average-brightness ICS source, which implements a number of improvements to increase the interaction repetition rate, as well as the efficiency and stability of the ICS interaction itself. In this paper, we will describe these improvements, as well as plans for future experiments.

### Magnet Design and Testing of a FFAG Betatron for Industrial and Security Applications

S. Boucher, R. B. Agustsson, P. Frigola, A. Y. Murokh, M. Ruelas (RadiaBeam) F. H. O'Shea, J. B. Rosenzweig, G. Travish (UCLA)

The fixed-field alternating-gradient (FFAG) betatron has emerged as a viable alternative to RF linacs as a source of high-energy radiation for industrial and security applications. RadiaBeam Technologies is currently developing an FFAG betatron with a novel induction core made with modern low-loss magnetic materials. The principle challenge in the project has been the design of the magnets. In this paper, we present the current status of the project, including results of the magnet design and testing.

### Generation of Electron Beam Train with Adjustable Spacing for Coherently Enhanced Terahertz Radiation Source

Y.-C. Du, W.-H. Huang, R. K. Li, W. Liu, C.-X. Tang (TUB)

We proposed a method to generate a train of electron beams with adjustable spacing for producing coherently enhanced terahertz radiation source. In this scheme, the train of electron beams is generated by a DC gun and a mask placed in a region of the beam line where the beam transverse size is dominated by the correlated energy spread. Particle tracking simulations and analysis show that the number, length, and spacing of the train can be controlled through the parameters of the beam and mask, and it is feasible to generate narrow-band THz radiation.

### Coherent Terahertz Radiation Emitted by Sub-Picosecond Electron Bunches in a Magnetic Chicane

M. P. Dunning, G. Andonian, A. M. Cook, E. Hemsing, S. Reiche, J. B. Rosenzweig, D. Schiller (UCLA) M. Babzien, K. Kusche, V. Yakimenko (BNL) A. Y. Murokh (RadiaBeam)

Coherent radiation emitted by relativistic electrons traversing the magnetic field gradients of a chicane bunch compressor was extracted and transported for measurement, using a dedicated terahertz beamline at the

Accelerator Test Facility (ATF) at Brookhaven National Laboratory (BNL). Measurements include frequency spectrum, angular distribution, and polarization of the radiation. Previous measurements indicate that the electron bunch length is approximately 150fs, with a peak current exceeding 1.5kA. Measurements of radiation from the short pulses are compared to predictions from QUINDI, a new simulation code developed at UCLA to model radiation emitted by charged particles in bending systems. In addition to being a source of broadband terahertz radiation, the system is also used as a non-invasive, single-shot, relative bunch length diagnostic to monitor compression in the chicane.

### Exploring the Feasibility of Stand Alone Muon Facility for MuSR Research

The current paper discusses possible designs for a high intensity stand alone muon source for muSR studies of condensed matter. In particular we shall focus upon the potential implementation of a new generation of high power but relatively compact and cost effective proton drivers based on non-scaling fixed field alternating gradient (ns-FFAG) accelerator technology. The technical issues which must be addressed are also considered.

**A. Bungau** (University of Huddersfield) R. Cywinski (University of Leeds) P. J.C. King, J. S. Lord (STFC/RAL)

TU6PFP050

### Development and Optimisation of the Muon Target at the ISIS-RAL Muon Facility

The pulsed muon channel of the ISIS facility at Rutherford Appleton Laboratory has been successfully commissioned and operated for many years as a tool for MuSR studies in condensed matter research. At the present time, the graphite target, of dimensions 50\*50\*7 mm oriented at 45 degrees to a proton beam of 800 MeV energy, gives 16000 surface muons per double proton pulse passing through the entrance aperture of the aluminium window which separates the muon beamlines from the main proton beam. Potential improvements to the target geometry, and optimisation of the design and estimated performance of the muon target are presented in this paper.

**A. Bungau** (University of Huddersfield) R. Cywinski (University of Leeds)

TU6PFP051

### GEANT4 Simulations of the ISIS Muon Target at Rutherford Appleton Laboratory

MuSR science requires the availability of intense beams of polarised positive muons. At the ISIS pulsed muon facility at Rutherford Appleton Laboratory the muons are generated from a low Z thin slab graphite target inserted in the proton beam. We report on the use of the Monte Carlo simulation code Geant4 in simulations of the performance of the current muon target. The results are benchmarked against the experimental performance of the target.

**A. Bungau** (University of Huddersfield) R. Cywinski (University of Leeds) P. J.C. King, J. S. Lord (STFC/RAL)

TU6PFP052

### Structural and Optical Properties of AlN/Si System

R. Dhunna, I. P. Jain, C. Lal, V. Sisodia (UOR)

Aluminum nitride (AlN) is a wide band gap III-V semiconductor material which is often used for optical applications. Thin films of aluminum nitride were deposited by ion beam sputtering in an Ar-N<sub>2</sub> atmosphere on Si (100). For film preparation the N<sub>2</sub> flow was kept 5 sccm and the ratio of N<sub>2</sub> and Ar was 4:1. The films have been characterized by grazing incidence X-ray diffraction, X-ray reflectivity, atomic force microscopy and optical spectroscopy. GIXRD shows that the structure of as-deposited sample of AlN is hexagonal. It is observed that neither ion-beam induced dissociation of the nitride film nor enhanced nitrogen diffusion across the interface takes place after irradiation. XRR was used to determine the thickness of the films. The reflectance of the irradiated films increases in the range of 200 -- 280 nm. UV-vis spectra were taken in Kubelka Munk (KM) units for as-deposited and irradiated samples. The band gap was calculated for both types of samples which show that the band-gap of irradiated films of aluminum nitride decreases due to increase in metal content at the surface. AFM confirms that the roughness of aluminum nitride increases by irradiation.

Aluminum nitride (AlN) is a wide band gap III-V semiconductor material which is often used for optical applications. Thin films of

### Simulation of Longitudinal Phase Space Painting for the CSNS RCS Injection

L. Liu, J. Qiu, J. Tang, T. Wei (IHEP Beijing)

China Spallation Neutron Source (CSNS) is a high power proton accelerator-based facility. One of the primary concerns in designing high-intensity proton facilities is the radio-activation caused by uncontrolled beam loss that can limit the machine's availability and maintainability. For the rapid cycling synchrotron (RCS) of the CSNS, the repetition frequency is too high for the longitudinal motion to be fully adiabatic. Significant beam loss happens during the RF capture and initial acceleration of the injection period. The design of the CSNS RCS injection system has been attempting to reduce the beam loss by increasing the beam emittance and beam uniformity to alleviate the transverse space charge effects. The beam loss due to the RF capture, acceleration and the bunch factor is the dominance to determine the longitudinal injection mode and the RF pattern in the RCS. This paper presents simulation studies on the longitudinal motion in the RCS and optimized longitudinal painting schemes are given.

China Spallation Neutron Source (CSNS) is a high power proton accelerator-based facility. One of the primary concerns in design-

### An RF Scenario for Protons and Ions in the PS2

S. Hancock, M. Benedikt, C. Carli (CERN)

The PS2 is proposed as a replacement for the ageing PS and will provide proton beams with kinetic energies up to 50 GeV. It must also deliver Pb<sup>54+</sup> ions, for which the revolution frequency swing will be more than a factor of two. The favoured rf scenario considers a 40 MHz accelerating system and is motivated by the possibility of chopping at up to 40 MHz in the SPL, the proposed proton injector. Using the same principal rf system for ions implies pushing for an unprecedented tuning range and the introduction of a new rf system in LEIR, the existing ion source. We present a solution to the disparate requirements of protons and ions based on a 40 MHz rf system with switchable tuning ranges to cover the large frequency swing required.

The PS2 is proposed as a replacement for the ageing PS and will provide proton beams with kinetic energies up to 50 GeV. It must

### Longitudinal Painting Schemes for H<sup>-</sup> Charge Exchange Injection into the PS2

Minimization of direct space charge tune shift at injection into the PS2 is important for the reduction of beam losses. A determining parameter for the tune shift is the bunching factor, defined as mean current over peak current for one RF period. Various longitudinal painting schemes for PS2 injection, all based on synchrotron motion, have been studied with respect to the resulting bunching factors. In particular, schemes using the SPL high-frequency chopper and different energy-spreads and offsets of the incoming beam as well as SPL beam energy modulations on have been simulated with the ESME code.

**C. Carli**, M. Benedikt, S. Hancock (CERN) V. Knuenz, I. Vonderhaid (TU Vienna)

### Operational Experience with First Circulating Beam in the LHC

Following a series of injection tests, the first attempts to pass beam around both directions of the LHC were successful and led rapidly to circulating beam in the counter clockwise direction (beam 2) and many turns of beam 1. Unfortunately the beam commissioning was curtailed by the incident in sector 34. However, measurements performed during this first commissioning period should that the magnet model of the machine had delivered optics close to nominal, and also very good performance of beam instrumentation and supporting software. Details of the machine set-up and the commissioning procedures are detailed. The measurements performed and the key results from this period are described.

**M. Lamont**, R. Alemany-Fernandez, R. Bailey, P. Collier, B. Goddard, V. Kain, A. Macpherson, L. Ponce, S. Redaelli, W. Venturini Delsolaro, J. Wenninger (CERN)

### An Alternative Approach to Project X

The mission need of Project X is to establish an intensity frontier for particle physics research, or more precisely, to build a facility for providing 2 MW proton beams at 120 GeV for neutrino and other particle studies. An 8 GeV SRF linac would meet this need. However, a more cost effective approach would be a combination of a 2 GeV SRF linac and an 8 GeV synchrotron. It would also meet the mission need but be less costly since a synchrotron is significantly cheaper than a SRF linac. It would retain the ability to use a 2 GeV SRF linac for ILC technology development. It could reuse the existing Debuncher enclosure\* and Booster RF. The transport line of 2 GeV H-minus particles would be shorter than the present 8 GeV design since stronger bending magnets can be used. The blackbody stripping of H-minus particles would no longer be a problem and the requirement of a cryogenic beam screen could be eliminated. The efficiency of stripping foil would be higher and injection loss (kJ) would be reduced by a factor of 4. This paper introduces this alternative approach and describes briefly the major components in the design. A preliminary cost comparison is also presented.

**W. Chou** (Fermilab)

\*W. Chou, "A Simple Transition-Free Lattice of an 8 GeV Proton Synchrotron," this conference.

### Numerical Studies of High-Intensity Injection Painting for Project X

A. I. Drozhdin, L. G. Vorobiev (Fermilab)

Injection painting enables the mitigation of space charge and stability issues, and may be indispensable for the Project-X at Fermilab, delivering high-intensity proton beams to HEP experiments. Numerical simulations of multi-turn phase space painting have been performed for the FNAL Recycler Ring, including a self-consistent space charge model, lattice nonlinearities,  $H^+$  stripping, particle loss and foil heating. Different painting waveforms were studied to build a uniform (KV-like distribution) and other phase space distributions.

### Current and Future High Power Operation of Fermilab Main Injector

I. Kourbanis, P. Adamson, B. C. Brown, D. Capista, W. Chou, D. K. Morris, K. Seiya, G. H. Wu, M.-J. Yang (Fermilab)

Currently Main Injector delivers 330KW of beam power at 120 GeV by using multi-batch slip stacking. The beam power is expected to increase to 400KW after installing clearing gap kickers to eliminate the injection kicker gap loss. The plan to increase the beam power to 700KW for NOvA and the role of MI in Project-X (2.1MW operation) will be discussed.

### Progress in Multi-Batch Slip Stacking at the Fermilab Main Injector and Future Plans

K. Seiya, B. Chase, J. E. Dey, P. W. Joireman, I. Kourbanis, J. Reid (Fermilab)

The multi-batch slip stacking has been used for operation since January, 2008 and effectively increased proton intensity to the NuMI target by 50% in a MI cycle. The MI accepts 11 pulses at injection energy from the Booster and sends two pulses to Anti-proton production and nine to the NuMI beam line. The total beam power on a cycle was increased to 340 KW on average. We have been doing beam studies in order to increase the beam power to 400 kW and to control the beam loss. We also discuss 12 batch slip stacking scheme which is going to be used for future Neutrino experiments.

### Preparations for Muon Experiments at Fermilab

M. J. Syphers, M. Popovic, E. Prebys (Fermilab) C. M. Ankenbrandt (Muons, Inc)

The use of existing Fermilab facilities to provide beams for two muon experiments — the Muon to Electron Conversion Experiment (Mu2e) and the Muon g-2 Experiment — is under consideration. Plans are being pursued to be able to perform these experiments following the completion of the Tevatron Collider Run II with no impact to the on-going Main Injector neutrino program by using spare Booster cycles to provide 8.9 GeV/c protons on target. Utilizing the beam lines and storage rings used today for antiproton accumulation, beams can be prepared for these experiments with minimal disruption, reconfiguration or expansion of the Fermilab accelerator infrastructure. The proposed operational scenarios and required alterations to the complex are described.



### Synchrotron Operation with Intermediate Charge State Heavy Ions

In order to achieve the goals of the FAIR project, the heavy ion beam intensities have to be increased by two orders of magnitude.

**P. J. Spiller** (GSI)

Space charge limits and significant beam loss in stripper stages disable a continuation of the present high charge state operation. However, in the energy range of SIS18 and SIS100, the chosen intermediate charge state for uranium 28+, is lower than the equilibrium charge state. Thus ionisation processes due to collisions with rest gas atoms become the main issue with respect to potential beam loss. Therefore, the SIS100 design concept is focused on the goal to minimize the beam-rest gas interaction and consequently the beam loss by charge change: SIS100 is the first synchrotron which has been optimised for the acceleration of intermediate charge state heavy ion operation. Ionisation beam loss, desorption processes and pressure stabilization were the driving issues for the chosen system layout and for several technological approaches. Beside focusing the SIS100 design on this specific issue an extended upgrade program is actually being realized to accommodate SIS18 for the intermediate charge state booster operation.

### Feasibility of a Common Proton Driver for a Neutron Spallation Source and a Neutrino Factory

Multi MW Proton Driver in the few GeV range are required for a neutron spallation source being studied in the framework of the ISIS upgrade at RAL and for the production of muon beam for a Neutrino Factory.

**J. Pasternak**, M. Aslaninejad, K. R. Long (Imperial College of Science and Technology, Department of Physics) **J. Pasternak**, J. K. Pozimski (STFC/RAL) C. M. Warsop (STFC/RAL/ISIS)

Although the requirements for the time structure of proton beams are different, we investigate the possibility to share the proton driver between the two facilities. We assume the beam for both facilities is accelerated in a linac followed by rapid cycling synchrotron (RCS) at 50 Hz repetition rate to 3.2 GeV. One part of the bunch train after extraction from the RCS can be sent to the neutron production target and the other part of the extracted beam can be sent to another RCS, where further acceleration and final bunch compression can be performed to meet the specification of the Neutrino Factory target. The preliminary study of the final bunch compression is presented.

### Status of the J-PARC 3-GeV RCS

The J-PARC 3-GeV rapid cycling synchrotron (RCS) has been beam commissioned since October 2007 and it has been able to

**M. Kinsho** (JAEA/J-PARC)

provide downstream facilities, the 50-GeV synchrotron (MR) and the Materials and Life Science Facility (MLF) with stable beam required from them. After beam deliver operation to the MR and MLF, while the priority has been given to their beam tuning, the RCS also continues further beam studies toward higher beam intensity. On September 18th, 2008, the RCS achieved the beam power of 210kW to beam dump with 25Hz. This presentation will concentrate itself on the outcome of the J-PARC RCS commissioning program, including the discussion on the issues of the high-power operation.

**Beam Commissioning of Spallation Neutron and Muon Source at J-PARC**

S. I. Meigo, M. Futakawa, T. Kai, F. Noda, M. Ohi, S. Shinichi (JAEA/J-PARC) H. Fujimori (J-PARC, KEK & JAEA)

In J-PARC, Materials and Life Science Facility (MLF) is aimed at promoting experiments using the world highest intensity pulsed neutron and muon beams which are produced at a thick mercury target and a thin carbon graphite target, respectively, by 3-GeV proton beams. The first beam was achieved at the target without significant beam loss. To obtain the beam profile at the target, we applied an activation technique by using thin aluminum foil. In order to obtain reliable profile, it is required that a small number of shots for the beam adjustment and the beam stability. Since beam monitors works very well located at the beam transport line even in the first beam, the beam centralization can be finished by very small number of shots. The stability of beam for each pulse is recognized to be smaller than 1 mm. After many shots of irradiation, the 2-D beam profile can be obtained. It is found that the observed profile shows good agreement with the prediction calculation including the beam scattering at the proton beam window. The beam emittance is measured by the MWPM. It is found that the rms-beam emittance agree with the calculation by the SIMPSONS.

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**Beam Loss Issues Connected to the Foil Scattering: Estimation vs. Measurement at the RCS of J-PARC**

P. K. Saha, H. Hotchi, K. Yamamoto, M. Yoshimoto (JAEA/J-PARC) Y. Irie (KEK)

The beam loss issues connected to the nuclear scattering together with the multiple Coulomb scattering at the charge-exchange foil during the multi-turn injection has been studied in detail for the RCS (Rapid Cycling Synchrotron) of J-PARC (Japan Proton Accelerator Research Complex). Recently, during the beam commissioning of RCS, some experimental data related to such issue has been taken and thus a comparison of the measured beam loss to the estimated one is reported in this paper. When the beam loss from such a source is unavoidable, a realistic estimation is quite important for a fair design of the injection system and the vicinity in order to reduce especially, the uncontrolled beam loss.

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**Longitudinal Painting Studies in the J-PARC RCS**

F. Tamura, K. Hasegawa, M. Nomura, A. Schnase, T. Shimada, H. Suzuki, M. Yamamoto (JAEA/J-PARC) K. Hara, C. Ohmori, M. Toda, M. Yoshii (KEK/JAEA)

In the J-PARC RCS, we employ the longitudinal painting methods, the momentum offset injection method and applying the second harmonic RF voltages, to increase the bunching factor so that the space-charge tune shift is reduced. By the dual-harmonic operation with wide-band MA loaded cavities, in which each single cavity is driven by a superposition of the fundamental and the second harmonic RF signals, we can generate a large amplitude second harmonic RF voltage without extra cavities for the second harmonic RF. We present the results of the beam tests for the longitudinal painting in the J-PARC RCS. Also, we present the beam behavior at very high beam power.

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### Physics Design of the PEFP RCS

The proton engineering frontier project (PEFP) is designing the rapid cycling synchrotron (RCS) whose main purpose is the spallation neutron source. The PEFP 100-MeV linac will be the injector to the RCS. The output energy and beam power are 1 GeV and 60 kW at the initial stage. We studied the  $H^{1-}$  charge exchange injection with transverse and momentum painting schemes. In order to enhance the machine versatility, we studied the slow extraction options for the nuclear physics and medical research in addition to the single turn extraction for the spallation neutron source. This paper summarizes the present status of the physics design of the RCS.

**J.-H. Jang**, Y.-S. Cho, H. S. Kim, H.-J. Kwon (KAERI) Y. Y. Lee (BNL)

### The Beam Dynamics Design for J-PARC Linac Energy Upgrade

The output energy of J-PARC linac is planned to be upgraded from 190 MeV to 400 MeV by adding an ACS (Annular Coupled Structure linac) section. The ACS is a variety of coupled-cavity structure linac newly devised for former JHP (Japan Hadron Project), and its original beam dynamics design for J-PARC was presented in LINAC02 [M. Ikegami et. al., in Procs. of LINAC02, p. 629]. Extensive R&D studies have been conducted since then to establish the feasibility of ACS, where four ACS modules have been fabricated and successfully high-power tested. In parallel, the beam dynamics design of the ACS has been further optimized to reflect the experience obtained in the R&D studies and reduce the cost for mass production. In this paper, the revised beam dynamics design of the J-PARC ACS is presented with some simulation results with a particle simulation code.

**T. Morishita**, H. Sako, Y. Yamazaki (JAEA/J-PARC) H. Ao (JAEA/LINAC) M. Ikegami (KEK)

### Exploration of Design Alternatives for an 8 GeV Proton Linac at Fermilab

An 8 GeV proton linac is being considered for the Fermilab accelerator complex. A design calls for five superconducting cavity types: three types of half-wave and two types of multi-cell elliptical structures. The elliptical cavity types have a frequency of 1.3 GHz with a  $\beta = 0.81$  and a  $\beta = 1$  and provide acceleration from 420 MeV to 8 GeV. An alternative concept would be to use an additional 1.3 GHz elliptical cavity type starting at 150 MeV. The alternative design may reduce project cost and risk. It would increase the technology overlap between Project X and the International Linear Collider. Preliminary simulations show the alternative linac layout has adequate longitudinal acceptance. This paper will discuss the beam dynamics studies for the alternative linac layout in comparison with the baseline layout.

**X. Wu**, C. Compton, M. Doleans, W. Hartung, F. Marti, R. C. York, Q. Zhao (NSCL)

### SNS Superconducting Linac Power Ramp-Up Status and Plan

S.-H. Kim, D. E. Anderson, I. E. Campisi, F. Casagrande, M. T. Crofford, R. I. Cutler, G. W. Dodson, J. Galambos, T. W. Hardek, S. Henderson, M. P. Howell, D.-O. Jeon, Y. W. Kang, K.-U. Kasemir, S. W. Lee, J. Mammosser, M. P. McCarthy, Y. Zhang (ORNL)

The Spallation Neutron Source (SNS) is a second generation pulsed-neutron source and designed to provide a 1-GeV, 1.44-MW proton beam to a mercury target for neutron production. Since the initial commissioning of accelerator complex in 2006, the SNS has

begun neutron production operation and beam power ramp-up has been in progress toward the design goal. Since the design beam power is almost an order of magnitude higher compared to existing neutron facilities, all subsystems of the SNS were designed and developed for substantial improvements compared to existing accelerators and some subsystems are first of a kind. Many performance and reliability aspects were unknown and unpredictable, for which it takes time to understand the systems as a whole and/or needs additional performance improvements. A power ramp-up plan has been revised based on the operation experiences and understandings of limits and limiting conditions through extensive studies with an emphasis on machine availability. In this paper the operational experiences of SNS Superconducting Linac (SCL), the power ramp-up status and plans will be presented including related subsystem issues.

### Coherent Electron Cooling Proof-of-Principle Experiment at RHIC

E. Pozdeyev, I. Ben-Zvi, J. Bengtsson, M. Blaskiewicz, A. V. Fedotov, Y. Hao, A. Kayran, V. Litvinenko, G. Wang (BNL) G. I. Bell, D. L. Bruhwiler, A. V. Sobol (Tech-X) O. A. Shevchenko, N. Vinokurov (BINP SB RAS)

Coherent electron cooling (CEC) has a potential to significantly boost luminosity of high-energy, high-intensity hadron-hadron and electron-hadron colliders such as LHC and eRHIC. In a CEC system, a hadron beam interacts with a cooling electron beam.

A perturbation of the electron density caused by ions is amplified and fed back to the ions to reduce the energy spread and the emittance of the ion beam. To demonstrate feasibility of CEC we plan a proof-of-principle experiment at RHIC. In this experiment, the RHIC ion beam will be cooled at an energy lower than the typical operational RHIC energy. In this paper, we describe the experimental setup and present results of analytical estimates and simulations of CEC for the proposed experiment.

### Analytical Studies of Coherent Electron Cooling

G. Wang, M. Blaskiewicz, V. Litvinenko (BNL)

This work is to model all three processes of the coherent electron cooling through analytical approach. We show that either close

form solution or simple numerical solution can be found for all three processes under certain assumptions. The electron beam is treated as an infinite plasma and its velocity distributions are assumed to be Lorentzian. In the FEL amplifier, 1d theory is applied with the energy spread and space charge effects being taken into account.

### Progress in Antiproton Production at the Fermilab Tevatron Collider

Run II has been ongoing since 2001. Peak luminosities in the Tevatron have increased from approximately  $10 \times 10^{30} \text{ cm}^{-2} \text{ sec}^{-1}$  to  $300 \times 10^{30} \text{ cm}^{-2} \text{ sec}^{-1}$  – a factor of 30 improvement. A significant contributing factor in this remarkable progress is a greatly improved antiproton production capability. Since the beginning of Run II, the average antiproton accumulation rate has increased from  $2 \times 10^{10} \text{ p/hr}$  to about  $24 \times 10^{10} \text{ p/hr}$ . Peak antiproton stacking rates presently exceed  $25 \times 10^{10} \text{ p/hr}$ . The antiproton stacking rate has nearly doubled in the last two years alone. A variety of improvements have contributed to the recent progress in antiproton production. The process of transferring antiprotons to the Recycler Ring for subsequent transfer to the collider has been significantly restructured and streamlined, allowing more time to be utilized for antiproton production. Improvements to the target station have greatly increased the antiproton yield from the production target. The performance of the Antiproton Source stochastic cooling systems has been enhanced by improvements to the cooling electronics, accelerator lattice optimization, and improved operating procedures.

**R. J. Pasquinelli**, B. E. Drendel, K. Gollwitzer, S. R. Johnson, V. A. Lebedev, A. F. Leveling, J. P. Morgan, V. P. Nagaslaev, D. W. Peterson, A. D. Sondgeroth, D. Vander Meulen, S. J. Werkema (Fermilab)

### Optimization of Electron Cooling in the Recycler

Antiprotons in Fermilab's Recycler ring are cooled by a 4.3 MeV, 0.1A DC electron beam as well as by a stochastic cooling system. In this paper we will describe electron cooling improvements recently implemented: adjustments of electron beam line quadrupoles to decrease the electron angles in the cooling section and a better stabilization and control of the electron energy.

**A. V. Shemyakin**, A. V. Burov, K. Carlson, L. R. Prost, M. Sutherland, A. Warner (Fermilab)

### Status of the 2 MeV Electron Cooler Development for COSY Juelich

The design, construction and installation of a 2 MeV electron cooling system for COSY-Juelich is proposed to further boost the luminosity even with strong heating effects of high-density internal targets. In addition the 2 MeV electron cooler for COSY is intended to test some new features of the high energy electron cooler for HESR at FAIR in Darmstadt. The design of the 2 MeV electron cooler will be accomplished in cooperation with the Budker Institute of Nuclear Physics in Novosibirsk, Russia. A new developed prototype of the high voltage section, consisting of a gas turbine, magnetic coils and high voltage generator with electronics was successfully tested. Special emphasis is given to a voltage stability better than  $10^{-4}$ . First experiments with three combined high voltage sections, arranged in a SF6 pressurized gas tank are reported.

**J. Dietrich** (FZJ) M. I. Bryzgunov, A. D. Goncharov, V. V. Parkhomchuk, V. B. Reva, D. N. Skorobogatov (BINP SB RAS)

### Stochastic Cooling for the HESR at the FAIR Facility

H. Stockhorst, R. Maier, D. Prasuhn, R. Stassen (FZJ) T. Katayama (CNS)

The High Energy Storage Ring (HESR) of the future International Facility for Antiproton and Ion Research (FAIR) at the GSI in Darmstadt will be built as an anti-proton cooler ring in the momentum range from 1.5 to 15 GeV/c. An important and challenging feature of the new facility is the combination of phase space cooled beams with internal targets. In addition to electron cooling transverse and longitudinal stochastic cooling are envisaged to accomplish these goals. A detailed numerical analysis of the Fokker-Planck equation for longitudinal filter and time-of-flight cooling including an internal target and intrabeam scattering has been carried out to demonstrate the stochastic cooling capability. Model predictions have been compared to experimental cooling results with internal targets at the COSY facility. Experimental results at COSY to compensate the large mean energy loss induced by an internal Pellet target similar to that being used by the PANDA experiment at the HESR with a barrier bucket cavity (BB) will be presented. Experimental tests of stochastic filter cooling with internal target and BB operation as well as expected cooling properties for the HESR are discussed.

The High Energy Storage Ring (HESR) of the future International Facility for Antiproton and Ion Research (FAIR) at the GSI in Darmstadt will be built as an anti-proton

### First Year of Physics at CNGS

I. Efthymiopoulos, A. Ferrari, E. Gschwendtner, A. Pardons, L. Sarchiapone, H. Vincke, J. Wenninger (CERN) D. Autiero (IN2P3 IPNL) A. Guglielmi (INFN/LNL) P. R. Sala (Istituto Nazionale di Fisica Nucleare)

National Laboratory, LNGS, in Italy, where two large and complex detectors, OPERA and ICARUS, are located. After a brief overview of the facility, the major events since its commissioning in 2006 will be discussed. Emphasis will be given on the design challenges and operation constraints coupled to such a high-intensity facility summarizing the acquired experience. Highlights of the 2008 operations, which was the first complete year of physics in CNGS with  $1.78 \cdot 10^{19}$  protons delivered on target, will be presented.

The CNGS facility (CERN Neutrinos to Gran Sasso) aims at directly detecting muon-neutrino to tau-neutrino oscillations. An intense muon-neutrino beam ( $10^{17}$  muon-neutrino per day) is generated at CERN and directed over 732 km towards the Gran Sasso

### Non-Scaling FFAG Accelerator Variants for HEP and Medical Applications

C. Johnstone (Fermilab) S. R. Koscielniak (TRIUMF)

The quest for higher beam power and duty factor and precisely controlled beams at reasonable cost has generated world-wide interest in Fixed-field Alternating Gradient accelerators (FFAGs). A new concept in non-scaling FFAGs to stabilize the betatron tune is under development. The emphasis to date has been on electron and proton accelerators, yet many facilities utilize  $H^-$  front ends. This concept naturally extends to  $H^-$  FFAGs and under conditions of rapid acceleration, the FFAG functions essentially as a recirculating linac with a common-aperture arc. As such it may be suitable for replacement of aging  $H^-$  linac sections. For a slow acceleration cycle, an  $H^-$  FFAG machine can exploit  $H^-$  techniques to control extraction and intensity, and represents an innovation in proton therapy accelerators. Prototype RF and magnet component design have been initiated. For ten-turn acceleration, the rf cavities in a 10-100 MeV FFAG cannot be re-phased on the revolution time scale, and local adjustment of the pathlength is the proposed approach. For slow acceleration, broad-band, low-frequency rf can be applied. The basic optics and components for such FFAGs are presented.

The quest for higher beam power and duty factor and precisely controlled beams at reasonable cost has generated world-wide in-

### Commissioning of the Muon Test Area Beamline at Fermilab

A new experimental area, the Muon Test Area, has been constructed to develop, test, and verify muon ionization apparatus using the 400-MeV proton beam from the Fermilab Linac. Since muon-cooling apparatus is being developed for facilities that involve the capture, collection and cooling of  $\sim 10^{13}$  muons at a repetition rate of 15 Hz, conclusive tests require full Linac beam, or  $\sim 10^{13}$  protons/pulse at 15 Hz. A beamline has been designed which includes specialized insertions for linac beam diagnostics and beam measurements, greatly enhancing the functionality of the line in addition to providing beam for MTA experiments. Installation of the beamline is complete and first beam was achieved in November, 2008. The design, operational flexibility, and characteristics of the MTA beamline will be presented.

**C. Johnstone**, F. G. Garcia, M. A. Gerardi, W. S. Higgins, M. J. Kucera, M. R. Kufer, D. L. Newhart (Fermilab)

TU6PFP081

### Baseline Design for the ESS-Bilbao Superconducting Proton Accelerator

A baseline design for the proton linear accelerator as proposed by the European Spallation Source-Bilbao bid to host the installation (ESS-B) is here described. The new machine concept incorporates advances which have been registered within high power accelerators during the last decade. The design of such a new accelerator layout heavily relies upon low-beta superconducting spoke resonators which are already under development.

**F. J. Bermejo** (Bilbao, Faculty of Science and Technology) I. Bustinduy, D. Fernandez-Cañoto (ESS Bilbao) V. Etxebarria (University of the Basque Country, Faculty of Science and Technology) J. Lucas (Elytt Energy) L. Uriarte (Fundacion TEKNIKER)

TU6PFP082

### Conceptual Design of the ESS-Scandinavia Accelerator and Target

The conceptual design of the European Spallation Source-Scandinavia (ESS-S) is presented. The accelerator system baseline draws heavily on state-of-the-art mature technologies that are being employed in the CERN Linac4 and SPL projects, although advances with spoke resonator and sputtered superconducting cavities are also being evaluated for reliable performance. Irradiation damage due to proton beam losses is a key issue for linac and target components. Their optimized design is performed from an engineering perspective, using the last updated versions of mechanical design codes which were already qualified for irradiated components. Finally, future upgrades of power and intensity of the proton linac are considered, including the design optimization of the Target Station (proton/neutron converter), with the possibility of increasing the average pulsed power deposition up to 7.5 MW. All possible upgrades will be taken into account for the final design review, in the frame of the costs and constraints given with the site decision.

**S. Peggs** (BNL) M. Lindroos (CERN)

TU6PFP083

### A 15 MeV Accelerator Scheme Based on a DC Photo-Injector and a RF Superconducting Linac

A 15 MeV accelerator scheme based on a DC photo-injector and a RF superconducting linac has been proposed as a new facility for radiography applications. The design of a 15 MeV, 2 kA peak current, electron accelerator for the DEINOS

**D. Guilhem** (CEA/DAM - ile de France, Service CEF)

TU6PFP084

project is presented. The beam operating condition is a limited number of bunches up to twenty electron micro-pulses of 100 ps time duration and 200 nC bunch charge emitted at 352 MHz repetition rate from a Cs<sub>2</sub>Te photocathode and accelerated to 2.5 MeV in the DC diode before injection into a superconducting linac. A general description of the main accelerator components and the beam dynamics simulations are presented. The overall beam dynamics simulation process based on LANL POISSON-SUPERFISH and PARMELA codes and the results will be reviewed.

### Time Structure of Particle Production in the MERIT High-Power Target Experiment

I. Efthymiopoulos, A. Fabich, A. Grudiev, F. Haug, J. Lettry, M. Palm, H. Pernegger, R. R. Steerenberg (CERN) J. R.J. Bennett (STFC/RAL/ASTeC) O. Caretta, P. Loveridge (STFC/RAL) A. J. Carroll, V. B. Graves, P. T. Spampinato (ORNL) H. G. Kirk, H. Park, T. Tsang (BNL) K. T. McDonald (PU) N. V. Mokhov, S. I. Striganov (Fermilab)

The MERIT experiment is a proof-of-principle test of a target system for high power proton beam to be used as front-end for a neutrino factory complex or a muon collider. The experiment took data in autumn 2007 with the fast extracted beam from the CERN Proton Synchrotron (PS) to a maximum intensity of about  $30 \cdot 10^{12}$  protons per

pulse. We report results from the portion of the MERIT experiment in which separated beam pulses were delivered to a free mercury jet target with time intervals between pulses varying from 2 to 700 microseconds. The analysis is based on the responses of particle detectors placed along side and downstream of the target.

### LHC Beams from the CERN PS Booster

B. Mikulec, A. Blas, C. Carli, A. Findlay, K. Hanke, G. Rumolo, J. Tan (CERN)

The CERN PS Booster (PSB) produces a variety of beam flavours for the LHC. While the nominal LHC physics beams require 6 Booster bunches with intensities up to

$1.6 \cdot 10^{12}$  protons per bunch, during the LHC commissioning single bunch beams with variable intensities as low as  $5 \cdot 10^9$  protons have to be provided reproducibly. The final transverse and in many cases also the final longitudinal beam characteristics have to be achieved already in the PSB and can be very demanding in terms of beam brightness and stability. The optimized production schemes for the different LHC beam flavours in the PSB and the achieved machine performance are presented. Experience with the first beams sent to the LHC in September 2008 is discussed. An overview of the first measured results with a new production scheme of the nominal LHC beam using single instead of double-batch beam transfer from the PSB to the PS is also given.

### High Intensity Beams from the CERN PS Booster

B. Mikulec, M. Chanel, A. Findlay, K. Hanke, D. Quatraro, G. Rumolo, J. Tan, R. Tomas (CERN)

The CERN Proton Synchrotron Booster (PSB) has been running for more than 30 years. Originally designed to accelerate particles from 50 to 800 MeV, later upgraded to

an energy of 1 GeV and finally 1.4 GeV, it is steadily being pushed to its operational limits. One challenge is the permanent demand for intensity increase, in particular for CNGS and ISOLDE, but also in view of LINAC4. As it is an accelerator working with very high space charge during the low energy part of its cycle, its operational conditions have to be precisely tuned. Amongst other things resonances must be avoided, stop band crossings optimized and the machine impedance minimized. Recently, an operational intensity record was achieved with



$>4.25 \cdot 10^{13}$  protons accelerated. An orbit correction campaign performed during the 2007/2008 shutdown was a major contributing factor to achieving this intensity. As the PSB presently has very few orbit correctors available, the orbit correction has to be achieved by displacing and/or tilting some of the defocusing quadrupoles common to all 4 PSB rings. The contributing factors used to optimize performance will be reviewed.

### Chopper for Intense Proton Beams at Repetition Rates up to 250 kHz

A chopper system for high intensity proton beams of up to 200 mA and repetition rates up to 250 kHz is under development at IAP to be tested and applied at the Frankfurt Neutron Source FRANZ. The chopper system consists of a fast kicker for transversal separation of the beams and a static septum magnet to lower the dynamic deflection angle. Multi-particle simulations and preliminary experiments are presented. The simulations were made using a Particle in Cell (PIC)-Code developed at IAP. It permits the study of collective effects of compensation and secondary electrons on the proton beam in time-dependent kicker fields. A magnetic kicker with high repetition rate would entail high power consumption while electrostatic deflection in combination with intense beams can lead to voltage breakdown. Therefore a Wien filter-type ExB configuration consisting of a static magnetic dipole field and a pulsed electric field to compensate the magnetic deflection is discussed. The 25 kV high voltage pulser (250 kHz, 100 ns) will apply fast MOSFET transistor technology in the primary circuit, while the high voltage is provided at the secondary circuit around a metglas transformer core.

C. Wiesner, L. P. Chau, M. Droba, O. Meusel, I. Mueller, U. Ratzinger (IAP)

TU6PFP088

### Acceleration of Ions via a Shock Compression in a Critical Density Plasma Using a CO<sub>2</sub> Laser

The possibility of using a CO<sub>2</sub> laser (10 micron wavelength) to drive a plasma density compression and achieve effective ion acceleration in gaseous targets (density  $> \sim 1e19 \text{cm}^{-3}$ ) is explored. A parameter scan is performed with a set of particle in cell simulations in OSIRIS\*, both in 2D and 3D, for various laser intensities, linear/circular polarization pulses, and plasma densities. Results show that, to generate the shock compression, plasma density must be increased above the critical value to account for the relativistic motion of the electrons. Under these conditions, 2-5MeV ions are observed with moderate intensity ( $a_0=3$ ) laser pulses. Finally, configurations to generate a shock structure are suggested, that will more efficiently accelerate the particles. This scenario is also of particular relevance to fast-ignition, inertial confinement fusion, and implications to those regimes can be obtained from numerical simulations by using the appropriate density normalization.

F. S. Tsung, C. Joshi, W. B. Mori (UCLA) S. F. Martins (Instituto Superior Tecnico)

\*R. A. Fonseca et al, LNCS 2329, III-342, Springer-Verlag, (2002)

TU6PFP089

### High intensity demonstrations in the J-PARC 3-GeV RCS

The beam commissioning of the J-PARC 3-GeV RCS started in October 2007. The initial machine parameter tuning and underlying beam studies were completed in February 2008 through various beam dynamics measurements, such as optical functions, turn-by-turn beam positions, and transverse and longitudinal beam profiles. Now the RCS is in transition

H. Hotchi (JAEA/J-PARC)

TU6PFP090

from the first commissioning phase to the next challenging stage and our efforts hereafter will be focused on higher beam power operations. In this paper, we describe experimental results obtained in the high intensity demonstrations in October 2008, together with the corresponding simulation results.

### Performance of the Bump System for the Painting Injection at J-PARC

T. Takayanagi, H. Hotchi, Y. Irie, J. Kamiya, M. Kinsho, P. K. Saha, T. Togashi, T. Ueno, M. Watanabe, M. Yoshimoto (JAEA/J-PARC)  
H. Harada (Hiroshima University, Graduate School of Science)

The painting injection of the 3-GeV RCS in J-PARC has been tested since May in 2008. The shift bump-magnets, which give a constant bump field in a horizontal plane during injection, comprise four magnets con-

connected in series. However, the total integrated magnetic field over the four magnets is not zero because of the magnetic field interferences with the neighboring quadrupole magnets. So the gap of each magnet was adjusted by inserting thin insulators into the splitting plane of the side yoke so that the field integration becomes zero. The thickness was determined experimentally. The closed orbit distortion due to the field imbalances was then confirmed to be less than 1 mm. Another four paint bump-magnets are also necessary to give time-dependent fields. They are connected to their own power supplies, separately. The excitation of each magnet is calibrated by using the beam so that the created bump orbit satisfies the position and inclination at the injection point, and there are no orbit distortions outside the injection area. As for a vertical plane, a vertical paint magnet is located pi-radian upstream of the injection point to control the vertical angle of the beam.

### Commissioning Results of the Upgraded Neutralized Drift Compression Experiment

S. M. Lidia, P. K. Roy, P. A. Seidl, W. L. Waldron (LBNL) E. P. Gilson (PPPL)

Recent changes to the NDCX beamline offer the promise of higher current compressed bunches, with correspondingly larger fluences, delivered to the target plane for ion-

beam driven warm dense matter experiments. We report modeling and commissioning results of the upgraded NDCX beamline that includes a new induction bunching module with approximately twice the volt-seconds and greater tuning flexibility, combined with a longer neutralized drift compression channel.

### Fast Correction Optics to Reduce Chromatic Aberrations in Longitudinally Compressed Ion Beams

S. M. Lidia, E. P. Lee, D. Ogata, P. A. Seidl, W. L. Waldron (LBNL)  
S. M. Lund (LLNL)

Longitudinally compressed ion beam pulses are currently employed in ion-beam based warm dense matter studies. Compression arises from an imposed time-dependent lon-

gitudinal velocity ramp followed by drift in a neutralized channel. Chromatic aberrations in the final focusing system arising from this chirp increase the attainable beam spot and reduce the effective fluence on target. We report recent work on fast correction optics that remove the time-dependent beam envelope divergence and minimizes the beam spot on target. We present models of the optical element design and predicted ion beam fluence, as well as benchtop measurements of pulsed waveforms and response.

### Compact Proton Injector and First Accelerator System Test for Compact Proton Dielectric Wall Cancer Therapy Accelerator

We are developing a compact proton accelerator for cancer treatment by using the dielectric high-gradient insulator wall technology. The goal is to fit the compact dielectric wall proton therapy machine inside a conventional treatment room. To make the proton dielectric wall accelerator (DWA) compact requires a compact proton source capable of delivering protons in a sub-ns bunch. We are testing all the essential DWA components, including the compact proton source, on the First Accelerator System Test (FAST), which is designed to be taken apart and rebuilt many times to increase system performance by using improved components. The proton source being investigated currently is a surface flashover source. Five induction cells with HGI in the acceleration gaps are used to provide the 300-keV, 20-ns injector voltage for the proton injector. The physics design and the configuration of the injector and FAST will be presented.

**Y.-J. Chen**, D. T. Blackfield, G. J. Caporaso, E. G. Cook, S. Falabella, G. Guethlein, J. R. Harris, S. A. Hawkins, S. D. Nelson, B. R. Poole, R. A. Richardson, S. Sampayan, L. Wang, J. A. Watson (LLNL) D. W. Pearson (TomoTherapy) J. T. Weir (CPAC)

TU6PFP094

### Beamline for Warm Dense Matter Experiment Using the KEK Digital Accelerator

The KEK digital accelerator (KEKDA), which is an injector-free induction synchrotron capable of accelerating any ions with their possible charge state, is under construction\*. This machine is an interesting device as a driver to explore a Warm Dense Matter (WDM) state. The irradiation onto a target at a small focal spot (< a few mm) with a short pulse duration (< 100 nsec) is required to create an interesting WDM state. The target temperature based on an equation-of-state fitted from SESAME table data is estimated as a function of the focal spot size and the ion number per bunch. Final focusing of an ion beam bunch extracted from KEKDA is realized through a half mini-beta system. For this purpose, the beamline has been carefully designed. Beam parameters, such as Twiss parameter, and the guiding magnet parameters will be given together with the drawing of the beamline.

**T. Kikuchi** (Nagaoka University of Technology) K. Horioka (TIT) T. Sasaki (Nihon University) K. Takayama (KEK)

\*T. Adachi et al., "Modification of the KEK PS-Booster as a Digital Accelerator", in this conference.

TU6PFP095

### Cold-Cathode Kiloampere Electron Gun with Secondary Emission at Relativistic Voltage

Magnetron Injection Gun with voltage up - 10-00 kV and current more 1 kA was calculated, designed and manufactured. The gun was tested in nanosecond and microsecond operating modes. The application of nanosecond voltage pulses with amplitude up to 600 kV permitted to obtain the secondary-emission current up to 5 kA. The cathode testing in microsecond mode permitted to obtain beam pulse with amplitude up to 1.2 kA at voltage of 400 kV in magnetic field of 0.3 T. There were obtained beam traces on the copper plate. Traces had the form of rings with diameter of 125 mm and width of 5 mm. The secondary emission nature of the cathode current was established. The identification was held basing on considered features of the exciting and on the maintenance of the secondary emission current. However, there is the probability of the parasitic explosive emission at extremely high voltage values since 800 kV. The gun may be used for charge particle accelerators in injectors and RF power sources. Results of the work and prospects of the secondary emission gun development are discussed.

**S. A. Cherenshchykov** (NSC/KIPT)

TU6PFP096

### Collective Instabilities and Beam-Plasma Interactions for an Intense Ion Beam Propagating through Background Plasma

R. C. Davidson, M. Dorf, I. Kaganovich, H. Qin, E. Startsev (PPPL)

This paper presents a survey of the present theoretical understanding based on advanced analytical and numerical studies of collective interactions and instabilities for intense one-component ion beams, and for intense ion beams propagating through background plasma. The topics include: discussion of the condition for quiescent beam propagation over long distances; the electrostatic Harris instability and the transverse electromagnetic Weibel instability in highly anisotropic, one-component ion beams; and the dipole-mode, electron-ion two-stream instability (electron cloud instability) driven by an unwanted component of background electrons. For an intense ion beam propagating through a charge-neutralizing background plasma, the topics include: the electrostatic electron-ion two-stream instability; the multispecies electromagnetic Weibel instability; and the effects of a velocity tilt on reducing two-stream instability growth rates. Operating regimes are identified where the possible deleterious effects of collective processes on beam quality are minimized.

This paper presents a survey of the present theoretical understanding based on advanced analytical and numerical studies of

### Multi-Meter-Long Plasma Source for Heavy Ion Beam Charge Neutralization

P. Efthimion, R. C. Davidson, E. P. Gilson (PPPL) B. G. Logan, P. A. Seidl, W. L. Waldron (LBNL)

Plasma are a source of unbound electrons for charge neutralizing intense heavy ion beams to focus them to a small spot size and compress their axial length. To produce long plasma columns, sources based upon ferroelectric ceramics with large dielectric coefficients have been developed. The source utilizes the ferroelectric ceramic BaTiO<sub>3</sub> to form metal plasma. The drift tube inner surface of the Neutralized Drift Compression Experiment (NDCX) is covered with ceramic material. High voltage (~8kV) is applied between the drift tube and the front surface of the ceramics. A BaTiO<sub>3</sub> source comprised of five 20-cm-long sources has been tested and characterized, producing relatively uniform plasma in the 5x10(10) cm(-3) density range. The source has been integrated into the NDCX device for charge neutralization and beam compression experiments. Initial beam compression experiment yielded current compression ratios ~ 120. Recently, an additional 1 meter long source was fabricated to produce a 2 meter source for NDCX compression experiments. Present research is developing higher density sources to support beam compression experiments for high density physics applications.

Plasma are a source of unbound electrons for charge neutralizing intense heavy ion beams to focus them to a small spot size and compress their axial length. To produce

### High Power Target for 0.5 MW Photo-Fission Electron and 100 kW Proton Driver

P. G. Bricault, M. Dombisky (TRIUMF)

The TRIUMF-ISAC facility is dedicated to the production of rare isotope beams (RIB) for a large variety of physics programs. We utilize the 500 MeV H<sup>1-</sup> cyclotron as a driver for our exotic beams production. The rare isotopes created during the impact diffuse out of the target material and then effuse to the ion source to produce a rare isotope beam. Over the past ten years we developed a high power target capable of operating up to 100 uA, making ISAC the most powerful ISOL facility. For TRIUMF's next five-year plan we are planning to build two new target stations for a total of three simultaneous RIBs to users. In conjunction with the actual ISAC-I target station we are planning to have another 200 uA proton beam extracted from a currently unused beam port (BL4), and from photofission of U nuclei using an electron linac. According to our simulation, a 0.5 MW, 50 MeV electron machine can produce 10<sup>14</sup> photo-fission/s We will present the development of our new 100 kW high power target for both proton and photo-

The TRIUMF-ISAC facility is dedicated to the production of rare isotope beams (RIB) for a large variety of physics programs. We

fission and discuss the various converter choices, liquid metal target or water-cooled rotating wheel that will allow the operation of a 0.5 MW photofission driver.

### Temperature and Stress Rise Induced by Cracks in Accelerating Structures

The achievable gradient of accelerating structures is limited by dark current capture, RF breakdown and cyclic fatigue. We consider only one effect related to the cyclic

fatigue which can be important for reliable operation of high gradient structures, viz. the temperature and stress rise caused by the RF magnetic fields which can be increased in cracks. We made detailed analysis and simulations on the temperature and stress distribution and temporal evolution in the vicinity of cracks of different shapes on the copper when there is a heat flux, and compared the results to the case of a smooth metallic plane. We found out that the temperature will approximately double at the crack upper corners and stress will increase several times at the crack bottom at the beginning and then drop as the crack grows. This analysis gives some insight of the cyclic fatigue leading to the formation of microcracks and crack growth.

**W. Zhu**, T. M. Antonsen, J. Mizrahi, G. S. Nusinovich, G. Sharon (UMD)

### Commissioning of the Low Energy Beam Transport of the Front End Test Stand

The Front End Test Stand (FETS) at the Rutherford Appleton Laboratory is intended to demonstrate the early stages of acceleration (0-3 MeV) and beam chopping required for high power proton accelerators, including proton drivers for pulsed neutron spallation sources and neutrino factories. A Low Energy Beam Transport (LEBT), consisting

of three solenoids and four drift sections, is used to transport the  $H^-$  beam from the ion source to the FETS Radio Frequency Quadrupole. We present the status of the commissioning of the LEBT and compare particle dynamics simulations with preliminary measurements of the  $H^-$  beam transport through the LEBT.

**J. J. Back** (University of Warwick) J. Alonso (Fundacion Tekniker) F. J. Bermejo (Bilbao, Faculty of Science and Technology) R. Enparantza (Fundacion TEKNIKER) D. C. Faircloth, A. P. Letchford, P. Wise (STFC/RAL/ISIS) C. Gabor (STFC/RAL/ASTeC) J. Lucas (Elytt Energy) J. K. Pozimski (STFC/RAL) P. Savage (Imperial College of Science and Technology, Department of Physics)

## TU6RF — Afternoon Poster ACTECH T11, T12, T24, T28, PPHIB T16

### The New Generation Power Supplies for the Circular Polarized Undulator at the APS

B. Deriy, A. L. Hillman, J. Wang (ANL)

The Circular Polarizing Undulator (CPU) had been used for about 10 years at the APS to generate X-rays with variable polarization (circular and linear) switching at rates up to 10 Hz. The CPU consists of two main coils with maximal currents 1600A (about 30kW power) and 400A (4kW power) and seven additional correcting coils. Aging and obsolescence of some of the CPU PS critical components resulted in deterioration of its performance and elevated maintenance. To resolve the issue and to comply with the new requirements for the beam stability at the APS storage ring, the new PS and control electronics for the CPU have been proposed. The new 8-channel Arbitrary Function Generator generating unique complex waveforms for the correctors to minimize orbit distortion during the main coils PS switching will also be discussed in this paper.

The Circular Polarizing Undulator (CPU) had been used for about 10 years at the APS to generate X-rays with variable polarization

### A High Resolution DPWM Generation Topology for Digitally Controlled Precision DC/DC Converters at the APS

G. Feng, B. Deriy, T. Fors, J. Wang (ANL)

The APS storage ring uses DC/DC converters to power the magnets. At present, the best resolution for current regulation is 16 bits, while 18 bits is preferred for future improvement. It is calculated that a 20-bit digital pulse width modulation (DPWM) is required to realize 18-bit regulation resolution. This would require a 20-GHz system clock if conventional DPWM method is used. This paper proposes a new DPWM topology to achieve 20-bit DPWM without gigahertz system clock. The proposed topology uses a combination of a field programmable gate array (FPGA) and a serializer chip TLK2541. The FPGA calculates the desired PWM signals and sends them to TLK2541. Then, TLK2541 generates corresponding high-resolution DPWM pulses. This DPWM strategy only requires a 100-MHz system clock to generate 20-bit DPWM signals. It simplifies the system design and reduces the cost. A FPGA development kit has been used to develop a prototype system to verify the proposed topology. This paper discusses the circuit topology, the current regulation algorithm, and the experiment results.

The APS storage ring uses DC/DC converters to power the magnets. At present, the best resolution for current regulation is 16

### Commissioning of the New AGS MMPS Transformers

E. M. Bajon (BNL)

The Brookhaven AGS Main Magnet Power Supply is a thyristor control supply rated at 5.5KAmps,  $\pm 9KV$ . The peak magnet power is 50MW, which is fed from a motor/generator manufactured by Siemens. During rectify and invert operation, the P Bank power supplies are used. During the flattops the F Bank power supplies are used. The P Bank power supplies are fed from two 23MVA transformers and the F Bank power supplies are fed from two 5.3 MVA transformers. The fundamental frequency of the F Bank power supplies is 1440Hz while the P banks were 720Hz. It was very important to reduce the ripple during rectify to improve polarized proton operations. For this reason and also because the original transformers were 45 years old we replaced these transformers with new ones and we made the fundamental frequency of both P and F banks 1440 Hz. This paper will highlight the major hurdles that were

The Brookhaven AGS Main Magnet Power Supply is a thyristor control supply rated at 5.5KAmps,  $\pm 9KV$ . The peak magnet power

involved during the installation of the new transformers. It will present waveforms while running at different power levels up to 6MW full load and show the transition from the F-Bank power supplies to the P-Banks and also show the improvements in ripple made on the P-Bank power supplies.

### Progress on the R&D of the CSNS Power Supply System

The 1.6GeV proton synchrotron proposed in the CSNS Project is a 25Hz rapid-cycling synchrotron (RCS) with 80MeV Linac. Beam power is aimed to 100kW at 1.6GeV. In this paper the designs of the prototype of DTL-Q power supply and the prototype of the resonant network with one mesh exciting in series will be introduced.

J. Zhang (IHEP Beijing)

TU6RFP004

### Precision Magnet Power Supply for Accelerator Application at VEC Centre, Kolkata

Precision DC magnet power supplies play an important role in accelerator application. The output load current of these power supplies is highly stabilized and varies from 5ppm to 100ppm depending upon the requirement of various functions of the magnets to be energized. A large number of such power supplies ranging from 10A to 2000A are being used in VEC Centre, Kolkata for both the K=130 room temperature cyclotron and K=500 superconducting cyclotron. The paper discusses the various design considerations, aspects and important features of these power supplies. This includes measurement of DC load current with DCCT for high accuracy and isolation from power circuit, various regulating loops to obtain high stability, Peltier temperature controller to control drift in the sensitive components of the regulating circuit, pre-regulator circuit to reduce power loss in the series pass element, energy dump system for superconducting magnet power supply. Frequent line voltage outages and dips and the RF noise interferences were the major disturbances that highly affected the performances of these power supplies. The paper also discusses the remedial actions for those disturbances along with others.

A. S. Banerjee (DAE/VECC)

TU6RFP005

### Power Supplies of PETRA III

PETRA III is a new high-brilliance synchrotron radiation source on the DESY site in Hamburg-Bahrenfeld. The existing storage ring PETRA was converted into one of the most brilliant x-ray sources worldwide. The reconstruction of the storage ring started on July 2, 2007 and ends beginning 2009. During this time all magnet power supplies were renewed. The main ring magnets as dipole, series quadrupoles and sextupole magnets are fed by SCR-supplies that had been used for the HERA machine. Also from HERA switched mode (SM) power parts with 400A / 150V have been modified and reused. For other magnets SM power parts with the nominal data  $\pm 55A$ , 200A and 600A, each having 50 V nominal output voltage, have been purchased. As pre-rectifier for the SM supplies diode rectifiers are foreseen. The steerer power supplies have nominal data of 10A/40V or 5A/60V. All power supplies are equipped with a 20 bit digital regulation that was developed at DESY. To increase the uptime of the machine a redundancy system was introduced consisting of contactors that switches spare supplies onto the magnet load in case of a failure. The first working experiences are reported.

H.-J. Eckoldt (DESY)

TU6RFP006

TU6RFP007

**Fermilab's Booster Correction Element Power Supply Silicone Temperature Rise**

G. E. Krafczyk, H. Pfeffer, G. J. Warchol (Fermilab)

Fermilab is in the process of upgrading its Booster Correction Element System to include full field correction element magnets to correct position and chromaticity throughout the booster cycle. From a reliability standpoint, it is important to limit both the maximum temperature and the repetitive temperature cycling of the silicone junctions of the switching elements. We will describe how we measured these parameters and the results of our measurements.

TU6RFP008

**A Dual Triangle Timing Circuit For Improved Performance of 4-Quadrant H-Bridge Switchers**

G. E. Krafczyk, H. Pfeffer, G. J. Warchol (Fermilab)

Fermilab is in the process of upgrading its Booster Correction Element System to include full field correction element magnets to correct position and chromaticity throughout the booster cycle. This upgrade requires power supplies with maximum outputs of  $\pm 180\text{V}/\pm 65\text{A}$ , with current bandwidths of 5kHz and with slew rates of min to max current in 1ms. For seamless operation around zero current and voltage, we use continuous switching on both sides of the bridge. Although the straightforward way of coordinating the switching on both sides of the bridge can be accomplished with one triangle timing wave and one voltage reference, we have found that using two triangle waves yields a switching coordination that effectively doubles the frequency of the differential ripple on the load and allows for better and cheaper filtering of the output ripple.

TU6RFP009

**ALS FPGA-Based Digital Power Supply Controller for Ramped Power Supplies in the Booster**

J. M. Weber, M. J. Chin, C. Steier, E. C. Williams (LBNL)

The Advanced Light Source (ALS) is a third generation synchrotron light source that has been operating since 1993 at Berkeley Lab. Recently, the ALS was upgraded to achieve Top-Off Mode, which allows injection of 1.9GeV electron beam into the Storage Ring approximately every 30 seconds. Modifications required for Top-Off operation included replacing the booster dipole and quadrupole magnet power supplies to increase the peak booster beam energy from 1.5GeV to 1.9GeV. Each new power supply was originally controlled by an analog controller that performs the current feedback loop and, in concert with other modules in the control chassis, determines the output of the ramped power supply. The new digital power supply controller performs the current feedback loop digitally to provide greater output stability and resolution. In addition, it provides remote monitoring of feedback loop signals, interlocks, and status signals, as well as remote control of the power supply operation via Ethernet. This paper will present the ALS Digital Power Supply Controller module requirements and design.

TU6RFP010

**TLS Corrector Magnet Power Supplies Upgrade**

K.-B. Liu, P. C. Chiu, K. T. Hsu, K. H. Hu (NSRRC)

Corrector magnets of TLS storage ring are served with linear power supplies (corrector magnet power supplies), with some modifications the long-term output current stability and ripple of these linear power supplies were improved from 500



ppm to 50 ppm. But these linear power supplies are very low efficiency, low power factor and about 20Hz low frequency response bandwidth that waste power, noisy and unable to serve fast orbit correction. MCOR30 is a modular switching power converter with smaller volume, high efficiency and above 100Hz frequency response bandwidth, replacing these linear power supplies with MCOR30s that could save power and increasing orbit correction response.

### Increasing Output Current Stability by Adding an External Current Control Loop

The Agilent 6682A power supply is used as a dipole magnet power supply of Booster to storage ring (BTS) transport line, its output current stability is less than 100 ppm although specification is 1000 ppm. The performance of Agilent 6682A is quite good for TLS operational requirement but not suitable for less than 10 ppm output current stability general requirement of power supplies of TPS. Circuitry modification of Agilent 6682A to reach less than 10 ppm output current stability is hard to implement; but utilize analog programming function of Agilent 6682A with adding an external current control loop the output current stability of Agilent 6682A could be improved to less than 10 ppm.

K.-B. Liu (NSRRC)

TU6RFP011

### Conduction EMI and EMC Measurement and Testing in NSRRC Power Supply

The Quadrupole DC power supplies are working the storage ring of NSRRC. There must output high quality current performance that is long-term stability and output current ripple must under 100ppm. Storage ring have 18 units power supply from Q1 to Q3 working together when beam current in 1.5GeV status. The power supplies also are all most working in 85%. We just build a new conduction EMI and EMC measurement and lab to measure and testing the switching Quadrupole DC power supply. Using the Quadrupole switching mode power supply and working high load condition to measure the conduction noise. The current signal pass standard LISN and Spectrum analyzer will get the conduction noise. We can use a noise separator to separate common EMI noise and differential-mode EMI noise for EMI filter design. The measurement result is illustrated in the paper.

C.-Y. Liu, Y.-H. Liu (NSRRC)

TU6RFP012

### Conductive EMI Test of Magnet Power Supply in NSRRC

The purpose of this paper is to estimate the conductive Electromagnetic Interference (EMI) from magnet power supply in NSRRC. A LISN system was conducted to measure the EMI spectrum of power supply. The different frequency range of conductive EMI was measured. For the future TPS (Taiwan Photon Source) power supply design, the EMI signals must be lower than TLS kicker. Therefore reducing and eliminating the interference of electromagnetic waves will be a very important issue. A filter and shielding method were used to test the effects of reducing EMI. The EMI prevention scheme will be used in the future.

Y.-H. Liu, J.-R. Chen, C.-Y. Liu (NSRRC)

TU6RFP013

**The EMI Reduction of Pulsed Magnets**

Y.-H. Liu, C. K. Chan, C.-H. Chang, J.-R. Chen, C.-S. Fann, C.-S. Yang (NSRRC)

The purpose of this paper is to reduce the Electromagnetic Interference (EMI) from kicker itself. Analysis of the EMI strength and direction are the beginning missions. The different frequency range of radiated EMI are measured and analysis. For the future TPS(Taiwan Photon Source) injection kicker design, the EMI signals must be lower than TLS kicker. Therefore reducing and eliminating the interference of electromagnetic waves will be a very important issue. A hybrid shielding method was used to test the effects of reducing radiated EMI. The copper and u-metal with different thickness were enclosed kicker itself to prevent the radiated EMI from the space. The reduction of radiated EMI showed that the effects of these material. The EMI prevention scheme will be used in the future.

**High Precision Voltage Reference for High Precision Magnet Power Supplies**

S.-H. Jeong, D. E. Kim, K.-H. Park (PAL) B.-K. Kang (POSTECH)

This paper presents a high resolution voltage reference, which is suitable to build high precision magnet power supplies for accelerators. It consists of a digital signal processor (DSP), a field programmable gate array (FPGA), and a digital to analog converter (DAC) board. The DAC board uses two commercial 16-bit D/A converters and an analog signal processing circuit to achieve a resolution higher than 20-bit. The proposed voltage reference has a resolution of 20-bit (1 ppm) for the +10 V full-scale, and 21-bit (0.5 ppm) for the  $\pm 10V$  full-scale. The short- and long-term stabilities are  $\sim 1$  and 5 ppm, respectively. The controllability and reproducibility of the output voltage to a step input was  $\sim 1$  ppm (10  $\mu V$ ). An equivalent bandwidth of the voltage reference was  $\sim 5$  KHz. These experimental results show that the proposed voltage reference may be applied to many other systems which require a high-resolution and cost-effective voltage reference with a good long-term stability, besides to a magnet power supply development. The voltage reference can be interfaced with the Ethernet (including EPICS), CAN, and RS232C.

**Klystron Cathode Heater Power Supply System Based on the High-Voltage Gap Transformer**

P. A. Bak, A. A. Korepanov, V. D. Zabrodin (BINP SB RAS) V. Vogel (DESY)

Power system for the klystron cathode heater power supply has been developed to transfer 800 Watts up to 130 kV potential based on the high-voltage gap transformer. Power transfer has been implemented resonant way on the frequency of 19.5 kHz using coupled LC-loops with further transformation to DC. Transformer coupling factor is of 0.58, high-voltage gap is 49 mm, and maximum calculated electric field intensity is 35 kV/cm. Primary winding is powered by the full bridge inverter using phase shifted pulse modulation. This inverter topology provides soft switching of the transistors in a wide range of power regulation (from 18 up to 800 Watts) without an auxiliary active resonant snubber circuits. High stability (0.3%) of the output power has been reached using proportional regulation in the feedback circuit. The achieved power conversion efficiency of inverter is more than 0.95 in the regulation range; efficiency of the whole power system is more than 0.88. The reliable operation of the power system is guaranteed on three types of klystrons (Toshiba E3736; Thales TH1801; CPI VKL8301). The work has been performed within the European XFEL project.

### Digitally Controlled High Availability Power Supply

This paper will report on the test results of a prototype 1320 watt power module for a high availability power supply. The module

D. J. MacNair (SLAC)

will allow parallel operation for N+1 redundancy with hot swap capability. The two quadrant output of each module allows pairs of modules to provide a 4 quadrant (bipolar) operation. Each module employs a novel 4 FET buck regulator arranged in a bridge configuration. Each side of the bridge alternately conducts through a small saturable ferrite that limits the reverse current in the FET body diode during turn off. This allows hard switching of the FETs with low switching losses. The module is designed with over-rated components to provide high reliability and better than 97% efficiency at full load. The modules use a Microchip DSP for control, monitoring, and fault detection. The switching FETS are driven by PWM modules in the DSP at 60 KHz. A Dual CAN bus interface provides for low cost redundant control paths. The DSP will also provide current sharing between modules, synchronized switching, and soft start up for hot swapping. The input and output of each module have low resistance FETs to allow hot swapping and isolation of faulted units.

### 10 Hz Pulsed Power Supplies and the DC Septum Power Supply for the ISIS Second Target Station (TS-2)

The Extracted Proton beam line for the ISIS second target station has two 10 Hz pulsed magnet systems and a DC Septum magnet

S. L. Birch, S. P. Stoneham (STFC/RAL/ISIS)

system which extract the protons from the existing 50 Hz beam line. The pulsed Kicker 1 magnet system deflects the beam 12.1 mrad, pulsed Kicker 2 deflects the beam 95 mrad and the DC Septum magnet system deflects the beam 307 mrad. This paper describes the topology, installation, testing and successful operation of each of the power supplies.

### Elettra Booster Magnet Power Supplies: One Year of Operations

The New Full-Energy Injector at Elettra, based on a 3 Hz, 100 MeV to 2.5 GeV booster has officially started its operations since

R. Visintini, D. M. Molaro (ELETTRA)

March 2008\*. The time schedule was fully respected notwithstanding the performance problems presented by some of the main magnet power supplies\*\*. The refurbishing plan, formally started at the end of the commissioning phase and carried on together with the manufacturer, has brought positive results in approaching the required specifications. The paper will describe the progress of the refurbishing and the experience with the other magnet power supplies, including the positive performances of the in-house low-current (5A) bipolar power supplies, especially designed for the linac pre-injector\*\*\*. A new version, fully digitally controlled, of these low-power power supplies will be adopted for some coils and magnets of the FERMI@Elettra project.

\*M. Svandrik, Status of the Elettra Booster Project, EPAC08

\*\*R. Visintini, Magnet power converters for the Elettra Booster, EPAC08

\*\*\*D. Molaro, A new bipolar PS for the Elettra booster, PCIM08

**Magnet Power Supplies for FERMI@Elettra**

R. Visintini, M. Cautero, D. M. Molaro (ELETTRA)

FERMI@Elettra is the new 4th-generation light source, based on a single-pass FEL, under construction at the Elettra Laboratory in Trieste, Italy. Some hundreds of magnets and coils need to be supplied along the accelerator sections and the undulators chains - mostly individually - with currents as low as 1.5 A up to 750 A. Starting from a successful design developed at Elettra\* for the full-energy injector\*\*, a new version of the existing 4-quadrant, 5 A PS has been studied. This new bipolar low-current PS, with full digital control, will be adopted for all 1.5 A and 5 A loads. The design of a bipolar PS for supplying the 20 A loads is in progress. This paper will describe the proposed PS system for the magnets and coils of FERMI@Elettra. The focus will be on the solutions adopted to minimize the number of different PS types. Particular stress will be laid upon the in-house design.

\*D, Molaro et al. - A new bipolar power supply for Elettra booster pre-injector correctors - PCIM08

\*\*R. Visintini et al. - Magnet power converters for the new Elettra full energy injector - EPAC08

**New Generation Transtechnik Modular Power Supply TT-MoPS for Accelerators**

M. Hohmann (Transtechnik)

TT-MoPS Next Generation Modular Power Supply Transtechnik designed a new generation of a high flexible high current modular Power Supply. The target was to combine the experience of the CERN-LHC-Project with the requirements of the market and some new ideas. High reliability-best performance; Strongly modular-to meet a wide range of specifications; External calibration-fully automatically calibration without moving the rack installation; Easy to repair@module level-plug and play solution for high availability; Easy to configure-Fast notation, fast implementation, easy maintainability; High accuracy-about 100ppm current regulation; For our customer STFC Rutherford Appleton Laboratories, Transtechnik produces a modular system for output voltage up to 125 VDC (CERN LHC-Product: 18V/±40V) and a current loading between 100 A and 500 A (CERN LHC-Product:13,5kA/21kA/600A). The system consists of with a new generation of standard Power Supply modules which allow combination of the shelf Power Supply to a customised Power Supply in a flexible and comfortable way(optional Modifikation:n+1 redundancy; un/-load module for high current inductors and high voltage modules-CEBU).

**First Results for the Beam Commissioning of the CERN Multi-Turn Extraction**

S. S. Gilardoni, F. Arnold Malandain, E. Benedetto, T. Bohl, S. Cettour Cave, K. Cornelis, H. Damerou, F. Follin, T. Fowler, F. Franchi, P. Freyermuth, H. Genoud, R. Giachino, M. Giovannozzi, S. Hancock, Y. Le Borgne, D. Manglunki, G. Metral, L. Pereira, J. P. Ridewood, Y. Riva, M. Schokker, L. Sermeus, R. R. Steerenberg, B. Vanderpe, J. Wenninger (CERN)

The Multi-Turn Extraction, a new type of extraction based on beam trapping inside stable islands in the horizontal phase space, has been commissioned during the 2008 run of the CERN Proton Synchrotron. Both single- and multi-bunch beams with a total intensity up to  $1.4 \times 10^{13}$  protons have been extracted with efficiencies up to 98%. Further-

more, injection tests in the CERN Super Proton Synchrotron were performed, with the beam then accelerated and extracted to produce neutrinos for the CERN Neutrino to Gran Sasso experiments. The results of the extensive measurement campaign are presented and discussed in details.

## Installation and Hardware Commissioning of the Multi-Turn Extraction at the CERN Proton Synchrotron

The implementation of new Multi-turn extraction at the CERN Proton Synchrotron required major hardware changes for the nearly 50-year old accelerator. The installation of new PFNs and refurbished kicker magnets for the extraction, new sextupole and octupole magnets, new power converters, together with an in-depth review of the machine aperture leading to the design of new vacuum chambers was required. As a result, a heavy programme of interventions had to be scheduled during the winter shut-down 2007-8. The newly installed hardware and its commissioning is presented and discussed in details.

**S. S. Gilardoni**, D. Allard, M. J. Barnes, O. E. Berrig, A. Beuret, D. Bodart, P. Bourquin, R. Brown, M. Caccioppoli, F. Caspers, J.-M. Cravero, C. De Almeida Martins, C. G.A. Dehavay, T. Dobers, M. Dupont, G. Favre, T. Fowler, F. Franchi, M. Giovannozzi, J. Hansen, M. Karppinen, C. Lacroix, E. Mahner, V. Mertens, J. Monteiro, R. Noulibos, E. Page, R. Principe, C. Rossi, L. Sermeus, R. R. Steerenberg, G. Vandoni, G. Villiger, Th. Zickler (CERN)

## Initial Results from Beam Commissioning of the LHC Beam Dump System

Initial commissioning of the LHC beam dump system with beam took place in August and September 2008. The preparation, setting-up and the tests performed are described together with results of the extractions of beam into the dump lines. Analysis of the first detailed aperture measurements of extraction channels and kicker performance derived from dilution sweep shapes are presented. The performance of the other equipment subsystems is summarised, in particular that of the dedicated dump system beam instrumentation.

**B. Goddard**, I. V. Agapov, E. Carlier, L. Ducimetiere, E. Gallet, M. Gyr, L. K. Jensen, O. R. Jones, V. Kain, T. Kramer, M. Lamont, M. Meddahi, V. Mertens, T. Risselada, J. A. Uythoven, J. Wenninger, W. J.M. Weterings (CERN)

## Operational Considerations for the PSB $H^-$ Injection System

For the LINAC4 project the PS Booster (PSB) injection system will be upgraded. The 160 MeV  $H^-$  beam will be distributed to the 4 superimposed PSB synchrotron rings and horizontally injected by means of an  $H^-$  charge-exchange system. Operational considerations for the injection system are presented, including expected beam losses from field stripping of  $H^-$  and excited  $H^0$  and foil scattering, possible injection failure cases and expected stripping foil lifetimes. Loading assumptions for the internal beam dumps are discussed together with estimates of doses on various components, and a concept for the foil exchange system is presented.

**W. J.M. Weterings**, M. Aiba, J. Borburgh, C. Carli, T. Fowler, B. Goddard, H. Vincke (CERN)

TU6RFP026

**Beam Commissioning of Injection into the LHC**

V. Mertens, I. V. Agapov, B. Goddard, M. Gyr, V. Kain, T. Kramer, M. Lamont, M. Meddahi, J. A. Uythoven, J. Wenninger (CERN)

The LHC injection tests and first turn beam commissioning took place in late summer 2008, after detailed and thorough preparation. The beam commissioning of the downstream sections of the SPS-to-LHC transfer lines and the LHC injection systems is described. The details of the aperture measurements in the injection regions are presented together with the performance of the injection related equipment. The measured injection stability is compared to the expectations. The operational issues encountered are discussed.

The LHC injection tests and first turn beam commissioning took place in late summer 2008, after detailed and thorough preparation. The beam commissioning of the downstream sections of the SPS-to-LHC transfer lines and the LHC injection systems is described. The details of the aperture measurements in the injection regions are presented together with the performance of the injection related equipment. The measured injection stability is compared to the expectations. The operational issues encountered are discussed.

TU6RFP027

**Resonant Third-Integer Extraction from the PS2**

M. Gyr, W. Bartmann, M. Benedikt, B. Goddard, M. Meddahi (CERN) A. Koschik (ETHZ) D. Mayani Paras (UNAM)

the conceptual considerations for the sextupole locations and strengths, the separatrices at the extraction elements and the aperture implications for the overall machine. Calculations of the phase space separatrices have been computed with a new code for the physics of slow resonant extraction, which is briefly reviewed. Implications for the extraction equipment design and for the injection-extraction straight section optics are discussed.

For the proposed PS2 accelerator several extraction systems are needed, including a slow third-integer resonant extraction. The requirements are presented together with

TU6RFP028

**Laser Stripping for the PS2 Charge-Exchange Injection System**

B. Goddard, W. Bartmann (CERN) V. V. Danilov (ORNL) D. E. Johnson (Fermilab)

possible concept for a 4 GeV laser stripping system is outlined, using a three-step scheme with two magnetic stripping steps and a resonant excitation of the intermediate H0 atom. The requirements for the laser system are derived and issues of laser power discussed. Incorporation of such a system into the injection insertion is addressed. The expected injection efficiency and beam losses are derived together with the emittance increase expected from the injection process.

Laser stripping for  $H^{-}$  injection system into the proposed PS2 accelerator could provide an attractive alternative to the use of a conventional stripping foil. In this paper a

TU6RFP029

**Experience with the LHC Beam Dump Post-Operational Checks System**

J. A. Uythoven, J. Axensalva, V. Baggiolini, E. Carlier, E. Gallet, B. Goddard, V. Kain, M. Lamont, N. Magnin (CERN)

be declared to be 'as good as new' before the next injection is allowed. The analysis scope comprises the kicker waveforms, redundancy in kicker generator signal paths and different beam instrumentation measurements. This paper describes the implementation and the operational experience of the internal and external post-operational checks of the LHC beam dumping system during the commissioning of the LHC without beam and during the first days of beam operation.

After each beam dump in the LHC automatic post-operational checks are made to guarantee that the last beam dump has been executed correctly and that the system can

### Fast Injection into the PS2

The conceptual considerations of a fast injection system for protons and ions in the proposed PS2 accelerator are presented. Initial design parameters of the injection septum and kicker systems are derived, taking into account rise and fall times, apertures and machine optics. The requirements for an injection dump used for failures are described. Possible limitations and technical issues are outlined.

**J. A. Uythoven**, W. Bartmann, J. Borburgh, T. Fowler, B. Goddard, M. Meddahi (CERN)

TU6RFP030

### LHC Beam Dump System - Consequences of Abnormal Operation

The LHC beam dump system is one of the most critical systems concerning machine protection and safe operation. It is used to dispose of high intensity beams between 450 GeV and 7 TeV. Studies into the consequences of abnormal beam dump actions have been performed. Different error scenarios have been evaluated using particle tracking in MAD-X, including an asynchronous dump action, and the impact of different orbit and collimator settings. Losses at locations in the ring and the beam dump transfer lines have been quantified as a function of different settings of the dump system protection elements. The implications for the setting up and operation of these protection elements are discussed.

**T. Kramer**, B. Goddard, J. A. Uythoven (CERN)

TU6RFP031

### Improvements to Antiproton Accumulator to Recycler Transfers at the Fermilab Tevatron Collider

Since 2005, the Recycler has become the sole storage ring for antiprotons used in the Tevatron Collider. The operational role of the Antiproton Source has shifted exclusively towards producing antiprotons for periodic transfers to the Recycler. The process of transferring the antiprotons from the Accumulator to the Recycler has been greatly improved, leading to a dramatic reduction in the transfer time. The reduction in time has been accomplished with a net improvement in transfer efficiency and an increase in average stacking rate. This paper will describe the software improvements that streamlined the transfer process and other changes that contributed to a significant increase in the number of antiprotons available to the Collider.

**J. P. Morgan**, B. E. Drendel, D. Vander Meulen (Fermilab)

TU6RFP032

### AC Dipole System for Inter-Bunch Beam Extinction in Mu2e Beam Line

The Mu2e experiment has been proposed at Fermilab to measure the rate for muons to convert to electrons in the field of an atomic nucleus with unprecedented precision. This experiment uses an 8 GeV primary proton beam consisting of short ( $\sim 100$  nsec) bunches, separated by 1.7 usec. It is vital that out-of-bunch beam be suppressed at the level of  $1 \cdot 10^{-9}$  or less. Part of the solution to this problem involves a pair of matched dipoles operating resonantly at half the bunch rate. There will be a collimation channel between them such that beam will only be transmitted when the fields are null. The magnets will be separated by 180 degrees of phase advance such that their effects cancel for all transmitted beam. Magnet optimization

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TU6RFP033

considerations will be discussed, as will optical design of the beam line. Simulations of the cleaning efficiency will also be presented.

### SIS100/300 Extraction System Design - Beam Dynamics and Technological Challenges

N. Pyka, U. B. Blell, C. Muehle, E. Mustafin, A. Saa-Hernandez, P. J. Spiller, J. Stadlmann (GSI) A. Smolyakov (ITEP)

The FAIR heavy ion synchrotrons SIS100/300 will provide heavy ion and proton beams with variable time structure. Fast extraction of compressed single bunches from SIS100, fast beam transfer between SIS100 and SIS300 and slow extraction from SIS100 and SIS300 will be provided. High average beam intensities and the generation of an uninterrupted linac-like beam are enabled by combining both heavy ion synchrotrons in different operation modes (fast acceleration and stretcher operation). In order to reduce beam loss at slow extraction of intense heavy ion beams and to minimize the beam load in subsequent accelerator structures, dedicated ion optical settings of the basic lattice functions and higher order corrections will be applied. However, the tight geometrical constraints in the rather short straight sections and the need to extract from both synchrotrons, fast and slow, at the same position and in parallel to the beam transport system, require operation parameters of the extraction devices close to the limits of technical feasibility. Higher order beam dynamics simulations and technical developments will be presented.

### Development of Spill Control System for the J-PARC Slow Extraction

A. Kiyomichi, T. Adachi, R. Muto, H. Nakagawa, H. Sato, H. Someya, M. Tomizawa (KEK) T. I. Ichikawa, K. Mochiki, S. Onuma (Musasi Institute of Technology, Instrumentation and Control Laboratory) K. Noda (NIRS)

J-PARC (Japan Proton Accelerator Research Complex) is a new accelerator facility to produce MW-class high power proton beams at both 3GeV and 50GeV. The Main Ring (MR) of J-PARC can extract beams to the neutrino beam line and the slow extraction beam line for Hadron Experimental Facility. The slow extraction beam is used in various nuclear and particle physics experiments. A flat structure and low ripple noise are required for the spills of the slow extraction. We are developing the spill control system for the slow extraction beam. The spill control system consists of the extraction quadrupole magnets and feedback device. The extraction magnets consist of two kinds of quadrupole magnets, EQ (Extraction Q-magnet) which make flat beam and RQ (Ripple Q-magnet) which reject the high frequent ripple noise. The feedback system, which is using Digital Signal Processor (DSP), makes a ramping pattern for EQ and RQ from spill beam monitor. Here we report the construction status of the extraction magnets and the development of the feedback system.

### Beam Test of the Strip-Line Kicker at KEK-ATF

T. Naito, S. Araki, H. Hayano, K. Kubo, S. Kuroda, T. Okugi, N. Terunuma, J. Urakawa (KEK)

The kicker of the damping ring for the International linear collider(ILC) requires fast rise/fall times(3 or 6ns) and high repetition rate(3 MHz). A multiple strip-line kicker system is developing to realize the specification\*. We present results of the beam test at KEK-ATF by the strip-line kicker\*\*. The multi-bunch beam, which has 5.6ns bunch spacing in the damping ring, is extracted with 308ns duration. Two units of the strip-line electrodes are used to extract the beam. The scheme of the beam extraction



is same as the kicker of the ILC. A bump orbit and an auxiliary septum magnet are used with the kicker to clear the geometrical restriction.

\*T. Naito et. al., Proc. of PAC07, pp2772-2274

\*\*T. Naito et. al., Proc. of EPAC08, pp601-603

### Effects of the Residual Gas Scattering in Plasma Accelerator Experiments and Linacs

High vacuum has always been mandatory in particle accelerator. This is true especially for circular machine, where the beam make thousands or millions turns, and beam life-time is heavily affected by the residual gas scattering. In dimensioning the interaction chamber for a plasma accelerator experiment, because of gas needed and the diagnostics and control devices foreseen, the problem of the effect of the residual gas on the beam arose. Simulation of the beam interaction with the residual gas in the chamber has been performed with FLUKA code. The effects of different vacuum levels on the electron beam is reported and consequences on the beam quality in linacs is discussed.

**F. Broggi** (INFN/LASA) A. Bacci, A. R. Rossi, L. Serafini (Istituto Nazionale di Fisica Nucleare) A. Cianchi (INFN-Roma II) A. Clozza, G. Di Pirro (INFN/LNF)

TU6RFP037

### Conceptual Design of Beam Transport Lines for the PEEP User Facility

PEEP (Proton Engineering Frontier Project) beamlines will be supplied either 20-MeV or 100-MeV proton beams from the 100-MeV proton linear accelerator for beam applications. Each proton beam will be transported to 2 beamlines for industrial purpose and 3 beamlines for the researches. Beam distribution to 3 research beam lines will be conducted sequentially by programmable AC magnet. To provide flexibility of the irradiation conditions, each beam line is designed to have specific beam parameters. We have designed the beamlines to the targets for wide or focused beams, external or in-vacuum beams, and horizontal or vertical beams. The detail design of each beamline will be reported.

**B.-S. Park**, Y.-S. Cho, B. H. Choi, I.-S. Hong, J.-H. Jang, H. S. Kim, K. R. Kim, H.-J. Kwon, H. R. Lee (KAERI)

TU6RFP038

### Laser Stripping for H<sup>-</sup> Injection

The technique of H<sup>-</sup> charge exchange injection into a storage ring or synchrotron has been used for some years to provide large beam currents for spallation neutron sources such as ORNL's SNS and other applications, but it is intrinsically limited by the use of carbon or diamond stripping foils. A laser in combination with magnetic stripping has been used to demonstrate a new technique for high intensity proton injection, but several problems need to be solved for a practical system. Technology developed for use in Free-Electron Lasers is being applied to address the remaining challenges to a practical implementation of laser controlled H<sup>-</sup> charge exchange injection for the SNS. These technical challenges include (1) operation in vacuum, (2) the control and synchronization of the UV laser beam with the H<sup>-</sup> beam and to shape the proton beam, (3) the control and stabilization of the Fabry-Perot resonator, and (4) protection of the mirrors from radiation. The first objective is to demonstrate successful power recycling in the resonator and to design a system of mirrors to be located within the accelerator vacuum chamber with the required optical and thermal stabilization.

**K. B. Beard**, V. G. Dudnikov (Muons, Inc) V. V. Danilov (ORNL) M. D. Shinn (JLAB)

TU6RFP039

### Design of the TPS Injection System

C. K. Chan, C.-H. Chang, P. J. Chou, C.-S. Fann, G.-Y. Hsiung, Y.-H. Liu, C.-S. Yang (NSRRC) J.-R. Chen (National Tsing Hua University)

The Taiwan Photon Source (TPS) is a new 3 GeV synchrotron light source to be built at the National Synchrotron Radiation Research Center (NSRRC) in Taiwan. The design of TPS is aimed to provide a low-emittance and high-brilliance beam with operation in the top-up mode. In this paper we present the design of the TPS injection section and the transport line from booster to storage ring. The specifications and parameters of the septa, kickers, and ceramic chambers are also described.

### Computational Model of Hydrogen Ion Laser Stripping

T. V. Gorlov, V. V. Danilov, A. P. Shishlo (ORNL)

Thin carbon foils, used as strippers for charge exchange injection into high intensity proton rings, become radioactive and produce uncontrolled beam loss, which is one of the main factors limiting beam power in high intensity proton rings. There is a possibility to replace existing foils by laser-assisted stripping of negative hydrogen ions developed and demonstrated at the SNS in Oak Ridge. In this paper we present progress in the physics and computation of laser stripping. The physical model includes such factors as the Stark effect, the polarization of the laser field, and the spontaneous relaxation and autoionization of hydrogen atoms in a strong electromagnetic field. The model formulates a quantum mechanical problem that can be solved numerically using a module created for the PyORBIT parallel code developed at the SNS.

### An Electron Beam SNS Foil Test Stand

R. W. Shaw, D. P. Bontrager, M. A. Plum (ORNL) C. S. Feigerle (University of Tennessee) C. F. Luck (ORNL RAD)

Nanocrystalline diamond foils are now in use for injection stripping at the SNS. Typical dimensions are 17x25 mm x 300-350 ug/cm<sup>2</sup> physical thickness. Corrugations of the foil help to maintain flatness, but after ca. 300 C of injected charge curling is observed. We continue to experiment with foil preparation techniques. To allow independent stripper foil testing without impacting SNS neutron production, we have assembled a 30 keV electron beam foil test facility to investigate foil lifetimes. At 30 keV acceleration, a 1.6 mA/mm<sup>2</sup> electron beam imparts the same peak heating load to a carbon foil as the injected and circulating current of the 1.4 MW SNS. At this energy the electron stopping distance is approximately six-fold longer than the foil thickness. The electron gun is capable of 5 mA current in a focal spot less than 1 mm FWHM diameter. Two foil stations are available for sequential tests, and foils can be rotated relative to the beam to vary their effective thickness. A 6 us risetime optical pyrometer records instantaneous foil temperatures over the 60 Hz heating profile. A CCD camera captures foil images over time. Results using this test stand are described.

### Optimization of the Booster to SPEAR Transport Line for Top-Off Injection

J. A. Safranek, W. J. Corbett, X. Huang, J. J. Sebek (SLAC)

In the past, SPEAR3 has had typically 50 to 70% injection efficiency. Much of the lost injected beam hit the small gap vacuum chambers at the insertion devices. We are now implementing injection with photon beamline shutters open, so these

losses create Bremsstrahlung down the photon beamlines, increasing radiation levels on the photon experimental floor. In this paper, we describe work done to better control the booster to SPEAR (BTS) transport line beam so as to reduce losses during injection. We have used new BTS BPM electronics to control the transport line trajectory. The trajectory response on these BPMs has been used to correct the BTS optics. We use turn-by-turn BPM readings of the injected beam in SPEAR to optimize the BTS trajectory in all six transverse and longitudinal coordinates. We use turn-by-turn profile measurements of the injected beam to verify the BTS optics correction. The stainless steel windows have been removed from the BTS vacuum system to reduce the transverse dimensions of the injected beam.

### Options for an 11 GeV RF Beam Separator for the Jefferson Lab CEBAF Upgrade

The CEBAF accelerator at Jefferson Lab has had, since first demonstration in 1996, the ability to deliver a 5-pass electron beam to experimental halls (A, B, and C) simultaneously. This capability was provided by a set of three, room temperature 499 MHz rf separators in the 5th pass beamline. The separator was two-rod, TEM mode type resonator, which has a high shunt impedance. The maximum rf power to deflect the 6 GeV beams was about 3.4kW. The 12 GeV baseline design does not preserve the capability of separating the 5th pass, 11 GeV beam for the 3 existing halls. Several options for restoring this capability, including extension of the present room temperature system or a new superconducting design in combination with magnetic systems, are under investigation and are presented.

J. R. Delayen, M. Spata, H. Wang (JLAB) J. R. Delayen (ODU)

TU6RFP044

### New Beam Injection System with a Single Pulsed Sextupole Magnet at the Photon Factory Storage Ring

We successfully demonstrated a new beam injection method using a single pulsed sextupole magnet (PSM). The PSM has a parabolic-shaped magnetic field, which is expected to provide an effective kick to the injected beam without little effects on the stored beam. We installed the PSM injection system at the Photon Factory storage ring (PF-ring) and succeeded in injecting the beam into PF-ring and storing the current up to 450 mA. This is the first demonstration of the PSM beam injection in electron storage rings. We also tested top-up injection and confirmed that dipole oscillation of the stored beam was sufficiently reduced compared with that generated by the conventional injection system. In this conference, we will present the experimental results and the advantages of the PSM beam injection.

H. Takaki, N. Nakamura (ISSP/SRL) K. Harada, T. Honda, Y. Kobayashi, T. Miyajima, S. Nagahashi, T. Obina, M. Shimada, A. Ueda (KEK) S. Matsuba (Hiroshima University, Graduate School of Science)

TU6RFP045

### A New Single-Lens Shaper Design with Diffraction Suppression Consideration

This paper introduces a new single lens laser beam shaper, which is capable of redistributing a beam with Gaussian profile to a beam with super-Gaussian profile, and simulates diffraction effects on laser beam inside and after the shaper. This design relieves "ringing" in shaped profile and maintains good transversal uniformity after the beam shaper.

C. Liu (CASA) C. Liu (PKU/IHIP) S. Zhang (JLAB)

TU6RFP046

**Demonstration and Optimization of a Drive Laser for an X-Band Photoinjector**

D. J. Gibson, S. G. Anderson, C. P.J. Barty, S. M. Betts, F. V. Hartemann, M. J. Messerly, H. H. Phan, M. Shverdin, C. Siders (LLNL)

Recently, a drive laser for an 2.86 GHz rf photoinjector, designed to provide a pulse that has a flat temporal and spatial profile, has been built, commissioned, and put into service as part of the LLNL Compton-scattering source program. This laser is based on an all-fiber oscillator and front-end amplification system, and provides both the laser light to generate the electrons as well as the rf signal that is amplified to accelerate them. Now, a new 11.424 GHz photoinjector is being developed, which has required a revised design of for the laser system. The higher frequency has placed more stringent requirements on the synchronization stability, delivered pulse length, and pulse rise times to maintain the desired emittance. Presented here are the overall design and measured performance of the current system and a discussion of what changes are being made to address observed shortcomings and more demanding requirements to make the system ready for the next-generation Compton-scattering source.

Recently, a drive laser for an 2.86 GHz rf photoinjector, designed to provide a pulse that has a flat temporal and spatial profile, has been built, commissioned, and put into

**Upgrade of the FRIB Prototype Injector for Liquid Lithium Film Testing**

S. A. Kondrashev, A. Barcikowski, Y. Momozaki, B. Mustapha, J. A. Nolen, P. N. Ostroumov, B. Reed, R. H. Scott (ANL)

of such a film has been demonstrated recently at ANL. Film thickness should be measured, and its temporal and spatial stability under high power ion beam irradiation should be verified. Intense beams of light ions generated by the FRIB prototype injector can be used for this task. The injector consists of an ECR ion source followed by a LEBT. A DC 3.3 mA/75 kV proton beam has been generated at the LEBT output. Proton beam power will be brought to required level by adding the second acceleration tube. A low energy electron beams (LEEB) technique, based on the thickness-dependent scattering of the electrons by the film, has been proposed as a fast-response on-line film thickness monitoring. A LEEB test bench has been built to verify this technique. The transmission of electrons through the carbon foils of different thicknesses was measured and compared with results of CASINO simulations. Agreement between the experimental and numerical results allows quantitative measurements of film thickness using the LEEB.

The development of a uniform and stable high velocity, thin liquid lithium film stripper is essential for the Facility for Rare-Isotope Beams (FRIB) Project. The formation

**The Wire Technology for Magnetic Shield Fabrication**

V. S. Avagyan (CANDLE) I. A. Pribitko (ChSTU)

developed. The required bonding pressure is provided by the difference in thermal expansion coefficient of the bonding samples and the external wire. Presented method broadens the technological capabilities of bonding samples and can be used for development of various devices in accelerators. The method has been successfully applied for fabrication of "ATLAS" hadron calorimeter magnetic shield at LHC.

The new method of diffusion bonding in vacuum or hydrogen, to obtain the tubular billet from the magnetic permalloy tape is

### Monitoring the FLASH Cryomodule Transportation from DESY Hamburg to CEA Saclay: Coupler Contact, Vacuum, Acceleration and Vibration Analysis

With a view to the series production of one hundred, 12 m long XFEL 1.3 GHz cryomodules and their transportation from the assembly site at CEA Saclay (F) to the installation site at DESY Hamburg (D) a test transportation of a FLASH cryomodule has been performed, in the condition foreseen for the mass transportation. The present study examines the stresses induced on the module and verify the damping capabilities of the transport frame in order to minimize risk of damage to the most critical components. During the transportation, acceleration and vibration have been monitored as well as coupler antenna contacts and vacuum performances. This paper describes the analysis performed and compares those results to the data of a similar transportation study at Fermilab for the CM1 cryomodule.

M. W. McGee (Fermilab) R. Amirikas, M. Boehnert, C. Engling, D. Hoppe, K. Jensch, D. Kostin, C. Mueller, H. Remde, O. Sawlanski, J. Wojtkiewicz (DESY) S. Barbanotti, A. Bosotti, M. Fusetti, P. M. Michelato (INFN/LASA) S. Berry, M. Dorlot, O. Napoly, C. G. Thomas-Madec (CEA) A. Bertolini (Albert Einstein, Leibniz Universität)

### Transport of DESY 1.3 GHz Cryomodule at Fermilab

In an exchange of technology agreement, Deutsches Elektron-Synchrotron (DESY) Laboratory in Hamburg Germany has provided a 1.3 GHz cryomodule "kit" to Fermilab. The cryomodule components (qualified dressed cavities, cold mass parts, vacuum vessel, etc.) sent from Germany in pieces were assembled at Fermilab's Cryomodule Assembly Facility (CAF). The cavity string was assembled at CAF-MP9 Class 10 cleanroom and then transported to CAF-ICB cold mass assembly area via a flatbed air ride truck. Finite Element Analysis (FEA) studies were implemented to define location of instrumentation for initial coldmass transport, providing modal frequencies and shapes. Subsequently, the fully assembled cryomodule CM1 was transported to the SRF Accelerator Test Facility at New Muon Lab (NML). Internal geophones (velocity sensors) were attached during the coldmass assembly for transport (warm) and operational (cold) measurements. A description of the isolation system that maintained alignment during transport and protected fragile components is provided. Shock and vibration measurement results of each transport and modal analysis are discussed.

M. W. McGee, T. T. Arkan, E. Borissov, J. R. Leibfritz, W. Schappert (Fermilab) S. Barbanotti (INFN/LASA)

### Transatlantic Transport of Fermilab 3.9 GHz Cryomodule to DESY

In an exchange of technology agreement, Fermilab has built and delivered a 3.9 GHz (3rd harmonic) cryomodule to Deutsches Elektron-Synchrotron (DESY) Laboratory to be installed in the TTF/FLASH beamline. Transport to Hamburg, Germany was completed via a combination of flatbed air ride truck and commercial aircraft, while minimizing transition or handling points. Initially, destructive testing of fragile components, transport and corresponding alignment stability studies were performed in order to assess the risk associated with transatlantic travel of a fully assembled cryomodule. Data logged tri-axial acceleration results of the transport with a comparison to the transport study predicted values are presented.

M. W. McGee, J. Grimm, D. R. Ollis (Fermilab)

TU6RFP053

**Controlled Emittance Blow Up in the Tevatron**

C.-Y. Tan, J. Steimel (Fermilab)

We have designed and commissioned a system which blows up the transverse emittance of the anti-proton beam without affecting the proton beam. It consists of a bandwidth limited noise source centered around the betatron tune, a power amplifier and a directional stripline kicker. The amount of blow up is controlled by the amount of energy delivered to the anti-protons betatron bands.

We have designed and commissioned a system which blows up the transverse emittance of the anti-proton beam without affecting the proton beam. It consists of a bandwidth limited noise source centered around the betatron tune, a power amplifier and a directional stripline kicker. The amount of blow up is controlled by the amount of energy delivered to the anti-protons betatron bands.

TU6RFP054

**Lifetime and Polarized E-Beam Measurements in Duke Storage Ring**J. Zhang, J. Li, C. Sun, W. Wu, Y. K. Wu (FEL/Duke University)  
A. Chao (SLAC) H. Xu (USTC/NSRL)

storage ring typically operates in the one-bunch or two-bunch mode with a very high bunch current and a varying electron beam energy as low as 250 MeV. The study of the Touschek lifetime is important for improving the performance of the Duke storage ring based light sources, including the storage ring FELs and a FEL driven Compton gamma source, the High Intensity Gamma-ray Source. This work reports our lifetime measurement results for few-bunch operation of the Duke storage ring. The Touschek loss rate is reduced when an electron beam is polarized in the storage ring. The change of the Touschek lifetime can be used as a method to monitor polarization of the electron beam. In this work, we will also report our preliminary results of the electron beam energy measurements using the resonant depolarization technique.

Touschek scattering is the dominant loss mechanism for the electron beam in a low energy storage ring with a large bunch current. The Duke Free-Electron Laser (FEL)

TU6RFP055

**Measurements of the Temperature on Carbon Stripper Foils by Pulsed 650 keV H<sup>-</sup> Ion Beams**

A. Takagi, Y. Irie, I. Sugai, Y. Takeda (KEK)

Thick carbon foils (>300 ug/cm<sup>2</sup>) has been used for stripping of H<sup>-</sup> ion beam at the 3GeV Rapid Cycling Synchrotron (3GeV-RCS) of J-PARC, where foils with long lifetime against high temperature >1800 °K are strongly required for efficient accelerator operations. The key parameter to the foil lifetime is foil temperature attained during irradiation. We have recently developed a new irradiation system for lifetime measurement using the KEK 650 keV Cockcroft-Walton accelerator with high current pulsed and dc H<sup>-</sup> beam, which can simulate the high-energy depositions upon foils in the RCS. During irradiation tests by this system, the temperature of foil is measured by a thermometer in a dc mode, and by using a photo-transistor in a pulsed mode. This paper describes the pulsed measurements with 5-10 mA<sub>peak</sub>, 0.1-0.5 msec duration and 25 Hz repetition.

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TU6RFP056

**Design and Simulation of Microstrip Directional Coupler with Tight Structure and High Directivity**

T. Hu, L. Cao, J. Huang, D. Li, B. Qin, J. Yang (HUST)

The design study of Cyclotron CYCHU 10MeV has been developed at Huazhong University of Science and Technology (HUST). Because of the low center frequency (100MHz) of it's RF system, we should choose suitable directional couplers for the RF system which is supposed to be high-directivity and tight-structure. This paper analyses

The design study of Cyclotron CYCHU 10MeV has been developed at Huazhong University of Science and Technology

and synthesizes kinds of directional couplers, especially microstrip structure, for its tinier volume at the low center frequency compared with stripline and branch structures. The achievement of the high-directivity with microstrip configuration is carried out by the distributed capacitor to decrease the even and odd mode phase difference. Capacitive compensation is performed by the interdigital capacitors. The proposed structure is easy to fabricate and incorporate another microwave device due to planar microstrip.

### Status of the MICE Muon Ionization Cooling Experiment

Muon ionization cooling provides the only practical solution to prepare high brilliance beams necessary for a neutrino factory or muon colliders.

V. C. Palladino (INFN-Napoli)

The muon ionization cooling experiment (MICE) is under development at the Rutherford Appleton Laboratory (UK). It comprises a dedicated beam line to generate a range of input emittance and momentum, with time-of-flight and Cherenkov detectors to ensure a pure muon beam. A first measurement of emittance is performed in the upstream magnetic spectrometer with a scintillating fiber tracker. A cooling cell will then follow, alternating energy loss in liquid hydrogen and RF acceleration. A second spectrometer identical to the first one and a particle identification system provide a measurement of the outgoing emittance. By April 2009 it is expected that the beam and first set of detectors will have been commissioned, and a first measurement of input beam emittance may be reported. Along with the plan of measurements of emittance and cooling that will follow in the second half of 2009 and in 2010.

### Neutron Energy Spectra and Dose Equivalent Rates from Heavy-Ion Reactions below 20 MeV/u Using the PHITS Code

The Particle and Heavy Ion Transport Code (PHITS)\* has been typically used to predict radiation levels around high-energy (above

Y. Iwamoto (JAEA) K. Niita (RIST) R. M. Ronningen (NSCL)

100 MeV/u) heavy-ion accelerator facilities. However, predictions of radiation levels around low-energy (around 10 MeV/u) heavy-ion facilities are also desirable, but the reliability of PHITS at low energies has not been investigated. In this work, neutron energy spectra from 10 MeV/u  $^{12}\text{C}$  and  $^{16}\text{O}$  ions incident on C and Cu targets have been calculated using the quantum molecular dynamics (QMD) model coupled to the generalized evaporation model (GEM) in PHITS. In particular, the influence of the "switching time", defined as the time when the QMD calculation is stopped and the calculation switches to the GEM model, was studied. The calculated neutron energy spectra obtained using a value of 100 fm/c for the switching time agree well with the experimental data. We have also used PHITS to simulate an experimental study by Ohnesorge et al.\*\*, by calculating neutron dose equivalent rates, for 3-16 MeV/u  $^{12}\text{C}$ ,  $^{16}\text{O}$  and  $^{20}\text{Ne}$  beams incident on Fe, Ni and Cu targets. The calculated neutron dose equivalent rates agree well with the data.

\*H. Iwase, K. Niita and T. Nakamura, J. Nucl. Sci. Technol. 39, 1142 (2002).

\*\*W. F. Ohnesorge, H. M. Butler, C. B. Fulmer and S. W. Mosko, Health Physics 39, 633 (1980).

**Experimental Studies of the ReA3 Triple-Harmonic Buncher**

Q. Zhao, V. Andreev, J. Brandon, G. Machicoane, F. Marti (NSCL)

The National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University (MSU) is implementing a system called the ReA3 to reaccelerate rare isotope beams from projectile fragmentation to energies of about 3 MeV/u. The 80.5 MHz triple-harmonic buncher before the ReA3 Radio Frequency Quadrupole (RFQ) linac has recently been implemented and measurements made. Tests using beams from the Electron Cyclotron Resonance (ECR) ion source test stand are being performed. The beam properties after the buncher are fully characterized using various diagnostic tools (e.g. fast Faraday cup, energy analyzer, emittance scanner). As a result, the tuning procedures for the buncher operations are developed. We will present the detailed results of the beam based buncher studies and compare them with simulations.

**Note of Some Thermal Analytical Solutions in Accelerator Engineering**

A. Sheng (NSRRC)

Bending Magnet, linear undulator, elliptical polarized undulator and wiggler are all regular synchrotron radiation power profile that accelerator engineers would encounter while they are designing the high heat load components. Due to their characteristic type of power distribution, some temperature solutions are available and can be used as a parametric study, as well as optimized tool applicable on the thermomechanical design such as mask absorber, photon absorber, mirror or other heat load subsystems. The analytical solutions and some interrelation studies are also presented in this paper.

**Radiation Damage Studies with Fast Neutrons on Optical Materials**

J. E. Spencer (SLAC)

With the increasing use of lasers and electro- and fiber-optics in many technical areas there is a growing interest in testing optical materials for their environmental and radiation hardness under a variety of conditions including failure modes expected at colliders where the accelerator and detectors may be subjected to large fluences of hadrons, leptons and gammas to maximize operating efficiency and lifetime. When high power lasers are used there are additional constraints that drive the search for new materials that become especially important for the burgeoning field of laser acceleration. The effects of Cobalt x-rays on many materials were presented previously\* and the present (augmented) study with neutrons is a natural extension. Here we give the results of our latest measurements of the fast-neutron, stepped-dose program at the UC Davis, McClellan Nuclear Reactor that is intended to maximize total neutron dose under realistic operating conditions. Induced radioactivities observed for different materials are given as well where the results depend strongly on the dopants and solid state structure of the compounds.

\*Gamma Radiation Studies on Optical Materials, IEEE Trans. Nucl. Sci., Dec. 2002.



### Radiation Damage Studies with Fast Neutrons on REPMs

Many materials and electronics need to be tested for their environmental and radiation hardness under a variety of conditions including failure modes expected at colliders where the accelerator and detectors may be subjected to large fluences of hadrons, leptons and gammas to maximize the operating efficiency and lifetime of the facility. Examples are NdFeB magnets which are being considered for the damping rings and final focus, electronic and electro-optical components and devices which may be utilized in the detector readout and accelerator controls and CCDs required for the vertex detector. Effects of Cobalt x-rays on materials were presented and our understanding of the situation for rare earth permanent magnets at PAC03. Here we give the results of our latest measurements for the fast-neutron, stepped-dose program at the UC Davis, McClellan Nuclear Reactor intended to maximize total neutron dose under realistic operating conditions. Induced radioactivities observed for different manufacturer's are given that depend strongly on the dopants used to enhance characteristics such as Br, Hc1 or Tc. Various damage factors e.g separation of operating point and Hc1 are discussed.

**J. E. Spencer**, S. D. Anderson, Z. R. Wolf (SLAC) M. Boussoufi (UCD/MNRC) D. E. Pellet (UCD)

TU6RFP062

### The Development of a Slow-Wave Chopper Structure for Next Generation High Power Proton Drivers

A description is given of the development of a slow-wave chopper structure for the 3.0 MeV, 60 mA, H<sup>-</sup> U+203E OVERLINE s MEBT on the RAL Front-End Test Stand (FETS). Two candidate structures, the so called RAL 'Helical' and 'Planar' designs have been previously identified, and are being developed to the prototype stage. Three test assemblies have been designed by modelling their high frequency electromagnetic properties in the time domain, using a commercial 3D code, and their subsequent manufacture, using standard NC machining practice, has helped to validate the selection of machine-able ceramics and copper alloys. In addition, an electro-polishing technique has been developed that enables the 'fine tuning' of strip-line characteristic impedance, and edge radius. Measurements of the transmission line properties of the 'Helical' and 'Planar' test assemblies are presented.

**M. A. Clarke-Gayther** (STFC/RAL/ISIS)

TU6RFP063

### Coaxial Coupler for X-Band Photocathode RF Gun

X-band photocathode RF gun can be utilized to generate ultra-low emittance electron beams. In this paper, we present the design of a coaxial coupler for the X-band RF gun to avoid emittance growth caused by field asymmetries. A detailed 3D simulation of the coupler utilizing CST is performed, the microwave circuit analysis is accomplished, and the relation between the coupling factor and the coaxial coupler structure is obtained. This paper likewise presents the emittance comparison between the traditional coupler and the coaxial coupler.

**X. H. Liu, C.-X. Tang** (TUB)

TU6RFP064

**The MICE PID Detector Systems**

L. M. Cremaldi, D. A. Sanders, D. J. Summers (UMiss)

The international Muon Ionization Cooling Experiment (MICE) is being built at the Rutherford Appleton Laboratory (RAL), to demonstrate the feasibility of ionization cooling of muon beams. This is one of the major technological steps needed towards the development of a muon collider and a "neutrino factory" based on muon decays in a storage ring. MICE will use particle detectors to measure the cooling effect with high precision, planning to achieve an absolute accuracy on the measurement of emittance of 0.1% or better. The particle i.d. detectors and tracker must work under harsh environmental conditions due to high magnetic fringe fields and RF noise. We will describe the MICE particle i.d. detector systems, and show some current performance measurements of these detectors.

The international Muon Ionization Cooling Experiment (MICE) is being built at the Rutherford Appleton Laboratory (RAL), to

**Fast Tune Jump Magnets and Power Supplies**

J. W. Glenn, H. Huang, C. J. Liaw, I. Marnieris, W. Meng, J.-L. Mi, P. J. Rosas, J. Sandberg, J. E. Tuozzolo, W. Zhang (BNL)

In order to cross more rapidly the 82 weak resonances caused by the horizontal tune and the partial snakes, we plan to jump the horizontal tune 82 times during the acceleration cycle, 41 up and 41 down\*. To achieve this, the magnets creating this tune jump will pulse on in 100 microseconds, hold the current flat for about four milli-seconds and zero the current in another 100 microseconds. The magnets are old laminated beam transport magnets with longitudinal shims closing the aperture to reduce inductance and power supply current. The power supply uses a high voltage capacitor discharge to raise the magnet current, which is then switched to a low voltage supply, and then the current is switched back to the high voltage capacitor to zero the current. The current in each of the magnet pulses must match the order of magnitude change in proton momentum during the acceleration cycle. The magnet, power supply and cabling will be described with coast saving features and operational experience.

In order to cross more rapidly the 82 weak resonances caused by the horizontal tune and the partial snakes, we plan to jump the horizontal tune 82 times during the acceleration

\*Overcome Horizontal Depolarizing Resonances in the AGS with Tune Jump

**The Redesign, Installation and Commissioning of Light II-A Pulsed Power Generator and its Potential Application**

C. Wang, X. D. Jiang, S. M. Wei, N. G. Zeng, T. J. Zhang (CIAE) J. Z. Wang (Department of Physics, Central China Normal University)

Light II-A pulsed power generator was used as a power driver of pumping KrF laser at CIAE. The redesign of Light II-A pulsed power generator is based on the consideration that the machine will consist of one single Marx generator with two different experimental lines, which is presented in this paper. The original experimental line with characteristic impedance of  $5\Omega$  is remained, and a new line of low impedance (about  $1\Omega$ ) is added to the Marx generator. The structure design and the electric insulation design are introduced. It is also outlined here the manipulation of modeling the dynamic behavior of gas discharge arc as well as the circuit simulation results of the two experimental lines. Meanwhile a brief introduction is given to the potential application of the low impedance line.

Light II-A pulsed power generator was used as a power driver of pumping KrF laser at CIAE. The redesign of Light II-A pulsed power generator is based on the consider-

**Development of the Prototype Module of the 6MV/10MA Z-Pinch Test Stand**

In order to study the physics of fast Z-pinch- es and research the key issues of pulse power technology, a 10MA/6MV z-pinch primary test stand (PTS) composed of 24 modules will be built in IFP. The prototype module adopted capacitive storage scheme is composed of the 6MV/300kJ Marx-generator (MG), intermediate storage capacitor (IC), laser-triggered switch (LTS), pulse forming line (PFL), water self-breakdown switch (WS), and tri-plate pulse transmission line (PTL). The measured output current of the prototype is approximate 520kA, and output voltage is approximate 2.1MV. The unique multi-stage LTS based on uniform field distribution design and multi-pin unsymmetrical WS make the prototype modules have low systemic delay jitter which is necessary for synchronization of multi-module facility. 1- $\delta$  jitter of delay of the system is less than 4ns.

H. T. Li (CAEP/IFP)

TU6RFP068

**Development of a Prototype Kicker Magnet for CSNS/RCS Extraction**

China Spallation Neutron Source is a high intensity beam facility planed to build in future in China. It is composed of Linac, RCS and target station. The beam extraction from the RCS will be realized by ten vertical kicker magnet and one Lambertson magnet. One prototype kicker magnet has been successfully designed and developed in Institute of High Energy Physics. In this paper, the physical and structural design of the prototype kicker magnet are presented, and issues of the magnet development, construction and test are discussed.

W. Kang, Y. Hao, L. H. Huo, J. X. Song, L. Wang (IHEP Beijing)

TU6RFP069

**A Prototype of Pulsed Power Supply for CSNS/RCS Injection Painting Bump Magnets**

The prototype of pulsed power supply for injection painting bump magnets of CSNS/ RCS is being developed. This pulsed power supply consists of IGBT H bridges in series and parallel. The pulse current of the prototype is 18000A, the voltage is about 3KV and the equivalent frequency is about 1MHz. This paper will introduce this prototype in detail.

L. Shen, Y. L. Chi, C. Huang (IHEP Beijing)

TU6RFP070

**Development of a Prototype Bump Magnet for CSNS/RCS Injection**

China Spallation Neutron Source is a high intensity beam facility planed to build in future in China. It is composed of Linac, RCS and target station. Two sets of pulsed painting bump magnets, 4 magnets in each set , will be used in CSNS RCS to create a dynamic orbit bump for injection process. The design of these 8 bump magnets has been completed. One prototype bump magnet has been assembled and tested. In this paper, the magnetic field analysis, the eddy current and thermal consideration in the end plates of the prototype bump magnet are presented, and issues of the magnet development, construction and test are discussed.

J. X. Song, Y. Hao, L. H. Huo, W. Kang, L. Wang (IHEP Beijing)

TU6RFP071

**Fast Kicker**

**A. A. Mikhailichenko** (Cornell University, Department of Physics)

We use the peculiarities of interaction of relativistic beam with the electromagnetic wave and suggesting the kicker having the rise time coinciding with the rise time of the feeding pulse. In particular, we suggesting practical scheme of kicker able to generate kick angle 0.01 rad to 5 GeV beam establishing/ dropping in 0.1 nsec with ability for repetition rate up to 100 MHz.

**Voltage Droop Compensation For High Power Marx Modulators**

**D. Yu, P. Chen, M. Lundquist** (DULY Research Inc.)

Marx modulators, operated by the solid-state switches of Metal Oxide Semiconductor Field Effect Transistors (MOSFETs) or Insulated Gate Bipolar Transistors (IGBTs), offer an alternative to conventional high voltage modulators for rf power sources. They have the advantages of compact size, high-energy efficiency, high reliability, pulse width control and cost reduction. However, Marx modulators need a complex voltage compensation circuit if they are employed in long pulse applications such as the ILC project. We describe novel schemes to compensate the voltage droop of the Marx modulator and minimize the flattop fluctuation of the voltage pulse output through the utilization of inductances and the fast switching properties of solid-state switches. The feasibility of the schemes has been analyzed and relevant data will be presented.

**Marx Bank Technology for a Short Pulse ILC Modulator**

**M. K. Kempkes, F. O. Arntz, J. A. Casey, M. P.J. Gaudreau, I. Roth** (Diversified Technologies, Inc.)

Diversified Technologies, Inc. (DTI) has developed high power, solid-state Marx Bank designs for a range of accelerator and collider designs. We estimate the Marx topology can deliver equivalent performance to conventional designs, while reducing acquisition costs by 25-50%. In this paper DTI will describe the application of Marx based technology to a short-pulse modulator (500 kV, 265 A, 3 us) for the International Linear Collider. The primary challenge is minimizing the overall size and cost of the storage capacitors in the modulator. The design demands unique choices in components and controls, including the use of electrolytic capacitors. This paper will review recent progress in the modulator's development and testing being built a DOE Phase II SBIR grant.

**Design, Testing and Operation of the Modulator for the CTF3 Tail Clipper Kicker**

**M. J. Barnes, T. Fowler, G. Ravida** (CERN)

The goal of the present CLIC Test Facility (CTF3) is to demonstrate the technical feasibility of specific key issues in the CLIC scheme. The extracted drive beam from the combiner ring (CR), of 35 A in magnitude and 140 ns duration, is sent to the new CLic EXperimental area (CLEX) facility. A Tail Clipper (TC) is required, in the CR to CLEX transfer line, to allow the duration of the extracted beam pulse to be adjusted. Fours sets of striplines are used for the tail clipper, each consisting of a pair of deflector plates driven to equal but opposite potential. The tail clipper kick must have a fast field rise-time, of not more than 5 ns, in order to minimize uncontrolled beam loss. High voltage MOSFET switches have been chosen to meet the demanding specifications for the semiconductor switches

for the modulator of the tail clipper. This paper discusses the design of the modulator; measurement data obtained during testing and operation of the tail clipper is presented and analyzed.

### Measurement of the Longitudinal and Transverse Impedance of Kicker Magnets Using the Coaxial Wire Method

Fast kicker magnets are used to inject beam into and eject beam out of the CERN SPS accelerator ring. These kickers are generally ferrite loaded transmission line type magnets with a rectangular shaped aperture through which the beam passes. Unless special precautions are taken the impedance of the ferrite yoke can provoke significant beam induced heating, even above the Curie temperature of ferrite. In addition the impedance can contribute to beam instabilities. In this paper different variants of the coaxial wire method, both for measuring longitudinal and transverse impedance, are briefly discussed in a tutorial manner and do's and don'ts are shown on practical examples. In addition we present the results of several impedance measurements for SPS kickers using the wire method and compare those results with theoretical models.

**M. J. Barnes**, F. Caspers, T. Kroyer, E. Métral, F. Roncarolo, B. Salvant (CERN)

TU6RFP076

### Extraction Kicker Magnet Design for Main Injector

A fast kicker magnet has been designed for use in Main Injector at Fermilab. The magnet will be used for controlled removal of unbunched beam created in the slip stacking process. The strength of each of the six magnets is 75 G·m at 500 A. The aperture is 11.4 cm wide x 5.3 cm high x 64 cm long. The field rise time from 3% to 97% of less than 57 ns has been achieved along with a flattop variation of less than  $\pm 3\%$  variation. Results of simulation and measurements will be presented. The pulser is described in a companion paper.

**C. C. Jensen**, R. E. Reilly, I. Terechkine (Fermilab)

TU6RFP077

### Extraction Kicker Pulser Design for Main Injector

A fast kicker power supply has been designed for use in the Main Injector at Fermilab. The system will be used for controlled removal of unbunched beam created in the slip stacking process. A switch operating at 50 kV with a 3% to 97% rise time of less than 25 ns into a 50  $\Omega$  load is required. A thyatron and enclosure have been designed. A pulse length of 1.6  $\mu$ s is required so a cable pulse forming line is used. Results with and without a ferrite pulse sharpening line will be presented. The magnet is described in a companion paper.

**C. C. Jensen** (Fermilab)

TU6RFP078

### A High Voltage, High Rep-Rate, High Duty Factor Stacked Transformer Modulator

A high voltage modulator has been built and installed at Fermi Nation Accelerator Laboratory for the purpose of driving the gun anode of the Tevatron Electron Lens (TEL). It produces a defined voltage for each of the 36 (anti)proton bunches. This modulator employs five transformers to produce high voltage at a high repetition rate and high duty factor. It is capable of outputting sustained complex waveforms having peak voltages over 6 kV and average

**G. W. Saewert**, H. Pfeffer (Fermilab)

TU6RFP079

periodic rates up to 450 kHz with voltage transitions occurring at 395 ns intervals. This paper describes key aspects of the hardware design and performance.

### Cold Cathode Thyatron Based High-Voltage Kicker System for the Duke Accelerators: Performance and Improvements

V. Popov, S. F. Mikhailov, P. W. Wallace (FEL/Duke University)  
O. Anchugov, Yu. Matveev, D. A. Shvedov (BINP SB RAS)

The Duke FEL/HIGS (Free electron laser/High Intensity Gamma-ray source) facility has recently undergone through a series of major upgrade. As a part of this upgrade,

a kicker system was designed to provide reliable injection from the booster into the storage ring at any energy chosen from the range of 240 MeV to 1.2 GeV. Relatively new and not sufficiently studied switching device has been selected as a basic component to build a set of nanosecond resolution high-voltage generators. So called Pseudo-Spark Switch (PSS), also known as a cold cathode thyatron, has the same or slightly better jitter, reasonable range of switched high voltages and significantly lower heater power as compared to the traditional "hot" thyatrons. Despite of the fact that it requires more complicated triggering system, this device still seems very attractive as a driver for short pulse kickers. Almost three years of operation of the Duke FEL facility has revealed number of advantages and challenges related to the thyatrons of this type. In this paper we depict design features of the kicker system, discuss some accomplished improvements and summarize our three year experience.

### Field Compensation of the Injection Septum of the JPARC Main Ring Injection System

K. Fan (KEK)

The J-PARC that is under construction at JAEA will provide a high-intensity, high-power proton beam for experiments. To es-

cape the serious radiation problem due to the uncontrolled beam loss of the high-intensity beam, critical demands are imposed to the injection system design. The JPARC main ring (MR) injection system includes 2 septum magnets, a high-field septum and a low-field eddy-current septum. The high-field septum works in pulse mode, the eddy current effects not only degrade the gap field quality but also increase the leakage field, which increases the closed beam orbit distortion and cause beam loss. The first stage of MR beam commissioning at injection energy had been performed. The injection beam intensity is very low, however, the beam loss during the injection period was observed. It will be a severe problem that needs to be resolved to realize the high-intensity high-power beam operation in the future. Thus, the septum magnet was modified to improve the performance. Simulation shows that after modification, the leakage field can decrease a lot.

### Tests and Operational Experience with the DAFNE Stripline Injection Kicker

F. Marcellini, D. Alesini, S. Guiducci, P. Raimondi (INFN/LNF)

New injection stripline kickers are operating since December 2007 at the DAFNE collider. They are designed to operate with very

short pulse generators to perturb only the injected bunch and the two stored adjacent ones at 2.7 ns and are a test for the design of the fast kickers of the damping ring of the International Linear Collider (ILC). Stripline frequency response and impedance measurements have been performed to characterize the structure and are compared to the simulation results. Operational performances are also described, pointing out the problems occurred and the flexibility of the stripline structure that worked with both the short and the old pulse generators and has been used as an additional damping kicker to improve the efficiency of the horizontal multibunch feedback system.

### Measurement Results of the Characteristic of the Pulse Power Supply for the Injection Bump System in J-PARC 3-GeV RCS

The main circuit of the switching power supplies for the injection bump system is composed of multiple-connection of the IGBT assemblies. The element of the IGBT assembly, which is the power supply of the shift bump-magnets, is a type of 3300V-1200A and 6 kHz in elementary frequency. The power supply has the output performance of 20 kA / 6.6 kV. The synthetic frequency of the multiple-connection assemblies is over 48 kHz and the tracking error less than 1 % is proved. The beam commissioning test of long-term operation for about three-week was performed. The deviation of the exciting current from the programmed current pattern has been confirmed less than 1%. The peculiar characteristic of the pulse power supply has been obtained by the analysis on the frequency response of the exciting current and the magnetic field. In the FFT analytical result of the magnetic field, the peaks of 48 kHz and its higher harmonics that are related to the switching frequency was observed. The ground loop current and the voltage were also measured.

**T. Takayanagi**, Y. Irie, J. Kamiya, M. Kinsho, T. Togashi, T. Ueno, M. Watanabe, M. Yoshimoto (JAEA/J-PARC)

TU6RFP083

### Fast Disconnect Switch for ALS Storage Ring RF System High Voltage Power Supply

ALS is the 1.9GeV third generation synchrotron light source which has been operating since 1993 at Berkeley National Lab. Our team is now working on the design of a new RF power source (replacement of the existing 320kW klystron with 4 IOT's). In the new design the existing conventional crow-bar klystron protection system will be replaced with a fast disconnect switch. The switch will be constructed out of 16 high-voltage IGBT's connected in series equipped with static and dynamic balancing system. The main advantage of using this new technology is faster action and virtually no stress for the components of the high voltage power supply. This paper will describe the hardware design process and the test results of the prototype switch unit.

**S. Kwiatkowski**, K. M. Baptiste, J. Julian (LBNL)

TU6RFP084

### The Electron Accelerator Based on the Magnetron Gun

The structure and beam parameters of the accelerator based on the magnetron gun with a secondary-emission cathode are presented. The special feature of the impulse generator with a complete storage-capacitor discharge to energize the gun consists in the application of thyatron blocking and change-over to partial discharge conditions. At a voltage of up to 150 kV, the beam current up to 150 A., pulse duration of 10  $\mu$ s and pulse rate of 3 Hz were provided. The electron beam is annular in shape, has a diameter of 44 mm, the wall thickness being 2 mm. The amplitude and distribution adjustment of the magnetic field provides the beam thickness in the range from 1.5 mm to 3.5 mm. The coefficient of azimuthal nonuniformity of the beam is 1.1, the long-term beam current amplitude stability makes  $\pm 2\%$ . Samples of various materials were subjected to irradiation in the accelerator with the power density attaining  $\sim 4 \text{ MW/cm}^2$ .

**V. Zakutin**, A. N. Dovbnya, N. G. Reshetnyak (NSC/KIPT)

TU6RFP085

**A Macro-Pulsed 1.2 MW Proton Beam for the PSI Ultra Cold Neutron Source**

D. Reggiani, M. Daum, P.-A. Duperrex, G. Dzieglewski, U. P. Frei, T. Korhonen, A. C. Mezger, U. Muller, U. Rohrer (PSI)

At PSI, a new and very intensive Ultra-Cold Neutron (UCN) source based on the spallation principle will start operation at the end of 2009. From then on, two neutron spallation sources - the continuous wave SINQ and the macro-pulsed UCN source will be running concurrently at PSI. The 590 MeV, 1.2 MW proton beam will be switched towards the new spallation target for about 8 s every 800 s. This operation can be accomplished by means of a fast kicker magnet with a rise-time shorter than 1 ms. A beam dump capable of absorbing the full-intensity beam for a few milliseconds has been installed after the last bending magnet so that the kicking process and the beam diagnostic can be checked well before the UCN facility will be ready for operation. Recent tests have demonstrated the capability of switching the 1.2 MW beam with negligible losses and to center it through the beam line by using fast beam position monitors. Much longer beam pulses (up to 6 seconds) with reduced beam intensity have also been performed successfully.

**Development of High Stability Klystron-Modulator System for PLS-II 3.0-GeV Electron Linac**

S. S. Park, S. H. Kim, S.-C. Kim, S. H. Nam, Y. G. Son, J.-H. Suh (PAL)

The Pohang Accelerator Laboratory (PAL) will start its second upgrade of the Pohang Light Source (PLS) from 2009. For the upgrade, the linac energy will be increased from 2.5 GeV to 3 GeV. Furthermore, the injection to the PLS storage ring (SR) will be changed from fill-up mode to top-up mode. This requires high energy stability of the linac beam. Since the beam energy stability is governed by accelerating RF field stability, the modulator charging voltage stability becomes important. Therefore, it becomes necessary to improve our current modulator. We will present two different types of on-going R&D in the PLS linac to improve the modulator stability. The two types are a de-Qing system, which controls the modulator pulse forming network (PFN) charging voltage stability, and an inverter power supply, which provides highly stable charging voltage to the modulator.

**Design of Dual Gun System for the PLS-II Linear Accelerator**

Y. G. Son, K. R. Kim, S. H. Nam, S. J. Park (PAL)

The PLS-II, the major upgrade program of the PLS (Pohang Light Source, a 2.5-GeV 3rd generation light source), is planned at the Pohang Accelerator Laboratory. The PLS 2.5-GeV linear accelerator, being the full-energy injector for the PLS storage ring, should be upgraded to provide the beam energy of 3 GeV. For the PLS-II linac, we are going to establish a dual electron gun system in which two guns will be on the accelerator beamline with a bending magnet enabling immediate switching of guns. The dual gun system is expected to achieve high reliability for the top-up injection to the PLS-II storage ring. Also the gun will be upgraded to provide the beam energy of 200 keV and a pulse high-voltage modulator will be constructed. Fifteen-section PFNs will be connected in series to make final impedance of approximately 17.3 ohm. A new modulator applying the inverter technology will be used to charge the PFN and obtain more stable charging performances. In this article the authors would like to report on the design status of the accelerator beamline and inverter modulator for the dual gun system.



### Resonant Kicker System Development at SLAC

The design and installation of the Linear Coherent Light Source\* at SLAC National Accelerator Laboratory has included the development of a kicker system for selective beam bunch dumping. The kicker is based on an LC resonant topology formed by the 50 uF energy storage capacitor and the 64 uH air core magnet load and has a sinusoidal pulse period of 400us. The maximum magnet current is 500 A. The circuit is weakly damped, allowing most of the magnet energy to be recovered in the energy storage capacitor. The kicker runs at a repetition rate of 120Hz. A PLC-based control system provides remote control and monitoring of the kicker via EPICS protocol. Fast timing and interlock signals are converted by discrete peak-detect and sample-hold circuits into DC signals that can be processed by the PLC. The design and experimental characterization of the systems is presented.  
\*<http://ssrl.slac.stanford.edu/lcls/>

T. G. Beukers, J. W. Krzaszczak, M. H. Larrus, A. C. de Lira (SLAC)

TU6RFP089

### ILC Marx Modulator Development Program Status

A program is underway at SLAC to develop a Marx-topology klystron modulator for the International Linear Collider\* project. It is envisioned as a smaller, lower cost, and higher reliability alternative to the bouncer-topology baseline design. The application requires 120 kV ( $\pm 0.5\%$ ), 140 A, 1.6 ms pulses at a rate of 5 Hz. The Marx constructs the high voltage pulse without an output transformer, large at these parameters, by instead combining a number of lower voltage cells in series. The modularity of the Marx topology is further exploited to achieve a redundant, high-availability design. The ILC Marx employs solid state elements; IGBTs and diodes, to control the charge, discharge and isolation of the cells. The SLAC designs are oil-free; air is used for high voltage insulation and cooling. The first generation prototype, P1, is undergoing life testing. Development of a second generation prototype, P2, is underway. Status updates for both prototypes will be presented.

C. Burkhart, T. G. Beukers, M. A. Kemp, R. S. Larsen, K. J.P. Macken, M. N. Nguyen, J. Olsen, T. Tang (SLAC)

\*ILC Reference Design Report, <http://www.linearcollider.org/cms/?pid=1000437>

TU6RFP090

### Development of an Adder-Topology ILC Damping Ring Kicker Modulator

The injection and extraction kickers (50  $\Omega$ ) for the ILC damping rings will require highly reliable modulators to deliver  $\pm 5$  kV, 2 ns flat-top ( $\sim 1$  ns rise and fall time) electrical pulses at up to 6 MHz\*. An effort is underway at SLAC National Accelerator Laboratory to meet these requirements using a transmission line adder topology to combine the output of an array of  $\sim 1$  kV modules. The modules employ an ultra-fast hybrid driver/MOSFET that can switch 33 A in 1.2 ns. Experimental results for a scale adder structure will be presented.

T. Tang, C. Burkhart (SLAC)

\*ILC Reference Design Report, <http://www.linearcollider.org/cms/?pid=1000437>

TU6RFP091

**Report on a New SLAC ESB L-Band Modulator and Klystron Test Stand**

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We report on the recent installation, commissioning and first months of operations of a new L-Band RF Station in SLAC's End Station B experimental area. The ILC-type modulator was first operated as a stand alone device and later connected to a 10 MW Multi-Beam L-Band Klystron. Stability of operations over several weeks of combined Modulator and Klystron operations will be presented as well. Long term goal is to operate the L-Band RF Station in this setup for about one year to determine the reliability and stability of the particular devices used.

We report on the recent installation, commissioning and first months of operations of a new L-Band RF Station in SLAC's End Station B experimental area. The ILC-type modulator was first operated as a stand

**Redesign of the H-Bridge Switch Plate of the SNS High Voltage Converter Modulator**

M. A. Kemp, C. Burkhart, M. N. Nguyen (SLAC) D. E. Anderson (ORNL)

performance require increased modulator reliability. An effort is underway at SLAC National Accelerator Laboratory to redesign the modulator H-bridge switch plate with the goals of increasing reliability and performance\*\*. The major difference between the SLAC design and the existing design is the use of press-pack IGBTs. Compared to other packaging options, these IGBTs have been shown to have increased performance in pulsed-power applications, have increased cooling capability, and do not fragment and disassemble during a fault event. An overview of the SLAC switch plate redesign is presented. Design steps including electrical modeling of the modulator and H-bridge, development of an integrated IGBT clamping mechanism, and heat sink performance validation are discussed. Experimental results will be presented comparing electrical performance of the SLAC switch plate to the existing switchplate under normal and fault conditions.

The 1-MW High Voltage Converter Modulators\* have operated in excess of 250,000 hours at the Spallation Neutron Source. Increased demands on the accelerator performance

\*W. A. Reass, et al., "Design, Status, and First Operations of the Spallation Neutron Source Polyphase ...", PAC, 2003

\*\*M. A. Kemp, et al., "Next Generation IGBT Switch Plate ...," LINAC, 2008.

**Advanced IGBT Gate Drive for the SNS High Voltage Converter Modulator**

M. N. Nguyen, C. Burkhart, M. A. Kemp (SLAC) D. E. Anderson (ORNL)

that effort, a new IGBT gate driver has been developed. The drivers are an integral part of the switch plate, which are essential to ensuring fault-tolerant, high-performance operation of the modulator. The redesigned drivers improve upon the existing gate drives in several ways. The new gate driver has improved fault detection and suppression capabilities; suppression of shoot-through and over-voltage conditions, monitoring of excess di/dt and  $V_{ce,sat}$ , and redundant power isolation are some of the added features. Also, triggering insertion delay is reduced by a factor of four compared to the existing driver. This presentation details the design and performance of the new IGBT gate driver. A detailed schematic and description of the construction are included. Operation of the fast over-current detection circuits, active IGBT over-voltage protection circuit, shoot-through prevention and control power isolation breakdown detection circuit are discussed.

SLAC National Accelerator Laboratory is developing a next generation H-bridge switch plate\*, a critical component of the SNS High Voltage Converter Modulators\*\*. As part of

\*W. A. Reass, et al., "Design, Status, and First Operations of the Spallation Neutron Source Polyphase ...", PAC, 2003

\*\*M. A. Kemp, et al., "Next Generation IGBT Switch Plate ...," LINAC, 2008.

### Towards a PEBB-Based Design Approach for a Marx-Topology ILC Klystron Modulator

Introduced by the U. S. Navy more than a decade ago\*, the concept of Power Electronic Building Blocks (PEBBs) has been successfully applied in various applications. It is well accepted within the power electronics arena that this concept offers the potential to achieve increased levels of modularity and compactness. This approach is thus ideally suited for applications where easy serviceability and high availability are key, such as the ILC. This paper presents a building block approach for designing Marx modulators. First the concept of "bricks and buses" is briefly discussed. Then a PEBB-oriented design is presented for the basic Marx cell of a 32-cell Marx modulator to power an ILC klystron; 120 kV, 140 A, 1.6 ms pulses at a repetition rate of 5 Hz. Each basic Marx cell is composed of a main cell and a correction cell that compensates the main cell droop. The main cell has a stored energy of 2.1 kJ per Marx cell and the correction cell an additional 0.5 kJ. This design allows over 30% of the total stored energy in the Marx modulator, 84 kJ, to be delivered in the output pulse, 26.9 kJ, while keeping the droop within a  $\pm 0.5\%$  range.

K. J.P. Macken, T. G. Beukers, C. Burkhart, M. A. Kemp, M. N. Nguyen, T. Tang (SLAC)

\*T. Ericson. 'Power Electronics Building Blocks - A systematic approach to power electronics.' In: Proceedings of Power Engineering Society Summer Meeting, Seattle, WA, 16-20 July 2000.

### A New Concept of a Fast Magnetic Kicker System: Bridged-T Network Lumped Kicker

A new concept of a fast magnetic kicker system - the bridged-T network lumped kicker - is proposed. The rise time is as fast as that of a transmission line kicker, while the input-impedance can be matched with a characteristic impedance of the pulse power supply. The proposed scheme is compared with several conventional schemes. The demonstration of this proposed scheme is also performed. The results show expected performances.

T. Oki (Tsukuba University)

### A MOSFET Solid-State Modulator for Fast Kicker in NSRL

The light pulse interval adjustment at Hefei Light Source (HLS) can be realized by using pulsed orbit bump technique, this requires

Y. C. Xu, H. Hao, D. H. He, X. Q. Wang (USTC/NSRL)

for high-frequency repetitive, high magnetic flux density, short pulse kicker magnet system of which the power supply modulator should be specially designed. The technique of solid state modulator based on MOSFET is being developed in National synchrotron Radiation Laboratory (NSRL). In this paper, the design of a prototype of solid-state modulator with 20 MOSFETs in parallel is introduced, including triggering system, drive circuit, transformer configuration. In which, the resonance induced by parasitic capacitance and inductance is studied, and the influence of the resonance is effectively reduced through reasonable design. This prototype power supply can archive 100ns width power pulse output with 200A summit current to the kicker.

## WE5PF — Morning Poster RFSYS T06, T07, T25

WE5PFP001

### The Effects of Field Emitted Electrons on RF Surface

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The proposed Muon Cooling System for the Neutrino Factory operates with high accelerating gradient in the presence of magnetic field. This can significantly increase the risk of RF breakdown. Field Emission is the most frequently encountered RF breakdown

that occurs at sites with local electromagnetic field enhancement. Surface defects can be considered as possible emission sites. Upon Impact, generally the majority of electron's energy is converted into stress and heat. In return, the damage inflicted can create additional emission sites. This paper presents the work under way, which aims to model certain physical phenomena during both emission and impact of electrons. The three-dimensional field profile of an 805 MHz pill-box cavity is modelled by Comsol Multiphysics. A tracking code written in-house is employed to track particles, providing sufficient data such as energy and speed at small time steps. This would allow the study of local heat transfer, applied surface stresses and secondary electron yield upon impact with the RF surface. In addition, the effects of externally applied magnetic field on electron's behaviour are to be investigated.

WE5PFP002

### Impedance Measurements of MA Loaded RF Cavities in J-PARC Synchrotrons

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J-PARC consists of a 181 MeV linac, a 3GeV Rapid Cycling Synchrotron (RCS) and a 50 GeV Synchrotron (MR). The RCS is designed to accelerate a high intensity proton beam. One of the key issues of the RCS RF system

is how to achieve the very high accelerating field gradient of more than 20kV/m. This is impossible with conventional ferrite-loaded cavities. We reach this goal by the development of Magnetic Alloy (MA) core loaded RF cavities. We installed 10 RF cavities in the RCS tunnel on May 2007. The RCS beam commissioning was started on September 2007 and we successfully accelerated a proton beam up to 3GeV on October 2007. We also employed MA cores for MR RF cavities and use a cut core configuration to adjust the Q-value. The MR beam commissioning was started on May 2008. We didn't have any trouble caused by the MA cores during operation. We measured the impedance of the RF cavities several times at the shutdown periods. We show the results of impedance measurements. From these results, we can make an assumption about the core condition.

WE5PFP003

### Higher Harmonic Voltages in J-PARC RCS Operation

A. Schnase, M. Nomura, F. Tamura, M. Yamamoto (JAEA/J-PARC) E. Ezura (KEK) K. Hara, K. Hasegawa, C. Ohmori, T. Shimada, H. Suzuki, M. Toda, M. Yoshii (KEK/JAEA)

The J-PARC Rapid Cycling Synchrotron (RCS) uses broadband magnetic alloy loaded cavities to create the acceleration voltages needed for rapid cycling at 25 Hz rate. Besides the desired second harmonic

of the acceleration frequency, which is employed in the painting process of RCS injection, also unwanted harmonics can be found at the acceleration gaps of the cavities. Here, the effect of the vector sums of undesired harmonics during the acceleration process is estimated.

**Titanium Nitride Coating as a Multipactor Suppressor on RF Coupler Ceramic Windows**

LAL-Orsay is developing an important effort on R&D studies on RF power couplers. One of the most critical components of those devices is the ceramic RF window that allows the power flux to be injected in the coaxial line. The presence of a dielectric window on a high power RF line has a strong influence on the multipactor phenomena. To reduce this effect, the decrease the secondary emission yield (SEY) of the ceramic window is needed. Due to its low SEY coefficient, TiN coating is used for this goal. In this framework, a TiN sputtering bench has been developed in LAL. The reactive sputtering of TiN needs the optimisation of gas flow parameters and electrical one, to obtain stoichiometric deposit. XRD analysis was performed to control the film composition and stoichiometry. Measurements point out how the Nitrogen vacancy on the film can be controlled acting on the N<sub>2</sub> flow. In addition, the coating thickness must be optimized so that the TiN coating effectively reduces the SEY coefficient but does not cause excessive heating, due to ohmic loss. For this purposes, multipactor level breakdown and resistance measurements were done for different deposit thickness.

**W. Kaabi, H. Jenhani, A. Variola (LAL) G. Keppel, V. Palmieri (INFN/LNL)**

WE5PFP004

**The Normal Conducting RF Cavity for the MICE Experiment**

The international muon ionization cooling experiment (MICE) requires low frequency and normal conducting RF cavities to compensate for muon beams' longitudinal energy lost in the MICE cooling channel. Eight 201-MHz normal conducting RF cavities with conventional beam irises terminate by large and thin beryllium windows are needed. The cavity design is based on a successful prototype cavity for the US MUCOOL program. The MICE RF cavity will be operated at 8-MV/m in a few Tesla magnetic fields with 1-ms pulse length and 1-Hz repetition rate. The cavity design, fabrication, post process plans and as well as integration to the MICE cooling channel will be discussed and presented in details.

**D. Li, A. J. DeMello, S. P. Virostek, M. S. Zisman (LBNL)**

WE5PFP005

**Gridded-Wire Windows for High Pressure RF Cavities**

In muon RF accelerating cavities, expensive thin, beryllium foils are used to close cavity ends to increase the on-axis electric field, and reduce the RF power requirement; they tend to displace at high power and detune the cavity. Gridded-tube windows, which are grid-like structures composed of tubes, have been proposed but not yet tested for use in vacuum cavities. In this project proposing gridded windows, composed of wires, for use with high pressure RF cavities. Gridded-wire RF windows are being designed to overcome the large displacement problem found experimentally in beryllium foil windows, and consequently to prevent cavity detuning. Complete designs of a gridded-wire window will be devised for use with high pressure RF cavities. The design process will include performing electromagnetic, thermal, and structural simulations in addition to studying the feasibility of fabrication.

**M. Alsharo'a, R. P. Johnson (Muons, Inc) M. Gosz, D. M. Kaplan, S. Nair (Illinois Institute of Technology) A. Moretti (Fermilab)**

WE5PFP006

### Building Twisted Waveguide Accelerating Structures

Y. W. Kang (ORNL) M. H. Awida, J. L. Wilson (University of Tennessee)

Lately, RF properties of twisted waveguide structures were investigated to show that slow-wave accelerating fields can be excited and used for acceleration of particle at various velocities. To build a practical accelerating cavity structure using the twisted waveguide, more development work was needed: cavity structure tuning, end effect of the structures, incorporating beam pipes, input power coupling, and HOM damping, etc. In this paper, the practical aspects of the above designs to make complete accelerating structures are discussed with the results of computer simulations and bench measurements.

### RF Breakdown of Metallic Surfaces in Hydrogen at 805 MHz

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In an earlier report, microscopic images of the surfaces of metallic electrodes used in high-pressure gas-filled 805 MHz RF cavity experiments were used to investigate the mechanism of RF metal breakdown of tungsten, molybdenum, and beryllium electrode surfaces. These studies have been extended to include tin, aluminum, and copper. In these experiments, the dense hydrogen gas in the cavity prevents electrons or ions from being accelerated to high enough energy to participate in the breakdown process so that the only important variables are the fields and the metallic surfaces. The distributions of breakdown remnants on the electrode surfaces are compared to the maximum surface gradient predicted by an ANSYS model of the cavity, which shows a power law dependence on the maximum gradient as expected from Fowler-Nordheim behavior of electron emission from a cold cathode. We report results from this high pressure technique to study maximum gradients and breakdown remnant distributions for Sn, Be, Cu, Al, Mo, and W.

### RF Breakdown Studies Using Pressurized Cavities

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Many present and future particle accelerators are limited by the maximum electric gradient and peak surface fields that can be realized in RF cavities. Despite considerable effort, a comprehensive theory of RF breakdown has not been achieved and mitigation techniques to improve practical maximum accelerating gradients have had only limited success. Recent studies have shown that high gradients can be achieved quickly in 805 MHz RF cavities pressurized with dense hydrogen gas without the need for long conditioning times, because the dense gas can dramatically reduce dark currents and multipacting. In this project we use this high pressure technique to suppress effects of residual vacuum and geometry found in evacuated cavities to isolate and study the role of the metallic surfaces in RF cavity breakdown as a function of magnetic field, frequency, and surface preparation. An RF test cell with replaceable electrodes (e.g. Mo, Cu, Be, W, and Nb) and pressure barrier capable of operating both at high pressure and in vacuum is being designed, built, and tested.

**L-Band (700 MHz) High-Power Ferroelectric Switch/Phase Shifter**

Measurements are reported for a one-third version of a L-band high-power ferroelectric phase shifter. The device is designed to allow fast adjustments of cavity coupling in an accelerator where microphonics, RF source fluctuations, or another uncontrolled fluctuations could cause undesired emittance growth. Experimental measurements of switching speed, phase shift and insertion loss vs. externally-applied voltage are presented. An average switching rate of 0.5 ns or better for each degree of RF phase has been observed.

**S. V. Shchelkunov**, J. L. Hirshfield (Omega-P, Inc.) S. Kazakov (KEK) V. P. Yakovlev (Fermilab)

**PAMELA: Development of the RF System for a Non-Relativistic Non-Scaling FFAG**

AMELA (Particle Accelerator for MEDical Applications) is a newly developed fixed field accelerator, which has capability for rapid beam acceleration, which is interesting for practical applications such as charged particle therapy. PAMELA aims to design a particle therapy facility using Non-Scaling FFAG technology, with a target beam repetition rate of 1kHz, which is far beyond that of conventional synchrotron.

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To realize the repetition rate, the key component is rf acceleration system. The combination of a high field gradient and a high duty factor is a significant challenge. In this paper, options for the system and the status of their development are presented.

**RF Deflector for Bunch Length Measurement at Low Energy at PSI**

RF deflectors are crucial diagnostic tools for bunch length and slice emittance measurements with sub-picosecond resolution. Their use is essential in commissioning and operation of VUV and X-ray FELs. The 250MeV FEL injector, under construction at PSI, will use two of them. The first one will be installed after the gun at low energy ( $\sim 7\text{MeV}$ ), the second one at the end of the Linac at high energy (250MeV). The first RF deflector consists of a single cell standing wave cavity working on the TM<sub>110</sub> deflecting mode, and tuned at 2997.912 MHz (frequency of the linac structures). In this note we report the motivation of this measurement, beam dynamics and beam diagnostics considerations and the RF design and simulations of this cavity.

**A. Falone**, M. Bopp, H. Fitze, Y. Kim, M. Pedrozzi, V. Schlott, L. Stingelin (PSI) D. Alesini, A. Clozza, L. Ficcadenti, L. Palumbo (INFN/LNF)

### Development of Solid Freeform Fabrication (SFF) for the Production of RF Photoinjectors

P. Frigola, R. B. Agustsson, S. Boucher, A. Y. Murokh (RadiaBeam)  
H. Badakov, P. Musumeci, J. B. Rosenzweig, G. Travish (UCLA) D.  
Cormier, T. Mahale (NCSU) L. Faillace (INFN/LNF)

Electron beam based additive fabrication techniques have been successfully applied to produce a variety of complex, fully dense, metal structures. These methods, collectively known as Solid Freeform Fabrication (SFF) are now being explored for use in radio frequency (RF) structures. SFF technology may make it possible to design and produce near-netshape copper structures for the next generation of very high duty factor, high gradient RF photoinjectors. The SFF process discussed here, Arcam Electron Beam Melting (EBM), utilizes an electron beam to melt metal powder in a layer-by-layer fashion. The additive nature of the SFF process and its ability to produce fully dense parts are explored for the fabrication of internal cooling passages in RF photoinjectors. Following an initial feasibility study of the SFF process, we have fabricated a copper photocathode, suitable as a drop-in replacement for the UCLA 1.6 cell photoinjector, with internal cooling channels using SFF. Material analysis of the prototype cathode and new designs for a high duty factor photoinjector utilizing SFF technology will be presented.

### Development and Fabrication of X-Band Deflecting Cavity at 11.424 GHz

A. Y. Murokh, R. B. Agustsson, P. Frigola, E. Spranza (RadiaBeam)  
D. Alesini (INFN/LNF) J. B. Rosenzweig (UCLA) V. Yakimenko  
(BNL)

An X-band Traveling wave Deflector mode cavity (XTD) has been developed at Radiabeam Technologies to perform longitudinal characterization of the sub-picosecond ultra-relativistic electron beams. The device is optimized for the 100 MeV electron beam parameters at the Accelerator Test Facility (ATF) at Brookhaven National Laboratory, and is scalable to higher energies. An XTD is designed to operate at 11.424 GHz, and features short filling time, femtosecond resolution, and a small footprint. Initial results for fabrication, tuning, and vacuum tests are presented. The plans for installation and commissioning are discussed.

### Upgrade of the RF System of Siberia-2 Electron Storage Ring / SR Source

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S. A. Krutikhin, I. V. Kuptsov, G. Y. Kurkin, S. V. Motygin, V. M.  
Petrov, A. M. Pilan, A. G. Tribendis, N. Vinokurov (BINP SB RAS)  
V. Korchuganov (RRC)

The project of upgraded RF System of Siberia-2 Electron Storage Ring / SR Source, Moscow, Russia, is presented. The upgraded RF system will allow to increase the total accelerating voltage up to 1.8MV and ensure operation of the storage ring with new superconducting wiggler at beam currents up to 0.3A. RF system operates at 181MHz. It consists of 3 single bi-metal cavities, 2 power amplifiers based on GU-101A tetrodes with output power of 200kW, power transmission lines and control system. Parameters of the upgraded RF system are given, the design of its main elements is shown.



### Shunt Impedance of SAMEER 6 MeV Linac Structure

Shunt impedance of an accelerating structure is an important parameter. It gives an idea of the power coupled to the beam. A 6 MeV to 15 MeV 'S' band standing wave side coupled linac structure is developed in SAMEER\*. The measurement of the shunt impedance of the cavity is done using bead pull method. The shunt impedance is calculated after plotting the electric field profile. The calculation is done using a C code which first calculates the area of the plot and then uses appropriate variables to give the final value of the shunt impedance. The automation of the bead pull setup is planned and then the integration of calculation and automated setup. This paper describes the method used in the code and outlines the results of the measurement.

\*R. Krishnan et.al. submitted in this conference.

**T. S. Dixit**, A. Deshpande, V. C. Hatode, R. Krishnan, C. S. Nainwad (SAMEER)

WE5PFP016

### Processing and Breakdown Localization Results for an L-Band Standing-Wave Cavity

An L-band (1.3 GHz), normal-conducting, five-cell, standing-wave cavity that was built as a prototype capture accelerator for the ILC is being high-power processed at SLAC.

The goal is to demonstrate stable operation at 15 MV/m with 1 msec, 5 Hz pulses and the cavity immersed in a 0.5 T solenoidal magnetic field. This paper summarizes the performance that was ultimately achieved and describes a novel analysis of the modal content of the stored energy in the cavity after a breakdown to determine on which iris it occurred.

**F. Wang**, C. Adolphsen (SLAC)

WE5PFP017

### Results from the CLIC X-Band Structure Test Program at NLCTA

As part of a SLAC-CERN-KEK collaboration on high gradient X-band structure research, several prototype structures for the CLIC linear collider study have been tested using two of the high power (300 MW) X-band rf stations in the NLCTA facility at SLAC. These structures differ in terms of their manufacturing (brazed disks and clamped quadrants), gradient profile (amount by which the gradient increases along the structure which optimizes efficiency and maximizes sustainable gradient) and HOM damping (use of slots or waveguides to rapidly dissipate dipole mode energy). The CLIC goal in the next few years is to demonstrate the feasibility of a CLIC-ready baseline design and to investigate alternatives which could bring even higher efficiency. This paper summarizes the high gradient test results from the NLCTA in support of this effort.

**C. Adolphsen**, G. B. Bowden, V. A. Dolgashev, L. Laurent, S. G. Tantawi, F. Wang, J. W. Wang (SLAC) S. Doebert, A. Grudiev, G. Riddone, W. Wuensch, R. Zennaro (CERN) Y. Higashi, T. Higo (KEK)

WE5PFP018

### Coupler Development and Processing Facility at SLAC

A new facility to clean, assemble, bake and rf process TTF3-style power couplers has been completed and is in operation at SLAC. This facility includes a class-10 cleanroom,

bake station and an L-band source capable of producing up to 4 MW pulses. This paper describes the facility, test

**C. Adolphsen**, A. A. Haase, D. Kiehl, C. D. Nantista, T. N. Nieland, J. Tice, F. Wang (SLAC)

WE5PFP019

results from processing pairs of couplers that will be used in cryomodules at FNAL, and efforts to simplify the design and manufacturing of the couplers for large scale use at ILC. Also, tests of the couplers to explore their power limits for use in an FNAL superconducting proton linac are presented.

### Multipacting and Dark Current Simulation for Muon Collider Cavity

L. Ge, K. Ko, Z. Li, C.-K. Ng (SLAC) D. Li (LBNL) R. B. Palmer (BNL)

The muon cooling cavity for Muon Collider works under strong external magnetic fields. It has been observed that this external magnetic field can enhance the multipacting activities and dark current heating.

As part of a broad effort to optimize external magnetic field map and cavity shape for minimal dark current and multipacting, we use SLAC's 3D parallel code Track3P to analyze the multipacting and dark current issues of the design. Track3P has been successfully used to predict multipacting phenomena in cavity and coupler designs. It provides unprecedented capabilities for simulating large-scale accelerator structure systems, including realistic 3D details and low turn-around times. In this paper, we present the comprehensive multipacting and dark current simulations for Muon Collider cavities.

### Klystron Cluster Scheme for ILC High Power RF Distribution

C. D. Nantista, C. Adolphsen (SLAC)

We present a concept for powering the main linacs of the International Linear Collider (ILC) by delivering high power RF from the surface via overmoded, low-loss waveguides at widely spaced intervals.

The baseline design employs a two-tunnel layout, with klystrons and modulators evenly distributed along a service tunnel running parallel to the accelerator tunnel. This new idea eliminates the need for the service tunnel. It also brings most of the warm heat load to the surface, dramatically reducing the tunnel water cooling and HVAC requirements. In the envisioned configuration, groups of 70 klystrons and modulators are clustered in surface buildings every 2.4 km. Their outputs are combined into two half-meter diameter circular  $T_{10}^{01}$  mode evacuated waveguides. These are directed via special bends through a deep shaft and along the tunnel, one upstream and one downstream. Each feeds approximately 1.2 km of linac with power tapped off in 10 MW portions at 38 m intervals. The power is extracted through a novel coaxial tapoff (CATO), after which the local distribution is as it would be from a klystron. This tapoff design is also employed in reverse for the initial combining.

### Progress of the S-Band RF Systems of the FERMI@Elettra Linac

A. Fabris, A. O. Borga, G. D'Auria, P. Delgiusto, O. Ferrando, A. Franceschinis, F. Gelmetti, M. M. Milloch, A. Milocco, G. C. Pappas, F. Pribaz, A. Rohlev, C. Serpico, N. Sodomaco, R. Umer, L. Veljak, D. Wang (ELETTRA)

FERMI@Elettra is a seeded FEL user facility under construction at Sincrotrone Trieste, Italy. The linac is based on S-band normal conducting technology. It will use the accelerating sections of the original Elettra linac injector, seven sections received from CERN

after LIL decommissioning and two additional sections to be constructed for a total number of 18 S-band accelerating structures. Installation of the machine is presently being carried on. This paper will provide a summary of the requirements of the different parts of the S-band RF system and of the options for a possible upgrade path both in energy and reliability. The ongoing activities on the main subassemblies, in particular regarding the tests and the installation work, are also presented.

**The  $3\pi/4$  Backward TW Structure for the FERMI@Elettra Linac**

The FERMI@ELETTRA project will use the existing ELETTRA linac. The linac includes seven accelerating sections, each section is a

**C. Serpico, P. Craievich (ELETTRA)**

backward traveling (BTW) structure comprised of 162 nose re-entrant cavities coupled magnetically. Furthermore, there are specialized input and output cavities specifically designed to match the structure to the RF source and load. These BTW accelerating structures work on the  $3\pi/4$  mode which was chosen to optimize the structure efficiency and to achieve a simple RF tuning setup. These accelerating sections are powered by a TH2132A 45 MW klystron providing a 4.5 microsecond rf pulse and are coupled to a Thomson CIDR. In this paper the  $3\pi/4$  backward BTW structures are investigated and the results of the electromagnetic simulations are presented.

**Optimal Timing for Spark Recovery in the TRIUMF Cyclotron**

In the TRIUMF cyclotron when a spark occurs it is necessary to shut off the RF drive and to initiate a RF restart procedure. It is

**K. Fong (TRIUMF)**

also desirable to restore the full operational dee voltage as soon as possible in order to prevent thermal detuning of the resonant cavity. However, when the RF drive is shut off, the disappearance of Lorentz force on the resonator hot-arms causes the hot-arms to vibrate at their mechanical resonant frequency. When the RF field is being restored, the electromagnetic resonance is coupled to the mechanical resonance through the Lorentz force, and the amplitudes of both the mechanical vibration and the RF field depend on the timing when RF drive is re-applied. Computer simulations and experimental results will be presented to demonstrate that an optimum exists as to when to initiate the RF restart. With this optimal timing, the Lorentz force is used to damp the mechanical vibrations of the hot-arms. The reduction in hot-arm vibrations increases the probability of successful restarts as well as reduces the stress on the RF components.

**Numerical Calculus of Resonant Frequency Change by 3D Reconstruction of Thermal Deformed Accelerator Tube**

Thermal deformation caused by Non-uniform temperature distribution in disk-loaded waveguide will affect the resonant frequency of LINAC deeply. Formerly, re-

**Z. Shu, M. J. Li, L. G. Shen, Y. Sun, X. C. Wang, W. Zhao (USTC/PMPI) Y. J. Pei (USTC/NSRL)**

searchers evaluated it by experiments or experience and gave their conclusion roughly and linearly. A new approach of integration of multi-disciplinary is adopted to study the relationship more accurately. After loading the loss RF power on the accelerator tube wall, the thermal deformation is calculated in software I-DEAS, and a deformed finite element model is obtained. Then nodes on inner surfaces of the cavities were extracted and sort by a customized program. According to these nodes, a new solid model is reconstructed with a self developed 3D reconstruction technology in ANSYS. B-Spline interpolation technique is used to fit a group of curves first, and then to reconstruct NURBS surfaces. The final reconstructed deformed solid model, obtained by closing the surfaces, can be exported in IGES format which is used to recalculate the resonant frequency in Microwave Studio again. The error of the reconstruction can be controlled within 3 micrometers. The resonant frequency change of every cavity can be accurately calculated.

Parietti L, etc., Thermal structural analysis and frequency shift \*\*

Zhou, Zu-Sheng, etc. Thermal structural analysis and test \*\*

**Preliminary Design for the Third Harmonic Cavity of Hefei Advanced Light Source**

C.-F. Wu, S. Dong, G. Feng, X. D. He, W. Li, G. Liu, L. Wang, S. C. Zhang (USTC/NSRL) Z. P. Li (USTC)

Hefei advanced Light Source (HALS) will be a high brightness light source with about 0.2 nm-rad emittance at 1.5GeV. Ultra low beam emittance and relatively low beam energy of HALS would result in poor beam lifetime. The beam lifetime will be affected strongly by Touschek scattering. The installation of a third harmonic cavity in HALS ring is proposed to be used for lengthening the bunch and increasing the Touschek-dominated beam lifetime. In the paper, the calculations for beam longitudinal beam dynamics with a harmonic RF voltage are given. A preliminary shape of the cavity has been chosen to satisfy beam dynamics requirements and to damp the higher order modes to a harmless level in order to avoid instabilities. The design and electromagnetic properties of the resonant modes have been studied with Microwave Studio.

Hefei advanced Light Source (HALS) will be a high brightness light source with about 0.2 nm-rad emittance at 1.5GeV. Ultra low beam emittance and relatively low beam energy of

**Active Quasi-Optical Ka-Band RF Pulse Compressor**

O. A. Ivanov, A. M. Gorbachev, V. A. Isaev, A. A. Vikharev, A. L. Vikharev (IAP/RAS) J. L. Hirshfield (Yale University, Physics Department) M. A. LaPointe (Yale University, Beam Physics Laboratory)

Experimental investigations of an active Ka-band microwave pulse compressor are presented. The compressor is based on a running wave three mirror quasi-optical resonator utilizing a diffraction grating whose channels embody plasma discharge tubes as the active switch. The principle of compression is based on quickly changing the output coupling coefficient (Q-switching) by initiating plasma discharges in the grating channels. Excitation of the resonator was achieved with a few 100 kW of 34.29 GHz microwaves in 700 nS pulses from the magnicon in the Yae Ka-band Test Facility. A power gain of at least 7:1 in the compressed pulse with a duration of 10-15 nS was achieved.

Experimental investigations of an active Ka-band microwave pulse compressor are presented. The compressor is based on a running wave three mirror quasi-optical resonator utilizing a diffraction grating whose channels embody plasma discharge tubes as

**Using Cerenkov Light to Detect Field Emission in Superconducting Cavities**

Y. Torun (IIT)

Superconducting RF cavities are made of a thin metal shell (typically Niobium) with liquid Helium around it housed within another metal vessel. This geometry is effectively a Cerenkov radiator between two mirrors. Electrons stripped from the inner surface due to field emission can get accelerated by the electric field inside the cavity, punch through the cavity wall and still have enough energy to be faster than light in He. Detection of Cerenkov light generated by the electrons through an optical port integrated into the vessel can serve as a very sensitive diagnostic for field emission in cavity R&D and production as well as in operating superconducting linear accelerators. We report on simulation results for calculating the effective light yield in such a system to establish the feasibility of the technique.

Superconducting RF cavities are made of a thin metal shell (typically Niobium) with liquid Helium around it housed within another

**RF Power Coupler Development for Superconducting Spoke Cavities at Nuclear Physics Institute in Orsay**

E. Rampnoux, S. Berthelot, P. Blache, S. Bousson, D. Grolet, J. Lesrel, L. Lukovac, G. Olry (IPN)

The development of RF power couplers for superconducting low-beta SPOKE cavities, performed at Nuclear Physics Institute in

Orsay in the framework of the EURISOL Design Study, has led to the design of a 20 kW RF power coaxial coupler showing very good RF performances and the implementation of a test stand to condition two of these couplers at 20 kW CW power in the traveling wave mode at 352,2 MHz by using a half-wave resonant cavity. Composed by a ceramic disk, the coaxial power coupler developed shows on one hand a very good 50 ohms matching on a large bandwidth like 760 MHz, after an electromagnetic optimisation of the window area, and on the other hand a simplified design with regard to the classic coaxial couplers. Characteristics of the power coupler and the test stand will be described, and the low RF power test of the coaxial window and the conditioning at high RF power of two couplers will be presented.

### Simplification of the End Group Geometry for 1.3 GHz SC Accelerating Structures

The construction of new large superconducting accelerators, such as ILC, requires substantial cost reductions and a simplification of the production processes of the SC cavities is desirable. A costly and highly complex part of the SC cavity is the connection system between the cavity and the He tank, i.e. the end group with the end dish. Different new geometries of this region have been studied using Finite Element (FE) analysis and compared with the actual solution presently used at FLASH (TTF geometry). The compatibility of the proposed solution also with the present lateral tuner and the new coaxial tuner has been analyzed too. One important characteristic of these designs is the elimination of the stiffening structure for the first and last cavity cells, which would not significantly affect the final stiffening of the cavity. After the validation of our FE model, two simplified end groups with a new geometry have been built and tested.

**P. M. Michelato**, L. Monaco, C. Pagani, N. Panzeri (INFN/LASA)

### Development of an Acceptance Test Procedure for the XFEL SC Cavities Tuners

Cavity tuners are needed to precisely tune the resonant frequency of TESLA SC cavities for European XFEL linac. Although several units of the currently used device, originally designed at Saclay for TTF and then developed at DESY, have been manufactured and tested so far, a permanent installation like the XFEL poses higher requirements in terms of reliability and reproducibility. XFEL indeed requires about 10-00 tuners to be produced in a relatively short time and then to simultaneously work in cryogenic environment, each of them being equipped with a stepper motor driving unit and two piezoelectric actuators. In this frame, an acceptance test procedure, here presented, has been studied, its main goal being the cross-check of issues affecting reliability: installation, mechanical coupling of active elements to cavity, motor and fast actuators functionality. An electronic equipment has been developed for driving signals, sensors and data management, specifically aiming toward an automatic and user-friendly routine in view of a large scale application. The procedure has been then applied for calibration purposes of a sample cavity assembly, the experimental results are also presented.

**R. Paparella**, A. Bosotti (INFN/LASA) C. Albrecht, L. Lilje (DESY)

### Cold Testing and Recent Results of the Blade Tuner for CM2 at FNAL

An extensive validation activity has been conducted since year 2007 for the coaxial Blade Tuner for TESLA SC cavities. During this activity, performances and limits of

**R. Paparella**, A. Bosotti, C. Pagani, N. Panzeri (INFN/LASA) J. Knobloch, O. Kugeler, A. Neumann (BESSY GmbH)

prototype models have been deeply investigated through detailed test sessions inside CHECHIA (DESY) and HoBi-CaT (BESSY) horizontal cryostats as well as F. E. modeling and analyses. The result is an improved design for the Blade Tuner, specifically meant to satisfy the incoming ILC-level performance requirements, fulfill pressure vessels regulations and keep Ti / S. S. material compatibility. Recent Blade Tuner activities and results will be presented in this paper in view of the installation of 8 units in the second cryomodule of ILCTA facility at Fermilab, and also of our contribution to both incoming S1-Global (KEK) and ILC-HiGrade projects. The manufacturing process of the first set of 8 tuners, from production to room temperature validation for the whole series, will be also reviewed. Then results will be shown from the cold tests recently performed, where special effort has been made in evaluating the accuracy and repeatability of fast and slow tuning action at few Hz range.

### Fabrication Experience of the Third Harmonic Superconducting Cavity Prototypes for the XFEL

P. Pierini, A. Bosotti, R. Paparella, D. Sertore (INFN/LASA) E. Vogel (DESY)

Three superconducting 3.9 GHz cavity prototypes have been fabricated for the XFEL linac injector, with minor modifications to the rf structures built by FNAL for the

FLASH linac. This paper describes the production and preparation experience, the initial measurements, the plans for the XFEL series production and the cryogenic test infrastructure under preparation at INFN Milano.

### Low Beta Elliptical Cavities for Pulsed and cw Operation

P. Pierini, S. Barbanotti, A. Bosotti, P. M. Michelato, L. Monaco, R. Paparella (INFN/LASA)

The two TRASCO elliptical superconducting cavities for low energy (100-200 MeV) protons have been completed with equipping them with cold tuner and a magnetic shield

internal to the helium tank. One of the two structures is now available for significant tests of Lorentz Force Detuning control of these low beta structures under pulsed conditions for future high intensity linac programs, as SPL or the ESS. The second structure will be integrated in a single cavity cryomodule under fabrication for the prototypical activities of the EUROTRANS program for nuclear waste transmutation in accelerator driven systems.

### Prototyping PEFP Low-Beta Copper Cavity

S. An, Y.-S. Cho, B. H. Choi, Y. M. Li, Y. Z. Tang, L. Zhang (KAERI)

A superconducting radio frequency (SRF) cavity with a geometrical beta of 0.42 has been designed to accelerate a proton beam

after 100 MeV at 700 MHz for an extended project of Proton Engineering Frontier Project (PEFP). In order to confirm the RF and mechanical properties of the cavity, and to produce documentation for a procurement and quality control for an industrial manufacture of the cavities, two prototype copper cavities have been produced, tuned and tested. In this paper, the copper cavity's production, tuning and testing are introduced. The testing results show that the low-beta cavity and its tuning system can work as we design.

**Full Temperature Mapping System for Standard 1.3 GHz 9-cell Elliptical SRF Cavities**

A temperature mapping system with 4608 100-ohm Allen-Bradley resistors has been built and tested at LANL. With this temperature mapping system we were able to locate lossy regions in the 1.3 GHz 9-cell SRF cavity due to field emission and direct heating. The results of the temperature mapping have been correlated with the inside surface inspection of the cavity and will be shown together with Q-E curves. A brief description of the mapping system and improvements that have been made in the recent months will also be mentioned in the paper.

**T. Tajima**, A. S. Bhatta, A. Canabal, G. V. Eremeev, F. L. Krawczyk (LANL)

WE5PFP036

**SRF Cavity High-Gradient Study at 805 MHz for Proton and Other Applications**

MHz elliptical SRF cavities have been used for SNS as the first application for protons. At LANL, an R&D started to explore a capability of getting high-gradient cavities (40-50 MV/m) at this frequency for the future applications such as proton and muon based interrogation testing facility added to the LANSCE accelerator and a power upgrade of the LANSCE accelerator for the fission and fusion material test station. Optimized cell designs for "standard", "low-loss" and "re-entrant" shapes, cavity test results for "standard" single-cell cavities with temperature mapping as well as surface inspection results will be presented.

**T. Tajima**, A. S. Bhatta, G. V. Eremeev, F. L. Krawczyk, R. J. Roybal (LANL)

WE5PFP037

**Studies on the Effect of Coating Nb with Thin Layers of Another Superconductor such as NbN and MgB2**

We are currently testing the effect of coating Nb with a thin layer of another superconductor such as NbN and MgB2. Gurevich's theory of multi-layered coating predicts an enhancement of the critical magnetic field, giving us hope to increase the achievable accelerating gradient to above 50 MV/m in elliptical cavities. CW test results of 3 GHz Nb single-cell cavities coated with ~100 nm NbN at LANL and 11.4 GHz <1  $\mu$ s high-power pulsed test results of 2" Nb disk samples coated with ~100 nm MgB2 will be presented.

**T. Tajima**, A. Canabal, G. V. Eremeev (LANL) I. E. Campisi (ORNL) V. A. Dolgashev, S. G. Tantawi (SLAC) X. Xi (Penn State University)

WE5PFP038

**Development of a Superconducting Half Wave Resonator for Beta = 0.53**

A medium-velocity half wave resonator has been designed and prototyped at the National Superconducting Cyclotron Laboratory for use in a heavy ion linac. The cavity is designed to provide 3.7 MV of accelerating voltage at an optimum beta =  $v/c = 0.53$ , with peak surface electric and magnetic fields of 32.5 MV/m and 79 mT, respectively. The resonant frequency is 322 MHz. The cavity was designed to reduce sensitivity to bath pressure fluctuations while maintaining a structure that can be easily fabricated, cleaned, and tuned. Deep draw forming dies and a copper cavity prototype were fabricated to confirm tolerances and formability. A prototype tuner was built; the helium vessel and power coupler have been designed.

**J. Popielarski**, S. Bricker, C. Compton, W. Hartung, M. J. Johnson, F. Marti, J. Oliva, R. C. York (NSCL)

WE5PFP039

Measurements were performed to confirm finite element predictions for the mechanical modes, bath pressure sensitivity, tuner stiffness, and tuning range.

### SRF Activities for ILC at MHI

K. Sennyu, H. Hara, K. Kanaoka, T. Yanagisawa (Mitsubishi Heavy Industries, Ltd, MHI) M. Matsuoka (MHI)

We report on the activities and achievements at MHI about cavity fabrication for ILC. Some new procedures of cavity fabrication for industrialization are reported.

### 1500 MHz Passive SRF Cavity for Bunch Lengthening in the NSLS-II Storage Ring

T. Yanagisawa (Mitsubishi Heavy Industries, Ltd, MHI) T. L. Grimm (Niowave, Inc.) J. Rose (BNL)

NSLS-II is a new ultra-bright 3GeV 3rd generation synchrotron radiation light source. The performance goals require operation with a beam current of 500mA and a bunch

current of at least 0.5mA. Ion clearing gaps are required to suppress ion effects on the beam. The natural bunch length of 3mm is planned to be lengthened by means of a third harmonic cavity in order to increase the Touschek limited lifetime. After an extensive investigation of different cavity geometries a passive, superconducting 2-cell cavity has been selected for prototyping. The cavity is HOM damped with ferrite absorbers on the beam-pipes. The 2-cell cavity simplifies the tuner design as compared to two independent cells. Tradeoffs between the damping of the higher order modes, thermal isolation associated with the large beam tubes and overall cavity length are described. A copper prototype has been constructed and measurements of fundamental and higher order modes will be compared to calculated values.

### Rugged Ceramic Window for RF Applications

M. L. Neubauer, R. P. Johnson (Muons, Inc) T. Elliott, R. A. Rimmer (JLAB)

High-current RF cavities that are needed for many accelerator applications are often limited by the power transmission capability of the pressure barriers (windows) that separate the cavity from the power source.

Most efforts to improve RF window design have focused on alumina ceramic, the most popular historical choice, and have not taken advantage of new materials. Alternative window materials such as sapphire, aluminum nitride, and ALON™ have been investigated and tested for material properties. A candidate has been chosen to be used in a window for high power testing at Thomas Jefferson National Accelerator Facility.

### Beam Pipe HOM Absorber for 750 MHz RF Cavity

M. L. Neubauer, R. Sah (Muons, Inc) E. P. Chojnacki, M. Liepe (CLASSE) H. Padamsee (Cornell University)

Superconducting HOM-damped (higher-order-mode-damped) RF systems are needed for present and future storage ring and linac applications. Superconducting RF (SRF)

systems typically contain unwanted frequencies or higher order modes (HOM) that must be absorbed by ferrite and other lossy ceramic-like materials that are brazed to substrates mechanically attached to the drift tubes



adjacent to the SRF cavity. These HOM loads must be thermally and mechanically robust and must have the required broadband microwave loss characteristics, but the ferrites and their attachments are weak under tensile stresses and thermal stresses and tend to crack. A HOM absorber with improved materials and design will be developed for high-gradient 750 MHz superconducting cavity systems. RF system designs will be numerically modeled to determine the optimum ferrite load required to meet the broadband loss specifications. Several techniques for attaching ferrites to the metal substrates will be studied, including full compression rings and nearly-stress-free ferrite assemblies. Prototype structures will be fabricated and tested for mechanical strength.

### High Power Co-Axial SRF Coupler

There are over 35 coupler designs for SRF cavities ranging in frequency from 325 to 1500 MHz. Two-thirds of these designs are coaxial couplers using disk or cylindrical ceramics in various combinations and configurations. While it is well known that dielectric losses go down by several orders of magnitude at cryogenic temperatures, it not well known that the thermal conductivity also goes down, and it is the ratio of thermal conductivity to loss tangent (SRF ceramic Quality Factor) and ceramic volume which will determine the heat load of any given design. We describe a novel robust co-axial SRF coupler design which uses compressed window technology. This technology will allow the use of highly thermally conductive materials for cryogenic windows. The mechanical designs will fit into standard-sized ConFlat® flanges for ease of assembly. Two windows will be used in a coaxial line. The distance between the windows is adjusted to cancel their reflections so that the same window can be used in many different applications at various frequencies.

M. L. Neubauer (Muons, Inc) R. A. Rimmer (JLAB)

### Experimental Studies of Capacitive Power Coupler for SRF Accelerators

A power coupler has been designed for the Superconducting Radio Frequency (SRF) accelerator of Free Electron Laser (FEL) project under construction at Peking University\*, which is based on the capacitive coupling structure proposed by KEK\*\*. More detailed engineering issues, such as copper plating, brazing, and assembly, have also been taken into account. During the construction of the power coupler, its influences on the beam and the diagnostic system have been analyzed, such as RF kick and cross-talking; while some experiments have been done on the model door-knob including holding rods and a 2-cell cavity made by copper. The power couplers are supposed to be assembled to the accelerating cavities in January 2009, and the testing progress and results will be reported in this article.

F. S. He, J. K. Hao, F. Wang, W. Xu, B. C. Zhang, K. Zhao (PKU/IHIP)

\*HE Feisi, et al. Chinese Physics C, <http://hepnp.ihep.ac.cn/qikan/manage/wenzhang/2007-0157.pdf>

\*\* H Matsumoto, et al. PAC05. <http://accelconf.web.cern.ch/AccelConf/p05/PAPERS/WPAT084.PDF>

### Multipacting and Dark Current Simulation for High Gradient Accelerator Structures

Normal conducting accelerator structures such as the X-Band NLC structures and the CLIC structures have been found to suffer damage due to RF breakdown and/or dark current when processed to high gradients. Improved understanding of these issues is desirable for the development of structure designs and processing techniques that improve the structure high gradient performance. While

Z. Li, A. E. Candel, L. Ge, K. Ko, C.-K. Ng, G. L. Schussman (SLAC) A. Grudiev, W. Wuensch (CERN) T. Higo (KEK)

vigorous experimental efforts have been put forward to explore the gradient parameter space via high power testing, comprehensive numerical multipacting and dark current simulations would complement measurements by providing an effective probe for observing interior quantities. In this paper, we present studies of multipacting, dark current, and the associated surface heating in high gradient accelerator structures using the parallel finite element simulation code Track3P. Comparisons with the high power test of the CLIC accelerator structures will be presented.

### A Compact Alternative Crab Cavity Design at 400 MHz for the LHC Upgrade

Z. Li, L. Xiao (SLAC)

Crab cavities are proposed for the LHC upgrade to improve the luminosity. In the local crabbing scheme, the crab cavities are located close to the interaction region and the transverse separation between the two beam lines at the crab cavity location can only accommodate an 800-MHz cavity of the conventional elliptical shape. Thus the baseline crab cavity design for the LHC upgrade is focused on the 800-MHz elliptical cavity shape although a lower frequency cavity is preferable due to the long bunch length. In this paper, we present a compact 400-MHz design as an alternative to the 800-MHz baseline design. The compact design is of a half-wave resonator (HWR) shape that has a small transverse dimension and can fit into the available space in the local crabbing scheme. The optimization of the HWR cavity shape and the couplers for the HOM, LOM, and SOM damping will be presented.

### 800MHz LHC Crab Cavity Conceptual Design

L. Xiao, Z. Li, C.-K. Ng, A. Seryi (SLAC)

In this paper, we present a 800MHz crab cavity conceptual design for LHC upgrade, including the cell shape optimization, and LOM, SOM, HOM and input coupler design. The compact coax-to-coax coupler scheme is proposed to couple to the LOM and SOM modes which can provide strong coupling to the LOM and SOM modes. HOM coupler design uses a two-stub antenna with a notch filter to couple to the HOM modes in the horizontal plane and reject the operating mode at 800MHz. All the damping results for the LOM/SOM/HOM modes satisfy their damping requirements. The multipacting in cell and couplers is simulated as well. And the issue of the cross-coupling between the input coupler and LOM/SOM couplers due to cavity asymmetry is addressed. The power coming out of the LOM/SOM/HOM couplers are estimated. All the simulations are carried out using SLAC developed parallel EM simulation codes Omega3P, S3P and Track3P.

### Phase Control Testing of Two Superconducting Cavities in a Vertical Cryostat

P. Goudket, R. Bate, C. D. Beard, B. D. Fell, P. A. McIntosh, S. M. Patalwar (STFC/DL/ASTeC) P. K. Ambattu, G. Burt, A. C. Dexter, B. D.S. Hall, M. I. Tahir (Cockcroft Institute, Lancaster University)

The ILC crab cavities require very tight phase control in order to operate within the ILC parameters. In order to verify that the phase control system met the design tolerances, two single-cell niobium 3.9GHz superconducting dipole-mode cavities were tested in a liquid helium cryostat. The preparation of the cavities, design of the testing apparatus and performance of the phase control system are described in this paper.

### Assembly of the ERL International Cryomodule (ERIC) at Daresbury Laboratory

The collaborative development of an optimised cavity/cryomodule solution for application on ERL facilities, has now progressed to final assembly and testing of the cavity string components and their subsequent cryomodule integration. This paper outlines the verification of the various cryomodule sub-components and details the processes utilised for final cavity string integration. The paper also describes the modifications needed to facilitate this new cryomodule installation and ultimate operation on the ALICE facility at Daresbury Laboratory.

**P. A. McIntosh**, R. Bate, C. D. Beard, S. M. Patalwar (STFC/DL/ASTeC) A. Buechner, F. G. Gabriel (FZD) M. A. Cordwell, J. Strachan (STFC/DL) J. N. Corlett, D. Li, S. M. Lidia (LBNL) M. Liepe, H. Padamsee (CLASSE) T. I. Smith (Stanford University)

WE5PFP050

### RF System for SSRF Storage Ring

RF system for SSRF (Shanghai Synchrotron Radiation Facility) Storage Ring consists of three RF stations, each of which has a klystron, one superconducting RF module and its low level RF feedback control. A 300kW klystron will feed the RF power to the superconducting cavity via a circulator and waveguides. Three CESR type 499.654MHz superconducting modules with tuning range  $\pm 150$ kHz are now in operation. A digitalized I/Q technology based on FPGA is adopted in its low level control. The commissioning and the performance of whole RF system will be described in details in this paper.

**J. F. Liu**, M. Chen, Z. Q. Feng, H. T. Hou, C. Luo, D. Q. Mao, Zh. G. Zhang, S. J. Zhao, Y. B. Zhao (SINAP)

WE5PFP051

### First Cold Test with the TRIUMF ISAC-II Phase II Cryomodule

An energy upgrade in the Radioactive Ion Beam (RIB) facility at ISAC-II will see the installation of 20MV of superconducting heavy ion linac. The addition includes

**R. E. Laxdal**, K. Fong, A. Grassellino, W. R. Rawnsley, I. Sekachev, V. Zvyagintsev (TRIUMF)

twenty beta=11% bulk niobium quarter wave cavities housed in three cryomodules with six cavities in the first two and eight cavities in the last. Each cavity is specified to add 1MV in accelerating potential corresponding to peak surface fields of  $\sim 30$ MV/m. Transverse focusing is achieved with a 9T superconducting solenoid inside each cryomodule. The first module in the expansion has now been assembled and tested. Developments include a new ball screw tuner, locally produced cavities, modified coupler design and LN<sub>2</sub> cryogenic circuits. The new developments are described and the results of the first cold tests are presented.

WE5PFP052

### Design of Superconducting Parallel Bar Deflecting and Crabbing RF Structures

A new concept for a deflecting and crabbing rf structure based on half-wave resonant lines was introduced recently\*. It offers

**J. R. Delayen**, H. Wang (JLAB) J. R. Delayen (ODU)

significant advantages to existing designs and, because of its compactness, allows low frequency operation. This concept has been further refined and optimized for superconducting implementation. Results of this optimization and application to a 400 MHz crabbing cavity and a 499 MHz deflecting cavity are presented.

\*A New TEM-Type Deflecting and Crabbing RF Structure, J. R. Delayen and H. Wang, Proc. LINAC08

WE5PFP053

### HOM Survey of the First CEBAF Upgrade Style Cavity Pair

F. Marhauser, E. Daly, G. K. Davis, M. A. Drury, C. Grenoble, J. Hogan, J. P. Preble, C. E. Reece, R. A. Rimmer, K. Tian, H. Wang (JLAB)

For the planned CEBAF upgrade ten new cryomodules are required to increase the beam energy to the envisaged 12 GeV. Extensive cavity and cryomodule R&D has been done previously, including the installation of a new cryomodule dubbed "Renaissance" in CEBAFs north linac in 2007. It houses both seven-cell low loss and high gradient type of cavities thereby serving as a testbed to address and cope with crucial technological challenges. Based on this experience a final iteration on the upgrade cavity has been performed to improve various aspects of HOM-damping and thermal stability. Two such cavities have been produced and qualified. A thorough cavity HOM-survey has been performed to verify the integrity of the cavities and to guarantee the impedance requirements of each crucial HOM. This paper details the results of HOM-surveys performed for the first two upgrade style low loss cavities tested both individually in a vertical Dewar and horizontally in a dedicated cavity pair cryomodule. The safety margin to the worst beam break-up scenario at 12 GeV has been concluded.

### Improved Performance of JLab 7-Cell Cavities by Electropolishing

C. E. Reece, A. C. Crawford, R. L. Geng (JLAB)

The great majority of experience in niobium SRF cavity processing at Jefferson Lab is with BCP etching. This has been used on CEBAF cavities and others totaling over 500 in number. With improved process quality control, field emission is now largely controlled and other factors limit performance. All of the prototype cavities developed for the 12 GeV upgrade, although meeting minimum requirements, have demonstrated a Q-drop in the 17 -- 23 MV/m range that is not remedied by 120 C bake. Most of these cavities received >250 micron removal by BCP etch. Three of these cavities are being electropolished using the protocol under development within ILC R&D activities. The first such cavity was transformed from  $Q = 3 \cdot 10^{10}$  at 17 MV/m to quench from  $1 \cdot 10^{10}$  at 35 MV/m. The details of this and two subsequent electropolished JLab 7-cell cavities will be reported.

### A Family of L-Band SRF Cavities for High Power Proton Driver Applications

R. A. Rimmer, F. Marhauser (JLAB)

Recent global interest in high duty factor or CW superconducting linacs with high average beam power highlights the need for robust and reliable SRF structures capable of delivering high average RF power to the beam with moderate HOM damping, low interception of halo and good efficiency. Potential applications include proton or  $H^{-}$  drivers for spallation neutron sources, neutrino physics, waste transmutation, subcritical reactors, and high-intensity high-energy physics experiments. We describe a family of SRF cavities with a range of Betas capable of transporting beam currents in excess of 10 mA CW with large irises for minimal interception of halo and HOM and power couplers capable of supporting high average power operation. Goals include an efficient cell shape, high packing factor for efficient real-estate gradient and strong HOM damping to ensure stable beam operation. Designs are being developed for low-frequency (e.g. 650-975 MHz), but can easily be scaled to high-frequency (e.g. 1.3-1.5 GHz), depending on the application. We present the results of conceptual design studies, simulations and prototype measurements.

### Integrated Surface Topography Characterization of Various Polished Niobium for Superconducting Particle Accelerators

As SRF cavities approach fundamental material limits, there is increased interest in understanding the details of topographical influences on performance limitations. Micro- and nano-roughness are implicated in direct geometrical field enhancements and complications of the composition of the 50 nm surface layer in which the super-currents flow. Interior surface etching (BCP/EP) to remove mechanical damage leaves surface topography, including pits and protrusions of varying sharpness. These may promote RF magnetic field entry, locally quenching superconductivity, so as to degrade cavity performance. A more incisive analysis of surface topography than the widely-used average roughness is needed. In this study, a power spectral density (PSD) approach based on Fourier analysis of surface topography data acquired by both stylus profilometry and atomic force microscopy (AFM) is being used to distinguish the scale-dependent smoothing effects. The topographical evolution of the varied starting state Nb surface (CBP/ EBW) as a function of applied etching, polishing steps and conditions is reported, resulting in a novel qualitative and quantitative description of Nb surface topography.

H. Tian, C. E. Reece (JLAB) M. J. Kelley, H. Tian (The College of William and Mary)

### Basic Electropolishing Process Research and Development in Support of Improved Performance of SRF Cavities for Future Accelerators

Future accelerators require unprecedented cavity performance, which is strongly influenced by interior surface nanosmoothness. Electropolishing is the technique of choice

to be developed for high-field superconducting radiofrequency cavities. Electrochemical impedance spectroscopy (EIS) and related techniques point to the electropolishing mechanism of Nb in a sulfuric and hydrofluoric acid electrolyte of controlled by a compact surface salt film under F- diffusion-limited mass transport control. These and other findings are currently guiding a systematic characterization to form the basis for cavity process optimization, such as flowrate, electrolyte composition and temperature. This integrated analysis is expected to provide optimum EP parameter sets for a controlled, reproducible and uniform surface leveling for Nb SRF cavities.

H. Tian, C. E. Reece (JLAB) M. J. Kelley, H. Tian (The College of William and Mary)

### Design, Prototype and Measurement of APS Single-Cell Crab Cavity

After design optimization of a squashed elliptical single-cell crab cavity at 2.8 GHz, a copper prototype has been bench measured in order to determine its rf properties and the effectiveness of waveguide damping of parasitic modes, especially the low-order mode (LOM)\*. We also present detailed results of the RF cold test at 2K on niobium single-cell and two-cell prototype cavities operating either in the zero or pi mode. Further progress will be discussed on the design of high-order mode (HOM) waveguide damping, the analysis of the Lorenz force detuning simulations by ANSYS, and the prototype of on-cell damping in which a waveguide port is attached directly on the cavity's long equator. Details of LOM/HOM impedance calculations and experimental bench measurements will be reported and compared to strict requirements for satisfying the APS impedance budget.

H. Wang, G. Cheng, G. Ciovati, P. Kneisel, R. A. Rimmer, L. Turlington (JLAB) A. Nassiri, G. J. Waldschmidt (ANL)

\*J. Shi et. al., "Superconducting RF Deflecting Cavity Design and Prototype for Short X-ray Pulse Generation", EPAC 2008, paper MOPP155.

### Buffered Electropolishing – A New Way for Achieving Extremely Smooth Surface Finish on Nb SRF Cavities to be Used in Particle Accelerators

A. T. Wu, G. Ciovati, A. C. Crawford, R. Manus, H. L. Phillips, C. E. Reece, R. A. Rimmer, W. Sommer, J. S. Williams (JLAB) F. Eozénu (CEA) X. Y. Lu (PKU/IHIP) J. Mammosser (ORNL)

A new surface treatment technique for niobium (Nb) Superconducting Radio Frequency (SRF) cavities called Buffered Electropolishing (BEP) has been developed at JLab. It was found that BEP could produce the

smoothest surface finish on Nb samples ever reported in the literature. Experimental results revealed that the Nb removal rate of BEP could reach as high as  $4.67 \mu\text{m}/\text{min}$ . This is significantly faster\* than that of the conventional electropolishing technique employing an acid mixture of HF and H<sub>2</sub>SO<sub>4</sub>. An investigation is underway to determine the optimum values for all relevant BEP parameters so that the high quality of surface finish achieved on samples can be realized within the geometry of an elliptical RF cavity. Toward this end, single cell Nb cavities are being electropolished by BEP at both CEA-Saclay and JLAB. These cavities will be RF tested and the results will be reported through this presentation.

\*Xiangyang Lu et al, to be published.

### Commissioning of the SRF Surface Impedance Characterization System at Jefferson Lab

B. Xiao, R. L. Geng, F. Marhauser, H. L. Phillips, C. E. Reece, H. Wang (JLAB) M. J. Kelley (The College of William and Mary)

Much remains to be learned regarding the details of SRF performance effects with material variation, including niobium treated in different ways, and different bulk/thin

film materials that are fabricated under different conditions. A facility that can measure small samples' RF properties in a range of 0~180mT magnetic field and 2~20k temperature is necessary in order to answer this question. The Jefferson Lab surface impedance characterization (SIC) system has been designed to attempt to meet this requirement. The SIC system uses a sapphire-loaded cylindrical Nb cavity at 7.5GHz with 50mm diameter flat sample placed on a non-contacting end plate and a calorimetric technique to directly measure the rf dissipation in the sample in response to known rf fields over  $\sim 1 \text{ cm}^2$ . We report on the commissioning of this system and its first uses for characterizing materials. Preliminary tests with Nb thin film sample sputtered on Cu substrate, and bulk Nb sample have been done at low field. The presently available hardware is expected to enable tests up to 20 mT peak magnetic field on the sample CW. Paths to higher field tests have been identified.

### Surface Analysis of "Hotspot" Regions from a Single Cell SRF Cavity

X. Zhao, G. Ciovati, P. Kneisel, C. E. Reece, A. T. Wu (JLAB)

SRF cavities are observed to be limited by non-linear localized effects. The variation of local material parameters between "hot" and

"cold" spots is thus of intense interest. Such locations were identified in a BCP etched large-grain single-cell cavity and removed for examination by high resolution electron microscopy (SEM), electron-back scattering diffraction microscopy (EBSD), and scanning Auger electron spectroscopy (SAM). Pits with clear crystal facets were observed on both "Hotspot" and "Coldspot" specimens. The pits were found in-grain and on "Y"-shaped junction of three crystals. They are interpreted as etch pits induced by surface crystal defects (e.g., dislocations). All "Coldspots"

examined had obvious low density of etching pits or very shallow tri-crystal boundary junction. EBSD revealed crystal structure surrounding the pits via crystal phase orientation mapping. This study suggests a mechanism by which BCP etching creates pits on large-grain Nb cavity surfaces and sharp-edged topography in fine-grain Nb. Field enhancements at very deep, sharp and densely populated etching pits may then cause distributed hotspots and limit cavity performance.

### Medium Field Q-Slope Studies in Superconducting Cavities

The quality factor of superconducting radio-frequency cavities typically degrades with increasing field at moderate gradients before the on-set of field emission. The origin of the so called medium field Q-slope is not fully described and understanding it would be important in order to develop a cavity design or treatment which minimizes this effect, allowing us to produce cavities with reduced cryogenic losses. This paper will present an analysis of the medium field Q-slope data measured on cavities at different frequencies treated with buffered chemical polishing (BCP) at TRIUMF. The data is compared with existing models and agreements-discrepancies will be highlighted.

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### Cavity Load Impedance Diagnostic at the Australian Synchrotron

RF cavities are routinely detuned slightly from resonance to maintain Robinson stability of the beam as beam loading increases.

**R. T. Dowd**, K. Zingre (ASCo)

Detuning the cavities results in a reduction of the overall energy efficiency of the RF and can waste many MW hours of energy per year. It is therefore desirable to only detune as much as required by the beam loading to maintain stability. A new system for monitoring the load impedance of the Storage Ring RF cavities has been developed at the Australian Synchrotron. The system utilises the Analogue devices AD8302 chip to monitor the load impedance of the Cavities and allow for more efficient detuning of the system. An overview and commissioning results of this system will be presented.

### Development of RF System Model for CERN Linac2 Tanks

An RF system model has been created for the CERN Linac2 Tanks. RF systems in this linac have both single and double feed architectures. The main elements of these systems are: RF power amplifier, main resonator, feed-line and the amplitude and phase feedback loops. The model of the composite system is derived by suitably concatenating the models of these individual sub-systems. For computational efficiency the modeling has been carried out in the base band. The signals are expressed in in-phase - quadrature domain, where the response of the resonator is expressed using two linear differential equations, making it valid for large signal conditions. MATLAB/SIMULINK has been used for creating the model. The model has been found useful in predicting the system behaviour, especially during the transients. In the paper we present the details of the model, highlighting the methodology, which could be easily extended to multiple feed RF systems.

**G. Joshi** (BARC) V. Agarwal, G. Kumar (Indian Institute of Technology Bombay) M. Vretenar (CERN)

## Low-Level Radio Frequency Control Development for the National Synchrotron Light Source II

H. Ma, J. Rose (BNL)

The National Synchrotron Light Source-II (NSLS-II) is a new ultra-bright 3GeV 3rd generation synchrotron radiation light source. The performance goals require operation with a beam current of 500mA and a bunch current of at least 0.5mA. The position and timing specifications of the ultra-bright photon beam imposes a set of stringent requirements on the radio Frequency (RF) control, among which, for example, is the 0.14 degree phase stability, and the flexibility of handling varying beam conditions. To meet these requirements, a digital implementation of the LLRF is chosen in order to be able to take the advantage of the power of precision signal processing and control that only DSP technology can provide. The initial design of NSLS II LLRF control solution is comprised of a FPGA-based basic field controller, a dual ASIC DSP co-processor directly coupled to the FPGA controller, as well as a local CPU which monitors the operation, stores the data, and facilitates the tests and development. The prototype of the basic FPGA field controller hardware has been designed. The first sample has been fabricated, and is currently being tested.

## The ERL Cold Emissions Test and the Low Level RF System Results

C. Schultheiss, A. Burrill, C. Pai, A. Zaltsman (BNL)

This paper describes the results from the Energy Recovery Linac Cold Emissions Test, with emphasis on the Low Level RF (LLRF) System. The LLRF system is composed of a Phase-Locked Loop (PLL) and includes two mechanical tuners that are used to adjust the cavity's resonant frequency. A stepper motor is used for coarse adjustment of the resonant frequency, while a piezo-stack is used for fine tuning, and to cancel the cavity microphonics. The cavity microphonics were measured and used in the LLRF loop design. The piezo-stack and the PLL can interact with one another, the loop characteristics were chosen to eliminate this possibility. The loop design and results are presented here.

## Design of a Linear-Quadratic-Gaussian Controller for a Single-Cavity Rigid-Bunch RF System

N. A. Towne, H. Ma, J. Rose (BNL)

NSLS-II is a new ultra-bright 3GeV 3rd generation synchrotron radiation light source. The performance goals require operation with a beam current of 500mA and a bunch current of at least 0.5mA. The position and timing specifications of the photon beam place tolerances on the phase stability of the RF cavity fields of less than 0.15 degrees jitter. This study develops computational methods for the construction of LQG controllers for discrete-time models of single-cavity rf systems coupled to rigid-bunch beams able to meet this tolerance. It uses Matlab's control-systems toolbox and Simulink to synthesize the LQG controller; establish resolutions of state variables, ADCs, DACs, and matrix coefficients that, in a fixed-point controller provide essentially undiminished performance; simulate closed-loop performance; and assess sensitivity to variations of the model. This machinery is applied to NSLS-II-, CLS-, and NSLS VUV-ring models showing exceptional noise suppression and bandwidth. Thoughts are given on the validation and tuning of the rf model by machine measurements, DSP implementations, and future work.



### Alternative Cavity Tuning Control for CRM Cyclotron

In the commissioning phase of CRM cyclotron, the RF cavity resonance frequency changes rapidly due to cavity thermal instability and electronics interference inside

tuning loop. To solve the later issue, a set of cavity tuning control electronics has been re-designed, fabricated and tested in 2008. The new tuning control electronics and related experimental results will be described in this paper. A wide dynamic range phase detector with double balanced mixer were selected to detect the cavity detuning angle by comparing the phase difference between the cavity pickup signal and cavity driven signal. One analogue P. I. controller was utilized for loop regulation, taking advantage of shorter developing time. A current amplifier is also included to magnify the driven ability of the P. I. regulator for cavity fine tuning motors. A careful layout has been performed to avoid interference between RF part, DC small signal part and the current amplifier part. The desk experiment yields good phase detection sensitivity and acceptable stability after the mixer reaches natural thermal balance.

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WE5PFP069

### Modelling and Simulation of the RF System for SPIRAL2

The acceleration of non relativistic particles, with a velocity lower than light velocity, in an RF cavity is more complex than for rela-

tivistic particles. Non-linear behaviours appear on the accelerator voltage because of the phase slippage inside the cavity. Moreover, a superconducting RF cavity is sensitive to various perturbations like mechanical vibrations (microphonics) and Lorentz force detuning. These perturbations produce a significant detuning of the cavity, leading a strong instability for the amplitude and phase of the field because of the narrow bandwidth of the accelerating mode. We will present a simulation approach of the cavity and its LLRF system control in order to ensure proper cavity operation under perturbations in the framework of the SPIRAL2 project.

O. Piquet, M. Luong (CEA)

WE5PFP070

### Transient Analysis of RF Cavities under Beam Loading

The conventional electrical model analogy of a RF cavity is a shunt RLC circuit supplied by two current sources representing

the RF amplifier and the beam. In the literature, the impedance of the cavity is often calculated in the Fourier domain. This type of cavity modelling has two drawbacks: First, it assumes a perfect matching between the cavity and the amplifier therefore it neglects the reflected voltage. And, second, it does not provide any information about the cavity transient response, for example at startup or upon beam arrival, while this information can be very important for the design of the regulation loops. In this work we will remove these drawbacks by calculating the cavity impedance in Laplace domain taking the reflected voltage into account. We will then modify our model so that it also includes the influence of the beam on the cavity. For transient RF simulations, though, a typical problem is the long simulation time due to the relatively slow transient response compared to the RF period. To overcome this problem, finally, we will present a mathematical method to map the cavity frequency response from RF to baseband to reduce the simulation time significantly.

H. Hassanzadegan, R. Grino (UPC) D. Einfeld (ALBA)

WE5PFP071

### A Modular Digital LLRF Control System for Normal as well as Superconducting RF Accelerators

N. Pupeter, B. A. Aminov, F. Aminova, A. Borisov, M. Getta, W. Jalmuzna, T. Jezynski, S. Kolesov, H. Piel, D. Wehler (CRE) S. Simrock (DESY)

For future applications in Light Sources and Large Scale Linear Accelerators we have developed a fully digital LLRF system which overcomes the intrinsic problems of analogue and semi digital LLRF systems by realizing all functions in the high speed cores of FPGAs. Due to its modular design using either the ATCA or the VME form factor the LLRF system can be configured conveniently according to the specific requirements of the accelerator to control the rf field in individual resonators or in a combination of cavities. The LLRF input stage can be custom designed for rf frequencies of up to 3.9 GHz. The hardware and software architectures of the Cryoelectra digital LLRF control system are presented.

For future applications in Light Sources and Large Scale Linear Accelerators we have developed a fully digital LLRF system which overcomes the intrinsic problems of analogue and semi digital LLRF systems by re-

### Demonstration of an ATCA Based LLRF Control System at FLASH

S. Simrock, M. K. Grecki, T. Jezynski, W. Koprek (DESY) K. Czuba (Warsaw University of Technology, Institute of Electronic Systems) G. W. Jablonski, W. Jalmuzna, D. R. Makowski, A. Piotrowski (TUL-DMCS)

Future RF Control systems will require simultaneous data acquisition of up to 100 fast ADC channels at sampling rates of around 100 MHz and real time signal processing within a few hundred nanoseconds. At the same time the standardization of low-level systems are common objectives for all laboratories for cost reduction, performance optimization and machine reliability. Also desirable are modularity and scalability of the design as well as compatibility with accelerator instrumentation needs including the control system. All these requirements can be fulfilled with the new telecommunication standard ATCA when adopted to the domain of instrumentation. We describe the architecture and design of an ATCA based LLRF system for the European XFEL. Initial results of the demonstration of such a system at the FLASH user facility will be presented.

Future RF Control systems will require simultaneous data acquisition of up to 100 fast ADC channels at sampling rates of around 100 MHz and real time signal processing within a few hundred nanoseconds. At the same time the standardization of low-

### First Beam Commissioning of the 400 MHz LHC RF System

A. C. Butterworth, M. E. Angoletta, L. Arnaudon, P. Baudrenghien, T. Bohl, O. Brunner, E. Ciapala, F. Dubouchet, W. Höfle, T. P.R. Linnecar, P. Maesen, J. C. Molendijk, E. N. Shaposhnikova, J. Tuckmantel, D. Valuch, U. Wehrle, F. Weierud (CERN)

Hardware commissioning of the LHC RF system was successfully completed in time for first beams in LHC in September 2008. All cavities were conditioned to nominal field, power systems tested and all Low level synchronization systems, cavity controllers and beam control electronics were tested and calibrated. Beam was successfully captured in ring 2, cavities phased, and a number of initial measurements made. These results are presented and tests and preparation for colliding beams in 2009 are outlined.

Hardware commissioning of the LHC RF system was successfully completed in time for first beams in LHC in September 2008. All cavities were conditioned to nominal field, power systems tested and all Low level synchronization systems, cavity controllers

### A New CERN PS Transverse Damper

Since 1999 the PS has been operated without active transverse damping thanks to an increase of the coupling between the transverse planes and the reduction of injection steering errors. Although the LHC requirements are met by these means, a new transverse feedback system has been commissioned to reinforce the robustness of operation and avoid the blow-up generated by residual injection steering errors. This system could also allow the reduction of the chromaticity and reduce the slow incoherent losses during the long PS injection plateau. It could also stabilize the high energy instabilities that appear occasionally with the LHC nominal beam and may be a limiting factor for ultimate LHC beam. Highlights include a signal processing with an automatic delay adapting itself to the varying revolution frequency, a programmable betatron phase adjustment along the cycle, pick-ups that have been re-furbished with electronics covering the very low frequency of the first betatron line and a compact wideband high-power solid state amplifier that drives the strip-line kicker via an impedance matching transformer. The overall system is described together with experimental results.

A. Blas, J. M. Belleman, E. Benedetto, F. Caspers, D. C. Glenat, R. Louwarse, M. Martini, E. Métral, V. Rossi, J. P.H. Sladen (CERN)

### General Purpose Digital Signal Processing VME-Module for 1-Turn Delay Feedback Systems of the CERN Accelerator Chain

In the framework of the LHC project and the modifications of the SPS as its injector, the concept has been developed of a global digital signal processing unit (DSPU) that implements in numerical form the architecture of low-level RF systems. Since 2002 a Digital Notch Filter with programmable delay for the SPS Transverse Damper has been fully operational with fixed target and LHC-type beams circulating in the SPS. The approach, using an FPGA as core for the low-level system, is very flexible and allows the upgrade of the signal processing by modification of the original firmware. The development for the LHC 1-Turn delay Feedback has benefited from the same methodology and similar technology. The achieved performances of the LHC 1-T Feedback are compared with project requirements. The project flow for the LHC 1-T Feedback allows synergy with several other applications. The CERN PS Transverse Damper DSPU, with automatic delay compensation adapting the loop delay to the time of flight of the particles and Hilbert Filters for single pick-up betatron phase adjustment, is presented. A modified DSPU module with digital inputs employed for the LHC Transverse Damper is also presented.

V. Rossi (CERN)

### Analysis of DESY-FLASH LLRF Measurements for the ILC Heavy Beam Loading Test

In September 2008 the DESY-FLASH accelerator was run with up to 550, 3 nanocoulomb bunches at 5 Hz repetition rate. This test is part of a longer term study aimed at validating ILC parameters by operation as close as possible to ILC beam currents and RF gradients. The present paper reports on the analysis that has been done in order to understand the RF control system performance during this test. Actual klystron power requirements and beam stability are evaluated with heavy beam loading conditions. Results include suggested improvements for upcoming tests in 2009

G. I. Cancelo, B. Chase, M. A. Davidsaver (Fermilab) V. Ayvazyan, S. Simrock (DESY) J. Carwardine (ANL) T. Matsumoto, S. Michizono (KEK)

### Development of SCRF Cavity Resonance Control Algorithms at Fermilab

Y. M. Pischalnikov, R. H. Carcagno, D. F. Orris, W. Schappert (Fermilab)

and microphonics. Algorithms that have been developed and tested for the 1.3GHz (ILC-style) SCRF cavities (Capture Cavity II) will be reported.

Progress has been made at Fermilab on the development of feed-forward and feed-back algorithms used to compensate SCRF cavity detuning, which is caused by Lorentz Forces

### Development of a Digital System Damping Longitudinal Quadrupole Oscillations

M. Mehler, H. Klingbeil, M. Kumm, U. Laier, K.-P. Ningel (GSI)

High intensity ion beams are required, making it necessary to damp longitudinal coupled and uncoupled bunch oscillations. For this purpose, a closed-loop control system was designed. Its processing part is based on digital signal processors (DSP) and field programmable gate arrays (FPGA) whose advantage is their adaptability to different problems by software changes. Experiments with a prototype were performed at the existing synchrotron SIS12/18 at GSI concentrating on the damping of longitudinal coupled bunch quadrupole oscillations of the lowest order. The configuration of the electronic system is described and results of the machine development experiments are reported. Finally, an outlook to the application in SIS100 is given.

SIS100 is a synchrotron that will be built in the scope of the FAIR (Facility for Antiproton and Ion Research) project. High inten-

### The Intelligent Gate Control for the Induction Acceleration System in the KEK Digital Accelerator

T. Iwashita, T. Adachi, Y. Arakida, T. Kono, H. Someya, K. Takayama, M. Wake (KEK)

arbitrary ions with their possible charge states\*\*. An outline of the acceleration scenario is described and a necessary control system fully integrating the induction acceleration system is given in details. The KEK-DA is a rapid cycle synchrotron operating at 10 Hz; the accelerating pulse voltage must be dynamically varied in time to follow the ramping magnetic field. A novel technique combining the pulse density control and intermittent operation of acceleration cells is required. The intelligent gate control system which uses 1 GHz digital signal processors (DSPs) has been designed. Now R&D works of front-end ADC board to generate the trigger gate from a beam signal are going on. The beam signal digitized by fast ADC is processed to identify the bunch center. The whole system is demonstrated with high voltage outputs.

The KEK-DA (Digital Accelerator) is a modification of the KEK 500 MeV booster\*, in which an induction acceleration system is employed. It has an ability to accelerate

\*K. Takayama et al., "All-ion accelerators: An injector-free synchrotron" JOURNAL OF APPLIED PHYSICS -10-1, 063304 (2007)

\*\*T. Adachi et al., in this conference

**Digital Low-Level RF Control System with Four Intermediate Frequencies at STF**

Digital low-level rf (LLRF) control system has been installed in many linear accelerators to stabilize the accelerating field. In the digital LLRF system, the rf signal is down-converted into intermediate frequency for sampling at analog-to-digital converter (ADC) and the number of ADC required for vector sum feedback operation is equal to the number of cavity. In order to decrease the number of the ADCs required, a digital LLRF control system using different four intermediate frequencies has been developed at STF (Superconducting RF Test Facility) in KEK. This digital LLRF control system was operated with four superconducting cavities and the rf field stability under feedback operation was estimated. The result of the performance will be reported.

**T. Matsumoto**, S. Fukuda, H. Katagiri, S. Michizono, T. Miura, Y. Yano (KEK) Y. Okada (NETS)

WE5PFP081

**Evaluation of Digital Feedback Control at 972 MHz rf System in J-PARC Linac**

Upgrade of J-PARC linac has been planned using 972 MHz rf system. The rf field regulation is required to be less than  $\pm 1\%$  in amplitude and  $\pm 1\text{deg.}$  in phase. The basic digital llrf concept is same as the present 324 MHz llrf system using a compact PCI crate. The main alterations are rf and clock generator (RF&LK), mixer and IQ modulator (IQ&ixer) and digital llrf algorithm. Since the typical decay time is faster (due to higher operational frequency than present 324 MHz cavity), chopped beam compensation is one of the main concerns. Performance of the digital feedback system using a cavity simulator is summarized.

**S. Michizono**, Z. Fang, T. Matsumoto, S. Yamaguchi (KEK) T. Kobayashi (JAEA/J-PARC) Y. Okada (NETS)

WE5PFP082

**Vector-Sum Control of Superconducting rf Cavities at STF**

Vector-sum control of 4 superconducting cavities is examined at STF in KEK. The digital llrf control is carried out and the stabilities of rf fields are obtained. Various studies such as feedback margin necessary for enough field regulation, effects of perturbations of cavity detuning or klystron HV and so on. Performance degradation by elimination of circulators is also studied from the viewpoint of llrf system.

**S. Michizono**, S. Fukuda, T. Matsumoto, T. Miura, Y. Yano (KEK) Y. Okada (NETS)

WE5PFP083

**LLRF Feedback Control Stability at STF**

At Superconducting RF Test Facility (STF) in KEK, feedback control stability for individual cavity or 4-cavities based on vector-sum technique was experimentally evaluated. The first trial of adaptive feedforward, gain margin for feedback loop-delay, and instabilities due to TM010 passband modes except for the pi-mode will be reported.

**T. Miura**, S. Fukuda, H. Katagiri, T. Matsumoto, S. Michizono, Y. Yano (KEK) Y. Okada (NETS)

WE5PFP084

### The Arithmetic Study of the Prototype Digital LLRF for CSNS Linac

Z. C. Mu (Institute of High Energy Physics, CAS) S. Fu, J. Li, X. A. Xu (IHEP Beijing)

The CSNS linac specifies the RF control accuracy on the scale of 1% in amplitude and  $1^\circ$  in phase. We will adopt the technology of the digital IQ complex demodulation in order to achieve that accuracy. This paper mainly introduces some feedback and feedforward control algorithm implementation, including the adaptive feedforward control, the saturation limitation and etc. Now the hardware and software of the prototype system have been set up. Some test results of the system with the RFQ accelerator of the ADS project at IHEP will be illustrated in this paper.

### Evaluation of the Analog and Digital Receiver Section in the Libera LLRF System

B. B. Baricevic, C. J. Bocchetta, R. Cerne, Z. Lestan, U. Mavric, B. Repic (Instrumentation Technologies)

In a feedback system the disturbances added in the receiver section are one of the major contributors to the amplitude and phase fluctuations of the fields in the RF cavities that are being controlled. It is therefore crucial to thoroughly evaluate the receiver section of the control system. Measurement results of parameters like amplitude noise, phase noise, coupling between RF channels, linearity and temperature dependent drifts of the receiver are presented. We also discuss what the influences of some of the measured parameters on phase and amplitude stability of the RF fields are. Finally, we summarize the results of the measurements and their impact on the future development of the Libera LLRF system.

### Automatic Frequency Matching for Cavity Warming-up in J-PARC Linac Digital LLRF Control

T. Kobayashi (JAEA/J-PARC) S. Anami, Z. Fang, S. Michizono, S. Yamaguchi (KEK) H. Suzuki (JAEA)

In the J-PARC Linac LLRF, for the cavity warming-up, the cavity resonance is automatically tuned to be the accelerating frequency (324MHz and 972MHz) with a mechanical tuner installed on the cavity. Now we are planning to introduce a new method of the cavity-input frequency matching into the digital LLRF control system instead of the cavity resonance tuning for the cavity warming-up. For the frequency matching with the detuned cavity, the RF frequency is modulated by way of phase rotation with the I/Q modulator, while the source oscillator frequency is still fixed. The phase rotation is automatically controlled by the FPGA. The detuned frequency of the cavity is obtained from phase gradient of the cavity field decay at the RF-pulse end. No hardware modification is necessary for this frequency modulation method. The cost reduction or the high durability for the mechanical tuner is expected in the future. The results of the frequency modulation test will be reported in this presentation.

### Direct Sampling of rf Signal for 1.3 GHz Cavity

Y. Okada (NETS) S. Fukuda, H. Katagiri, T. Matsumoto, S. Michizono, T. Miura, Y. Yano (KEK)

Intermediate-frequency conversion technique has been widely used for rf signal detection. However, this technique has disadvantages such as temperature dependence higher order modes of downconverters. One of our recent attractive developments is the high-speed data

acquisition system that combines commercial FPGA board ML555 and fast ADC (ADS5474 14bit, maximum 400MS/s and bandwidth of 1.4 GHz). Direct measurements of 1.3 GHz rf signals are carried out with 270 MHz sampling. The direct sampling method can eliminate a down-converter and avoid calibration of non-linearity of the down-converter. These results are analyzed and compared with conventional measurement system.

### Study of Direct RF Feedback with the Pedersen Model

The direct RF feedback has been adopted in storage ring to reduce the beam loading effect for maximizing the stored beam current. Its performance in reducing beam loading is determined by the operational parameters, including the feedback gain, RF phase shift and the loop delay time. This paper presents a mathematical method, based on the Pedersen model, to study the effects of the direct RF feedback on beam loading. Through an example, the influences of different operational parameters on the performance of the direct RF feedback is analyzed by examining the characteristic equation of the feedback loop. The Nyquist criterion is applied for the determination of system stability.

**L.-H. Chang**, M.-C. Lin, Y.-H. Lin, C. H. Lo, Ch. Wang, M.-S. Yeh (NSRRC)

WE5PFP089

### Energy Saving for Booster RF System in NSRRC

The SRRC booster synchrotron is used to accelerate the electron beam from 50 MeV to 1.5 GeV. The energy loss of each electron in the booster ring must be compensated by the rf system in the booster ring. We describe the energy saving control of the rf system for the booster of 1.5 GeV Taiwan Light Source.

**M.-S. Yeh** (NSRRC)

WE5PFP090

### Status of the Spallation Neutron Source Prototype Accumulator Ring LLRF System

The Spallation Neutron Source (SNS) has recently installed a prototype low level radio frequency (LLRF) control system for initial testing. This system is designed to replace the original fixed frequency, two harmonic Accumulator Ring LLRF system used to maintain a gap in the proton beam for extraction to the target. This prototype system is based on the hardware for the Linac LLRF system that has been modified to operate at the low frequencies required for the ring. The goal of the final system is to leverage the mature hardware and software of the Linac systems with the added flexibility needed to support the heavy beam loading requirements of the Accumulator Ring.

**M. T. Crofford** (ORNL)

WE5PFP091

### High Intensity Beam Performance of the SNS Accumulator Ring LLRF Control System

Four ferrite loaded resonant radio frequency (RF) cavity structures and one resistive wall current monitor (WCM) located in the South leg of the Spallation Neutron Source (SNS) accumulator ring are used to maintain a clean 250+ ns gap required for low loss extraction of beam to the target. Three of the Ring RF cavities operate at the fundamental accumulator ring revolution frequency ( $\sim 1.05$  MHz) while the fourth cavity operates at the second harmonic ( $\sim 2.10$  MHz). The SNS ring low-level RF (LLRF) control system employs dynamic cavity tuning and PID feedback control to

**M. F. Piller**, M. T. Crofford, T. W. Hardek (ORNL) K. Smith (BNL)

WE5PFP093

regulate the amplitude and phase of the fields in the ring RF structures. The SNS linear accelerator (linac) recently produced 700kW of beam power at 60 Hz corresponding to 13.5 uC of charge per pulse in the ring. This paper discusses operation and performance of the SNS ring LLRF system with high intensity beam loading.

### Phase Amplitude Detection (PAD) and Phase Amplitude Control (PAC) for PxFEL

W. H. Hwang, M.-H. Chun, K. M. Ha, Y. J. Han, D. T. Kim, S. H. Kim (PAL) R. Akre (SLAC)

In PAL, We are preparing the 3GeV Linac by upgrading the present 2.5GeV Linac and new 10GeV PxFEL project. The specification of the beam energy spread and rf phase is tighter than PLS Linac. In present PLS 2.5 GeV Linac, the specifications of the beam energy spread and rf phase are 0.6%(peak) and 3.5 degrees(peak) respectively. And the output power of klystron is 80 MW at the pulse width of 4 microseconds and the repetition rate of 10 Hz. In PxFEL, the specifications of the beam energy spread and rf phase are 0.1%(rms) and 0.1 degrees(rms) respectively. We developed the modulator DeQing system for 3GeV linac and PxFEL. And the phase amplitude detection system(PAD) and phase amplitude control(PAC) system is needed to improve the rf stability. This paper describes the microwave system for the PxFEL and the PAD and PAC system.

In PAL, We are preparing the 3GeV Linac by upgrading the present 2.5GeV Linac and new 10GeV PxFEL project. The specification of the beam energy spread and rf phase is

### Application of Non-Linear Time-Domain RF Simulations to Longitudinal Emittance Studies for the LHC

T. Mastorides, J. D. Fox, C. H. Rivetta, D. Van Winkle (SLAC)

A non-linear time-domain simulation has been developed that can determine technical limitations, effect of non-linearities and imperfections, and impact of additive noise on the interaction of the beam with the Impedance Control Radio Frequency (RF) systems. We present a formalism for the extraction of parameters from the time-domain simulation to determine the sensitivity of the beam longitudinal emittance and dilution on the RF system characteristics. Previous studies\* have estimated the effect of a noise source on the beam characteristics assuming an independent perturbation source of the RF voltage and a simplified beam model with no coupling. Using the time-domain simulation we present the dependence of the accelerating voltage noise spectrum on the various RF parameters and the technical properties (such as non-linearities, thermal noise, frequency response etc.) of the LLRF system components. Future plans to expand this formalism to coupled bunch studies of longitudinal emittance growth in the LHC at nominal and upgraded beam currents are briefly summarized.

A non-linear time-domain simulation has been developed that can determine technical limitations, effect of non-linearities and

\*J. Tuckmantel, Synchrotron Radiation Damping in LHC and Longitudinal Bunch Shape, LHC Project Report 819.

### Damping Effect Studies for X-Band High Gradient Structures

S. Pei, V. A. Dolgashev, Z. Li, S. G. Tantawi, J. W. Wang (SLAC)

The next generation linear collider should have the capability to accelerate high performance beam with reduced cost, X-band high gradient normal conducting accelerating structure is one of the appropriate choice for beam acceleration. However, the transverse wake field effect which can deteriorate the beam performance is a critical issue. In this paper, we examined dipole mode damping effectiveness in three kinds of X-band, Pi-mode standing wave structures with no detuning. The three kinds of structure are structure with cylindrical "iris slot", structure with cylindrical choke and structure with locally damping waveguides. We try to achieve  $Q_{ext} < 20$  in the first and second dipole mode pass bands, the characteristics of the 3rd dipole band is also investigated.

The next generation linear collider should have the capability to accelerate high performance beam with reduced cost, X-band



**Data Analysis of LLRF Measurement with Beam Off at FLASH**

FLASH facility has an impressive DAQ system. In order to measure the system stability, determine the electronic noise levels and gauge the perturbations to the system, we

did some studies on the LLRF system with beam off for crymodule ACC4 to ACC6. In this paper, we present our data analysis results in both time domain and frequency domain, the key findings are summarized.

**S. Pei**, C. Adolphsen (SLAC) J. Carwardine (ANL) N. J. Walker (DESY)

WE5PFP097

**Feedback Configuration Tools for LHC Low Level RF System**

The LHC Low Level RF System (LLRF) is a complex multi-VME crate system which is used to regulate the superconductive cavity gap voltage as well as to lower the impedance

as seen by the beam through low latency feedback. This system contains multiple loops with several parameters which must be set before the loops can be closed. In this paper, we present a suite of matlab based tools developed to perform the preliminary alignment of the RF stations and the beginnings of the closed loop model based alignment routines. We briefly introduce the RF system and in particular the base band (time domain noised based) network analyzer system built into the LHC LLRF. The main focus of this paper is the methodology of the algorithms used in the routines within the context of the overall system. Measured results are presented which validate the technique. Because the RF systems are located underground in a location which is relatively un-accessible even without beam and completely un-accessible when beam is present, these tools will allow CERN LLRF experts to maintain and tune their LLRF systems from a remote location similar to what was done very successfully in PEP-II at SLAC.

**D. Van Winkle**, J. D. Fox, T. Mastorides, C. H. Rivetta (SLAC) P. Baudrenghien, A. C. Butterworth, J. C. Molendijk (CERN)

WE5PFP098

**TRIUMF e-Linac RF Control System Design**

The rf control system for the 1.3 GHz TRIUMF e-linac elliptical superconducting cavities is a hybrid analogue/digital design. It

is based in part on an earlier design developed for the 1/4 wave superconducting cavities of the ISACII linac. This design has undergone several iterations in the course of its development. In the current design, down-conversion to an intermediate frequency of 138MHz is employed. The cavity operates in a self-excited feedback loop, while phase locked loops are used to achieve frequency and phase stability. Digital signal processors are used to provide amplitude and phase regulation, as well as mechanical cavity tuning control. This version also allows for the rapid implementation of operating firmware and software changes, which can be done remotely, if the need arises. This paper describes the RF control system and the experience gained in operating this system with a single-cavity test facility.

**M. P. Lavery**, K. Fong, Q. Zheng (TRIUMF)

WE5PFP099

**Beam Loading Effects on the RF Control Loops of a Double-Harmonic Cavity System for FAIR**

The effects of heavy beam loading on the RF control loops of a double-harmonic cavity system are examined. This cavity system

**D. Lens** (TU Darmstadt, RTR) P. Hülsmann, H. Klingbeil (GSI)

WE5PFP100

that will be realized at the GSI Helmholtzzentrum für Schwerionenforschung in the scope of the SIS18 upgrade program consists of a main broadband cavity and a second harmonic narrowband cavity. The cavities comprise both an amplitude and a phase feedback loop. In addition, the narrowband cavity includes a feedback loop which controls its resonance frequency to follow the main RF frequency. After modelling the cavity system and the feedback loops, an analytic controller design is presented. In addition, longitudinal beam dynamics are added to the cavity model to allow a detailed simulation of the cavity-beam interaction. Realistic simulation results are given for an acceleration cycle of heavy-ions to demonstrate the performance of the RF control loops.

## RF System Modeling for the CEBAF Energy Upgrade

T. E. Plawski, C. Hovater (JLAB)

The RF system model based on MATLAB has been developed for analyzing the basic characteristics of the LLRF control system being designed for the 12 GeV Energy Upgrade of the CEBAF accelerator. In our model, a typically complex cavity representation is simplified to in-phase and quadrature (I&Q) components. Lorentz Force and microphonic detuning is incorporated as a new quadrature carrier frequency (frequency modulation). Beam is also represented as in-phase and quadrature components and superpositioned with the cavity field vector. Afterward signals pass through two low pass filters, where the cutoff frequency is equal to half of the cavity bandwidth then they are demodulated using the same detuning frequency. Because only baseband I&Q signals are calculated, the simulation process is very fast when compared to other controller-cavity models. During the design process we successfully analyzed gain requirements vs. field stability for different superconducting cavity microphonic backgrounds and Lorentz Force coefficients. Moreover, we were able to evaluate different types of a LLRF structures: GDR\* and SEL\*\* as well as klystron power requirements for different cavities and beam loads.

\*Generator Driven Resonator

\*\*Self Excited Loop

## The RF Phase Reference Distribution System Concept for the European XFEL

K. Czuba, K. Antoszkiewicz (Warsaw University of Technology, Institute of Electronic Systems) S. Simrock, H. C. Weddig (DESY)

One of the most important requirements for the XFEL RF system is to assure a very precise RF field stability within the accelerating cavities. The required amplitude and phase stability equals respectively  $dA/A < 3 \cdot 10^{-5}$ ,  $d\phi < 0.01$  deg @ 1.3GHz in the injector and  $dA/A < 1 \cdot 10^{-3}$ ,  $d\phi < 0.1$  deg @ 1.3GHz in the main linac section of the XFEL facility. Fulfilling such requirements is a very challenging task for the 1.5 km long main linac system and about 3.4 km length of the entire facility. Thousands of electronic and RF devices must be precisely phase synchronized for effective controlling of the RF field parameters. We describe the the proposed architecture of the RF Master Oscillator and the Phase Reference Distribution System for the XFEL. Design choices were based on the experience gained during the commissioning of the FLASH phase reference distribution system and on many laboratory experiments with distribution system components. Proposed system parameter analysis shows that the given requirements for the distributed signal phase stability can be fulfilled easily for the main linac section. Fulfilling the injector requirements may require using optical distribution techniques.

## WE5RF — Morning Poster LSAFEL A05, A06, T15

### Current Status of the Design of TPS 3 GeV Booster Synchrotron

The design work of the concentric booster for Taiwan Photon Source (TPS) has been well in progress. The circumference is 496.8 m. It consists of modified FODO cells with defocusing quadrupole and sextupole fields built in bending magnets, and combined-function focusing quadrupoles with imbedded focusing sextupole. The emittance is about 10 nm-rad at 3 GeV. Several modifications on the structure were made to improve the beam dynamics behaviors. Good dynamic aperture and nonlinear behavior as well as good tunability are shown. The effects of closed orbit correction for different places of correctors are compared. The repetition rate is 3 Hz, and the eddy current effect is also discussed.

**H. C. Chao**, H.-P. Chang, P. J. Chou, C.-C. Kuo, G.-H. Luo, H.-J. Tsai (NSRRC)

WE5RFP001

### Design Status of Transfer Lines in TPS

The booster design of Taiwan Photon Source (TPS) has been significantly revised. Therefore, the transfer line from linac to booster (LTB) and the one from booster to storage ring (BTS) have been redesigned accordingly. The design of LTB transfer line has been simplified to reduce the number of magnets. The length of BTS transfer line has been greatly reduced. The design goal of transfer lines is to achieve high efficiency for beam injection. The status of current progress will be reported.

**P. J. Chou**, H.-P. Chang, C.-C. Kuo, W. T. Liu (NSRRC)

WE5RFP002

### Study of Transverse RF Deflecting Structures in QBA Lattice of TPS for Generation Subpicosecond Pulses

Quadruple Bend Achromat (QBA) low emittance lattice of 3 GeV Taiwan Photon Source (TPS) allows us to consider three configurations for location of a pair of superconducting transverse RF deflecting cavities for generation ultra short X-ray pulses. The available arrangements for location of cavities in a super-period of TPS are investigated. We find that use of such deflecting cavities in the middle of two QBA lattices in a super-period of TPS provides better conditions for emittance of electron beam.

**H. Ghasem**, G.-H. Luo (NSRRC)

WE5RFP003

### Study of Errors due to Deflecting Structures in QBA Low Emittance Lattice of 3 GeV Taiwan Photon Source

Deflecting cavity generates a correlation between longitudinal position and vertical momentum of electrons in the synchrotron light sources for production short X-ray pulses. Use of such structures leads to growth in vertical amplitude and slope of stored electrons. Since errors are characteristic of real machine, any errors associated with the photon compression system must be considered and the tolerance of them must be evaluated. In this paper we present

**H. Ghasem**, G.-H. Luo (NSRRC)

WE5RFP004

simulation of main errors due to deflecting structures, QBA lattice and injection system and find tolerances of them.

### Bunch Lengthening in 3 GeV Taiwan Photon Source Using Harmonic Cavity

H. Ghasem (NSRRC)

A superconducting accelerating RF cavity is going to be installed in 3GeV Taiwan Photon Source (TPS). It causes a reduction in bunch length in contrast with operation of normal type of RF cavity. A higher harmonic RF cavity is usually considered as an important tool to control the bunch length in the storage rings. The harmonic cavity in lengthening mode can also be helpful for improving the lifetime which is usually dominated in the storage rings by large angle intrabeam scattering (Touschek). In this paper we study the effects of third active harmonic cavity on bunch length of the TPS ring. We present the procedure, the simulation and the formulae to analyze the effects of third harmonic cavity on the rms bunch length while the main superconducting RF system is operated in 3MV. It is shown that the longitudinal rms electron bunches will lengthen up to 7.9 times for the optimum operation of the harmonic system.

A superconducting accelerating RF cavity is going to be installed in 3GeV Taiwan Photon Source (TPS). It causes a reduction in bunch

### Progress Report of the TPS Lattice Design

C.-C. Kuo, H.-P. Chang, H. C. Chao, P. J. Chou, G.-H. Luo, A. Rusanov, H.-J. Tsai (NSRRC)

A 3 GeV synchrotron light source is planned to be built at the existing site of NSRRC campus. The project is called the Taiwan Photon Source (TPS). It will provide x-ray photon beam with brilliance several orders higher than the one generated by the existing 1.5 GeV synchrotron. The design issues of accelerator lattice for the 3 GeV storage ring and booster injector will be presented. These issues cover the properties of linear and nonlinear beam dynamics, the optimization of dynamic aperture and momentum acceptance, collective beam instabilities and lifetime issues, the effects caused by various error sources and technical measures to suppress these error effects, etc.

A 3 GeV synchrotron light source is planned to be built at the existing site of NSRRC campus. The project is called the Taiwan Photon Source (TPS). It will provide x-ray photon

### Generation of Sub-Hundred Femtosecond X-Ray via Inverse Compton Scattering

N. Y. Huang, S. S. Yang (NTHU) J. H. Chen, C. S. Chou, W. K. Lau, A. P. Lee, C. C. Liang (NSRRC)

The feasibility of generating sub-hundred femtosecond X-ray pulses based on inverse Compton scattering of relativistic electron pulses of 50-100 fsec with an 800 nm, 37.5 GW infrared Ti:Sapphire laser has been studied. The short electron bunches are produced by compressing the energy chirped beam from a thermionic cathode rf gun with an alpha magnet\*. These bunches have an intensity of ~0.1 nC per bunch and are accelerated to 15-30 MeV with an S-band constant gradient traveling-wave linear accelerating structure. They are then guided to the laser-beam interaction chamber and are focused for the scattering. With this method, X-ray peak photon flux as high as  $2 \times 10^{17}$  photons/sec is achievable at ~1 Å wavelength. This femtosecond X-ray source is planned to be used for studying ultrafast phenomena in nanostructure. Mean to improve average X-ray photon flux by using optical cavity to re-circulate IR laser pulses is also investigated.

The feasibility of generating sub-hundred femtosecond X-ray pulses based on inverse Compton scattering of relativistic electron pulses of 50-100 fsec with an 800 nm, 37.5

\*P. Kung, H. C. Lihn and H. Wiedemann, "Generation and Measurement of 50-fs (rms) Electron Pulses", Phys. Rev. Lett. Vol.73, p.967-970, August 1994.

### Ultra-Low Vertical Emittance at the SLS

Utilizing a large number of non-dispersive (24) and dispersive (12) skew quadrupoles the betatron coupling and the vertical spurious dispersion can be simultaneously reduced to extremely small values. As a result the achieved vertical emittance begins to approach its ultimate limit, set by the fundamental quantum nature of synchrotron radiation, which in the SLS case is  $\sim 0.55$  pm.rad. At the same time emittance measurements based on the fitting of a diffraction limited vertical photon beam from a dipole have been pushed to the limit in order to verify this ultra-low vertical emittance.

**M. Boge**, A. Luedeke, A. Streun (PSI) ? . Andersson (MAX-lab)

WE5RFP008

### Correction of Imperfections in the SLS Storage Ring Lattice

Installation of narrow gap insertion devices and operation at large positive chromaticities for suppression of coupled bunch instabilities had a negative impact on energy acceptance and beam lifetime in the SLS storage ring, because particles from Touschek scattering events were lost due to crossing resonances intersecting the beam's tune footprint. In order to suppress the resonance driveterms, 48 small corrector magnets have been installed recently as additional windings on the ring sextupoles: 12 auxiliary sextupoles and 36 skew quadrupoles, with 24 of them at zero, 12 at maximum dispersion. First, the symmetry of linear optics was restored by different methods, which we will compare. Then, based on measurements of vertical dispersion and also by empirical manipulation of skew quadrupolar and sextupolar modes of the Hamiltonian, energy acceptance and Touschek lifetime of the storage ring could be successfully restored to values in agreement with simulations for the ideal lattice. Suppression or controlled excitation of vertical dispersion allows either to achieve ultra-low vertical emittance or to increase lifetime proportional to beam height.

**A. Streun**, M. Boge, A. Luedeke (PSI)

WE5RFP009

### Low-Alpha Operation of the SLS Storage Ring

Recently tentative top-up operation of the Swiss Light Source (SLS) storage ring at low momentum compaction factor has been started. We will present an analysis of the longitudinal dynamics and simulations of the injection process, and explain our method to ensure closed orbit stability. First experimental results will be shown and compared to the model predictions.

**D. K. Kalantaryan**, G. A. Amatuni, D. Gishyan, L. M. Hovhannisyanyan (CANDLE) M. Boge, V. Schlott, A. Streun (PSI) S. T. Hakobyan (YSU)

WE5RFP010

### Characterization of MLS THz Radiation at a Dedicated Beamline

The Physikalisch-Technische Bundesanstalt (PTB), the German national metrology institute is operating the low-energy electron storage ring Metrology Light Source (MLS) in Berlin-Adlershof in close cooperation with the BESSY GmbH. The MLS is designed and prepared for a special machine optics mode (low-alpha operation mode) based on a sextupole and

**R. Muller**, A. Bawagan, A. Hoehl, R. Klein, G. Ulm (PTB) J. Feikes, M. V. Hartrott, U. Schade, G. Wuestefeld (Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Elektronen-Speicherring BESSY II)

WE5RFP011

octupole correction scheme, for the production of coherent synchrotron radiation in the FIR and THz region. At the MLS two bending magnet beamlines dedicated to the use of IR and THz synchrotron radiation were built. An IR beamline optimized for the MIR to FIR is now in operation. First measurements at this beamline showed the potential of the MLS as a source of THz radiation\*. However, the propagation of sub-terahertz electromagnetic waves from the source point to the experiment through such a typical IR beamline is strongly affected by diffraction. This is why we decided to build a dedicated THz beamline with larger extraction optics. We present first results from the commissioning of the dedicated THz beamline.

\*R. Müller et al., Proc. of EPAC08, 2058 (2008)

### Analysis of the Orbit Response Matrix and Correction of Beta Function at the SAGA Light Source

Y. Iwasaki, T. Kaneyasu, S. Koda, Y. Takabayashi (SAGA) H. Ohgaki (Kyoto IAE)

The procedure of accelerator modeling using orbit response matrix fitting is well known and widely adopted at many light sources, we also examined the model fitting

to diagnose optics and to restore the periodicity of the storage ring optics. In the modeling procedure we used the tracking code TRACY2, because it can calculate the orbit response matrix including energy offset caused by the dipole kick. The multi-parameter fitting was carried out by using SVD algorithm implemented in the Labview mathematical package. In the fitting procedure, we fixed a steering magnet field to the value obtained from the orbit measurement using screen monitor to avoid explicit solution between the steering strengths and the BPM gains. By adopting the orbit response matrix fitting, it was found that the quadrupole strength is about 3-5% larger than the calculated value obtained from magnetic measurement data and output current of the power supply. In the conference, we will report on the result of the modeling procedure and its application to the optics correction.

### Linear Coupling Measurement and Control at the SAGA Light Source

Y. Iwasaki, T. Kaneyasu, S. Koda, Y. Takabayashi (SAGA)

Linear transverse coupling parameter in the SAGA Light Source storage ring has been measured by closest approach of the beta-

tron tunes to the difference resonance. The coupling was 1.1% constant at nominal working point without skew correction. For controlling the coupling constant, the auxiliary coil circuits for horizontal and vertical orbit corrections equipped inside the sextupole were changed to produce skew quadrupole field. Prior to this modification, we investigated the magnetic properties of the skew quadrupole magnet by harmonic analysis using Poisson 2D code, and the influence to the dynamic aperture of the storage ring by using tracing code TRACY2. It was found that the single skew quadrupole magnet has field strength of 2.4 T/m at maximum current of 25 A. The skew magnet allows us to control the coupling constant up to 68% at nominal working point. The coupling constant was well controlled by the skew magnet, but the field strength was 44% larger than that obtained in the 2D magnetic analysis. In the conference, we will report on the coupling control by the skew magnet and its influence to dynamic aperture, beam lifetime and beam size.

### Present Status of Synchrotron Radiation Facility SAGA-LS

SAGA Light Source (SAGA-LS) is a 1.4 GeV synchrotron light source consisting of an injector linac and a storage ring of 75.6 m circumference. The SAGA-LS has been routinely operated with low emittance of 25 nm-rad since its official opening in February 2006. Machine improvements, including upgrades on the control system and grid pulsar for the injector linac, construction of a new septum magnet and beam monitor systems, and current increase from 100 to 200 mA, have been made in the past years. Along with the accelerator improvements, installation and development of new insertion devices have started. The SAGA-LS ring has six 2.5-m long straight sections available for insertion devices. A planar type undulator of Saga University is in operation. In addition, an APPL-10<sup>-2</sup> type undulator producing variably polarized light has been installed during the winter shutdown of 2008. In order to address user demand for high flux hard x-rays, design of a superconducting wiggler is under discussion. Construction of an experimental setup to produce MeV photons by the laser Compton scattering is in progress, preparing for precise beam energy measurement and user experiments in future.

**T. Kaneyasu**, Y. Iwasaki, S. Koda, Y. Takabayashi (SAGA)

### Concepts for the PEP-X Light Source

SSRL and SLAC groups are developing a long-range plan to transfer its evolving scientific programs from the SPEAR3 light source to a much higher performing photon source that would be housed in the 2.2-km PEP-II tunnel. While various concepts for the PEP-X light source are under consideration, including ultimate storage ring and ERL configurations, the present baseline design is a very low-emittance storage ring. A hybrid lattice has DBA or QBA cells in two of the six arcs that provide a total ~30 straight sections for ID beam lines extending into two new experimental halls. The remaining arcs contain TME cells. Using ~100 m of damping wigglers the horizontal emittance at 4.5 GeV would be ~0.1 nm-rad with >1 A stored beam. PEP-X will produce photon beams having brightnesses near 10<sup>22</sup> at 10 keV. Studies indicate that a ~100-m undulator could have FEL gain and brightness enhancement at soft x-ray wavelengths with the stored beam. Crab cavities or other beam manipulation systems could be used to reduce bunch length or otherwise enhance photon emission properties. The present status of the PEP-X lattice and beam line designs are presented and other implementation options are discussed.

**R. O. Hettel**, K. L.F. Bane, K. J. Bertsche, Y. Cai, V. A. Dolgashov, J. D. Fox, X. Huang, Z. Huang, T. Mastorides, C.-K. Ng, Y. Nosochkov, A. Novokhatski, T. Rabedeau, C. H. Rivetta, J. A. Safranek, J. Seeman, J. Stohr, G. V. Stupakov, S. G. Tantawi, L. Wang, M.-H. Wang, U. Wienands, L. Xiao (SLAC) I. Lindau (Stanford University) C. Pellegrini (UCLA)

### Short Bunch Measurements in SPEAR3

Recent experimental results and advances in the theory of short-bunch dynamics have lead to an improved understanding of the parameters and limitations of short-bunch operation in storage rings. In this paper the measurement and analysis of short bunches under a variety of operational parameters is reported for SPEAR3.

**W. J. Corbett**, X. Huang (SLAC) W. X. Cheng (BNL)

**Prospect of an IR or THz Beamline at SSRL**

X. Huang, J. A. Safranek (SLAC)

A preliminary plan for an infrared or terahertz beamline at SSRL is studied. Using chicane in a straight section allows us to re-design a section of the vacuum chamber and extract infrared/terahertz beam with a large acceptance. Under the low alpha operational mode, the terahertz beam power can be greatly enhanced by the coherent synchrotron radiation (CSR) effect. Calculations of photon beam flux and brightness and the shielding and CSR effects are presented.

A preliminary plan for an infrared or terahertz beamline at SSRL is studied. Using chicane in a straight section allows us to re-

**Further Reduction of Beam Emittance of PEP-X Using Quadruple Bend Achromat Cell**

M.-H. Wang, Y. Cai, Y. Nosochkov (SLAC)

SLAC National Accelerator Laboratory is studying an option of building a high brightness synchrotron light source machine, PEP-X, in the existing PEP-II tunnel<sup>\*,\*\*</sup>. By replacing 6 arcs of FODO cells of PEP-II High Energy Ring (HER) with two arcs of DBA and four arcs of TME and installation of 89.3 m long damping wiggler an ultra low beam emittance of 0.14 nm-rad (including intra-beam scattering) at 4.5 GeV is achieved. In this paper we study the possibility to further reduce the beam emittance by releasing the constraint of the dispersion free in the DBA straight. The QBA (Quadruple Bend Achromat) cell is used to replace the DBA. The ratio of outer and inner bending angle is optimized. The dispersion function in the non-dispersion straight is controlled to compromise with lower emittance and beam size at the dispersion straight. An undulator of period length 23 mm, maximum magnetic field of 1.053 T, and total periods of 150 is used to put in the 30 straights to simulate the effects of these IDs on the beam emittance and energy spread. The brightness including all the ID effects is calculated and compared to the original PEP-X design.

SLAC National Accelerator Laboratory is studying an option of building a high brightness synchrotron light source machine,

\*R. Hettel et al., "Ideas for a Future PEP-X Light Source", EPAC08, p.2031(2008).

\*\*M-H Wang et al., "Lattice Design of PEP-X as a Light Source Machine at SLAC", EPAC08, p.2127(2008).

**Deformation and Thermal Analysis for SSRF Septum Magnets**

L. Ouyang, M. Gu, B. Liu (SINAP)

Special attentions were paid to coils and their supports design, because the coils are made of OFHC coppers which are prone to accumulate plastic deformation by the magnetic shock force on them. On the process of optimization, LS-DYNA FEM was used to simulate the large deformation for coils which will cause the deformation. At the same time, ANSYS thermal-electric coupled field analysis was carried out to model the heat and temperature distribution on the coils and their supports.

There are 6 in-vacuum eddy current septum magnets used for Booster injection, extraction, and Storage Ring injection in SSRF.

**Operational Advances at Elettra and its New Full Energy Injector**

E. Karantzoulis, A. Carniel, S. Krecic (ELETTRA)

A full energy injector consisting of a 100 MeV linac and an up to 2.5 GeV booster is in operation since March 2008 replacing the previous 1 GeV linac injector to be used after refurbishing and upgrade for the new fourth generation light source (FEL) currently under construction at Sincrotrone Trieste. The measurements on the new injector, problems and

A full energy injector consisting of a 100 MeV linac and an up to 2.5 GeV booster is in operation since March 2008 replacing the



solutions employed to increase its efficiency, reproducibility and reliability, aiming towards top-up operations in the near future, and its impact on the Elettra storage ring are presented and discussed.

### Operation and Performance of the SOLEIL Storage Ring

After two years of operation, the SOLEIL 3rd generation synchrotron light source is delivering photons to 20 beamlines with a current of 250mA in multibunch or hybrid modes, and 60 mA in 8 bunch mode. The radiation control of the beamline hutch is performed at 300 mA, but recently a 455mA current was stored during machine tests following the installation of the second RF cryomodule. It is foreseen to reach the maximum current of 500mA in the early 2009 and to operate in top-up mode from then on. The new transverse feedback loop has enabled to improve the performance of the single bunch and multibunch beams. The beam position stability is in the range of few micrometers thanks to the efficiency of the fast orbit feedback. Fifteen insertion devices are now installed in the storage ring, ten others are under construction, and a cryogenic undulator is under development. A big effort is being taken in order to compensate the effects of these insertion devices on the machine performance. The good operation performance achieved in 2007 (first year) has been improved in 2008 during which ~4 000 hours will have been delivered to the users with a 95.5% availability and a 30 hours MTBF.

**J.-M. Filhol**, J. C. Besson, P. Brunelle, L. Cassinari, M.-E. Couprie, J. Denard, C. Herbeaux, N. Hubert, J.-F. Lamarre, J.-P. Lavieville, P. Lebasque, M.-P. Level, A. Loulergue, P. Marchand, A. Nadji, L. S. Nadolski, R. Nagaoka, M.-A. Tordeux (SOLEIL)

WE5RFP021

### General Status of SESAME

SESAME is a 3rd generation synchrotron light source facility under construction in Allan, Jordan, 30 km North-West of Amman. SESAME consists of a 2.5 GeV storage ring, a 22.5 MeV Microtron and an 800 MeV Booster. The Microtron was installed at its final position and its subsystems have been successfully tested. The commissioning with beam of the Microtron will start in March 2009. The installation of the Booster is expected to take place in summer 2009. Most of the storage ring subsystems are ready for call for tender. The progress of SESAME project including beamlines status will be reported in this paper.

**A. Nadji** (SOLEIL)

WE5RFP022

### Status of UVSOR-II and Light Source Developments

UVSOR, a 750 MeV synchrotron light source of 53m circumference, had been operated for more than 20 years. After a major upgrade in 2003, this machine was renamed to UVSOR-II. The ring is now routinely operated with low emittance of 27 nm-rad and with four undulators. The test run of the top up injection has been started. The latest result will be reported. By utilizing a part of the existing FEL system and an ultra-short laser system, coherent synchrotron radiation and coherent harmonic generation have been extensively studied, under international collaborations. A new program on the coherent light source developments has been started, which includes upgrades of the undulator and the laser system and a construction of dedicated beam-lines.

**M. Adachi**, K. Hayashi, M. Katoh, J. Yamazaki (UVSOR) M. Hosaka, Y. Takashima, N. Yamamoto (Nagoya University) T. Tanikawa (Sokendai)

WE5RFP023

WE5RFP024

### HALS: Our Future Light Source in NSRL

L. Wang, G. Feng, W. Li, L. Liu, S. C. Zhang (USTC/NSRL)

Hefei Light Source is a second generation VUV light source, whose performance cannot meet the requirements of synchrotron radiation users at the present time. One year ago, the concept of the Hefei Advanced Light Source, whose main features are ultra low beam emittance and high brilliance in VUV and soft X-ray range, was brought forward. In the preliminary design study, a medium scale storage ring and multi bend achromat focusing structure were adopted to achieve beam emittance lower than 0.2 nm.rad. Linear and nonlinear parameter optimizations were performed to obtain large on-momentum and off-momentum dynamic aperture. The design status will be introduced briefly in the presentation.

Hefei Light Source is a second generation VUV light source, whose performance cannot meet the requirements of synchrotron radiation users at the present time.

WE5RFP025

### The Design Consideration of Full Energy Booster of HALS

L. Wang, G. Feng, W. Li, L. Liu, S. C. Zhang (USTC/NSRL)

Hefei Advanced Light Source is proposed advanced VUV and soft X-ray light source in NSRL. The main body of HALS is a ultra low emittance storage ring, whose dynamic aperture was severely limited by strong nonlinear effects. While the top-off operation is only measure to fight the poor beam lifetime in HALS, high injection efficiency is important issue in physical design. To obtain comfortable performance of injection, the low emittance full energy booster was needed. In the design stage, schemes of independent booster and booster in same tunnel of storage ring were considered and evaluated. The design consideration was presented in this paper.

Hefei Advanced Light Source is proposed advanced VUV and soft X-ray light source in NSRL. The main body of HALS is a ultra low emittance storage ring, whose dynamic aperture was severely limited by strong nonlinear effects.

WE5RFP026

### Impedance Budget for Hefei Advanced Light Source

W. Xu, L. Wang (USTC/NSRL)

Hefei Advanced Light Source (HALS) has been proposed by and will be built in National Synchrotron Radiation Laboratory (NSRL). HALS is a storage ring with high brightness, ultra-low emittance less than 0.2nmrad at the energy of 1.5GeV. In this paper, we present the preliminary calculation of wakes and impedances produced by various components of the storage ring. The potential well distortion and current threshold due to longitudinal microwave instability will be estimated in the end.

Hefei Advanced Light Source (HALS) has been proposed by and will be built in National Synchrotron Radiation Laboratory (NSRL). HALS is a storage ring with high brightness, ultra-low emittance less than 0.2nmrad at the energy of 1.5GeV.

WE5RFP027

### Simulation of Hefei Advanced Light Source (HALS) Injection System

S. C. Zhang (USTC/NSRL)

Hefei Advanced Light Source(HALS) is a super low emittance storage ring and has a very poor beam life time. In order to run the ring stably, Top-up injection will be necessary. Injection system will greatly affect the quality of beam. This article first give a physics design of injecting system. Then the injecting system is tracked under different errors. The responses of storage beam and injecting beam is given in the article.

Hefei Advanced Light Source(HALS) is a super low emittance storage ring and has a very poor beam life time. In order to run the ring stably, Top-up injection will be necessary.

**Coherent Soft X-Ray Generation in the Water Window with the EEHG Scheme**

Recently Stupakov\* has suggested a scheme entitled echo-enabled harmonic generation (EEHG) for producing short wavelength FEL radiation that allows far higher harmonic numbers to be accessed as compared with the normal limit arising from incoherent energy spread. We have studied the feasibility of a single EEHG stage to generate coherent radiation in the "water window" (2- 4 nm wavelength) directly from a UV seed laser at ~200-nm wavelength. By adjusting the temporal overlap region of the two lasers producing energy modulation in the EEHG scheme, we find it may be possible to vary the duration of the output coherent soft x-ray pulse. We present time-dependent simulation results which explore these ideas and also examine the sensitivity of the scheme to various input electron beam parameters.

\*G. Stupakov, Preprint SLAC-PUB-13445

D. Xiang, G. V. Stupakov (SLAC) W. M. Fawley (LBNL)

WE5RFP028

**Full Electromagnetic Simulation of Free-Electron Laser Amplifier Physics via the Lorentz-Boosted Frame Approach**

Recently\* it has been pointed out that numerical simulation of some systems containing charged particles with highly relativistic directed motion can be speeded up by orders of magnitude by choice of the proper Lorentz boosted frame. A particularly good example is that of short wavelength free-electron lasers (FELs) in which a high energy electron beam interacts with a static magnetic undulator. In the optimal boost frame with Lorentz factor  $\gamma_F$ , the red-shifted FEL radiation and blue shifted undulator have identical wavelengths and the number of required time-steps (presuming the Courant condition applies) decreases by a factor of  $\gamma_F$ -squared for fully electromagnetic simulation. We have adapted the WARP code\*\* to apply this method to several FEL problems including coherent spontaneous emission (CSE) from pre-bunched e-beams, radiation in multi-wavelength undulators, and the effective lengths of undulators with entrance and exit matching ramps. We also discuss some preliminary results from applying the boosted-frame method to Coherent Synchrotron Radiation calculations.

\*J.-L. Vay Phys. Rev. Lett. 98, 130405 (2007)

\*\*D. P. Grote, A. Friedman, J.-L. Vay, and I. Haber, AIP Conf. Proc., 749, 55 (2005).

W. M. Fawley, J.-L. Vay (LBNL)

WE5RFP029

**Development of a Precision Tunable Gamma-Ray Source Driven by a Compact X-Band Linac**

A precision, tunable gamma-ray source driven by a compact, high-gradient X-band linac is under development at LLNL. High-brightness, relativistic electron bunches produced by the linac interact with a Joule-class, 10 ps laser pulse to generate tunable gamma-rays in the 0.5-2.5 MeV photon energy range via Compton scattering. The source will be used to excite nuclear resonance fluorescence lines in various isotopes; applications include homeland security, stockpile science and surveillance, nuclear fuel assay, and waste imaging and assay. The source design, key parameters, and current status will be presented.

F. V. Hartemann, F. Albert, S. G. Anderson, C. P.J. Barty, D. J. Gibson, M. J. Messerly, M. Shverdin, C. Siders (LLNL) V. A. Semenov (UCB)

WE5RFP030

**Dynamics of Seeded Free Electron Laser Harmonic Cascades**

W. Graves (MIT)

Harmonic cascade FELs amplify and upconvert the coherent radiation from a seed laser to a higher photon energy by manipulating electron dynamics in an undulator. There are a variety of ways to achieve this, for example by choosing particular harmonic ratios, by controlling exponential FEL gain in intermediate stages, by different combinations of electron beam energy, undulator period, and field strength parameter, or by using a fresh-bunch approach or not. In this work several of the alternatives are reviewed, and a method is chosen that provides stable output for a large harmonic ratio and low noise amplification while requiring modest electron beam parameters.

**Design of the Wisconsin FEL Seeded Soft X-Ray FEL Undulator Lines**

W. Graves, F. X. Kaertner, D. E. Moncton (MIT) J. Bisognano, M. Bissen, R. A. Bosch, M. A. Green, K. Jacobs, K. J. Kleman, R. A. Legg, R. Reininger (UW-Madison/SRC)

The seeded FEL performance of a number of Wisconsin FEL (WiFEL) undulator lines is described. The experimental design requirements include coverage of a broad wavelength range, rapid wavelength tuning, variable polarization, and variable pulse energy. The beam parameters allow experiments ranging from those requiring low peak power with high average spectral flux to those that need high peak power and short pulse lengths in the femtosecond range. The FELs must also be stable in timing, power, and energy while satisfying constraints on electron beam quality and fluctuations, undulator technologies, and seed laser capabilities. Modeling results are presented that illustrate the design performance over the full wavelength range of the facility.

**Consideration for NILPRP Free Electron Laser Project**

F. Scarlat, E. S. Badita, G. Georgescu, R. Medianu, E. Mitru, M. Oane, A. M. Scarisoreanu (INFLPR) V. Babin, E. Carstea, I. S. Dontu, S. Miclos, C. M. Radu, E. Ristici, M. I. Rusu, D. Savastru, M. Tautan (Mustata) (INOE 2000) A. Dafinei, M. R. Leonovici (Bucharest University, Faculty of Physics)

NILPRP FEL project consists of five subsystems: RF injector, compressor, linear accelerator, seeded laser and an optical klystron which in its turn, is consisting of two identical undulators separated by a dispersion section. Starting from the final values for the 1 GeV energy beam electron, the 1 kA beam current electron and the 250 nm wavelength seeded laser, this paper presents the calculation results for each subsystem in the seeded coherent harmonics generation scheme, for to obtain FEL radiation in VUV range in the first stage. This calculation considered the possibility to obtain, in the second stage, FEL radiation in X soft range. Also, different beamlines for several applications, e.g. neutrons, positrons, high energy photons are presented.

**Drive Laser System for the NSRRC Photoinjector**

C. S. Chou, W. K. Lau, A. P. Lee, C. C. Liang (NSRRC) N. Y. Huang, W. K. Luo (NTHU)

A 266nm ultra-violet laser system has been installed as the drive laser of the NSRRC photoinjector. According to beam dynamic studies for the photoinjector, a 10ps uniform cylindrical beam will be generated at the Cu cathode to reduce emittance growth due to space charge and transverse RF fields in the photoinjector cavity. The main part of this system is diode laser pumped, 798nm regenerative IR

amplifier that can provide 85fs pulse at 3.85mJ pulse energy. The conversion of frequency from IR to 266nm UV is achieved by a third harmonic generator. UV output pulse energy exceeds 300uJ. Synchronization between seed laser and the high power microwave system can be better than 1ps. In order to produce a uniform cylindrical beam for emittance reduction in the photoinjector, a refractive UV beam shape and a pulse stacking temporal beam shape are being implemented.

### Desktop, 20-MW Superradiance FEL at THz Frequencies

We study the generation of THz electron pulse trains from a 6 MeV photocathode electron gun driven by a beat-wave laser

Y.-C. Huang, C. H. Chen (NTHU) W. K. Lau (NSRRC)

with a variable beat frequency [1]. We numerically inject the electrons into a single-pass FEL undulator. Owing to the prebunched electron pulse train, the quick shoot-up of the FEL power overcomes the space-charge debunching force in the 6 MeV beam. With nominal beam parameters and an initial bunching factor >5%, the FEL can reach 20-MW saturation power at 6 THz in a half meter long undulator. The length of this 20MW THz FEL, from the beginning of the electron gun to the end of the wiggler, is less than a meter. We will report our experimental progress of this work in the conference.

[1] Yen-Chieh Huang, "Laser-beat-wave bunched beam for compact superradiance sources," International Journal of Modern Physics B, Vol. 21 Issue 3/4, p277-286 (2007).

### The PKU Terahertz Facility at Peking University

The PKU Terahertz facility (PTF) is planned as a compact, high power Terahertz user facility based on the coherent undulator radiation concept and the superconducting radiofrequency technology for the linear accelerator.

K. Yu, S. W. Quan, W. Xu, K. Zhao, F. Zhu, J. Zhuang (PKU/IHIP)

By utilizing a 3.5-cell DC-SC (DC-Superconducting) photoinjector, the PTF will provide high average power, coherent terahertz radiation with quasi-monochromaticity and wavelength tunable between 400um ~ 1200um, serving as a powerful tool for frontier researches and practical applications in the THz realm. Key components of the 3.5-cell DC-SC photoinjector have been prepared and the beamline is under construction. In this paper, the technical layout of the injector and the conceptual design of the PTF will be presented.

### A Simple Longitudinal Phase Space Diagnostic

For proper operation of the LCLS x-ray free-electron laser, measurement and control of the electron bunch longitudinal phase space

K. J. Bertsche, P. Emma (SLAC) O. A. Shevchenko (BINP SB RAS)

is critical. The LCLS accelerator includes two bunch compressor chicanes to magnify the peak current. These magnetic chicanes can generate significant coherent synchrotron radiation (CSR), which can distort the phase space distribution. We propose a diagnostic scheme by exciting a weak skew quadrupole at an energy-chirped, high dispersion point in the first bunch compressor (BC1) to reconstruct longitudinal phase space on an OTR screen after BC1, allowing a detailed characterization of the CSR effects.

**Improving Beam Stability in the LCLS Linac**

F.-J. Decker, R. Akre, A. Brachmann, W. S. Colocho, Y. T. Ding, D. Dowell, P. Emma, J. C. Frisch, A. Gilevich, G. R. Hays, P. Hering, Z. Huang, R. H. Iverson, K. D. Kotturi, A. Krasnykh, H. Loos, A. Miahnahri, H.-D. Nuhn, D. F. Ratner, J. L. Turner, J. J. Welch, W. E. White, J. Wu (SLAC)

The beam stability for the Linac Coherent Light Source (LCLS) at SLAC is important for good X-Ray operation. Although most of the jitter tolerances are met, there is always room for improvement. Besides the short term pulse-to-pulse jitter, we will also discuss oscillation sources of longer time

cycles from seconds (feedbacks), to minutes (cooling systems), and up to the 24 hours caused by the day-night temperature variations.

**Characterisation and Reduction of Transverse RF Kicks in the LCLS Linac**

F.-J. Decker, R. Akre, K. J. Bertsche, A. Brachmann, W. S. Colocho, Y. T. Ding, D. Dowell, P. Emma, J. C. Frisch, A. Gilevich, G. R. Hays, P. Hering, Z. Huang, R. H. Iverson, A. Krasnykh, H. Loos, H.-D. Nuhn, D. F. Ratner, H. Smith, J. L. Turner, J. J. Welch, W. E. White, J. Wu (SLAC)

The electron beam for the Linac Coherent Light Source (LCLS) at SLAC is accelerated by disk-loaded RF structures over a length of 1 km. The mainly longitudinal field can sometimes exhibit transverse components, which kick the beam in x and/or y. This is normally a stable situation, but when a

klystron, which powers some of these structures, has to be switched off and another one switched on, different kicks can lead to quite a different orbit. Some klystrons, configured in an energy and bunch length feedback, caused orbit changes of up to 1 mm, which is about 20 times the sigma beam size. The origins and measurements of these kicks and some efforts (orbit bumps) to reduce them will be discussed.

**Start-to-End Simulations of the LCLS Accelerator and FEL Performance at Very Low Charge**

Y. T. Ding, A. Brachmann, F.-J. Decker, D. Dowell, P. Emma, J. C. Frisch, A. Gilevich, G. R. Hays, P. Hering, Z. Huang, R. H. Iverson, H. Loos, A. Miahnahri, H.-D. Nuhn, D. F. Ratner, J. L. Turner, J. J. Welch, W. E. White, J. Wu (SLAC) C. Pellegrini (UCLA)

The Linac Coherent Light Source (LCLS) is an x-ray Free-electron Laser (FEL) being commissioned at SLAC. Recent beam measurements have shown that, using the LCLS injector-linac-compressors, the beam emittance is very small at 20 pC\*. A similar low

charge operation mode was also suggested and studied\*\*. In this paper we perform start-to-end simulations of the entire accelerator including the FEL undulator and study the FEL performance versus the bunch charge. At 20 pC charge, these calculations associated with the measured beam parameters suggest the possibility of generating a longitudinally coherent single x-ray spike with 2-femtosecond duration at a wavelength of 1.5 nm. At ~100 pC charge level, our simulations show an x-ray pulse with 20 femtosecond duration and up to 1012 photons at a wavelength of 1.5 Å. These results open exciting possibilities for ultrafast science and single shot molecular imaging.

\*A. Brachmann et. al., to be published.

\*\*J. Rosenzweig et al., Nuclear Instr. and Meth. A 593, 39-44 (2008); S. Reiche et al., Nucl. Instr. And Meth. A 593, 45-48 (2008).

### First Results of the LCLS Laser-Heater System

The Linac Coherent Light Source (LCLS) is an x-ray Free-Electron Laser (FEL) project presently in a commissioning phase at SLAC. The very bright electron beam required for the FEL is also susceptible to a micro-bunching instability\* in the magnetic bunch compressors, prior to the FEL undulator.

The uncorrelated electron energy spread can be increased by an order of magnitude to provide strong Landau damping against the instability without degrading the free-electron laser performance. To this end, a 'laser-heater' system has been installed in the LCLS injector, which modulates the energy of a 135-MeV electron bunch with an IR laser beam in a short undulator, enclosed within a four-dipole chicane. The last half of the chicane time-smears the energy modulation leaving an effective thermal energy spread increase. We present the first commissioning results of this system, its operational issues, and its impact on the micro-bunching instability.

\*Z. Huang et. al., Phys. Rev. ST Accel. Beams 7, 074401 (2004).

**P. Emma**, R. F. Boyce, A. Brachmann, R. Carr, F.-J. Decker, Y. T. Ding, D. Dowell, S. A. Edstrom, J. C. Frisch, A. Gilevich, G. R. Hays, P. Hering, Z. Huang, R. H. Iverson, Yu. I. Levashov, H. Loos, A. Miahnahri, H.-D. Nuhn, B. D. Poling, D. F. Ratner, J. L. Turner, J. J. Welch, W. E. White, Z. R. Wolf, J. Wu (SLAC)

### Polarization Analysis of Nonlinear Harmonic Radiation in a Crossed-Planar Undulator

There is a growing interest in producing intense, coherent x-ray radiation with an adjustable and arbitrary polarization state.

The crossed-planar undulator\* was first proposed by Kim for rapid polarization control in synchrotron radiation and free electron laser (FEL). Recently, a statistical analysis shows a degree of polarization over 80% is obtainable for a SASE FEL near saturation\*\*. In such a scheme, nonlinear harmonic radiation is generated in each undulator and its polarization is controllable in the same manner. In this paper, we study the degree of polarization for the nonlinear harmonic radiation. We also discuss methods to reduce the FEL power fluctuations by operating the crossed undulator in the saturation regime.

\*K.-J. Kim, Nucl. Instrum. Methods A 445, 329 (2000)

\*\*Y. Ding and Z. Huang, Phys. Rev. ST Accel. Beams 11, 030702 (2008)

**H. Geng**, Y. T. Ding, Z. Huang (SLAC) **H. Geng** (USTC/NSRL)

### Optics Design for a Soft X-Ray FEL at the SLAC A-Line

LCLS capabilities can be significantly extended with a second undulator aiming at the soft x-ray spectrum (1- 5 nm). To allow for simultaneous hard and soft x-ray operations,

14 GeV beams at the end of the LCLS accelerator can be intermittently switched into the SLAC A-line (the beam transport line to End Station A) where the second undulator may be located. In this paper, we discuss the A-line optics design for transporting the high-brightness LCLS beams using the existing tunnel. To preserve the high brightness of the LCLS beams, special attentions are paid to effects of incoherent and coherent synchrotron radiation. Start-to-end simulations using realistic LCLS beam distributions are carried out.

**H. Geng**, Y. T. Ding, P. Emma, Z. Huang, Y. Nosochkov, M. Woodley (SLAC)

**Tolerance Study for the Echo-Enabled Harmonic Generation Free Electron Laser**

D. Xiang, G. V. Stupakov (SLAC)

The echo-enabled harmonic generation free electron laser (EEHG FEL) holds great promise in generation of coherent soft x-ray directly from a UV seed laser within one stage. The density modulation in the harmonic generation process is affected by the smearing effect caused by the fluctuations of energy and current along the beam, as well as the field error of the dispersive elements. In this paper we study the tolerance of the EEHG FEL on beam quality and field quality.

The echo-enabled harmonic generation free electron laser (EEHG FEL) holds great promise in generation of coherent soft x-ray

**Microbunching Instability in Velocity Bunching**

D. Xiang, J. Wu (SLAC)

Microbunching instability is one of the most challenging threats to FEL performances. The most effective way to suppress microbunching instability is to increase the relative slice energy spread of the beam. In this paper we show that the velocity bunching inherently mitigates the microbunching instability. PARMELA simulation indicates that the initial current modulations are suppressed in velocity bunching process, which may be attributed to the strong Landau damping from the relatively large relative slice energy spread.

Microbunching instability is one of the most challenging threats to FEL performances. The most effective way to suppress mi-

**Peak Current, Energy, and Trajectory Regulation and Feedback for the LCLS Electron Bunch**

J. Wu, R. Akre, A. Brachmann, P. Chu, F.-J. Decker, Y. T. Ding, D. Dowell, S. A. Edstrom, P. Emma, D. Fairley, J. C. Frisch, A. Gilevich, G. R. Hays, P. Hering, Z. Huang, R. H. Iverson, H. Loos, A. Miahnahri, H.-D. Nuhn, D. F. Ratner, J. L. Turner, J. J. Welch, W. E. White (SLAC)

The Linac Coherent Light Source is an x-ray Free-Electron Laser (FEL) project being commissioned at SLAC. The very bright electron beam required for the FEL is subjected to various sources of jitter along the accelerator. The peak current, centroid energy, and trajectory of the electron bunch are controlled precisely at the highest repetition rate possible with feedback systems. We report commissioning experience for these systems. In particular, there is high frequency content in the electron bunch current spectrum, and we report its impact on the systems. Due to the coupling of the betatron motion and the dispersion component of the electron trajectory, a fast in-line model\* is incorporated. For the longitudinal feedback, we report the performance of two different configurations: one with RF system as direct actuators, which are nonlinear, and the other with artificially formed linear energy and energy-chirp actuators. Since the electron bunch is compressed to a final peak current of 2 to 3 kA, coherent synchrotron radiation and other wakefields are included for precise control of the electron bunch parameters. Machine performance is compared to start-to-end simulations.

The Linac Coherent Light Source is an x-ray Free-Electron Laser (FEL) project being commissioned at SLAC. The very bright electron beam required for the FEL is subjected to various sources of jitter along the accelerator. The peak current, centroid energy, and trajectory of the electron bunch are controlled

\*P. Chu et al., these PAC09 proceedings



### Simulations of a Recirculating Superconducting FEL Driver

We explore a design for a free-electron laser driver which utilises 1.3 GHz CW accelerating structures to deliver longitudinally compressed electron bunches with repetition rates potentially up to 1 MHz. A 200 pC bunch is tracked from a normal conducting RF photocathode gun and compressed in two stages to approximately 200 fs RMS bunch length with a final energy of 2.2 GeV. This is achieved through injection at 200 MeV, then two-pass recirculation in a 1 GeV main linac. A relatively long final bunch length is chosen to allow reasonable jitter tolerances for seeding in the FEL. We discuss start-to-end modelling of this system, including the limitations from coherent radiation emission in compressors and arcs.

P. H. Williams, D. Angal-Kalinin, J. K. Jones, B. D. Muratori (STFC/DL/ASTeC) H. L. Owen (UMAN)

WE5RFP047

### The Use of Phase Shifters for Optimizing Free Electron Lasers

In single-pass FELs, for the amplification process to be effective, it is necessary to compensate the phase advance of photons with respect to electrons in the break region between undulators. In fact, most of the FELs are based on the use of phase shifters between different undulator sections in order to allow the control of the relative phase advance. In this work we present different methods in which the use of phase shifters can be useful for a further improvement of the FEL performance.

E. Allaria (ELETTRA) G. De Ninno (University of Nova Gorica)

WE5RFP048

### Extending the FERMI FEL2 towards Shortest Wavelengths

The second FEL line of the FERMI project was originally designed for providing long optical pulses (about 1ps) in the spectral range between 40 and 10 nm. Recent developments of both the FERMI scientific case and of new possible configurations of the FERMI linac stimulated a revision of the original setup in order to exploit new possibilities and fulfill requirements. In this work we deeply investigated the most relevant FEL configurations that may be implemented for the FERMI FEL2, showing that a revision of the original double-cascade high-gain harmonic generation is the most promising. According to numerical simulations, using the electron-beam parameters expected from the FERMI linac, the spectral range for FEL2 can now be extended down to 5 nm, and a significant amount of power can be produced also in the 1-nm spectral range. Moreover, the proposed setup is flexible enough for exploiting future developments of new seeding sources like HHG in gases.

E. Allaria (ELETTRA) G. De Ninno (University of Nova Gorica)

WE5RFP049

### The X-Band System for the FERMI@ELETTRA FEL Project

The single pass FEL facility FERMI@ELETTRA, in construction at the ELETTRA laboratory in Trieste, foresees very short electron bunches with a very high beam quality at the entrance of the undulator chain. The machine layout foresees the installation of an X-band 4th harmonic accelerating section before the first bunch compressor, to linearize the longitudinal phase space thus reducing the effects of Coherent Synchrotron Radiation (CSR) in the compressor. Here an overall description of the X-band system and the ongoing activities are reported.

G. D'Auria (ELETTRA)

WE5RFP050

## Dark Current Suppression at XFEL/SPring-8 by Using the Combination of Sextupole Magnets with a Small Magnetic Chicane

H. Tanaka, T. Hara, H. Kitamura, N. Kumagai, K. Togawa (RIKEN/SPring-8)

The compact XFEL facility under construction in the SPring-8 campus aims at generation of SASE based XFEL at the wavelength of  $\sim 0.1$  nm in 2010. Toward the smooth completion of the beam commissioning and achieving the reliable SASE XFEL operation, it is critically important to suppress the dark current upstream of the accelerator as much as possible. We thus investigated a removal scheme of the spatially diverged and energy deviated electrons forming the dark current by using sextupole magnets, which are installed over the C-band accelerating structures. The beam simulation showed that the combination of the distributed sextupole magnets with a small chicane, which locates in the adequate middle of the C-band accelerating structures, could efficiently remove the dark current emitted from the C-band acceleration structures. Here, we present the simulation results and the dark current suppression scheme designed for the compact XFEL facility at SPring-8.

The compact XFEL facility under construction in the SPring-8 campus aims at generation of SASE based XFEL at the wavelength of  $\sim 0.1$  nm in 2010. Toward the smooth

## Development of Accelerator Based THz Sources at Tohoku University

H. Hama, F. Hinode, M. Kawai, K. Nanbu, M. Yasuda (Tohoku University, School of Science)

We have developed an independently-tunable-cells (ITC) RF gun consisted with two cavities and thermionic cathode in order to produce bunch length around a hundred femto-second. Possibility of pre-bunched FEL is investigated by numerical simulations. In case of the bunch length shorter than wavelength, the FEL interaction seems to be different from conventional way. High intensity and short FEL pulse is possibly obtained\*. In a broad band regime, coherent spontaneous THz radiation is progressed. A ring type source consisted with isochronous arcs can provide the coherent THz pulses from every bending magnets. The project has aimed multi-user facility\*\*. In addition, a compact DC gun is also under development. Measured normalized emittance is less than  $1\mu\text{rad}$  for a beam energy of 50 keV and a beam current of 300 mA. This low emittance beam is quite suitable for driving Smith-Purcell Backward Wave Oscillator FEL in THz region. Detail of the DC gun and prospect will be presented\*\*\*.

To develop a coherent Terahertz (THz) light sources, producing very short electron bunch has been progressed at Laboratory of Nuclear Science, Tohoku University. We

\*M. Yasuda et al., Proc. FEL08, (2008) in press.

\*\*H. Hama et al., New J. Phys. 8 (2006) 292.

\*\*\*K. Kasamsook et al., Proc. FEL07, (2007) 417 - 420.

## Temporal Shaping of UV Laser with alpha-BBO Serials

L. X. Yan, Q. Du, Y.-C. Du, Hua,,J. F. Hua, W.-H. Huang, R. K. Li, C.-X. Tang (TUB)

The report takes efforts on the temporal shaping of the driving laser. Method based on pulse stacking by birefringent crystal of  $\alpha$ -BBO serials was used to directly shape ultraviolet laser pulse. Using four pieces of  $\alpha$ -BBO crystals to separate a input UV pulse with appropriate duration into 16 sub-pulses can form a quasi flat-top laser pulse suitable for cathode driving. The group delay dispersion induced by the crystals was also carefully considered.

The report takes efforts on the temporal shaping of the driving laser. Method based on pulse stacking by birefringent crystal of  $\alpha$ -BBO serials was used to directly shape

### Single Spike Radiation Production and Diagnostic at SPARC

In this paper a possible experiment with the existing SPARC photoinjector is described to generate sub-picosecond high brightness electron bunches able to produce single spike radiation pulses at 500 nm with the SPARC self-amplified spontaneous emission free-electron laser (SASE-FEL). The main

purpose of the experiment will be the production of short electron bunches as long as few SASE cooperation lengths, the determination of the shape of the radiation pulse and the validation of the single spike scaling law, in order to foresee operation at shorter wavelength in the future operation with SPARX. We present in this paper start to end simulations and preliminary experimental data of the beam production and FEL performance, and discuss the layout of the machine, including the diagnostics to measure the FEL pulse length. The experience, gained from this experiment, will help in the configuration of the VUV and X-ray FEL SPARX to obtain FEL pulses below 10 fs.

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### Helical Microbunching of a Relativistic Electron Bunch

The resonant harmonic interaction of an electron beam (e-beam) with an EM input field in a helical undulator is explored. The e-beam is coupled to the input radiation field at frequency harmonics through transverse gradients in the EM field, and helical micro-bunching of the e-beam is shown to occur naturally at the higher harmonics with the injection of a simple gaussian laser mode onto a cylindrically symmetric e-beam. This approach is under investigation as a method to generate a strongly pre-bunched e-beam seed for superradiant emission of light that carries orbital angular momentum in a downstream free-electron laser.

**E. Hemsing**, A. Marinelli, P. Musumeci, J. B. Rosenzweig, R. Tikhoplav (UCLA) A. Gover (University of Tel-Aviv, Faculty of Engineering) S. Reiche (PSI)

### Long Path Length Experimental Study of the Propagation of Longitudinal Space Charge Waves in the University of Maryland Electron Ring

In high current, space-charge-dominated electron beams, density fluctuations launch space charge waves that lead to energy modulation. The energy modulations may cause further density modulations in any

dispersive element and can, for example, excite the microbunching instability in X-FELs. Hence, it is important to understand the evolution of density modulations on intense beams as well as control them. Multi-turn operation of the University of Maryland Electron Ring (UMER) enables the experimental study of the evolution of space-charge-dominated beams over long path length. A single 5ns, density modulation is introduced on a rectangular 100ns electron beam pulse using photoemission from a laser. The density perturbation evolves into a pair of oppositely travelling space charge waves. Experimental measurement of the wave speed for various beam currents and perturbation strengths agrees with simulation (WARP) and 1-D theory. Additional experimental results are presented on the beam response that results from introducing a controlled energy modulation on the density modulated beam and are compared with fluid theory. Evidence of wave breaking at large perturbation amplitudes is reported.

**J. C.T. Thangaraj**, B. L. Beaudoin, S. Bernal, M. Cornacchia, D. W. Feldman, I. Haber, R. A. Kishek, P. G. O'Shea, M. Reiser, D. F. Sutter (UMD)

### Microbunching Gain of the Wisconsin FEL Beam Spreader

R. A. Bosch, K. J. Kleman (UW-Madison/SRC) J. Wu (SLAC)

The microbunching gain of a free-electron laser (FEL) driver is affected by the beam spreader that distributes bunches to the FEL beam lines. For the Wisconsin FEL (WiFEL), analytic formulas and tracking simulations indicate that a beam spreader design with a low value of R56 has little effect upon the gain.

### Single-Stage Bunch Compression for the Wisconsin FEL

R. A. Bosch, K. J. Kleman (UW-Madison/SRC) J. Wu (SLAC)

The microbunching gain of the driver for the Wisconsin FEL (WiFEL) is reduced by more than an order of magnitude by using a single-stage bunch compressor rather than a two-stage design. This allows compression of a bunch with lower energy spread for improved FEL performance.

### Diffusive Radiation from Rough Surfaces for Beam Diagnostics

Zh. S. Gevorkian (YerPhI)

Diffusive Radiation is originated by the passage of charged particles through a randomly inhomogeneous medium. DR appears when the conditions for multiple scattering of pseudophotons are fulfilled in the medium. Such a situation can be realized when a charged particle slides over a rough surface. One of the important properties of DR is that the maximum of emission lies at large angles from particle velocity direction. Therefore it can be used for detection of beam touch to the accelerators vacuum chamber wall in case when generated photons will be observed on the opposite side of vacuum chamber. Such a diagnostics can be especially useful for observation of storage rings beam halo.

### Development of a Elliptically Polarizing Undulator

J. D. Kulesza, A. Deyhim, E. Van Every, D. J. Waterman (Advanced Design Consulting, Inc) K. I. Blomqvist (MAX-lab)

The magnetic design of pure-permanent magnet Apple-II elliptically polarizing undulators (EPU) is discussed. The design specification for this EPU include; maximum period length 60 mm, maximum length inclusive space needed for the phase change 900 mm, in horizontal phase the fundamental photon energy 11 eV at 21 mm gap, the maximum operating temperature is 350C. The minimum remanence of the magnet material is 1.27 T. The EPU was designed with correction coils for the horizontal and vertical first and second integrals and the normal and skew quadrupoles as the specified ranges were very small. There is a 0.4 mm separation between the arrays on the same girder to reduce the drop in field strength at  $x = 0$  in planar phase. In this paper we describe the mechanical design, magnetic design, and data from factory acceptance tests.

### Development of a Hybrid Wiggler/Undulator MPW-80

An overview is presented of the mechanical and magnetic design and the actual magnetic measurement. The design requirements and mechanical difficulties for holding, positioning, and driving the magnetic arrays are explored. The structural and finite element analysis, magnetic design, and electrical considerations that influenced the design are then analyzed. This wiggler will be installed at ALBA a new synchrotron radiation source being built at the site of the Centre Direccional in Cerdanyola del Vallès, nearby Barcelona, and will produce ultra-violet and X-ray beams of exceptional brightness. This is a hybrid 80 mm period length with 12.5 mm gap and 300 mm maximum gap, and roughly 1100 mm long. The pole material is Vanadium Permendur and the magnet material has a minimum remanence of 1.22 T.

**J. D. Kulesza**, A. Deyhim, E. Van Every, D. J. Waterman (Advanced Design Consulting, Inc) K. I. Blomqvist (MAX-lab)

WE5RFP061

### Cancellation of the Planar Hall Probe Effect Using a New Two-Sensor Design

Hall probe is the best way to do tuning and measurements of insertion devices. Horizontal Hall probe magnetic field measurements in the presence of a strong vertical magnetic field were tested in 1997. The next step of this investigation was reported at the 2004 FEL Conference. Hall probe horizontal field measurements in the presence of a vertical magnetic field are complicated due to the influence of the Planar Hall probe effect on the resulting Hall voltage. 2-axis Sentron Hall probe was used for the Linear Coherent Light Source devices. By positioning the Hall probe accurately in the vertical direction, the probe could be used for fast measurements and tuning of FEL devices. To eliminate the high sensitivity to the positioning of the probe, a new type of Hall probe, consisting of two sensors combined so as to cancel the influence of the PHE, was developed at the Institute of Electrical Engineering, Slovak Academy of Sciences. The results of tests done at the APS showed that it is not sensitive to vertical position and is 60 times less sensitive than a Bell probe to the angle between the Hall sensor current and the in-plane component of the field direction.

**I. Vasserman**, B. Berkes, J. Z. Xu (ANL) J. Kvitkovitc (Slovak Academy of Sciences, Institute of Electrical Engineering)

WE5RFP062

### Performance of the Production Support and Motion Systems for the Linac Coherent Light Source Undulator System

The Linac Coherent Light Source (LCLS), now being commissioned at the Stanford Linear Accelerator Center (SLAC) in California, and coming online for users in the very near future, will be the world's first x-ray free-electron laser user facility. Design and production of the undulator system was the responsibility of a team from the Advanced Photon Source (APS) at Argonne National Laboratory (ANL). A sophisticated, five-axis, computer-controlled support and motion system positions and stabilizes all beamline components in the undulator system. The system also enables undulators to be retracted from the beam by 80 mm without disturbing the rest of the beamline components. An overview of the support and motion system performance, including achieved results with a production unit that was reserved at Argonne for this purpose, is presented.

**M. White**, J. T. Collins, P. K. Den Hartog, G. Pile, S. E. Shoaf, S. J. Stein, E. Trakhtenberg, J. Z. Xu (ANL)

WE5RFP063

### A New Superconducting Undulator for the ANKA Synchrotron Light Source

C. Boffo, M. Borlein, W. Walter (BNG) T. Baumbach, A. Bernhard, D. Wollmann (University of Karlsruhe) S. Casalbuoni, A. W. Grau, M. Hagelstein, R. Rossmann (FZK) E. M. Mashkina (University Erlangen-Nuernberg)

Superconducting insertion devices (IDs) are very attractive for synchrotron light sources since they allow increasing the flux and/or the photon energy with respect to permanent magnet IDs. Babcock Noell GmbH (BNG) is completing the fabrication of a 1.5 m long unit for ANKA at FZK. The period length of the device is 15 mm for a total of 100.5 full periods plus an additional matching period at each end. The key specifications of the system are: a K value higher than 2 and the capability of withstanding a 4 W beam heat load and a phase error of 3.5 degrees. In addition, during the injection phase of the machine, the nominal gap of 5 mm can be increased up to 25 mm. The magnets have been tested with liquid helium in a vertical dewar and are now being installed in the cryostat. This paper describes the technical design concepts of the device and the status of the assembly process.

### Fabrication of 11 Permanent Magnet Undulators for PETRA III and FLASH

G. Sikler, W. Gaertner, St. Sattler (BNG) A. Schoeps, M. Tischer (DESY)

Babcock Noell GmbH manufactured for DESY 11 identical planar permanent magnet-undulators (8 for the PETRA III upgrade and 3 for FLASH). The positioning accuracy and the movement reproducibility of the two girders, defining the magnetic gap of an undulator, are of vital importance for the quality of the synchrotron light. To reach the desired performance a high quality standard was kept during the choice and procurement of the components, during the high precision machining of the parts and during the assembly phase. After the alignment, laser tracker-measurements were made and evaluated for all the 11 systems. Both, the means by which the accuracy and reproducibility were achieved, and the results of the measurements will be presented here.

### A Simple Model-Based Magnet Sorting Algorithm for Undulators

G. Rakowsky, T. Tanabe (BNL)

Various magnet sorting strategies have been used to minimize trajectory and phase errors in undulators, ranging from intuitive pairing of high- and low-strength magnets, to full 3D FEM simulation with actual 3-axis Helmholtz coil magnet data. In the extreme, the 3D FEM analysis is repeated tens of thousands of times within a magnet swapping loop, to minimize a cost function, such as rms trajectory wander or rms phase error. This paper presents a simpler model-based approach. First, trajectory displacement or angle error signatures of each component of magnet error are derived from a 3D undulator model. Then, for any given sequence of magnets, the error trajectories are computed by cumulatively summing the scaled displacements and/or angles. The cost function of interest is then minimized by swapping magnets according to one's favorite optimization algorithm. 100,000 iterations take only minutes, so dozens of solutions can be compared to select the "best-of-the-best". This approach was applied recently at NSLS to a planar-hybrid undulator, which required no subsequent trajectory or phase shimming. Application to determining some mechanical tolerances is also illustrated.

**First Operational Experience with a Cryogenic Permanent Magnet Undulator at ESRF**

A cryogenically cooled in-vacuum undulator was installed in the ID6 test beamline of the ESRF in January 2008. This 2 metre long hybrid undulator has a period of 18 mm. The magnetic assembly is based on NdFeB permanent magnets cooled at a temperature close to 150 K. A liquid nitrogen closed loop is used for the cooling of the undulator. This cooling system is well adapted for achieving a uniform temperature along the magnetic assembly. An important part of the study was focused on the heat budget of the undulator under beam in the different filling modes delivered at the ESRF. The impact of the undulator on the ultra high vacuum of the ring was investigated with several warming/cooling cycles. This paper presents the main outcomes from this first experience. Finally the measured X-ray spectra measured by the ID6 beamline are presented.

G. Lebec, J. Chavanne, C. Penel, F. Revol (ESRF)

WE5RFP067

**Design, Development and Testing of Diagnostic Systems for Superconducting Undulators**

Within the framework of a joint research activity of the European project IA-SFS (RII3-CT2004-506008) four synchrotron facilities have jointly developed diagnostic systems for superconducting undulators. Four work packages have been successfully completed: Design and construction of a test cryostat for field measurements; design and construction of a mock-up coil; field measurement and field error compensation; diagnostics and measurement of the spectrum of low energy electrons responsible for beam heat load in a superconducting undulator. The development advanced the knowledge of magnetic field error compensation considerably and might be of help in understanding the different beam heat load sources. Based on the development a second generation planar superconducting undulator with 15 mm period length for the synchrotron light source ANKA has been specified and procured.

M. Hagelstein, T. Baumbach, S. Casalbuoni, A. W. Grau, B. K. Kostka, R. Rossmanith, D. Saez de Jauregui (FZK) A. Bernhard, D. Wollmann (University of Karlsruhe) J. Chavanne, P. Elleaume (ESRF) B. Diviacco (ELETTRA) E. M. Mashkina (University Erlangen-Nurnberg, Institute of Condensed Matter Physics) E. J. Wallen (MAX-lab)

WE5RFP068

**Electron Multipacting to Explain the Pressure Rise in the ANKA Cold Bore Superconducting Undulator**

Preliminary studies performed with the cold bore superconducting undulator installed in the ANKA storage ring suggest that the beam heat load is mainly due to the electron wall bombardment. Electron bombardment can both heat the cold vacuum chamber and induce an increase in the pressure because of gas desorption. In this contribution we compare the measurements of the pressure in a cold bore performed in the electron storage ring ANKA with the prediction obtained using the equations of gas dynamic balance in a cold vacuum chamber exposed to synchrotron radiation and electron bombardment. The balance results from two competitive effects: the photon and electron desorption of the gas contained in the oxide layer of the chamber wall and of the gas cryosorbed, and the cryopumping of the cold surface. We show that photodesorption alone cannot explain the pressure rise observed and that electron multipacting is needed.

S. Casalbuoni, M. Hagelstein, D. Saez de Jauregui, S. Schleede (FZK)

WE5RFP069

**Undulator System for Seeded FEL Experiment at FLASH**

H. Delsim-Hashemi, J. Rossbach (Uni HH) Y. Holler, A. Schoeps, M. Tischer (DESY)

The undulator system for the seeded FEL experiment at FLASH is composed of four hybrid variable gap undulators with total length of 10 m: three PRN2 each 2 m long and the 4 m long U33 (old PETRAII undulator). In this paper the simulation results for the magnetic field quality and its reproducibility level, as a function of gap size, is presented and compared with the given circumstance of U33 undulator. The measurement results on demagnetization of the end magnets of U33 are presented and its consequences for the project are discussed.

The undulator system for the seeded FEL experiment at FLASH is composed of four hybrid variable gap undulators with total length of 10 m: three PRN2 each 2 m long

**Overview of Quasi-Periodic Undulators**

S. Sasaki (HSRC)

QPU structures. One of the first most productive improvements was introducing the quasi-periodicity by modifying the magnetic field in a periodic undulator instead of modifying the period length\*\*. In addition to this practical improvement, a slight modification of creation theory of one-dimensional quasi-periodicity gave another advantage for building this type of device. As the result, many different types of QPUs for generating both linearly and elliptically polarized radiations have been installed in the synchrotron radiation (SR) facilities worldwide. Furthermore, some more SR facilities are considering to building such devices in order to improve their performance. In the presentation, we will discuss about limitations and possible improvements of performance of QPU on the basis of synchrotron radiation physics and mathematics of quasi-periodicity.

After the first demonstration of original quasi-periodic undulator (QPU) at the NII-IV\*, there have been many modifications for

\*Kawai, et al, Proc. EPAC96, p.2549.

\*\*Diviacco, Walker, ELETTRA Technical Note ST/M-TN-97/11, 1997, Chavanne, et al, Proc. EPAC98, p.2213, Diviacco, et al, ibid., p.2216.

**Fast Local Bump System for the Helicity Switching at the Photon Factory**

S. Matsuba (Hiroshima University, Graduate School of Science) K. Harada, Y. Kobayashi, T. Miyajima, S. Nagahashi, T. Obina, M. Shimada, R. Takai (KEK)

nets and tandem APPL-10<sup>-2</sup> type CPUs. In addition, fast correction magnets for a leakage of the bump were prepared. We designed the bump magnets with a core length of 0.15 m, a pole gap of 21 mm and the coils of 32 turns, which were excited by bipolar power supplies with a capacity of  $\pm 100$  A and  $\pm 50$  V since a switching frequency of more than 10 Hz and a bump angle of 0.3 mrad were required for user experiments. The bump magnets and one of CPUs were installed at PF-ring in March 2008, and the experiments for the machine development using a stored beam have been progressed. In this conference, we present the first experimental results with the bump system.

A fast local bump system for the helicity switching of a circular/linear polarized undulator (CPU) has been developed at the Photon Factory storage ring (PF-ring). The system consists of five identical bump mag-



### Magnetic Design of a Hybrid Undulator for Compact Terahertz FEL

The design of compact terahertz (THz) radiation source based on free electron laser (FEL) has been implemented, whose concept machine is consisting of an independently tunable cell thermionic RF gun (ITC-RF Gun), an accelerating structure with symmetry RF-incoupler and coaxial load RF-outcoupler, a hybrid undulator combined with an optical resonance cavity of hole-coupling mode. The aim of the project is to provide a stable coherent THz [1~3THz] source. The hybrid undulator system is the critical component for compact terahertz FEL. Emission wavelength is related to the period and the peak magnetic field of the hybrid undulator. In particular, the magnetic structure by adding other two magnetic blocks on both sides of each pole will increase the field strength and avoid too small gap. Simulations using RADIA and OPERA/TOSCA are presented. The feature of designs, optimization of the magnetic parameters and field analysis will be discussed.

**J. Xiong**, M. Fan, K. F. Liu, B. Qin, P. Tan, Y. Q. Xiong, J. Yang (HUST) Y. J. Pei (USTC/NSRL)

WE5RFP073

### Generation of Periodic Magnetic Field Using Bulk High-Tc Superconductor

A short period undulator with strong magnetic field will play an important role in future light source. We proposed a new type of staggered array undulator by use of bulk high-Tc superconductor\*.

We have constructed a prototype of the undulator using DyBaCuO bulk superconductors and a normal conducting solenoid. In the conference, we will present results of the magnetic field measurement and discuss on the feasibility of the new type bulk high-Tc staggered array undulator.

\*R. Kinjo et al., Proceedings of the FEL2008, in press.

**T. Kii**, M. A. Bakr, K. Higashimura, R. Kinjo, K. Masuda, H. Ohgaki, T. Sonobe, K. Yoshida, H. Zen (Kyoto IAE)

WE5RFP074

### High Performance Short-Period Undulators Using High Temperature Superconductor Tapes

Superconducting undulators are currently under development at a number of light sources to serve as the next generation of insertion devices, with higher fields providing enhanced spectral range for users. Most of these devices are designed with wire-based technologies appropriate for periods greater than ~10mm. New undulator concepts yielding very short-period, high-field devices with periods of a few millimeters and a  $K \sim 1$  have the potential to significantly reduce the cost and enhance the performance of FEL's. Here we describe a design using high temperature superconductor tapes that are commercially available, and that promise a cost-effective fabrication process using micromachining or lithography. Detailed magnetic and spectral performance analysis will be provided.

**S. Prestemon**, D. R. Dietderich, A. Madur, S. Marks, D. Schlueter (LBNL)

WE5RFP075

### Status of UCLA Helical Permanent-Magnet Inverse Free Electron Laser

A helical undulator, utilizing permanent-magnet of cylindrically symmetric (Halbach) geometry has been developed at UCLA's Neptune Facility. The initial prototype is a short 10 cm, 7 periods long helical undulator, designed to

**A. Knyazik** (UCLA)

WE5RFP076

test the electron-photon coupling by observing the micro-bunching has been constructed and is currently being tested in the Neptune facility. An Open Iris-Loaded Waveguide Structure (OILS) scheme which conserves laser mode size and wave fronts throughout the undulator, is utilized to avoid Gouy phase shift caused by focusing of the drive laser. Coherent Transition Radiation and Coherent Cherenkov Radiation is used for micro-bunching diagnostic. Currently the undulator has been built, magnets were calibrated via pulsed wire method.

### Development of Dy Poles for HTS Undulator Applications

A. Y. Murokh, R. B. Agustsson, P. Frigola (RadiaBeam) V. Solovyov (BNL)

A High Temperature Superconducting Dysprosium Pole Undulator (HTS-DPU) is proposed to achieve an ultra-high peak field in a very short period undulator structure.

This design utilizes the unique ferromagnetic properties of dysprosium (Dy) at liquid nitrogen temperature. The fabrication of textured Dy fabricated via economic and highly reproducible process is studied experimentally with the goal to achieve sufficient magnetic anisotropy and desired field saturation level at a practical cost. In addition, utilizing the latest capabilities of the 2G HTS wire is investigated. The practical implementation of HTS-DPU would enable the development of short period insertion devices with superior performance.

### Magnetic and Mechanical Characterization of the Two Variable Polarization Undulators for the ALBA Project

D. Zangrando, R. Bracco, B. Diviacco, D. La Civita, D. Millo, M. Musardo, G. Tomasin (ELETTRA) F. Becheri, J. Campmany, C. Colldelram, D. Einfeld, J. V. Gigante (ALBA) M. Zeus (LLS)

Two variable polarization undulators have been designed and constructed as a Collaboration between CELLS and Sincrotrone Trieste\*. In this paper the main magnetic and mechanical feature are summarized. Field

optimization techniques are described, showing the achieved performance in terms of phase, trajectory and field integral errors.

\*D. Zangrando et al. Design of two variable polarization undulators for the ALBA project, EPAC 2008, Genova, Italy

### Field Optimization in Superconducting Undulators

S. Chunjarean (SLRI) C.-S. Hwang, J. C. Jan, F.-Y. Lin, P. H. Lin (NSRRC) H. Wiedemann (SLAC)

Highest photon beam brightnesses are achieved in radiation from undulators. Very short period length and high fields, reached only in superconducting undulators, are de-

sired to produce hard X-rays. In lower energy storage rings this is not enough, but radiation at higher harmonics (7th and up) are desirable. This is possible only if the undulator fields and periods are near perfect. Shimming methods as applied for room temperature permanent magnet undulators cannot be used for such superconducting magnets. The effect of field and period tolerances on higher harmonics photon beam brightnesses will be presented and limiting tolerances will be discussed. A variety of different field optimization techniques together with some measurements on test magnets will be discussed and evaluated to their usefulness as a high photon energy and high brightness radiation source.

### Development and Installation of Insertion Devices at SOLEIL

SOLEIL storage ring presents a very high fraction of the total circumference dedicated to accommodate insertion devices. Over the presently planned 25 insertion devices presenting a large variety of systems, 15 have been already installed and commissioned by

**F. Marteau**, C. Benabderrahmane, P. Berteaud, F. Briquez, L. Chapuis, O. V. Chubar, M.-E. Couprie, T. K. El Ajjouri, J.-M. Filhol, C. A. Kitegi, O. Marcouille, M. Massal, M. Valleau, J. Veteran (SOLEIL)

the end of 2008. The UV-VUV region is covered with electromagnetic devices (one HU640 and 3 HU256), offering tuneable polarisations. An electromagnet/permanent magnet undulator using copper sheets as coils for fast switching of the helicity is under construction. 13 APPLE-II types undulators, with period ranging from 80 down to 36 mm, provide photons in the 0.1-10 keV region, some of them featuring tapering or quasi-periodicity. 5 U20 in-vacuum undulators cover the 3-30 keV range whereas an in-vacuum wiggler, with magnetic forces compensation via adequate springs is designed to cover the  $10^{-50}$  keV spectral domain. R&D on cryogenic in-vacuum undulator has also been launched. A magnetic chicane using permanent magnet dipoles has also been designed in order to accommodate two canted undulators on the same straight section. The processes for optimizing the insertion devices and their achieved performances will be described.

### Development of an Electromagnetic/Permanent Magnet Helical Undulator for Fast Polarization Switching

A new electromagnetic/permanent magnets helical undulator, with a 65 mm magnetic period is under development at SOLEIL for providing a rapid switching of the photon

**F. Marteau**, P. Berteaud, F. Bouvet, L. Chapuis, M.-E. Couprie, J. P. Daguerre, J.-M. Filhol, A. Mary, K. Tavakoli (SOLEIL)

polarization required to perform dichroism experiments. The vertical field will be produced by coils fed by a fast switching power supply, with a maximum current of 350 A and a polarity switching time shorter than 100ms. The coils consist of copper sheets cut by water jet method. 26 layers of copper will be stacked together while 10 of them will be water cooled. The current-regulated power supply should be able to operate in the 4 quadrants with a 50 ppm current resolution over the full scale. The design of this home made power supply will be described. The horizontal field will be generated by NdFeB permanent magnets. The design vertical and horizontal peak field values in the helical configuration are 0.24 T at the minimum 15.5 mm gap. The magnetic design and the correction scheme will be described. A prototype was built to characterise and validate the technical choices, and the results will be discussed. The efficiency of the cooling system and the results of the magnetic measurements will be presented.

### A Short Undulator Utilizing Novel Materials

The goal of the LUX project at Ludwig-Maximilians University in Munich is to create 5 keV photons for protein crystallography. Simultaneously, it will be used to test the emerging technology of cryogenic permanent magnets for use in table top Free-Electron Lasers. The high flux and short wavelength requirements for crystallography translate into large magnetic fields created by very small magnets. We discuss some of the challenges encountered in designing such a lattice and propose solutions.

**F. H. O'Shea** (UCLA)

**Characterization of the BNL ATF Compton X-Ray Source Using K-Edge Absorbing Foils**

O. Williams, G. Andonian, E. Hemsing, J. B. Rosenzweig (UCLA)  
M. Babzien, K. Kusche, J. H. Park, I. Pogorelsky, V. Yakimenko (BNL)

It is possible to obtain spectral and angular information of inverse Compton sources using only an x-ray imaging device and various foils with K-edges in the many keV energy range. Beam parameters are chosen such that on-axis photons are above the K-edge for a given material, where absorption is strong and there is relatively zero transmission. Photons observed off-axis are red-shifted and fall below the K-edge, therefore being transmitted and creating a "donut" pattern, or "lobes" in the ideal case for a circularly or linearly polarized laser, respectively. We present simulation and experimental results of the double differential spectrum (DDS) for angle and energy of Compton photons generated at the BNL ATF.

It is possible to obtain spectral and angular information of inverse Compton sources using only an x-ray imaging device and various foils with K-edges in the many keV energy range. Beam parameters are chosen such

**Spectral Characterisation of the ANKA-SCU Radiation**

A. Bernhard, T. Baumbach, F. Burkart, S. Ehlers, G. Fuchert, P. Peiffer, M. Wolf, D. Wollmann (University of Karlsruhe) R. Rossmanith, D. Saez de Jauregui (FZK)

The ANKA superconductive undulator (SCU14) is continuously operated since 2005. The main objective of this operation was to investigate the interactions between the undulator and the stored electron beam and to characterise the undulator radiation. The characterisation of the undulator radiation was done with a short test beamline designed for spatially and spectrally resolved measurements of the undulator radiation intensity. This contribution summarises the results of these measurements. The spectra are cross-correlated with the magnetic field measurements carried out earlier.

The ANKA superconductive undulator (SCU14) is continuously operated since 2005. The main objective of this operation was to investigate the interactions between the undulator and the stored electron beam and

**Magnetic Field Transients in Superconducting Undulators**

S. Ehlers, T. Baumbach, G. Fuchert, P. Peiffer, D. Wollmann (University of Karlsruhe) A. Bernhard, R. Rossmanith (FZK) D. Schorerling (IMFD)

The next step towards introducing superconductive undulators as the new generation of insertion devices is to understand the impact of dynamic effects in the superconducting coils on the accelerator beam. These effects are seen as a temporal drift of the beam orbit, originating from transients of the magnetic field. The first systematic time resolved measurements of such drifts have been performed ANKA. Orbit displacement during several different ramping cycles, for different ramp rates and relaxation times, has been investigated. This contribution summarises the results of the measurements. The persistent current effects in the superconducting wires, as well as eddy currents in the yoke are discussed as possible sources for the transients.

The next step towards introducing superconductive undulators as the new generation of insertion devices is to understand the impact of dynamic effects in the superconducting coils on the accelerator beam. These

**New Materials for Superconductive Insertion Devices**

P. Peiffer, T. Baumbach, A. Bernhard, D. Wollmann (University of Karlsruhe) R. Maccaferri (CERN) M. Noe, R. Rossmanith, T. Schneider (FZ Karlsruhe)

Many next generation undulators for advanced light sources or FELs and damping wigglers demand a higher total field strength than that achievable with state of the art technology like iron bodies with NbTi wire coils. Also NbTi is known to be sensitive to heat load. Possible next steps in the development of

Many next generation undulators for advanced light sources or FELs and damping wigglers demand a higher total field strength than that achievable with state of the art technology like iron bodies with

superconductive magnetic devices can be the use of Nb<sub>3</sub>Sn, MgB<sub>2</sub> or high temperature superconductors. Advantages, disadvantages and limits of these materials are discussed in this contribution.

### Experimental Demonstration of the Induction-Shimming Concept in Superconductive Undulators

Recently a new concept for automatically reducing magnetic field errors in superconductive undulators was proposed. According to this proposal the field errors are compensated by an array of coupled high temperature superconductor loops attached to the surface of the superconductive undulator. The field errors induce currents in the coupled type II-superconducting loops and, as a result, the magnetic field generated by these currents minimizes the field errors. In this paper the results of a first successful experimental test of this concept are described.

**D. Wollmann**, T. Baumbach, A. Bernhard, P. Peiffer (University of Karlsruhe) A. W. Grau, R. Rossmannith (FZK) E. M. Mashkina (University Erlangen-Nuernberg)

### Harmonic Motion of Electron Trajectory in Planar Undulator

For planar undulator, the expression of electron trajectory including harmonic motion has been deduced. It were shown that the electrons oscillate at odd harmonics in the transverse direction, and at even harmonics in the axial direction; the amplitude of nth harmonic oscillation is proportional to the nth power of ratio of undulator deflection parameter to the electron energy.

**Q. K. Jia** (USTC/NSRL)

## WE6PF — Afternoon Poster COLLIDER, LEAC

### Commissioning of RHIC Spin Flipper

M. Bai, A. K. Jain, A. U. Luccio, Y. Makdisi, M. Mapes, W. Meng, S. Nayak, P. Oddo, C. Pai, C. Pearson, P. H. Pile, V. Ptitsyn, T. Roser, T. Russo, J. E. Tuozzolo, P. Wanderer (BNL)

A new design of spin flipper for RHIC was commissioned during the RHIC polarized proton run 2009. Unlike the traditional technique of using a single RF solenoid or dipole, this allows one to achieve full spin flip

with spin tune staying at half integer\*. An introduction of the apparatus setup as well as the commissioning results is presented in the paper.

\*M. Bai, T. Roser, Phys. Rev. ST Accel. Beams 11, 0910<sup>01</sup> (2008)

### Longitudinal Collision Area Measurements at RHIC

K. A. Drees, R. C. Lee, S. Nemesure (BNL)

With increased luminosity demands from RHIC experiments, management of longitudinal collision area in the interaction regions

has become progressively more important. The discrepancy between recorded luminosity (collisions occurring within the most central detector components) and delivered luminosity (collisions occurring anywhere along the overlap region of the two circulating bunches) ranges up to 40% depending on details of a given detector. Online vertex monitoring from the experiments allows immediate quality control of the longitudinal collision area including the width of the distribution and the center position of the collision area. A graphical interface was developed for immediate display of the vertex distributions in the RHIC main control room. Data from the PHENIX detector are shown and discussed and compared to wall current monitor measurements of the two beams.

### Results from Vernier Scans at RHIC during PP Runs 2005-2008

K. A. Drees, T. D'Ottavio (BNL)

Using the Vernier Scan (or Van der Meer Scan technique), where one beam is swept stepwise across the other while measuring

the collision rate as a function of beam displacement, the transverse beam profiles, the luminosity and the effective cross section of the collision monitoring processes can be measured. Data and results from the 2005, 2006 and 2008 polarized proton runs using different collision detectors are presented and compared.

### Beam Dynamics and Expected RHIC Performance with 56MHz RF Upgrade

A. V. Fedotov, I. Ben-Zvi (BNL)

Recently, an upgrade of RHIC storage RF system with a superconducting 56 MHz cavity was proposed. This upgrade will provide

significant increase in the acceptance of storage RF bucket. Presently, the short bunch length for collisions is obtained via RF gymnastics with bunch rotation (called "re-bucketing"), because the length of 197MHz bucket of 5 nsec is too short to accommodate long bunches otherwise. However, some increase in the longitudinal emittance occurs during re-bucketing. The 56MHz cavity will produce sufficiently short bunches which would allow one

to operate without re-bucketing procedure. This paper summarizes simulation of beam evolution due to Intra-beam scattering (IBS) for beam parameters expected with the 56 MHz SRF cavity upgrade. Expected luminosity improvement is shown both for Au ions at 100 GeV/nucleon and for protons at 250 GeV.

### IBS and Possible Luminosity Improvement for RHIC Operation below Transition Energy

There is a strong interest in low-energy RHIC collisions in the energy range below present RHIC transition energy. These collisions will help to answer one of the key questions in the field of QCD about the existence and location of a critical point on the QCD phase diagram. For low-energy RHIC operation, particle losses from the RF bucket are of particular concern since the longitudinal beam size is comparable to the existing RF bucket at low energies. However, operation below transition energy allows us to exploit an Intra-beam Scattering (IBS) feature that drives the transverse and longitudinal beam temperatures towards equilibrium by minimizing the longitudinal diffusion rate using a high RF voltage. Simulation studies were performed with the goal to understand whether one can use this feature of IBS to improve luminosity of RHIC collider at low-energies. This paper presents results of simulations which show that additional luminosity improvement for low-energy RHIC project may be possible with high RF voltage from a 56 MHz superconducting RF cavity that is presently under development for RHIC.

A. V. Fedotov (BNL)

### Overview of the Magnetic Nonlinear Beam Dynamics in the RHIC

In the article we review the nonlinear beam dynamics from nonlinear magnetic fields in the Relativistic Heavy Ion Collider. The nonlinear magnetic fields include the magnetic field errors in the interaction regions, chromatic sextupoles, and sextupole component from arc dipoles. Their effects on the beam dynamics and long-term dynamic apertures are evaluated. The online measurement and correction methods for the IR nonlinear errors, nonlinear chromaticity, and horizontal third order resonance are reviewed. The overall strategy for the nonlinear effect correction in the RHIC is discussed.

Y. Luo, M. Bai, J. Beebe-Wang, J. Bengtsson, R. Calaga, W. Fischer, A. K. Jain, N. Malitsky, S. Peggs, F. C. Pilat, V. Ptitsyn, G. Robert-Demolaize, T. Satogata, S. Tepikian, D. Trbojevic (BNL) R. Tomas (CERN)

### Dynamic Aperture Evaluation for the RHIC Polarized Proton in 2009

In preparation for the RHIC polarized proton run 2009, simulations were carried out to evaluate the million turn dynamic apertures for different beta\*s at the proposed beam energies of 100 GeV and 250 GeV. One goal of this study is to find out the best beta\* for this run. We also evaluated the effects of the second order chromaticity correction. The second order chromaticities can be corrected with the MAD8 Harmon module or by correcting the horizontal and vertical half-integer resonance driving terms.

Y. Luo, M. Bai, J. Beebe-Wang, W. Fischer, C. Montag, G. Robert-Demolaize, T. Satogata, S. Tepikian, D. Trbojevic (BNL)

### Reduction of Beta\* and Increase of Luminosity at RHIC

F. C. Pilat, M. Bai, D. Bruno, K. A. Drees, V. Litvinenko, Y. Luo, N. Malitsky, G. J. Marr, V. Ptitsyn, T. Satogata, S. Tepikian, D. Trbojevic (BNL)

The reduction of beta\* beyond the 1m design value at RHIC has been consistently achieved over the last 6 years of RHIC operations, resulting in an increase of luminosity for different running modes and species. During the recent 2007-08 deuteron-gold run the reduction to 0.70 from the design 1 m achieved a 30% increase in delivered luminosity. The key ingredients in allowing the reduction have been the capability of efficiently developing ramps with tune and coupling feedback, orbit corrections on the ramp, and collimation at injection and on the ramp, to minimize beam losses in the final focus triplets, the main aperture limitation for the collision optics. We will describe the operational strategy used to reduce the b\*, at first squeezing the beam at store, to test feasibility, followed by the operationally preferred option of squeezing the beam during acceleration, and the resulting luminosity increase obtained in the Cu-Cu run in 2005, Au-Au in 2007 and the deuteron-Au run in 2007-08. We will also include beta squeeze plans and results for the upcoming 2009 run with polarized protons at 250 GeV.

The reduction of beta\* beyond the 1m design value at RHIC has been consistently achieved over the last 6 years of RHIC operations, resulting in an increase of luminosity for different running modes and species.

### RHIC Low Energy Tests and Initial Operations

T. Satogata, L. Ahrens, M. Bai, J. M. Brennan, D. Bruno, J. J. Butler, K. A. Drees, A. V. Fedotov, W. Fischer, M. Harvey, T. Hayes, W. Jappe, R. C. Lee, W. W. MacKay, G. J. Marr, R. J. Michnoff, E. Pozdeyev, T. Roser, F. Severino, K. Smith, S. Tepikian, N. Tsoupas (BNL)

There is significant interest in RHIC heavy ion collisions at center of mass energies of 5-50 GeV/u, motivated by a search for the QCD phase transition critical point. The low end of this energy range is nearly a factor of four below the nominal RHIC injection center of mass energy of 19.6 GeV/u. There are several operational challenges in the low-energy regime, including harmonic number changes, longitudinal acceptance, magnet field quality, lattice control, and luminosity monitoring. We report on the results of beam tests with protons and gold in 2007--9, including first RHIC operations at  $\sqrt{(s_{NN})} = 9.2$  GeV and low-energy nonlinear field corrections at  $\sqrt{(s_{NN})} = 5$  GeV.

There is significant interest in RHIC heavy ion collisions at center of mass energies of 5-50 GeV/u, motivated by a search for the QCD phase transition critical point. The low end of this energy range is nearly a factor of four below the nominal RHIC injection center of mass energy of 19.6 GeV/u. There

### Nonlinear Orbit Correction for RHIC Low Energy Operations

T. Satogata, J. Beebe-Wang, Y. Luo, S. Tepikian (BNL)

There is significant interest in RHIC heavy ion operations down to  $\sqrt{(s_{NN})} = 5$  GeV, motivated by a search for the QCD phase transition critical point. At this energy, sextupole fields of the main superconducting dipoles dominate the lattice behavior and routine linear orbit corrections fail to converge. We report on simulation tests and first machine results of an iterative nonlinear orbit correction algorithm, using a nonlinear model based on RHIC magnet measurements.

There is significant interest in RHIC heavy ion operations down to  $\sqrt{(s_{NN})} = 5$  GeV, motivated by a search for the QCD phase



### Integration of the Forwards Detectors inside the LHC Machine

Several forwards detectors have been installed in the LHC long straight sections located on each side of the experimental caverns. Most of these detectors have been designed by the LHC experiments to study the forwards physics while some of them are dedicated to the measurement of the LHC luminosity. The integration and installation of the forwards detectors have required an excellent coordination between the experiments and the different CERN groups involved into the design and installation of the LHC accelerator. In some cases the integration of these detectors has required a modification of the standard beam lines in order to maximise the physics potentiality of the detectors. Finally, additional systems have been installed in the LHC tunnel to ensure the operation of the forwards detectors in a high radiation environment.

A.-L. Perrot, R. Appleby, D. Macina (CERN)

WE6PFP011

### LHC Cleaning Efficiency with Imperfections

The performance reach of the LHC depends on the magnitude of beam losses and the achievable cleaning efficiency of its collimation system. The ideal performance reach for the nominal Phase 1 collimation system is reviewed. However, unavoidable imperfections affect any accelerator and can further deteriorate the collimation performance. Multiple static machine and collimator imperfections were included in the LHC tracking simulations. Error models for collimator jaw flatness, collimator setup accuracy, the LHC orbit and the LHC aperture were set up, based to the maximum extent possible on measurements and results of experimental beam tests. It is shown that combined "realistic" imperfections can reduce the LHC cleaning efficiency by about a factor 11 on average.

C. Bracco, R. W. Assmann, S. Redaelli, Th. Weiler (CERN)

WE6PFP012

### Beam Commissioning Plan for LHC Collimation

The Large Hadron Collider extends the present state-of-the-art in stored beam energy by 2-3 orders of magnitude. A sophisticated system of collimators is implemented along the 27 km ring and mainly in two dedicated cleaning insertions, to intercept and absorb unavoidable beam losses which could induce quenches in the superconducting magnets. 88 collimators per beam are initially installed for the so called Phase 1. An optimized strategy for the commissioning of this considerable number of collimators has been defined. This optimized strategy maximizes cleaning efficiency and tolerances available for operation, while minimizing the required beam time for collimator setup and ensuring at all times the required passive machine protection. It is shown that operational tolerances from collimation can initially significantly relaxed.

C. Bracco, R. W. Assmann, S. Redaelli, Th. Weiler (CERN)

WE6PFP013

### Chromatic LHC Optics Effects on Collimation Phase Space Cuts

The different levels of LHC collimators must be set up by respecting a strict setting hierarchy in order to guarantee the required performance and protection during the different operational machine stages. The available margins are a fraction of a beam sigma. Two different sub-systems establish betatron and momentum collimation for the LHC. Collimator betatron phase space cuts are defined for a central on-momentum particle. However, due to the chromatic

C. Bracco, R. W. Assmann (CERN)

WE6PFP014

features of the LHC optics and energy deviations of particles, the different phase space cuts become coupled. Starting from the basic equation of the transverse beam dynamics, the influence of off-momentum beta-beat and dispersion on the effective collimator settings has been calculated. The results are presented, defining the allowed phase space regions from LHC collimation. The impacts on collimation-related setting tolerances and the choice of an optimized LHC optics are discussed.

### Luminosity Optimization and Calibration in the LHC

M. Lamont, R. Alemany-Fernandez, H. Burkhardt, S. M. White (CERN)

The ability of a particle collider to produce the required number of events, the luminosity, is usually used to size its performances. As demonstrated in many accelerators optimizing and calibrating the luminosity can be done using the Van Der Meer method which consist of shifting one beam with respect to the other while recording the event rate. In the LHC it is planned to perform those scans at the four interaction points using the data from the machine detectors as well as the ones from the experiments. A graphical user interface (GUI) has been developed for this purpose. We looked into procedures to quantify and if possible minimize the systematic errors coming from the measurements and the beam parameters and will discuss how we plan on using the relevant informations such as the vertex position or background measurements coming from the experiments.

### Study of High Beta Optics Solution for TOTEM

H. Burkhardt, Y. I. Levinsen, S. M. White (CERN)

The TOTEM experiment requires special high beta optics solutions. We report on studies of optics for an intermediate beta\* = 90 m, as well as a solutions for a very high beta\* of 1540 m, which respect all known constraints. These optics are rather different from the normal physics optics and will require global tune changes or adjustments.

### LHC Abort Gap Cleaning with the Transverse Damper

E. Gianfelice-Wendt (Fermilab) B. Goddard, W. Höfle, V. Kain, M. Meddahi, E. N. Shaposhnikova (CERN) A. Koschik (ETH)

In the Large Hadron Collider --LHC, particles not captured by the RF system at injection or leaking out of the RF bucket may quench the superconducting magnets during beam abort. The problem, common to other superconducting machines, is particularly serious for the LHC due to the very large stored energy in the beam. For the LHC a way of removing the unbunched beam has been studied and it uses the existing damper kickers to excite resonantly the particles travelling along the abort gap. In this paper we describe the results of simulations performed with MAD-X for various LHC optics configurations, including the estimated multipolar errors.

### Optimization of the LHC Separation Bumps Including Beam-Beam Effects

The LHC beams will cross each other and experience perturbations as a result of the beam-beam effect at the four interaction points. An offset between the colliding

beams combined with these perturbations can be the source of unwanted effects such as emittance growth or the excitation of resonances. During the process of putting them into collisions the beams will be separated by a significant portion of beam sigmas and the various effects that occur during this phase could be a limitation for LHC operation. A re-tuning of the beam crossing scheme, minimizing the collapsing time of the separation bumps and taking into account the hardware limitations is proposed as well as an analysis of the orbit and emittance effects in the presence of beam-beam interactions. Here we discuss the limitations of the actual separation scheme and look into possible actions to minimize them.

**T. Pieloni**, H. Burkhardt, S. D. Fartoukh, W. Herr, S. M. White (CERN)

WE6PFP018

### First Beam-Based Aperture Measurements for CERN Large Hadron Collider

Various LHC injection tests were performed in August and early September 2008 in preparation for the circulating beam operation. These tests provided the first opportunity

to measure with beam the available mechanical aperture in two LHC sectors (2-3 and 7-8). The aperture was probed by exciting free oscillations and local orbit bumps of the injected beam trajectories. Intensities of a few  $1 \cdot 10^9$  protons were used to remain safely below the quench limit of superconducting magnets in case of beam losses. In this paper the methods used to measure the mechanical aperture, the available on-line tools, and beam measurements for both sectors are presented. Detailed comparisons with the expected results from the as-built aperture models are also presented. It is shown that the measurements results are in good agreement with the LHC design aperture.

**S. Redaelli**, I. V. Agapov, B. Dehning, M. Giovannozzi, R. Tomas (CERN) R. Calaga (BNL) F. Roncarolo (UMAN)

WE6PFP019

### Study with One Global Crab Cavity at IR4 for LHC

Modern colliders bring into collision a large number of bunches per pulse or per turn to achieve a high luminosity. The long-range beam-beam effects arising from parasitic encounters at such colliders are mitigated by introducing a crossing angle. Under these conditions, crab cavities can be used to restore effective head-on collisions and, thereby, to increase the geometric luminosity. In this paper, we study performance implications of a single global crab cavity in the LHC, for both the nominal LHC optics and one possible upgrade. In particular, we discuss the impact of a global LHC crab cavity, installed in IR4, on dynamic aperture, luminosity, closed orbit, and on the collimation cleaning efficiency.

**Y. Sun**, R. W. Assmann, J. Barranco, R. Tomas, Th. Weiler, F. Zimmermann (CERN) R. Calaga (BNL)

WE6PFP020

WE6PFP021

**First Beta-Beating Measurement in the LHC**

R. Tomas, M. Aiba, M. Giovannozzi, G. Vanbavinckhove, J. Wenninger (CERN) R. Calaga (BNL) A. Morita (KEK)

In 2008 beam successfully circulated in the LHC. Thanks to an excellent functioning of the BPM system and the related software, injection oscillations were recorded for the first 90 turns at all BPMs. The analysis of these data gives the unique opportunity of evaluating the periodic optics and inferring possible error sources.

WE6PFP022

**Beta-Beating Corrections in the SPS as a Testbed for the LHC**

R. Tomas, M. Aiba, G. Vanbavinckhove, J. Wenninger (CERN) R. Calaga (BNL) A. Morita (KEK)

For several years optics measurement and correction algorithms have been developed for the LHC. During 2008 these algorithms have been directly tested in the SPS and RHIC. The experimental results proving the readiness of the applications are presented.

WE6PFP023

**Status of the CLIC Beam Delivery System**

R. Tomas, H.-H. Braun, B. Dalena, G. Rumolo, D. Schulte (CERN) D. Angal-Kalinin (STFC/DL/ASTeC) A. Seryi (SLAC)

The CLIC BDS is experiencing the careful revision from a large number of world wide experts. This was particularly enhanced by the successful CLIC'08 workshop held at CERN. Numerous new ideas, improvements and critical points are arising, establishing the path towards the Conceptual Design Report by 2010.

WE6PFP024

**ATF2 Ultra-Low IP Betas Proposal**

R. Tomas, F. Zimmermann (CERN) S. Bai (IHEP Beijing) P. Bambade (LAL) S. Kuroda, T. Tauchi, J. Urakawa (KEK) A. Seryi, G. R. White (SLAC)

The CLIC Final Focus System has considerably larger chromaticity than those of ILC and its scaled test machine ATF2. We propose to reduce the IP betas of ATF2 to reach a CLIC-like chromaticity. This would also allow to study the FFS tuning difficulty as function of the IP beam spot size. Both the ILC and CLIC projects will largely benefit from the ATF2 experience at these ultra-low IP betas.

WE6PFP025

**Analysis of Energy Deposition Patterns in the LHC Inner Triplet and the Resulting Impact on the Phase II Luminosity Upgrade Design**

E. Y. Wildner, F. Cerutti, A. Ferrari, A. Mereghetti, E. Todesco (CERN) F. Broggi (INFN/LASA)

Recent studies show that the energy deposition for the LHC phase one luminosity upgrade, aiming at a peak luminosity  $2.5 \cdot 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ , can be handled by appropriate shielding. The phase II upgrade aims at a further increase of a factor 4, possibly using Nb<sub>3</sub>Sn quadrupoles.

This paper describes how the main features of the triplet layout, such as quadrupole lengths, gaps between magnets, and aperture, affect the energy deposition in the insertion. We show the dependence of the triplet lay-out on the energy deposition patterns in the insertion magnets. An additional variable which is taken into account is the choice of conductor, i.e. solutions with Nb-Ti and Nb3Sn are compared. Nb3Sn technology gives possibilities for increasing the magnet apertures and space for new shielding solutions. Our studies give a first indication on the possibility of managing energy deposition for the phase II upgrade.

### Linear and Nonlinear Optics Checks during LHC Injection Tests

In early LHC commissioning, linear and "higher-order" polarity checks were performed for one octant per beam, by launching suitable free betatron oscillations and then inverting a magnet-circuit polarity or strength. Circuits tested included trim quadrupoles, skew quadrupoles, lattice sextupoles, sextupole spool-pieces, Landau octupoles, and skew sextupoles. A nonzero momentum offset was introduced to enhance the measurement quality. The low-intensity single-pass measurements proved sufficiently sensitive to verify the polarity and the amplitude of (almost) all circuits under investigation, as well as the alignment of individual trim quadrupoles. A systematic polarity inversion detected by this measurement helped to pin down the origin of observed dispersion errors. Later, the periodic "ring dispersion" was reconstructed from the full first-turn trajectory of an injected off-momentum beam, by removing, at each location, the large incoming dispersion mismatch, forward-propagated via the optics model. Various combinations of inverted trim quadrupoles were considered in this model until reaching a good agreement of reconstructed dispersion and prediction.

**F. Zimmermann**, S. D. Fartoukh, M. Giovannozzi, V. Kain, M. Lamont, Y. Sun, R. Tomas (CERN) R. Calaga (BNL)

### Beam Losses and Background Loads on Collider Detectors due to Beam-Gas Interactions in the LHC

With a fully-operational high-efficient colimation system in the LHC, nuclear interactions of circulating protons with residual gas in the machine beam pipe can be a major sources of beam losses in the vicinity of the collider detectors, responsible for the machine-induced backgrounds. Realistic modeling of elastic and inelastic interactions of 7-TeV protons with nuclei in the vacuum chamber of the cold and warm sections of the LHC ring - with an appropriate pressure profile - is performed with the STRUCT and MARS15 codes. Multi-turn tracking of the primary beams, propagation of secondaries through the lattice, their interception by the tertiary collimators TCT as well as properties of corresponding particle distributions at the CMS and ATLAS detectors are studied in great detail and results presented in this paper.

**A. I. Drozhdin**, N. V. Mokhov, S. I. Striganov (Fermilab)

### Recent Experience with Electron Lens Beam-Beam Compensation at the Tevatron

Tevatron Electron Lenses (TEL) have reliably demonstrated correction of the bunch-to-bunch tune shift induced by long-range beam-beam interactions. The second and most important intended application of TEL is compensation of the nonlinearity of head-on beam-beam force.

**V. Kamerzhiev**, G. F. Kuznetsov, G. W. Saewert, V. D. Shiltsev, A. Valishev (Fermilab)

We report on the first studies of head-on beam-beam compensation with the second generation Gaussian profile TEL. We evaluate the effect of TEL on beam life time and emittance and compare the observed results with simulations.

### Tevatron Electron Lens Upgrade

V. Kamerdzhev, G. W. Saewert (Fermilab)

A novel high voltage modulator had been under development for 1.5 years. It was completed tested on the bench and became a part of the TEL2 system in October 2008. The modulator is used to drive the electron gun anode. We provide technical details on the stacked transformer modulator, analyze its performance and discuss the design challenges. The results of the beam studies made possible by the new high voltage modulator are reported.

### Characteristics of Beam Diffusion and its Application to Hadron Colliders

H. J. Kim, T. Sen (Fermilab)

We study beam diffusion due to non-linear particle dynamics in hadron storage rings. Growth of particle amplitudes may be described by a diffusion in action variables. The diffusion coefficients characterize the effects of the various nonlinearities present in the accelerators. We evaluate these coefficients via multi-particle tracking and use them to find numerical solutions of a three dimensional diffusion equation. The solutions yield the time evolution of the beam density distribution function for a given set of machine and beam parameters. This technique enables us to follow the beam intensity and emittance growth for the duration of a luminosity store, something that is not feasible with direct particle tracking. The numerical results are compared with measurements in the Tevatron and RHIC.

### Simulations of Long-Range Beam-Beam Compensation in LHC

H. J. Kim, T. Sen (Fermilab)

The compensation of long-range beam-beam interactions with current carrying wires in the Large Hadron Collider is studied by multiparticle tracking. In the simulations, we include the effect of long-range collisions together with the nonlinearities of IR triplets, sextupoles, and head-on collisions. The model includes the wires placed at the locations reserved for them in the LHC rings. We estimate the optimal parameters of a wire for compensating the parasitic beam-beam force by long-term simulations of emittance growth and lifetime. Benefits to the luminosity due to the wires are investigated.

### Study of Electron Lens in RHIC

H. J. Kim, T. Sen (Fermilab)

A beam-beam simulation code (bbsimc) has been developed to study the interaction between counter moving beams in colliders and its compensation through a low energy electron beam. This electron beam is expected to improve intensity lifetime and luminosity of the colliding beams by reducing the betatron tune shift and spread from the head-on collisions. In this paper we discuss the results of beam simulations with the electron lens in the Relativistic Heavy Ion Collider (RHIC). We study the effects of the electron beam profile, strength, position, and noise on the betatron tunes, dynamic aperture, emittance growth and beam lifetime.

### Analytical Description of Tevatron Integrated Luminosity

The recent record-setting performance of the Fermilab Tevatron is the culmination of a long series of efforts to optimize the many parameters that go into generating integrated luminosity for the colliding beams experiments. While several complex numerical computer models exist that are used to help optimize the performance of the Tevatron collider program, here we take an analytical approach in an attempt to illustrate the most fundamental aspects of integrating luminosity in the Tevatron. The essential features, such as weekly integrated luminosity and store length optimization, can be understood in a transparent way from basic operational parameters such as antiproton stacking rate and observed beam emittance growth rates in the Tevatron. Comparisons of the analytical model with operational data are provided.

**M. J. Syphers** (Fermilab)

WE6PFP033

### Electron Lens for Beam-Beam Compensation at LHC

Head-on beam-beam effect may become a major performance limitation for the LHC in one of the upgrade scenarios. Given the vast experience gained from the operation of Tevatron electron lenses, a similar device provides significant potential for mitigation of beam-beam effects at the LHC. In this report we present the results of simulation studies of beam-beam compensation and analyze potential application of electron lense at LHC and RHIC.

**A. Valishev, V. D. Shiltsev** (Fermilab)

WE6PFP034

### Suppression of Beam-Beam Tune Spread Using Hollow Electron Beam

Significant difference in transverse size of the proton and antiproton bunches at collision points is known to cause deterioration of the larger (proton) beam life time at Tevatron. The reason is believed to be in the combination of large betatron tune spread induced by the high nonlinearity of the beam-beam force, and limited tune space. We consider the prospects for application of hollow electron beam for beam-beam tune spread suppression.

**A. Valishev** (Fermilab)

WE6PFP035

### Tracking and Tolerances Study for the ATLAS High Beta Optics

For luminosity and total cross section measurement, the standard LHC physics optics has been modified for the ATLAS experiment in the so-called high beta optics with a beta star of 2600m. The high beta optics takes into account the whole LHC ring. Protons are, then, tracked from the Interaction Point to the detectors. Tolerances on the beta star are given and the effect of misalignment errors is checked. We show the final High beta optics used and the impact of the misalignment effect on the measurement.

**S. Cavalier, M. Heller** (LAL) **H. Burkhardt, P. M. Puzo, S. M. White** (CERN)

WE6PFP036

### 3D Strong-Strong Simulations of Wire Compensation of Long-Range Beam-Beam Effects at LHC

J. Qiang (LBNL)

In this paper, we report on studying wire compensation of long-range beam-beam effects using a fully 3D strong-strong beam-beam model. The simulations include two head-on collisions with 0.3 mrad crossing angle and 64 long-range beam-beam collisions near IP 1 and IP5. We found that using conducting wires with appropriate current level will compensate the tail emittance growth due to long-range beam-beam effects. The random fluctuation of current level should be controlled below 0.1% level for a good compensation. Lowering the long-range beam-beam separations by 20% together with wire compensation will improve the luminosity by a few percentage. Further reducing the beam-beam separations causes significant beam blow-up and decrease of luminosity.

In this paper, we report on studying wire compensation of long-range beam-beam effects using a fully 3D strong-strong beam-beam

### Strong-Strong Beam-Beam Simulation of Crab Cavity Compensation at LHC

J. Qiang (LBNL)

Crab cavity is proposed to compensate the geometric luminosity loss of crossing angle collision at LHC upgrade. In this paper, we report on strong-strong beam-beam simulation of crab cavity compensation at LHC using the BeamBeam3D code. Simulation results showed that using a pair of local compensation for each beam could significantly improve the beam luminosity at collision. However, this improvement could be lost with random offset errors from the RF deflection cavities.

Crab cavity is proposed to compensate the geometric luminosity loss of crossing angle collision at LHC upgrade. In this paper, we

### Emittance Growth due to Beam-Beam Effects with a Static Offset in Collision in the LHC

T. Pieloni (PSI) W. Herr (CERN) J. Qiang (LBNL)

Under nominal operational conditions, the LHC bunches experience small unavoidable offset at the collision points caused by long range beam-beam interactions. Although the geometrical loss of luminosity is small, one may have to consider an increase of the beam transverse emittance, leading to a deterioration of the experimental conditions. In this work we evaluate and understand the dynamics of beam-beam interactions with static offsets at the collision point. A study of the emittance growth as a function of the offset amplitude in collisions is presented. Moreover, we address the effects coming from the beam parameters such as the initial transverse beam size, bunch intensity and tune.

Under nominal operational conditions, the LHC bunches experience small unavoidable offset at the collision points caused by long

### Simulation of Compensation Mechanisms for Head-On and Parasitic Beam-Beam Collisions at LHC

A. C. Kabel (SLAC)

Progress in code capabilities and computational hardware make it feasible to simulate the full non-linear lattice dynamics of a storage-ring collider such as LHC, including head-on and parasitic beam-beam collisions, with simulated time approaching the operationally relevant timescale. The parallel tracking code PLIBB has been optimized toward this goal; its tracking capabilities include non-linear magnetic lattice elements, the beam-beam effect in the weak-strong or strong-strong approximation, and beam-beam compensation by electron lenses and current wires. A new PIC-based strong-strong capability includes the massively parallel treatment of multi-bunch effects. We will present simulation results for a series of parasitic and head-on beam-beam compensation scenarios.

Progress in code capabilities and computational hardware make it feasible to simulate the full non-linear lattice dynamics of a stor-



**Petavac: 100 TeV Proton-Antiproton Colliding Beams with High Luminosity**

A conceptual design is presented for a 100 TeV proton-antiproton collider consisting of a single storage ring based upon 16.5 T dipoles, installed in the 83 km circumference SSC tunnel, fed using a proportionately expanded antiproton source. Provisions have been designed to intercept synchrotron light on room-temperature photon stops and to suppress electron cloud effect using a continuous clearing electrode running throughout the collider. Beams would be separated using split dipoles so that 20 ns bunch spacing should be attainable. Synchrotron damping time of half-hour would help to stabilize against mechanisms for slow emittance growth. It is reasonable to project the potential for a luminosity of  $1 \cdot 10^{35}/\text{cm}^2/\text{s}$ .

**P. M. McIntyre, A. Sattarov** (Texas A&M University)

WE6PFP041

**Design of Interaction Region at SuperKEKB**

SuperKEKB is an upgrade plan for the KEKB project. One of the key issue at SuperKEKB is the IR (Interaction Region) design. We plan to squeeze the vertical beta function down to 3 mm. In this paper, we give a brief summary of the present design and discuss problems related to the IR design such as the dynamic aperture, the physical aperture in IR, heating of IR components and the detector beam background.

**Y. Funakoshi, T. Kageyama, K. Kanazawa, H. Koiso, K. Ohmi, Y. Ohnishi, N. Ohuchi, K. Oide, K. Shibata, M. Tawada** (KEK) **M. Iwasaki** (University of Tokyo)

WE6PFP042

**Recent Progress of KEKB**

Crab cavities were installed at KEKB at the beginning of 2007. The beam operation with the crab cavities is in progress. In this paper, machine performance with crab crossing is described focusing on a specific luminosity and a beam lifetime issue related to the dynamic beam-beam effects.

**Y. Funakoshi** (KEK)

WE6PFP043

**Lattice Design for SuperKEKB**

Lattice design for SuperKEKB is based on the present KEKB lattice. The unit-cell structure of KEKB has a wide range of flexibility, therefore main beam-optical parameters can be adjusted without changing the arcs. The interaction region (IR) and the other straight sections are changed to squeeze the vertical beta function to 3 mm at IP, keeping sufficient dynamic apertures. Recent progress such as a new design of IR with superconducting quadrupole magnets at 1.9 K, traveling focus scheme by using crab cavities, local chromaticity correction for the high energy ring, is presented.

**H. Koiso, A. Morita, Y. Ohnishi, K. Oide** (KEK)

WE6PFP044

### Beam Dynamics for Very High Beam-Beam Parameter in an $e^+e^-$ Collider

K. Ohmi (KEK)

Beam-beam tune shift parameter characterizes the strength of the nonlinear interaction due to the beam-beam collision. The tune shift has been measured in many  $e^+e^-$  colliders and has been an indicator for the collider performance. The record for the tune shift is known as 0.07-0.1 depending on the parameter of the collider, especially the radiation damping rate. We discuss the fundamental limit of the tune shift can be very high ( $>0.2$ ) depending on the choice of collider parameter, which concerns operating point near the half integer tune, head-on collision and travel focus.

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### Variations in Beam Phase and Related Issues Observed in KEKB

T. Ieiri, K. Akai, M. Tawada, M. Tobiyama (KEK)

KEKB is a multi-bunch, high-current electron-positron collider. Newly installed crab cavities realized an effective head-on collision, while maintaining finite-angle crossing orbits. Bunches form a single train followed by a beam abort gap. We observed a beam phase advancing along a train due to transient beam loading. Since there is a difference in the beam phase between the two beams, a longitudinal displacement of the collision vertex is expected under the crabbing collision. Estimated variations agree with those detected by the Belle\*. A displacement in the horizontal beam position was observed in correspondence with the variations in the beam phase. We found that the horizontal displacement was caused by a transverse kick of the crab cavities to phase-shifted bunches. Moreover, a rapid phase advancing was observed at the leading part in a train in the LER. We suspect that some longitudinal wakes with low Q values in accelerator components might contribute to the rapid change in the beam phase.

\*H. Kichimi et al., to be published.

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### The SuperB Project and Site Layout

S. Tomassini, M. E. Biagini, R. Boni, E. Di Pasquale, L. Pellegrino, R. Ricci, C. Sanelli, F. Sgammà (INFN/LNF) P. Raimondi, J. Seeman (SLAC)

The SuperB collider project aims at the construction of an asymmetric high luminosity B-Factory in the Tor Vergata University campus in Rome (Italy). The engineering aspects of the SuperB design and construction with the aim to reuse at maximum the PEP II components will be presented. Sinergies with the Italian FEL project SPARX, which will start civil construction this year, will be discussed. The two projects can share the Linac tunnel and other facilities. A study of ground motion will also be presented.

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### Low Beta Region Muon Collider Detector Design

M. A.C. Cummings (Muons, Inc) D. Hedin (Northern Illinois University)

Detector designs for muon colliders have lacked coverage in the forward and backward angular regions, limiting their physics potential. These regions require massive shielding, mainly due to the intense radiation produced by the decay electrons from the muon beams. Emerging technologies for instrumentation could be used to detect particles in these regions that were filled with inert material in previous designs. New solid state photon sensors that are fine-grained, insensitive to magnetic fields, radiation-resistant, fast, and inexpensive can be used with highly segmented detectors in the regions near the

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beams. We are developing this new concept by investigating the properties of these new sensors and including them in numerical simulations to study interesting physics processes and backgrounds to improve the designs of the detector, the interaction region, and the collider itself.

### Crab Waist Collision Scheme: Numerical Simulations versus Experimental Results

A novel scheme of crab waist collisions has been successfully tested at the electron-positron collider DAFNE, Italian Phi-factory. In this paper we compare numerical simulations of the crab waist beam-beam interaction with obtained experimental results. For this purpose we perform weak-strong and quasi strong-strong beam-beam simulations using a realistic DAFNE lattice model that has proven to reproduce reliably both linear and nonlinear collider optics.

**P. A. Piminov**, E. B. Levichev, D. N. Shatilov (BINP SB RAS) C. Milardi, M. Zobov (INFN/LNF) K. Ohmi (KEK)

WE6PFP049

### Longitudinal Bunch Position Control for the SuperB Accelerator

The use of normal conducting cavities and an ion-clearing gap will cause a significant RF accelerating voltage gap transient and longitudinal phase shift of the individual

**C. H. Rivetta**, K. J. Bertsche, M. K. Sullivan (SLAC) A. Drago (INFN/LNF)

bunches along the bunch train in both rings of the SuperB accelerator. Small relative centroid position shifts between bunches of the colliding beams will have a large adverse impact on the luminosity due to the small beta  $y^*$  at the interaction point (IP). We investigate the possibility of minimizing the relative longitudinal position shift between bunches by reducing the gap transient in each ring and matching the longitudinal bunch positions of the two rings at the IP using feedback/feedforward techniques in the LLRF. The analysis is conducted assuming maximum use of the klystron power installed in the system.

WE6PFP050

### Further Progress on a Design for a Super-B Interaction Region

We present an improved design for a Super-B interaction region. The new design minimizes local bending of the two colliding beams by separating all beam magnetic elements near the Interaction Point (IP). The total crossing angle at the IP is increased from 50 mrad to 60 mrad. The first magnetic element is a six slice Permanent Magnet (PM) quadrupole with an elliptical aperture allowing us to increase the vertical space for the beam. This magnet starts 36 cm from the Interaction Point (IP). This magnet is only seen by the Low-Energy Beam (LEB), the High-Energy Beam (HEB) has a drift space at this location. This allows the preliminary focusing of the LEB which has a smaller beta  $y^*$  at the IP than the HEB. The rest of the final focusing for both beams is achieved by two super-conducting side-by-side quadrupoles (QD0 and QF1). These sets of magnets are enclosed in a warm bore cryostat located behind the PM quadrupole for the LEB. We describe this new design for the interaction region.

**M. K. Sullivan**, K. J. Bertsche (SLAC) S. Bettoni (CERN) E. Paoloni (University of Pisa and INFN) P. Raimondi (INFN/LNF)

WE6PFP051

### Changing the PEP-II Center-of-Mass Energy from 10 GeV to 11 GeV

M. K. Sullivan, K. J. Bertsche, F.-J. Decker, S. Ecklund, A. S. Fisher, J. D. Fox, A. Novokhatski, C. H. Rivetta, J. Seeman, D. Van Winkle, U. Wienands, W. Wittmer, G. Yocky (SLAC) W. X. Cheng (BNL)

The PEP-II B-Factory was designed and optimized to run at the Upsilon 4S resonance (10.580 GeV with a 9 GeV  $e^-$  beam and a 3.1 GeV  $e^+$  beam). The interaction region (IR) used permanent magnet dipoles to bring the beams into a head-on collision. The first focusing element for both beams was also a permanent magnet. The IR geometry, masking, beam orbits and beam pipe apertures were designed for 4S running. Even though PEP-II was optimized for the 4S, we successfully changed the center-of-mass energy (Ecm) down to the Upsilon 2S resonance and completed an Ecm scan from the 4S resonance up to 11.2 GeV. The luminosity throughout these changes remained near  $1 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ . The Ecm was changed by moving the energy of the high-energy beam (HEB). The beam energy differed by more than 20% which produced significantly different running conditions for the RF system. The energy loss per turn changed 2.5 times over this range. We describe how the beam energy was changed and discuss some of the consequences for the beam orbit in the interaction region. We also describe some of the RF issues that arose and how we solved them as the high-current HEB energy changed.

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### A Proposed Fast Luminosity Feedback for the Super-B Accelerator

M. K. Sullivan, K. J. Bertsche, R. C. Field, A. S. Fisher (SLAC) A. Drago (INFN/LNF)

the PEP-II accelerator. During the last two runs of PEP-II and BaBar (2007-2008), we had an improved luminosity feedback system that was able to maintain peak luminosity with faster correction speed than the previous system. The new system utilized fast dither coils on the High-Energy Beam (HEB) to independently dither the x position, the y position and the y angle at the IP, at roughly 100 Hz. The luminosity signal was then read out with three independent lock-in amplifiers. An overall correction was computed based on the lock-in signal strengths and beam corrections for position in x and y and in the y angle at the IP were simultaneously applied to the HEB. With the 100 times increase in luminosity for the SuperB design, we propose using a similar fast luminosity feedback that can operate at frequencies between DC and 1 kHz, high enough to be able to follow and nullify any vibrational beam motion from the final focusing magnets.

We present a possible design for a fast luminosity feedback for the Super-B Interaction Point (IP). The design is an extension of the fast luminosity feedback installed on

### Polarized Beams in the SuperB High Energy Ring

W. Wittmer, U. Wienands (SLAC) M. E. Biagini, P. Raimondi (INFN/LNF) A. V. Bogomyagkov, I. Koop, S. A. Nikitin (BINP SB RAS)

The proposed SuperB factory will provide longitudinal polarized electrons to the experiment. Vertically polarized electrons will be injected into the High Energy Ring; the vertical spin orientation will be locally rotated into the longitudinal direction before the interaction point and back afterwards to avoid spin depolarization. The spin rotators can be designed using compensated solenoids—as proposed by Zholents and Litvinenko—to rotate the spin into the horizontal plane, followed by dipoles for horizontal spin rotation into the longitudinal direction. Such spin rotators have been matched into the existing lattice and combined with the crab-waist IR. Several ways of achieving this are explored, that differ in the degree of spin matching achieved and the overall geometry of the interaction region. The spin rotation can also be achieved by a series of dipole magnets only, which present a different optical matching problem. We will compare the different scenarios leading up to the adopted solution.

The proposed SuperB factory will provide longitudinal polarized electrons to the experiment. Vertically polarized electrons will be injected into the High Energy Ring; the vertical spin orientation will be locally rotated

### Simulation and Observation of Beam-Beam Induced Emittance Growth in RHIC

In the recent years the peak luminosity of the RHIC polarized proton run has been improved. However, as a consequence, the luminosity lifetime is reduced. The beam emittance growth during the beam storage is a main contributor to the luminosity lifetime reduction, and it seems to be caused mainly by the beam-beam effect during collision. It is, therefore, important to better understand the beam-beam collision effects in RHIC with the aid of particle tracking codes. A simulation study of the emittance growth is performed with RHIC machine parameters using the LIFETRAC code\*. The initial results of this study were reported in an earlier paper\*\*. In order to achieve a better understanding and to provide guidance for future RHIC operations, we present an in depth investigation of the emittance growth for a range of RHIC operation tunes, bunch lengths and initial emittance. The simulation results are also compared to the available data from experimental measurements.

J. Beebe-Wang, S. Y. Zhang (BNL)

\*D. Shatilov, et al., "Lifetrac Code for the Weak-Strong Simulation of the Beam-Beam Effects in Tevatron", PAC05 proc.

\*\*J. Beebe-Wang, "Emittance Growth due to Beam-Beam Effect in RHIC", PAC07 Proc.

### Investigation of the Radiation Background in the Interaction Region of a RHIC-Based Medium-Energy Electron-Ion Collider (MEeIC)

A staged approach towards the development of a high energy RHIC-based electron-ion collider has been proposed in BNL\*. In the first stage, a medium-energy electron-ion collider (MEeIC) would be constructed. It would utilize a high energy ion beam, accelerated in one of the two existing rings of the RHIC facility, colliding with a medium energy (4GeV) electron beam, generated by a proposed energy-recovery linac. As a part of the design and investigation of the interaction region, it is necessary to estimate the level of background radiation in the physics experiment detector. The primary radiation distribution can be readily calculated by employing electromagnetic theory. However, the secondary radiation is due to a diffuse scattering of soft X-ray off rough surfaces. In this paper, we first calculate the primary radiation spectrum and apply the kinematic Born approximation deduced from the scattering dynamics. Next, the diffuse scattering cross section is calculated as a function of the material and surface properties of the MEEIC vacuum system. Finally, the minimization of the radiation background level by the choices of the material and surface properties is discussed.

J. Beebe-Wang (BNL)

\*V. Ptitsyn et al., "MEeIC - staging approach to eRHIC", these proceedings.

### Beam-Beam Interaction Study of Medium Energy Electron-Ion Collider

Medium Energy Electron Ion Collider (MEeIC), the first stage design of eRHIC, includes a multi-pass ERL that provides 4GeV high quality electron beam to collide with the ion beam of RHIC. It delivers a minimum luminosity of  $10^{32} \text{ cm}^{-2}\text{s}^{-1}$ . Beam-beam effects present one of major factors limiting the luminosity of colliders. In this paper, both beam-beam effects on electron beam and proton beam in MEEIC are investigated. First, the beam-beam interaction can induce specific head-tail type instability of the proton beam referred to as kink instability. Thus, beam stability conditions should be established to avoid proton beam loss. Also, the electron beam transverse disruption by collisions has

Y. Hao, V. Litvinenko, V. Ptitsyn (BNL)

to be evaluated to ensure beam quality is good enough for the energy recovery pass. The relation of proton beam stability, electron disruption and consequential luminosity is carried out after thorough discussion.

### Electron Pinch Effect in Beam-Beam Interaction of ERL Based eRHIC

Y. Hao, V. Litvinenko, V. Ptitsyn (BNL)

Beam-beam effects present one of major factors limiting the luminosity of colliders. In the linac-ring option of the eRHIC design, an electron beam accelerated in a superconducting energy recovery linac collides with a proton beam circulating in the RHIC ring. Some specific features of beam-beam interactions should be carefully evaluated for the linac-ring configuration. One of the most important effects on ion beam stability originates from a strongly focused electron beam because of the beam-beam force. This electron pinch effect makes the beam-beam parameter of the ion beam several times larger than the design value, and leads to the fast emittance growth of the ion beam. The electron pinch effect can be controlled by adjustments of electron lattice and the incident emittance. We present results of simulations optimizing ion beam quality in the presence of this pinch effect.

Beam-beam effects present one of major factors limiting the luminosity of colliders. In the linac-ring option of the eRHIC design,

### Interaction Region Design for a RHIC-Based Medium-Energy Electron-Ion Collider

C. Montag, J. Beebe-Wang (BNL)

of the RHIC interaction regions is currently under investigation. To minimize costs, the interaction region of this collider has to utilize the present RHIC magnets for focussing of the high-energy ion beam. Meanwhile, electron low-beta focussing needs to be added in the limited space available between the existing separator dipoles. We discuss the challenges we are facing and present the current design status of this e-A interaction region.

As first step in a staged approach towards a RHIC-based electron-ion collider, installation of a 4 GeV energy-recovery linac in one

### eRHIC Ring-Ring Design with Head-on Beam-Beam Compensation

C. Montag, M. Blaskiewicz, W. Fischer, W. W. MacKay, E. Pozdeyev (BNL)

limit can be increased by means of an electron lens that compensates the beam-beam effect experienced by the electron beam. This scheme requires proper design of the electron ring, providing the correct betatron phase advance between interaction point and electron lens. We review the performance of the eRHIC ring-ring version and discuss various parameter sets, based on different cooling schemes for the proton/ion beam.

The luminosity of the eRHIC ring-ring design is limited by the beam-beam effect exerted on the electron beam. Recent simulation studies have shown that the beam-beam

### Beta\* and Beta\* Waist Measurement and Control at RHIC

V. Ptitsyn, A. J. Della Penna, V. Litvinenko, N. Malitsky, T. Satogata (BNL)

ensure the agreement of the actual machine optics with the design one, more precise measurements and control of beta\* value and beta\* waist location became necessary. The paper presents the results of the implementation of

During the course of last RHIC runs the beta-functions at the collision points (beta\*) have been reduced gradually to 0.7m. In order to maximize the collision luminosity and ensure

the technique applied in last two RHIC runs. The technique is based on well-known relation between the tune shift and the beta function and involves precise betatron tune measurements using BBQ system as well as specially developed knobs for beta\* and beta\* waist location control.

### MEeIC - Staging Approach to eRHIC

Design of a medium energy electron-ion collider (MEeIC) is under development at Collider-Accelerator Department, BNL. The design envisions a construction of 4 GeV electron accelerator in a local area inside the RHIC tunnel. The electrons will be produced by a polarized electron source and accelerated in the energy recovery linac. Collisions of the electron beam with 100 GeV/u heavy ions or with 250 GeV polarized protons will be arranged in the existing IP2 interaction region of RHIC. The luminosity of electron-proton collisions at  $10^{32} \text{ cm}^{-2} \text{ s}^{-1}$  level will be achieved with 40 mA CW electron current with presently available parameters of the proton beam. Efficient cooling of proton beam at the collision energy may bring the luminosity to  $10^{33} \text{ cm}^{-2} \text{ s}^{-1}$  level. The important feature of the MEEIC is that it would serve as first stage of eRHIC, a future electron-ion collider at BNL with both higher luminosity and energy reach. The majority of the MEEIC accelerator components will be used for eRHIC.

V. Ptitsyn, J. Beebe-Wang, I. Ben-Zvi, A. V. Fedotov, Y. Hao, A. Kayran, V. Litvinenko, C. Montag, E. Pozdeyev, T. Roser, S. Tepikian, D. Trbojevic, N. Tsoupas (BNL) A. Deshpande (Stony Brook University)

WE6PFP062

### A Concept for a Polarized Electron-Nucleon Collider at the HESR of the FAIR Project

The feasibility of a polarized Electron-Nucleon Collider (ENC) with a center-of-mass energy up to 13.5 GeV for luminosities above  $2 \cdot 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$  is presently under consideration. The proposed concept integrates the planned 14 GeV High-Energy Storage Ring (HESR) for protons/deuterons and an additional 3 GeV electron ring. Calculations of cooled beam equilibria including intra-beam scattering and beam-beam interaction have been performed utilizing the BetaCool code. A special design of the interaction region is required to realize back-to-back operation of the HESR storage ring together with the elaborated collider mode. For polarized proton/deuteron beams additional equipment has to be implemented in several machines of the acceleration chain and the HESR to preserve the beam's polarization. A scheme for polarized electrons is still under investigation. In this presentation the required modifications and extensions of the HESR accelerator facility at the future International Facility for Antiproton and Ion Research (FAIR) are discussed and the proposed concept is presented.

A. Lehrach (FZJ) K. Aulenbacher, A. Jankowiak (IKP) W. Hillert (ELSA) T. Weis (DELTA)

WE6PFP063

### Achromatic Interaction Point Design

Designers of high-luminosity energy-frontier muon colliders must provide strong beam focusing in the interaction regions. However, the construction of a strong, aberration-free beam focus is difficult and space consuming, and long straight sections generate an off-site radiation problem due to muon decay neutrinos that interact as they leave the surface of the earth. Without some way to mitigate the neutrino radiation problem, the maximum energy of a muon collider will be limited to about 4 TeV. A new concept for achromatic low beta designs is being developed, in which the interaction region telescope,

Y. S. Derbenev, S. A. Bogacz (JLAB) C. M. Ankenbrandt, V. Ivanov, R. P. Johnson, G. M. Wang (Muons, Inc)

WE6PFP064

optical correction elements, and final focusing magnets are installed in the bending arcs. The concept, formulated analytically, combines space economy, a preventative approach to compensation for aberrations, and a reduction of neutrino flux concentration. An analytical theory for the aberration-free, low beta, spatially compact insertion is being developed including analysis beyond second order aberration terms. Dynamic aperture, momentum acceptance, and error sensitivity studies have been initiated for comparison to previous designs.

### Recent Progress on Design Studies of High-Luminosity Ring-Ring Electron-Ion Collider at CEBAF

Y. Zhang, S. A. Bogacz, A. Bruell, P. Chevtsov, Y. S. Derbenev, R. Ent, G. A. Krafft, R. Li, L. Merminga, B. C. Yunn (JLAB)

The conceptual design of a ring-ring electron-ion collider based on CEBAF has been continuously optimized to cover a wide center-of-mass energy region and to achieve

high luminosity and polarization to support next generation nuclear science programs. Here, we summarize the recent design improvements and R&D progress on interaction region optics with chromatic aberration compensation, matching and tracking of electron polarization in the  $10^{-8}$  ring, beam-beam simulations and ion beam cooling studies.

### Opportunities for a Low to Medium Energy Electron-Ion Collider Based on CEBAF and Staging Approach to ELIC

Y. Zhang, S. A. Bogacz, Y. S. Derbenev, T. Horn, M. Hutton, C. Hyde, G. A. Krafft, A. W. Thomas, C. Weiss (JLAB)

Significant efforts have been made recently at JLab for exploring the possibility of a low to medium energy polarized ring-ring electron-ion collider based on the CEBAF. It

is envisioned that the electron beam of this collider will take full advantage of the 12 GeV upgraded CEBAF with an energy range up to 11 GeV. The ion complex will consist of sources, SRF injection linac, booster and storage-collider rings, and will provide ion beams with similar energy ranges as the electron beam or up to 30 GeV/c. Currently, various combinations of colliding electron and ion energies are under consideration, aiming for maximum science productivity, and the opportunity of a green field design of the ion complex allows us to achieve the maximum optimization for the intended science programs. Several design features including traveling focusing and staged ion beam cooling will help to suppress collective instabilities and to improve the collider capability, pushing luminosity to the level at or above  $10^{33}$  s $^{-1}$ cm $^{-2}$ . This low to medium energy collider could also serve as a first stage of ELIC, a high energy high luminosity (up to  $10^{35}$  s $^{-1}$ cm $^{-2}$ ) polarized electron-ion collider at JLab.

### Simulation Studies of Beam-Beam Effects of Electron-Ion Collider at CEBAF

Y. Zhang (JLAB) J. Qiang (LBNL)

The collective beam-beam effect can potentially cause a rapid growth of beam sizes and reduce the luminosity of a collider to

an unacceptably low level. The ELIC, a proposed ultra high luminosity electron-ion collider based on CEBAF, employs high repetition rate crab crossing colliding beams with very small bunch transverse sizes and very short bunch lengths, and collides them at up to 4 interaction points with strong final focusing. All of these features can make the beam-beam effect challenging. In this paper, we present simulation studies of the beam-beam effect in ELIC using a self-consistent strong-strong beam-beam simulation code developed at Lawrence Berkeley National



Laboratory. This simulation study is used for validating the ELIC design and for searching for an optimal parameter set.

### Emittance Evolution of the Drive Electron Beam in Helical Undulator for ILC Positron Source

The effect of ILC positron source's helical undulator to the drive electron beam is of great interest. People have been looking into the effect of wakefield, quad misalignment and also the effect of radiation. In this paper we'll report an emittance damping effect of the ILC positron source undulator to the drive electron beam and our QUAD-BPM error simulation results. For 100m RDR undulator, the emittance of drive electron beam will be damped down by about 1% instead of growing as the damping is stronger than quantum excitation for this RDR undulator with the RDR drive electron beam. Quad-BPM misalignment simulations show that a 20um rms misalignment error in a 250m long undulator beamline can cause about 5% emittance growth in drive electron beam. Taking into consider the damping effect of undulator, the net emittance growth will be smaller.

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WE6PFP068

### ILC Main Linac Beam Dynamics Incorporating Cavity Fabrication Errors

Higher order modes (HOMs) have been simulated with finite element and finite difference computer codes for the ILC superconducting cavities, currently under investigation for the ILC. In particular, HOMs in KEK's Ichiro type of cavity and Cornell University's Reentrant design are the focus of this work. A detuning of the higher order modes will be observed as a result of errors in fabrication of the cavities. Further, the cool down to cryogenic operational temperature will cause the cavity shape to alter, in order to compensate this effect on the fundamental mode mechanical tuners will be employed to alter the length of the cavity and regain field flatness. This process will further shift the higher order modes for a each cavity. In this paper we present results of beam dynamics simulations in which models of the detuning effects described above have been incorporated, and the emittance dilution due to this realistic long range wake has been recorded. We take advantage of the latest beam dynamics codes in order to perform these simulations.

C. J. Glasman, R. M. Jones (UMAN)

WE6PFP069

### Photon Backgrounds at the CLIC Interaction Point due to Losses in the Post-Collision Extraction Line

The CLIC beam delivery system focuses 1.5 TeV electron and positron beams to a nanometre-sized cross section when colliding them at the interaction point (IP). The intense focusing leads to large beam-beam effects, causing the production of beamstrahlung photons, coherent and incoherent electron-positron pairs, as well as a significant disruption of the main beam. The transport of the post-collision beams requires a minimal loss extraction line, with high acceptance for energy deviation and divergence. The current design includes vertical bends close to the IP in order to separate the charged particles with a sign opposite to the main beam into a diagnostic-equipped intermediate dump, whilst transporting the photons and the main beam to the main dump. Photon and charged particle losses on the collimators and dumps result in a

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WE6PFP070

complex radiation field and IP background particle fluxes. In this paper, the electromagnetic backgrounds at the IP, which arise from these losses, are calculated, and the potential impact on the detector is discussed.

### ATF2 Spot Size Tuning Using the Rotation Matrix Method

A. Scarfe, R. Appleby (UMAN) D. Angal-Kalinin, J. K. Jones (STFC/DL/ASTeC)

The Accelerator Test Facility (ATF2) at KEK aims to experimentally verify the local chromaticity correction scheme to achieve a vertical beam size of 37nm. The facility is a scaled down version of the final focus design proposed for the future linear colliders. In order to achieve this goal, high precision tuning methods are being developed. One of the methods proposed for ATF2 is a novel method known as the 'rotation matrix' method. Details of the development and testing of this method, including orthogonality optimisation and simulation methods, are presented.

The Accelerator Test Facility (ATF2) at KEK aims to experimentally verify the local chromaticity correction scheme to achieve a vertical beam size of 37nm. The facility is a

### Ultimate Positron Polarization at ILC

A. A. Mikhailichenko (Cornell University, Department of Physics)

We are analyzing ILC positron source for best polarization and efficiency. 70% polarization looks feasible for 170 m undulator at 150 GeV. Conversion efficiency and polarization at 500 GeV considered also. We are making suggestions for reaching 80% positron polarization AT ILC as well.

We are analyzing ILC positron source for best polarization and efficiency. 70% polarization looks feasible for 170 m undulator

### Scheme for gamma-gamma Collisions at ILC

A. A. Mikhailichenko (Cornell University, Department of Physics)  
H. Aksakal (N. U)

We consider a scheme for gamma-gamma collisions at ILC. In our scheme the electron beam from 5 GeV injector-Linacs, present in ILC scheme, used in FEL amplifier. The laser radiation from solid-state laser amplified in this FEL and directed to nearby IP point for further Compton back scattering. Two additional ~50 m helical undulators and master laser system of intermediate power required for this scheme at ILC.

We consider a scheme for gamma-gamma collisions at ILC. In our scheme the electron beam from 5 GeV injector-Linacs, present in ILC scheme, used in FEL amplifier. The

### Failures in the Main Linac of the International Linear Collider and their Effect on the Beam Delivery System

I. Melzer-Pellmann, D. Kruecker, F. Poirier, N. J. Walker (DESY)

The International Linear Collider (ILC) relies on very high beam powers and very small beam emittance to achieve the ambitious luminosity of  $2 \cdot 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ . The potential for damage to the accelerator hardware in the event of some machine failure will require a sophisticated machine protection system. The small apertures in the Beam Delivery System (BDS) - specifically the collimators (by definition the smallest apertures in the machine) are particularly critical. Possible failures in the Main Linac of the ILC and their impact on the BDS are studied using the MERLIN C++ library\*. We show that the machine is safe for at least one bunch in case of one of the described failures; a fast abort system is designed to safely extract the remainder of the bunches in the pulse to a dump. Investigated are phase and voltage shifts of the klystrons, quadrupole and corrector coil failures.

The International Linear Collider (ILC) relies on very high beam powers and very small beam emittance to achieve the ambi-

\*Merlin - A C++ Class Library for Accelerator Simulations; <http://www.desy.de/~merlin>.

### Study of the Effect of the Non-Linear Magnetic Fields in the Extraction Region of the ATF Extraction Line on the Emittance Growth

Since several years, the vertical beam emittance measured in the Extraction Line (EXT) of the Accelerator Test Facility (ATF) at KEK, has been significantly larger than that measured in the damping ring (DR) itself. The EXT line that transports the beam to the ATF2 Final Focus beam line has been rebuilt, but the extraction itself remains in most part unchanged, with the extracted beam transported off-axis horizontally in two of the quadrupoles, beyond the linear region for one of them. A few other nearby magnets have also modelled or measured non-linearity. In case of a residual vertical beam displacement, this can result in increased vertical emittance through coupling between the two transverse planes. Tracking studies as well as measurements have been carried out to study this effect and the induced sensitivity of beam optical parameters to the trajectory at injection, in view of deriving tolerances for reproducible and stable operation.

**M. Alabau**, P. Bambade, G. Le Meur, F. Touze (LAL) A. Faus-Golfe (IFIC) S. Kuroda (KEK) M. Woodley (SLAC)

WE6PFP075

### CLIC Drive Beam Frequency Multiplication System Design

The CLIC drive beam current, produced by the 1 GHz fully loaded Linac, will be multiplied by a factor of 24 by the frequency multiplication system, to generate the high power beam representing the CLIC power source. The frequency multiplication system is composed by one delay loop plus two combiner rings. All rings will be isochronous, will contain trajectory tuning wigglers, and all magnets will be normal conducting. The design of the rings, with special emphasis on the rf deflectors characteristics, is presented.

**C. Biscari**, D. Alesini, A. Ghigo, F. Marcellini (INFN/LNF) J. B. Jeanneret (CERN)

WE6PFP076

### Beam Test Results with the FONT4 ILC Prototype Intra-Train Beam Feedback System

We present the results of beam tests of the FONT4 ILC prototype intra-train beam feedback system. The system comprises a stripline BPM, a fast analogue BPM signal processor, a custom FPGA-based digital feedback board, a high-power fast-response drive amplifier, and a stripline kicker. The hardware was deployed at the Accelerator Test Facility at KEK. Trains comprising three electron bunches were extracted from the ATF damping ring, with bunch spacing c. 150ns. The feedback loop was closed by measuring the position of bunch 1 and correcting bunches 2 and 3. We report the performance of the feedback, including gain studies, the correction dynamic range, latency measurement, and quality of the beam position correction. The system achieved micron-level bunch stabilisation with a latency of c. 140ns.

**P. Burrows**, R. Apsimon, C. I. Clarke, B. Constance, H. Dabiri Khah, A. F. Hartin, C. Perry, J. Resta-López, C. Swinson (JAI) G. B. Christian (ATOMKI) A. Kalinin (STFC/DL/ASTeC)

WE6PFP077

## Functional Requirements on the Design of the Detectors and the Interaction Region of an $e^+e^-$ Linear Collider with a Push-Pull Arrangement of Detectors

T. W. Markiewicz, M. Oriunno, A. Seryi (SLAC) K. Buesser (DESY)  
P. Burrows (OXFORDphysics) A. A. Mikhailichenko (Cornell University, Department of Physics) B. Parker (BNL) T. Tauchi (KEK)

The Interaction Region of the International Linear Collider\* is based on two experimental detectors working in a push-pull mode. A time efficient implementation of this model sets specific requirements and challenges

for many detector and machine systems, in particular the IR magnets, the cryogenics and the alignment system, the beamline shielding, the detector design and the overall integration. This paper attempts to separate the functional requirements of a push pull interaction region and machine detector interface from the conceptual and technical solutions being proposed by the ILC Beam Delivery Group and the three detector concepts\*\*. As such, we hope that it provides a set of ground rules for interpreting and evaluation the MDI parts of the proposed detector concept's Letters of Intent, due March 2009. The authors of the present paper are the leaders of the IR Integration Working Group within Global Design Effort Beam Delivery System and the representatives from each detector concept submitting the Letters Of Intent.

\*ILC Reference Design Report, ILC-Report-2007-01.

\*\*Materials of IR Engineering Design Workshop, 2007, <http://www-conf.slac.stanford.edu/ireng07>

## Conceptual Design of the Drive Beam for a PWFALC

S. Pei, M. J. Hogan, T. O. Raubenheimer, A. Seryi (SLAC) H.-H. Braun, R. Corsini, J.-P. Delahaye (CERN)

Plasma Wake-Field Acceleration (PWFA) has demonstrated acceleration gradients above 50 GeV/m. Simulations have shown drive/witness bunch configurations that

yield small energy spreads in the accelerated witness bunch and high energy transfer efficiency from the drive bunch to the witness bunch, ranging from 30% for a Gaussian drive bunch to 95% for shaped longitudinal profile. These results open the opportunity for a linear collider that could be compact, efficient and more cost effective than the present microwave technologies. A concept of a PWFA-based Linear Collider (PWFA-LC) has been developed by the PWFA collaboration. In this paper, we will describe the conceptual design and optimization of drive beam, which includes the drive beam linac and distribution system. We apply experience of the CLIC drive beam design to this study. We discuss parameter optimization of the drive beam linac structure and evaluate the drive linac efficiency in terms of the drive beam distribution scheme and the klystron/modulator requirements.

## Optics Design for FACET

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FACET is a proposed facility at SLAC National Accelerator Laboratory for beam driven plasma wakefield acceleration research. It is proposed to be built in the SLAC linac

sector 20, where it will be separated from the LCLS located downstream and will gain the maximum beam energy from the upstream two kilometers of linac. FACET will also include an upgrade to linac sector 10, where a new  $e^+$  compressor chicane will be installed. The sector 20 will require a new optics consisting of two chicanes for  $e^+$  and  $e^-$  bunch length compression, a final focus system and an extraction line. The two chicanes will allow the transport of  $e^-$  and  $e^+$  bunches together, their simultaneous compression and proper positioning of  $e^+$  bunch behind  $e^-$  at the plasma Interaction Point (IP). For a minimal cost, the new optics will mostly use the existing

SLAC magnets. The desired beam parameters at the IP are: up to 23 GeV beam energy,  $2 \cdot 10^{10}$  charge per bunch, 10 micron round beam spot without dispersion and 25 micron bunch length. Details of the FACET optics design and results of particle tracking simulations are presented.

### A Concept of Plasma Wake Field Acceleration Linear Collider (PWFA-LC)

Plasma Wake-Field Acceleration (PWFA) has demonstrated acceleration gradients above 50 GeV/m. Simulations have shown drive/witness bunch configurations that yield small energy spreads in the accelerated witness bunch and high energy transfer efficiency from the drive bunch to the witness bunch, ranging from 30% for a Gaussian drive bunch to 95% for shaped longitudinal profile. These results open the opportunity for a linear collider that could be compact, efficient and more cost effective than the present microwave technologies. A concept of a PWFA-based Linear Collider (PWFA-LC) has been developed and is described in this paper. The scheme of the drive beam generation and distribution, requirements on the plasma cells, and optimization of the interaction region parameters are described in detail. The research and development steps, necessary for further development of the concept, are also outlined.

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### Power Saving Optimization for Linear Collider Interaction Region Parameters

Optimization of Interaction Region parameters of a TeV energy scale linear collider has to take into account constraints defined by phenomena such as beam-beam focusing forces, beamstrahlung radiation, and hour-glass effect. With those constraints, achieving a desired luminosity of about  $2 \cdot 10^{34}$  would require use of  $e^+e^-$  beams with about 10 MW average power. It is shown in this paper that application of the "travelling focus" regime [V. Balakin, 1991] may allow reduction of required beam power by at least a factor of two, helping cost reduction of the collider, while keeping the beamstrahlung energy loss reasonably low. The technique is illustrated in application to 500 GeV CM parameters of the International Linear Collider. Application of this technique may also in principle allow recycling the  $e^+e^-$  beams and/or recuperation of their energy.

A. Seryi (SLAC)

### Free Electron Laser for gamma-gamma Collider at a Low-Energy Option of International Linear Collider

Different scenarios of a start-up with international linear collider (ILC) are under discussion at the moment in the framework of the Global Design Effort (GDE). One of them assumes construction of the ILC in stages from some minimum CM energy up to final target of 500 GeV CM energy. Gamma-gamma collider with CM energy of 180 GeV is considered as a candidate for the first stage of the facility. In this report we present conceptual design of a free electron laser as a source of primary photons for the first stage of ILC.

E. Saldin, E. Schneidmiller, M. V. Yurkov (DESY) A. Seryi (SLAC)

WE6PFP084

### High Average Power Lasers for the Photon Collider

J. Gronberg (LLNL) A. Seryi (SLAC)

A high energy photon-photon collider can be created by the combination of electron linear accelerators with terawatt peak power lasers to create high energy photon beams through Compton backscattering. The realization of this option requires of order 10kW of average laser power if each laser pulse is used once and discarded. Proposals for recirculating cavities to allow the laser light to be reused open the potential for laser systems with much lower required average power. We review the current status of laser technology and it's ability to realize a photon collider system.

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WE6PFP085

### Halo and Tail Simulations with Application to the CLIC Drive Beam

M. Fitterer, A.-S. Muller (University of Karlsruhe) E. Adli, H. Burkhardt, B. Dalena, M. Fitterer, D. Schulte (CERN) I. Ahmed (NCP)

and extended these simulations to lower energies as relevant for the CLIC drive beam.

We report about generic halo and tail simulations and estimates. Previous studies were mainly focused on very high energies as relevant for the beam delivery systems of linear colliders. We have now studied, applied

WE6PFP086

### Operation of a Free Hg Jet Delivery System for a High-Power Target Experiment

V. B. Graves, A. J. Carroll, P. T. Spampinato (ORNL) I. Efthymiopoulos, A. Fabich (CERN) H. G. Kirk (BNL) K. T. McDonald (PU)

Operation of a mercury jet delivery system is presented. The delivery system is part of the Mercury Intense Target (MERIT) Experiment, a proof-of-principle experiment conducted at CERN in 2007 which demonstrated the feasibility of using an unconstrained jet of mercury as a target for a future Neutrino Factory or Muon Collider. The Hg system was designed to produce a 1-cm-diameter, 20 m/s Hg jet inside a high-field (15 Tesla), 15-cm-bore solenoid magnet. A high-speed optical diagnostic system allowed observation of the interaction of the jet with both 14- and 24-GeV proton beams. Performance of the Hg system during the in-beam experiment will be presented.

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WE6PFP087

### Muon Ionisation Cooling in Reduced RF

C. T. Rogers (STFC/RAL/ASTeC) M. Martini (CERN)

In Muon Ionisation Cooling, closely packed high-field RF cavities are interspersed with energy-absorbing material in order to reduce particle beam emittance. Transverse focussing of the muon beams is achieved by superconducting magnets. This results in the RF cavities sitting in intense magnetic fields. Recent studies have shown that this may limit the peak gradient that can be achieved in the RF cavities. In this paper, we study the effect that a reduced RF gradient may have on the cooling performance of the Neutrino Factory lattice and examine methods to mitigate the effect.

In Muon Ionisation Cooling, closely packed high-field RF cavities are interspersed with energy-absorbing material in order to reduce particle beam emittance. Transverse focussing of the muon beams is achieved by superconducting magnets. This results in the RF cavities sitting in intense magnetic fields. Recent studies have shown that this may limit the peak gradient that can be achieved in the RF cavities. In this paper, we study the effect that a reduced RF gradient may have on the cooling performance of the Neutrino Factory lattice and examine methods to mitigate the effect.

### Neutrino Factory Muon Collider Front End Simulation Comparisons

Earlier studies on the front end of a neutrino factory or muon collider have relied on a single simulation tool, ICOOL. We present here a cross-check against another simulation tool, G4beamline. We also perform a preliminary study in economizing the number of RF cavity frequencies and gradients. We conclude with a discussion of future studies.

**D. V. Neuffer** (Fermilab) C. Y. Yoshikawa (Muons, Inc)

WE6PFP088

### Muon Capture, Phase Rotation, and Precooling in Pressurized RF Cavities

Bright muon beams are required for muon colliders, neutrino factories, and intense muon sources. In the most recent neutrino factory simulation study, high energy protons hit a target to generate pions that decay into a diffuse cloud of muons that is: 1) captured in strong magnetic fields, 2) bunched, 3) phase-energy rotated by strong RF electric fields, and 4) pre-cooled by passing the beam through a low-Z energy absorber. These four processes are done sequentially, with inefficiency, extra length and expense, and large muon losses. Pressurized RF cavities will enable higher gradient RF within magnetic fields than is possible with evacuated cavities, thus allowing more options for the initial stages of a muon cooling channel. The status of designs of the capture, phase rotation, and precooling systems of muon beams in pressurized cavities is described.

**D. V. Neuffer** (Fermilab) C. M. Ankenbrandt, R. P. Johnson, C. Y. Yoshikawa (Muons, Inc)

WE6PFP089

### MANX, A 6-D Muon Beam Cooling Experiment for RAL

MANX is a 6-dimensional muon ionization cooling demonstration experiment based on the concept of a helical cooling channel (HCC) in which a beam of muons loses energy in a continuous helium or hydrogen absorber while passing through a special superconducting magnet called a helical solenoid (HS). The goals of the experiment include tests of the theory of the HCC and the HS implementation of it, verification of the simulation programs, and a demonstration of effective 6D cooling of a muon beam. We report the status of the experiment and in particular, the proposal to have MANX follow MICE at the Rutherford-Appleton Laboratory (RAL) as an extension of the MICE experimental program. We describe the economies of such an approach which allow the MICE beam line and much of the MICE apparatus and expertise to be reused.

**K. Yonehara**, V. S. Kashikhin, M. J. Lamm, A. V. Zlobin (Fermilab) R. J. Abrams, C. M. Ankenbrandt, M. A.C. Cummings, R. P. Johnson, S. A. Kahn (Muons, Inc)

WE6PFP090

### Commissioning the MICE Muon Beam

The international Muon Ionisation Cooling Experiment (MICE) is under construction at the Rutherford Appleton Laboratory (RAL). The MICE Muon Beam is derived from the 800 MeV proton synchrotron, ISIS, and is required to deliver muon beams with momentum in the range  $140 \text{ MeV}/c$  to  $240 \text{ MeV}/c$  and emittance in the range  $2\pi \text{ mm rad}$  to  $12 \pi \text{ mm rad}$ . The beam line has been installed and is being commissioned. This paper describes the design and implementation of the beam line, discusses the issues that remain to be addressed, and presents the results that have been obtained.\*

**K. R. Long** (Imperial College of Science and Technology, Department of Physics)

WE6PFP091

\*Submitted on behalf of the MICE collaboration

### Feasibility of Injection/Extraction Systems for Muon FFAG Rings in the Neutrino Factory

J. Pasternak, M. Aslaninejad (Imperial College of Science and Technology, Department of Physics) J. S. Berg (BNL) D. J. Kelliher, S. Machida (STFC/RAL/ASTeC) J. Pasternak (STFC/RAL)

Non-scaling FFAG rings have been proposed as a solution for muon acceleration in the Neutrino Factory. In order to achieve small orbit excursion and small time of flight variation, lattices with a very compact cell structure and short straight sections are required. The resulting geometry dictates very difficult constraints on injection/extraction systems. The feasibility of injection/extraction is discussed and various implementations focusing on minimization of kicker/septum strength are presented.

structure and short straight sections are required. The resulting geometry dictates very difficult constraints on injection/extraction systems. The feasibility of injection/extraction is discussed and various implementations focusing on minimization of kicker/septum strength are presented.

### Reverse Emittance Exchange for Muon Colliders

C. M. Ankenbrandt, A. Afanasev, V. Ivanov, R. P. Johnson, G. M. Wang (Muons, Inc) S. A. Bogacz, Y. S. Derbenev (JLAB)

Muon collider luminosity depends on the number of muons in the storage ring and on the transverse size of the beams in collision. Six-dimensional cooling schemes now being

developed will reduce the longitudinal emittance of a muon beam so that smaller high frequency RF cavities can be used for later stages of cooling and for acceleration. However, the bunch length at collision energy is then shorter than needed to match the interaction region beta function. New ideas to shrink transverse beam dimensions by lengthening each bunch (reverse emittance exchange and bunch coalescing) will help achieve high luminosity in muon colliders with fewer muons. Analytic expressions for the reverse emittance exchange mechanism are derived, including a new resonant method of beam focusing. Correction schemes for the aberrations were explored, and a lattice to implement them was proposed. To mitigate space charge detuning and wake field effects, a scheme was invented to coalesce smaller intensity bunches after they are cooled and accelerated to high energy into intense bunches suitable for a muon collider.

### A Quasi-Isochronous Muon Collection Channel

C. M. Ankenbrandt, C. Y. Yoshikawa (Muons, Inc) D. V. Neuffer (Fermilab)

Intense muon beams have many potential applications. However, muons originate from a tertiary process that produces a diffuse swarm. To make useful beams, the

swarm must be rapidly collected and cooled before the muons decay. A promising new concept for the collection and cooling of muon beams to increase their intensity and reduce their emittances is investigated: the use of a nearly isochronous helical cooling channel (HCC) to facilitate capture of the muons into a few RF bunches. Such a distribution could be cooled quickly and then coalesced efficiently into a single bunch to optimize the luminosity of a muon collider. An analytical description of the method is presented followed by simulation and optimization studies. Practical design constraints and integration into a collider, neutrino factory or intense beam scenario are discussed and plans for further studies are addressed.



### Integrating the MANX 6-D Muon Cooling Experiment into the MICE Spectrometers

The MANX experiment is to demonstrate the reduction of 6D muon phase space emittance using a continuous liquid absorber to provide ionization cooling in a helical solenoid magnetic channel. The experiment involves the construction of a short two-period long helical cooling channel (HCC) to reduce the muon invariant emittance by a factor of 3. The HCC would replace the current MICE 4D cooling experiment now being setup at the Rutherford Appleton Laboratory. The MANX experiment would use the existing MICE spectrometers and muon beam line. The study reported here considers various approaches to integrate the MANX experiment using the MICE spectrometers. The goal is to match the beam into and out of the MANX experiment so as to minimize losses between the MICE spectrometers and the MANX HCC. The matching schemes, simulated using the G4beamline tracking program, are compared with regard to minimization of losses, minimization of emittance blowup at the MANX and MICE spectrometer interfaces, and cost effectiveness.

**S. A. Kahn**, R. J. Abrams, M. A.C. Cummings (Muons, Inc) K. Yonehara (Fermilab)

### Particle Refrigerator

For studies of the behavior and properties of particles and nuclei, relativistic particle and ion beams are needed having high brightness: low normalized emittance and high intensity. This is especially difficult for beams of particles produced from interactions of other particles, such as unstable ions, antiprotons, muons, etc. The technique of frictional cooling, originally developed for muon beams, can be applied to other particles and ions, producing beams of exceptionally low normalized emittance. However, frictional cooling has the problem that such a channel has a very small momentum acceptance, and thus has not been of practical value. This device increases the momentum acceptance by two to three orders of magnitude, making it possible to handle much larger intensities with much higher transmission, while preserving the exceptionally low normalized emittance of the output. This paper describes simulation studies of the device used to optimize the design and performance of the particle refrigerator for a variety of ions and particles, and presents an inexpensive experiment to test and verify the simulations, using alpha particles from a radioactive source.

**T. J. Roberts** (Muons, Inc) D. M. Kaplan (Illinois Institute of Technology)

### Pulsed Magnet Arc Designs for Recirculating Linac Muon Accelerators

We have previously considered the application of fast pulsing quadrupoles to increase the focusing of muon beams as they gain energy in the linac region of a recirculating linear accelerator (RLA) in order to allow more passes. In this work we consider the use of pulsed magnets, both quads and dipoles, to reduce the number of beam lines needed for the return arcs of the RLA. We investigate the required relationships between the linac parameters (length and energy gain) and the momentum acceptance of the return arcs and consider the optimum strategy for accelerating both muon charge signs.

**G. M. Wang**, R. P. Johnson (Muons, Inc) S. A. Bogacz (JLAB) D. Trbojevic (BNL) **G. M. Wang** (ODU)

### Multipass Arc Lattice Design for Recirculating Linac Muon Accelerators

G. M. Wang (ODU) S. A. Bogacz (JLAB) R. P. Johnson, G. M. Wang (Muons, Inc) D. Trbojevic (BNL)

Recirculating linear accelerators (RLA) are the most likely means to achieve the rapid acceleration of short-lived muons to multi-GeV energies required for Neutrino Factories and TeV energies required for Muon Colliders. One problem is that in the simplest schemes, a separate return arc is required for each passage of the muons through the linac. In the work described here, a novel arc optics based on a Non Scaling Fixed Field Alternating Gradient (NS-FFAG) lattice is developed, which would provide sufficient momentum acceptance to allow multiple passes (two or more consecutive energies) to be transported in one string of magnets. With these sorts of arcs and a single linac, a Recirculating Linear Accelerator (RLA) will have greater cost effectiveness and reduced losses from muon decay. We will develop the optics and technical requirements to allow the maximum number of passes by using an adjustable path length to accurately control the returned beam phase to synchronize with the RF.

### Muon Storage Rings for a Neutrino Factory

C. R. Prior (STFC/RAL/ASTeC)

The goal of a Neutrino Factory is to generate intense beams of neutrinos from muon decay to facilitate study of aspects of the Standard Model such as CP violation, the mass hierarchy, and the neutrino mixing angle  $\theta_{13}$ . Intense muon beams are created and accelerated in a system of particle accelerators to energies of 20-50 GeV. They are then allowed to decay in dedicated storage rings with long straight sections aligned on suitably chosen long-range detectors. A variety of geometries are possible, and the rings' design and construction present demanding challenges for accelerator R & D, covering not only beam optics but touching on geological and engineering aspects of constructing almost vertical storage rings several hundred metres below the Earth's surface. The basic ideas are described in this paper and are demonstrated by three possible models developed over the last two years.

### Pulsed-Focusing Recirculating Linacs for Muon Acceleration

S. A. Bogacz (JLAB) R. P. Johnson, G. M. Wang (Muons, Inc)

Neutrino Factories and Muon Colliders require rapid acceleration of short-lived muons to multi-GeV and TeV energies. A Recirculating Linear Accelerator (RLA) that uses International Linear Collider (ILC) RF structures can provide exceptionally fast and economical acceleration to the extent that the focusing range of the RLA quadrupoles allows each muon to pass several times through each high-gradient cavity. A new concept of rapidly changing the strength of the RLA focusing quadrupoles as the muons gain energy is being developed to increase the number of passes that each muon will make in the RF cavities, leading to greater cost effectiveness. We discuss the optics and technical requirements for RLA designs, using RF cavities capable of simultaneous acceleration of both  $\mu^+$  and  $\mu^-$  species, with pulsed Linac quadrupoles to allow the maximum number of passes.

### The Study of a Li Lens System as a Final Cooler for a Muon Collider

We describe the Li Lens concept for a cooler for the transverse emittance for a  $\mu+\mu^-$  collider. Different configurations are discussed such as Linear Cooler, Ring Coolers all with Li Lens inserts. We then describe a program to study the construction of Liquid Li Lens and a possible experiment at FNAL.

**D. B. Cline** (UCLA)

WE6PFP101

### Optimized Parameters for a Mercury Jet Target

A study of target parameters for a high-intensity, liquid mercury jet target system for a neutrino factory or muon collider is presented. Using the MARS code, we simulate particle production initiated by incoming protons with kinetic energies between 2 and 100 GeV. For each proton beam energy, we optimize the geometric parameters of the target: the mercury jet radius, the incoming proton beam angle, and the crossing angle between the mercury jet and the proton beam. The number of muons surviving through an ionization cooling channel is determined as a function of the proton beam energy

**X. P. Ding**, D. B. Cline (UCLA) J. S. Berg, H. G. Kirk (BNL)

WE6PFP102

### CesrTA Layout and Optics

The Cornell Electron Storage Ring has been reconfigured as a test accelerator (CesrTA) for the investigation of the beam physics of a linear collider damping ring. The low beta interaction region optics have been replaced with simple FOFO lattice structures. Superconducting damping wigglers are located in straights where horizontal dispersion can be constrained to be zero to minimize horizontal emittance. The flexibility of the CESR optics allows for an energy reach of 1.5 GeV /beam  $\rightarrow$  6.0 GeV /beam and a wide range of emittances and radiation damping times. We exploit that flexibility for measurements of the dependencies of various phenomena, on energy, emittance, and damping rate. At 2 GeV beam energy, with no damping wigglers, the minimum horizontal emittance is 10 nm. With 16 meters of wiggler magnets operating at 1.9 T, the horizontal emittance is reduced by a factor of four to 2.5 nm and the radiation damping time to 56 ms. With tuning and alignment we expect to reach a vertical emittance approaching that of the International Linear Collider (ILC) damping rings. We report on the details of the CesrTA optics and the measurements of optical parameters.

**D. L. Rubin**, M. J. Forster, S. B. Peck, D. Sagan, J. P. Shanks (CLASSE)

WE6PFP103

### CesrTA Low Emittance Tuning – First Results

The Cornell Electron Storage Ring has been reconfigured as a test accelerator (CesrTA) for low emittance damping ring R&D for the International Linear Collider (ILC). We are developing low emittance tuning techniques with a goal of 1) achieving a vertical emittance approaching that of the ILC damping rings and 2) Gaining an understanding of the effectiveness of those techniques. We will use gain mapping to characterize beam position monitor (BPM) electrode gains, orbit response analysis to determine BPM button misalignments, betatron phase and coupling measurements to characterize optical errors, and orbit and dispersion measurements to locate sources of vertical dispersion. We are investigating a nondestructive dispersion

**J. P. Shanks**, M. G. Billing, S. S. Chapman, M. J. Forster, S. B. Peck, D. L. Rubin, D. Sagan, J. W. Sexton (CLASSE)

WE6PFP104

measurement that depends on exciting a synchrotron oscillation and monitoring the phase and amplitude at each BPM. We have developed the analysis tools necessary to correct magnet and alignment errors. An x-ray beam size monitor is being deployed that will allow us to monitor vertical emittance in real time, allowing for empirical tuning of beam size. We will describe the measurement and correction techniques and show data demonstrating their efficacy.

### Lattice Options for the CLIC Damping Rings

Y. Papaphilippou, F. Antoniou (CERN) P. Raimondi (INFN/LNF)  
S. V. Sinyatkin, P. Vobly, K. Zolotarev (BINP SB RAS)

Optics design optimisation studies have been undertaken for the CLIC damping ring lattice. Main parameters such as the ring energy and output longitudinal emittance were reconsidered in order to reduce the detrimental effect of collective instabilities. In this respect, the low emittance arc cell length was rationalized taking into account space and magnet design requirements. The straight section cell filled with super-conducting wigglers was modified to accommodate a robust absorption scheme. Several low emittance rings were considered and compared with respect to their dynamic aperture and the IBS-dominated output emittances.

### Non-Linear Dynamics Considerations for the CLIC Damping Rings

Y. Papaphilippou (CERN) Ch. Skokos (Max Planck Institute for the Physics of Complex Systems)

Following the linear optics optimization of the CLIC damping rings arc cells, the non-linear dynamics effects were reviewed. Non-linear dynamics tools such as frequency maps and resonance analysis are employed to study the effect of chromaticity sextupoles for a conventional and an interleaved family scheme. In the same spirit, the importance of magnet fringe fields, multi-pole field errors in the magnets and the effect of damping wigglers were evaluated for establishing realistic magnet error tables and foresee adequate magnet correction systems.

### Design Considerations for the CLIC Pre-Damping Rings

F. Antoniou (National Technical University of Athens) Y. Papaphilippou, F. Zimmermann (CERN)

The CLIC pre-damping rings have to accommodate a large emittance beam, coming in particular from the positron target and reduce its size to low enough values for injection into the main damping rings. In particular, polarized positron stacking imposes stringent requirements with respect to longitudinal acceptance and damping times. Linear lattice design options based on low-emittance cells, multiple bend cells and the inclusion of damping wigglers are compared with respect to linear optics functions, tunability, chromatic properties and acceptance. The optics of special regions for the placement of injection, extraction and RF elements are also presented. Non-linear dynamics simulations are finally undertaken for evaluating and maximizing the rings dynamic aperture, especially for large momentum spreads.

### Beam Based Calibration of Slow Orbit Bump at NSLS Booster

The orbit bumps in NSLS booster are used to move the beam orbit within 2mm to the extraction septum aperture in a time scale

of millisecond at extraction in order to reduce the required strength of the fast extraction kicker. Since before extraction, the beam stays on the distorted orbit for thousands of revolutions, there is a concern that this may cause charge losses. In order to find the optimal orbit bump setpoint which brings the maximum distortion at the extraction position and minimum distortions at other places, we developed the extraction model and performed an experiment to validate it. Afterwards, the model was applied to optimize the extraction process.

X. Yang, T. V. Shaftan (BNL)

### Operation of the FLASH Linac with Long Bunch Trains and High Average Current

XFEL and ILC both intend to accelerate long beam pulses of a few thousand bunches and high average current. It is expected that the superconducting accelerating cavities will eventually be operated close to their respective gradient limits as they are pushed to higher energies. In addition, a relative energy stability of  $<10^{-4}$  must be maintained across all bunches. These parameters will ultimately push the limits of several sub systems including the low-level rf control, which must properly compensate for the heavy beam loading while avoiding problems from running the cavities close to their quench limits. An international collaboration led by DESY has begun a program of study to demonstrate such ILC-like conditions at FLASH, which serves as a prototype for both XFEL and ILC. The objective is to achieve reliable operation with pulses of 2400 3-nC bunches spaced by 330 ns (a current of 9 mA) while meeting the required energy stability and while operating accelerating cavities close to their quench limits. Other goals include measurement of cryoload from HOM heating and evaluation of rf power overhead for the ILC. The paper will describe the program and report recent results.

N. J. Walker, V. Ayvazyan, L. Froehlich, S. Schreiber (DESY) J. Carwardine (ANL)

### Simultaneous Injections of Various Energy Particles into Two Rings in KEK Injector LINAC

The  $e^+/e^-$  injector LINAC in KEK usually successively injects into four rings, which are Low Energy Ring (LER) of KEKB

(3.5GeV/ $e^+$ ), High Energy Ring (HER) of KEKB (8.0GeV/ $e^-$ ), Photon Factory (PF) (2.5GeV/ $e^-$ ) and Advanced Ring for pulse X-rays (PF-AR) (3.0GeV/ $e^-$ ). While LINAC continuously injects into LER and HER alternatively every about five minutes, keeping both of KEKB rings almost their full operating currents. It takes about one minute to switch beam mode of LINAC. PF and PF-AR are injected a few times in a day. Time for PF or PF-AR including mode-switch had taken about 20 minutes for each other. For PF injection, the switching time was shortened in 2005 and the occupancy time is about 5 minutes. In 2008, we succeeded to make the switching time shorter, 2 seconds for HER/LER, and Pulse-to-pulse alternatively injection for PF/HER using an event system. Especially for KEKB, the short switching time is contributed to provide high currents and to improve luminosity at which beam lives are too short to keep the high currents. In 2009, we have a plan to inject also for LER/HER pulse-to-pulse alternatively.

N. Iida (KEK)

**The First Two Years of Operation of the 1.5GeV cw Electron Accelerator MAMI C**

A. Jankowiak, K. Aulenbacher, O. Chubarov, M. Dehn, H. Euteneuer, R. G. Heine, P. Jennewein, H. J. Kreidel, U. Ludwig-Mertin, O. Ott, G. S. Stephan, V. Tioukine (IKP)

In December 2006 the maximum output energy of the cw race track microtron cascade MAMI B was increased to 1508MeV by the successful commissioning of the world wide first Harmonic-Double-Sided-Microtron (HDSM)\* as a new fourth stage. Since then MAMI C was in operation for more than 15000 hours, delivering approx. 10000 hours the maximum beam energy of 1508MeV. We will report about our operational experiences and the recent machine developments concerning e.g. the increase of the energy and stabilisation of the output energy down to  $10^{-6}$ . Topics of machine reliability and stability will be addressed and the operation under different demands of nuclear physics experiments described.

\*K.-H. Kaiser et al., NIM A 593 (2008) 159 - 170, doi:10.1016/j.nima.2008.05.018

**Current Status of the 12 MeV UPC Race-Track Microtron**

Yu. A. Kubyshin, A. Crisol, X. Gonzalez Arriola, J. P. Rigla, F. Roure (UPC) A. V. Alov, V. I. Shvedunov (MSU) J. Berenguer Sau, G. Montoro (EPSC) D. Carrillo, L. García-Tabarés, F. Toral (CIEMAT) J. Lucas (Elytt Energy)

A compact race-track microtron (RTM) with the maximal output energy 12 MeV is under construction at the Universitat Politècnica de Catalunya (UPC) in collaboration with the Skobeltsyn Institute of Nuclear Physics of the Moscow State University, CIEMAT and

a few Spanish industrial companies and medical centers. The RTM end magnets are four-pole systems with the magnetic field created by a rare-earth permanent magnet material. As a source of electrons a 3D off-axis electron gun is used. These elements together with a C-band accelerating structure, dipole magnets, which allow to extract the electron beam with energy from 6 MeV to 12 MeV in 2 MeV step, and a focusing quadrupole are placed inside a vacuum chamber. We report on the current status of the technical design and results of tests of some of the components.

## WE6RF — Afternoon Poster ACTECH T13, T19, T20, ADVCON A14

### Lowering the Cost of the ILC SRF Cavity Helium Vessel

From past work we found that within the cost of the String Assembly that dominates the overall cost of the cryomodules for ILC,

J. J. Sredniawski, D. Holmes, T. Schultheiss (AES)

the greatest cost elements are the helium vessel with the 2 phase pipe assembly, the niobium material, and the SRF cavity fabrication\*. The cost of niobium is dependant upon market supply and demand and is essentially out of our control. We have carried out an aggressive study to reduce the cost of cavity fabrication in a high production environment\*\*, which leaves the helium vessel for further investigation. It is recognized that significant cost savings may be realized if the helium vessel could be constructed of stainless steel instead of titanium material as is currently planned. To facilitate this change (AES) has designed a niobium to stainless steel transition assembly that will interface the helium vessel to the SRF Cavity at each end. Details of the design and analysis of the low cost helium vessel assembly are discussed along with potential cost reductions for the ILC high production run.

\*E. Bonnema, J. Sredniawski, "ILC RF Unit Industrial Cost Study Methodology & Results"

\*\*A. Favale, J. Sredniawski, M. Calderaro, E. Peterson, "ILC Cavity Fabrication Optimization for High Production"

### Design of an ERL Linac Cryomodule

A cryomodule design for the Cornell Energy Recovery Linac (ERL) will be based on TTF technology, but must have several unique features dictated by the ERL beam parameters.

E. P. Chojnacki, S. A. Belomestnykh, R. Ehrlich, M. Liepe, H. Padamsee, J. Sears, E. N. Smith, V. Veshcherevich (CLASSE)

The main deviations from TTF are that the HOM loads must be on the beamline for sufficient damping, that the average power through the RF couplers is low, and that cw beam operation introduces higher heat loads. Several of these challenges were addressed for the Cornell ERL Injector, from which fabrication and operational insight was gained. A baseline design for the Cornell ERL Linac cryomodule will be presented that includes fabrication and operational considerations along with thermal and mechanical analyses.

### Helium II Calorimetry for the Detection of Abnormal Resistive Zones in LHC Sectors

Following the incident on a LHC sector due to an electrical arc on the main dipole bus-bar circuit, post-mortem analysis of previ-

L. J. Tavian (CERN)

ous current plateaus has shown abnormal temperature drift in the helium II baths of some magnets in the concerned area. In order to identify other possible risky areas, a detection system based on calorimetry using available precision cryogenic thermometers has been first validated by applying calibrated heating in the magnet cold-mass and then implemented in the different sectors. On the 3-km long continuous helium II cryostat of each LHC sector, this method allows detecting abnormal dissipations in the W-range, i.e. additional resistive heating due to abnormal resistance of about 20 n $\Omega$  at 7 kA and less than 10 n $\Omega$  at nominal current. The paper describes the principle and the methodology of this calorimetric method and gives the results obtained on the LHC sectors.

WE6RFP001

WE6RFP002

WE6RFP003

### Dependence of Superconducting Wire Motion on the Base Insulating Material in Magnetic Field

K. Ruwali (GUAS/AS) K. Hosoyama, K. Nakanishi (KEK) Y. Teramoto, A. Yamanaka (Toyobo Research Institute)

Main cause of premature quench in superconducting magnet is the heat generated due to sudden superconducting wire motion. The wire motion occurs where electro-

magnetic force to conductors exceeds frictional force on surfaces of the conductors. Hence, frictional properties of the conductors and winding structures are important parameters for characterizing stability of the superconducting windings. Experiments were carried out to detect the superconducting wire motion under the influence of varying electromagnetic force. The wire movement is detected by observing the spike in voltage of the superconducting sample wire. From the time profile of voltage spike, distance moved by superconducting wire is estimated. Insulating material such as Dyneema random sheet, Dyneema non-woven sheet and Dyneema fiber cloth were used at the interface of superconducting wire and base material. Dyneema has low frictional coefficient and negative thermal expansion. The experimental findings will be discussed.

### Plan of the S1-Global Cryomodules for ILC

N. Ohuchi, H. Hayano, N. Higashi, H. Nakai, K. Tsuchiya, A. Yamamoto (KEK) T. T. Arkan, H. Carter, M. S. Champion, J. Grimm, J. S. Kerby, D. V. Mitchell, T. J. Peterson, M. C. Ross (Fermilab) S. Barbanotti, C. Pagani, P. Pierini (INFN/LASA) L. Lilje (DESY)

In an attempt at demonstrating an average field gradient of 31.5 MV/m as per the design accelerating gradient for ILC, a program called S1-Global is in progress as an international research collaboration among KEK, INFN, FNAL, DESY and SLAC. The

S1-Global cryomodule will contain eight superconducting cavities from FNAL, DESY and KEK. The cryomodule will be constructed by joining two half-size cryomodules, each 6 m in length. The module containing four cavities from FNAL and DESY will be constructed by INFN. The design of this module is based on an improved 3rd generation TTF design. KEK will modify the 6-meter STF cryomodule to contain four KEK cavities. The designs of the cryomodules are ongoing between these laboratories, and the operation of the system is scheduled at the KEK-STF from June 2010. In this paper, the S1-Global cryomodule plan and the module design will be presented. 'S1-Global collaboration' as a co-author.

### Minimization of the Cryogenic Loading of a 2K SRF Module on a 4.5K Cryogenic Plant

M. H. Chang, M.-C. Lin, C. H. Lo, M. H. Tsai, Ch. Wang (NSRRC)

Lowering the operating temperature of SRF module to 2K will elevate its performance greatly. Therefore, 2K SRF development will

be one of tendencies to meet the performance demands in the future. In NSRRC, there is enough cooling capacity in 4.5K cryogenic plant can be available for the development of 2K SRF. However, due to the total energy consumption in 2K SRF is great, thus how to minimize the energy consumption is of importance. For this reason, we plan to use heat exchanger (HEX) devices to recover the available energy to achieve energy saving. It is known the different configuration layout and efficiency in HEXs will affect not only the cryogenic loading in 4.5K cryogenic plant but also the pumping speed of a set of warm compressors. In this paper, we estimate the needed cryogenic loading and the magnitude of pumping speed for different HEX's configuration layouts at a specified efficiency to obtain the optimal design of heat recovery system.



### The Cryogenic System Designed for SRF Protection and the Device Upgrading for Cryogenic System by Pronunciation, Counts, Warn Lamps

As the unusual trouble of the cryogenic system, the compressor return circuit is unable to retrieve the helium, will cause the resonance for cavity liquid helium evaporation which cause rise the inside of SRF pressure and cryogenic pressure pipeline (Suction Line) gradually. The effective is safely pressed (Spring Relief Pressure), can reduce the Burst Disk break immediately, and can remove the pressure to dangerous. On the other hand, the complicated system needs to be simple and clear that let the control room operator grasp to the important correct of information, to users or every group who on duty inquired, we set up five devices to display with the light and pronunciation radio in the control room, easy know the situation of the machine. In addition, we setup device when the recover compressor is started, will count times and how long it is in the panel of SRF rack.

**F.-T. Chung** (NSRRC)

In order to obtain the design, manufacturing and operational experiences on the cryomodule toward ILC, a 1.3GHz single 9 cell SC cavity test cryomodule was designed by IHEP (Institute of High Energy Physics) and TIPC (Technical Institute of Physics and Chemistry) jointly. This cryomodule will be used as a 1.3GHz 9 cell SC cavity horizontal test facility. we also designed the cryogenic system for the cryomodule and it will be operate at 2.0K, with the saturated superfluid helium. In this paper, we will report the design, the simulation results and other consideration. This cryomodule will be built in the near future at IHEP.

### Design of 1.3 GHz Single 9 Cell SC Cavity Test Cryomodule for ILC Collaboration at IHEP

In order to obtain the design, manufacturing and operational experiences on the cryomodule toward ILC, a 1.3GHz single 9 cell SC cavity test cryomodule was designed by IHEP (Institute of High Energy Physics) and TIPC (Technical Institute of Physics and Chemistry) jointly. This cryomodule will be used as a 1.3GHz 9 cell SC cavity horizontal test facility. we also designed the cryogenic system for the cryomodule and it will be operate at 2.0K, with the saturated superfluid helium. In this paper, we will report the design, the simulation results and other consideration. This cryomodule will be built in the near future at IHEP.

**T. X. Zhao**, L.-Y. Xiong, L. Zhang, Z. G. Zong (TIPC) J. Gao, Q. J. Xu, J. Y. Zhai (IHEP Beijing) L. Q. Liu (Technical Institute of Physics and Chemistry) **T. X. Zhao** (Graduate School of the Chinese Academy of Sciences)

### Investigations on Absorber Materials at Cryogenic Temperatures

In the framework of the ongoing CEBAF 12 GeV upgrade program improvements are being made to refurbish cryomodules housing JLab's original 5-cell cavities. Recently we have started to look into a possible simplification of the HOM-absorber design combined with the need to find alternative material candidates. The absorbers are implemented in two HOM-waveguides immersed in the helium bath and need to operate at 2K. We therefore have built a cryogenic setup to perform measurements on sample load materials to investigate their lossy characteristics and variations from room temperature down to 2K. Initial results are presented in this paper.

**F. Marhauser**, S. Castagnola, C. Dreyfuss, T. Elliott, K. Macha, R. Manus, R. A. Rimmer, S. Williams (JLAB)

**Optical Diagnostic Results for the MERIT High-Power Target Experiment**

H. G. Kirk, H. Park, T. Tsang (BNL) J. R.J. Bennett (STFC/RAL/ASTeC) O. Caretta, P. Loveridge (STFC/RAL) A. J. Carroll, V. B. Graves (ORNL) I. Efthymiopoulos, A. Fabich, F. Haug, J. Lettry, M. Palm (CERN) K. T. McDonald (PU)

We report on the analysis of data collected from the optical diagnostics of the MERIT experiment which was run at CERN in the fall of 2007. The breakup of the free mercury jet resulting from the impact of intense proton beams from the CERN PS within a

magnetic field environment is described.

**Pattern Recognition of the Multi-Turn 6D Motion of Halo Particles through a Bent Si Crystal**

G. Robert-Demolaize, K. A. Drees, S. Peggs (BNL)

As the increase in luminosity remains a high-profile issue for current and future accelerator projects, protecting superconducting

magnets from beam induced quenches implies using state-of-the-art halo cleaning devices given the required beam intensities. Dedicated beam experiments have been scheduled at CERN and Fermilab to gain a better understanding and more accurate description of the multi-turn, single particle dynamics involved in a crystal-based collimation system for high energy proton machines. Such a system uses the physics of a bent silicon crystal (channeling or volume reflection) to force halo particles onto secondary target collimators installed downstream of the crystal at appropriate phase advance locations. In order to be successful, these experiments require not only state-of-the-art detection devices but also dedicated data analysis. We review the proposed layout of the single particle detection system for these experiments and its consequences and constraints on the available information. A fast simulation algorithm and the methods for data analysis are also presented.

**Simulation of the LHC Collimation System Using MERLIN**

H. L. Owen, S. Alshammari, R. J. Barlow, A. M. Toader (UMAN)

The LHC Collimators are designed to remove halo particles such that they do not impinge onto either detectors or other vulnerable

regions of the storage ring. However, the very high 7 TeV energy means that their design is critical, as is the modelling of the absorption, scattering and wakefield effects upon the passing bunches. Existing simulations are being performed using Sixtrack and K2. We compare these simulations with results obtained using the MERLIN code, which includes a fuller description of the scattering and wakefield processes.

**Cornell ERL Phase-1a Electron Beam Dump**

X. Liu (Cornell University, Department of Physics) I. V. Bazarov, B. M. Dunham, Y. Li, K. W. Smolenski (CLASSE)

The electron beam dump for Cornell University's phase 1a ERL program was designed for 600 kW electron beam power at beam energies between 5 and 15 MeV. In a tradeoff

between thermal conductivity and neutron yield, aluminum was chosen over copper for the material. It consists of a body and an outer jacket, with cooling water channels in between. The dump body also serves as the vacuum envelope; it is 20 mm thick, so most electrons stop in the dump body. The dump body is made of three sections electron-beam welded together. It has a cylindrical shape with a cone at the end, about 0.5 m in diameter and 3

m in overall length. The naturally small ERL electron beam is enlarged and rastered in a circular pattern using magnets at the entrance. The enlarged electron beam strikes the dump surface at an average angle of about 8 degree. The dump was modeled with GEANT4, and its inside profile was designed so the thermal load is nearly evenly distributed over the surface. A quadrant detector normally intercepting a very small fraction of the beam is located at the entrance of the dump to monitor the electron beam centering and rastering. The dump was installed in October 2008.

### A High Current PET Target and Compact Industrial Beamline System

Many of today's PET cyclotrons are delivered from the factory for fully-automated "black box" operation in a hospital-based clinical program. Simplicity and ease of operation by non-specialists is desired, and this is achieved in-part through relatively low current targets bolted directly to the PET cyclotron's main vacuum tank. However, commercial-scale production of short-lived radiopharmaceuticals is becoming increasingly prevalent where substantially higher-current target operation\* requiring greater optimization of beam parameters through compact external beamlines\*\*,\*\*\* is necessary to meet ever-more demanding production schedules and delivery commitments. This paper describes a system which incorporates the highest current and highest power PET water targets and a short well-instrumented beamline for beam centring/focusing and maximum productivity.

**M. P. Dehnel** (D-Pace) M. H. Stokely, B. Wieland (Bruce Technologies Inc.)

\*M. Stokely et al, WTTC11, Cambridge, 2006, p.102.

\*\*M. P. Dehnel et al, NIM B 261, 2007, p. 809.

\*\*\*J. E. Theroux et al, CYC2007, Giardini Naxos, Italy, 2007, p. 361.

### Energy Deposition Studies for Possible Ceramic Phase II Collimators

Due to the known limitations of Phase I LHC collimators in stable physics conditions, the LHC collimation system was complemented by additional 30 Phase II collimators. The Phase II collimation system is designed to reach several important goals like to improve cleaning efficiency, to limit radiation damage to jaw surface and to improve the set-up time. For these reasons, different possible innovative collimation designs were taken in consideration. Advanced jaw materials, including new composite materials (e.g. Cu -- Diamond), jaw SiC insertions, coating foil, in-jaw instrumentation (e.g. BPM) and improved mechanical robustness of the jaw are the main features of the ceramic Phase II collimators, one of the most promising designs developed at CERN. The FLUKA Monte Carlo code is extensively used to evaluate the behavior of these collimators in the most radioactive areas of LHC, supporting the mechanical integration. These studies aim to identify the possible critical points along the IR7 line.

**L. Lari** (EPFL) R. W. Assmann, M. Brugger, F. Cerutti, A. Ferrari, L. Lari, M. Mauri, V. Vlachoudis, Th. Weiler (CERN)

### Advanced Materials for Future Phase II LHC collimators

Phase I collimators, equipped with Carbon-Carbon jaws, effectively met specifications for the early phase of LHC operation. However, the choice of carbon-based materials is expected to limit the nominal beam intensity mainly because of the high RF impedance and limited efficiency of the

**A. Dallocchio**, G. Arnau-Izquierdo, K. Artoos, A. Bertarelli (CERN)

collimators. Moreover, C/C may be degraded by high radiation doses. To overcome these limitations, new Phase II secondary collimators will complement the existing system. Their extremely challenging requirements impose a thorough material investigation effort aiming at identifying novel materials combining very diverse properties. Relevant figures of merit have been identified to classify materials: Metal-diamonds composites look a promising choice as they combine good thermal, structural and stability properties. Molybdenum is interesting for its good thermal stability. Ceramics with non-conventional RF performances are also being evaluated. The challenges posed by the development and industrialization of these materials are addressed in a collaboration program, involving academic and industrial partners and complementing material research with an innovative design.

### Collimation Considerations for PS2

J. Barranco (UPC) W. Bartmann, M. Benedikt, Y. Papaphilippou (CERN)

A main concern in a high intensity accelerator is the evaluation and minimization of uncontrolled losses, using collimation systems. A two-stage system is foreseen for the PS2 which may be located in one of the two straight sections of the ring. The potential losses at injection are estimated using the ORBIT code including the effect of longitudinal and transverse space charge force. Off-bucket particle losses, at the beginning of ramping, are also considered. The different collimation scenarios are studied and compared with respect to the efficiency and robustness obtained.

### Energy Deposition Studies for the LHC Insertion Region Upgrade Phase-1

F. Cerutti, F. Borgnolutti, A. Ferrari, A. Mereghetti, E. Y. Wildner (CERN)

While the Large Hadron Collider (LHC) at CERN is starting operation with beam, aiming to achieve nominal performance in the shortest term, the upgrade of the LHC interaction regions is actively pursued in order to enhance the physics reach of the machine. Its first phase, with the target of increasing the LHC luminosity to  $2\text{-}3 \cdot 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ , relies on the mature Nb-Ti superconducting magnet technology and is intended to maximize the use of the existing infrastructure. The impact of the increased power of the collision debris has been investigated through detailed energy deposition studies, considering the new aperture requirements for the low-beta quadrupoles and a number of other elements in the insertions. Effective solutions in terms of shielding options and design/layout optimization have been envisaged and the crucial factors have been pointed out.

### Simulation Results for Crystal Collimation Experiment in SPS UA9

E. Laface, W. Scandale (CERN) G. Cavoto (INFN-Roma)

The UA9 experiment will take place in 2009 at the CERN-SPS and will evaluate the feasibility of silicon crystals as primary collimators for a storage ring. A crystal placed at 6 sigma from the beam core will deviate protons towards two roman pots and a tungsten absorber (TAL). In this paper the authors show simulations of the expected beam dynamics and of the capture efficiency into the secondary collimator. The result of these simulations will guide us in interpreting the experimental data expected in UA9.

**A Synchrotron Condition on the Grazing Function  $g$  for Efficient Crystal Collimation**

The grazing function  $g$  is introduced – a synchrotron optical quantity that parametrizes the rate of change of total angle with respect to synchrotron amplitude for grazing particles. The grazing function is particularly important for crystal collimators, which have limited acceptance angles. The implications for RHIC, SPS, Tevatron and LHC crystal implementations are discussed. Propagation of the grazing function is described, through drifts, dipoles and quadrupoles, with particular reference to matched FODO cells. An analytic approximation is derived for the maximum value of  $g$  in a matched FODO cell, and is shown to be in good agreement with a realistic numerical example. The grazing function is shown to scale linearly with FODO cell bend angle, but to be independent of FODO cell length.

V. P. Prevtali (CERN) S. Peggs (BNL) V. P. Prevtali (EPFL)

WE6RFP020

**Beam Loss Predictions for the UA9 Crystal Collimation Experiment**

The UA9 experiment at the SPS aims at testing bent crystals for usage as collimators with high energy stored proton and heavy ion beams. The experiments will try to establish crystal-based cleaning efficiency with slowly diffusing beam halo. One method for evaluating efficiency relies on Roman Pots and is described elsewhere. An alternative method relies on observing the beam loss signals around the ring. Comparisons of losses escaping from standard collimators and bent crystals will allow determination of cleaning efficiency, equivalent to the definition used for the LHC collimation design. This alternative method is described and simulations with LHC collimation tracking tools for UA9 are discussed. The predicted beam losses along the SPS ring are presented for different orientations and amorphous layer thicknesses of the crystal. The effect of different diffusion speeds for the beam are discussed.

V. P. Prevtali, R. W. Assmann, S. Redaelli (CERN) V. P. Prevtali (EPFL) I. A. Yazygin (IHEP Protvino)

WE6RFP021

**Simulations of Crystal Collimation for the LHC**

Bent crystals are promised to provide a path towards significant improvement of cleaning efficiency for high power collimation systems. In this paper a possible implementation of a crystal-enhanced collimation system is evaluated for the LHC. Simulation studies were performed with the same state-of-the-art tracking codes as used for the design of the conventional LHC collimation system. The numerical models are described and predictions for the local and global cleaning efficiency with a crystal-based LHC collimation system are presented. Open issues and further work towards a crystal collimation design for the LHC are discussed.

V. P. Prevtali, R. W. Assmann, S. Redaelli (CERN) V. P. Prevtali (EPFL) I. A. Yazygin (IHEP Protvino)

WE6RFP022

### Operational Experience with a LHC Collimator Prototype in the CERN Super-Proton Synchrotron

S. Redaelli, O. Aberle, R. W. Assmann, C. Bracco, B. Dehning, M. Jonker, R. Losito, A. Masi, M. Sapinski, Th. Weiler, C. Zamantzas (CERN)

A full scale prototype of the Large Hadron Collider (LHC) collimator was installed in 2004 in the CERN Super Proton synchrotron (SPS). During three years of operation the prototype has been used extensively for

beam tests, for control tests and also to benchmark LHC simulation tools. This operational experience has been extremely valuable in view of the final LHC implementation as well as for estimating the LHC operational scenarios, most notably to establish procedures for the beam-based alignment of the collimators with respect to the circulating beam. This was made possible by installing in the SPS a first prototype of the LHC beam loss monitoring system. The operational experience gained at the SPS, lessons learnt for the LHC operation and various accelerator physics effects that could limit the efficiency of the collimator alignment procedures are presented.

### The UA9 Experiment at the CERN-SPS

W. Scandale (CERN)

The UA9 experiment intends to assess the possibility of using bent silicon crystals as primary collimators to direct the beam halo

onto a secondary absorber, thus reducing outscattering, beam losses in critical regions and radiation load. The experiment will be performed in the CERN-SPS in storage mode with a low intensity 120 GeV/c proton beam. The beam will be perturbed to create a diffusive halo as in the RD22 experiment. The setup consists of four stations. The crystal station contains two goniometers for crystals. The first tracking station houses silicon strip detectors for single particle tracking. The second tracking station contains the same kind of detectors for tracking. The two stations will allow to measure  $x-x'$  densities and collimation efficiencies with high precision. The TAL station, at 90 degrees phase advance, is a 600 mm long tungsten secondary collimator. The observables of the experiment are the collimation efficiencies, the measurement of the phase space and the cleaning efficiency deduced from the losses along the ring. We present here the layout of the experiment and the way we expect to collect data in 2009.

### Fermilab Main Injector Collimation Systems: Design, Commissioning and Operation

B. C. Brown, P. Adamson, D. Capista, A. I. Drozhdin, D. E. Johnson, I. Kourbanis, N. V. Mokhov, D. K. Morris, I. L. Rakhno, K. Seiya, V. I. Sidorov, G. H. Wu, M.-J. Yang (Fermilab)

The Fermilab Main Injector is moving toward providing 400 kW of 120 GeV proton beams using slip stacking injection of eleven Booster batches. Loss of 5% of the beam at or near injection energy results in 1.5 kW of

beam loss. A collimation system has been implemented to localize this loss with the design emphasis on beam not captured in the accelerating rf buckets. More than 90% of these losses are captured in the collimation region. We will report on the construction, commissioning and operation of this collimation system. Commissioning studies and loss measurement tools will be discussed. Residual radiation monitoring of the Main Injector machine components since 2004 will be used to demonstrate the effectiveness and limitations of these efforts.

### Performance Evaluation of the CLIC Baseline Collimation System

We review the current status of the collimation system of the Compact Linear Collider (CLIC). New calculations are done to study

**J. Resta-López** (JAI)

the survivability of the CLIC energy spoiler in case of impact of a full bunch train considering the most recent beam parameters. The impact of the collimator wakefields on the luminosity is also studied using the updated collimator apertures, and we evaluate the beam position jitter tolerance that is required to preserve the nominal luminosity. Moreover, assuming the new collimation depths, we evaluate the collimation efficiency.

WE6RFP026

### Performance and Upgrades to the SNS Collimator Systems

As the SNS beam power is increased, the collimator systems are becoming correspondingly more important. The High Energy Beam Transport (HEBT) transverse collimators are now routinely used during neutron production. We are in the process of redesigning the HEBT momentum collimation system due to problems with gas production from radiolysis. The Ring collimators are designed for two-stage operation but to date they are mainly used in one-stage mode. In this paper we will discuss the status, the operational performance, and upgrades to the collimation systems.

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WE6RFP027

### ISOL Target Simulations

The combined time required for diffusion release from target materials and effusive-flow of short-lived ion species must be minimized at ISOL based radioactive ion beam (RIB) facilities. Computational simulation studies with state-of-the-art codes offer cost effective means for designing targets with optimized diffusion release properties and vapor transport systems with short path lengths, as required for such applications. To demonstrate the power of the technique for designing optimum thickness targets, analytic solutions to the diffusion equation are compared with those obtained from a finite-difference code for radioactive particle release from simple geometries. The viability of the Monte Carlo technique as a practical means for optimally designing vapor transport systems is demonstrated by simulating the effusive-flow of neutral particles through several complex vapor transport systems. Important issues which affect the yield rates of short-lived species generated in high power ISOL targets are also discussed.

**Y. Zhang**, G. Alton, R. Remec (ORNL) Z. Liu (IUCF)

WE6RFP028

### Parametric Studies of an 18 MW Water Beam Dump for a Future Electron Linear Collider

We report on parametric studies to optimize the design of an 18 MW beam dump using bulk flow of water to remove heat deposited from 500 GeV 4 Hz pulsed electron beam for

**J. W. Amann**, R. Arnold, D. R. Walz (SLAC) S. Pal, P. Rai, P. Satyamurthy, V. Tiwari (BARC)

possible use at a future electron linear collider. Three areas of study are presented: influence of asymmetric beam spots on the maximum energy density in the water using FLUKA; distribution in space and time of the velocity and temperature of water circulated in the dump vessel from computational fluid dynamics calculations with Fluent; and distribution of heat, prompt radiation, and activation deposited in the dump water vessel and surrounding

WE6RFP029

shielding with FLUKA. Preliminary layouts for the water circulation path, water vessel, and shielding arrangements will be presented.

### Recent Progress on the Design of a Rotatable Copper Collimator for the LHC Collimation Upgrade

J. C. Smith, L. Keller, S. A. Lundgren, T. W. Markiewicz (SLAC)

The Phase II upgrade to the LHC collimation system calls for complementing the 30 high robust Phase I graphite collimators with 30 high Z Phase II collimators. One option is to use metallic rotatable collimators and this design will be discussed here. The Phase II collimators must be robust in various operating conditions and accident scenarios. Design issues include: 1) Collimator jaw deflection due to heating and sagitta must be small when operated in the steady state condition, 2) Collimator jaws must withstand transitory periods of high beam impact with no permanent damage, 3) Jaws must recover from accident scenario where up to 7 full intensity beam pulses impact on the jaw surface and 4) The beam impedance contribution due to the collimators must be small to minimize coherent beam instabilities. The current design will be presented.

### Prospects for Integrating a Hollow Electron Lens into the LHC Collimation System

J. C. Smith (SLAC) R. W. Assmann, V. P. Prevtali (CERN) A. I. Drozhdin, V. D. Shiltsev, A. Valishev (Fermilab)

It has been proposed to use a hollow electron lens with the LHC beam collimation system\*. The hollow electron beam would be used as a beam scraper and positioned at a closer sigma than the primary collimators to increase the halo particle diffusion rate striking the primaries. In this paper we use multi-turn beam tracking simulations to analyze the effectiveness of such a lens when integrated into the LHC collimation system.

\*Shiltsev, V. et al. "LHC Particle Collimation by Hollow Electron Beams," Proceedings EPAC08, MOPC098 (2008)

### Morphology of a Powder Jet as a Target for the Neutrino Factory

O. Caretta, C. J. Densham, P. Loveridge (STFC/RAL) T. W. Davies (Exeter University) R. M. Woods (Gericke LTD)

This paper proposes a technology based on fluidized powder which could be employed as a high power target (and beam dump), for example in a future Neutrino Factory or Muon Collider. A fluidized powder target is believed to bring together some advantages of both the solid and liquid phase whilst avoiding some of their drawbacks. The current Neutrino Factory and Muon Collider proposals require the use of a high Z target material withstanding beam ionisation heating of around 1 MW. The article proposes to use a dense tungsten powder jet as an alternative to the baseline open mercury jet for interaction with the proton beam inside the high field capture solenoid. The preliminary experimental results on the production and on the characteristics of a dense horizontal tungsten powder jet are presented. The morphology of the jet is analysed and presented as a function of the driving parameters (e.g. pneumatic supply pressure, boundary conditions of the jet, etc.). A test rig was developed to investigate the reliability of lean and dense phase pneumatic conveying of tungsten powder and the results of such experiments are discussed in the paper.



### Design and Development of the T2K Pion Production Target

The T2K experiment will utilise the highest pulsed power proton beam ever built to generate an intense beam of neutrinos. This uses the conventional technique of colliding the 0.75 MW 30 GeV proton beam with a graphite target and using a magnetic horn system to collect pions of one charge and focus them into a decay volume where the neutrino beam is produced. The target is a two interaction length (900 mm long) graphite target supported directly within the bore of the first magnetic horn which generates the required field with a pulsed current of 300 kA. This paper describes the design and development of the target system required to meet the demanding requirements of the T2K facility. Challenges include radiation damage, shock waves resulting from a 100 K temperature rise in the graphite material during each beam spill, design and optimisation of the helium coolant flow, and integration with the pulsed magnetic horn. Conceptual and detailed engineering studies were required to develop a target system that could satisfy these requirements and could also be replaced remotely in the event of a target failure.

C. J. Densham (STFC/RAL)

WE6RFP033

### Beam Impact Studies for ILC Collimators

Spoilers in the ILC Beam Delivery System are required to survive without failure a minimum of 1-2 direct impacts of 250 GeV-500 GeV bunch of electrons or positrons, in addition to maintaining low geometric and resistive wall wake fields. The likelihood of spoiler survival was determined using finite element models of thermal and mechanical properties of the spoilers, with realistic patterns of energy deposition as input. The second phase of an experiment to calibrate the finite element models using electron beam data will be performed in the ATF2 extraction line, by subjecting a small sample of Ti-6Al-4V to bunches of electrons. The displacement of the surface will be measured with a Velocity Interferometer System of Any Reflector (VISAR). This paper shows the project plan as well as results of the simulations and expected readout from the VISAR.

G. Ellwood (STFC/RAL)

WE6RFP034

### Design of Momentum Spoilers for the Compact Linear Collider

The postlinac energy collimation system of the Compact Linear Collider (CLIC) protects the machine by intercepting mis-steered beams due to possible failure modes in the linac. The collimation is based in a spoiler-absorber scheme. The mission of the spoiler is to protect the main downstream absorber by dispersing the beam, via multiple Coulomb scattering, in case of a direct hit. We present the design of energy spoilers for CLIC, considering the following requirements: spoiler survival to the deep impact of an entire bunch train, and minimisation of spoiler wakefield effects during normal operation. Different configurations of the spoiler are studied in order to achieve an optimum performance.

J.-L. Fernandez-Hernando (STFC/DL/ASTeC) J. Resta-López (JAI)

WE6RFP035

### Activation and Residual Equivalent Dose Rate Studies for an ILC Betatron Spoiler Prototype

After different wakefield test beams and radiation damage studies a prototype design for the International Linear Collider (ILC)

J.-L. Fernandez-Hernando (STFC/DL/ASTeC)

WE6RFP036

spoilers of the betatron collimation system in the Beam Delivery System (BDS) is under development. Studies of activation and residual equivalent dose rate are needed in order to achieve an optimum design as well as to assess the radiation shielding requirements.

### Initial Studies and a Review of Options for a Collimator System for the Linac4 Accelerator

J.-L. Fernandez-Hernando, D. Angal-Kalinin (STFC/DL/ASTeC)  
F. Gerigk, A. M. Lombardi, R. Losito (CERN)

Linac4 is a 160 MeV  $H^-$  linac which will replace the existing Linac2, a 50 MeV proton linac, at CERN as a first step of the upgraded LHC proton injector chain. No collima-

tion system is foreseen in the baseline design but it will become mandatory for operation at highest duty cycle in order to reduce activation of the machine. Such a system will also help to reduce activation at low duty cycle. A review of different collimation options, initial studies on collimator designs capable of intercepting beam power of 10, 25 and 50 Watts at energies between 50 and 160 MeV, the activation of such designs and the downstream elements are shown in this paper.

### An FEA Study of Stress Waves Generated in the T2K Beam Window from the Interaction with a High Power Pulsed Proton Beam

M. T. Rooney, C. J. Densham (STFC/RAL) Y. Yamada (KEK)

The target station of the T2K neutrino facility requires a beam window to separate the target chamber, containing helium at at-

mospheric pressure, from the secondary beam line, which is maintained at ultra high vacuum. In addition to withstanding this differential pressure, the window must survive induced stresses due to intense heating resulting from interaction with a 0.75 MW pulsed proton beam. The design consists of a hemispherical double window with forced convection helium cooling in the volume enclosed, manufactured from titanium alloy. Preliminary analysis suggested that 'shock' waves induced by the pulsed nature of the beam will form the dominant mode of stress. The finite element software ANSYS Mechanical (V10) has been used to simulate the effect of beam impingement on a variety of window thicknesses in an attempt to find the optimum geometry. Results have shown that through thickness stress waves can be amplified if successive bunches arrive in phase with the waves generated by previous bunches. Therefore, thickness has been shown to be a critical variable in determining the window's resistance to induced thermal shock.

### Solid Target for a Neutrino Factory

G. P. Skoro (Sheffield University) J. J. Back (University of Warwick)  
J. R.J. Bennett (STFC/RAL/ISIS) S. J. Brooks (STFC/RAL/ASTeC)  
C. J. Densham, T. R. Edgecock, P. Loveridge (STFC/RAL)

The UK programme of high power target developments for a Neutrino Factory is centred on the study of high-Z materials (tungsten, tantalum). A description of lifetime shock tests on candidate materials is given

as a part of the research into a solid target solution. A fast high current pulse is applied to a thin wire of the sample material and the lifetime measured from the number of pulses before failure. These measurements are made at temperatures up to  $\sim 2000$  K. The stress on the wire is calculated using the LS-DYNA code and compared to the stress expected in the real Neutrino Factory target. It has been found that tantalum is too weak at these temperatures but a tungsten wire has reached over 26 million pulses (equivalent to more than ten years of operation at the Neutrino Factory). Measurements of the surface velocity of the wire using a laser interferometry system

(VISAR) are in progress, which, combined with LS-DYNA modelling, will allow the evaluation of the constitutive equations of the material. An account is given of the optimisation of secondary pion production and capture in a Neutrino Factory and of the latest solid target engineering ideas.

### MICE Target Operation and Monitoring

The MICE experiment requires a beam of low energy muons to test muon cooling. This beam is derived parasitically from the

**C. N. Booth, P. Hodgson, P. J. Smith** (Sheffield University)

ISIS accelerator at the Rutherford Appleton Laboratory. A novel target mechanism has been developed which allows the insertion of a small titanium target into the proton beam on demand, for the final couple of milliseconds before extraction. The first operational linear drive was installed onto ISIS in January of 2008. Since then, it has operated for over 100,000 actuations. Studies have been performed of particle production and collection by the MICE beam-line, as well as verification of the reliability of the target drive itself. The target data acquisition system records not only the position of the target throughout the ISIS acceleration cycle, but also the outputs from beam loss monitors placed around the synchrotron. Data will be presented showing the stability of the target's motion and the correlation of beam loss and particle production with the timing and depth of the target's intersection with the circulating beam.

### MICE Target Hardware

The MICE Experiment requires a beam of low energy muons to demonstrate muon cooling. This beam is derived parasitically from the

**P. J. Smith, C. N. Booth, P. Hodgson** (Sheffield University)

ISIS accelerator. A novel target mechanism has been developed that inserts a small titanium target into the proton beam on demand. The target remains outside the beam envelope during acceleration and then overtakes the shrinking beam envelope to enter the proton beam during the last 2 ms before beam extraction. The technical specifications for the target mechanism are demanding, requiring large accelerations and precise and reproducible location of the target each cycle. The mechanism operates in a high radiation environment, and the moving parts are compatible with the stringent requirements of the accelerator's vacuum system. This paper will describe the design of the MICE target and how it is able to achieve its required acceleration whilst still meeting all of the necessary requirements for operation within the ISIS vacuum. The first operational linear electromagnetic drive was installed onto ISIS in January 2008 and has since been operated for over one hundred thousand actuations.

### The FERMI@elettra Beam Dump

The FERMI@elettra electron beam dump is designed for a 1nC, 1.8 GeV, 50Hz repetition rate beam. Using GEANT simulations, materials are chosen to absorb 99% of the beam energy and to limit the radio-isotope production. In addition, from the energy deposition distribution inside the dump, the thermal load is estimated. The necessary requirements, the design and the expected performance are presented and discussed.

**S. Ferry, E. Karantzoulis** (ELETTRA)

### The FERMI@elettra Collimators

S. Ferry, C. Bontoiu, P. Craievich, S. Di Mitri, E. Karantzoulis (ELETTRA)

To avoid damages on permanent magnets by the electrons, collimators will be installed in FERMI@elettra. Their dimensions and shape are defined through the beam optics and the induced wake fields while GEANT simulations are performed to determine their absorption efficiency and thermal load for both normal operating conditions and in case of miss-steering. The design, the simulations and the expected performance of the collimators are presented and discussed.

### Fabrication of Silicon Crystals for Channeling Experiments in Accelerators

A. Mazzolari, S. Baricordi, P. Dalpiaz, V. Guidi, G. Martinelli, D. Vincenzi (UNIFE) E. Bagli (INFN-Ferrara)

Channeling in bent crystals is a technique with high potential to steer charged-particle beams for several applications in accelerators physics. Channeling and related techniques underwent significant progress in the last years. Distinctive features of performance increase was the availability of novel ideas other than new techniques to manufacture the crystal for channeling. We show the technology to fabricate crystals through non conventional silicon micromachining techniques. Characterization of the realized crystals highlighted that the crystals are free of lattice damage induced by the preparation. The crystals were positively tested at the external line H8 of the SPS with 400 GeV protons for investigation on planar and axial channelings as well as on single and multiple volume reflection experiments by the H8-RD22 collaboration. Selected single- and multi-crystal are candidates for the experiment UA9--an experiment on beam collimation at the CERN SPS.

### DESY EDMS: Information Management for World-Wide Collaborations

L. Hagge, J. Buerger, J. A. Dammann, S. Eucker, A. Herz, J. Kreuzkamp, S. Panto, S. Suehl, D. Szepielak, P. Tumidajewicz, N. Welle (DESY)

The DESY Engineering Data Management System, DESY EDMS, is a fully Web-based central information management platform at the European XFEL and the Global Design Effort for the International Linear Collider (ILC GDE). It provides functionality for managing documents and 3D CAD data and for performing configuration and change management. It can control complex information structures and keep track of their dependencies and history, i.e. their evolution over time. Due to its powerful capabilities for automating workflows and controlling information access, the DESY EDMS can coordinate processes and manage authorizations and responsibilities in large and complex organizations, which may include several institutes and industrial partners. Applications of the DESY EDMS range from small-scale document management for work groups, up to managing the complexity of world-wide collaborations during design and construction activities. The poster describes the architecture of the DESY EDMS, introduces some of its use cases and reports lessons learned in developing and operating the system.

### The XFEL Roombook - Processes and Tools for Designing the Technical Infrastructure of the European XFEL

The European XFEL has started the construction of the underground buildings. Now, the detailed design of the technical infrastructure has to be completed, covering HVAC (heating, ventilation, air conditioning), MEP (mechanical, electrical and plumbing), communication, transportation and safety. The design process is centered around the XFEL Roombook: The XFEL Roombook contains a complete catalog of XFEL buildings, floors and rooms. Future user groups specify requirements on their rooms, which are collected in a central database (Requirements Management System, RMS). Engineers create floor plans and design drawings based on the requirements. Project members can access room information, requirements and floor plans through the Web interface of the XFEL Roombook. The XFEL Roombook is in production since summer 2009 and has become a well accepted information platform for infrastructure design. The paper describes the planning process, the supporting tools and lessons learned.

**L. Hagge**, S. Eucker, J. Kreutzkamp (DESY)

### Remotely Operated Train for Inspection and Measurement in CERN's LHC Tunnel

Personnel access to the LHC tunnel will be restricted to varying extents during the life of the machine due to radiation and cryogenic hazards. For this reason a remotely operated modular inspection train, (TIM) running on the LHC tunnel's overhead monorail has been developed. In order to be compatible with the LHC personnel access system, a small section train that can pass through small openings at the top of sector doors has now been produced. The basic train can be used for remote visual inspection; additional modules give the capability of carrying out remote measurement of radiation levels, environmental conditions around the tunnel, and even remote measurement of the precise position of machine elements such as collimators. The paper outlines the design, development and operation of the equipment including preparation of the infrastructure. Key features of the trains are described along with future developments and intervention scenarios.

**K. Kershaw**, C. Bertone, P. Bestmann, T. Feniet, D. Forkel-Wirth, J. L. Grenard, N. Rousset (CERN)

### Radiation Zoning for Vacuum Equipment of the CERN Large Hadron Collider

Beam losses in high-energy particle accelerators are responsible for beam lifetime degradation. In the LHC beam losses will create a shower of particles while interacting with materials from the beam pipes and surroundings, resulting in a partial activation of material in the tunnel. Efforts have been made during the accelerator design to monitor and to reduce the activation induced by beam losses. Traceability for all vacuum components has been established providing a tool to follow-up individually each component or subcomponents installed in the tunnel, regardless of their future destination e.g. recycling or disposal. In the latter case, the history of vacuum components will allow calculating the beam-induced activation and permit comparisons with in-situ and ex-situ measurements. This zoning will also help to reduce collective and individual radiation doses to personnel during interventions. The paper presents the vacuum system layout and describes the LHC vacuum zoning and its implementation using an ORACLE© database.

**E. Mahner**, S. Chemli, P. Cruikshank, D. Forkel-Wirth, J. M. Jimenez (CERN)

### Optimisation of the Powering Tests of the LHC Superconducting Circuits

R. Schmidt, B. Bellesia, M. P. Casas Lino, C. Fernandez-Robles, M. Pojer, R. I. Saban, M. Solfaroli Camillocci, A. Vergara-Fernández (CERN)

The Large Hadron Collider has 1572 superconducting circuits which are distributed along the eight 3.5 km LHC sectors. Time and resources during the commissioning of the LHC technical systems were mostly consumed by tests of each circuit of the collider: the powering tests. The tests consisted in carrying out several powering cycles at different current levels for each superconducting circuit. The Hardware Commissioning Coordination was in charge of planning, following up and piloting the execution of the test program. The first powering test campaign was carried out in summer 2007 for sector 7-8 with an expected duration of 12 weeks. The experience gained during these tests was used by the commissioning team for minimising the duration of the following powering campaigns to comply with the stringent LHC Project deadlines. Improvements concerned several areas: strategy, procedures, control tools, automatism, resource allocation led to an average daily test rate increase from 25 to 200 tests per day. This paper describes these improvements and details their impact on the operation during the last months of LHC Hardware Commissioning.

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### The Conceptual Design of TPS Grounding System

T.-S. Ueng, J.-C. Chang, Y.-C. Lin (NSRRC)

The TPS (Taiwan Photon Source) of NSRRC is in the design stage now. The grounding system is crucial to the safety issue, the electrical reference level, the electrical noise and the EMI problems. In order to provide a high quality electrical environment, the grounding system should be designed carefully. The soil resistivity of the construction site was investigated first. Many different configurations of the ground grid layouts were simulated and compared. Beside the horizontal ground-conductors, the vertical ground-electrodes of 30 m are considered to be installed below the ground surface and they will reach the ground water level in hopes of minimizing the resistance of ground grid. The main goal is to obtain a ground grid with resistance lower than 0.2 ohm. A rectangular ground grid will also be installed under the new utility building. It will be connected to the ground grid of TPS to further reduce the resistance of whole grounding system, and also to eliminate the potential difference between them.

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### Experiments and Numerical Simulation of the Air Conditioning System Design for the 3GeV TPS Storage Ring

J.-C. Chang, Y.-C. Chung, C. Y. Liu, A. Sheng, Z.-D. Tsai (NSRRC)

The air conditioning system for the 3.0 GeV Taiwan Photon Source (TPS) is currently under the design phase. This paper presents the latest design of the air conditioning system for the TPS. The capacity of the air handling unit (AHU), the dimension and layout of the wind duct were specified. A full-scale model of the wall, ceiling and wind ducts of the 1/24 section ring was constructed. Data of temperature variations in the model were collected. Numerical analysis was also applied to simulate the air flow and temperature distribution in the storage ring. In the 3-dimensional Computational Fluid Dynamics (CFD) simulation, magnets of the booster and the storage ring, girders, cable trays, front ends and the supplied air wind duct are modelled. The numerical simulated results were compared with data of the experiment.

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### Power Saving Schemes in the NSRRC

To cope with increasing power cost and to confront huge power consumption of the Taiwan Photon Source (TPS) in the future, we have been conducting several power saving schemes since 2006 in the National Synchrotron Radiation Research Center (NSRRC). Those power saving schemes include optimization of chiller operation, air conditioning system improvement, power factor improvement and the lighting system improvement.

**J.-C. Chang**, Y.-C. Chung, K. C. Kuo, K. Li, Y.-C. Lin, C. Y. Liu, A. Sheng, Z.-D. Tsai, T.-S. Ueng (NSRRC)

WE6RFP052

### Simulation and Design of the High Precision Temperature Control for the De-Ionized Cooling Water System

Previously, the Taiwan Light Source (TLS) has proven that the temperature stability of de-ionized cooling water is one of the most critical factors of electron beam stability. A series of efforts were devoted to these studies and promoted the temperature stability of the de-ionized cooling water system within  $\pm 0.1^\circ\text{C}$ . Further, a high precision temperature control  $\pm 0.01^\circ\text{C}$  has been conducted to meet the more critical stability requirement. Using flow mixing mechanism and specified control philosophy can minimize temperature variation effectively. The paper declares the mechanism through simulation and verifies the practical influences. The significant improvement of temperature stability between cooling devices and de-ionized water are also presented.

Z.-D. Tsai, J.-C. Chang, J.-R. Chen (NSRRC)

WE6RFP053

### Design and Performance of Resonance Frequency Control Cooling System of PEFP DTL

The objectives of the cooling system of Proton Engineering Frontier Project (PEFP) Drift Tube Linac (DTL) operated in combination with the low-level RF system (LLRF) are to regulate the resonant frequency of the drift tube cavities of 350 MHz. To provide an effective means of bringing the PEFP DTL up for a resonance condition within  $\pm 5$  kHz, the prototype of the cooling system has been designed and fabricated to investigate the performance features for the servo stabilization of the cavity resonant frequency. As a result, it is estimated that the resonant frequency could be regulated less than  $\pm 1$  kHz with this proposed feedback temperature controlled cooling system although introducing a little nonlinear features as the reference operating temperature changes. This report describes the design and performance test results of a cooling system, including the size of water pumping skid components and the temperature control scheme.

**K. R. Kim**, H.-G. Kim (PAL) Y.-S. Cho, H.-J. Kwon (KAERI)

WE6RFP054

### The Argonne Wakefield Accelerator Facility (AWA): Upgrades and Future Experiments

The Argonne Wakefield Accelerator Facility is dedicated to the study of advanced accelerator concepts based on electron beam driven wakefield acceleration and RF power generation. The facility employs an L-band photocathode RF gun to generate high charge short electron bunches, which are used to drive wakefields in dielectric loaded structures as well as in metallic structures (iris loaded, photonic band gap, etc). Accelerating gradients as high as 100 MV/m have been reached in dielectric loaded

**M. E. Conde**, S. P. Antipov, W. Gai, F. Gao, R. Konecny, W. Liu, J. G. Power, Z. M. Yusof (ANL) C.-J. Jing (Euclid TechLabs, LLC)

WE6RFP055

structures, and RF pulses of up to 44 MW have been generated at 7.8 GHz. In order to reach higher accelerating gradients, and also be able to generate higher RF power levels, a photocathode with higher quantum efficiency is needed. Therefore, a new RF gun with a Cesium Telluride photocathode will replace the electron gun that has been used to generate the drive bunches. In addition to this, a new L-band klystron will be added to the facility, increasing the beam energy from 15 MeV to 23 MeV, and thus increasing the total power in the drive beam to a few GW. The goal of future experiments is to reach accelerating gradients of several hundred MV/m and to extract RF pulses with GW power level.

### Development of a Non-Axisymmetric Permanent Magnet Focusing System for Elliptic Charged-Particle Beams

T. M. Bemis, M. H. Lawrence, J. Z. Zhou (Beam Power Technology, Inc.) C. Chen (MIT/PSFC)

High-brightness space-charge-dominated elliptic electron or ion beams have wide applications in high-power rf sources, particle accelerators, and/or ion implantation.

Building upon recent inventions and theoretical studies on the generation and transport of elliptic charged-particle beams, a basic research and development program is being carried out to experimentally demonstrate a high-brightness, space-charge-dominated elliptic electron beam using a non-axisymmetric permanent magnet focusing system and an elliptic electron gun. Results of the design of such an elliptic electron beam system are presented.

### Wake Fields in Photonic Crystal Accelerator Structures and Application to RF Sources

G. R. Werner, C. A. Bauer, J. R. Cary, T. Munsat (CIPS)

The RF properties of photonic crystals (PhCs) can be exploited to avoid the parasitic higher order modes (HOMs) that

degrade beam quality in accelerator cavities and reduce efficiency and power in RF generators. Computer simulations show that long-range wake fields are significantly reduced in accelerator structures based on dielectric PhC cavities, which can be designed to trap only those modes within a narrow frequency range. A 2D PhC structure can be used to create a 3D accelerator cavity by using metal end-plates to confine the fields in the third dimension; however, even when the 2D photonic structure allows only a single mode, the 3D structure may trap HOMs, such as guided modes in the dielectric rods, that increase wake fields. For a 3D cavity based on a triangular lattice of dielectric rods, the rod positions can be optimized (breaking the lattice symmetry) to reduce radiation leakage using a fixed number of rods; moreover, the optimized structure has reduced wake fields. Using computer simulation, wake fields in pillbox, PhC, and optimized photonic cavities are calculated; a design for a klystron using the optimized photonic cavity structure is presented.

### TBA Scheme with Ion/Proton Driving Beam

A. A. Mikhailichenko (Cornell University, Department of Physics)

We are considering a TBA scheme for electron-positron collisions with Ion/Proton driving beam. We compare the proposed

scheme and the CLIC one coming to conclusion, that Ion/Proton driving TBA scheme looks more attractive.



### OSC with Optical Restrain of Heating Core

We are considering an Optical Stochastic Cooling scheme with optically eliminated radiation from the core of the beam. For these purposes, the screen located at the image plane of optical system, has the optical transmission which is linearly changing from not transparent at the center to the fully transparent at the sides.

**A. A. Mikhailichenko** (Cornell University, Department of Physics)  
E. G. Bessonov (LPI)

WE6RFP059

### A 26 GHz Dielectric Based Wakefield Power Extractor

High frequency, high power rf sources are needed for many applications in particle accelerators, communications, radar, etc. We have developed a 26GHz high power rf source based on the extraction of wakefields from a relativistic electron beam. The extractor is designed to couple out rf power generated from a high charge electron bunch train traversing a dielectric loaded waveguide. Using a 20nC bunch train (bunch length of 1.5 mm) at the Argonne Wakefield Accelerator (AWA) facility, we expect to obtain a steady 26GHz output power of 148 MW. The extractor has been fabricated and bench tested along with a 26GHz Power detector. The first high power beam experiments should be performed prior to the Conference. Detailed results will be reported.

**C.-J. Jing**, A. Kanareykin, A. L. Kustov, P. Schoessow (Euclid TechLabs, LLC) M. E. Conde, W. Gai, F. Gao, R. Konecny, J. G. Power (ANL) S. Kazakov (KEK)

WE6RFP060

### A Transverse Modes Damped Dielectric Loaded Accelerating Structure

As the dimensions of accelerating structures become smaller and beam intensities higher, the transverse wakefields driven by the beam become quite large with even a slight misalignment of the beam from the geometric axis. These deflection modes can cause inter-bunch beam breakup and intra-bunch head-tail instabilities along the beam path, and thus BBU control becomes a critical issue. All new metal based accelerating structures, like the accelerating structures developed at SLAC or power extractors at CLIC, have designs in which the transverse modes are heavily damped. Similarly, minimizing the transverse wakefield modes (here the HEM<sub>mn</sub> hybrid modes in Dielectric-Loaded Accelerating (DLA) structures) is also very critical for developing dielectric based high energy accelerators. We have developed a 7.8GHz transverse mode damped DLA structure. The design and bench test results are presented in the article.

**C.-J. Jing**, A. Kanareykin, P. Schoessow (Euclid TechLabs, LLC) M. E. Conde, W. Gai, R. Konecny, J. G. Power (ANL)

WE6RFP061

### Development of a THz Source Based on a Diamond Structure

There has been considerable progress in using microfabrication techniques to produce experimental rf sources. These devices have for the most part been based on micromachined copper surfaces or silicon wafers. We are developing THz diamond wakefield structures produced using Chemical Vapor Deposition (CVD) technology. The electrical and mechanical properties of diamond make it an ideal candidate material for use in dielectric rf structures: high breakdown voltage (~600 MV/m), extremely low dielectric losses and the highest thermoconductive coefficient available for removing waste heat from the device.

**A. Kanareykin**, P. Schoessow (Euclid TechLabs, LLC) R. Gat (Coating Technology Solution, Inc.)

WE6RFP062

These structures are based on cylindrical diamond dielectric tubes that are manufactured via a relatively simple and inexpensive chemical vapor deposition (CVD) process, plasma assisted CVD. Use of the CVD process is a much simpler method to achieve high quality rf microcavities compared to other microfabrication techniques. We are designing a number of diamond rf structures with fundamental TM<sub>01</sub> frequencies in the 0.1-1 THz range. Numerical simulations of planned experiments with these structures will be reported.

### Studies of Beam Breakup in Dielectric Structures

A. Kanareykin, C.-J. Jing, A. L. Kustov, P. Schoessow (Euclid TechLabs, LLC) W. Gai, J. G. Power (ANL)

Beam breakup (BBU) effects resulting from parasitic wakefields provide a potentially serious limitation to the performance of dielectric structure based accelerators. We report here on comprehensive numerical studies and planned experimental investigations of BBU and its mitigation in dielectric wakefield accelerators. An experimental program is planned at the Argonne Wakefield Accelerator facility that will focus on BBU measurements in a number of high gradient and high transformer ratio wakefield devices. New pickup-based beam diagnostics will provide methods for studying parasitic wakefields that are currently unavailable at the AWA. The numerical part of this research is based on a particle-Green's function beam dynamics code (BBU-3000) that we are developing. The code allows rapid, efficient simulation of beam breakup effects in advanced linear accelerators. The goal of this work is to compare the results of detailed experimental measurements with accurate numerical results and ultimately to study the use of external FODO channels for control of the beam in the presence of strong transverse wakefields.

### Accelerator Applications of New Nonlinear Ferroelectric Materials

P. Schoessow, A. Kanareykin (Euclid TechLabs, LLC) V. P. Yakovlev (Fermilab)

Materials possessing large variations in the permittivity as a function of the electric field exhibit a rich variety of phenomena for electromagnetic wave propagation such as frequency multiplication, wave steepening and shock formation, solitary waves, and mode mixing. New low loss nonlinear microwave ferroelectric materials present interesting and potentially useful applications for both advanced and conventional particle accelerators. Accelerating structures (either wakefield-based or driven by an external rf source) loaded with a nonlinear dielectric may exhibit significant field enhancements. Nonlinear transmission lines can be used to generate short, high intensity rf pulses to drive fast rf kickers. In this paper we will explore the large signal permittivity of these new materials and applications of nonlinear dielectric devices to high gradient acceleration, rf sources, and beam manipulation. We describe planned measurements using a planar nonlinear transmission line to study the electric field dependence of the permittivity of these materials. Diagnostics include appearance of harmonics with a cw drive signal and sharpening of a pulse waveform as it propagates.

### The CLIC Positron Sources Based on Compton Schemes

The CLIC polarized positron source is based on a positron production scheme in which polarized photons are produced by Compton process. Compton backscattering happens in a so-called "Compton ring" where an electron beam of 1.06 GeV interacts with a powerful laser beam amplified in an optical resonator. The circularly-polarized gamma rays are sent on to a target, producing pairs of longitudinally polarized electrons and positrons. An Adiabatic Matching Device maximizes the capture of the positrons. A normal-conducting 2 GHz Linac accelerates the beam up to 2.424 GeV before injection into the Pre-Damping Ring (PDR). The nominal CLIC bunch population is  $4.4 \times 10^{10}$  particles per bunch. Since the photon flux coming out from a "Compton ring" is not sufficient to obtain the requested charge, a stacking process is required in the PDR. Another option is to use a "Compton Energy Recovery Linac" where a quasi-continual stacking in the PDR could be achieved. A third option is to use a "Compton Linac" which would not require stacking. We describe the overall scheme as well as advantages and constraints of the three different options.

**L. Rinolfi**, H.-H. Braun, Y. Papaphilippou, D. Schulte, A. Vivoli, F. Zimmermann (CERN) F. Antoniou (National Technical University of Athens) I. R. Bailey, L. Zang (Cockcroft Institute) E. V. Bulyak, P. Gladkikh (NSC/KIPT) R. Chehab (IN2P3 IPNL) J. A. Clarke (STFC/DL/ASTeC) O. Dadoun, P. Lepercq, R. Roux, A. Variola, Z. F. Zomer (LAL) W. Gai, W. Liu (ANL) T. Kamitani, T. Omori, J. Urakawa (KEK) M. Kuriki (HU/AdSM) H. Monard (CLIO/ELISE/LCP) I. Pogorelsky, V. Yakimenko (BNL) T. Takahashi (Hiroshima University, Graduate School of Science)

### Optical Diagnostic for Off-Axis Electrons in a Laser Wakefield Accelerator

Theoretical work\* on electro-optic shock produced from the interaction of intense laser radiation with  $\sim 1\%$  critical plasma suggests that second harmonic radiation will be emitted at the Cherenkov angle. This radiation pattern is produced under similar conditions as when off-axis electrons\*\* were observed. These electrons are of particular interest since they are well suited for external injection into a laser wakefield acceleration structure. Recent experimental results at the U. S. Naval Research Laboratory, using a 10 TW, 50 fs, Ti-Sapphire laser, have shown the existence of such a second harmonic ring. Characterization of this optical radiation and its relationship to off-axis electrons will be presented.

**M. H. Helle** (Georgetown University) D. F. Gordon, A. Ting (NRL) D. Kaganovich (Icarus Research, Inc.)

\*D. F. Gordon et al., Phys. Rev. Lett. 101, 45004 (2008).

\*\*D. Kaganovich et al. Phys. Rev. Lett. 100, 215002 (2008).

### The International Design Study for the Neutrino Factory

The International Design Study for the Neutrino Factory has been established by the Neutrino Factory community to deliver a Reference Design Report for the facility by 2012\*. The baseline design for the facility, developed from that defined in the ISS\*\*, will provide  $10^{21}$  muon decays per year from 25 GeV stored muon beams. The facility will serve two neutrino detectors; one situated at source-detector distance of between 3000–5000 km, the second at 7000–8000 km. The conceptual design of the accelerator facility will be described and its performance will be presented. Muon storage rings have also been proposed as the basis of a multi-TeV lepton-antilepton 'Muon Collider'. The R&D required to deliver the Neutrino

**K. R. Long** (Imperial College of Science and Technology, Department of Physics)

Factory and that required to realise the Muon Collider have many synergies including: the pion-production target; ionisation cooling; rapid acceleration of large emittance beams; and the provision of high-gradient accelerating cavities that operate in high magnetic fields. The principal synergies will be described and the common R&D path will be discussed. Finally, the organisation of the IDS-NF and its relation to the EUROnu Design Study will also be described\*\*\*.

\*The decision point identified by the CERN Council Strategy Group.

\*\*The International Scoping Study for a future Neutrino Factory and super-beam facility.

\*\*\*Submitted on behalf of the IDS-NF.

### Multi-Mode Accelerating Structure with High Filling Factor

S. V. Kuzikov, M. E. Plotkin (IAP/RAS)

recently\*. The structure is aimed to increase threshold breakdown surface field and thus to provide a high gradient. This threshold increase is to be brought about by designing cavities of the structure to operate simultaneously in several harmonically-related  $TM_{n,n,0}$  modes, thereby reducing the effective exposure time of the cavity surface to the peak fields. The more number of the operating modes is the more reduction of the exposure time. Unfortunately, a big amount of modes leads to limitation for cavity length and practical limitation of filling factor. In order to avoid this, it is suggested to operate with several  $TM_{n,n,l}$  modes with non-zero longitudinal indices. These modes are able to provide the long interaction of a moving bunch with RF fields along the cavity. Such regime requires for the longitudinal index  $l$  to be strictly proportional the mode frequency. A cylindrical shape cavity design is also considered.

\*S. V. Kuzikov, S. Yu. Kazakov, M. E. Plotkin, J. L. Hirshfield, High-Gradient Multi-Mode Two-Beam Accelerating Structure, Proc. of EPAC'08 Conf., Genoa, June 23-27, 2008, WEPP133.

### Multi-Mode Cavity Design to Raise Breakdown Thresholds

S. V. Kuzikov (IAP/RAS) J. L. Hirshfield (Yale University, Physics Department) S. Kazakov (Omega-P, Inc.)

allows excitation in several equidistantly-spaced eigen modes by a bunched drive beam in such a way that the RF fields reach peak values only during time intervals that can be much shorter than for excitation of a single mode, thus exposing the cavity surfaces to strong fields for shorter times. This feature is expected to raise the breakdown and pulse heating thresholds. In order to measure an increase in breakdown threshold surface electric field due to this reduction of exposure time during each RF period, a high-power experiment is planned. Preliminary calculations show that such a study in which comparison of breakdown threshold would be made of a conventional single-mode cavity with a multi-mode cavity can in principle be carried out using the drive beam of the CTF-3 test stand at CERN.

A new two-beam accelerating structure based on periodic chain of rectangular shape multi-mode cavities was suggested

A multi-mode cavity design for a two-beam accelerator aimed to achieve an accelerating gradient exceeding 150 MeV/m is reported.

The cavity has a square cross section which

### Improving the Reliability of a LWFA with Ionization Induced Trapping

In many current LWFA experiments, the non-optimal laser pulse must undergo a significant temporal and/or spacial modification before  $e^-$  trapping occurs. This in turn

W. Lu, C. Joshi, W. B. Mori (UCLA) S. F. Martins (Instituto Superior Tecnico)

leads to a significant shot-to-shot variation in the output spectrum of the accelerated  $e^-$ . The reliability of the accelerated  $e^-$  could be improved if the injection process could be made to be deterministic. We are exploring ionization induced trapping as a way to precisely control  $e^-$  injection in the wake using particle in cell simulations in OSIRIS\*. First, a typical LWFA configuration is used with a mixture of He and N gas. He provides the  $e^-$  that sustain the plasma wakefield, and the higher ionization levels of N feed the  $e^-$  trapping at the back of the laser. Simulations show the effective trapping with acceleration up to 200MeV (30fs,  $a_0=2.5$  laser), and confirm the role of the He. The second technique is based on wakefield generation by a beatwave in a low density plasma ( $1.2 \cdot 10^{16} \text{ cm}^{-3}$ ). Results show the expected  $e^-$  trapping, acceleration above 250MeV, and final dephasing in the wakefield. Finally, we explore the parameter range and optimal configuration to reduce energy spread of the output beams.

\*R. A. Fonseca et al, LNCS 2329, III-342, Springer-Verlag, (2002)

### Emission of Collimated X-Ray Radiation in Laser-Wakefield Experiments Using Particle Tracking in PIC Simulations

It is now accepted that self-trapped electrons in a laser wakefield accelerator operating in the "bubble" regime undergo strong periodic oscillations about the wakefield axis because of the focusing force provided by the ions. This betatron motion of the off-axis electrons results in the

J. L. Martins, S. Fonseca, S. F. Martins, L. O. Silva (Instituto Superior Tecnico) C. Joshi, W. B. Mori (UCLA)

emission of x-ray radiation strongly peaked in the forward direction. Even though the x-rays are broadband with a synchrotron-like spectrum, their brightness can be quite high because of their short pulse duration and strong collimation. We employ particle tracking in particle in cell simulations with OSIRIS\*, combined with a post-processing radiation diagnostic, to evaluate the features of the radiation mechanisms of accelerated electrons in LWFA experiments. We show and discuss results for a 1.5 GeV laser wakefield accelerator stage. A study of the angular dependence of the radiated power is also presented and compared with theoretical models. This analysis also allows for the direct calculation of the radiation losses of the self-injected bunch.

\*R. A. Fonseca et al, LNCS 2329, III-342, Springer-Verlag, (2002)

### Density Transition Measurement for the Electron Injection in Laser Wakefield Accelerator

The electron injection into the acceleration phase of the laser wakefield accelerator (LWFA) the key issues for the stable operation of the LWFA. For the controlled electron injection, a sharp downward electron density transition is one

J. Kim, J.-U. Kim, S. H. Yoo (KERI)

candidate. When the laser pulse pass the sharp electron density transition, the electron from the high density region is injected into the acceleration phase. For this injection scheme, a very sharp electron density transition, the distance of the density change must be shorter than the plasma wavelength, is needed. A shock structure of plasma generated at the gas target is one candidate for such a sharp electron density transition structure. To find out the feasible condition of the density structure, the electron density was measured by an interferometer with different time. A 200 ps, 100 mJ laser was used to generate plasma. A frequency doubled femto-second laser

was used as a probe beam. The measured electron density structure which is compared with a 2D PIC simulation, indicates that feasible condition can be generated 1.2 ns after the laser pulse. This electron density structure will be used for the laser wakefield acceleration experiments.

### Controlled Injection of Electrons in the Sharp Phase Mixing Region of LWFA

S. H. Yoo (KERI)

To generate the good quality electron bunch, stable fast injection is very important issue in the laser wakefield accelerator(LWFA).

One of the self-injection methods is the wave breaking\*. In this scheme, the density transition scale length is much larger than plasma skin depth. After a new self-injection mechanism using the sharp density transition scheme was proposed\*\*, the experiment for the generation of the plasma shock structure have been conducted\*\*\*. In this scheme, while one can reduce the wave breaking, the electron can be injected effectively using a phase mixing. Thus, the sharp density transition scheme is promising candidate method for the more stable generation of good quality electron bunch. In this scheme, the main issue is that the finding optimum conditions in which the injected electrons only in the first period of laser wake wave are accelerated further. In this paper, optimum conditions of sharp density transition scheme have been studied using Particle-In-Cell simulations. And the transverse parabolic profile is used to increase the beam quality. Throughout the extensive simulation work, the optimum conditions for the experiments at KERI is presented.

\*S. Bulanov, et. al., Phys. Rev. E, 58, R5257 (1998)

\*\*H. Suk, et. al., Phys. Rev. Lett. 86, 1011 (2001)

\*\*\*J. U. Kim, et. al., 69, 026409 (2004)

### Undulator-Based Laser Wakefield Accelerator Electron Beam Diagnostic

M. S. Bakeman, W. M. Fawley, W. Leemans, K. Nakamura, K. E. Robinson, C. B. Schroeder, C. Toth (LBNL)

We discuss the design and current status of experiments to couple the THUNDER undulator to the Lawrence Berkeley National Laboratory (LBNL) laser wakefield accelerator (LWFA).

Currently the LWFA has achieved quasi-monoenergetic electron beams with energies up to 1 GeV\*. These ultra-short, high-peak-current, electron beams are ideal for driving a compact XUV free electron laser (FEL)\*\*. Understanding the electron beam properties such as the energy spread and emittance is critical for achieving high quality light sources with high brightness. By using an insertion device such as an undulator and observing changes in the spontaneous emission spectrum, the electron beam energy spread and emittance can be measured with high precision. The initial experiments will use spontaneous emission from 1.5 m of undulator. Later experiments will use up to 5 m of undulator with a goal of a high gain, XUV FEL.

\*W. P. Leemans et al., Nature Physics, Volume 2, Issue 10, pp. 696-699 (2006).

\*\*C. B. Schroeder et al., Proceedings AAC08 Conference (2008).

### Multi-GeV Laser Wakefield Accelerator Stages and Controlled Injection

Collider and light source applications of laser wakefield accelerators will likely require staging of controlled injection with multi-GeV accelerator modules to produce and maintain the required low emittance and energy spread. We present simulations of upcoming 10 GeV-class LWFA stages, towards eventual collider modules for both electrons and positrons\*. Laser and structure propagation are controlled through a combination of laser channeling and self guiding. Electron beam evolution is controlled through laser pulse and plasma density shaping, and beam loading. This can result in efficient stages which preserve high quality beams. We also present results on controlled injection of electrons into the structure to produce the required low emittance bunches using plasma density gradient\*\* and colliding laser pulses. Tools for accurately modeling emittance and energy spread will be discussed\*\*\*.

\*E. Cormier-Michel et al., Proc. Adv Accel. Workshop 2008.

\*\*C. G.R. Geddes et al., PRL 2008.

\*\*\*E. Cormier-Michel et al, PRE 2008; C. G.R. Geddes et al, Proc. Adv Accel. Workshop 2008.

**C. G.R. Geddes**, G. Bouquot, E. Cormier-Michel, E. Esarey, W. Leemans, G. R.D. Plateau, C. B. Schroeder, C. Toth (LBNL) D. L. Bruhwiler, J. R. Cary, B. M. Cowan, C. Nieter, K. Paul (Tech-X)

WE6RFP075

### Experimental Study of Self-Trapping in Capillary Discharge Guided Laser Wakefield Acceleration

Laser wakefield acceleration experiments were carried out by using various hydrogen-filled capillary discharge waveguides. Self-trapping of electrons showed strong correlation with the delay between the onset of the discharge current and arrival of the laser pulse (discharge delay). By de-tuning discharge delay from optimum guiding performance, self-trapping was found to be stabilized. Several possible scenarios for the enhanced trapping will be discussed along with spectroscopy of the transmitted laser light and the discharge recombination light.

**K. Nakamura**, C. G.R. Geddes, A. J. Gonsalves, C. Lin, D. Panasenko, C. B. Schroeder, C. Toth (LBNL) E. Esarey, W. Leemans (University of Nevada, Reno)

WE6RFP076

### Development of Water Jet Plasma Mirror for Staging of Laser Wakefield Accelerators

Staging Laser Wakefield Accelerators (LWFA), which is necessary in order to substantially increase the electron beam energy, requires incoupling additional laser beams into accelerating stages. To preserve high accelerating gradient of LWFA, it is imperative to minimize the distance that is needed for laser incoupling. Using a conventional mirror with PW-class lasers will require the incoupling distance to be as long as tens of meters due to limitations imposed by laser induced damage of the optic. In this presentation we will describe a new approach for the laser incoupling that is based on planar water jet plasma mirror. The plasma mirror can operate as close as few cm to the focus of the laser thus minimizing the coupling distance. Using a water jet instead of a solid target avoids mechanical scanning of the target surface as well as contamination of the vacuum by laser breakdown debris. Experimental results showing performance of the water jet plasma mirror will be presented and progress in staging experiments will be discussed

**D. Panasenko**, E. Cormier-Michel, E. Esarey, C. G.R. Geddes, A. J. Gonsalves, W. Leemans, C. Lin, N. H. Matlis, K. Nakamura, G. R.D. Plateau, C. B. Schroeder, A. J. Shu, C. Toth (LBNL)

WE6RFP077

**Design Considerations for a Laser-Plasma Linear Collider**

C. B. Schroeder, E. Esarey, C. G.R. Geddes, W. Leemans, C. Toth (LBNL)

Laser-driven plasma-based accelerators have made rapid progress in the last several years, yielding high-quality GeV electron beams accelerated over several centimeters.\*

Due to the ultra-high accelerating gradients, employing laser-plasma-accelerator technology has the potential to significantly reduce the linac length (and therefore cost) of a future lepton collider. The prospects and design considerations for a next-generation electron-positron linear collider based on laser-plasma accelerators are discussed. Staging of ultra-high gradient laser-plasma accelerating structures is examined, and plasma density scaling laws are derived for relevant collider parameters. Emittance growth via beam-plasma scattering is analyzed. An example of self-consistent parameters for a 1 TeV laser-plasma-based collider is presented.

\*W. P. Leemans et al., "GeV electron beams from a centimetre-scale accelerator," Nature Physics 2, 696 (2006).

**Length Scaling of the Electron Energy Gain in the Self-Guided Laser Wakefield Regime Using a 150 TW Ultra-Short Pulse Laser Beam**

D. H. Froula, J. Bonlie, L. Divol, S. H. Glenzer, P. Michel, J. Palastro, D. Price, J. E. Ralph, J. S. Ross, C. Siders (LLNL) C. E. Clayton, C. Joshi, K. A. Marsh, A. E. Pak (UCLA) B. B. Pollock, G. R. Tynan (UCSD)

Recent laser wakefield acceleration experiments at the Jupiter Laser Facility, Lawrence Livermore National Laboratory, will be discussed where the Callisto Laser has been upgraded and has demonstrated 60 fs, 10 J laser pulses. This 150 TW facility is providing

the foundation to develop a GeV electron beam and associated betatron x-ray source for use on the petawatt high-repetition rate laser facility currently under development at LLNL. Initial self-guided experiments have produced high energy monoenergetic electrons while experiments using a multi-centimeter long magnetically controlled optical plasma waveguide are investigated. Measurements of the electron energy gain and electron trapping threshold using 150 TW laser pulses will be presented.

**Space-Charge Waves on Relativistic Elliptic Electron Beams**

C. Chen, A. E. Brainerd, J. Z. Zhou (MIT/PSFC)

Relativistic elliptic electron beams have applications in the research and development of a new class of elliptic- or sheet-beam kly-

strons which have the potential to outperform conventional klystrons in terms of power, efficiency, and operating voltage. This paper reports on results of a small-signal analysis of space-charge waves on a relativistic elliptic electron beam in a perfectly-conducting beam tunnel. A dispersion relation is derived. A computer code is developed and used in studies of the dispersion characteristics of various relativistic elliptic electron beams.

**The Design of Advanced Photonic Bandgap (PBG) Structures for High Gradient Accelerator Applications**

R. A. Marsh, B. J. Munroe, M. A. Shapiro, R. J. Temkin (MIT/PSFC)

The design of advanced photonic bandgap (PBG) accelerator structures is examined. PBG structures are chosen for their wakefield damping. A potential disadvantage of



PBG structures, as well as damped detuned structures, is the increased wall currents at the structure surface due to the reduced surface area, leading to higher pulsed wall heating. Research is carried out to improve the pulsed heating performance of PBG structure concepts while maintaining higher order mode damping. Wakefield damping parameters are discussed and a quantitative figure of merit is expressed to evaluate and compare PBG concepts. Pulsed heating performance in PBG structures is improved by breaking perfect symmetry and allowing deformation of both rod and lattice geometry. A final design for an improved pulsed heating performance PBG structure for breakdown testing at 11.424 GHz is presented and discussed.

### Design of Photonic Bandgap (PBG) Accelerator Structures with Reduced Symmetry

The design of new photonic bandgap (PBG) accelerator structures and their properties will be presented. PBG structures show promise for obtaining higher acceleration gradients because of the damping of high order modes (HOMs) exhibited by the design. Current work in PBG design has focused on structures with triangular or square lattices, leading to structures with 4 or 6 rods in the inner row. We are investigating structures with reduced symmetry such as 5 or 7 rods in the inner row. This work is intended to develop new PBG designs that display a good accelerator mode while reducing the HOM content. Specific designs showing the accelerator and high order modes will be presented and compared with conventional PBG designs.

**B. J. Munroe**, R. A. Marsh, M. A. Shapiro, R. J. Temkin (MIT/PSFC)

WE6RFP082

### Metamaterial-Based Linear Accelerator Structure

Negative refraction metamaterials (NR MTL) have been developed at microwave, THz, and optical frequencies. At present, microwave MTL's are studied for applications such as microwave filters and patch antennas. Accelerator-relevant applications, such as measuring electron bunch length using its inverse Cherenkov radiation in a NR MTL, have also been proposed. Here we propose a MTL based linear accelerator structure. The MTL is built as an array of complimentary split-ring resonators cut in two metallic plates. The accelerating electron bunch traverses between the plates. The operating mode's properties and standard accelerator parameters (R/Q, accelerating gradient, etc.) of the proposed structure will be reported.

**M. A. Shapiro**, J. R. Sirigiri, R. J. Temkin (MIT/PSFC) G. Shvets (The University of Texas at Austin)

WE6RFP083

### Neutral Dual Ion Beams in Undulator Linear Accelerator with Electrostatic Undulator

In the paper referenced below\*, it was shown that the flux of neutral dual ion beams in linear undulator accelerator with RF undulator (UNDULAC-RF) can be done very large. It is possible because the positive and negative charged ions are bunching and accelerating in the same bunch. Accelerating force value in such accelerator is proportional to squared particle charge. This method of increasing the ion beam intensity can be also used in other type of undulator linac with electrostatic undulator (UNDULAC-E)\*\*. The results of the dynamics simulation for neutral dual ion beams in UNDULAC-E are presented in this paper. Some problems of UNDULAC-E resonator design are also discussed.

**E. S. Masunov**, S. M. Polozov (MEPhI)

WE6RFP084

\*E. S. Masunov, S. M. Polozov, Phys. Rev. ST AB, 11, 2008, 074201

\*\*E. S. Masunov, Sov. Phys. -- Tech. Phys., vol. 35, N<sup>o</sup> 8, pp. 962-965. 1990

**Wakefield Excitation in Plasma Filled Dielectric Structure by a Train of Electron Bunches**

I. N. Onishchenko, V. Kiselev, A. Linnik, V. Mirny, V. Uskov  
(NSC/KIPT)

Essential increase of wakefield intensity at excitation by a long train of relativistic electron bunches when the rectangular dielectric structure is filled with plasma was experimentally observed. A train of bunches was produced by the linear resonant accelerator. Parameters of the beam: energy 4.5 MeV, pulsed current 0.5 A, pulse duration 2 mksec. Such macro-pulse consists of a periodic sequence of 6000 electron bunches. Each electron bunch has duration 60 psec, diameter 1.0 cm, angular spread 0.05 mrad, charge 0.16 nC. Bunches repetition frequency is 2805 MHz. Transit channel for bunches is filled with gas at various pressure. The first portion of the bunches ionizes gas so that plasma frequency is equal to bunch repetition frequency and to the frequency of principal eigen mode of the dielectric structure. Excitation enhancement at such resonant conditions is being studied taking into account the improvement of bunch train propagation in the transit channel and electrodynamic change of the dielectric structure at filling with plasma.

**Analytical and Numerical Investigation of a Coaxial Two-Channel Dielectric Wakefield Accelerator**

G. V. Sotnikov (NSC/KIPT) J. L. Hirshfield (Yale University, Physics Department) T. C. Marshall, G. V. Sotnikov (Omega-P, Inc.) S. V. Shchelkunov (Yale University, Beam Physics Laboratory)

A new scheme for a dielectric wakefield accelerator is proposed that employs a cylindrical multi-zone dielectric structure configured as two concentric dielectric tubes with outer and inner vacuum channels for drive and accelerated bunches. Analytical and numerical studies have been carried out for such coaxial dielectric-loaded structures (CDS) for high-gradient acceleration. An analytical theory of wakefield excitation by particle bunches in a multi-zone CDS has been formulated. Numerical calculations were made for an example of a CDS using dielectric tubes of material with dielectric permittivity 5.7, having external diameters of 2.121 mm and 0.179 mm with inner diameters of 2.095 mm and 0.1 mm. An annular 5 GeV, 5 nC electron bunch with RMS length of 0.14 mm energizes a wakefield on the structure axis having an accelerating gradient of ~600 MeV/m with a transformer ratio ~8. The period of the accelerating field is ~0.38 mm. Full numerical simulation using a PIC code has confirmed results of the linear theory and furthermore has shown the important influence of the quenching wave. The simulation also has shown stable transport of drive and accelerated bunches through the CDS.

**Development and Testing of X-Band Dielectric-Loaded Accelerating Structures**

S. H. Gold (NRL) W. Gai, R. Konecny, W. Liu, J. G. Power (ANL) C.-J. Jing, A. Kanareykin (Euclid TechLabs, LLC) A. K. Kinhead (Icarus Research, Inc.)

Dielectric-loaded accelerating (DLA) structures, in which a dielectric liner is placed inside a cylindrical metal tube, offer the potential of a simple, inexpensive alternative to copper disk-loaded structures for use in high-gradient rf linear accelerators. A joint Naval Research Laboratory/Euclid Techlabs/Argonne National Laboratory study is under way to investigate the performance of X-band DLA structures using high-power 11.43-GHz radiation from the NRL Magnicon Facility\*. The initial goal of the program has been to develop structures capable of sustaining high accelerating gradients. The two significant limitations that have been discovered relate to multipactor loading of the structures and rf breakdown at joints between ceramic sections. We will report the

results of several recent structure tests that have demonstrated significant progress in addressing both of these issues. The longer-range goal of the program is to study electron acceleration in DLA structures. For this purpose, we are developing an X-band DLA test accelerator. We will also report the results of initial operation of a 5-MeV injector for the new accelerator.

\*C. Jing, W. Gai, J. Power, R. Konecny, S. Gold, W. Liu and A. Kinkead, IEEE Trans. Plasma Sci., vol. 33, pp.1155-1160, August 2005.

### Photonic Bandgap Fiber Wakefield Experiment at SLAC

An experimental effort is currently underway at the SLAC National Accelerator Laboratory to focus a 50pC, 60 MeV electron beam into the hollow core of a commercial photonic bandgap fiber. The wakefield radiation produced in the fiber will be spectrally analyzed using a spectrograph in order to detect the frequency signatures of fiber modes that could be used as accelerating modes in a laser-driven fiber-based accelerator scheme. We discuss the current status of the experiment, including efforts to successfully focus the electron beam through the fiber aperture and to collect the produced wakefield radiation.

**R. J. England**, E. R. Colby, C. McGuinness, R. J. Noble, R. Siemann, J. E. Spencer, D. R. Walz (SLAC) R. Ischebeck (PSI) T. Plettner (Stanford University) C. M.S. Sears (MPQ)

WE6RFP088

### Applications of a Plasma Wake Field Accelerator

An electron beam driven Plasma Wake-Field Accelerator (PWFA) has recently sustained accelerating gradients above 50GeV/m for almost a meter. Future experiments will transition from using a single bunch to both drive and sample the wakefield, to a two bunch configuration that will accelerate a discrete bunch of particles with a narrow energy spread and preserved emittance. The plasma works as an energy transformer to transform high-current, low-energy bunches into relatively lower-current higher-energy bunches. This method is expected to provide high energy transfer efficiency (from 30% up to 95%) from the drive bunch to the accelerated witness bunch. The PWFA has a wide variety of applications and also has the potential to greatly lower the cost of future accelerators. We discuss various possible uses of this technique such as: linac based light sources, injector systems for ring based synchrotron light sources, and for generation of electron beams for high energy electron-hadron colliders.

**M. J. Hogan**, I. Blumenfeld, N. A. Kirby, S. Pei, T. O. Raubenheimer, A. Seryi, P. Tenenbaum (SLAC) C. Huang, C. Joshi, W. Lu, W. B. Mori (UCLA) T. C. Katsouleas (Duke University) P. Muggli (USC)

WE6RFP089

### Woodpile Structure Fabrication for Photonic Crystal Laser Acceleration

We present recent progress in the fabrication of a 3D photonic crystal laser accelerator structure. Direct acceleration of electrons by lasers offer promising improvements over traditional RF acceleration techniques in terms of cost, gradient, technology used, and short temporal bunches produced. Microbunching and net acceleration experiments were successfully performed at the E163 facility at SLAC, setting the stage for design, fabrication, and testing of optical structures. This paper describes work done at the Stanford Nanofabrication Facility towards fabricating such structures. A process based on standard optical lithographic techniques was used to fabricate a four layer woodpile photonic crystal with a bandgap centered at  $4.55\mu\text{m}$  and a full width half max of  $2.71\mu\text{m}$ . Infrared spectroscopy

**C. McGuinness** (SLAC)

WE6RFP090

measurements were taken and compared with simulations yielding good agreement. SEM images were used to measure fabrication deviations in rod width, rod shape, layer thickness, and alignment, and further simulations are being done to study the effect of these deviations on properties of the accelerating mode excited in the defect of a 20 layer structure currently under design.

### Parallel Fluid Simulations of Nonlinear Beam Loading in Laser Wakefield Accelerators

D. L. Bruhwiler, B. M. Cowan, K. Paul (Tech-X) J. R. Cary (CIPS)  
E. Cormier-Michel, C. G.R. Geddes, C. B. Schroeder (LBNL) E.  
Esarey, W. Leemans (University of Nevada, Reno)

Laser wakefield accelerators (LWFA) have accelerated  $\sim 100$  pC electron bunches to GeV energies over cm scale distances, via self-trapping from the plasma. Self-trapping cannot be tolerated in staged LWFA mod-

ules for high-energy physics applications. The  $\sim 1\%$  energy spread of self-trapped electron bunches is too large for light source applications. Both difficulties could be resolved via external injection of a low-emittance electron bunch into a quasilinear LWFA, for which the dimensionless laser amplitude is less than two. However, significant beam charge will result in nonlinear beam loading effects, which will make it challenging to preserve the low emittance. The cold, relativistic fluid model of the parallel VORPAL framework\* will be used to simulate the laser-driven electron wake, in the presence of an idealized electron beam. Profiles of the electron beam density, laser pulse envelope and plasma channel will be varied to find a nonlinear beam loading configuration that approximately flattens the electric fields across the beam. Hybrid fluid-PIC simulations will be used to measure the self-consistent emittance growth of the beam.

\* C. Nieter and J. R Cary, J. Comp. Phys. 196 (2004), p. 448.

### Axial and Near-Axis Channeling Effects of Positive and Negative High-Energy Particle Beams

V. Guidi (UNIFE)

The H8RD22 collaboration has accomplished an extensive study of axial channeling in the external lines of the CERN SPS.

For 400 GeV protons, it was recorded deflection by about 90% of the particles by a short crystal, by far exceeding the performance of previous experiments. Axial channeling with 150 GeV negative hadrons was also firmly observed with deflection capability comparable to the case of positive particles. Near-axis effect such as multiple-volume reflections in a single crystal as a result of the superposition of volume reflections by a series of parallel planes sharing the same axis was investigated with 400 GeV protons. Confirmation of theoretical expectation was observed, in particular most of the particles were deflected by about 50 urad, four times the deflection angle imparted by a single volume reflection of most efficient planes. In this case the angular acceptance was sensitively broader than for the case of channeling. In summary, channeling in axial mode and multi-volume reflections were proven to be two mechanisms for manipulation steering of high-energy particle beams, which side most established techniques such as planar channeling and volume reflection.\*

\*Contribution on behalf of the H8RD22 collaboration.

**Positron Acceleration by Using a Particle Beam Driven Wake Field in Plasma**

Plasma Wake Field Accelerator (PWFA) has a very attractive accelerating gradient which can be three orders of magnitude higher than that of the traditional accelerator. In this paper the positron acceleration in a particle beam driven PWFA is studied both in the linear and weakly nonlinear region by using Particle In Cell (PIC) simulation. A preliminary parameters design is obtained for such acceleration scheme.

**W. An**, C. Huang, W. Lu, W. B. Mori (UCLA) T. C. Katsouleas (Duke University)

WE6RFP093

**Preliminary Study of the Arc for a Muon Collider with 1.5 TeV CM Energy and Using 20T HTS Dipole Magnets**

We describe preliminary study of the design of a Muon Collider using 20T Dipole Magnets such a collider could be constructed at FNAL.

**D. B. Cline**, X. P. Ding, A. A. Garren (UCLA) R. C. Gupta, H. G. Kirk (BNL) R. J. Weggel (Particle Beam Lasers, Inc.)

WE6RFP094

**Observation of Narrow-Band Terahertz Coherent Cherenkov Radiation from a Dielectric Structure**

We report experimental observation of narrow-bandwidth pulses of coherent Cherenkov radiation produced when a sub-picosecond electron bunch travels along the axis of a hollow circular cylindrical dielectric-loaded waveguide. For an appropriate choice of dielectric structure properties and driving electron beam parameters, the device operates in a single-mode regime, producing radiation in the THz range. We present measurements showing the emission of a narrowly-peaked spectrum from a fused silica tube 1 centimeter long with sub-millimeter transverse dimensions. We discuss the agreement of this data with theoretical and computational predictions, as well as possibilities for future study and application.

**A. M. Cook**, J. B. Rosenzweig, R. Tikhoplav, S. Tochitsky, G. Travish, O. Williams (UCLA)

WE6RFP095

**Vacuum Laser Acceleration Proof of Principle at BNL-ATF**

The novel and revolutionary concept of VLA proof of principle is described in this paper. The simulation with the current BNL-ATF parameter shows that electron beam can get net energy from intense laser beam. The initial 20 MeV electron beam with energy spread of 0.001 can get hundreds of keV energy gain with energy spread of 0.010 by interacting with a laser  $a_0=1$ . BNL-ATF's spectrometer can tell 0.0001 accuracy of energy spread and distinguish 0.001 accuracy energy spread. The proposal has been approved by BNL-ATF and the experiment for this proof of principle is going to be scheduled.

**L. S. Shao**, D. B. Cline, X. P. Ding (UCLA) K. Kusche, I. Pogorelsky, V. Yakimenko (BNL)

WE6RFP096

**Simulations of 25 GeV PWFA Sections: Path Towards a PWFA Linear Collider**

C. Huang, W. An, C. E. Clayton, C. Joshi, W. Lu, K. A. Marsh, W. B. Mori, M. Tzoufras (UCLA) I. Blumenfeld, M. J. Hogan, N. A. Kirby, T. O. Raubenheimer, A. Seryi (SLAC) T. C. Katsouleas (Duke University) P. Muggli (USC)

Recent Plasma Wake-Field Acceleration (PWFA) experiments at Stanford Linear Accelerator Center has demonstrated electron acceleration from 42GeV to 84GeV in less than one meter long plasma section. The accelerating gradient is above 50GeV/m,

which is three orders of magnitude higher than those in current state-of-art RF linac. Further experiments are also planned with the goal of achieving acceleration of a witness bunch with high efficiency and good quality. Such PWFA sections with 25 GeV energy gain will be the building blocks for a staged TeV electron-positron linear collider concept based on PWFA (PWFA-LC). We conduct Particle-In-Cell simulations of these PWFA sections at both the initial and final witness beam energies. Different design options, such as Gaussian and shaped bunch profiles, self-ionized and pre-ionized plasmas, optimal bunch separation and plasma density are explored. Theoretical analysis of the beam-loading\* in the blow-out regime of PWFA and simulation results show that highly efficient PWFA stages are possible. The simulation needs, code developments and preliminary simulation results for future collider parameters will be discussed.

\*M. Tzoufras et al, Phys. Rev. Lett. 101, 145002 (2008).

**High Transformer Ratio PWFA for Application on XFELs**

W. Lu, W. An, C. Huang, C. Joshi, W. B. Mori (UCLA) M. J. Hogan, T. O. Raubenheimer, A. Seryi (SLAC)

Fourth generation of light sources (e.g., LCLS and the XFEL) require high energy electron drivers (16-20GeV) of very high quality. We are exploring the possibility of

using a high transformer ratio PWFA to meet these challenging requirements. This may have the potential to reduce the size of the electron drivers by a factor of 5 or more, therefore making these light source much smaller and more affordable. In our design, a high charge (5-10nC) low energy driver (1-3GeV) with an elongated current profile is used to drive a plasma wake in the blowout regime with a high transformer ratio (5 or more). A second ultra-short beam that has high quality and low charge beam (1nC) can be loaded into the wake at a proper phase and be accelerated to high energy (5-15GeV) in very short distances (10s of cms). The parameters can be optimized, such that high quality (0.1% energy spread and 1mm mrad normalized emittance) and high efficiency (60-80%) can be simultaneously achieved. The major obstacle for achieving the above goals is the electron hosing instabilities in the blowout regime. In this poster, we will use both theoretical analysis and PIC simulations to study this concept.

**Investigation of Ionization Induced Electron Trapping in a Laser Wakefield Accelerator**

A. E. Pak, C. Joshi, K. A. Marsh (UCLA)

Controlling the trapping of electrons into accelerating wakefields is an important step to obtaining a stable reproducible electron

beam from a laser wakefield accelerator (LWFA). Recent experiments at UCLA have focused on using the different ionization potentials of gases as a mechanism for controlling the trapping of electrons into an LWFA. The accelerating wakefield was produced using an ultra-intense ( $I_0 \sim 10^{19} \text{ W / cm}^2$ ), ultra-short ( $\tau_{\text{FWHM}} \sim 40 \text{ fs}$ ) laser pulses. The laser pulse was focused onto the edge of column of gas created by a gas jet. The gas was a mixture of helium and nitrogen. The rising edge of the laser pulse fully ionizes the helium and the first five bound electrons of the nitrogen. Only at the peak of the laser pulse is it intense enough to ionize the most tightly bound electrons of the nitrogen. Electrons which are ionized at the peak of laser pulse are born into a favorable phase space within

the accelerating wakefield and are subsequently trapped and accelerated. The accelerated electrons were dispersed using a dipole magnet with a  $\sim 1$  Tesla magnetic field onto a phosphor screen. Electron beam energy spectrum charge and divergence were measured.

### Self-Guiding of Ultra-Short, Relativistically Intense Laser Pulses through Underdense Plasmas in the Blowout Laser Wakefield Accelerator Regime

The self-guiding of relativistically intense but ultra-short laser pulses has been experimentally investigated as a function of laser power, plasma density and plasma length in the so-called "blowout" regime. Although etching of the short laser pulse due to diffraction and local pump depletion erodes the the head of the laser pulse, an intense portion of the pulse is guided over tens of Rayleigh lengths, as observed by imaging the exit of the plasma. Spectrally-resolved images of the laser pulse at the exit of the plasma show evidence for photon acceleration as well as deceleration (pump depletion) in a well defined narrow guided region. This is indicative of the self-guided pulse residing in the wake excited in the plasma. Energy outside the guided region was found to be minimized when the initial conditions at the plasma entrance were closest to the theoretical matching conditions for guiding in the blowout regime. The maximum extent of the guided length is shown to be consistent with the nonlinear pump depletion length predicted by theory.

**J. E. Ralph**, F. Fang, C. Joshi, W. Lu, K. A. Marsh, W. B. Mori, A. E. Pak, F. S. Tsung (UCLA)

### Development of a Magnetically Controlled Optical Waveguide for Laser Wakefield Acceleration (LWFA)

We present experimental results showing the formation of a laser produced optical waveguide, suitable for laser guiding, when applying a high external magnetic field around a gas cell. This technique is directly applicable to wakefield acceleration and has been established at the Jupiter Laser Facility; an external magnetic field prevents radial heat transport, resulting in an increased electron temperature gradient [D. H. Froula et.al., Plasma Phys. Control. Fusion, 51, 024009 (2009)]. Interferometry and spatially resolved Thomson-scattering diagnostics measure the radial electron density profile, and show that multiple-centimeter long waveguides with minimum electron densities of  $10^{17}$  to  $10^{18}$   $\text{cm}^{-3}$  can be produced. Temporally resolved Thomson-scattering is also performed to characterize the evolution of the density channel in time. This work was performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344 and was partially funded by the Laboratory Directed Research and Development Program under project tracking code 06-ERD-056.

**B. B. Pollock**, J. S. Ross, G. R. Tynan (UCSD) L. Divol, D. H. Froula, S. H. Glenzer (LLNL)

### Progress towards a 9.37GHz Disc-Loaded Waveguide Structure Filled with Low Loss Dielectric

One of the major concerns in the development of hybrid dielectric-iris-loaded structure is the performance of the used dielectric. The previous dielectric is machinable but the loss tangent is slightly high. So we adopt the new dielectric (Mg-Ca-Ti-O) with loss tangent of about  $2 \cdot 10^{-4}$ . Because of its high hardness and brittleness, the machining technology

**X. D. He**, S. Dong, Y. J. Pei, C.-F. Wu (USTC/NSRL)

and methods are attempted. In this paper, we present a new design of the structure. The model cavities and the coupler for this structure with the new dielectric are investigated experimentally. The experiment results are accorded with the simulated results. In the end, the amplitude and phase shift of the electric field and R/Q of this structure at the operation frequency are even got by a bead-pull experiment.

### Development of X-Band Photonic Band Gap Accelerating Structure

Z. P. Li (USTC) S. Dong, X. D. He, C.-F. Wu (USTC/NSRL)

multi-cell PBG structure was designed based on a time domain simulation. A multi-cell PBG structure was then built and cold-tested. As the damping of the wakefields is an important issue, we've studied the HOMs in this structure. The results show that the PBG structure has a quality of effective damping of unwanted HOMs, some methods of damping are introduced here.

We present the new experimental results for an X-band (11.42GHz) metallic PBG accelerating cavity. The coupler of a traveling-wave

### Gamma Ray Sources Based on Plasma Wakefield Accelerators

D. A. Jaroszynski, M. P. Anania, E. Brunetti, S. Chen, S. Cipiccia, B. Ersfeld, J. Gallacher, M. R. Islam, R. C. Issac, G. Raj, A. J. W. Reitsma, R. P. Shanks, G. Vieux, G. H. Welsh, S. M. Wiggins (USTRAT/SUPA) R. Bendoyro, J. M. Dias, F. Fiuza, N. Lemos, M. Marti, J. L. Martins, L. O. Silva (Instituto Superior Tecnico) N. Bourgeois (University of Oxford) P. S. Foster, R. Pattathil (STFC/RAL) S. M. Hooker, T. Ibbotson (University of Oxford, Clarendon Laboratory) D. Maneuski, V. O'Shea (University of Glasgow)

present new opportunities for harnessing laser-driven plasma waves to accelerate electrons to high energies and use these as a basis for ultra-compact radiation sources with unprecedented peak brilliance and pulse duration. We have demonstrated a brilliant tabletop gamma ray source based on enhanced betatron emission in a plasma channel which produces  $> 10^9$  photons per pulse in a bandwidth of 10-20%. We present results of a compact synchrotron source based on a LWFA and undulator and discuss the potential of developing an FEL based this technology. Finally we discuss the plans for the Scottish Centre for the Application of Plasma-based Accelerator (SCAPA), which is being set up to develop and apply compact radiation sources, laser-driven ion sources and LWFAs.

Advances in laser-plasma wake field accelerators (LWFA) have now reached the point where they can be considered as drivers of compact radiation sources covering a large spectral range. We present recent results from the Advanced Laser Plasma High-energy Accelerators towards X-rays (ALPHA-X) project. These include the first ultra-compact gamma ray source producing brilliant 10fs pulses of x-ray photons  $> 150\text{keV}$ . We

### Multi Cavity Proton Cyclotron Accelerator

M. A. LaPointe (Yale University, Beam Physics Laboratory) J. L. Hirshfield (Yale University, Physics Department) S. Kazakov (Omega-P, Inc.) V. P. Yakovlev (Fermilab)

The structure consists of a cascade of RF cavities in a nearly uniform magnetic axial field. The proton energy gain mechanism relies upon cyclotron resonance acceleration in each cavity. In order to check the concept and determine its limits, an engineering design is presented of a four cavity electron counterpart test accelerator under construction that will mimic parameters of the multi-cavity proton accelerator.

A detailed analysis is presented of a new concept for a high current, high gradient proton beam accelerator in a normal conducting (i.e. room temperature) structure.



## TH5PF — Morning Poster BDEMF D03, D05, D06

### Large Scale Simulations of the Fermilab 8-GeV H-minus Linac: Beam Loss Studies from Machine Errors and H<sup>-</sup> Stripping

The latest version of PTRACK\*, the parallel version of the beam dynamics code TRACK, is capable of simulating a very large number of particles (a billion or more). In the case

of the Fermilab 8-GeV H-minus linac, it is possible to simulate the actual number of particles in the bunch. Taking advantage of this capability we are revisiting our original beam loss studies\*\*, but this time with larger statistics and including a new process of beam loss which is the stripping of H<sup>-</sup> ions. TRACK has recently been updated\*\*\* with the possibility of stripping H<sup>-</sup> by three different processes, namely black body radiation, Lorentz force stripping and residual gas interactions. Results of ideal end-to-end simulations (no errors) with the actual number of particles in a beam bunch (860M) as well as error simulations for different sets of errors with 10M and eventually 100M particles per seed will be presented and discussed. These simulations are being performed on Argonne's new petascale computing facility "BG/P".

\* J. Xu et al, Proceedings of HB-2008.

\*\* P. Ostroumov, B. Mustapha and V. A. Aseev, Proceedings of Linac-06.

\*\*\* J.-P. Carneiro, B. Mustapha and P. Ostroumov, submitted to PRST-AB.

**B. Mustapha**, P. N. Ostroumov, J. Xu (ANL) J.-P. Carneiro (Fermilab)

TH5PFP001

### Simulation of Electron Cloud Density Distributions in RHIC Dipoles at Injection and Transition

In this report we summarize electron-cloud simulations for the RHIC dipole regions at injection and transition to estimate if scrubbing at injection would reduce the electron cloud density at transition. We simulate the horizontal electron cloud distribution in the RHIC dipoles for secondary electron yields (SEY) from 1.1 to 2.0 at injection (with a bunch intensity of  $1.3 \times 10^9$ ) and at transition (with a bunch intensity of  $1.2 \times 10^9$ ). Also, we unveil the sensitivity to rather small changes in bunch intensity from  $1.0 \times 10^9$  to  $1.5 \times 10^9$ , when SEY keep at 1.4 and 1.5 both for injection and transition.

**P. He**, W. Fischer (BNL)

TH5PFP002

### Physics Design for Beam Halo Experiment for ADS in China

The beam halo is the dominant particle loss mechanism in high-intensity proton linacs. A periodic-focusing channel consisting of 28 quadrupoles has been designed for beam halo experiment. It provides a platform to study the most relevant mechanisms for the development of beam halo. Mismatch, parametric resonances and envelope instabilities have been studied by simulating beam behavior in the channel with the PARMILA code, where the first four quadrupoles produce various mismatch conditions. The channel is located after a 3.5MeV radio frequency quadrupole (RFQ). Beam diagnostic instruments are inserted within the channel for beam halo measurement.

**J. Peng**, S. Fu, T. G. Xu (IHEP Beijing) Y. F. Ruan (Institute of High Energy Physics, CAS)

TH5PFP003

**Final Design of the IFMIF-EVEDA Low Energy Beam Transport Line**

N. Chauvin, O. Delferriere, R. D. Duperrier, R. Gobin, A. Mosnier, P. A.P. Nghiem, D. Uriot (CEA) M. Comunian (INFN/LNL)

During the EVEDA (Engineering Validation and Engineering Design Activities) phase of the IFMIF (International Fusion Materials Irradiation Facility) project, a 125 mA/9 MeV accelerator prototype will be built, tested and operated in Rokkasho-Mura (Japan). The injector section of this accelerator is composed by an ECR source, delivering a 140 mA deuteron beam at 100 keV, and a low energy beam transport (LEBT) line required to match the beam for the RFQ injection. The proposed design for the LEBT is based on a dual solenoids focusing scheme. In order to take into account the space charge compensation of the beam induced by the ionisation of the residual gas, a 3D particle-in-cell code (SOLMAXP) has been developed for the beam dynamics calculations. The LEBT parameters have been optimized in order to maximize the beam transmission through the RFQ. The final LEBT design, as well as the simulation results, are presented.

During the EVEDA (Engineering Validation and Engineering Design Activities) phase of the IFMIF (International Fusion Materials Irradiation Facility) project, a 125 mA/9 MeV

**Optimization Results of Beam Dynamics Simulations for the Superconducting HWR IFMIF Linac**

N. Chauvin, R. D. Duperrier, A. Mosnier, P. A.P. Nghiem, D. Uriot (CEA)

The 250 mA, 40 MeV cw deuteron beam required for the International Fusion Materials Irradiation Facility (IFMIF) will be provided by two 125 mA linacs. In order to accelerate the beam from 5 MeV to 40 MeV, a superconducting linac, housed in four cryomodules, is proposed. The design is based on two beta families ( $\beta=0.094$  and  $\beta=0.166$ ) of half-wave resonators (HWR) at 175 MHz. The transverse focusing is achieved using one solenoid coil per lattice. This paper presents the extensive multi-particle beam dynamics simulations that have been performed to adapt the beam along the SC-HWR structure in such a high space charge regime. As one of the constraints of the IFMIF linac is hands-on maintenance, specific optimizations have been done to minimize the beam occupancy in the line (halo). A Monte Carlo error analysis has also been carried out to study the effects of misalignments or field imperfections.

The 250 mA, 40 MeV cw deuteron beam required for the International Fusion Materials Irradiation Facility (IFMIF) will be provided by two 125 mA linacs. In order to

**IFMIF-EVEDA Accelerators: Strategies and Choices for Optics and Beam Measurements**

P. A.P. Nghiem, N. Chauvin, O. Delferriere, R. D. Duperrier, A. Mosnier, D. Uriot (CEA) M. Comunian (INFN/LNL) C. Oliver (CIEMAT)

The two IFMIF (International Fusion Materials Irradiation Facility) accelerators will each have to deliver 5 MW of deuteron beam at 40 MeV. To validate the conceptual design, a prototype, consisting of one 9 MeV accelerator called EVEDA (Engineering Validation and Engineering Design Activity), is being constructed. Beam dynamics studies are entering the final phase for the whole EVEDA and for the accelerating part of IFMIF. The challenging point is to be able to reconcile the very strong beam power and the hands-on maintenance constraint. At energies up to 5 MeV, difficulties are to reach the requested intensity under a very strong space charge / compensation regime. Over 5 MeV, difficulties are to make sure that beam losses can be maintained below  $10^{-6}$  of the beam intensity. This paper will report the strategies and choices adopted in the optics design and the beam measurement proposal.

The two IFMIF (International Fusion Materials Irradiation Facility) accelerators will each have to deliver 5 MW of deuteron beam at 40 MeV. To validate the conceptual design, a prototype, consisting of one 9 MeV accelera-

### Diffusion Rate in Tevatron Using Flying Wire

Beam loss in accelerators can cause problems such as background in experiments and damage to accelerator components. Beam loss also limits the lifetime of the beam in circular accelerators. One source of beam loss is beam diffusion. Beam diffusion is the tendency of particles to move from the core to the tail of the beam which increases the beam width. We measure the rate of beam diffusion in the Tevatron using a flying wire beam profile monitor. The change in the beam width as a function of time for many stores is analyzed.

**S. Shiraishi** (Enrico Fermi Institute, University of Chicago) **R. Tesarek** (Fermilab)

TH5PFP007

### Accelerator Physics Concept for Upgraded LHC Collimation Performance

The LHC collimation system is implemented in phases, in view of the required extrapolation by 2-3 orders of magnitude beyond Tevatron and HERA experience in stored energy. All available simulations predict that the LHC proton beam intensity with the "phase 1" collimation system may be limited by the impedance of the collimators or cleaning efficiency. Maximum efficiency requires collimator materials very close to the beam, generating the dominant resistive impedance in the LHC. Above a certain intensity the beam is unstable. On the other hand, even if collimators are set very close to the beam, the achievable cleaning efficiency is predicted to be inadequate, requiring either beam stability beyond specifications or reduced intensity. The accelerator physics concept for upgrading cleaning efficiency, for both proton and heavy ion beams, and reducing collimator-related impedance is described. Besides the "phase 2" secondary collimators, new collimators are required in a few super-conducting regions.

**R. W. Assmann**, G. Bellodi, J. M. Jowett, E. Métral, Th. Weiler (CERN)

TH5PFP008

### Studies on Combined Momentum and Betatron Cleaning in the LHC

Collimation and halo cleaning for the LHC beams are performed separately for betatron and momentum losses, requiring two dedicated insertions for collimation. Betatron cleaning is performed in IR7 while momentum cleaning is performed in IR3. A study has been performed to evaluate the performance reach for a combined betatron and momentum cleaning system in IR3. The results are presented.

**R. W. Assmann**, G. Bellodi, C. Bracco, V. P. Previtali, S. Redaelli, Th. Weiler (CERN)

TH5PFP009

### Assessment of CERN PSB Performance with Linac4 by Simulations of Beams with Strong Direct Space Charge Effects

The performance of the CERN PS Booster (PSB) synchrotron is believed to be limited mainly by direct space charge effects at low energy. The main motivation to construct Linac4 is to raise the PSB injection energy to mitigate direct space charge effects. Simulation studies to better understand low energy beam dynamics will be described. Investigations on the influence of parameters of the injected beam on the performance of the PSB are described.

**C. Carli**, M. Aiba, B. Goddard, M. Martini (CERN)

TH5PFP010

### Simulation of Beam-Gas Scattering in the LHC

Y. I. Levinsen, H. Burkhardt (CERN) V. Talanov (IHEP Protvino)

We report on background studies for the LHC with detailed simulations. The simulations now include generation of beam-gas scattering in combination with multiturn tracking of protons. Low beta optics and available aperture files for this configuration have been used to generate loss maps according to the pressure distribution in the LHC.

### Non Relativistic Broad Band Wake Fields and Potential-Well Distortion

D. Quatraro, A. Findlay, B. Mikulec, G. Rumolo (CERN)

The usual approach and treatment for the interaction of a particle beam with wake fields start from the assumption of ultrarelativistic beams. This is not the case, for example, for the Proton Synchrotron Booster (PSB) whose particles have a kinetic energy up to 1.4 GeV, with a relativistic gamma close to 2.5. There are some examples in literature which derive non ultrarelativistic formulas for the resistive wall impedance. In this paper we have extended the Broad-Band resonator model, allowing the impedance to have poles even in the half upper complex plane, in order to obtain a wake function different from zero for  $z$  greater than zero. The Haissinski equation has been numerically solved showing longitudinal bunch shape changes with the energy. In addition some longitudinal bunch profile measurements, taken for different energies and bunch intensities at the PSB, are shown.

### Coherent Tune Shift and Instabilities Measurements at the CERN Proton Synchrotron Booster

D. Quatraro, A. Blas, M. Chanel, A. Findlay, B. Mikulec, G. Rumolo (CERN)

To understand one contribution to the intensity limitations of the CERN Proton Synchrotron Booster (PSB) in view of its operation with beams from Linac 4, the impedance of the machine has been characterized. Measurements of tune shift as a function of the intensity have been carried out in order to estimate the low frequency imaginary part of the impedance. Since the PSB is a low energy machine, these measurements have been done at two different energies, so as to enable us to disentangle the effect of the indirect space charge and resistive wall from the contribution of the machine impedance. An estimation of the possible resonant peaks in the impedance spectrum has been made by measuring a fast instability in Ring 4.

### Non Relativistic Resistive Wall Wake Fields and Single Bunch Stability

D. Quatraro, G. Rumolo (CERN)

The usual approach for the resistive pipe wall assumes the beam moves with the speed of light. For many low energy rings, such as the Proton Synchrotron Booster (PBS), possible performance limitations may arise from non relativistic resistive wall wake fields. In this regime not only the head of the bunch can interact with the tail but also the vice versa holds. In this paper we analyze numerical results showing the resistive wake field calculated from non relativistic impedance models. In addition we analyze the well known two particles model assuming that even the trailing particle can affect the leading one. We observe significant changes in the stability domain.

**Recent Developments for the HEADTAIL Code: Updating and Benchmarks**

The HEADTAIL code models the evolution of a single bunch interacting with a localized impedance source or an electron cloud, optionally including space charge. The newest version of HEADTAIL relies on a more detailed optical model of the machine taken from MAD-X and is more flexible in handling and distributing the interaction and observation points along the simulated machine. In addition, the option of the interaction with the wake field of specific accelerator components has been added, such that the user can choose to load dipolar and quadrupolar components of the wake from the impedance database Z-BASE. The case of a single LHC-type bunch interacting with the realistic distribution of the kicker wake fields inside the SPS has been successfully compared with a single integrated beta-weighted kick per turn. The current version of the code also contains a new module for the longitudinal dynamics to calculate the evolution of a bunch inside an accelerating bucket.

**D. Quatraro**, G. Rumolo, B. Salvant (CERN)

TH5PFP015

**Incoherent Linear Tune Shift due to Crab Collision with a Crossing Angle**

The use of crab cavities in the LHC may not only raise the luminosity, but it could also complicate the beam dynamics, e.g. crab cavities might not only cancel synchrotron resonances excited by the crossing angle but they could also excite new ones. In this paper, we use a weak-strong beam-beam model to study the incoherent linear tune shift of the weak beam, for the crab collision case with a finite crossing angle. This tune shift is also compared with that for a head-on collision, both analytically and numerically.

**Y. Sun**, F. Zimmermann (CERN)

TH5PFP016

**Space Charge Simulations for the Mu2e Experiment at Fermilab**

The proposed Mu2e experiment will present a number of challenges for the Fermilab accelerator complex. The Accumulator and Debuncher rings of what is currently the antiproton complex will be required to handle proton beams with intensities several orders of magnitude larger than the antiproton beams they now carry, leading to a substantial space-charge tune shift. The protons will be then be extracted from the Debuncher using resonant extraction. We present results from simulations of 3D space charge effects for Mu2e beam parameters, with emphasis on how they affect the resonant extraction process.

**J. F. Amundson**, P. Spentzouris, E. G. Stern (Fermilab)

TH5PFP017

**Recent Advances in the Synergia Accelerator Simulation Framework**

The Synergia framework has been enhanced to include new Poisson solvers and new collective physics effects. Synergia now includes Sphyaena, a solver suite that provides the ability to handle elliptical beam pipes. Resistive wall effects, including intra- and inter-bunch effects in the presence of multiple bunches are also available. We present an overview of the updates in Synergia, focusing on these developments.

**J. F. Amundson**, P. Spentzouris, E. G. Stern (Fermilab)

TH5PFP018

**Microwave Transmission through the Electron Cloud at the Fermilab Main Injector: Simulation and Comparison with Experiment**

P. Lebrun (Fermilab) P. Stoltz, S. A. Veitzer (Tech-X)

Simulation of the microwave transmission properties through the electron cloud at the Fermilab Main Injector have been implemented using the plasma simulation code "VORPAL". Phase shifts and attenuation curves have been calculated for the lowest frequency TE mode, slightly above the cutoff frequency, in field free regions, in the dipoles and quadrupoles. Preliminary comparisons with experimental results are discussed and will guide the next generation of experiments.

Simulation of the microwave transmission properties through the electron cloud at the Fermilab Main Injector have been implemented using the plasma simulation code "VORPAL". Phase shifts and attenuation curves have been calculated for the lowest frequency TE mode, slightly above the cutoff frequency, in field free regions, in the dipoles and quadrupoles. Preliminary comparisons with experimental results are discussed and will guide the next generation of experiments.

**Beam Studies with Electron Columns in Tevatron**

V. D. Shiltsev, V. Kamerzhiev, G. F. Kuznetsov (Fermilab) A. L. Romanov (BINP SB RAS)

We report preliminary results of experimental studies of "electron columns" in the Tevatron. 150 GeV beam of protons ionized residual gas and ionization electrons are stored in an electrostatic trap immersed into strong longitudinal magnetic field. Shifts of proton betatron frequencies are reported.

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**Simulation of rf Manipulations with Space Charge for the FAIR Synchrotrons**

O. Boine-Frankenheim, O. Chorniy (GSI)

The conservation of the longitudinal beam quality through the SIS-18/100 synchrotron chain is of major importance for the FAIR accelerator project as well as for the SIS-18 upgrade. The generation of a short, intense heavy ion bunch at the end of the machine cycle defines a tight budget for the tolerable longitudinal emittance growth. Potential sources of bunch quality degradation are intensity effects and non-adiabatic rf ramps during the rf capture in SIS-18 and during the barrier bucket pre-compression in SIS-100. The time spend on rf manipulations has to be as small as possible in order to maximize the repetition rate. We report about theoretical and experimental studies in SIS-18 of optimized voltage ramps for rf capture into single and double rf buckets, including space charge and beam-loading effects. Further we show that longitudinal space charge can improve the efficiency of rf manipulations. As an example we present an optimized barrier bucket pre-compression scheme for SIS-100.

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**High Intensity Beam Dynamics Benchmarking Studies in the SIS18 Synchrotron**

G. Franchetti, I. Hofmann (GSI)

The prediction of beam loss for long term storage of a high intensity beam is a challenging task essential for the SIS100 design. On this ground an experimental campaign using a high intensity beam has been performed at GSI on the SIS18 synchrotron with the purpose of extending a previous benchmarking experiment made at the CERN-PS in the years 2002-2003. We report here the results of this experimental campaign and the benchmarking with the simulation predictions.

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**High Intensity Nonlinear Dynamics in SIS100**

Beam loss control in SIS100 is relevant for the design of collimators and for maintaining vacuum quality. We present the status of the studies of beam degradation, due to space charge and magnet imperfections during the accumulation at injection energy. The impact of magnet misalignment on resonances and beam trapping/scattering effects is discussed.

**G. Franchetti** (GSI)

TH5PFP023

**Space-Charge Driven Emittance Coupling in CSNS Linacs**

In the conventional design of rf linacs, the space-charges are not in three-dimension thermal equilibrium. The space-charge couples the longitudinal and transverse will cause equipartitioning process which causes the emittance growth and the halo formation. In the design of the Chinese Spallation Neutron Source (CSNS) linac, three cases are investigated using the Hofmann stability charts to analysis and optimize the layout. In this paper, we present the equipartitioning beam study of the CSNS Alvarez DTL linac.

**X. Yin** (GSI) **S. Fu, J. Peng** (IHEP Beijing)

TH5PFP024

**An Efficient 125mA, 40MeV Deuteron DTL for Fusion Material Tests**

One major concern of the fusion-based energy generation is the material damage due to the high flux of fast neutrons. Therefore, testing of fusion reactor materials is a key step to realize the utilization of the environment-friendly, safe and economic nuclear fusion power. The required high-flux, high energy neutrons for testing will be provided by the D-Li reaction based on a high power accelerator system, which includes two 175MHz, 125mA and 40MeV CW linear accelerators working in parallel. Taking advantages of the KONUS dynamics concept and the H-mode DTL structure, an efficient DTL accelerator has been designed for covering the acceleration after the RFQ. An insight comparison between the H-DTL scheme and other proposals is made and presented.

**C. Zhang, M. Busch, H. Klein, H. Podlech, U. Ratzinger** (IAP)

TH5PFP025

**Effects of Coherent Resonances for the JPARC Main Ring at the Moderate Beam Power**

Crossing different types of resonances is unavoidable for the high beam power operation of the JPARC Main Ring. The 'lattice' resonances are caused by the realistic machine imperfection including the field and alignment errors. In addition the 'space charge' resonances will lead to the emittance growth. The mechanism of the emittance dilution for the realistic machine imperfection in combination with the space charge effects should be studied in the self-consistent manner. In frame of this report we analyze different coherent modes of the space charge dominated beam at the injection energy for the JPARC Main Ring for some basic operation scenario of the machine. This analysis allows to identify the most dangerous resonances and to understand the effect of the emittance dilution remaining after the resonance correction. The study has been performed by using the PTCORBIT code.

**A. Y. Molodozhentsev, E. Forest** (KEK)

TH5PFP026

### Observation and Analysis of Electron Cloud Instability of SNS Ring

Z. Liu (IUCF) S. M. Cousineau, V. V. Danilov, C. Deibebe, J. A. Holmes, A. P. Shishlo (ORNL)

Coupled electron-proton (e-p) oscillation has been proven a source of beam instability in the PSR storage ring. Due to the similarities between the PSR and SNS storage ring,

e-p instability is considered a possible obstacle of the intense accelerator production by our accelerator\*. Measurements of beam oscillations consistent with e-p behavior have been observed under various conditions in the SNS ring. These measurements will be discussed along with simulations showing the e-p instability could be suppressed by appropriate beam bunch shape modification.

\*V. Danilov, et al, "Accumulation of high intensity beam and first observations of instabilities in the SNS accumulator ring", proceedings of HB2006, Tsukuba, Japan

### Longitudinal Particle Simulation for J-PARC RCS

M. Yamamoto, K. Hasegawa, M. Nomura, A. Schnase, T. Shimada, H. Suzuki, F. Tamura (JAEA/J-PARC) E. Ezura, K. Hara, C. Ohmori, A. Takagi, M. Toda, M. Yoshii (KEK) K. Horino (Nippon Advanced Technology Co. Ltd.)

J-PARC RCS is in the beam commissioning period. Some longitudinal beam gymnastics and the acceleration has been successfully performed under the high intensity operation. We have developed a longitudinal particle tracking code, which includes beam

loading and space charge effects. The comparison between the beam test result and the particle tracking simulation is described.

### Optical Measurement System of Laser-Cooled Mg Ion Beam

M. Nakao, T. Ishikawa, A. Noda, H. Souda, M. Tanabe, H. Tongu (Kyoto ICR) M. Grieser (MPI-K) K. Jimbo (Kyoto IAE) S. Shibuya (AEC) T. Shirai (NIRS)

Transverse laser cooling experiments of 24Mg<sup>+</sup> beam have been carried out at S-LSR, which is a small ion storage and cooler ring. According to a simulation, it is expected that under such a condition as the difference of

synchrotron and betatron tunes is near integer, synchro-betatron coupling occurs and transverse laser cooling will be achieved\*. In order to confirm this situation, the horizontal beam size and momentum spread are measured optically with CCD camera and PAT (post acceleration tube), respectively\*\*,\*\*\*. CCD camera observes fluorescence from the beam at the laser cooling section. Typical measured horizontal beam size is 0.5mm (1 sigma). In some condition, an increase of fluorescence strength is observed, which indicates the beam concentration to the center, where the beam and the laser can interact. PAT is utilized for measurement of a longitudinal beam velocity profile. By application of electric potential to the PAT, the beam velocity is slightly modified. Since only particles which have velocities in a certain region can interact with the laser, the time variation of the fluorescence during voltage sweep represents the longitudinal velocity profile of the beam.

\*H. Okamoto, Phys. Rev. E 50, 4982 (1994)

\*\*B. Wanner et al., Phys. Rev. A 58, 2242 (1998)

\*\*\*T. Ishikawa, Master's thesis, Kyoto University (2008)



### Recent Approach to Crystalline Beam with Laser-Cooling at Ion Storage Ring, S-LSR

Creation of 3-dimensional crystalline beam by application of laser-cooling for a Mg ion beam with kinetic energy of 40 keV is a major research subject of the ion storage ring, S-LSR, at ICR, Kyoto University\*. Based on the success of longitudinal laser cooling in

**A. Noda**, M. Nakao, H. Souda, H. Tongu (Kyoto ICR) M. Grieser (MPI-K) K. Jimbo (Kyoto IAE) I. N. Meshkov, A. V. Smirnov (JINR) K. Noda, T. Shirai (NIRS) H. Okamoto (HU/AdSM) S. Shibuya (AEC)

2007\*\*, an approach to extend the effect of laser cooling to the transverse degree of freedom has been performed. An indication of heat transfer from the horizontal to longitudinal direction has been obtained by synchro-betatron coupling. By application of bunched beam laser cooling at the operation point around (2.07, 1.10), the momentum spread of the cooled ion beam has been observed to have a peak at a synchrotron tune around 0.07 and simultaneously transverse beam size seems to be reduced in this region. An increase of beam brightness in the horizontal profile has also been observed by measuring spontaneous emission of absorbed laser light. In the present paper, strategy to reach the final 3-dimensional crystalline state by application of 3-dimensional laser cooling by careful adjustment of coupling among 3 degrees of freedom is to be presented based upon the recent experimental results.

\*A. Noda, M. Ikegami, T. Shirai, *New Journal of Physics*, 8, 288-307(2006).

\*\*M. Tanabe et al., *Applied Physics Express* 1, 028001-1-028001-3 (2008).

### Laser Cooling Experiment with Resonant Coupling at S-LSR

Laser cooling experiments have been carried out at Small Laser-equipped Storage Ring(S-LSR). In order to achieve transverse cooling, a resonant coupling method\* is applied. In this method, the transverse temperature is

**H. Souda**, M. Nakao, A. Noda, M. Tanabe, H. Tongu (Kyoto ICR) M. Grieser (MPI-K) K. Jimbo (Kyoto IAE) S. Shibuya (AEC) T. Shirai (NIRS)

cooled indirectly by synchro-betatron coupling, through an RF electric field at a straight section with a finite dispersion of 1.0 m. In this experiment, a Mg<sup>+</sup> beam is cooled by a co-propagating laser with a wavelength of 280 nm under various values of tunes and several difference resonant conditions of a synchrotron and betatron tune. The momentum spread are measured by observing laser-induced fluorescence light by using a post acceleration tube. The transverse beam profiles are measured with a CCD camera. When the synchrotron tune and the horizontal betatron tune are 0.065 and 2.064, respectively, an enhancement of momentum spread is observed. In this resonant condition the momentum spread is increased from  $1.5 \times 10^{-4}$  to  $3.0 \times 10^{-3}$  at  $3 \times 10^7$  stored particles. The effect of resonant coupling for transverse beam sizes is now under investigation. The tune dependence and time variation of the beam sizes by laser cooling is also a subject in the present experiments.

\*H. Okamoto, *Phys. Rev. E* 50, 4982 (1994)

### Status of Electron-Cloud Build-Up Simulations for the Main Injector

We provide a brief status report on measurements and simulations of the electron-cloud in the Fermilab Main Injector. Areas of agreement and disagreement are spelled out, along with their possible significance.

**M. A. Furman** (LBNL) I. Kourbanis, R. M. Zwaska (Fermilab)

**Touschek Lifetime Measurements at Ultrasmall Horizontal Emittance in the ALS**

C. Steier, L. Yang (LBNL)

The Touschek lifetime in low energy or small emittance lepton storage rings strongly depends on the particle density in bunches. In the usual parameter range, this dominates other effects and the lifetime gets shorter with higher the bunch density, i.e. with smaller beam emittance. However, once one gets to extremely small horizontal emittances, this is no longer the case. Since the Touschek scattering process is an energy transfer from the transverse plane to the longitudinal one at a place of dispersion, the Touschek lifetime actually increases, once the transverse temperature (i.e. emittance) gets small enough. In the usual Touschek lifetime formulas, this is accounted for with a complicated multiparameter function (form factor). This presentation will present to our knowledge the first direct measurements of the Touschek lifetime in this region of reversed dependence on horizontal emittance, as well as comparison with theory. The measurements were carried out at the ALS at reduced beam energy and ultrasmall horizontal emittance.

**Observation of Nonlinear Space-Charge Induced Phase Space Wave-Breaking and Emittance Growth in a High-Brightness Photoinjector**

S. G. Anderson, G. G. Anderson, C. P.J. Barty, R. D. Berry, D. J. Gibson, F. V. Hartemann, M. J. Messerly, M. Shverdin, C. Siders, A. M. Tremaine (LLNL) H. Badakov, A. Fukasawa, B. D. O'Shea, J. B. Rosenzweig (UCLA) P. Frigola (RadiaBeam)

We investigate the contribution of non-uniform transverse charge distributions to the emittance of high peak brightness photoinjector electron beams. Through simulation and theoretical investigation of the temporally-resolved radial phase space of the beam, the effects of longitudinal and radial distribution non-uniformities are easily distinguished. For radial non-uniformities, the mechanism that leads to emittance growth is transverse phase space wave-breaking induced by non-linear space-charge forces. A 'pepper-pot' based radial phase space measurement technique is used at the T-REX photoinjector at LLNL to experimentally observe the bifurcation of phase space resulting from this wave-breaking and the effect of varying transverse laser intensity distributions on the electron beam emittance. The emittance is found to increase with the amount of non-uniformity in the laser pulse intensity on the photo-cathode, in good agreement with predictions of theory and simulation.

**Space Charge Waves in Mismatched Beams**

B. R. Poole, D. T. Blackfield, Y.-J. Chen, J. R. Harris (LLNL) P. G. O'Shea (UMD)

Mismatch oscillations resulting from the propagation of space charge waves in intense beams may lead to halo generation and possible beam loss, and modify longitudinal beam dynamics. These oscillations have amplitudes and frequencies different from that of the main beam and are particularly important in machines such as the University of Maryland Electron Ring (UMER), in which the beam dynamics scale to parameters associated with heavy ion fusion drivers. We use the particle-in-cell (PIC) code, LSP, to simulate space charge wave dynamics in an intense electron beam propagating in a smooth focusing channel with 2-D cylindrical symmetry. We examine the evolution of linear and nonlinear density perturbations in the UMER parameter range for both matched and mismatched beams. Comparisons between LSP simulations and numerical models are presented.

### Conceptual Design of a 20 GeV Electron Accelerator for a 50 keV X-Ray Free-Electron Laser Using Emittance Exchange Optics and a Crystallographic Mask

At Los Alamos National Laboratory we are actively exploring the feasibility of constructing a 50-keV x-ray free-electron laser. For such a machine to be feasible, we need

to limit the cost and size of the accelerator and, as this is intended as a user facility, we would prefer to use proven, conventional accelerator technology. Using recent developments in transverse-to-transverse and transverse-to-longitudinal emittance exchange optics <sup>\*</sup>, <sup>\*\*</sup>, we present a conceptual 20-GeV conventional electron accelerator design capable of producing an electron beam with a normalized transverse emittance as low as 0.2 mm-mrad, a root-mean-square (RMS) beam length of 74 fs, and an RMS energy spread of 0.01%. We also explore the possibility of introducing a crystallographic mask into the beam line. Combined with a transverse-to-longitudinal emittance exchange optic, we show that such a mask can be used to modulate the electron beam longitudinally to match the x-ray wavelength. This modulation, combined with the very low transverse beam emittance, allows us to not only generate 50-keV x-rays with a 20-GeV electron beam, but also drastically decrease the length of the required undulator.

<sup>\*</sup>P. Emma, Z. Huang, K. -J. Kim, and P. Piot, Phys. Rev. ST Accel. Beams 9, 100702 (2006).

<sup>\*\*</sup>B. E. Carlsten and K. A. Bishofberger, New J. Phys. 8, 286 (2006).

S. J. Russell, K. Bishofberger, B. E. Carlsten, D. C. Nguyen, E. I. Smirnova (LANL)

TH5PFP036

### Performance on the Spectral Element Discontinuous Galerkin Simulations with Moving Window for Wake Field Calculations

We developed a moving window algorithm for the SEDG time-domain code, NekCEM, for wake field calculations. NekCEM is a

highly efficient and spectrally accurate electromagnetic solver using the spectral element discontinuous Galerkin (SEDG) method based on body-fitted spectral element hexahedral meshes. When the domain of interest is around a moving bunch within a certain distance, one does not need to carry out full domain simulations. Moving window approach has been a natural consideration in such circumstance to have significant reduction in computational cost for the conventional low-order methods such as FDTD method. However, there have not been studies on the high-order methods, especially the SEDG method, based on the moving window approach. We implemented 3D moving window option for wake field calculations on various conducting cavities including the 9-cell TESLA cavity. We will demonstrate the performance of the SEDG simulations on moving window meshes.

M. Min, P. F. Fischer (ANL)

TH5PFP037

### Intrabeam Scattering Effect Calculated for a Non-Gaussian Distributed Linac Beam

A preliminary calculation using the beam parameters of the Linac Coherent Light Source (LCLS) indicates a noticeable growth

in energy spread and bunch length due to the intrabeam scattering (IBS) effect. However, the LCLS beam has a non-Gaussian distribution in longitudinal phase space, which is contrary to the assumptions of the calculation. We present here a strategy used in the program "elegant" for performing IBS calculations for a non-Gaussian longitudinal beam distribution in a linac. A detailed simulation result based on the LCLS beam parameters and lattice is given.

A. Xiao, M. Borland (ANL)

TH5PFP038

**Solving Vlasov Equation for Beam Dynamics Simulation**

J. Xu, B. Mustapha, P. N. Ostroumov (ANL)

Kinetic space plasma simulations are dominated by PIC (Particle-In-Cell) codes. Due to the inherent noise in PIC simulations, interest in directly solving the Vlasov equation is increasing. With the fast development of supercomputers, this is becoming more realistic. We present our preliminary work on solving the Vlasov equation for beam dynamics simulations\*. A high order Spectral Element Method has been applied to achieve high accuracy, easy interpolation, and parallelization. Due to the inherent instability of the Vlasov equation, a spectral filter has been added and mass conservation has been satisfied. The proposed algorithms were validated on 1D1V simulations. A paraxial model of the Vlasov equation (2D2V) has also been studied and compared with PIC simulations at ANL using the BG/P supercomputer.

\*J. Xu, P. Ostroumov and J. Nolen, "Highly Scalable Parallel Algorithm for 2D2V Vlasov Equation with High Order Spectral Element Method", poster on SC08, Austin, Texas, Nov.15-20, 2008.

**Optical Matching of EMMA Cell Parameters Using Field Map Sets**

Y. Giboudot (Brunel University) F. Meot (CEA)

The Non Scaling FFAG EMMA lattice allows an important displacement of the magnets in the radial direction. From this peculiarity, interesting studies of beam dynamics can be performed comparing simulated and experimental results. Being able to study a specific resonance, choosing a certain set of parameters for the lattice is really challenging. Simulations have been done integrating particle trajectories with Zgoubi through Magnetic Field Map created with OPERA. From a chosen tune evolution, one can find the corresponding magnets' configuration required by interpolating between a various sets of Field Map. Relative position and strength of the magnets are degrees of freedom. However, summing field maps requires a special care since the real magnetic field created by two magnets is not obviously linearly dependent on each single magnet. For this reason, frequently used hard edge and fringe field models may not be accurate enough. This linearity of the magnetic field has been studied directly through OPERA finite element method solutions and further on with Zgoubi tracking results.

**Particle Tracking Studies Using Dynamical Map Created from Finite Element Solution of the EMMA Cell**

Y. Giboudot, A. Khan (Brunel University) T. R. Edgecock (STFC/RAL) A. Wolski (The University of Liverpool)

The unconventional size and the possibility of transverse displacement of the magnets in the EMMA non-scaling FFAG motivates a careful study of particle behavior within the EMMA ring. The magnetic field map of the doublet cell is computed using a Finite Element Method solver; particle motion through the field can then be found by numerical integration, using (for example) OPERA, or ZGOUBI. However, by obtaining an analytical description of the magnetic field (by fitting a Fourier-Bessel series to the numerical data) and using a differential algebra code, such as COSY, to integrate the equations of motion, it is possible to produce a dynamical map in Taylor form. This has the advantage that, after once computing the dynamical map, multi-turn tracking is far more efficient than repeatedly performing numerical integrations. Also, the dynamical map is smaller (in terms of computer memory) than the full magnetic field map; this allows different configurations of the lattice, in terms of magnet positions, to be represented very easily using a set of dynamical maps, with interpolation between the coefficients in different maps\*.

\*yoel.giboudot@stfc.ac.uk

### Simulation Studies on the Electron Cloud Instability in the CSNS Ring

The electron proton (e-p) instability has been observed in many proton accelerators. It will induce transverse beam size blow up, cause beam loss and restrict the machine performance. A simulation code is developed to study the electron proton instability in the CSNS ring. The code simulates the dynamics of the proton beam and electron cloud, including their space charge effects. The results of numerical simulation of the electron cloud instability are presented.

N. Wang, Q. Qin (IHEP Beijing)

TH5PFP042

### Density Estimation Techniques for Charge Particle Beams with Applications to Microbunching Instability

We discuss various density estimation techniques to represent charge particle distributions in beam dynamics simulation codes. A detailed analysis of the different methods shows that for an accurate, reliable and efficient modeling of microbunching instability a careful control of numerical noise is required. In particular, we compare a standard particle-in-cell scheme plus denoising via wavelets thresholding with a meshless Monte-Carlo method used in statistical estimation. We implement them in a Vlasov-Maxwell solver and show results for FELs systems.

G. Bassi (Cockcroft Institute) G. Bassi (The University of Liverpool) B. Terzic (Northern Illinois University)

TH5PFP043

### The Influence of Cell Misalignments and Cavity Perturbations on Large Accelerating Linac Structures Investigated Using Mode Matching and the Globalised Scattering Matrix Technique

It is necessary to be able to accurately predict the performance of the any proposed baseline accelerator design in which the effects of couplers, trapped modes, Wakefields, realistic machining and alignment errors as well as numerous other important effects have been taken into consideration. Traditionally used numerical schemes (such as Finite element and Finite difference) require vast resources and time, not only that but the inclusion of realistic defects and misalignments into the baseline configuration will prove time consuming as it will potentially require remeshing of the problem. Here we present a mode matching scheme which utilises a globalised scattering matrix approach that allows large scale electromagnetic field calculations to be obtained rapidly and efficiently. The scalar product of all the S matrices used within this paper has been determined analytically and is calculated only once per transition, adding to the efficiency of the calculation. The influence of cell misalignments and cavity perturbations on the main accelerating linacs of XFEL and CLIC are exhibited. The wake-fields in super-structures and segments of entire modules are also presented

I. R.R. Shinton, R. M. Jones (UMAN)

TH5PFP044

### Rapid Cavity Prototyping and Optimisation Using a Globalised Scattering Matrix Approach

I. R.R. Shinton, R. M. Jones (UMAN)

Cavity design using traditional mesh based numerical means (such as the finite element or finite difference methods) requires numerous calculations and convergence studies in order to obtain accurate values and cavity optimisation is often not achieved. The mode matching method is a mature electromagnetic concept in which the analytical solutions of Maxwell's equations are given as a series expansion of modes; the electromagnetic fields are subsequently given by field matching at the interfaces between the sub-regions of a given structure. Previous mode matching schemes, although extremely accurate and efficient, were limited to sharp transitions. Here we present a mode matching scheme which utilises a globalised scattering matrix approach that allows cavities with curved surfaces to be accurately simulated allowing rapid cavity prototyping and optimisation to be achieved. We assume an infinite periodic structure from which dispersion relationships are obtained. The scalar product of all the S matrices used within this paper has been determined analytically and is calculated only once per transition. Results on structures in the CLIC and XFEL main linacs are presented.

### Condor as a Resource for Accelerator Research

J. D.A. Smith (Cockcroft Institute)

This work reports on the developments of a computational infrastructure framework that aids achievement of computational research objectives. Examples from a broad range of accelerator problems will be presented, along with ways in which the workflow can be modified.

### Electron Cloud Modeling Considerations at the CESR Test Accelerator

J. R. Calvey, J. A. Crittenden, G. Dugan, M. A. Palmer (CLASSE)

The Cornell Electron Storage Ring (CESR) has recently begun operation as a test accelerator for next generation linear collider damping rings. This program, known as CesrTA, includes a thorough investigation of synchrotron radiation generated electron cloud effects. CESR is capable of operating with a variety of bunch patterns and beam currents, as well as with both electron and positron beams. Understanding the buildup of the cloud under these conditions requires the use of well validated simulation programs. This paper will discuss three such programs- POSINST, ELOUD and CLOUDLAND, which have been benchmarked against each other in parameter regimes relevant to CesrTA operating conditions, with the aim of understanding systematic differences in the calculations.

### A Methodology for Collimating Intra-Beam Scattered Particles in an Energy Recovery Linac

M. P. Ehrlichman, G. H. Hoffstaetter (CLASSE)

The theories of beam loss and emittance growth by Touschek and Intra-beam Scattering formulated for beams in storage rings have recently been extended to linacs. In most linacs, these effects are not relevant, but they become important in Energy Recovery Linacs (ERLs) not only because of their large current, but also because the deceleration of the spent beam increases relative energy spread and transverse oscillation amplitudes. In this paper, we describe

simulations implemented in BMAD, Cornell's beam dynamics code, that provide a wealth of data about scattering losses. The simulations give the locations where scattering occurs and the locations where the scattered particles are lost. The latter can be used to produce a profile of radiation generated by scattered particles colliding with the beam chamber. We also discuss a methodology for building a collimation scheme to control where beam losses occur and protect sensitive regions from exposure. The simulations are used to determine the trajectory of the scattered particles, which are analyzed to determine optimal locations for collimators. Additionally, we determine the background of scattered particles exiting the linac.

### Acceleration of Symplectic Integrator with Graphical Processing Units

The study of nonlinear effects in storage rings requires massively parallel particle tracking over a range of initial conditions.

J. Rowland, I. P.S. Martin (Diamond)

Stream processing architectures trade cache size for greatly increased floating point throughput in the case of regular memory access patterns. The symplectic integrator of Tracy-II\* has been implemented in CUDA\*\* on the nVidia stream processor and used to calculate dynamic apertures and frequency maps for the Diamond low-alpha lattice. To facilitate integration with existing workflows the the lattice description of Accelerator Toolbox\*\*\* is re-used. The new code is demonstrated to achieve a two orders of magnitude increase in tracking speed over a single CPU core and benchmarks of the performance and accuracy against other codes are presented.

\*J. Bengtsson, Tracy-2 User's Manual, Feb 1997.

\*\*NVIDIA, NVIDIA CUDA Programming Guide 1.1.pdf

\*\*\*A. Terebilo - ACCELERATOR MODELING WITH MATLAB ACCELERATOR TOOLBOX, PAC 2001

### Fast Multipole Approximation of 3D Self Fields Effect in High Brightness Electron Beams

In this paper the Fast Multipole Approximation is described with regard to the problem of modelling self fields effects in low emittance, high brightness electron beams of interest for future accelerators and light sources.

M. Quattromini, L. Giannessi (ENEA C. R. Frascati)

This well established technique is known to scale as  $O(N)$  or  $O(N \log N)$  (depending on details of the implementation) with the number of particles involved in the simulation. Performances and results as a standalone technique or as a method for fast calculation of boundary conditions together with other approaches based on PDEs are discussed, along with details of a parallel implementation in the tracking code Tredi.

### Numerical Algorithms for Dispersive, Active, and Nonlinear Media with Applications to the Paser

The PASER is one of the first advanced accelerator modeling applications that requires a more sophisticated treatment of dielectric and paramagnetic media properties than simply assuming a constant permittivity or permeability.

P. Schoessow, A. Kanareykin (Euclid TechLabs, LLC) L. Schächter (Technion)

So far the PASER medium has been described by a linear, frequency-dependent, single-frequency, scalar dielectric function. We have been developing algorithms to model the high frequency response of dispersive, active, and nonlinear media with an emphasis on areas most useful for PASER simulations. The work described also has applications for modeling of other electromagnetic problems involving realistic dielectric and magnetic media. Results to be reported include treatment of multiple

TH5PFP049

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Lorentz resonances based on auxiliary differential equation, Fourier, and hybrid approaches, and Kerr, Brillouin, and Raman optical nonlinearities.

TH5PFP052

### Electron Cloud Simulations for ANKA

U. Iriso (ALBA) S. Casalbuoni (FZK) G. Rumolo, F. Zimmermann (CERN)

One of the key issues for the developments of superconducting insertion devices is the understanding of the beam heat load in the vacuum chamber. The beam heat load observed in the superconducting cold bore undulator installed in the ANKA storage ring is higher than the one predicted by the synchrotron radiation and resistive wall heating. A non linear increase of the dynamic pressure with the beam current is also observed in the cold bore. In order to investigate whether the nature of these effects is due to an electron cloud formation, we have performed several simulations using the ECLLOUD code.

TH5PFP053

### Graphical Front-End and Object-Oriented Design for IonEx, an Ion Extraction Modeling Code

L. Grubert, N. Barov, B. Cluggish, S. Galkin, J. S. Kim (Far-Tech, Inc.)

IonEx is a new hybrid, meshless, cross-platform, 2D code which can model the extraction of ions from a plasma device. The application includes a user-friendly Graphical User Interface (GUI), which contains a geometry editor for specifying the domain. The design of IonEx utilizes the object-oriented functionality of C++, which provides an efficient means of incorporating a magnetic field, an arbitrary geometry, and an unlimited number of ion species into a simulation. Visualization of the resulting trajectories and emittances is accomplished through the GUI; OpenGL is used to accelerate the graphics. In this paper we will briefly review the physics and computational methods used, highlight important aspects of the object-oriented design, discuss the primary features of the GUI, describe the current status of IonEx, and present some simulation results.

TH5PFP054

### Validation and Application of GEM (General ECRIS Modeling)

L. Zhao, B. Cluggish, J. S. Kim (Far-Tech, Inc.)

GEM, developed by FAR-TECH Inc, is a self consistent hybrid code to simulate general ECRIS plasma. It calculates EDF (electron distribution function) using a bounce-averaged Fokker-Planck code and calculates the ion flow using a fluid code, which has been modified to implement new boundary settings including fixed boundary ion velocities or fixed sheath potentials at both ends of the device. Extensive studies on the convergence and performance of the code have been performed. Also, GEM has been connected to MCBC (Monte Carlo beam capture) code and the validations of the code using ANL ECR-I charge breeding data and other published experiments are underway. The typical converged solutions of GEM and the comparisons with the experiments will be presented and discussed.



### Mathematica Application for Methodical Ionization Cooling Channel Design

Existing codes for accelerator design (e.g. MAD) are not well suited for ionization cooling channels where particles exhibit strongly dissipative and nonlinear motion. A system of Mathematica programs was developed which allows to: 1) find periodic orbit and eigenvectors of the transfer matrix around it with account of (regular part of) ionization losses and feeddown effect from nonlinear fields; 2) compute emittance growth due to scattering and straggling, find equilibrium values (if exist); 3) analyze nonlinear effects such as dependence of tunes and damping rates on the amplitudes, resonance excitation; 4) perform tracking with account of stochastic processes. Underlying theory and application to helical cooling channel are presented.

**Y. Alexahin** (Fermilab)

TH5PFP055

### Using PARMILA 2 with the Particle Beam Optics Laboratory (PBO Lab)

A PARMILA 2 Module has been developed for the Particle Beam Optics Laboratory (PBO Lab). PARMILA 2 is a FORTRAN program used to both design and simulate radiofrequency ion linear accelerators. The program can be used to design radiofrequency accelerators that include drift tube linac (DTL) structures, coupled cavity linac (CCL) structures, coupled-cavity drift tube linac (CC-DTL) structures, and superconducting accelerator structures. PARMILA 2 can also be used to simulate beams in these structures and in transport lines that with magnetic, radiofrequency and electrostatic beam optics elements. PBO Lab provides a sophisticated graphic user interface (GUI) for multiple optics codes. From the same familiar interface users can run TRANSPORT, TURTLE, MARYLIE, TRACE 3-D and DECAY-TURTLE. PARMILA 2 now joins this suite of optics codes available as PBO Lab Modules. New PBO Lab tools have been developed to assist users in utilizing different optics codes to simulate and validate the performance of an accelerator designed with PARMILA 2. An overview of the new PARMILA 2 module and associated new tools is presented and some of the GUI features are illustrated.

**G. H. Gillespie**, W. Hill (G. H. Gillespie Associates, Inc.)

TH5PFP056

### Measured and Calculated Field Properties of the SIS 100 Magnets Described Using Elliptic and Toroidal Multipoles

The first full size superconducting dipole magnets for the SIS 100 Tm synchrotron were built and tested. The achieved magnetic field has been measured with a rotating coil probe. An intensive Finite Element R&D, necessitated by the used superconducting cable as well as by the complex mechanical coil and yoke structure, allows calculating the field with high accuracy. Elliptic multipoles were used to describe the field within the whole aperture of the vacuum chamber. As the final design for the SIS 100 dipoles is curved, we developed toroidal multipoles describing the field within a curved magnet, and enabling us to interpret the measurement of a rotating coil probe within such magnets. We describe the performance of the magnetic measurement system, present the measured field properties and compare them to the calculated ones.

**E. S. Fischer**, A. Mierau, P. Schnizer (GSI) P. G. Akishin (JINR)  
R. V. Kurnyshov (Electroplant) B. Schnizer (TUG/ITP) P. A. Shcherbakov (IHEP Protvino)

TH5PFP057

TH5PF058

**RFQ Particle Dynamic Simulation Program Development**

J. M. Maus, R. A. Jameson, A. Schempp (IAP)

For the development of high energy and high duty cycle RFQs accurate particle dynamic simulation tools are important optimize designs especially in high current applications. To describe the external fields in RFQs the poisson equation has to be solved taking the boundary conditions into account. In the newly developed subroutines this is done by using a finite difference method on a grid. The results of this improvement are shown and compared to the old two term and multipole expansions.

TH5PF059

**Numerical Calculation of Wake Fields in Structures with Conductive Walls**

A. V. Tsakanian (Uni HH) M. Dohlus, I. Zagorodnov (DESY)

Based on TE/TM splitting algorithm a new (longitudinally) dispersion-free numerical scheme is developed to evaluate the wake fields in structures with finite wall conductivity. The impedance boundary condition in this scheme is modeled by the one dimensional wire connected to boundary cells. A good agreement of the numerical simulations with the analytical results is obtained. The developed code allows to calculate multipole wake potentials of arbitrary shaped geometries with walls of finite high conductivity.

TH5PF060

**Space Charge and Undulator Focusing**

L. M. Hein (Humboldt University Berlin) A. N. Matveenko (Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Elektronen-Speicherring BESSY II) A. Meseck (BESSY GmbH)

While designing accelerator, there is often the decision between a fast analytical modelling and a time-consuming tracking. In many cases, where space charge has to be taken into account, particle tracking seems to be the only way. The new program "P12" copes with space charge in a linear manner. P12 is designed for fast calculation of lattices for high electron energy. Furthermore it provides a new subroutine for dealing with focussing at elliptical undulators. Calculations and results will be shown and discussed.

TH5PF061

**SVD Analysis of Time-Domain Electromagnetic Field Data for Extracting Modes inside RF**

S. Ahmed, D. M. Kaplan (Illinois Institute of Technology) A. Moretti (Fermilab)

Excitation of desired electromagnetic (EM) modes inside an RF cavity is important for maximum energy transfer from wave to particle and for beam stability. However, the excitation of higher-order modes (HOM) is inevitable and leads to beam instability -- thus suppression of HOM is important. Given the number of variables, no simple estimate is possible; hence, a detailed analysis becomes necessary. Available commercial and freeware packages solve Maxwell's equations in frequency/time domain and compute modes at discrete frequencies, which is time consuming. We propose an approach to extract ultra-wide-band spectrum of modes excited inside a system using singular value decomposition (SVD) analysis. This can be accomplished with the help of time-domain solver which could be any suitable commercial package or self-developed code (FDTD in our case) and using the Gaussian waveform for excitation. This approach has advantages over the conventional one: it is computationally fast and makes it easy to predict possible modes and filter out

noise. The SVD analysis of time-domain EM data is a novel approach toward quantitative identification of modes and helpful in designing mode suppressors.

### Numerical Study of Collective Effects for Muon Beams

The study of Muon beam optics is crucial for future Neutrino Factory and Muon Collider facilities. At present, the GEANT4-based simulation tools for Muon beam tracking such as G4beamline and G4MICE are based on single particle tracking without collective effects taken into account. However, it is known that collective effects such as space charge and wakefields for muons (in matters or vacuum) are not ignorable. As the first step, space charge computation has been implemented into muon tracking. The basic algorithm is particle to particle interactions through retarded electro-magnetic fields. The momentum impulse by collective effects is imposed on every particle at each collective step, and the G4beamline main code is used for tracking. Comparisons to LANL Parmela are illustrated and analyzed. Optimizations of the algorithm are also underway to gain less computing time and more accuracy. Moreover, the idea of enhancing ionization cooling efficiency by utilizing the collective effect due to polarized charges in matter appears to be possible, and the preliminary estimation has been done.

**D. Huang** (IIT) D. M. Kaplan (Illinois Institute of Technology) K. Y. Ng (Fermilab) T. J. Roberts (Muons, Inc)

TH5PFP062

### A Dispersion Free Three-Dimensional Space-Charge Modeling Method

We present the theoretical and numerical results of a dispersion free time-dependent Green's function method which can be utilized for calculating electromagnetic space-charge fields due to arbitrary current in a conducting pipe. since the Green's function can be expanded in terms of solutions to the wave equation, the numerical solutions to the fields also satisfy the wave equation yielding a completely dispersion free numerical method. This technique is adequately suited for modeling bunched space-charge dominated beams, such as those found in high-power microwave sources, for which the effects of numerical grid dispersion and numerical Cherenkov radiation are typically found when using FDTD type methods.

**M. Hess, C. S. Park** (IUCF)

TH5PFP063

### Computational Modeling of Electromagnetic Space-Charge Physics in RF Photoinjectors

Near the cathode in a photoinjector, the electron beam is emitted with low energy, and its dynamics are strongly affected by the beam's space-charge fields. This can cause beam loss at the cathode due to virtual cathode formation. In general, a fully electromagnetic code can correctly predict the beam space-charge fields, beam dynamics, and beam loss. However, an electrostatic type algorithm would overestimate the space-charge fields since it does not incorporate relativistic time-retardation effects which limit the size of the fields near the cathode. IRPSS (Indiana RF Photocathode Source Simulator) can calculate the electromagnetic space-charge fields using a Green's function method to a high-precision, and can track beam dynamics in the RF photoinjector. Using IRPSS, we simulated the beam dynamics and beam loss near the cathode for the Argonne Wakefield Accelerator 1.3 GHz gun\* and compared those results to electrostatic codes, such as PARMELA and ASTRA.

**C. S. Park, M. Hess** (IUCF)

\*P. Schoessow, PAC 2009.

TH5PFP064

### Cubes in OLAP Systems

I. D. Valova (ICSR)

Cube is one of the most frequently used notions in On-Line Analytical Processing (OLAP) systems (infocube, hypercube, one-dimensional cube, two-dimensional cube, etc., up to N-dimensional cube). In the course of our study on applications of such geometric figure in the systems for analytical data processing and respective operators, used for analysis of multidimensional models, we resolved to step aside and to study the use of this geometric figure also in other modern sciences. In this paper we investigate how the various scientific branches are interpreting and using this common geometric figure.

### Beam Dynamics Study of a C-Band Linac Driven FEL with S-Band Photo-Injector

V. Fusco, M. Ferrario (INFN/LNF)

High gain free electron lasers require the production of a high brightness electron beam that is a low emittance, high current beam. To this aim the injector and linac design and their operation are the leading edge. The successful operation of the SCSS FEL driven by a C-band linac has demonstrated that C-band is a mature technology and it is very attractive in terms of gradient and compactness. In this paper it is described a beam dynamics study, made with the Homdyn code, for a C-band linac driven FEL with S-band photo-injector. The key point is to match the longitudinal phase space of the S-band photo-injector with the C-band linac using the velocity bunching technique. The result is a brightness up to  $10^{15}$  A/m<sup>2</sup>, obtained with a low emittance and a relaxed peak current.

### Longitudinal Phase Space Tomography at J-PARC RCS

M. Yoshimoto, N. Hayashi, F. Tamura, M. Yamamoto (JAEA/J-PARC) M. Yoshii (KEK/JAEA)

In order to observe two-dimensional beam profiles in the longitudinal phase space, the reconstruction techniques with the computer tomography algorithms can be adopted at the J-PARC RCS. On the assumption that the longitudinal profiles should not be disturbed for one period of the synchrotron oscillation, such two-dimensional profiles can be reconstructed easily from one-dimensional bunch beam profiles, which are measured for every turn by the wall current monitor. In this presentation, we introduce the experimental results and the comparison to the longitudinal beam tracking simulation, and we discuss the technical issues and applicability of this longitudinal tomography techniques.

### Simulation of the Alignment of Linear Accelerators

J. Dale, A. Reichold (JAI)

The alignment of the next generation of linear accelerators will be much more critical than that of currently existing machines. This is especially true for very long machines with ultra low emittance beams; such as the ILC and CLIC. The design and study of such machines will require a large number of simulations. However; full simulation of misalignment currently requires computer programs which are very resource intensive. A model which can be used to rapidly generate reference networks with the required statistical properties will be presented. The results for emittance growth in the ILC main linac using the model with Dispersion Matched Steering (DMS) applied are also shown.

### Simulation of Pellet Target Experiments with BETACOOOL Code

In last years at GSI (Germany) new accelerator complex project FAIR is being realized. One of the most important goals of this project is carrying out an experiment with internal target PANDA. To achieve maximum beam luminosity value the pellet target was chosen. Using pellet target leads to a problem with irregular beam luminosity. Such luminosity variations usually have a very big amplitude. This effect can reflect on detector parameters negatively. Numerical simulation of PANDA experiment is connected to two time-scale different processes. The first one is the short-time process, which describes beam luminosity variations while one pellet is crossing of the ion beam. The long-time process of the beam parameter evolution (particle number, transverse and longitudinal profiles) are defined by the beam losses and equilibrium between target heating and electron cooling.

**D. A. Krestnikov** (JINR/DLNP) R. Pivin, A. O. Sidorin, A. V. Smirnov (JINR)

TH5PFP069

### Application of the Adaptive Mesh Refinement Technique to Particle-in-Cell Simulations of Beams and Plasmas

The development of advanced accelerators often involves the modeling of systems that involve a wide range of scales in space and/or time, which can render such modeling extremely challenging. The Adaptive Mesh Refinement technique can be used to significantly reduce the requirements for computer memory and the number of operations. Its application to the fully self-consistent modeling of beams and plasmas is especially challenging, due to properties of the Vlasov-Maxwell system of equations. Most recently, we have begun to explore the application of AMR to the modeling of laser plasma wakefield accelerators (LWFA). For the simulation of a 10GeV LWFA stage, the wake wavelength is  $O[100\mu\text{m}]$  while the electron bunch and laser wavelength are typically submicron in size. As a result, the resolution required for different parts of the problem may vary by more than two orders of magnitude in each direction, corresponding to up to 6 orders of magnitude of possible (theoretical) savings by use of mesh refinement. We present a summary of the main issues and their mitigations, as well as examples of application in the context of LWFA and similar beam-plasma interaction setup.

**J.-L. Vay**, C. G.R. Geddes (LBNL) A. Friedman, D. P. Grote (LLNL)

TH5PFP070

### Multiobjective Optimization in Accelerator Design and Optimization

Multiobjective optimization has been used in many fields including accelerator related projects. Here we use it as a powerful tool for lattice design and optimization, which includes betatron functions, brightness and dynamics properties.

**L. Yang**, D. Robin, F. Sannibale, C. Steier, W. Wan (LBNL)

TH5PFP071

### Modeling Acceleration Schedules for NDCX-II

The Virtual National Laboratory for Heavy-Ion Fusion is developing a physics design for NDCX-II, an experiment to study warm dense matter heated by ions near the Bragg-peak energy. Present plans call for using about thirty induction cells to accelerate 30 nC of  $\text{Li}^+$  ions to more than 3 MeV, followed by neutralized drift-compression. To heat targets to useful temperatures, the beam must be

**W. M. Sharp**, A. Friedman, D. P. Grote (LLNL) E. Henestroza, M. Leitner, W. L. Waldron (LBNL)

TH5PFP072

compressed to a sub-millimeter radius and a duration of about 1 ns. An interactive 1-D particle-in-cell simulation with an electrostatic field solver, acceleration-gap fringe fields, and a library of realizable analytic waveforms has been used for developing NDCX-II acceleration schedules. Multidimensional source-to-final-focus simulations with the particle-in-cell code Warp have validated this 1-D model and have been used both to design transverse focusing and to compensate for injection non-uniformities and 3-D effects. Results from this work are presented, and ongoing work to replace the analytic waveforms with output from circuit models is discussed.

### Ion Effect Issues in PETRA III

G. X. Xia (MPI-P) M. Ivanyan (CANDLE) K. Manukyan, K. A. Sargsyan (YSU) R. Wanzenberg (DESY)

At DESY the PETRA accelerator has been converted into a new 3rd generation high-brilliance synchrotron radiation facility called PETRA III. For the first commissioning in spring 2009 a positron beam is used. In the future it is also foreseen to operate the synchrotron light source with an electron beam. Ion effects pose a potential problem to the electron beam operation of PETRA III. In this paper, a weak-strong simulation code is employed to study the ion effect issues in detail for different operation scenarios.

### Putting Space Charge into G4beamline

K. B. Beard, T. J. Roberts (Muons, Inc)

The G4beamline program is based on the well-established Geant4 toolkit used to simulate the interactions of particles and photons with matter. Until now, only a single particle at a time could be tracked and there are no interactions between particles. Recent designs for high pressure RF cavities and other novel devices achieving extreme muon cooling require that the effect of space charge be included in the simulations. A new tracking manager in G4beamline propagates a number of particles (typically 1,000-10,000) in parallel, stepping all particles in time. This allows all of the usual Geant4 physics interactions to be applied, plus collective computations. A simple macroparticle-based model is used to represent  $\sim 1 \cdot 10^8$  charges with an ellipsoidal charge density. At intervals the appropriate macroparticle size and shape are recalculated, the electric and magnetic fields are determined, and an impulse is applied to the simulated particles. Comparisons to standard space charge codes are presented.

### Simulation Tools for the Muon Collider Feasibility Study

T. J. Roberts (Muons, Inc) R. C. Fernow (BNL)

The U. S. muon collider community is mobilizing itself to produce a "Design Feasibility Study" (DFS) for a muon collider. This is happening on an aggressive schedule and must include the best possible simulations to support and validate the technical design. The DFS for a muon collider will require innovative new approaches to many aspects of accelerator design, and the simulations to support it will require tools with features and capabilities that are equally innovative and new. Two computer programs have emerged as the preferred and most commonly used simulation tools within the muon collider community: ICOOL (primary author: Dr. Fernow), and G4beamline (primary author: Dr. Roberts). We describe the ongoing development and testing of both tools for the DFS, including a common suite of tests to ensure that both tools give accurate and realistic results, as well as innovative user-friendly interfaces with emphasis on graphical user interfaces and windows.

### Particle Tracking in Matter-Dominated Beam Lines

Most computer programs that calculate the trajectories of particles in accelerators assume that the particles travel in an evacuated chamber. The development of muon beams, which are needed for muon colliders and neutrino factories and are usually required to pass through matter, is limited by the lack of user-friendly numerical simulation codes that accurately calculate scattering and energy loss in matter. Geant4 is an internationally supported tracking toolkit that was developed to simulate particle interactions in large detectors for high energy physics experiments, and includes most of what is known about the interactions of particles and matter. Geant4 has been partially adapted in a program called G4beamline to develop muon beam line designs. The program is now being developed and debugged by a larger number of accelerator physicists studying muon cooling channel designs and other applications. Space-charge effects and muon polarization are new features that are being implemented.

**T. J. Roberts**, K. B. Beard (Muons, Inc) S. Ahmed, D. M. Kaplan (Illinois Institute of Technology) D. Huang (IIT)

TH5PFP076

### Adaptive-Grid Wavelet-Based Algorithm for Solving the Poisson Equation in Particle-in-Cell Simulations

We present a wavelet-based algorithm for the solution of the Poisson equation in particle-in-cell simulations which exhibits better scaling properties than the traditional Green's function and FFT approach. This algorithm also provides unique possibilities for adaptive resolution PIC simulations and parallelization of the Poisson solver. The algorithm described in this work is derived in a self-contained manner from theory to implementation, with the intent of encouraging the adoption of this wavelet-space technique by researchers with no prior experience in wavelet techniques. The algorithm was implemented in a test program to verify correctness, and extensive test runs of the application were executed to examine the numerical accuracy and scaling properties of the algorithm. These tests demonstrate that the wavelet-space approach is a competitive algorithm for the solution of the Poisson equation in a particle-in-cell simulation.

**B. Terzic**, B. Sprague (Northern Illinois University)

TH5PFP077

### Low-Frequency Time Domain Numerical Studies of Transition Radiation in a Cylindrical Waveguide

Transition radiation is frequently used to determine the time profile of a bunched relativistic particle beam. Emphasis is usually given to diagnostics sensitive to wavelengths in the infrared to optical portion of the spectrum. In this study, MAFIA simulations are used to make quantitative statements regarding the low-frequency (DC to microwave) behavior of transition radiation from a mirror inclined at 45 degrees relative to the particle beam trajectory. For ease of interpretation, a moving semi-infinite line charge (step function) confined within a cylindrical beam pipe is modeled. Simulation results are presented and compared with a simple theoretical free space result.

**X. Sun**, G. Decker (ANL)

TH5PFP078

## Statistical Analysis of Multipole Components in the Magnetic Field of the RHIC Arc Regions

J. Beebe-Wang, A. K. Jain (BNL)

The existence of multipolar components in the dipole and quadrupole magnets is one of the factors limiting the beam stability in the RHIC operations. Therefore, the statistical properties of the non-linear fields are crucial for understanding the beam behavior and for achieving the superior performance in RHIC. In an earlier work<sup>\*</sup>, the field quality analysis of the RHIC interaction regions (IR) was presented. Furthermore, a procedure for developing non-linear IR models constructed from measured multipolar data of RHIC IR magnets was described. However, the field quality in the regions outside of the RHIC IR regions had not yet been addressed. In this paper, we present the statistical analysis of multipolar components in the magnetic fields of the RHIC arc regions. The emphasis is on the lower order components, especially the sextupole in the arc dipole and the 12-pole in the quadrupole magnets, since they are shown to have the strongest effects on the beam stability. Finally, the inclusion of the measured multipolar components data of RHIC arc regions and their statistical properties into tracking models is discussed.

<sup>\*</sup>J. Beebe-Wang and A. Jain, "Realistic Non-linear Model and Field Quality Analysis in RHIC Interaction Regions", proc. of PAC 2007, page 4309-4311 (2007)

## Results from a Test Fixture for Button BPM Trapped Mode Measurements

P. Cameron, B. Bacha, A. Blednykh, I. Pinayev, O. Singh (BNL)

Three-dimensional electromagnetic simulations have suggested a variety of measures to mitigate the problem of button BPM trapped mode heating. A test fixture, using a combination of commercial-off-the-shelf and custom machined components, was assembled to validate the simulations. We present details of the fixture design, measurement results, and a comparison of the results with the simulations.

## Comparative Study of Button BPM Trapped Mode Heating

P. Cameron, O. Singh (BNL)

The outer circumference of a BPM button and the inner circumference of the button housing comprise a transmission line. This transmission line typically presents an impedance of a few tens of ohms to the beam, and couples very weakly to the 50  $\Omega$  coaxial transmission line that comprises the signal path out of the button. The modes which are consequently excited and trapped often have quality factors of several hundred, permitting resonant excitation by the beam. The combination of short bunches and high currents found in modern light sources and colliders can result in the deposition of tens of watts of power in the buttons. The resulting thermal distortion is potentially problematic for maintaining high precision beam position stability, and in the extreme case can result in mechanical damage. We present here a simple algorithm that uses the input parameters of beam current, bunch length, button diameter, beampipe aperture, and fill pattern to calculate a figure-of-merit for button heating. Data for many of the world's light sources and colliders is compiled in a table.



### Matrix Solution of Coupling Impedance in Multi-Layer Circular Cylindrical Structures

Continuing interest in computing the coupling impedance of cylindrical multi-layer beam tubes led to several recent publications. A novel matrix method is here presented in which radial wave propagation is treated in analogy to longitudinal transmission lines. Starting from the Maxwell equations the solutions for monopole and dipole electromagnetic fields are in each layer described respectively by a  $2 \times 2$  and  $4 \times 4$  matrix. Assuming isotropic material properties within one layer, the radially transverse field components at the inner boundary of a layer are uniquely determined by matrix transfer of the field components at its outer boundary. By imposing power flow constraints on the matrix, field matching between layers is enforced and replaced by matrix multiplication. The wall impedance is found as eigen solution to the scalar Helmholtz equation with the additional boundary condition that the longitudinal magnetic field vanishes at the inner beam tube wall. The matrix method is demonstrated via the example of the longitudinal impedance of a multi-layer HOM absorber, involving a ceramic tube with metal coating and an external ferrite layer.

H. Hahn (BNL)

TH5PFP082

### Eddy Current Shielding by Electrically Thick Vacuum Chambers

We investigate AC response of accelerator vacuum chambers to external magnetic field, when the wall thickness is comparable or greater than the skin depth. Good agreement was established between experimental measurements, analytical modeling, and ANSYS simulations. Based on the results we suggest a transfer function model for electrically thick vacuum chambers with arbitrary transverse cross-section.

B. Podobedov, L. Ecker, D. A. Harder, G. Rakowsky (BNL)

TH5PFP083

### Computation of Resistive Wakefields for Collimators

A technique has been developed which enables the calculation of resistive particle wake effects. The technique can simply be calculated to any order, and is easy and quick to evaluate. No assumptions are made about the range of the interaction, but this is especially useful for short range effects. We show how the exact evaluation compares with various common approximations for some simple cases, and implement the technique in the Merlin and PLACET simulation programs. The extension from cylindrical to rectangular apertures is highlighted.

R. J. Barlow, A. M. Toader (UMAN)

TH5PFP084

### Exact CSR Wakes for the 1-D Model

The forces from Coherent Synchrotron Radiation (CSR) on the particle bunch itself can be computed exactly for a line charge. Modeling a finite bunch by a line charge often produces a very good model of the CSR forces, and the full bunch can then be propagated under these forces. This 1-D model of CSR has often been used with a small angle approximation, an ultra relativistic approximation, and the approximation that radiation originating in one dipole can be neglected in the next dipole. Here we use Jefimenko's forms of Maxwell's equations, without such approximations, to calculate the wake-fields due to the longitudinal CSR force in multiple bends and drifts. Several interesting

C. E. Mayes, G. H. Hoffstaetter (CLASSE)

TH5PFP085

observations are presented, including multiple bend effects, shielding by conducting parallel plates, and bunch compression.

### About Non Resonant Perturbation Field Measurement in Standing Wave Cavities

A. Mostacci, L. Palumbo (Rome University La Sapienza) D. Alesini, L. Ficcadenti, B. Spataro (INFN/LNF)

We discuss the use of non resonant bead pull technique for measuring fields in standing wave accelerating structures. From the Steele perturbation theory, one can derive

the relation between the magnitude and phase of the field in the cavity and the complex reflection coefficient. The effect of the bead size, the calibration of the bead and the comparison with the more common resonant techniques are addressed. As an example, we discuss the measurement on a X-band bi-periodic cavity proposed for linearizing emittance at the Frascati photo-injector SPARC.

### CSR Impedance due to a Bend Magnet of Finite Length with a Vacuum Chamber of Arbitrary Cross Section

G. V. Stupakov (SLAC) I. A. Kotelnikov (BINP SB RAS)

We study the impedance due to coherent synchrotron radiation (CSR) generated by a short bunch of charged particles passing

through a bend magnet of finite length in a vacuum chamber of a given cross section. Our method represents a further development of the previous papers\*. In this method we decompose the electromagnetic field of the beam into the eigenmodes of the toroidal chamber. We derive a system of equations for the expansion coefficients in the series, and develop a numerical algorithm for practical calculations. We illustrate our general method by calculating the CSR impedance of a beam moving in a vacuum chamber of rectangular cross section.

\*G. V. Stupakov and I. A. Kotelnikov, PRST-AB 6, 034401 (2003); T. Agoh, K. Yokoya, PRST-AB, 7, 054403 (2004)

### HOM Sensitivity in the PEP-II HER Vacuum Chamber

S. P. Weathersby, A. Novokhatski, M. K. Sullivan (SLAC)

Synchrotron radiation is the main source of heating in the PEP-II storage ring collider.

This heating is reduced substantially in the

ring as lattice energy is lowered. When beam energy was lowered in the PEP-II High Energy Ring (HER) during an energy scan, temperatures at particular locations rose in response. We observe unexpected temperature rise correlating with bunch length, which decreases when HER lattice energy is lowered. Bunch length measurements confirm this energy correlation. In this case temperature rise clearly identify HOM sensitive beam chamber elements. Reduction of gap voltage helps to reduce this heating

### Trapped Mode Study in the LHC Rotatable Collimator

L. Xiao, C.-K. Ng, J. C. Smith (SLAC) F. Caspers (CERN)

A rotatable collimator is proposed for the LHC phase II collimation upgrade. When

the beam crosses the collimator, trapped

modes will be excited that result in beam energy loss and collimator power dissipation. Some of the trapped modes can also generate transverse kick on the beam and affect the beam operation. In this paper the parallel

eigensolver code Omega3P is used to search for all the trapped modes below 2GHz in the collimator, including longitudinal modes and transverse modes. The loss factors and kick factors of the trapped modes are calculated as function of the jaw positions. The amplitude ratio between transverse and longitudinal trapped mode intensity can be used as a direct measure of the position of the beam. We present simulation results and discuss the results.

### Fringe Field Properties in Magnets with Multipole or Mid-Plane Symmetry

The design of an accelerator with a large energy acceptance requires careful consideration of fringe-field effects\*. This applies particularly to the design of fixed-field alternating gradient (FFAG) accelerators. We consider magnets in straight and curved geometries, and with multipole or mid-plane symmetries. The longitudinal magnet profiles we consider include a simple hyperbolic tangent and a more realistic six-parameter Enge function. We show that when the fields are modeled using power series expansions in a transverse parameter, the domain of convergence is determined by the fringe-field decay length. We also demonstrate the use of these models in the tracking code PTC\*\*.

G. I. Bell, D. T. Abell (Tech-X)

\*M. Berz, B. Erdelyi, and K. Makino, "Fringe field effects in small rings of large acceptance", PRSTAB 3, 124001, 2000

\*\*E. Forest, Y. Nogiwa, F. Schmidt, "The FPP and PTC Libraries", ICAP'2006

### Comparison of Analytical and Numerical Results for Broadband Coupling Impedance

Beam coupling impedances have been identified as an appropriate quantity to describe collective instabilities caused through beam-induced fields in heavy ion synchrotron accelerators such as the SIS-18 at the planned SIS-100 at the GSI facility. The impedance contributions caused by the multiple types of beamline components need to be determined to serve as input condition for later stability studies. This paper will present an approach exploiting the abilities of commercial FDTD wake codes such as CST PARTICLE STUDIO® for a benchmark problem with cylindrical geometry. Since exact analytical formulae are available, the obtained numerical results will be compared. Special attention is paid towards the representation of the particle beam as the source of the EM fields and conductive losses.

L. Haenichen, W. F.O. Muller, T. Weiland (TEMF, TU Darmstadt)  
A. M. Al-Khateeb, O. Boine-Frankenheim (GSI)

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### Five Cell Method of Tuning of Biperiodic Linear Standing Wave $\pi/2$ Accelerating Structures

The five parameter method of tuning of biperiodic  $\pi/2$  linear accelerating structure is presented. The method consists in analytical calculation of the five parameters determining the dispersion relation of such structure: two eigen frequencies  $f_a$  and  $f_c$  of accelerating and coupling cavities, the first coupling coefficient  $k_{ac}$  and two second coupling coefficients  $k_{aa}$  and  $k_{cc}$ , using five measured dispersion frequencies. Usually the process of tuning is based on sets of 3 cavities however, to include directly also the second coupling coefficients  $k_{aa}$  and  $k_{cc}$ , one should consider sets composed of five cells. For each such set, using the dispersion relation, a set of five equations for five unknowns is solved by successive elimination of unknowns by expressing them in terms of  $F_a = f_a / f_{\pi/2}$ . For  $F_a$  one obtains biquadratic equation. Coefficients of

E. Plawski, S. Kulinski, M. Wojciechowski (The Andrzej Soltan Institute for Nuclear Studies, Centre Swierk)

usually the process of tuning is based on sets of 3 cavities however, to include directly also the second coupling coefficients  $k_{aa}$  and  $k_{cc}$ , one should consider sets composed of five cells. For each such set, using the dispersion relation, a set of five equations for five unknowns is solved by successive elimination of unknowns by expressing them in terms of  $F_a = f_a / f_{\pi/2}$ . For  $F_a$  one obtains biquadratic equation. Coefficients of

this equation are expressed as functions of measured quantities: dispersion phases and frequencies. Knowing  $f_a$  all other parameters are easily calculated and the Stop Band  $SB = f_a - f_c$ . In this way, on each step of building up the structure one can control precision of measurements and the Stop Band.

### Benchmarking Different Electromagnetic Codes for the High Frequency Calculation Using a Spherical Cavity

K. Tian, G. Cheng, F. Marhauser, H. Wang (JLAB)

Numerical electromagnetic (EM) simulation codes play a very important role in the particle accelerator community for designing RF cavities and solving advanced problems in the accelerator operation. In this study, we present benchmarking results for high-class commercial 3D EM codes in designing RF cavities today. These codes include Omega3P, CST Microwave Studio, Ansoft HFSS, and ANSYS. - A spherical cavity with a radius of 0.1 m is selected as the benchmark model due to its availability of analytical solutions and its truly curved boundary in the 3D space. We have maintained the same conditions for geometry, mesh sizes and computing hardware so that the results from different codes are comparable. We have compared not only the accuracy of resonant frequencies, but also that of surface EM fields, which are critical for superconducting RF cavities. By removing degenerated modes, we calculate all the resonant modes up to 10 GHz with the same mesh density, so that the geometry approximation and field interpolation error related to the wavelength can be observed.

### Beam Diagnostics with RF Deflecting Cavity in Tsinghua Thomson Scattering X-Ray Source

J. Shi, H. Chen, Y.-C. Du, W.-H. Huang, R. K. Li, C.-X. Tang (TUB)  
D. Li (LBNL)

Photocathode RF gun has been built at Tsinghua University for the Thomson Scattering X-ray Source. Preliminary experiments on this RF gun include characterizing this equipment and using the beam for a well-designed electron diffraction experiment. An RF deflecting cavity was inserted into the beam-line for bunch length measurement. This paper presents the design and fabrication of this deflecting cavity, as well as the set-up and the result of the diagnostics of bunch length.

### Numerical Simulation Design of Collinear Load of S-Band LINAC

Y. Sun, M. J. Li, L. G. Shen, Z. Shu, X. C. Wang (USTC/PMPI)  
Y. J. Pei (USTC/NSRL)

A collinear load which connects the end of accelerator section, with microwave-absorbing materials spraying inside, is adopted to absorb the remnant RF power of LINAC. Compared to waveguide load, it avoids beam transverse excitation, damps high order modes and don't need an output coupler, so that the focusing coil assemble easily and makes the accelerator compact. The power attenuation of materials is concerned with frequency,  $\epsilon$ ,  $\mu$  and coating thickness  $d$ . The influences of the parameters were analyzed by numerical calculation. Furthermore, the optimum  $d$  at 2856MHz (S-band) is acquired, which is applying the determined electromagnetic parameters of FeSiAl alloy, which is employed here. According to some requires:  $VSWR \leq 1.05$ , one-way attenuation should  $\geq 16$ db and so on, a tactics, such as the attenuation constant  $\alpha$  increased as index along the load is adopted, so that loss power on each cavity is equal. Taking advantage of Microwave Studio-Code T-Solver, the coating spraying scheme is optimized, the factor  $Q$ ,  $\alpha$  and the loss power distributed along 3D coordinates of the structure are calculated. They provide reliable data for collinear load design.

## TH5RF — Morning Poster INSTRUM T03, T17, T18, T24

### Development of Metamaterials for Cherenkov Radiation Based Particle Detectors

Metamaterials (MTMs) are periodic artificially constructed electromagnetic structures. The periodicity of the MTM is much smaller than the wavelength of the radiation being transported. With this condition satisfied, MTMs can be assigned an effective permittivity and permeability. Areas of possible application of MTMs in accelerator science are Cherenkov detectors and wakefield devices. MTMs can be designed to be anisotropic and dispersive. The combination of engineered anisotropy and dispersion can produce a Cherenkov radiation spectrum with a different dependence on particle energy than conventional materials. This can be a basis for novel non-invasive beam energy measurements. We report on progress in the development of these media for a proof-of-principle demonstration of a metamaterial-based beam diagnostic.

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TH5RFP001

### Simulations of the Beam Loss Monitor System for the LCLS Undulator Beamline

Simulations of the beam loss monitor (BLM) system built at the Advanced Photon Source (APS) for the Linear Coherent Light Source (LCLS) have been carried out using the Monte Carlo particle tracking code MARS. Cherenkov radiation generated by fast electrons in the quartz radiator of the BLM produces the signal used to estimate beam loss and dose in the LCLS undulator magnets. The calibration of the BLM signal with radiation components that cause undulator damage is the goal of the simulation effort. Beam loss has been simulated for several scenarios including undulator magnets in the normal operating position, "rolled-out" 80 mm from the beamline, and absent altogether. Beam loss is generated when an electron bunch strikes one of two targets: Al foil or carbon wire. In the former case, the foil is placed at OTR33, 85.8 m upstream of the FEL; in the latter, the first undulator beam finder wire (BFW01) position is used just upstream of the first magnet. The LCLS MARS model includes quadrupole focusing between OTR33 and the end of the FEL. The FODO lattice leads to complex loss patterns in the undulators consistent with betatron envelope maximums in both transverse planes.

**J. C. Dooling**, W. Berg, A. Pietryla, B. X. Yang (ANL) H.-D. Nuhn (SLAC)

TH5RFP002

### Development of a Fiber-Optic Beam Loss Position Monitor for the Advanced Photon Source Storage Ring

An array of fused-silica, fiber optic bundles has been built to spatially monitor e-beam loss in the APS storage ring (SR). A prototype beam loss position monitor (BLPM) has been installed on unoccupied undulator straight sections. The BLPM allows for 6 fiber bundles, 3 above and 3 below the beam. The center bundles are aligned with the beam axis. Presently, 4 bundles are used, 3 above and one in the center position below the beam. Each bundle is 3 m in length and composed of 61 220-micron-diameter fibers for a total aperture of 2 mm. The first 30 cm of each bundle are

**J. C. Dooling**, W. Berg, L. Emery, B. X. Yang (ANL)

TH5RFP003

aligned parallel to the beam in contact with the vacuum chamber. Light generated by fast electrons within the fibers is thought to come primarily from Cerenkov radiation. The rest of the fiber acts as a light pipe to transmit photons to shielded PMTs. Tests show good signal strength during stored-beam mode from Touschek scattering and deterministic losses that occur during top-up injection and beam dumps. Post-injection loss signals show spatial and temporal dynamics. Simulation work is expected to provide calibration for integrated losses that can be compared with progressive undulator demagnetization.

### TH5RFP004 First Full-Sector Closed-Loop Operational Experience for the FPGA-Based Broadband Beam Position Monitor at the APS

W. E. Norum, H. Bui, G. Decker, L. Emery, R. Laird, F. Lenkszus, R. M. Lill, H. Shang (ANL)

The Advanced Photon Source (APS), a third-generation synchrotron light source, has been in operation for eleven years. The monopulse radio frequency (rf) beam position monitor (BPM) is one of three BPM types now employed in the storage ring at the APS. It is a broadband (10 MHz) system designed to measure single-turn and multi-turn beam positions, but it suffers from an aging data acquisition system. The replacement BPM system retains the existing monopulse receivers and replaces the data acquisition system with high-speed analog-to-digital converters (ADCs) and a field-programmable gate array (FPGA) that performs the signal processing. The new system has been installed and commissioned in a full sector of the APS. This paper presents the results of testing of the beam position monitor which is now fully integrated into the storage ring orbit control and fast feedback systems.

### TH5RFP005 Measurement of the 4D Transverse Phase Space Distribution from an RF Photoinjector at the AWA

J. G. Power, M. E. Conde, W. Gai, F. Gao, W. Liu, Z. M. Yusof (ANL) P. Piot (Northern Illinois University)

Phase space measurements of RF photoinjectors have usually been done with multislit masks or scanning slits. These systems implicitly ignore the correlations between the X and Y planes and thus yield measurements of the projected 2D phase space distributions. In contrast, a grid-patterned pepper-pot is capable of measuring the full 4D transverse phase space distribution,  $f(x,x',y,y')$ . 4D measurements allow precise tuning of electron beams with large canonical angular momentum, important for electron cooling and flat beam transformation, as well as zeroing the magnetic field on the photocathode is zero for ultra low emittance applications (e.g. SASE FEL, ERL FEL). In this talk, we report on a parametric set of measurements to characterize the 4D transverse phase space of the 1 nC electron beam from the Argonne Wakefield Accelerator (AWA) RF photoinjector. The diagnostic is simulated with TStep, including the passage of the electron beam through the mask and tracking of the beamlets to the imaging screen. The phase space retrieval algorithm is then benchmarked against simulations and measurements.

### TH5RFP006 Bunch Current and Phase Detection for the APS PAR

C. Yao, W. E. Norum (ANL)

The Advanced Photon Source (APS) injector consists of a linac, a particle accumulator ring (PAR), and a booster synchrotron (booster). The PAR accumulates multiple linac bunches and compresses them into a single bunch for booster injection. Beam energy in the PAR is 325 MeV. Due to its low energy and relatively strong beam-loading effect, beam

charge and phase (or timing ) monitoring is critical to the stable operations of rf control loops. We implemented a monitor system with an FPGA processor, which provides both current monitor and stripline fast waveforms. The system provides a bunch charge reading with a data rate of up to 1 MHz and a beam phase resolution of 200 ps, which are sufficient for the rf phase control loops. The system is currently used for beam tuning and diagnostics during normal operation. We are planning to build an upgraded version with fast data output and included it in the new rf control loops. We present a description of the system and the measurement results.

### Tune Measurement System Upgrade with FPGA-Based Technology at the APS

The Advanced Photon Source (APS) has three circular machines: a 7-GeV electron storage ring (SR), a booster synchrotron (booster) of beam energy 325 MeV to 7 GeV, and a particle accumulator ring (PAR). Their tune measurement systems are based on HP 4396 network and spectrum analyzers (NASA) and HP 89400 vector spectrum analyzers (VSA). The instruments are no longer supported by the vendor and will need replacement in the future. An upgrade of these systems with FPGA-based processors has been implemented. The new systems provided faster tune history and bunch-by-bunch tune reading in addition to the original systems. We present a brief description of the implementation and performance of the new systems.

C. Yao, W. E. Norum, J. Wang (ANL)

TH5RFP007

### Upgrade of the Beam Position Monitors at the Brazilian Synchrotron Light Source

We describe the development of a new button-type beam position monitor (BPM) for the Brazilian Synchrotron Light Source (LNLS) electron storage ring. One third of the storage ring stripline BPMs were replaced with this new model, which counts on bellows, temperature stabilization and new support stands in order to achieve improved mechanical stability. Finally, in-vacuum heat absorbers were installed at the upstream vacuum tubes of the bending magnets to minimize the vacuum chamber motion due to the high thermal load. We also present performance results.

S. R. Marques, O. R. Bagnato, R. H.A. Farias, F. R. Francisco, R. T. Neuenschwander, F. Rodrigues, A. L. Rosa, R. M. Seraphim, P. F. Tavares, M. M. Xavier (LNLS)

TH5RFP008

### LNLS Experience with Libera Brilliance

This paper reports on the LNLS experience with the digital electron beam position monitor Libera Brilliance through the realization of several standard accelerator physics experiments, taking advantage mainly of the equipment's turn-by-turn capabilities.

L. Sanfelici, S. R. Marques, X. R. Resende (LNLS) K. Raizer (UNICAMP)

TH5RFP009

### Automating the Tune Measurement in the LNLS Control System

As part of our efforts to improve beam stability in LNLS light source, we developed a system for automating tune measurements in the storage ring. This system is based on a commercial spectrum analyzer controlled via a GPIB port fed by a

M. M. Xavier, S. R. Marques, A. F.A. G. Moreira (LNLS)

TH5RFP010

difference signal from a stripline pickup. Following a tandem-like approach, the software is divided in two parts: one inside the main operation software in the control system, which sends commands, and another one designed for receiving these commands and to suitably manage the analyzer. The system is capable of setting the analyzer for optimal measurements for almost all operating conditions of the machine. This is achieved through feedback algorithms and triggered events. This tool improves machine diagnostics during failure conditions such as undesired magnet changes and is fast enough to enable tune tracking during particular events, such as ID movements and energy ramps.

### BPM Button Mechanical Optimization to Minimize Distortion due to Trapped Mode Heating

P. Cameron, B. N. Kosciuk, V. Ravindranath, O. Singh (BNL)

The thermal distortion resulting from BPM button trapped mode heating is potentially problematic for achieving the high precision beam position measurement needed to provide the sub-micron beam position stability required by light source users. We present a button design that has been thermo-mechanically optimized via material selection and component geometry to minimize this thermal distortion. Detailed electromagnetic analysis of the button geometry is presented elsewhere in these proceedings.

The thermal distortion resulting from BPM button trapped mode heating is potentially problematic for achieving the high precision

### Development of High Stability Supports for NSLS-II RF BPMs

B. N. Kosciuk, R. Alforque, P. Cameron, I. Pinayev, S. Sharma, O. Singh (BNL)

The NSLS-II Light Source being built at Brookhaven National Laboratory is expected to provide submicron stability of the electron orbit in the storage ring in order to utilize fully the very small emittances and electron beam sizes. This requires high stability supports for BPM pick-up electrodes, located near insertion device source. Description of the efforts for development of supports including carbon tubes and invar rods is presented.

The NSLS-II Light Source being built at Brookhaven National Laboratory is expected to provide submicron stability of the electron orbit in the storage ring in order to utilize

### RHIC BPM System Average Orbit Calculations

R. J. Michnoff, P. Cerniglia, C. Degen, R. L. Hulsart, M. G. Minty, R. H. Olsen, T. Roser, T. Satogata (BNL)

RHIC BPM system average orbit was originally calculated by averaging positions of 10000 consecutive turns for a single selected bunch. Known perturbations in RHIC particle trajectories, with multiple frequencies around 10 Hz, contribute to observed average orbit fluctuations. In 2006, the number of turns for average orbit calculations was made programmable; this was used to explore averaging over single periods near 10 Hz. Although this has provided an average orbit signal quality improvement, an average over many periods would further improve the accuracy of the measured closed orbit. A new continuous average orbit calculation is currently under development and planned for use in the 2009 RHIC run. This paper will discuss the algorithm, performance with a simulated beam signal, and beam measurements.

RHIC BPM system average orbit was originally calculated by averaging positions of 10000 consecutive turns for a single selected bunch. Known perturbations in RHIC particle



### Evaluation of Heat Dissipation in the BPM Buttons

With growth of circulating current in the storage rings the heating of the beam position monitor (BPM) buttons due to the induced trapped modes is drastically increasing. Excessive heating can lead to the errors in the measuring of beam position or even catastrophic failures of pick-up assembly. In this paper we present calculations of heat generated in the button for different geometries and materials. The obtained results are used for the optimization of the BPM design for the NSLS-II project.

I. Pinayev, A. Blednykh (BNL)

TH5RF014

### Preliminary Design of Pinhole Cameras for NSLS-II Project

The NSLS-II Light Source being built at Brookhaven National Laboratory is expected to provide very small emittances and electron beam sizes. High resolution imaging systems are required in order to provide robust measurements. The pinhole cameras will utilize 5-fold magnification with a pinhole placed inside a crotch absorber. The pinhole is protected from high power synchrotron radiation with a filter made of refractory metal. In this paper we provide resolution analyses, heat load calculations, and optimization of NSLS-II pinhole cameras including beamline design.

I. Pinayev, O. V. Chubar, V. Ravindranath, O. Singh (BNL)

TH5RF015

### Comparison of RF BPM Receivers for NSLS-II Project

The NSLS-II Light Source being built at Brookhaven National Laboratory requires submicron stability of the electron orbit in the storage ring in order to utilize fully very small emittances and electron beam sizes. This sets high stability requirements for beam position monitors and a program has been initiated for the purpose of characterizing RF beam position monitor (BPM) receivers in use at other light sources. Present state-of-the-art performance will be contrasted with more recently available technologies. The details of the program and preliminary results are presented.

I. Pinayev, B. Bacha, A. J. Della Penna, O. Singh (BNL) G. Decker (ANL)

TH5RF016

### Grad-Level Proton and Neutron Radiation Damage of SiO<sub>2</sub> Detectors

SiO<sub>2</sub> quartz fibers of the LHC ATLAS 0-degree calorimeter (ZDC) anticipated to experience integrated doses of a few Grad at their closest position were exposed to 200 MeV protons and neutrons at the BNL Linac. Specifically, 1mm- and 2mm- diameter quartz (GE 124) rods were exposed to direct 200 MeV protons during the first phase of exposure leading to peak integrated dose of ~28 Grad. Exposure to a primarily neutron flux of 1mm-diameter SiO<sub>2</sub> fibers was also achieved with a special neutron source arrangement. In a post-irradiation analysis the quartz fiber transmittance was evaluated as a function of the absorbed dose. Dramatic degradation of the transmittance property was observed with increased radiation damage. In addition, detailed evaluation of the fibers under the microscope revealed interesting micro-structural damage features and irradiation-induced defects. This paper presents the results of the irradiation damage study.

N. Simos, G. Atoian, J. G. O'Connor (BNL)

TH5RF017

**Effects of High Proton Fluences on CdZnTe Detectors**

N. Simos, A. Aronson, A. E. Bolotnikov, R. James, H. Ludewig (BNL)

Brookhaven National Laboratory LINAC were used to bombard a set of CdZnTe detector crystals to fluences as high as  $2.6 \times 10^{16}$  protons/cm<sup>2</sup>. Following exposure a set of past-irradiation analyses were conducted to quantify the effects. These include (a) gamma-ray spectra analysis using a high-purity germanium detector in an effort to assess both the peak position shifting as a function of fluence and the spectral content, (a) resistivity and leakage current measurements, and (c) manifestation of radiation damage in the crystal microstructure. In addition, and based on the irradiation parameters used, a numerical prediction model was formulated aiming to benchmark the observed isotopes.

The effects of high fluences of energetic charged particles on CdZnTe detectors have been studied and are reported in this paper. Specifically, 200 MeV protons of the

**Optical Beam Profile Monitor at the RHIC Polarized Hydrogen Jet**

T. Tsang, S. Bellavia, R. Connolly, D. M. Gassner, Y. Makdisi, T. Russo, P. Thieberger, D. Trbojevic, A. Zelenski (BNL)

files in the vertical plane are obtained as well as measurements of the width of the gas jet in the beam direction. For gold ion beams, the fluorescence cross section is sufficiently large so that profiles can be obtained from the residual gas alone, albeit with long light integration times and lower number of Au ions than protons. We estimate the fluorescence cross-section of 100 GeV protons and Au ions on hydrogen gas to be  $6.6 \times 10^{-21}$  cm<sup>2</sup>  $\sim 1.7 \times 10^{-16}$  cm<sup>2</sup>, respectively\*. We calculate the beam emittance to provide an independent measurement of the RHIC beam. This optical beam diagnostic technique, utilizing the beam induced fluorescence from injected or residual gas, represents a step towards the realization of a simple and truly noninvasive beam monitor for high-energy particle beams together with a wall-current-monitor system and/or a low light level optical temporal measurement system, a 3-dimensional particle beam profile system can be envisioned providing routine diagnosis of high-energy particle beams.

A gas fluorescence beam profile monitor has been realized at the relativistic heavy ion collider (RHIC) using the polarized atomic hydrogen gas jet. RHIC proton beam pro-

\*T. Tsang, et. al., Rev. Sci. Instrum. 79, 10510<sup>3</sup> (2008).

**Beam Emittance Measurements in RHIC**

A. Zelenski (BNL)

Coulomb Nuclear Interference region. Polarimeter operation in the scanning mode gives polarization profiles and beam intensity profile measurements. This polarimeter is an ideal wire-scanner due to: extremely good signal/noise ratio and high counting rate, which allows accurate bunch by bunch emittance measurements during 100 ms time of the beam crossing. The measurements of the beam emittance in both vertical and horizontal planes will be possible after polarimeter upgrade for the 2009 polarized run. Two new vacuum chambers and two target motion mechanisms and detectors assembly will be installed in each ring. One polarimeter can be used for the vertical polarization and intensity profile measurements and the second can be used for the horizontal profile measurements. The absolute accuracy limitations and cross-calibration of different techniques will be also discussed.

The proton polarization measurements in AGS and RHIC are based on proton-carbon and proton-proton elastic scattering in the

### Beam Phase Monitor System Design for 100MeV Cyclotron

The beam phase monitor was designed to address phase slide issue, which can lead to significant beam loss inside 100MeV cyclotron. The measured phase information can be used to direct cyclotron magnetic field fine tuning. The system describes in this paper consists of the following part: 10 sets of beam phase pickup, a phase detector, a set of RF multiplexer and a phase shifter to compensate different phase offset generated by cables, connectors etc. The last one is a computer interface consisting of two 16 bits AD converters, one ARM 7 processor was included in this module to support RS232 connection and perform necessary signal process. All parts except the probe were located in one 3U VME standard crate, 8 slots were occupied and one user defined backplane was developed to carry necessary power supply lines and interconnections. Preliminary tests for the electronic system has been performed, and a good result was obtained in the procedure. Yet the leakage from RF cavity in the 100MeV cyclotron is still an undermined limitation for this application.

Z. G. Yin, F. P. Guan, S. G. Hou, B. Ji, Z. G. Li, L. P. Wen, H. D. Xie, T. J. Zhang (CIAE)

TH5RF021

### Ionization Beam Profile Monitor Designed for CSNS

An IPM system employs electrons or ions formed by beam ionization of residual gas, swept by a uniform electric field, amplified by a MCP and finally collected by a circuit board with strip anodes to get beam profiles. A set of IPM system will be built on RCS of CSNS to measure vertical and horizontal beam profiles. Detailed conceptual design of an IPM system for CSNS is described in this paper. Wire electrodes are introduced to get a more uniform electric field, and a 'C' type electromagnet is designed to exert a uniform magnetic field to the ionization area, which is parallel with the sweeping electric field and will inhibit the defocusing effects of space charge and recoil momentum.

Y. F. Zhang, S. Fu, T. G. Xu (IHEP Beijing)

TH5RF022

### Commissioning of the Probe Beam Linac for CTF3

We report the first results of the commissioning of the Linac that will provide a probe beam to the 2 beams test stand of the CTF3. This accelerator is based on a photo-injector gun driven by a laser system and on 3 accelerating structures, the first one being used for velocity bunching. A complete set of diagnostics (beam charge monitor, screens, beam position monitors, analysis dipole and deflecting cavity) is used to tune the accelerator to the nominal performances (200 MeV, 0.5 nC per bunch, 0.75ps bunch length, >20 mm.mrad normalised emittance)

W. Farabolini, D. Bogard, A. Curtoni, F. Peauger (CEA) E. Chevalley, M. Petrarca (CERN) R. Roux (LAL)

TH5RF023

### Instrumentation for High Frequency Cavity BPM in CALIFES

The probe beam linac of the CTF3 test facility, named CALIFES, is developed by the CEA Saclay, the LAL Orsay and CERN to deliver short bunches (0.75 ps) with a charge of 0.6 nC to the CLIC 12 GHz accelerating structures. To setup the machine and obtain a precise beam handling, six high resolution beam position monitors (BPMs), based on a radiofrequency reentrant cavity with an aperture of 18 mm, are installed along the linac. The associated electronics

C. Simon, D. Bogard, M. Luong (CEA)

TH5RF024

is composed of an analog signal processing electronics with a multiplexing to control the six monitors. Due to mechanical tolerances, dipole mode frequencies are different for each BPMs, 100 MHz IF frequency is, therefore, used so that monitors operate in single and multi-bunches. Digitalised signals from acquisition boards are made available to the operation crew thanks to the OASIS interfaces. In this paper, the BPMs acquisition and the signal post processing, to extract the beam position, will be discussed and first beam tests will be presented.

### Beam Measurements at the ALBA Linac

U. Iriso, G. Benedetti, A. Olmos (ALBA)

The ALBA Linac is a turn-key system able to produce 4 nC electron beams at 100 MeV beams with a normalized emittance below 30 mm\* $\mu$ rad. Beam position stability below 0.1 mm is measured using new BPM electronics. Thorough analysis are carried out to measure the beam emittance, energy and energy spread. This paper discusses the measurement techniques, analysis method, and results obtained during the Linac commissioning.

### X-Ray Beam Size Monitor Upgrade for CesrTA

J. P. Alexander, W. H. Hopkins, B. Kreis, H. Liu, M. A. Palmer, D. P. Peterson (CLASSE) C. J. Conolly, E. Fontes, A. Lyndaker, P. Revesz, J. J. Savino, R. D. Seeley (CHESS) J. W. Flanagan (KEK)

We report on the performance goals and design of the CESRTA x-ray beam size monitor (xBSM). The xBSM resolution must be sufficient to measure vertical beam sizes under 20 $\mu$ m. The xBSM images 2--4keV synchrotron radiation photons onto one-dimensional photodiode array. Instrumentation in the dedicated x-ray beam line includes upstream interchangeable optics elements (slits, coded apertures, and Fresnel zone plates), a monochromator and the InGaAs photodiode detector. To provide sufficient x-ray flux in 2 GeV operation, the beam line is evacuated, with only a thin diamond window isolating the detector vacuum from the damping ring. The readout is a beam-synchronized FADC that is sufficient to measure consecutive bunches independently in a 4ns bunch spacing configuration.

### CesrTA X-Ray Beam Size Monitor First Results

J. P. Alexander, W. H. Hopkins, B. Kreis, H. Liu, D. P. Peterson (CLASSE) J. W. Flanagan (KEK)

Engineering data sets were collected with the CESRTA x-ray beam size monitor (xBSM) during November 2008 and January 2009 runs. We report on the performance of the InGaAs photodiode array detector, including time response and signal-to-noise. We report on the observed measurement resolution for changes in the damping ring vertical beam size using the interchangeable optics elements: slits, coded apertures, and a Fresnel zone plates. Observed resolutions are compared to predictions based on characteristics of the optics elements.

### Upgrade of CESR-TA Beam Position Monitor for 4 ns-Spaced Bunches

The beam position monitoring (BPM) system upgrade for the CESR-Test Accelerator project (CESR-TA) is required to monitor the beam position and betatron motion for bunch trains of either electrons or positrons at 4 ns bunch spacing. It must also be configurable to monitor counter-rotating electron and positron trains at 14 ns spacing for synchrotron light source operation for the CHESS facility. In addition to position measurements, the system must also be able to measure betatron phase by synchronous detection of a driven beam for optics diagnosis and correction. This paper describes the characteristics of the BPM hardware upgrade, performance figures of the electronics designed for this purpose and the overall status of the upgrade effort. Examples of key measurement types and the analysis of data acquired from the new instruments will also be presented.

**M. G. Billing**, C. R. Strohman (Cornell University, Department of Physics) R. Meller, M. A. Palmer, M. C. Rendina, N. T. Rider (CLASSE)

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### Design and Implementation of CEsR-TA Super-Conducting Wiggler Beampipes with Thin Retarding Field Analyzers

Wiggler magnets are one of the key components in the ILC Damping Ring. It is critical to the ILCDR GDE to understand electron cloud (EC) growth and patterns, and to develop EC suppression techniques in the wiggler beampipes. The CESR-c superconducting wigglers, closely matching the parameters of the ILCDR wigglers, serve as unique testing vehicles. As part of the CEsR-TA project, we replaced the copper beampipes of two SCWs with EC diagnostic beampipes, where one of the beampipes is uncoated and the second is coated with a thin TiN film. Each of the EC diagnostic beampipes is equipped with three retarding field analyzers (RFAs) at strategic longitudinal locations in the wiggler field. Each of the RFAs has 12-fold segmentation to measure the horizontal EC density distribution. To maintain sufficient vertical beam aperture and to fit within the SCW warm bore, a thin style of RFA (with a thickness of 2.5 mm) has been developed and deployed. These SCWs with RFA-equipped beampipe have been installed and successfully operated in the re-configured CEsR-TA vacuum system. This paper describes the design and the construction of the RFA-equipped SCW beampipes and operational experience.

**Y. Li**, M. G. Billing, S. Greenwald, T. I. O'Connell, M. A. Palmer, J. P. Sikora, E. N. Smith, K. W. Smolenski (CLASSE) J. N. Corlett, R. Kraft, D. V. Munson, D. W. Plate (LBNL) K. Kanazawa, Y. Suetsugu (KEK) M. T.F. Pivi (SLAC)

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### Design, Implementation and First Results of Retarding Field Analyzers Developed for the CEsR-TA Program

A central component of the operation of the Cornell Electron Storage Ring as a Test Accelerator (CESR-TA) for ILC Damping Rings R&D is the characterization of electron cloud growth in each of the principal vacuum chamber types in use in the storage ring. In order to facilitate measurements in chambers with tightly constrained external apertures, retarding field analyzers have been developed that can be deployed in regions with as little as 3mm of available aperture. We report on the design, fabrication, characterization and operation of devices that are presently deployed in CESR drift, dipole, and wiggler chambers.

**M. A. Palmer**, M. G. Billing, J. R. Calvey, G. W. Codner, S. Greenwald, Y. Li, X. Liu, J. A. Livezey, R. Meller, J. P. Sikora, C. R. Strohman, W. S. Whitney, T. Wilksen (CLASSE)

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**Expected Performance of TOTEM BLMs at the LHC**

R. Appleby, R. J. Hall-Wilton, D. Macina, V. Talanov (CERN)

The associated beam loss monitors (BLMs) are crucial to monitor the position of the detectors and to provide a rapid identification of abnormal beam conditions for machine protection purposes. In this paper, the response of the TOTEM BLMs is considered and the protection thresholds are defined, with calculations made of the expected signal from protons grazing the TOTEM pot as a function of pot distance from the beam, and of the BLM signal from proton collisions at the CMS beam interaction point.

The TOTEM experiment at the LHC will operate at down to 10 sigma from the beam in the forward region of the CMS experiment.

**FLUKA Simulations and SPS Measurements for the LHC BRAN**

E. Bravin, S. M. White (CERN)

Depending on the expected level of luminosity for a given IP two different designs have been developed for LHC. At IP1 and IP5, the high luminosity experiments, the BRAN consist of a fast ionization chamber and at IP2 and IP8, where the collision rate will be smaller, they consist of fast polycrystalline-CdTe detectors. A better understanding of the performances of those detectors can be provided by detailed tracking simulations of the collision products coming from the IP within the detector. Here we report about the results of simulations done with FLUKA as well as a comparison with measurements done in the SPS.

The LHC collision rate monitors (BRAN) will be used to monitor and optimize the luminosity at the four interaction points (IP).

**Ringling in the Pulse Response of Long and Wideband Coaxial Transmission Lines due to Group Delay Dispersion**

G. Kotzian, F. Caspers, S. Federmann, W. Höfle (CERN) G. Kotzian (Graz University of Technology (TUG), Signal Processing and Speech Communication Laboratory (SPSC)) R. de Maria (BNL)

In particle accelerators coaxial cables are commonly used to transmit wideband beam signals covering many decades of frequencies over long distances. Those transmission lines often have a corrugated outer and/or inner conductor. This particular construction exhibits a significant amount of frequency dependent group delay variation. A comparison of simulations based on theoretical models and S11 and S21 network analyzer measurements up to 2.5 GHz is presented. It is shown how the non-linear phase response and varying group delay leads to ringing in the pulse response and subsequent distortion of signals transmitted through such coaxial transmission lines.

In particle accelerators coaxial cables are commonly used to transmit wideband beam signals covering many decades of frequencies over long distances. Those transmission lines often have a corrugated outer and/or inner conductor.

**First Experience with the LHC Beam Loss Monitoring System**

B. Dehning (CERN)

The LHC beam loss monitoring system (BLM) consists of about 4000 monitors observing losses at all quadrupole magnets and many other likely loss locations. At the first LHC operation in August and September 2008 all monitors were active and used to observe the losses during the initial beam steerings, at collimators, at the LHC dump and during aperture scans. The different loss patterns will be discussed and compared with the expectations originating

The LHC beam loss monitoring system (BLM) consists of about 4000 monitors observing losses at all quadrupole magnets

from simulations. The observed signals of the BLM system will be analysed in terms of response time, sensitivity cross talk between channels and noise performance.

### Energy Deposition Simulation and Measurements in a LHC Collimator and Beam Loss Monitors

The LHC collimators are protected against beam caused damages by measuring the secondary particle showers with beam loss monitors. Downstream of every collimator an ionisation chamber and a secondary emission monitor are installed to determine the energy deposition in the collimator. The relation between the energy deposition in the beam loss monitor and the collimator jaw is based on secondary shower simulations. To verify the FLUKA simulations the prototype LHC collimator installed in the SPS was equipped with beam loss monitors. The results of the measurements of the direct impact of the 26 GeV proton beam injected in the SPS onto the collimator are compared with the predictions of the FLUKA simulations. In addition simulation results from parameter scans and for mean and peak energy deposition with its dependencies are shown.

**B. Dehning** (CERN)

TH5RFP035

### Beam Condition Monitoring for the CMS Experiment at LHC

The CMS Beam Conditions and Radiation Monitoring System (BRM) is composed of eight different subsystems that perform monitoring of, as well as providing the CMS detector protection from, adverse beam conditions inside and around the CMS experiment. An overview of the design and performance of all of these systems are detailed in this contribution\*. In particular, the results from data taken with the first LHC beams in September 2008 are shown. The Beam Conditions and Monitoring Systems (BCM1 and BCM2) is based on radiation-hard diamond sensor. The BCM system will have a direct input into the LHC beam abort and injection inhibit. The BCM system is directly analogous to the LHC Beam Loss Monitors and is crucial for the safety and protection of CMS. The other BRM subsystems perform primarily a monitoring role, with their complimentary information being used to build up a coherent picture of the beam losses close to CMS. The BCM1F is also based upon diamond sensors, the Beam Scintillator Counters (BSC) are a series of scintillator tiles designed to provide hit and coincidence rates. Both the BCM1F and the BSC provide sub-bunch information on the timing patterns of beam losses.

**R. J. Hall-Wilton** (CERN)

\*On Behalf of the CMS Beam and Radiation Monitoring Group

TH5RFP036

### On the Continuous Measurement of the LHC Beta-Function - Prototype Studies at the SPS

Until now, the continuous monitoring of the LHC lattice has been considered as impractical due to tight constraints on the maximum allowed beam excitations and acquisition time usually required for betatron function measurements. As an further exploitation of the Base-Band-Tune (BBQ) detection principle, already widely used for tune diagnostic, a real-time beta-beat measurement prototype has been successfully tested at the CERN SPS based on the continuous measurement of the cell-to-cell betatron phase advance. Tests show that the phase resolutions is better than a degree corresponding to a peak-to-peak beta-beat resolution of about one percent. Due to the system's high sensitivity it required only micro-metre range

**R. J. Steinhagen**, A. Boccardi, E. Calvo Giraldo, M. Gasior, J. L. Gonzalez, O. R. Jones (CERN)

TH5RFP037

excitation, making it compatible with nominal LHC operation. This contribution discusses results, measurement systematics and possible additional exploitation that may be used to improve the nominal LHC performance.

### Longitudinal Schottky Spectrum of the Peak Bunch Amplitude Signal

E. N. Shaposhnikova, T. Bohl, T. P.R. Linnecar (CERN)

Diagnostic techniques based on the Schottky spectrum of the peak detected signal have been used at CERN for a long time to study the behaviour of bunched beams. In this paper it is shown how the measured spectrum is related to the particle distribution in synchrotron frequency. The experimental set-up used and its limitations are also presented together with examples of beam measurements in the SPS and LHC.

Diagnostic techniques based on the Schottky spectrum of the peak detected signal have been used at CERN for a long time to study

### Precision Beam Position Monitor for EUROTeV

L. Soby, F. Guillot-Vignot (CERN) I. Podadera Aliseda (CIEMAT)

PBPM, based on the inductive BPM presently used in the CERN Clic Test Facility (CTF3), aims to achieve a resolution of 100 nm and an accuracy of  $10\mu\text{m}$  in a 6 mm aperture. A dedicated test bench has been designed and constructed to fully characterize and optimize the PBPM. This paper describes the final design, present the test bench results and reports on the beam tests carried out in the CERN CTF3 Linac.

In the framework of EUROTeV, a Precision Beam Position Monitor (PBPM) has been designed, manufactured and tested. The new

### Resonant-Cavity Diagnostics for an Emittance Exchange Experiment

N. Barov, J. S. Kim, D. J. Newsham (Far-Tech, Inc.)

based beam diagnostics in order to map the transport matrix through the beamline. These will include cavity BPM and time-of-flight diagnostics, as well as quadrupole cavity x-y coupling diagnostics. The measurement system will be designed to fit within compact space requirements, while also maintaining a sufficient clear aperture and sensitivity. The RF design of the system, as well as RF cold-test data for the BPM cavities, is presented.

The emittance exchange experiment planned at the Argonne Wakefield Accelerator facility will rely on a set of cavity-

### An Improved Retarding Field Analyzer for Electron Cloud Studies

C.-Y. Tan, K. L. Duel, R. M. Zwaska (Fermilab)

installed in the Main Injector. From computer simulations and bench measurements, our RFA will have a 20% improvement in sensitivity compared to the Argonne National Laboratory (ANL) design. And when we couple our RFA to the matched rad-hard amplifier, S/N is also improved.

We have designed a retarding field analyzer (RFA) and a rad-hard amplifier which improves the sensitivity over the present RFA



### Bunch Length Monitoring at the A0 Photoinjector Using a Quasi-Optical Schottky Detector

Noninvasive bunch duration monitoring has a crucial importance for modern accelerators intended for short wavelength FEL's, colliders and in some beam dynamics experiments. Monitoring of the bunch compression in the Emittance Exchange Experiment at the A0 Photoinjector was done using a parametric presentation of the bunch duration via Coherent Synchrotron Radiation (CSR) emitted in a dipole magnet and measured with a wide-band quasi-optical Schottky Barrier Detector (SBD). The monitoring resulted in a mapping of the quadrupole parameters allowing a determination of the region of highest compression of the bunch in the sub-picosecond range. The obtained data were compared with those measured using the streak camera. A description of the technique and the results of simulations and measurements are presented and discussed in this report.

**G. M. Kazakevich**, M. A. Davidsaver, H. T. Edwards, R. P. Filler, T. W. Koeth, A. H. Lumpkin, S. Nagaitsev, J. Ruan, R. Thurman-Keup (Fermilab) Y. U. Jeong (KAERI) V. V. Kubarev (BINP SB RAS)

The challenge of mitigating the strong enhancements of the optical transition radiation (OTR) signal observed after bunch compression in the Advanced Photon Source (APS) linac chicane and at the Linac Coherent Light Source (LCLS) has recently been addressed. We have demonstrated a technique to mitigate the intensity of the coherent OTR (COTR) relative to the OTR signals on the APS beams at 325 MeV. Since the previously reported spectral content of the COTR at LCLS after the first compression stage is similar, the concepts should also apply to LCLS. We utilized the stronger violet content at 400 nm of the OTR compared to the observed gain factors of the COTR in the blue to NIR regime. We also demonstrated the use of an LSO:Ce scintillator that emits violet light to support lower-charge imaging. Spectral-dependence measurements of the COTR were done initially at the 325-MeV station using a series of band pass filters inserted before the CCD camera, but recent tests with an Oriel spectrometer with ICCD readout have extended those studies and confirmed the concepts. These techniques are complementary to the proposed use of a laser heater to mitigate the microbunching itself at LCLS.

### Mitigation of COTR due to the Microbunching Instability in Compressed Beams

The challenge of mitigating the strong enhancements of the optical transition radiation (OTR) signal observed after bunch compression in the Advanced Photon Source (APS) linac chicane and at the Linac Coherent Light Source (LCLS) has recently been addressed. We have demonstrated a technique to mitigate the intensity of the coherent OTR (COTR) relative to the OTR signals on the APS beams at 325 MeV. Since the previously reported spectral content of the COTR at LCLS after the first compression stage is similar, the concepts should also apply to LCLS. We utilized the stronger violet content at 400 nm of the OTR compared to the observed gain factors of the COTR in the blue to NIR regime. We also demonstrated the use of an LSO:Ce scintillator that emits violet light to support lower-charge imaging. Spectral-dependence measurements of the COTR were done initially at the 325-MeV station using a series of band pass filters inserted before the CCD camera, but recent tests with an Oriel spectrometer with ICCD readout have extended those studies and confirmed the concepts. These techniques are complementary to the proposed use of a laser heater to mitigate the microbunching itself at LCLS.

**A. H. Lumpkin** (Fermilab) W. Berg, YL. Li, S. J. Pasky, N. Sereno (ANL)

### Observation of Electron Clouds in the ANKA Undulator by Means of the Microwave Transmission Method

A superconducting undulator is installed in the ANKA electron storage ring. Electron clouds could potentially contribute to the heat load of this device. A microwave transmission type electron cloud diagnostic has been installed for the undulator section of the ANKA machine. We present the system layout with particular emphasis on the electron machine aspects. Hardware transfer function results and e-cloud data for different machine settings are discussed. Special care has been taken for front end filter design both on the microwave injection and pick-up side.

**K. G. Sonnad**, I. Birkel, S. Casalbuoni, E. Huttel, E. M. Mashkina, D. Saez de Jauregui, N. J. Smale (FZK) F. Caspers (CERN) A.-S. Muller, **K. G. Sonnad** (University of Karlsruhe) R. Weigel (Max-Planck Institute for Metal Research)

A superconducting undulator is installed in the ANKA electron storage ring. Electron clouds could potentially contribute to the heat load of this device. A microwave transmission type electron cloud diagnostic has been installed for the undulator section of the ANKA machine. We present the system layout with particular emphasis on the electron machine aspects. Hardware transfer function results and e-cloud data for different machine settings are discussed. Special care has been taken for front end filter design both on the microwave injection and pick-up side.

### Accurate Energy Measurement of the Electron Beam at Duke Storage Ring Using Compton Scattering Technique

C. Sun, J. Li, Y. K. Wu (FEL/Duke University) G. Rusev, A. Tonchev (TUNL)

A gamma-ray beam produced by Compton scattering of a laser beam with a relativistic electron beam has been used to measure electron beam parameters. In order to accurately

determine the electron beam energy, a model based upon Compton scattering cross-section has been derived to describe the energy spectrum of the gamma-ray beam. Using this model, we have successfully determined the energy of the electron beam in the Duke storage ring with a relative uncertainty of  $3 \times 10^{-5}$  using a  $\gamma$ -beam from the High Intensity  $\gamma$ -ray Source (HI $\gamma$ S).

### An LTS SQUID-Based High Precision Measurement Tool for Nuclear Physics

W. Vodel, R. Geithner, R. Neubert, P. Seidel (FSU Jena) A. Peters (HIT) M. Schwickert (GSI)

We describe an LTS SQUID-based high precision measurement tool for nuclear physics. This device makes use of the Cryogenic Current Comparator (CCC) principle and is able

to measure e.g. the absolute intensity of a high energy ion beam extracted from a particle accelerator or the so-called dark current, generated by superconductive RF accelerator cavities at high voltage gradients. The CCC mainly consists of a high performance LTS-DC SQUID system, a special toroidal pick-up coil, and a meander-shaped superconductive magnetic ring structure. The design of the CCC requires a thorough knowledge of several noise contributions to achieve a high current resolution. As the SQUID and the pick-up coil are extremely sensitive to external magnetic fields it is necessary to shield both sufficiently against any disturbing field sources. Theoretical investigations showed that with strong attenuation of external noise sources an improvement of the sensor performance is dependent on the ferromagnetic core material imbedded in the pick-up coil. Several materials were investigated and the temperature- and the frequency dependence measured. The current results will be presented and discussed.

### Particle Production in the MICE Beam Line

J. S. Graulich (DPNC)

The MICE experiment aims at demonstrating that the performances of the muon ionization technique are compatible with the

requirements of the neutrino factory and the muon collider. The experiment is running at the Rutherford-Appleton Laboratory in the UK using the ISIS proton beam on a dynamic target as a muon source. Brand new target system and muon beam line have been designed, built and installed during the last two years. On the other hand, particle identification detectors needed for the experiment have also been installed and commissioned. This presentation describes how we made use of Time of Flight detectors, aerogel Cherenkov counters and electro-magnetic calorimeter sensors to characterize the content of the MICE beam between 100 and 480 MeV/c.

### Performance of Coded Aperture X-Ray Optics with Low Emittance Beam at CsrTA

We are working on the development of a high-speed x-ray beam profile monitor for high-resolution and fast response for beam profile measurements to be used at CsrTA

**J. W. Flanagan**, H. Fukuma, H. Ikeda (KEK) J. P. Alexander, M. A. Palmer (CLASSE) G. S. Varner (UH)

and SuperKEKB\*. The optics for the monitor are based on a technique borrowed from x-ray astronomy, coded-aperture imaging, which should permit broad-spectrum, low-distortion measurements to maximize the observable photon flux per bunch. Coupled with a high-speed digitizer system, the goal is to make turn-by-turn, bunch-by-bunch beam profile measurements. Following initial tests with a low-resolution mask at large beam sizes (vertical size ~200  $\mu\text{m}$ ), a high-resolution mask has been made for use with low-emittance beams (vertical size ~10  $\mu\text{m}$ ) at CsrTA. The first performance results of the high-resolution mask on the low-emittance CsrTA beam are presented. \*J. W. Flanagan et al., Proc. EPAC08, Genoa, 1029 (2008).

TH5RFP048

### Real-Time Measurement System of Longitudinal Structure of Electron Bunch

It is important issue to stably provide a sub-millimeter electron bunch at the next generation light source, such as Energy Recovery Linac. It is well known that the quality of the short electron bunch is deteriorated by the coherent synchrotron radiation (CSR) emitted by itself. The effect depends on the longitudinal structure of the electron bunch. To suppress the effect, a measurement of the longitudinal structure bunch by bunch is effective. We proposed a real-time measurement system utilizing the CSR at the terahertz region. The measurement system enable us to resolve bunch by bunch information and monitor them in real-time.

**M. Shimada**, K. Harada, Y. Kobayashi, T. M. Mitsuhashi, T. Miyajima, T. Uchiyama (KEK)

TH5RFP049

### Measurements of Proton Beam Extinction of J-PARC MR Synchrotron

Proton beam extinction, defined as a ratio of the residual and the pulse beam intensity, should be less than  $10^{-9}$ , which is one of

**K. Yoshimura** (KEK) M. Aoki (Osaka University)

the key requirements to realize the future muon electron conversion experiment (COMET) proposed at J-PARC. Measurement of the pulse timing structure with enough sensitivity is the first step to achieve the required extinction level. We have developed two methods for the measurements; one by using fast-extracted beam and the other by using slow-resonant-extracted beam. This paper describes the schemes and the results of the measurements\*. These measurements would provide important information on the beam pulse structure to understand not only for MR beam but also the whole accelerator complex, including LINAC and booster RCS.

\*Submitted on behalf of the muon working group

TH5RFP050

TH5RFP051

**A Laser-Based Beam Profile Measuring Instrument for the Front End Test Stand at RAL**

D. A. Lee, P. Savage (Imperial College of Science and Technology, Department of Physics) C. Gabor (STFC/RAL/ASTeC) J. K. Pozimski (STFC/RAL)

The RAL Front End Test Stand is being constructed to demonstrate production of a high-quality, chopped 60 mA  $H^{+}$  beam at 3 MeV and 50 pps. In parallel to the accelerator development, non-destructive laser-

based beam diagnostics are being designed. This paper reports on the realisation of a laser-based profile instrument that will be able to reconstruct the complete 2D transverse beam density distribution by scanning a laser beam through the ion beam at a variety of angles and then computationally combining the results. Commissioning results are presented alongside plans for future developments.

TH5RFP052

**Fermilab HINS Proton Ion Source Beam Measurements**

W. M. Tam (IUCF) G. Apollinari, S. Chaurize, G. V. Romanov, V. E. Scarpine, W. M. Tam, R. C. Webber (Fermilab)

The proton ion source for the High Intensity Neutrino Source (HINS) Linac front-end at Fermilab has been successfully commissioned. It produces a 50 keV, 3 msec beam

pulse with a peak current greater than 20 mA at 2.5 Hz. The beam is transported to the radio-frequency quadrupole (RFQ) by a low energy beam transport (LEBT) that consists of two focusing solenoids, four pairs of steering magnets and a beam current transformer. To understand beam transmission through the RFQ, it is important to characterize the 50 keV beam before connecting the LEBT to the RFQ. A wire scanner and a Faraday cup are temporarily installed at the exit of the LEBT to study the beam parameters. Beam profile measurements are made for different LEBT settings and results are compared to those from computer simulations. In lieu of direct emittance measurements, a solenoid variation method based on profile measurements is used to reconstruct the beam emittance. Space charge effects at various beam currents are also analyzed.

TH5RFP053

**Design and Simulation of the Wire Scanner for Halo Formation Measurements in a Proton Linac Beam**

Y. F. Ruan (Institute of High Energy Physics, CAS) S. Fu, J. Peng, T. G. Xu (IHEP Beijing)

A high current proton RFQ accelerator has been constructed in China for the basic study of Accelerator Driven Subcritical System. A new beam line will be set up for the

3.54MeV, 45mA proton beam from the RFQ in order to study beam halo phenomenon. Therefore, 18 wire scanners consist of a thin carbon wire and a paddle type device called a scraper will be installed on the beam line to traverse the entire beam cross-section. So we can experimentally study the beam loss and beam halo. Some simulations results of the heat and stress on the devices by using finite element method software--ANSYS are presented and discussed.

### Construction and Characterization of the Inductive Pick-Up Series for Beam Position Monitoring in the TBL Line of the CTF3 at CERN

A set of two Inductive Pick-Up (IPU) prototypes with its associated electronics for Beam Position Monitoring in Test Beam Line (TBL) in the 3rd CLIC Test Facility (CTF3) at CERN were designed, constructed, characterized and tested by the IFIC. One of these two prototypes is already mounted in the first module of the TBL line for testing with beam. In the first part of this paper we described the first tests performed with beam in the prototype. The second part of this paper is dedicated to the description of the construction, performance characterization and installation of a series of 15 units, including its respective mechanical supports in the complete TBL line in spring 2009.

A. Faus-Golfe, C. Blanch Gutierrez, J. V. Civera-Navarrete, J. J. Garcia-Garrigos (IFIC)

### Libera Brilliance as a Single Pass BPM

Libera Brilliance is a standard device for beam position monitoring on circular synchrotron light sources. Initially, the idea of optimizing its signal processing for the single bunch measurement came from the users community. This was afterwards followed by the idea of using it on transfer lines on the same 3rd generation light sources as well as on injector system for the FELs. The device can be used on pickup buttons and on striplines. The single pass functionality is contained in newest Libera Brilliance software Release 2.0, no hardware changes are needed. The measurement principles and first measurements with results are presented.

A. Kosicek, B. B. Baricevic, M. Znidarcic (Instrumentation Technologies)

### Beam Diagnostics at IR Wavelengths at NSRL

Real time diagnostics is a fundamental tool for accelerator physics, particularly important to improve performances of existing synchrotron radiation sources, colliders and a key issue for 4th generation sources and FELs. We report the first measurements in the time and frequency domain performed at Hefei Light Source (HLS), the SR facility of the National Synchrotron Radiation Laboratory (NSRL), of the longitudinal bunch lengths. A fast uncooled HgCdTe photodiode optimized in the mid-IR range has been used to record at the IR port the length of the  $e^+e^-$  bunches. IR devices are compact and low cost detectors suitable for a bunch-by-bunch longitudinal diagnostics. The data are useful to investigate longitudinal oscillations and characterize the bunch length. The IR signal has been used to measure the synchrotron oscillation frequency, its harmonics in the multi-bunch mode and the bunch lengths in multi-bunch mode at different beam currents. For the first time, simultaneously, data have been collected at visible wavelengths using a fast photodiode at the diagnostics beamline of HLS. A comparison between IR data and diagnostics realized in the visible will be presented and discussed.

A. Bocci, A. Drago, A. Marcelli (INFN/LNF) C. Li, Z. Qi, B. Sun, B. Y. Wang, J. G. Wang (USTC/NSRL) J. P. Piotrowski (VIGO System S. A.)

TH5RFP054

TH5RFP055

TH5RFP056

**Fast Horizontal  $e^+$  Instability Measurements in DAFNE**

A. Drago (INFN/LNF)

In the more than decennial history of DAFNE, the Frascati  $e^+/e^-$  collider, the positron beam has always shown more difficulty to store high current than the  $e^-$  beam. Given that the two rings are identical, many types of measurement have been tried to figure out the problem and to solve it, but eventually only one technique has presented a crucial utility: the modal growth rate measurement. In principle this method could be implemented using a commercial spectrum analyzer with the right software procedure inside. Nevertheless it is much easier and faster to record data by the bunch by bunch feedback diagnostics and to use for analyzing the offline feedback programs. A large campaign of data taking has been done in DAFNE main rings during last fall. A comparison with growth rate records from previous years has pointed out clearly the difference with 2008 DAFNE performance showing the way to solve the beam current limit. In particular, measurements have been done versus different machine conditions. Very fast horizontal instability present only in the  $e^+$  ring has been characterized showing linear behavior versus beam current. These data have been used to figure out the current limit problem.

**Beam Diagnostics for Positron Beam at DAFNE by 3+L Experiment**

A. Drago, A. Bocci, A. Clozza, A. G. Grilli, A. Marcelli, R. S. Sorchetti (INFN/LNF) E. P. Emanuele (Universita degli Studi di Firenze) J. P. Piotrowski (VIGO System S. A.)

At the LNF (Laboratori Nazionali di Frascati) of the INFN a novel diagnostics experiment has been set-up to monitor the real time bunch behavior in the positron ring of the DAFNE collider. The experiment has been installed on a bending magnet exit port of the  $e^+$  ring. The front-end consists of a UHV chamber where a gold-coated plane mirror deflects the radiation through a ZnSe window. After the window, a compact optical layout in air focuses the radiation on an IR detector. Compact mid-IR fast uncooled HgCdTe photodiodes are used to measure the bunch by bunch emission. A preliminary alignment of the mirrors and a first characterization of the radiation emitted have been performed. Longitudinal measurements of the bunch behavior, both in time and in frequency domain, obtained with fast IR detectors are presented. This novel diagnostics now available is ready to allow monitoring in real time of the bunch-by-bunch positron emission. It has been designed to improve the DAFNE diagnostics with the main aim to identify and characterize positron bunch instabilities in the longitudinal plane. Developments for extending detection capability in the transverse planes are in progress.

**IPM System for the Main Ring Synchrotron of the J-PARC**

K. Satou, T. Toyama (J-PARC, KEK &amp; JAEA) H. Harada (Hiroshima University, Graduate School of Science) Y. Kato (JAEA/J-PARC)

We installed an ionization profile monitor (IPM) in the J-PARC Main Ring synchrotron to monitor turn by turn vertical profiles, which has a 32 ch multi-anode MCP for a signal read out device and an electron generator for a checking source for the MCP. To check MCP gain change, we adopt the pulse to pulse calibration using electrons from the electron generator. As for the DAQ system, we use oscilloscopes with 8 MW/ch (in maximum) and 200 MHz (in maximum) sampling. The present status of the IPM system will be reported. At present, we are developing two horizontal IPMs, these will be installed in dispersion-free straight sections and arc sections. The designed study of the new IPM will also be presented.

### Beam Based Alignment of the Beam Position Monitor at J-PARC RCS

The J-PARC RCS is an M-Watt class rapid cycling synchrotron and it has started to supply the beam to the neutron target and the MR.

**N. Hayashi** (JAEA/J-PARC)

In order to handle a large beam intensity, its physical aperture is designed to be more than 250mm including the BPM sensor head. Although its large size, the BPM system gives very precise data to measure beam optics parameters of the ring. For this purpose, the relative position and resolutions are only important. However, for even higher intensity, the absolute position information becomes important. We have carefully installed the BPM and we measured the position with respect to the quadrupole magnet (QM) nearby. But it is also necessary to check its absolute position by using beam. The beam based alignment technique is utilized. If each QM can be controlled independently, it is easier but it is not the case for RCS. There are seven families of QM, and only one family can be controlled at one time. We developed a new technique based on the simple case and applied to the J-PARC RCS. The paper describes this method and discussed about experimental results.

TH5RFP060

### Study of J-PARC Linac Beam Position Monitor as Phase Monitor

In the J-PARC LINAC, BPMs with 4 strip lines (up, down, right, left) have been used to monitor the beam position by taking log ratio of signals on the opposite (facing) sides of strip lines. We are studying possibility to monitor beam phase by measuring phase of summed signal of all four strip lines. In this paper, status of the study is presented.

**S. Sato, K. Hasegawa, A. Miura, T. Morishita, H. Sako, A. Ueno, H. Yoshikawa** (JAEA/J-PARC) **Z. Igarashi, M. Ikegami** (KEK) **T. Tomisawa** (JAEA/LINAC)

TH5RFP061

### Non-Destructive Two-Dimensional Transverse Profile Monitor for High Power Proton Beams

At the J-PARC RCS, two types monitor system are installed to observed the transverse beam profile. One is the multi-wire beam profile monitor (MWPM) and the other is the residual gas ionization profile monitor (IPM). They show the good performance in the beam commissioning, but they have the some problems. The MWPM is cannot be used for the circulating beam. The IPM is non-destructive type and can be measured the circulating beam profile for every turn, but it is too large device and too expensive to be build more. Thus we develop the new type of the non-destructive profile monitor. The new monitor is the electro static type and it has multi-electrodes. Then the two-dimensional transverse beam profile can be reconstructed from the pick-up signals to multi-electrodes.

**M. Yoshimoto, N. Hayashi, M. Kinsho** (JAEA/J-PARC) **Z. Kabeya** (MHI)

TH5RFP062

### Longitudinal Beam Dynamics in the HDSM at MAMI

The 1.5GeV Harmonic Double Sided Microtron (HDSM)\* as the fourth stage of the Mainz Microtron (MAMI) is now in routine operation for two and a half years\*\*. Simulations predicted a wide range of applicable longitudinal parameters with which the machine can be run. Measurements of the longitudinal acceptance proved that. The reproducibility

**M. Dehn, H. Euteneuer, A. Jankowiak** (IKP)

TH5RFP063

of different configurations is sufficient to support a fast and reliable set-up of the machine and to guarantee a stable long-term operation. But in order to optimise the configuration a reliable measurement of the phases and accelerating voltages in both linacs is essential. Each turn's phase information is provided by low-Q-TM010 resonators at both linacs when operating the machine with 10ns diagnostic pulses. The HDSM's four bending magnets are designed with a field gradient to compensate the vertical fringe defocusing. The decreasing field integral results in less synchronous energy gain per turn, automatically causing a change of the longitudinal phase. The calibration of the phase signals which in case of the RTMs could be easily done by exciting a synchrotron oscillation was improved to deliver precise phase data.

\*K.-H. Kaiser et al., NIM A 593 (2008) 159 - 170, doi:10.1016/j.nima.2008.05.018

\*\*A. Jankowiak et al., ID 2689, this conference

### Single Shot Emittance Measurement Using Optical Transition Radiation Screens at Energies above 100 MeV

N. Delerue, R. Bartolini (JAI) S. I. Bajlekov, L. S. Caballero-Bendixsen, T. Ibbotson (University of Oxford, Clarendon Laboratory) N. Bourgeois, P. A. Walker (University of Oxford) B. Buonomo, G. Mazzitelli (INFN/LNF) G. Doucas, S. M. Hooker, D. Urner (OXFORDphysics) C. A. Thomas (Diamond)

A method that uses Optical Transition Radiation (OTR) screens to measure in a single shot the emittance of an electron beam with an energy greater than 100 MeV is described. Our setup consists of 4 OTR screens located near a beam waist. A fit of the 4 profiles allows the reconstruction of the twiss

parameters and hence a calculation of the beam emittance. This layout has been simulated using Geant4 and will be tested at the DAFNE Beam Test Facility.

### Single Shot Emittance Measurements Using the Pepper-Pot Method at Energies above 100 MeV

N. Delerue, R. Bartolini, K. J. Peach (JAI) S. I. Bajlekov, L. S. Caballero-Bendixsen, T. Ibbotson (University of Oxford, Clarendon Laboratory) N. Bourgeois, P. A. Walker (University of Oxford) B. Buonomo, G. Mazzitelli (INFN/LNF) G. Doucas, S. M. Hooker, P. Lau, D. Urner (OXFORDphysics) C. A. Thomas (Diamond)

A method is described that uses a modified pepper-pot design to measure in a single shot the emittance of electron beams with energies above 100 MeV. The configuration consists of several thin layers of Tantalum with spacers in between, creating slits through which the electrons can be sampled.

Simulations using Geant4 and preliminary tests of this method are reported.

### Longitudinal Beam Profile Measurements at CTF3 Using Coherent Diffraction Radiation

M. Micheler, G. A. Blair, G. E. Boorman, V. Karataev (JAI) R. Corsini, T. Lefevre (CERN)

The diagnostics of a 6D phase space distribution is a crucial and a challenging task, which is required for modern and future installations such as light sources or linear colliders, like CLIC. The longitudinal profile is one of the parameters which needs to be monitored. A setup for the investigation of coherent diffraction radiation from a conducting screen as a tool for non-invasive longitudinal electron beam profile diagnostics has been designed and installed in the CRM line of the CLIC Test Facility (CTF3) at CERN. This setup also allows the measurements of Coherent Synchrotron Radiation from the last bending magnet.

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In this report we present the status of the experiment and show some preliminary results on coherent synchrotron radiation and coherent diffraction radiation studies. The plans for interferometric measurements of coherent radiation are also presented.

### About the Opportunity to Use Solid-State Photo Multipliers for not Destroying Synchrotron Diagnostics of High Energy Proton Beams

The opportunity application of the not destroying infra-red diagnostics method for measurement of intensity and geometrical parameters of proton beam in synchrotron using solid-state photo multipliers is considered.

M. V. Maltseva, A. A. Maltsev (JINR)

TH5RFP067

### Parameter Measuring Instruments for Ionizing Particle Scanning Bunches

Scanning pulse bunches of ionizing particles find wide application in radiation technologies. Parameters measurement of bunches

O. S. Posukhov, M. Styervoyedov (KhNU)

spatial site changing presents certain difficulties. There are two dosimetric devices of electrons scanning bunches in the present work considered. A radiation and acoustical effect of the deformation waves excitation arising at interaction of electrons pulsed bunch with a target material is put in a basis of devices functioning. Both devices contain a rod target on which ends piezoelectric acoustic detectors are located. They are used for thermosonic pulses raised in area of a bunch crossing with a rod target registration. In the second device the rod target is made of a ferromagnetic material, and instead of acoustic detectors for thermosonic pulses PMIP registration the communication coils registering converse magnetostrictive effect voltage are used. The electronic equipment of radiation and acoustical dosimeters allow to carry out complex measurements of a scanning bunch at reverse and forward motion along a rod target: speed and a scanning direction, crossing of a bunch with a rod target, a pulse current and the bunch sizes on a target.

TH5RFP068

### Acoustic Sensors Application for Acceleration Mode Adjustment Optimization

The mechanism of ultrasonic waves excitation by pulsed microwave field is used for electron accelerator operation mode adjustment.

O. S. Posukhov, S. Styervoyedov (KhNU)

One of the essential moments for achievement an optimal mode of acceleration in the linear accelerator is the correct choice of phases of accelerating electromagnetic waves in separate accelerating wave guides concerning a phase of the grouped bunch. Amplitude-frequency responses of the ultrasonic signals arising in a load absorbing part of SHF power which is not used substantially depend on conditions of energy resonant exchange between an accelerating electromagnetic field in a diaphragmatic waveguide and a bunch of accelerated particles. Thus the signal amplitude received from the acoustic sensors located on absorbing load, inversely proportional to the energy transferred to the accelerated bunch, is informative parameter at a choice of an optimal mode of acceleration. The signal amplitude of each signal is measured. After analog-to-digital conversion the information is entered into the computer for processing and decision-making in a regulation direction of microwave phase shift angle in a manual or automatic mode.

TH5RFP069

**Nanometer Resolution Beam Position Monitor for the ATF2 Interaction Point Region**

A. Heo, E.-S. Kim, H.-S. Kim (Kyungpook National University) R. C.D. Ainsworth, S. T. Boogert, G. E. Boorman (Royal Holloway, University of London) Y. Honda, T. Tauchi, N. Terunuma (KEK) S. H. Kim, Y. J. Park (PAL) A. Lyapin, B. Maiheu, M. Wing (UCL) J. May, D. J. McCormick, S. Molloy, J. Nelson, T. J. Smith, G. R. White (SLAC) S. Shin (Fermilab) D. Son (CHEP) D. R. Ward (University of Cambridge)

The ATF2 international collaboration is intending to demonstrate nanometer beam sizes required for the future Linear Colliders. The position of the electron beam focused down at the end of the ATF2 extraction line to a size as small as 35 nm has to be measured with nanometer resolution. For that purpose a special Interaction Point(IP) beam position monitor (BPM) was designed.

In this paper we report on the features of the BPM and electronics design providing the required resolution. We also consider the results obtained with BPM triplet which was installed in the ATF beamline and the first data from ATF2 commissioning runs.

**The TE Wave Transmission Method for Electron Cloud Measurements at Csr-TA**

S. De Santis, J. M. Byrd (LBNL) M. G. Billing, J. P. Sikora (CLASSE)

We report on the optimization of TE Wave measurements at the Csr-TA ring at Cornell University. The CESR storage ring is

currently used as a testbed for technologies to be used in the damping rings of the International Linear Collider. The TE Wave measurement method utilizes capacitive buttons (BPMs) in the ring to excite and detect a propagating electromagnetic wave corresponding to the beampipe's fundamental TE mode. The presence of low-energy electrons along the wave path changes its propagation characteristics, which can be detected by analyzing the received signal. By choosing the machine fill pattern (gaps and bunch trains length) it is possible to modulate the density of the electron cloud and derive information on its rise and fall times by observing the detected signal spectrum. The possibility of circulating both electron and positron beams in the ring enabled us to separate the contribution of primary photoelectrons, which are independent on the circulating particle nature, from the transverse resonant mechanism, which can increase the primary electron density many times over and which only takes place with a circulating positron beam.

**Remote Synchrotron Light Instrumentation Using Optical Fibers**

S. De Santis, J. M. Byrd, R. B. Wilcox (LBNL) Y. Yin (Y. Y. Labs, Inc.)

By coupling the emitted synchrotron light into an optical fiber, it is possible to transmit the signal at substantial distances from the light port, without the need to use expensive

beamlines. This would be especially beneficial in all those cases when the synchrotron is situated in areas not easily access because of their location, or due to high radiation levels. Furthermore, the fiber output can be easily switched, or even shared, between different diagnostic instruments. We present the latest results on the coupling and dispersion measurements performed at the Advanced Light Source in Berkeley.

### Test Results of the Luminosity Monitors for the LHC

The Luminosity Monitor for the LHC has been built at LBL and is going to be installed in the LHC in early 2009. The device designed for the high luminosity regions (ATLAS and CMS) is a gas ionization chamber, that is designed with the ability to resolve bunch by bunch luminosity as well as survive extreme levels of radiation. During the experimental R&D phase of its design, the prototype of this detector has been tested extensively in RHIC as well as in the SPS. Result of these experiments are shown here, with comments on the implications for early operations of the LHC.

**A. Ratti**, K. Chow, H. S. Matis, W. C. Turner (LBNL) E. Bravin (CERN) K. A. Drees (BNL)

TH5RFP073

### DARHT II Accelerator Beam Position Monitor Performance Analysis

Accurate and reliable beam position measurements are required to commission and operate the DARHT II Accelerator. The Beam Position Monitor (BPM) system developed for use on the DARHT II accelerator consists of 31 electro-magnetic detector assemblies, a computer network based data acquisition system, and custom analysis software. During an accelerator "shot", each BPM uses arrays of b-dot detectors to intercept the electron beam's changing magnetic field. Post shot analysis of the BPM data provides the beam current and position information used for steering and tuning subsequent shots. This paper will analyze the performance of the BPM system, now that several thousand beam shots have been achieved.

**J. B. Johnson**, C. Ekdahl (LANL) W. Broste (NSTec)

TH5RFP074

### Tune Measurements in the Los Alamos Proton Storage Ring

Precise measurement of the tunes in the Los Alamos Proton Storage Ring (PSR) is difficult because the beam is normally extracted immediately after accumulation, preventing the use of continuous-wave radio frequency measurements. Presented here is a method that takes advantage of the phase information in the response of the beam to a transverse oscillatory driving voltage. This technique offers much greater precision than using the amplitude spectrum alone.

**R. C. McCrady** (LANL)

TH5RFP075

### Prototype Beam Position and Phase Monitoring Electronics for LANSCE

Future improvements to the Los Alamos Neutron Scattering Center (LANSCE) include new Beam position and phase measuring systems that operate at 201.25 to 805 MHz. An effort is underway to build and test prototype electronics for these applications. We plan to use direct down conversion to 35 to 115 MHz followed by COTS FPGA hardware for in-phase and quadrature-phase (I/Q) signal processing. Self-calibration and system diagnostics circuits will be included. We are reporting on the status of these efforts.

**J. F. Power**, J. D. Gilpatrick (LANL)

TH5RFP076

**cRIO-Based Wire Scanner Motion Control**

J. D. Sedillo, J. D. Gilpatrick (LANL)

The Compact Reconfigurable Input/Output (cRIO) hardware manufactured by National Instruments (NI) is evaluated as a wire scanner motion controller. This particular configuration utilizes a NI cRIO-9074 system combined with various C-series modules for wire scanner motion control I/O. Programs for this system have been written in LabVIEW and a majority of the motion-control functionality has been programmed into the cRIO's FPGA in order to provide the fastest motion control processing possible with cRIO. Additional topics of interest include, cRIO-based resolver-to-digital conversion and closed-loop, stepper-based motion control

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**Advances in Multi-Pixel Photon Counter Technology**

R. J. Abrams (Muons, Inc) D. Hedin, V. Zutshi (Northern Illinois University)

stimulate improvements in MPPCs. Advanced electronic platforms to process their signals and provide integrated application-specific functions are needed to realize their capabilities. We are studying the performance characteristics of MPPCs as particle detectors for scintillating fiber hodoscopes, especially in cryogenic systems, and for calorimetry. A field programmable gate array (FPGA)-based data acquisition system will be used to determine the signal processing functions that are needed for an integrated electronics platform. The design and implementation of an application-specific integrated circuit (ASIC) that is integrated and packaged with the MPPC, and its incorporation into larger prototype systems will be described. Pre-prototype scintillating fiber counters and calorimeter modules with MPPC detectors will be constructed and tested using sources, cosmic rays and beam.

The multi-pixel photon counter (MPPC) is of great interest as a photon detector for high-energy physics, and other fields. New applications for muon collider detectors will

**Large Area Photo-Detectors with Millimeter and Picosecond Resolution: Simulations**

T. J. Roberts, R. J. Abrams, M. A.C. Cummings, V. Ivanov (Muons, Inc) H. J. Frisch (Enrico Fermi Institute, University of Chicago)

Many measurements in particle and accelerator physics are limited by the time resolution with which individual particles can be detected. This includes particle identification via time-of-flight in major experiments like CDF at Fermilab and Atlas and CMS at the LHC, as well as the measurement of longitudinal variables in accelerator physics experiments. Large-scale systems, such as neutrino detectors, could be significantly improved by inexpensive, large-area photo detectors with resolutions of a few millimeters in space and a few picoseconds in time. Recent innovations make inexpensive, large-area detectors possible, with only minor compromises in spatial and time resolution. The Geant4-based simulation program, G4beamline, is being used to simulate the inner workings of these detectors, leading to the ability to optimize their performance. Some program enhancements will be required, including interfacing to existing Geant4 facilities and low-energy physics processes. Development will begin on the additional physics processes necessary for the inner surfaces of a micro-channel plate. Simulations of the detectors await funding.

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### Study of the Stabilization to the Nanometer Level of Mechanical Vibrations of the CLIC Main Beam Quadrupoles

To reach the design luminosity of CLIC, the movements of the quadrupoles should be limited to the nanometer level in order to limit the beam size and emittance growth. Below 1 Hz, the movements of the main beam quadrupoles will be corrected by a

beam-based feedback. But above 1 Hz, the quadrupoles should be mechanically stabilized. A collaboration effort is ongoing between several institutes to study the feasibility of the "nano-stabilization" of the CLIC quadrupoles. The study described in this paper covers the characterization of independent measuring techniques including optical methods to detect nanometer sized displacements and analyze the vibrations. Actuators and feedback algorithms for sub-nanometer movements of magnets with a mass of more than 400 kg are being developed and tested. Input is given to the design of the quadrupole magnets, the supports and alignment system in order to limit the amplification of the vibration sources at resonant frequencies. A full scale mock-up integrating all these features is presently under design. Finally, a series of experiments in accelerator environments should demonstrate the feasibility of the nanometer stabilization.

**K. Artoos**, O. Capatina, M. Guinchard, C. Hauviller, F. Lackner, J. Pflingstner, H. Schmickler (CERN) B. Bolzon, L. Brunetti, N. Geffroy, A. Jeremie (IN2P3-LAPP) P. A. Coe, D. Urner (OXFORD-physics) M. Fontaine (CEA)

TH5RFP080

### Ground Vibration and Coherence Length Measurements for the CLIC Nano-Stabilization Studies

The demanding nanometer transverse beam sizes and emittances in future linear accelerators results in stringent alignment and nanometer vibration stability requirements.

For more than two decades, ground vibration measurements were made by different teams for feasibility studies of linear accelerators. Recent measurements were performed in the LHC tunnel and at different CERN sites on the surface. The devices to measure nanometer sized vibrations, the analysis techniques and the results are critically discussed and compared with former measurement campaigns. The implications of the measured integrated R. M.S. displacements and coherence length for the CLIC stabilization system are mentioned.

**K. Artoos**, O. Capatina, M. Guinchard, C. Hauviller (CERN) B. Bolzon, A. Jeremie (IN2P3-LAPP)

TH5RFP081

### Propagation Error Simulations Concerning the CLIC Active Pre-Alignment

The CLIC components will have to be pre-aligned within a tolerance of 10 microns over a sliding window of 200m all along the linacs, before injecting the first beam. Such tolerance is about 30 times more demanding than for the existing machines as the SPS and LHC; it is a technical challenge and a key issue for the CLIC feasibility. In order to define the CLIC alignment strategy from the survey and beam dynamics point of view, simulations have been undertaken concerning the propagation error due to the measurement uncertainties of the pre-alignment systems. The uncertainties of measurement, taken as hypotheses for the simulations, are based on the data obtained on several dedicated facilities. This paper introduces the facilities and the latest results obtained, as well as the simulations performed.

**T. Touzé**, H. Mainaud Durand, D. P. Missiaen (CERN)

TH5RFP082

**Ground Motion Studies at Fermilab**

V. D. Shiltsev, J. T. Volk (Fermilab) S. R. Singatulin (BINP SB RAS)

Understanding slow and fast ground motion is important for the successful operation and design for present and future colliders. Since 2000 there have been several studies of ground motion at Fermilab. Several different types of hydrostatic water levels have been used to study slow ground motion (less than 1 hertz) seismometers have been used for fast (greater than 1 hertz) motions. Data have been taken at the surface and at locations 100 meters below the surface. Data and results of both slow and fast ground motion will be discussed in particular the effects of natural and cultural sources of motion.

**Nanometer Order of Stabilization for Precision Beam Size Monitor (Shintake Monitor)**

T. Kume, Y. Honda, T. Tauchi, N. Terunuma (KEK) B. Bolzon, N. Geffroy, A. Jeremie (IN2P3-LAPP) Y. Kamiya (ICEPP) S. Komamiya, M. Orouku, T. S. Suehara, T. Yamanaka (University of Tokyo)

The ATF2, accelerator test facility has been developed confirming techniques for obtaining super low emittance beam for future particle accelerators. Here, the converged beam size is designed to be 37 nm, and a precision beam size monitor using interference

fringes as a reference called Shintake monitor is used for measuring it. In order to measure the beam size with resolution of better than 10%, relative position between the beam and the interference fringes should be stabilized within few nanometers. Highly rigid tables and mounts for the Shintake monitor and final focusing magnets are adopted with highly rigid floor to ensure relative position stability. Then, the Shintake monitor can be stabilized against the beam, since the beam fluctuates coherently with the final focusing magnets. On the other hand the interference fringes are stabilized against the Shintake monitor with precise phase control system. As a result, relative position between the beam and the interference fringes is stabilized based on rigidity of tables, mounts, and floor between them. We will present our conception for stabilization and results of vibration measurements for the Shintake monitor.

**Tunnel and Magnet Survey of KEKB after Ten Years of Operation**

M. Masuzawa, Y. Ohsawa, N. Ohuchi (KEK)

KEKB is a double-ring collider with a circumference of 3016 m. The two rings were built side-by-side in the TRISTAN tunnel, 11

m below ground. KEKB has been operating successfully for about 10 years, since 1999, and its peak luminosity continues to improve. During the summer shutdown of 2008, the magnet tilts were measured for the first time since installation and it was found that some magnets were rotated over time. The tunnel level marker and the magnet height were also surveyed. The south region of the tunnel is sinking, resulting in magnet level changes. The survey results will be reported in this paper.

**Linear Collider Test Facility: ATF2 Final Doublet Active Stabilization Pertinence**

CLIC is one of the current projects of linear colliders. Achieving a vertical beam size of 1 nm at the Interaction Point (IP) with several nanometers of fast ground motion imposes an active stabilization of final doublet magnets (FD) at a tenth of nm above 4Hz. ATF2 is a test facility for linear colliders whose first aim is to have a vertical beam size of 37nm. Relative motion tolerance between FD and the IP is of 7nm above 0.1Hz. Because ground motion is coherent between these two elements, they were fixed to the floor so that they move in a coherent way. Investigations are going on to have in 2011 a useful active stabilization for ATF2 in order to use it as a CLIC prototype. Parameters of a 2D ground motion generator were fitted on measurements to reproduce spatial and temporal spectra, so it can be used for ATF2 simulations. Thus, we evaluated the ideal response function that an active stabilization FD system would need to have to improve on the present ATF2 system. Because ground motion coherence is lost with upstream magnets, we simulated the integrated vibrations at the IP to evaluate the usefulness of their stabilization. These results were validated with measurements.

**B. Bolzon**, A. Jeremie (IN2P3-LAPP) P. Bambade (KEK) Y. Renier (LAL) D. Schulte, R. Tomas (CERN) A. Seryi (SLAC)

TH5RF086

**Linear Collider Final Doublet Considerations: ATF2 Vibration Measurements**

Future linear collider projects like ILC and CLIC will have beam sizes of a few nm. Vibration sources like ground motion can hamper the beam collisions. Relative jitter tolerance between the final focus magnets and the Interaction point (IP) is a fraction of the beam size. The ATF2 project proposes a test facility with a projected beam of 37nm. To measure the beam size with only 2% of error, vertical relative jitter tolerance (above 0.1Hz) between the final doublet magnets (FD) and the IP (with a Shintake beam Size Monitor: BSM) is of the order of 7nm while ground motion is of about 150nm. Thanks to determined adequate instrumentations, investigations were done to design supports for FD. Since ground motion measurements showed that this one is coherent up to 4m, more than the distance between FD and BSM, we chose a stiff support for FD fixed to the ground on its entire surface. Thus, FD and BSM should move in a coherent way. Vibration measurements show that relative motion between FD and BSM is only of 4.8nm and that flowing water in FD does not add any significant jitter. The FD support has been consequently validated on site at ATF2 to be within the vibration specifications.

**B. Bolzon**, N. Geffroy, A. Jeremie (IN2P3-LAPP)

TH5RF087

**Magnetic Center Measurements of the XFEL Undulator Quadrupoles**

The undulators of the European free-electron laser (XFEL) are 128 to 226 meters in length and divided into five meter long segments. Each segment ends with a quadrupole magnet to focus the electron beam and to maintain optimum spatial overlap between the electron and photon beams. At the Manne Siegbahn Laboratory a rotating coil instrument has been built to characterize these quadrupoles and to measure the position of the magnetic center. In combination with a coordinate measurement machine the magnetic center can be measured with respect to fiducials on the magnet. The aim is to measure the position of the magnetic center within 0.050 mm. In this work the experimental setup is presented together with fiducialization of test magnets.

**F. Hellberg**, H. Danared, A. Hedqvist (MSL) J. Pflueger (DESY)

TH5RF088

TH5RFP089

**The Development of On-Line Vibration Measurement and Trace System**

Z.-D. Tsai, J.-C. Chang, T.-S. Ueng (NSRRC)

The vibration issue is significant issue about the accelerator commission. The utility system has many mechanical parts and induces severe vibrations. For the purpose of tracing vibration source and preventing facility failure, the on-line vibration measurement and trace system has been developed. The system adopt programmable automation controller with FPGA function to conduct a series of data acquisition and algorithm. The system including specific analysis of time and frequency domain has also been integrated into the previous monitor and archive system. The user friendly interface may provide on-line analysis and trace vibration source via network anywhere and anytime.

The vibration issue is significant issue about the accelerator commission. The utility system has many mechanical parts and induces

TH5RFP090

**The Design and Prototype Tests of a Whole-Ring Girders Auto Alignment**

W. Y. Lai, J.-R. Chen, T. C. Tseng, H. S. Wang (NSRRC)

TPS (Taiwan Photon Source) is a new 3GeV ring to be constructed at NSRRC Taiwan. A motorized magnet girder system with 6 cam movers on 3 pedestals had been designed and tested to provide 6-axis precise adjustments. With 3 consecutive girders to form one section, there will be 72 girders in the whole ring. In order to align the girders precisely and quickly with less manpower, considering the deformation of the floor and limited space in the tunnel also frequent earthquakes in Taiwan, a whole-ring girders auto alignment system was thus proposed. This system consists of touched sensors between consecutive girders and laser PSD system between straight section girders in addition with electric leveling sensors on each girder. The system operating algorithm had been defined and program also fulfilled to be tested on a 3 girders prototype system. The detailed system design and testing results would be described in this paper.

TPS (Taiwan Photon Source) is a new 3GeV ring to be constructed at NSRRC Taiwan. A motorized magnet girder system with 6 cam

TH5RFP091

**Results from the Linear Collider Alignment and Survey (LiCAS) Experiment**

A. Reichold, C. Uribe Estrada, D. Urner, S. Q. Yang (OXFORD-physics) P. J. Brockill, J. Dale, M. Jones, G. R. Moss, R. Wastie (JAI) M. Schloesser (DESY)

The Linear Collider Alignment and Survey group has completed the evaluation of a robotic survey system for the ILC called the RTRS (Rapid Tunnel Reference Surveyor). We will present the results of our measurements at DESY and show simulations of the emittance growth in the ILC main linac after conventional and RTRS alignment. From the above we propose a minimal RTRS system that satisfies the ILC emittance requirements.

The Linear Collider Alignment and Survey group has completed the evaluation of a robotic survey system for the ILC called the RTRS (Rapid Tunnel Reference Surveyor). We will present the results of our measurements

TH5RFP092

**Interferometric IP Position Monitoring system for ATF2**

D. Urner, P. A. Coe (OXFORDphysics) A. Reichold, M. S. Warden (JAI)

The MONALISA group is developing a nanometre precision, interferometric system to continuously monitor relative position and orientation of crucial accelerator components. The most challenging role at a future linear collider will be monitoring the final focus quadrupoles. A combination of fixed frequency and frequency scanning interferometry (FSI) provides nanometre precision, real time readout every few milliseconds. We present a demonstration measurement system that we intend to install at ATF2 to measure the relative motion of QD0 and the shintake monitor and we will report on measurement results achieved in the laboratory.

The MONALISA group is developing a nanometre precision, interferometric system to continuously monitor relative position and orientation of crucial accelerator components.



### Fission Fragment Ion Source Radiation Protection

A Cf-252 fission source yields neutron-rich fission fragments. The Californium Rare Ion Breeder Upgrade (CARIBU) project is an upgrade to the Argonne Tandem Linear Accelerator System (ATLAS) that provides a 37 GBq (1 Ci) source of these radioactive ions for acceleration. Fission fragments stop in a gas catcher, are extracted into an ECR ion source to increase the charge state, and then accelerated in ATLAS. The radiation fields produced by an unshielded 1 Ci <sup>252</sup>Cf source are 46 rem/hr (neutron) and 4 R/hr (gamma) at 30 cm. A shielding system has been constructed that reduces the radiation fields to  $\leq 1$  mrem/hr at 30 cm from all accessible surfaces. The MCNPX code was used to model the transport of the spontaneous fission neutrons and gamma radiation, and the gamma radiation induced in the shielding materials by the neutrons. The primary neutron shielding material chosen was 5% borated polyethylene, enclosed in steel. Calculations are made for emissions of radioactive effluents, primarily noble gases, using the EPA CAP-88 computer program. The maximum credible incident scenario releases a small quantity of Cf-252. Calculated dose results and mitigation methods are presented.

S. I. Baker, E. F. Moore, R. C. Pardo, G. Savard (ANL)

TH5RFP093

### Beam Loss Monitors in the NSLS Storage Rings

Beam loss monitors have been used for more than a decade in the VUV ring at the NSLS. These have proved useful for optimizing injection and operation of the ring. Recently similar monitors have been installed in the Xray ring and are being used to better understand injection as well as operation of the ring. These units have been compared with the Bergoz Beam Loss Monitors, which have been mostly useful for operating beam losses. The experience with these units have led to an improved detector that is being considered by NSLS-II as a beam containment verification monitor, as well as diagnostic for optimization of injection efficiency.

S. L. Kramer, M. G. Fedurin (BNL)

TH5RFP094

### Fiber Optics for Fusion Applications

Fusion energy sources require the development of superconducting magnets beyond today's capabilities in order to achieve safe and reliable operation. New electromagnetic noise-immune sensors are needed to provide rapid and redundant quench protection for operational systems as well as to measure temperature and strain for studies of magnet behavior for engineering development. Optical fibers with Bragg gratings are planned to be imbedded within Nb<sub>3</sub>Sn and YBa<sub>2</sub>Cu<sub>3</sub>O<sub>x</sub> (YBCO) magnets to monitor strain, temperature, and irradiation, and to detect quenches. Protection methods for YBCO magnets, which have very slow quench propagation velocities, are also being developed. Associated instrumentation will allow real-time measurements to aid the development of high-field magnets that are subject to large Lorentz forces, to allow the effective detection of quenches so that the stored energy of operating magnets can be extracted and/or dissipated without damaging the magnet, and to determine the level of irradiation exposure to the conductor as a function of location.

J. Schwartz (NHMFL) R. P. Johnson, M. Turenne (Muons, Inc)

TH5RFP095

**Study of Beam Loss Measurement in J-PARC Linac**

A. Miura, K. Hasegawa, T. Morishita, H. Sako, H. Yoshikawa (JAEA/J-PARC) Z. Igarashi, M. Ikegami (KEK) S. Sato, T. Tomisawa, A. Ueno (JAEA/LINAC) H. Takahashi (JAEA)

loss records taken by the BLMs. This paper describes the results of the operational data and their comparisons with the dose rates of LINAC area.

Over hundred beam loss monitors (BLM) in the J-PARC LINAC have been used to measure the beam loss observed during the accelerator operation. Dose rates distributed in LINAC area were compared with beam

**Beam Loss Monitoring System for the SPring-8 Storage Ring**

Y. Shimosaki, K. Kobayashi, M. Oishi, M. Shoji, K. Soutome (JASRI/SPring-8)

serve and handle beam losses, a beam loss monitor for beam diagnostics has been developed and installed inside the tunnel of the ring. The monitoring system and results about the beam loss distribution during the operation will be reported.

One of the major concerns in the SPring-8 storage ring is an irradiation-induced damage due to beam loss to the environment surrounding the accelerator. In order to observe

**Development of a Photonic Crystal Fibre Laser Amplifier for Particle Beam Diagnostics**

L. J. Nevay, A. S. Aryshev, G. A. Blair, S. T. Boogert, L. Deacon, D. F. Howell, V. Karataev, R. Walczak (JAI) L. Corner, N. Delerue, L. J. Nevay, M. Newman (OXFORDphysics)

synchronised to an external frequency reference followed by chirped pulse amplification in ytterbium doped double clad fibre. This system produces 1uJ pulses in an adjustable burst envelope at a chosen frequency. These pulses are further amplified in a large mode area rod type photonic crystal fibre, allowing amplification to high pulse energies whilst maintaining a single spatial mode. The fibre is pumped in pulsed mode by a specially commissioned 400W diode laser fixed at the absorption peak of ytterbium at 976nm, independent of pumping regime. Pumping in a pulsed mode allows the high energies required for laser-wire at MHz repetition rates to be created without the need for active cooling of the laser. The light is frequency doubled to ~500nm to achieve higher laser-wire resolution.

We present the latest results on the development of a high power fibre laser system for the laser-wire project on ILC-like laser based beam diagnostics. The laser consists of a crystal oscillator at ~ 1um that can be

**The Laser Emittance Scanner for 1 GeV H<sup>-</sup> Beam**

D.-O. Jeon, A. V. Aleksandrov, S. Assadi, W. P. Grice, Y. Liu, A. A. Menshov, I. Nesterenko, J. Pogge, A. Webster (ORNL)

to build a slit because the stopping distance is more than 50 cm in copper. We propose to use a laser beam as an effective slit by stripping off the outer electron of the H<sup>-</sup> (making it neutral) upstream of a bend magnet and measuring the stripped component downstream of the bend magnet. The design and modeling of the system will be discussed. We are expecting to make a preliminary measurement in 2009.

A transverse phase space emittance scanner is proposed and under development for the 1-GeV H<sup>-</sup> SNS linac, using a laser beam as a slit. For a 1 GeV H<sup>-</sup> beam, it is difficult

## TH6PF — Afternoon Poster BDEMF D01, D02

### Injector Design for Turkish Accelerator Center Free Electron Laser Facility

Turkish Accelerator Center (TAC) Infrared (IR) Free Electron Laser facility (FEL) supported by State Planning Organization (SPO) of Turkey will be based on 15-40 MeV

energy range electron linac and two different undulators with 2.5 cm and 9 cm period lengths in order to obtain FEL in 2-200 micron wavelength range. The electron linac will consist of two superconducting ELBE modules which houses two 9-cell TESLA cavity in one module and can operate in cw mode. The electron bunches in cw mode and compatible with the main linac will be provided by a thermionic gun and an injector system which is totally based on normal conducting technology. In this study the injector design for TAC IR FEL is represented and beam dynamics issues were discussed for suitable injection to first accelerating module.

Mr. Aksoy, O. Yavas (Ankara University, Faculty of Engineering)  
S. O. Ozkorucuklu (SDU)

TH6PFP001

### Beam Dynamics Simulation for the CLIC Drive-Beam Accelerator

CLIC study aims at a center-of-mass energy for electron-positron collisions of 3TeV using room temperature accelerating structures at high frequency (12GHz) which are likely to

achieve 100 MV/m gradient. Due to conventional high frequency RF sources do not provide sufficient RF power for 100MV/m gradient, CLIC relies upon a two-beam-acceleration concept: The 12GHz RF power is generated by a high current electron beam (Drive Beam) running parallel to the main beam with deceleration in special Power Extraction Structures (PETS) and the generated RF power is transferred to the main beam. In order to obtain very high RF power at 12GHz frequency, injected beam into PETS should have 2.37GeV energy, 101A pulse current and pulse length around 240ns. Drive beam accelerator (DBA) accelerates the beam up to 2.37GeV in almost fully-loaded structures and the pulse after DBA contains more than 70000 bunches, has a length around 140 $\mu$ s and 4.2A pulse current. After some modifications in delay loop and in combiner rings the beam has 101A pulse current and 240ns pulse length. In this study simulations of some transverse beam parameters for different options for the lattice of the DBA are presented.

Mr. Aksoy, O. Yavas (Ankara University, Faculty of Engineering)  
D. Schulte (CERN)

TH6PFP002

### A Lattice Study for the Synchrotron Radiation Facility of the Turkish Accelerator Complex (TAC) with 3.56 GeV

The Turkish Accelerator Complex (TAC) is a project for accelerator based fundamental and applied researches supported by Turkish State Planning Organization (DPT). The proposed complex is consisted of 1 GeV electron linac and 3.56 GeV positron ring for a charm factory and a few GeV proton linac. Apart from the particle factory, it is also planned to produce synchrotron radiation from positron ring. In this study the lattice structure design of the positron storage ring is made to produce the third generation synchrotron light. It has been studied with different lattice structures (DBA, TBA, DDBA etc.) for TAC. It has been compared lattice structures and tried to find the best structure for lowest emittance.

K. Zengin (Ankara University, Faculty of Sciences)

TH6PFP003

### Search for Nonlinear Beam Dynamics Causes of Lifetime Reduction at the APS Storage Ring

L. Emery, M. Borland, V. Sajaev, A. Xiao (ANL)

During an operating period in which a sextupole unknowingly connected with the wrong polarity resulted in reduced beam lifetime, a list of machine physics experiments and simulations were developed to identify possible gradient errors of one or more sextupole magnets. We tried tune dependence on orbit, response matrix measurements at different momenta, sector-wise chromaticity measurements, empirical search with sextupole harmonics, and guidance from tracking simulations. The practicality of each will be discussed.

### Beam Purity Studies for a Facility for Rare Isotope Beams

L. L. Bandura, B. Erdelyi, J. A. Nolen (ANL) L. L. Bandura (Northern Illinois University)

An exotic beam facility for the production of rare isotopes such as the Facility for Rare Isotope Beams (FRIB) at Michigan State University will require a high resolution fragment separator to separate isotopes of varying mass and charge. The goal of the fragment separator is to produce a high-purity beam of one rare isotope. Sources of contamination in a beam such as this are isotopes with a similar magnetic rigidity to the separated isotope and those which are produced by fragmentation in the energy degrader. This can be particularly detrimental when a contaminating isotope has a large cross section. Here we investigate beam purity as a function of the separated isotope and the type of fragment separator setup used, i.e. one stage, two stage, or one stage with gas cell branch.

### A Realistic Corrective Steering Algorithm: Formalism and Applications

B. Mustapha, V. N. Aseev, P. N. Ostroumov (ANL)

The corrective steering algorithm in TRACK has been recently updated to be more realistic. A simplified formalism will be presented along with the method of implementation. As an important application, the algorithm was used to determine the number of correctors and monitors required for the front-end of the HINS project at Fermilab. The algorithm allowed us also to find the optimum locations for the correctors and monitors as well as the required corrector field strength and the required monitor precision for an effective correction. This correction procedure could be easily implemented in an accelerator control-room for real-time machine operations.

### Simulation of Linear Lattice Correction and Coupling Correction of an Energy Recovery Linac Designed for an APS Upgrade

V. Sajaev (ANL)

An energy recovery linac (ERL) is one of the candidates for an upgrade of the Advanced Photon Source (APS). In addition to the APS ring and full-energy linac, our design also includes a large turn-around arc that could accommodate new x-ray beamlines as well. In total, the beam trajectory length would be close to 3 km. The ERL lattice has strong focusing to limit emittance growth, and it includes strong sextupoles to keep beam energy spread under control and minimize beam losses. As in storage rings, trajectory errors in sextupoles will result in lattice perturbations that would affect

delivered x-ray beam properties. In storage rings, the response matrix fit method is widely used to measure and correct linear lattice errors. Here, we explore the application of the method to the linear lattice correction and coupling correction of an ERL.

### Emittance Coupling Control at the Australian Synchrotron

Emittance coupling in the Australian Synchrotron storage ring is currently controlled using a total of 28 skew quadrupoles. The LOCO method was used to calculate the skew quadrupole settings, using measured vertical dispersion and transverse coupling. This information is used to create a calibrated model of the machine, which is then used to calculate the required skew quadrupole settings needed to minimise coupling. This method has thus far achieved encouraging results for achieving ultra low (<2pm) vertical emittance. In this study we seek to explore the validity of the LOCO model based on empirical measurements and possible improvements of this method.

**R. T. Dowd**, M. J. Boland, G. LeBlanc, Y. E. Tan (ASCo)

### Low Alpha Configuration for Generating Short Bunches

Generating short bunches for time resolved studies or the generation of THz radiation has been done at many other light sources and is of increasing interest in the user community. Light sources not designed with ps bunches can usually tune the lattice to reduce ps bunches without much difficulty, sometimes referred to as a Low Alpha mode. At the Australian light source a low alpha configuration has been investigated. The results looking into the 'shaping' of the momentum compaction factor, beam stability and current limitations will be presented.

Y. E. Tan, D. R.T. Appadoo, M. J. Boland, R. T. Dowd (ASCo)

### Precision Closed Orbit Correction in a Fast Ramping Stretcher Ring

Acceleration of polarized electrons in a fast ramping circular accelerator poses challenging demands on the control and stabilization/correction of the closed orbit and the vertical betatron tune, in particular on the fast energy ramp. In order to successfully compensate depolarizing resonances at a ramping speed of up to 7.5 GeV/sec ( $dB/dt = 2$  T/sec), at ELSA the closed orbit is stabilized with high precision using a system of Beam Position Monitors and steerer magnets distributed along the ring. During acceleration, the beam positions are read out from the BPMs at a rate of 1 kHz and energy-dependent orbit corrections are applied accordingly by means of offline feed-forward techniques. The system is thus sensitive to dynamic effects and an orbit stabilization of 100 microns rms is achieved routinely. At the same time, the betatron tunes are stabilized to 0.01 by time-resolved tune measurement and appropriate manipulations of the machine optics. This presentation will cover the concepts and implementation of techniques for orbit stabilization required for the acceleration of a polarized electron beam in the fast ramping stretcher ring ELSA.

**A. Balling**, F. Frommberger, W. Hillert (ELSA)

**Beam-Based Alignment of the LNLS UVX Storage Ring BPMs**

L. Liu, R. H.A. Farias, X. R. Resende, P. F. Tavares (LNLS)

The UVX electron storage ring at the Brazilian Synchrotron Light Laboratory (LNLS) was recently equipped with power supplies that allow for individual variation of the quadrupole magnet strengths. This allows us to apply the widely used technique of beam-based alignment (BBA) of quadrupoles for this ring. In this report we present the BBA experimental results for UVX as well as an analysis of the accuracy and resolution of the method for our case.

The UVX electron storage ring at the Brazilian Synchrotron Light Laboratory (LNLS) was recently equipped with power supplies

**Analysis of the LNLS Storage Ring Optics Using LOCO**

X. R. Resende, R. H.A. Farias, L. Liu, P. F. Tavares (LNLS)

The synchrotron machine at the Brazilian Synchrotron Light Laboratory (LNLS) is a storage ring for 1.37 GeV electrons composed of six DBA cells whose lengths add up to around 93 meters of circumference. There are 18 horizontal and 24 vertical correctors available in the ring for correcting the orbit as measured at 24 BPMs. In the past, stored beams have been delivered which successfully fulfill user's stability and emittance demands. This has been accomplished by fine tuning the machine using mostly measured beam parameters. The ongoing commissioning of the a new undulator beamline, which is expected to become the most demanding one, puts pressure in the direction of improving existing models of the ring optics in order to envisage ways of improving beam quality. In this paper we discuss preliminary tests with LOCO\* at the LNLS. We report on the impact of the calibration of the machine based on LOCO calculations through the analysis of standard experiments and optics parameters such as beta-beat reduction, improvement of life-time and injection efficiency, and so on.

The synchrotron machine at the Brazilian Synchrotron Light Laboratory (LNLS) is a storage ring for 1.37 GeV electrons composed

\*LOCO in the Beam Dynamics Newsletter, 44, ICFA, December 2007.

**An Injection/Extraction Scenario for EMMA**

J. S. Berg (BNL)

EMMA is an experiment to study beam dynamics in a linear non-scaling fixed-field alternating gradient accelerator (FFAG). In accelerates an electron beam from 10 to 20 MeV kinetic energy. To optimally perform these studies, one must be able to inject the beam at any energy within the machine's energy range. Furthermore, because we wish to study the behavior of large-emittance beams in such a machine, the injection systems must be able to inject the beam anywhere within a transverse phase space ellipse with a normalized acceptance of 3 mm, and the extraction systems must be able to extract from that same ellipse. I describe a method for computing kicker and septum fields to achieve all of these requirements, and discuss how this interacts with the hardware constraints in the real magnet systems.

EMMA is an experiment to study beam dynamics in a linear non-scaling fixed-field alternating gradient accelerator (FFAG). In

**The Booster to AGS Transfer Line: Comparison between Model and Measurements**

K. A. Brown, L. Ahrens, R. Bonati, D. M. Gassner, J. W. Glenn, H. Huang, J. Morris, S. M. Nida, V. Schoefer, N. Tsoupas, K. Zeno (BNL)

The Booster to AGS (BtA) transfer line was designed to match both ions and protons into the AGS lattice. For proton beam operation the only constraint on the optics is to define a match to the AGS lattice. For ions

operation there are constraints introduced by a stripping foil in the upstream part of the transfer line. For polarized proton operation there is the complication that the lattice to match into in the AGS is distorted by the presence of two partial snake magnets. In the 2008 polarized proton run it was observed that there was an optical injection mismatch. Beam experiments were conducted that showed disagreement with the model. In addition, these studies revealed some minor problems with the instrumentation in the line. A new model and more reliable measurements of the transfer line magnet currents have been implemented. Another series of experiments were conducted to test these modifications and to collect a more complete set of data to allow better understanding of the beam dynamics during the transfer and better understanding of the instrumentation. In this paper we will present the results of these experiments and comparison to the new model of the BtA.

### Minimizing Emittance Growth during $H^-$ Injection in the AGS Booster

As part of the efforts to increase polarization and luminosity in RHIC during polarized proton operations we have modified the injection optics and stripping foil geometry in

K. A. Brown, L. Ahrens, C. J. Gardner, D. M. Gassner, D. Raparia, D. Steski, P. Thieberger, K. Zeno (BNL)

the AGS Booster in order to reduce the emittance growth during  $H^-$  injection. In this paper we describe the modifications, the injection process, and present results from beam experiments.

### Numerical Based Linear Optics Model for Dipole Magnets

In this paper, the algorithm for constructing a numerical linear optics model for dipole magnets directly derived from a 3D field map is discussed. The difference between the numerical model and K. Brown's analytic approach is investigated and clarified. We have found that the optics distortion due to the dipoles' fringe focusing must be properly taken into account to accurately determine the chromaticity. In NSLS-II, we have normal dipoles with 35-mm gap and dipoles for infrared sources with 90-mm gap. We apply our linear optics model of the dipole magnets to the NSLS-II lattice design.

Y. Li, R. C. Gupta, A. K. Jain, S. Krinsky, M. Rehak (BNL)

### Simulations on the AGS Horizontal Tune Jump Mechanism

A new horizontal tune jump mechanism has been proposed to overcome the horizontal intrinsic resonances and preserve the polarization of the proton beam in the AGS during the energy ramp.

F. Lin, H. Huang, A. U. Luccio, T. Roser (BNL)

An adiabatic change of the AGS lattice is needed to avoid the emittance growth in both horizontal and vertical motion, as the emittance growth can deteriorate the polarization of the proton beam. Two critical questions are necessary to be answered: how fast can the lattice be changed and how much emittance growth can be tolerated from both optics and polarization points of view? Preliminary simulations, using a realistic AGS lattice and acceleration rate, have been carried out to give a first glance of this mechanism. Several different conditions are presented in this paper.

TH6PFP018

### Study of Spin Coherence Time in the EDM Experiment

F. Lin, A. U. Luccio, N. Malitsky, W. Morse, Y. Semertzidis (BNL)  
C. J. Onderwater (KVI) Y. F. Orlov (CLASSE) R. M. Talman (CESR-LEPP)

A long polarization life time (spin coherence time), up to 1000 seconds, is a challenging requirement for searching a permanent deuteron Electric Dipole Moment (EDM) at the  $10^{-29}$  e.cm level. The experiment can be performed by measuring the beam polarization in a dedicated storage ring. Therefore, both beam and spin dynamics are needed to be fully studied and understood in an accurate, fast and reliable simulation environment. To address these studies, the Unified Accelerator Libraries (UAL) software has been extended with the SPINK module. This paper presents the simulation results of the new composite package and their comparison with those from the analytical approach and the COSY-Infinity program.

A long polarization life time (spin coherence time), up to 1000 seconds, is a challenging requirement for searching a permanent deuteron Electric Dipole Moment (EDM) at the  $10^{-29}$  e.cm level. The experiment can be

TH6PFP019

### Orbit Response Matrix Optics Correction at RHIC

T. Satogata, M. Bai, J. Bengtsson, G. Wang (BNL)

Orbit response matrix (ORM) measurements are used in many circular accelerators to measure and correct gradient and optics errors, beam position monitor (BPM) gain errors, and dipole corrector gain errors. Here we report on experience with ORM measurements and optics correction, including coupling, at the Relativistic Heavy Ion Collider (RHIC) with various optics configurations during 2009 physics operation. We also compare these results to those obtained with ac dipole and local quadrupole variation methods.

Orbit response matrix (ORM) measurements are used in many circular accelerators to measure and correct gradient and optics

TH6PFP020

### ILC RTML Extraction Lines for Single Stage Bunch Compressor

S. Seletskiy (BNL)

The use of single stage bunch compressor (BC) in the Damping Ring to the Main Linac beamline (RTML) requires new design of the extraction line (EL)\*. The EL located downstream the BC can be used both for an emergency abort dumping of the beam and the tune-up continual train-by-train extraction. It must accept both compressed and uncompressed beam with energy spread of 3.5% and 0.15% respectively. In this paper we report on an optics design that allowed minimizing the length of such extraction line while offsetting the beam dumps from the main line by the 5m distance required for acceptable radiation level in the service tunnel. Proposed extraction line can accommodate beams with different energy spreads at the same time providing the beam size suitable for the aluminum dump window.

The use of single stage bunch compressor (BC) in the Damping Ring to the Main Linac beamline (RTML) requires new design of

\*S. Seletskiy, P. Tenenbaum, D. Walz, N. Solyak, Design of the ILC RTML extraction lines, Proceedings of EPAC2008.

TH6PFP021

### Alignment and Stability of the ILC Detector Solenoid

S. Seletskiy (BNL)

In the ILC colliding beams must be focused to the nanometer size in order to reach desired luminosity. Mechanical alignment and magnetic stability of the Detector Solenoid (DS) and joint to it Weak Antisolensoid (WAS) strongly affect the quality of the beam in the interaction point (IP). We used a dedicated simulation code to study the effect of the DS-WAS system alignment and stability on the beam's parameters in the IP. We report the results of these studies and consider different scenarios for the compensation of the DS-WAS misalignment.

In the ILC colliding beams must be focused to the nanometer size in order to reach desired luminosity. Mechanical alignment and



### An NS-FFAG Gantry for the PAMELA Project

The PAMELA project to design an accelerator for hadron therapy using non-scaling Fixed Field Alternating Gradient (NS-FFAG) accelerators requires a gantry to take the beam to a patient. The NS-FFAG principle offers the possibility of a gantry much smaller, lighter and cheaper than conventional designs, with the added ability to accept a wide range of fast changing energies. This paper will build on work by D. Trbojevic and S. Machida to design a gantry with magnets most likely to be used in the PAMELA design. The design is presented along with tracking studies showing dispersion, beta functions and emittance plots at the start and end of the lattice.

**R. J.L. Fenning**, A. Khan (Brunel University) T. R. Edgecock (STFC/RAL) E. Keil (CERN) D. J. Kelliher, S. Machida (STFC/RAL/ASTeC) A. Sessler (LBNL) S. L. Sheehy, H. Witte, T. Yokoi (JAI) D. Trbojevic (BNL)

TH6PFP022

### Emittance Influence to Zumbro Lens in Proton Radiography

The capability of the chromatic correction of Zumbro Lens lies on the angle-position correlation, which is obtained by passing the beam through an expander or quadruples. However even after a long distance drift downstream the expander, the angle-position correlation can not be perfect because of the existence of finite emittance. This paper discusses the influence of the emittance to the chromatic correction and the optimization of beam status in phase space at the entrance of the expander.

**S. Wang** (CAEP/IFP)

TH6PFP023

### Beam Waist Manipulations at the ATF2 Interaction Point

The ATF2 project is the final focus system prototype for ILC and CLIC linear collider projects, with a purpose to reach a 37nm vertical beam size at the interaction point. We report on techniques developed based on simulation studies to adjust the horizontal and vertical beam waists independently in the presence of errors, at two different IP locations where the beam size can be measured with different accuracies. During initial commissioning, we will start with larger than nominal

**S. Bai**, J. Gao, X. Z. Zhu (IHEP Beijing) A. S. Aryshev (JAI) P. Bambade, T. Okugi (KEK) Y. Kamiya (ICEPP) D. J. McCormick, M. Woodley (SLAC) M. Orouku, T. Yamanaka (University of Tokyo)

$\beta$ -functions at the IP, to reduce the effects from higher-order optical aberrations and thereby simplify the optical corrections needed. The first measurements in such intermediate

$\beta$ -configurations are reported.

TH6PFP024

### Design Study of the CLIC Booster Linac with FODO Lattice

A new design of the 6.6GeV Booster linac for CLIC which is based on the FODO lattice is presented in this note. Particle tracking studies using PLACET [1] are performed in order to estimate the single-bunch and multi-bunch emittance growth.

**D. Wang**, J. Gao (IHEP Beijing)

TH6PFP025

First, the studies of optics are introduced. Then, the sing-bunch effects and multi-bunch effects are studied in the last two part of this note.

### Beam Dynamics Studies for the HIE-ISOLDE Linac at CERN

M. A. Fraser, R. M. Jones (UMAN) M. Lindroos, M. Pasini (CERN)

The upgrade of the normal conducting REX-ISOLDE heavy ion accelerator at CERN, under the HIE-ISOLDE framework, proposes the use of superconducting (SC) quarter-wave resonators (QWRs) to increase the energy capability of the facility from 3 MeV/u to beyond 10 MeV/u. A beam dynamics study of a lattice design comprising SC QWRs and SC solenoids has confirmed the design's ability to accelerate ions, with a mass-to-charge ratio in the range  $3 < A/q < 4.5$ , to the target energy with a minimal emittance increase. We report on the development of this study to include the implementation of real fields within the QWRs and solenoids. A preliminary error study is presented in order to constrain tolerances on the manufacturing and alignment of the linac.

### ALBA Booster Lattice Settings for Optimized Performances

G. Benedetti, D. Einfeld (ALBA)

The ALBA booster is a 100 MeV - 3 GeV ramping synchrotron, with large circumference and low emittance, cycling at 3 Hz. The lattice consists of a 4-fold symmetric modified FODO lattice with defocusing gradient dipoles. Magnetic measurements on all magnets have been performed: the studies and lattice settings to recover the design optics preserving good machine performances, such as the lattice flexibility, the low beta functions and large dynamic aperture at high chromaticities, are presented.

### Model Independent Analysis with Coupled Beam Motion

M. G. Billing, M. J. Forster, H. A. Williams (CLASSE)

This paper describes the results of measurements compared with the analysis of errors for a method of determining accelerator Twiss and coupling parameters from the singular value decomposition of beam position monitor data, taken on a turn-by-turn basis for a storage ring in fully coupled transverse beam coordinates. Using the transversely coupled-coordinate formalism described by Billing et al\*, the measurement technique expands on the work of Wang et al\*\*, which describes the SVD of the same data under the assumptions of no transverse coupling of the beam parameters. This particular method of data analysis requires a set of BPM measurements, taken when the beam is resonantly excited in each of its two dipole, betatron normal-modes of oscillation

\*M. Billing, et al, to be published in Phys. Rev. S T – Accel Beams

\*\*C. Wang, et al, Phys. Rev. S T – Accel Beams 6, 104001 (2003)

### Bunch Compression for a Short-Pulse Mode in Cornell's ERL

J. R. Thompson, G. H. Hoffstaetter (CLASSE)

The production of ultra-short x-rays in Cornell's Energy Recovery Linac (ERL) requires electron bunch lengths of less than 100fs

with minimal transverse emittance growth and energy spread. Because the linac consists of two sections separated by an arc, CSR forces limit the bunch length in the linac, and bunch compression has to be installed after acceleration. Creation of such short bunches requires a second order bunch compression scheme with correction of the third order dispersion. In this paper, we discuss possible bunch compression systems and explore the benefits of each using the tracking program TAO including CSR forces. Overall, we find that a FODO compressor utilizing dipole, quadrupole and sextupole magnets can achieve the design goals of the short pulse mode.

### Post-Linac Collimation System for the European XFEL

The post-linac collimation system should simultaneously fulfil several different functions. In first place, during routine operations, it should remove with high efficiency off-momentum and large amplitude halo particles, which could be lost inside undulator modules and become source of radiation-induced demagnetization of the undulator permanent magnets. The system also must protect the undulator modules and other downstream equipment against missteered and off-energy beams in the case of machine failure without being destroyed in the process. From beam dynamics point of view, the collimation section should be able to accept bunches with different energies (up to  $\pm 1.5\%$  from nominal energy) and transport them without deterioration not only of transverse, but also of longitudinal beam parameters. In this article we present the optics solution for the post-linac collimation system which fulfils all listed above requirements.

V. Balandin, R. Brinkmann, W. Decking, N. Golubeva (DESY)

### Low Sensitivity Option for Transverse Optics of the FLASH Linac at DESY

The aim of the FLASH facility linac is to create electron bunches of small transverse emittance and high current for the FLASH free-electron laser at DESY. Available operational experience indicates that in order to optimize SASE signal at different wavelengths or to fine-tune the FEL wavelength, empirical adjustment of the machine parameters is required and, therefore, the sensitivity of the beamline to small changes in the beam energy and in the magnet settings becomes one of the important issues which affects the final performance. In this article the transverse optics of the FLASH beamline with low sensitivity to changes in beam energy and quadrupole settings is presented. This optics is in operation since spring 2006 and has shown a superior performance with respect to the previous setup of the transverse focusing.

V. Balandin, N. Golubeva (DESY)

### A Low Momentum Compaction Lattice for the Diamond Storage Ring

With the aim of generating short pulse radiation, a low momentum compaction lattice has recently been commissioned for the Diamond storage ring. By introducing both positive and negative dispersion in the bending magnets it has been possible to operate the storage ring in a quasi-isochronous state, resulting in a natural electron bunch length of less than 1 pico-second. A description of the techniques used to develop the lattice is given, along with first results obtained during recent machine trials. Operation with both positive and negative momentum compaction factor is also described

I. P.S. Martin, J. Rowland, B. Singh, C. A. Thomas (Diamond) R. Bartolini, I. P.S. Martin (JAI)

### Double Mini-beta-Y Plus Virtual Horizontal Focussing Optics for the Diamond Storage Ring

B. Singh, R. T. Fielder, E. C. Longhi, I. P.S. Martin, C. Rau, U. H. Wagner (Diamond) R. Bartolini (JAI)

A proposal has been developed to modify a long insertion straight (~11.4 m long) of the DIAMOND storage ring. Additional quadrupoles provide two sections with small vertical beta-function values, in order to accommodate two canted in-vacuum undulators for the imaging and coherence branches of the I13 beam line. A further requirement was to provide a horizontal focussing of the emitted undulator radiation by means of a positive alpha-x in the second section. This optic is obtained using a small relaxation in the "pi-trick", approximately preserving the on-momentum nonlinear dynamics of the ring. The effects of the optic on beam dynamics (i.e. beam lifetime, injection etc.) and possible compensation schemes are presented.

### Beam Losses at the CERN PS Injection

S. Aumon, S. S. Gilardoni, O. Hans, F. C. Peters (CERN)

The maximum intensity the CERN PS has to deliver is continuously increasing. In particular, during the next years, one of the most intense beam ever produced in the PS, with up to  $3000 \cdot 10^{10}$  proton per pulse, should be delivered on a regular basis for the CNGS physics program. It is now known that the existing radiation shielding of the PS in some places is too weak and constitutes a major limitation due to large beam losses in specific locations of the machine. This is the case for the injection region: losses appear on the injection septum when the beam is injected in the ring and during the first turn, due also to an optical mismatch between the injection line and the PS. This paper presents the experimental studies and the simulations which have been made to understand the loss pattern in the injection region. Possible solutions to reduce the beam losses will be described, including the computation of a new injection optics.

### Studies on Single Batch Transfer of LHC Type Beams between the CERN PS Booster and the PS

C. Carli, A. Blas, A. Findlay, R. Garoby, S. Hancock, K. Hanke, B. Mikulec, M. Schokker (CERN)

At present, for most LHC type physics beams, six buckets of the PS operated with harmonic number  $h=7$  are filled in two transfers, and each of the PS Booster rings provides only one bunch. The scheme presented aims at replacing the double batch transfer by a single batch transfer and is of interest (i) for the nominal 25 ns LHC beams once the Booster injection energy has been increased after completion of Linac4 and (ii) already now for 50 ns and 75 ns LHC beams less demanding for the Booster in terms of beam brightness. Two bunches with the correct spacing must be generated in the Booster rings by superposition of an  $h=2$  RF system and a smaller  $h=1$  component. Theoretical considerations and first experimental results will be presented.

**Lattice Issues of the CERN PSB with  $H^-$  Charge Exchange Injection Hardware**

The motivation for the construction of CERN Linac4 is to improve the performance of the PSB by raising the injection energy and implementing a new  $H^-$  charge exchange multiturn injection scheme. Strategies to design the  $H^-$  charge exchange injection hardware and, in particular, to mitigate perturbations of the lattice will be reported and the proposed geometry described.

C. Carli, M. Aiba, M. Chanel, B. Goddard, W. J.M. Weterings (CERN)

TH6PFP036

**Low-Beta Insertions Inducing Chromatic Aberrations in Storage Rings and their Local and Global Correction**

As for the final focus systems of linear colliders, the chromatic aberrations induced by low-beta insertions can seriously limit the performance of circular colliders. The impact is two-fold: (1) a substantial off-momentum beta-beating wave travelling all around of the ring leading to a net reduction of the mechanical aperture of the low-beta quadrupoles but also impacting on the hierarchy of the collimator and protection devices of the machine, (2) a huge non-linear chromaticity, essentially  $Q''$  and  $Q'''$ , which, when combined with the geometric non-linear imperfection of the machine could substantially reduce the momentum acceptance of the ring by sending slightly off-momentum particles towards non-linear resonances. These effects will be analyzed and illustrated in the framework of the LHC insertions upgrade and a strategy for correction will be developed, requiring a deep modification of the LHC overall optics.

S. D. Fartoukh (CERN)

TH6PFP037

**Determination of the Chromaticity of the TI 8 Transfer Line Based on Kick Response Measurements**

The 3 km long TI 8 transfer line is used to transfer 450 GeV proton and ion beams from the SPS to LHC collider. As part of a detailed optics investigation program the chromaticity of the transfer line was measured. Kick response data of the transfer line was recorded for various extraction energy offsets in the SPS. The phase change advance was estimated by fitting the main quadrupole strengths of the model to the measured data, which then served as basis for the calculation of the natural chromaticity as well as the quadrupolar and sextupolar field errors over the whole transfer line. We briefly sketch the method and compare the results to the expected values.

K. Fuchsberger, S. D. Fartoukh, B. Goddard, O. R. Jones, V. Kain, M. Meddahi, V. Mertens, J. Wenninger (CERN)

TH6PFP038

**Beam Loss Control for the Unstripped Ions from the PS2 Charge Exchange Injection**

Control of beam losses is an important aspect of the  $H^-$  injection system for the PS2, a proposed replacement of the CPS in the CERN injector complex.  $H^-$  ions may pass the foil unstripped or be partially stripped to excited  $H^0$  states which may be stripped in the subsequent strong-field chicane magnet. Depending on the choice of the magnetic field, atoms in the ground and first excited states

W. Bartmann, J. Barranco, M. Benedikt, B. Goddard, T. Kramer, Y. Papaphilippou, H. Vincke (CERN)

TH6PFP039

can be extracted and dumped. The conceptual design of the waste beam handling is presented, including local collimation and the dump line, both of which must take into account the divergence of the beam from stripping in fringe fields. Beam load estimates and activation related requirements of the local collimators and dump are briefly discussed.

### Machine Studies During Beam Commissioning of the SPS-to-LHC Transfer Lines

M. Meddahi, I. V. Agapov, K. Fuchsberger, B. Goddard, W. Herr, V. Kain, V. Mertens, D. P. Missiaen, T. Risselada, J. A. Uythoven, J. Wenninger (CERN) E. Gianfelice-Wendt (Fermilab)

Through May to September 2008, further beam commissioning of the SPS to LHC transfer lines was performed. For the first time, optics and dispersion measurements were also taken in the last part of the lines, and into the LHC. Extensive trajectory and optics studies were conducted, in parallel with hardware checks. In particular dispersion measurements and their comparison with the beam line model were analysed in detail and led to propose the addition of a “dispersion-free” steering algorithm in the existing trajectory correction program.

### Beam Line Design for the CERN HiRadMat Test Facility

C. Hessler, R. W. Assmann, B. Goddard, M. Meddahi, W. J.M. Weterings (CERN)

other accelerator components such as beam entrance/exit windows and protection devices. For this purpose a dedicated High Radiation Material test facility (HiRadMat) is under study. This facility may be installed at CERN at the location of a former beam line. This paper describes the associated beam line which is foreseen to deliver a 450 GeV proton beam from SPS with an intensity of up to  $3 \cdot 10^{13}$  protons per shot. Different beam line designs will be compared and the choice of the beam steering and diagnostic elements will be discussed, as well as operational issues.

The LHC phase II collimation project requires beam shock and impact tests of materials used for beam intercepting devices. Similar tests are also of great interest for

### The 4 GeV $H^-$ Beam Transfer Line from the SPL to the PS2

M. Meddahi, M. Eshraqi, B. Goddard, C. Hessler, A. M. Lombardi (CERN)

4 GeV SPL to PS2  $H^-$  transfer line. The constraints, beam parameters and geometry requirements are summarised and a possible layout proposed, together with the magnet specifications. First considerations on longitudinal beam dynamics and on beam loss limitations from  $H^-$  lifetime are presented.

The proposed new CERN injector chain LINAC4, SPL, PS2 will require the construction of new beam transfer lines. A preliminary design has been performed for the

### Orbit, Optics and Chromaticity Correction for PS2 Negative Momentum Compaction Lattices

The effect of magnet misalignments in the beam orbit and linear optics functions are reviewed and correction schemes are applied to the negative momentum compaction lattices of PS2. Chromaticity correction schemes are also proposed and tested with respect to off-momentum optics properties. The impact of the correction schemes in the dynamic aperture of the different lattices is finally evaluated.

**Y. Papaphilippou**, J. Barranco, W. Bartmann, M. Benedikt, C. Carli (CERN) S. Peggs, D. Trbojevic, R. de Maria (BNL)

TH6PFP043

### Linear Optics Design of Negative Momentum Compaction Lattices for PS2

In view of the CERN Proton Synchrotron proposed replacement with a new ring (PS2), a detailed optics design as been undertaken following the evaluation of several lattice options. The basic arc module consists of cells providing negative momentum compaction. The straight section is formed with a combination of FODO and quadrupole triplet cells, to accommodate the injection and extraction systems, in particular the  $H^-$  injection elements. The arc is matched to the straight section with a dispersion suppressor and matching module. Different lattices are compared with respect to their linear optics functions, tuning flexibility and geometrical acceptance properties.

**Y. Papaphilippou**, J. Barranco, W. Bartmann, M. Benedikt, C. Carli, B. Goddard (CERN) S. Peggs, D. Trbojevic, R. de Maria (BNL)

TH6PFP044

### Beam-Based Alignment in the New CLIC Main Linac

In the main linac of the compact linear collider (CLIC) the beam induced wakefield and dispersive effects will be strong. In the paper the reference beam-based alignment procedure for the new CLIC parameters is specified and the resulting tolerances for static imperfections are detailed.

**D. Schulte** (CERN)

TH6PFP045

### Dynamic Effects in the New CLIC Main Linac

In the compact linear collider (CLIC) the tolerances on dynamic imperfections are tight in the main linac. In particular the limited beam delivery system bandwidth requires very good RF phase and amplitude stability. Transverse motion of the beam line components is also of concern. The resulting tolerances are detailed in the paper.

**D. Schulte**, R. Tomas (CERN)

TH6PFP046

### CLIC Main Beam Dynamics in the Ring to Main Linac Transport

F. Stulle, L. Rinolfi, D. Schulte (CERN) A. Ferrari (Uppsala University) A. Latina (Fermilab)

Prior to acceleration in the main linac, the particle beams created in the centrally located injector have to be transported to the outer ends of the CLIC site. This transport should not only preserve the beam quality but also shape, characterize and tune the phase space distribution to match the requirements at the entrance of the main linac. Hence, the performance of the transport downstream of the damping rings up to the main linac, the so called RTML, is crucial for the overall performance of CLIC. The RTML consists of a variety of components like bunch compressors, accelerating cavities, spin rotators, collimators, diagnostics sections, feedback and feedforward systems, each serving a distinct function. We discuss the different parts of the RTML and the beam dynamics challenges connected to them. Their status is outlined and results of beam dynamics simulations are presented.

Prior to acceleration in the main linac, the particle beams created in the centrally located injector have to be transported to the outer ends of the CLIC site. This transport

### Modeling the Tevatron Optics through Fourier Analysis of TBT Data

Y. Alexahin, E. Gianfelice-Wendt (Fermilab) V. V. Kapin (MEPhi)

Turn-By-Turn (TBT) data acquired by the Beam Position Monitors (BPMs) following a single kick may be Fourier analyzed to compute the machine tunes and the Mais-Ripken coupled twiss functions value at the BPMs location. The twiss functions are related to the eigenvectors of the one turn transport matrix. Machine quadrupoles and BPMs calibrations and tilts may be varied to match the measured tunes and eigenvectors and get a realistic model of the machine. The advantage with respect to other methods is the rapidity of the data acquisition. An off-line f77 code has been translated into C by using f2c. The code has been embedded in a C++ Tevatron console application for acquiring data and setting the fit parameters. In this paper we describe the method and its application to Tevatron. Results are presented.

Turn-By-Turn (TBT) data acquired by the Beam Position Monitors (BPMs) following a single kick may be Fourier analyzed to compute

### Measurement and Correction of the Fermilab Booster Optics

Y. Alexahin, E. Gianfelice-Wendt, W. Pellico, A. K. Triplett (Fermilab)

One of the major obstacles on the road to higher intensities in medium energy proton synchrotrons is the transverse space charge effect at injection which may lead to fast emittance blowup during bunching. Simulations showed that for such blowup to occur both space charge and focusing errors must be present which break the optics periodicity. Transverse coupling also can be a limiting factor not allowing both tunes to be sufficiently far from parametric resonance. Therefore it is important to accurately measure and correct focusing and coupling perturbations. Upgrade of the Fermilab Booster BPM system has improved the quality of the turn-by-turn data acquired in the ramping mode making it usable for optics reconstruction. In the present report we describe TBT measurements, data analysis and results of the Booster optics correction.

One of the major obstacles on the road to higher intensities in medium energy proton synchrotrons is the transverse space charge effect at injection which may lead to fast



### Lattice Studies for a High Luminosity Muon Collider

Recent advances in the HTS magnet technology and ionization cooling theory have re-launched the interest of the physics community in the realization of a high energy, high luminosity Muon Collider (MC). The large muon energy spread requires large momentum acceptance and the required luminosity calls for beta\* in the mm range. To avoid luminosity degradation due to the hour-glass effect, the bunch length must be comparatively small. To keep the needed RF voltage inside feasible limits the momentum compaction factor must be as small as possible. Under these circumstances chromatic effects correction, energy acceptance, dynamic aperture and longitudinal motion stability are main issues of a MC design. In this paper we give an overview of various lattice designs toward a high luminosity, large energy acceptance MC currently under study at Fermilab.

Y. Alexahin, E. Gianfelice-Wendt (Fermilab)

### Muon Collider Lattice with Local Interaction Region Chromaticity Correction

Muon collider is a promising candidate for the next energy frontier machine. In order to obtain peak luminosity of the order of

$1 \cdot 10^{35} / \text{cm}^2 / \text{s}$  in the TeV energy range the beta function at the interaction point should be smaller than 1cm. To obtain correspondingly small bunch length with a reasonable RF voltage (within 1GV) the momentum compaction factor should be smaller than  $1 \cdot 10^{-4}$  in the momentum range  $\sim 1\%$ . The lattice design must also provide sufficient dynamic aperture for  $\sim 20$  microns normalized beam emittance and minimum possible circumference. Together these requirements present a challenge which has never been met before. We offer a solution to this problem which has the following distinctive features: i) chromatic compensation achieved with sextupoles and dispersion generating dipoles placed near the IR quadrupoles (not in a special section), ii) low value of momentum compaction factor obtained by balancing positive contribution from the arcs with negative contribution from the suppressors of the generated in the IR dispersion. Theoretical aspects and various options will be discussed.

Y. Alexahin, E. Gianfelice-Wendt (Fermilab)

### A Simple Transition-Free Lattice of an 8 GeV Proton Synchrotron

A transition-free lattice is a basic requirement of a high-intensity medium-energy (several GeV) proton synchrotron in order

to eliminate beam losses during transition crossing. An 8 GeV synchrotron is proposed as a principal component in an alternative approach to Project X\*. This machine would be housed in the Fermilab antiproton source enclosure replacing the present Debuncher. A simple FODO lattice with high transition gamma has been designed. It uses just one type of dipoles and one type of quadrupoles (QF and QD are of same length). It has no transition crossing. It has a triangular shape with three zero dispersion straight sections, which can be used for injection, extraction, RF and collimators. The beta-functions and dispersion are low. This lattice has plenty of free space (for correctors and diagnostic devices) and good optical properties (e.g. large dynamic aperture, weak dependence of lattice functions on amplitude and momentum deviation).

\*W. Chou, "An Alternative Approach to Project X," this conference.

W. Chou (Fermilab)

### Linear and Nonlinear Beam Optics Studies in the SIS18

A. S. Parfenova, G. Franchetti (GSI)

The GSI heavy ion synchrotron SIS18 will be used as a booster for the SIS100 synchrotron of the new FAIR facility. The linear corrections and measurements are a necessary step before the nonlinear field errors can be applied. A tune response to a change in a sextupole magnet strength for a certain Closed Orbit (CO) deformation is used to verify beta-functions of the SIS18 model at the location of the ring's sextupoles for chromaticity correction. The progress in development of Nonlinear Tune Response Matrix (NTRM) technique to diagnose nonlinear field components is presented.

### Beam Dynamics Design of Debuncher System for J-PARC Linac Energy Upgrade

M. Ikegami (KEK) T. Morishita, H. Sako (JAEA/J-PARC) T. Ohkawa (Mitsubishi Heavy Industries, Ltd, MHI)

The output energy of J-PARC linac is planned to be upgraded from 181 MeV to 400 MeV by adding an ACS (Annular Coupled Structure linac) section. The debuncher system for J-PARC linac is also replaced in this energy upgrade. The new debuncher system will consist of two 972-MHz debuncher cavities with the separate-function configuration. In this configuration, the momentum jitter is corrected with the first debuncher, whereas the momentum spread is controlled with the second debuncher. This configuration is advantageous in simplifying the tuning procedure, and it is also beneficial in reducing the nonlinear effects of the debuncher cavities. In this paper, the beam dynamics design of the debuncher system is presented with some simulation results.

### Beam Dynamics Studies for a Neutrino Factor Decay Ring

M. Apollonio, M. Aslaninejad, J. Pasternak (Imperial College of Science and Technology, Department of Physics)

The Race Track design for the Decay Ring of a Neutrino Factory is studied with MADX. Optimisation of the working point, study of resonances, effects of misalignment and perturbation on the magnet elements, chromaticity and the problem of injection are considered. The extension of this study to other rings is discussed.

### Emittance Generation in MICE

M. Apollonio (Imperial College of Science and Technology, Department of Physics)

The Muon Ionisation Cooling Experiment (MICE) at RAL will be the first apparatus to study muon cooling at high precision. Muons are produced along a transport beam line in a super-conducting solenoid via pion decay and the final beam emittance is generated by tuning the quadrupoles for beam size matching the beam angular divergence in a variable-thickness diffuser, designed as a re-entrant mechanism inside the first solenoid, automatically changeable in a few minutes from 0 to 4X0. The initial normalized emittance of the beam (few mm rad) will be inflated up to 10 mm rad in order to cover the  $(e, P)$  matrix required by the experiment. Beam line tuning and details of the diffuser are presented.

### Orbit Response Matrix (ORM) Study of SNS Ring

Correction of the linear optics is an important step to improve the accelerator performance. A response matrix method\* has been implemented in the SNS ring, which identified the linear errors including calibration errors from quadrupole power supplies, and BPM and steering magnets offsets. These errors have been corrected, and resulting improvements in the high level application will be reported.

Z. Liu, S.-Y. Lee (IUCF) S. M. Cousineau, J. A. Holmes, M. A. Plum (ORNL) X. Huang (SLAC)

\*J. Safranek, "Experimental determination of storage ring optics using closed orbit response measurements", Nucl. Inst. and Meth. A388, (1997), pg. 27

### Beam Based Alignment Simulations and Measurements at the S-DALINAC

Operational Experience at the Darmstadt superconducting linac (S-DALINAC) showed unexpected effects on beam dynamics and beam quality.

F. Hug (TU Darmstadt)

So operators could observe transverse beam deflections by changing phases of the SRF-Cavities. Furthermore there has been occurred a growth of normalized transverse emittance by a factor of 2. The beam current in the S-DALINAC does not exceed  $60 \mu\text{A}$  so space-charge effects could be eliminated to be the reason for the observations. In this work the effect of misalignment of the SRF-Cavities in the linac has been examined using beam-dynamic simulations with the tracking code GPT and measurements on the electron beam of the S-DALINAC. By measuring the transverse deflection of the beam by changes of the phases of the SRF-Cavities and comparing results with GPT-simulations a misalignment of the 5-cell capture cavity and first 20-cell cavity of several mm in both transverse directions could be found. This misalignment can explain transverse deflections as well as emittance growth. A correction of misalignment has been carried out using the described results. First measurements showed no more emittance growth and less beam-deflections by SRF-Cavities.

### Touschek Background and Lifetime Studies for the SuperB Factory

The novel crab waist collision scheme under test at the DAFNE Frascati phi-factory finds its natural application to the SuperB project, the asymmetric  $e^+e^-$  flavour factory at very high luminosity with low beam currents and reduced background possibly located at Tor Vergata University.

M. Boscolo, M. E. Biagini, P. Raimondi (INFN/LNF) E. Paoloni (University of Pisa and INFN) M. K. Sullivan (SLAC)

The SuperB accelerator design requires a careful choice of beam parameters to reach a good trade-off between different effects. We present here simulation results for the Touschek backgrounds and lifetime obtained for the latest machine design. Distributions of the Touschek particle losses at the at the interaction region have been tracked into the detectors for further investigations. A set of collimators is foreseen to stop Touschek particles. Their position along the rings has also been studied, together with their shape optimization.

### Design of Beam Monitor Configuration for Upgraded 400-MeV J-PARC Linac

H. Sako, M. Ikegami, T. Morishita, S. Sato (JAEA/J-PARC)

The beam energy of J-PARC LINAC is planned to be upgraded from currently operated 181 MeV to 400 MeV by installation of ACS (Annular Coupled Structure linac). We have been designing configurations of beam diagnostics devices for the new linac; Beam Position Monitors (BPM's), Current Transformers (CT's), Wire Scanners (WS's) and Bunch Shape Monitors (BSM's) located at MEBT2 (Medium Energy Beam Transport), ACS, and L3BT (Linac to 3GeV-RCS Beam Transport). The design is based on beam dynamics studies for tuning schemes of beam energy measurements, orbit corrections, and transverse and longitudinal beam matching. Designed monitor configurations and preliminary simulation results especially focused on longitudinal matching scheme with BSM will be presented.

### Direct Methods of Optimization of Storage Ring Dynamic and Momentum Aperture

M. Borland (ANL)

Optimization of dynamic and momentum aperture is one of the most challenging problems in storage ring design. For storage-ring-based x-ray sources, large dynamic aperture is sought primarily to obtain high injection efficiency, which is important in efficient operation but also in protecting components from radiation damage. X-ray sources require large momentum aperture in order to achieve workable Touschek lifetimes with low emittance beams. The most widely applied method of optimizing these apertures is to minimize the driving terms of various resonances. This approach is highly successful, but since it is based on perturbation theory, it is not guaranteed to give the best result. In addition, the user must somewhat arbitrarily assign weights to the various terms. We have developed several more direct methods of optimizing dynamic and momentum aperture. These have been successfully applied to operational and design problems related to the Advanced Photon Source and possible upgrades.

### Measure of Dynamic Aperture Using the RHIC AC Dipole

M. Bai, F. C. Pilat, V. Ptitsyn (BNL)

As one of the critical parameters for a high energy collider, the dynamic aperture (DA) can be measured by blowing up the emittance with a kicker. We used this technique successfully at RHIC for comparative DA studies and we will recall the results. This technique can however be limited at high energy by insufficient kicker strength. In RHIC, we also explored the alternative technique of using the RHIC AC dipoles to induce coherent betatron oscillations as a way to measure DA. Experimental setup and results are discussed and compared with kicker based DA measurements.

### Touschek Lifetime Calculations for NSLS-II

B. Nash, S. L. Kramer (BNL)

The Touschek effect limits the lifetime for NSLS-II. The basic mechanism is Coulomb scattering resulting in a longitudinal momentum outside the momentum aperture. We present calculations for NSLS-II using a realistic lattice model including damping wigglers and engineering tolerances. Several effects are considered, such as physical apertures due to small vertical gaps in insertion devices, and the effect of increased chromaticity. Finally, we compare the results of analytical expressions for Touschek lifetime: the more accurate Piwinski equation is compared to Bruck's more approximate result.

### Impact of Higher-Order Multipole Errors in the NSLS-II Quadrupoles and Sextupoles on Dynamic and Momentum Aperture

Successful operation of NSLS-II requires sufficient dynamic aperture for injection, as well as momentum aperture for Touschek

B. Nash (BNL)

lifetime. We explore the dependence of momentum and dynamic aperture on higher-order multipole errors. For the momentum aperture, we find a surprising result in that for negative momentum deviation, multipole errors in the dispersion region cause a substantial decrease. This is traced to the fact that these off-momentum particles undergo large orbit deviations in the dispersion region which may bring the particles as far as 30 mm off axis for -2.5% energy deviation. This is close enough to the magnet poles, that the field errors impact the dynamic aperture. Increasing the bore radius of the quadrupoles and sextupoles in the dispersion region can decrease the higher-order multipoles and improve the dynamic aperture.

TH6PFP065

### The Correction of Linear Lattice Gradient Errors Using an AC Dipole

Precise measurement of optics from coherent betatron oscillations driven by ac dipoles have been demonstrated at RHIC and the

G. Wang, M. Bai, V. Litvinenko, T. Satogata (BNL)

Tevatron. For RHIC, the observed rms beta-beat is about 10%. Reduction of beta-beating is an essential component of performance optimization at high energy colliders. A scheme of optics correction was developed and tested in the RHIC 2008 run, using ac dipole optics for measurement and a few adjustable trim quadrupoles for correction. In this scheme, we first calculate the phase response matrix from the measured phase advance, then apply a singular value decomposition (SVD) algorithm to the phase response matrix to find correction quadrupole strengths. We present both theory and experimental results of this correction for the RHIC 2009 run.

TH6PFP066

### Analysis of Henon Map by Linear Algebraic Method

We present a newly developed method to analyze some non-linear dynamics problems such as the Henon map using a linear

L.-H. Yu, B. Nash (BNL)

matrix analysis method in linear algebra. Using the Henon map as an example, we analyze the spectral structure, the tune-amplitude dependence, the variation of tune and amplitude during the particle motion, etc., using the method of analysis of eigenvectors in Jordan spaces which is widely used in conventional linear algebra.

TH6PFP067

### Simulation of Particle Behavior in RCS of CSNS with Simpsons

We will simulate the single and multi particle behavior in the rapid cycling synchrotron (RCS) in Chinese Spallation Neutron Source (CSNS) using the code Simpsons. We also discuss single and multi particle behavior.

S. Y. Xu, S. Wang (IHEP Beijing)

TH6PFP068

### Design and Applications of an RF Traveling-Wave Transverse Deflector

J. R. Zhang (IHEP Beijing)

A 480mm long traveling-wave RF deflector is designed. It includes 9 cells and two couplers. The RF frequency is 2856MHz for our usable source. The mode is HEM<sub>11</sub> and per cell shift phase is . The brillouin curve was simulated and tested. On the test station of RF gun at Shanghai Deep-UV FEL, some tests are made and bunch length is measured.

### Effect of the Magnetic Multipoles in the ALBA Performance

M. Munoz, D. Einfeld, Z. Martí (ALBA)

The Spanish synchrotron light source ALBA is in the process of installation, with the large majority of components already manufactured and delivered. Among them, the magnets of the storage ring. As part of the acceptance process of the magnets, a campaign to measure the quality of them (magnetic length, effective bending and focusing, high order multipolar components) has been performed in-house and in the manufacturer. The results of this measures have been applied to the model of the storage ring, analyzing the effects in the performance (lifetime, dynamic aperture, orbit, etc). The results of the study confirm the quality of the magnet's design and manufacturing as well as the performance of the lattice.

### A New Technique for the Correction of Nonlinear Resonances in Synchrotrons

R. Bartolini, I. P.S. Martin, J. Rowland (Diamond) P. Kuske (BESSY GmbH) F. Schmidt (CERN)

A new method for the correction of nonlinear resonances in storage rings has been developed and tested at the Diamond Light Source. This method is based on the frequency analysis of the betatron motion and its connection to the nonlinear resonances driving terms. The experimental results on the correction of the nonlinear resonances are reported. Frequency Maps, dynamic aperture and lifetime measurements are used to confirm the improvement of the machine performance.

### Controlled Transverse Emittance Blow-Up in the CERN SPS

E. Métral, G. Arduini, F. Arnold Malandain, W. Höfle, D. Manglunki (CERN)

For several years, a large variety of beams have been prepared in the LHC injectors, such as single-bunch and multi-bunch beams, with 25 ns, 50 ns and 75 ns bunch spacings, nominal and intermediate intensities per bunch. As compared to the nominal LHC beam (i.e. with nominal bunch intensity and 25 ns spacing) the other beams can be produced with lower transverse emittances. Beams of low transverse emittances are of interest during the commissioning phase for aperture considerations and because of the reduced long-range beam-beam effects. On the other hand machine protection considerations might lead to prefer nominal transverse emittances for safe machine operations. The purpose of this paper is to present the results of controlled transverse emittance blow-ups using the transverse feedback and octupoles. The procedures tested in the SPS in 2008 allow to tune the transverse emittances up to nominal values at SPS extraction.

### Solenoid and Synchrotron Radiation Effects in CLIC

The emission of Synchrotron Radiation in the CLIC BDS is one of the major limitations of the machine performance. An extensive revision of this phenomenon is presented with special emphasis on the IP solenoid.

**B. Dalena**, D. Schulte, R. Tomas (CERN) D. Angal-Kalinin (STFC/DL/ASTeC)

TH6PFP074

### Measurement and Correction of Resonances in SOLEIL

The successful correction of non-linear resonances in DIAMOND using the BPM turn-by-turn data has motivated testing this approach in SOLEIL in collaboration with CERN. We report on the first experiences towards the correction of non-linear resonances in SOLEIL.

**R. Tomas**, M. Aiba, G. Vanbavinckhove (CERN) R. Calaga (BNL) A. Loulergue, A. Nadji, L. S. Nadolski, M.-A. Tordeux (SOLEIL)

TH6PFP075

### Schottky Diagnostics in the ANKA Storage Ring

The status of longitudinal and transverse Schottky observation systems for the synchrotron light source ANKA is presented. ANKA regularly operates in a dedicated low alpha mode with short bunches for the generation of coherent THz radiation. The Schottky measurement results are shown and compared with theoretical predictions for the regular as well as the different stages of the low alpha mode of operation. Special care had to be taken to control and mitigate the impact from strong coherent lines of the short bunches on the signal processing chain. The system setup is shown, expected and unexpected observations as well as applications are discussed.

**K. G. Sonnad**, I. Birkel, S. Casalbuoni, E. Huttel, N. J. Smale (FZK) F. Caspers (CERN) N. Hiller, A.-S. Muller, **K. G. Sonnad** (University of Karlsruhe) R. Weigel (Max-Planck Institute for Metal Research)

TH6PFP076

### Automating the Computation of Quadrupole Transfer Maps and Matrices Utilizing Magnetic Field Solutions

An automated procedure for the calculation of particle transfer maps using computed magnetic field data has been developed for several types of magnetic quadrupoles. The Automated Transfer Map Generator (ATMG) software used for these calculations combines the Analyst program and specialized modules of the Particle Beam Optics Laboratory (PBO Lab). Analyst's scripted solids capability is used to develop models of different magnet concepts. The geometry and material attributes for a given magnet concept are encapsulated by a small number of magnet parameters. Quadrupoles of the same basic concept can be simulated by using different values for the magnet parameters. The three-dimensional magnetic field solver (MS3p) of the Analyst program is used to obtain the fields. New PBO Lab modules are used to automate the field computation, and then calculate the transfer maps and matrices through third-order using the Venturini-Dragt method. Examples for three different types of magnetic quadrupole lenses are presented: electromagnetic air-core, electromagnetic iron-core, and rare-earth permanent magnet quadrupoles.

**G. H. Gillespie**, W. Hill (G. H. Gillespie Associates, Inc.) J. F. DeFord, B. Held (STAR, Inc.)

TH6PFP077

TH6PFP078

### Stability Boundary of Ion Beams in the FAIR Storage Rings

A. Dolinskyy, C. Dimopoulou, O. E. Gorda, S. A. Litvinov, F. Nolden, C. Peschke, F. Steck (GSI)

The FAIR Storage Rings (CR, RESR and NESR) are designed for efficient cooling, accumulation, deceleration and performing nuclear physics experiments with antiproton and rare isotopes beams. Tracking studies for all these rings have been performed to estimate the dynamic aperture and other properties of beam stability depending on the low and high field multipole components, fringe fields and field interference. The multipole limits have to be determined in order to provide a reasonable estimate of the stability boundary and needed correction of the low field multipoles. We report on quantitative studies of the effects of multipoles on the dynamic aperture of the rings, and show that the systematic multipole components in the present magnet designs are unlikely to impose a severe limitation.

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TH6PFP079

### Study of Integer Betatron Resonance Crossing in Scaling FFAG Accelerator

Y. Mori (KEK) A. Osanai (KURRI)

Complex at Kyoto University Research Reactor Institute (KURRI). The results were analyzed based on harmonic oscillator model and compared with beam tracking simulations.

Crossing of integer resonance in scaling FFAG accelerator has been studied experimentally with the injector of 150MeV FFAG

TH6PFP080

### Symplectic Expression for Chromaticity

Y. Seimiya, H. Koiso, K. Ohmi (KEK)

This is because many kinds of factor cause error, like machine error, so we can't include such error exactly in SAD. Therefore, on the contrary, we consider the model which includes error by using measurement data and derive Hamiltonian from it.

The value calculated by using general-purpose computer code SAD for the accelerator is sometimes different from actual measurements.

TH6PFP081

### Resonance Driving Term Experiment at DAFNE

C. Milardi (INFN/LNF) F. Schmidt (CERN)

A resonance driving term experiment has been performed at the Daphne accelerator in Frascati. This experiment makes use of a technique developed at CERN that uses a harmonic analysis of BPM data to determine resonance driving terms caused by linear and nonlinear imperfections. The aim has been to measure the longitudinal variation of sextupole nonlinear resonance terms and coupling resonances caused by skew quadrupoles. An essential part of this study consists of comparing these experimental results with model calculations using MADX/PTC. To this end, the particle positions are recorded at the location of the BPMs in the model followed by the same harmonic analysis of these model data.

A resonance driving term experiment has been performed at the Daphne accelerator in Frascati. This experiment makes use of a technique developed at CERN that uses a harmonic analysis of BPM data to determine resonance driving terms caused by linear and nonlinear imperfections. The aim has been to measure the longitudinal variation of sextupole nonlinear resonance terms and coupling resonances caused by skew quadrupoles. An essential part of this study consists of comparing these experimental results with model calculations using MADX/PTC. To this end, the particle positions are recorded at the location of the BPMs in the model followed by the same harmonic analysis of these model data.



**Formation of a Uniform Ion Beam Using Multipole Magnets**

It is possible to fold the tails of the transverse beam profile into the inside, or even to uniformize the beam distribution in the properly-designed nonlinear beam transport system. A two-dimensionally uniform beam profile was formed using sextupole and octupole magnets at the azimuthally-varying-field cyclotron facility of Japan Atomic Energy Agency. Such a uniform beam exhibits a unique feature in the viewpoint of a uniform irradiation system; as compared to the raster scanning system, it enables us to perform uniform irradiation over the whole area of a large sample at a constant particle fluence rate. For the application of materials sciences, uniformization of heavy-ion beams as well as protons has been performed. In order to reduce undesirable beam halos at the target, tail-folding of the spot beam is also planned using the nonlinear focusing method.

**Y. Yuri**, I. Ishibori, T. Ishizaka, S. Okumura, W. Yokota, T. Yuyama (JAEA/TARRI) S. Kubono, Y. Ohshiro, S.-I. Watanabe (CNS)

TH6PFP082

**Study of Diffusion in Action Space Using the Fokker-Planck Equation with PIC Simulation of Beam-Beam Interactions**

When the beam-beam parameter of a storage-ring collider is close to its threshold of chaotic coherent beam-beam instability, the beam particle distribution in transverse phase space deviates from a Gaussian distribution significantly. Because of beam-beam perturbations, the chaotic diffusion of particles from beam core to beam tails could result in a formation of beam halo. To study this beam-beam interaction induced chaotic diffusion, a computational method based on the Fokker-Planck equation has been developed to study the dynamics of the diffusion coefficient in action space by using the particle-in-cell simulation of beam-beam interactions. A study of the diffusion coefficient in phase space could provide information of the beam lifetime.

**J. Shi** (KU)

TH6PFP083

**Experimental Frequency Map Analysis Using Multiple BPMs**

Frequency map analysis is being widely used, nowadays, both in simulations to design or improve accelerator lattices, as well as in experiments to study the transverse nonlinear dynamics in accelerators. A significant challenge to the use of frequency map analysis in experiments is the usually very fast decoherence of transverse oscillations, caused by the large nonlinearities of state-of-the-art lattices. Due to the decoherence, the center of mass oscillations of bunches often disappear in less than 100 turns. A potential way to get around this limitation is the use of multiple BPMs distributed (symmetrically) around the storage ring. The presentation will describe the challenges multi-BPM frequency map analysis poses as well as initial results using the ALS.

**C. Steier**, D. Robin, L. Yang (LBNL)

TH6PFP084

**Beam Dynamics Studies for the FRIB Driver Linac**

A driver linac has been designed for the proposed Facility for Rare Isotope Beam (FRIB) at Michigan State University. FRIB is a lower cost and reduced scope alternative to the Rare Isotope Accelerator (RIA) project. The superconducting driver linac will accelerate stable isotope beams to

**Q. Zhao**, M. Doleans, D. Gorelov, F. Marti, T. P. Wangler, X. Wu, R. C. York (NSCL) J. Qiang (LBNL)

TH6PFP085

energies  $\geq 200$  MeV/u with a beam power up to 400 kW for the production of rare isotope beams. The driver linac consists of a front-end and two segments of superconducting linac connected by a charge stripping station. End-to-end beam simulation studies with high statistics have been performed using the RIAPMTQ and IMPACT codes on high performance parallel computers. These studies include misalignment of beam elements, rf amplitude and phase errors for cavities, and thickness variation of the stripping foil. Three-dimensional fields of the superconducting solenoids and cavities were used in the lattice evaluation. The simulation results demonstrate good driver linac performance. No uncontrolled beam losses were observed even for the challenging case of multiple charge state uranium beam acceleration. The beam dynamics issues will be discussed and the detail beam simulation results presented.

### Single Particle Dynamics in the University of Maryland Electron Ring

E. W. Nissen, B. Erdelyi (Northern Illinois University)

We undertake a study of the single particle dynamics in a model of the University of Maryland Electron Ring. This accelerator uses a low energy electron beam to study the effects of space charge on beam dynamics. However, due to this low energy, other effects that are seldom taken into account in high energy accelerators become important to the single particle dynamics of the beam. The simulation is performed using COSY Infinity, which allows further analysis of amplitude dependent tunes, as well as arbitrary integration order. The analysis includes the Earth's magnetic field, modeled using the Baker-Campbell-Hausdorff theorem, as a series of angular kicks. The analysis also includes the effects of image charges on the beam during injection and recirculation. The sixth order calculations also include theoretical magnetic field and alignment errors. These high order calculations allow for detailed examination of the steering solutions both in the injection assembly, and during recirculation. Furthermore the analysis includes an exhaustive search of the tune space to determine the optimum dynamic aperture, both for intercepting and recirculating experiments.

### Limiting Effects in the Transverse-to-Longitudinal Emittance Exchange for Low Energy Relativistic Electron Beams

M. M. Rihaoui, P. Piot (Northern Illinois University) W. Gai, J. G. Power (ANL)

Transverse to longitudinal phase space manipulation hold great promises, e.g., as a potential technique for repartitioning the emittances of a beam. A proof-of-principle experiment to demonstrate the exchange of a low longitudinal emittance with a larger transverse emittance is in preparation at the Argonne Wakefield Accelerator using a 15 MeV electron beam. In this paper we explore the limiting effects of this phase space manipulation method associated to high order optics and collective effects. A realistic start-to-end simulation of the planned proof-of-principle experiment including jitter studies is also presented.

### Integrable Accelerator Lattices with Periodic and Exponential Invariants

V. V. Danilov (ORNL)

The paper presents a new variety of one-dimensional nonlinear integrable accelerator lattices with periodic and exponential invariants in coordinates and momenta. Extension to two-dimensional transverse motion, based on a recently published approach\*, is discussed.

\*V. Danilov, "Practical Solutions for Nonlinear Accelerator Lattice with Stable Nearly Regular Motion", Phys. Rev. ST AB 11, 114001 (2008)

### Beam Transverse Issues at the SNS Linac

The Spallation Neutron Source (SNS) linac system is designed to deliver 1 GeV pulsed  $H^-$  beams up to 1.56 MW for neutron production. As beam power was increased from 10 kW to 660 kW in less than three years, beam loss in the accelerator systems – particularly in the superconducting linac (SCL), became more significant. In the previous studies, unexpected beam loss in the SCL was mainly attributed to longitudinal problems. However, our most recent simulations have focused on beam transverse effects. These include multipole components from magnet imperfections and dipole corrector windings of the linac quadrupoles. The effect of these multipoles coupled with other errors will be discussed.

Y. Zhang, A. V. Aleksandrov, C. K. Allen, J. Galambos, J. A. Holmes, J. G. Wang (ORNL)

### Adiabatic Formation and Properties of a Quasi-Equilibrium Beam Distribution Matched to a Periodic Focusing Lattice

This paper reports on recent advances in the development of a numerical scheme for describing the quiescent loading of a quasi-equilibrium beam distribution matched to a periodic focusing lattice\*. The scheme allows for matched-beam distribution formation by means of the adiabatic turn-on of the oscillating focusing field, and it is examined here for the cases of alternating-gradient quadrupole and periodic solenoidal lattices. Furthermore, various distributions are considered for the initial beam equilibrium. The self-similar evolution of the matched-beam density profile is observed for arbitrary choice of initial distribution function and lattice type. The numerical simulations are performed using the WARP particle-in-cell code.

\* M. Dorf et al., Phys. Rev. ST Accel. Beams, submitted for publication(2009).

M. Dorf, R. C. Davidson, H. Qin, E. Startsev (PPPL)

### Non-Abelian Courant-Snyder Theory for Coupled Transverse Dynamics of Charged Particles in Electromagnetic Focusing Lattices

Courant-Snyder theory gives a complete description of the uncoupled transverse dynamics of charged particles in electromagnetic focusing lattices. In this paper, Courant-Snyder theory is generalized to the case of coupled transverse dynamics with two degree of freedom. The generalized theory has the same structure as the original Courant-Snyder theory for one degree of freedom. The four basic components of the original Courant-Snyder theory, i.e., the envelope equation, phase advance, transfer matrix, and the Courant-Snyder invariant, all have their counterparts, with remarkably similar expressions, in the generalized theory presented here. The unique feature of the generalized Courant-Snyder theory is the non-Abelian (non-commutative) nature of the theory. In the generalized theory, the envelope function is generalized into an envelope matrix, and the envelope equation becomes a matrix envelope equation with matrix operations that are not commutative. The generalized theory gives a new parameterization of the 4D symplectic transfer matrix that has the same structure as the parameterization of the 2D symplectic transfer matrix in the original Courant-Snyder theory.

H. Qin, R. C. Davidson (PPPL)

### SuperB Factory Dynamic Aperture Study and Optimization

E. B. Levichev, P. A. Piminov (BINP SB RAS) M. E. Biagini, P. Raimondi, M. Zobov (INFN/LNF) D. Quattraro (CERN) W. Wittmer, G. Yocky (SLAC)

The project of the SuperB Factory with crab-waist collision scheme and extremely large luminosity addresses new challenges to the nonlinear beam dynamics study. Among these challenges are: low emittance lattice requiring strong sextupoles for chromatic correction, sub-mm vertical betatron function at the IP, crab sextupoles placed at both sides from the IP, space charge nonlinearities, which are not negligible for such low vertical emittance, spin rotators to receive the longitudinally polarized electron beam at the collision point, etc. In the paper we describe the results of the SuperB dynamic aperture study including the optimization of the arrangement of sextupoles and octupoles and the adjustment of the tune point for both large aperture and luminosity.

The project of the SuperB Factory with crab-waist collision scheme and extremely large luminosity addresses new challenges to the nonlinear beam dynamics study. Among these challenges are: low emittance lattice

### Study of the Nonlinear Beam Dynamics in Storage Ring with Strong Damping and Space Charge

E. B. Levichev, P. A. Piminov, D. N. Shatilov (BINP SB RAS)

damping rings, in which an extremely low vertical emittance is expected. We have studied the beam motion dynamically during the damping in the presence of the space charge effects and the realistic magnetic lattice with strong chromatic sextupoles and other nonlinearities. Such issues as the dynamic aperture, particles trapping in resonances, beam blow-up, and particles distribution deterioration, etc. are discussed.

Strong radiation damping and space charge effect introduce new features in the nonlinear motion of particles in the linear collider

### SPEAR3 Nonlinear Dynamics Tracking and Measurements

J. A. Safranek, W. J. Corbett, X. Huang, J. J. Sebek, A. Terebilo (SLAC)

method of measuring  $(x, y)$  frequency maps by exciting vertical oscillations using a strip line driven with a swept frequency. When the vertical oscillations reach the desired amplitude, the drive is cut, and an injection kicker excites horizontal oscillations. The subsequent free horizontal and vertical betatron oscillations are digitized turn-by-turn. We have used measured and tracked frequency maps in  $(x, y)$  and  $(x, \text{energy})$  to characterize and optimize the dynamic aperture, injection and lifetime of the SPEAR3 low emittance optics.

We present nonlinear dynamics measurements and tracking for the SPEAR3 storage ring. SPEAR3 does not have a vertical pinger magnet, so we have developed a

### Linear and Non-Linear Model Optimisation for SOLEIL Storage Ring

M.-A. Tordeux, P. Brunelle, A. Loulergue, A. Nadji, L. S. Nadolski (SOLEIL)

storage ring lattice model has been improved. First, the quadrupole lengths in the hard edge model were finely tuned to get good agreement with the experimental measurements of betatron tunes for different optics. Second, the non-linear model was modified to better fit with beam-based on-momentum frequency map measurements. A thick sextupole model has been introduced in addition to the non-linear effect of the fringe field in quadrupoles.

SOLEIL, the French 2.75 GeV third generation synchrotron light source, was commissioned 3 years ago. Thanks to beam-based measurements, the theoretical model of the

Simulated and measured tune shifts with transverse amplitudes are then compared. Finally a coupled machine model has been built thanks to crosstalk closed orbit acquisitions. A comparison with another model which is based on turn by turn beam position monitor data is presented. As a validation check, the coupling effect of the 10 m long HU640 undulator is evaluated through these coupled models.

### Analytical Calculation of the Smear for Long-Range Beam-Beam Interactions

The Lie-algebraic method is used to construct the non-resonant Courant-Snyder invariant (effective Hamiltonian) in the presence of an arbitrary number of long-range beam-beam interactions. Although only horizontal, the invariant includes the effects of alternating (horizontal and vertical) crossings in the LHC. The BCH concatenation of long-range kicks is carried out in action-angle coordinates and to first order in beam-beam parameter. Tracking evidence (a simple kick-matrix or Sixtrack) is presented to illustrate that with the LHC parameters and in absence of any other lattice perturbations the invariant is indeed preserved. The theory is used to extract the smear of the horizontal emittance and tune-shift as a function of initial amplitude. Examples are given for the "D0-first" LHC-upgrade scenario.

D. Kaltchev (TRIUMF) W. Herr (CERN)

TH6PFP096

### Beam Dynamics Optimization of the TRIUMF e-Linac Injector

TRIUMF proposes a 1/2 MW electron linac (e-linac) for radioactive ion beam production via photofission. The e-linac is to operate CW using 1.3 GHz superconducting (SC) technology. The accelerator layout consists of a 100 keV thermionic gun, a normal conducting buncher, an injector module, and main linac modules accelerating to a final energy of 50 MeV. The design beam current is 10 mA. The beam dynamics of the injector, where electrons make the transition to the fully relativistic state, has been identified as the most critical part of the design and is the subject of simulations (starting at the gun cathode) using realistic EM fields in PARMELA and TRACK. CW operation demands the novel choice of adopting an SC capture section. A preliminary design of the injector foresees a capture section composed either of two independent or two coupled single-cell cavities,  $\beta < 1$ , that increase the energy to about 500 keV, followed by one nine-cell cavity that boosts the energy up to 10 MeV. The design parameters are subjected to a global optimization program. In this paper we present results from the beam dynamics study as well as details and final outcome of the optimization process.

M. Marchetto, R. A. Baartman, Y.-C. Chao, S. R. Koscielniak, R. E. Laxdal, F. Yan (TRIUMF) N. Vaishali (DAE/VECC)

TH6PFP097

### Studies of the $\nu_r=3/2$ Resonances in the TRIUMF Cyclotron

The TRIUMF cyclotron is 6-fold symmetric, but has a 3rd harmonic magnetic field gradient error. As well, there is a 3rd harmonic component generated from the beating of the primary harmonics with the 9th harmonic. Both can contribute and drive the  $\nu_r=3/2$  resonance. As a consequence, the radial phase space ellipses become stretched and mismatched; this introduces a radial modulation of beam density and thereby causes a sensitivity of the extracted current to, for example, small changes in rf voltage. The cyclotron has "harmonic" correction coils, but these were designed to generate a first harmonic, not a third harmonic. Their 6-fold symmetric layout can only generate a 3rd harmonic at one particular phase and so can only partially compensate for this resonance. For a complete compensation,

Y.-N. Rao, G. Dutto, L. W. Root (TRIUMF)

TH6PFP098

the 6 pairs of this harmonic coil would have to shift in azimuth by  $\sim 30$ deg. This paper describes the simulations performed with COMA to study the effect of this resonance. Initial measurement results are also presented.

### Fast, Accurate Calculation of Dynamical Maps from Magnetic Field Data Using Generalised Gradients

D. Newton (The University of Liverpool) D. Newton, A. Wolski (Cockcroft Institute)

Analytic descriptions of arbitrary magnetic fields can be calculated from the generalised gradients\* of the on-axis field. Using magnetic field data, measured or computed on

the surface of a cylinder, the generalised gradients can be calculated by solving Laplace's equation to find the three-dimensional multipole expansion of the field within the cylinder. After a suitable transformation, this description can be combined with a symplectic integrator allowing the transfer map to be calculated. A new tracking code is under development in C++, which makes use of a differential algebra class to calculate the transfer map. The code has been heavily optimised to give a fast, accurate calculation of the transfer map for an arbitrary field. The multipole nature of the field description gives additional insights into fringe-field and pseudo-multipole effects and allows a deeper understanding of the beam dynamics.

\*Venturini M. and Dragt A., NIM Phys. Res. Sect. A, 427, 387 (1999)

### Computation of Transfer Maps from Surface Data with Applications to LHC Quadrupoles and ILC Damping Ring Wigglers

C. E. Mitchell (UMD)

Transfer maps for magnetic elements in storage and damping rings can depend sensitively on nonlinear fringe-field and high-order-

multipole effects. The inclusion of these effects requires a detailed and realistic model of the interior and fringe magnetic fields, including their high spatial derivatives. A collection of surface fitting methods has been developed for extracting this information accurately from 3-dimensional magnetic field data on a grid, as provided by various 3-dimensional finite element field codes. The virtue of surface methods is that they exactly satisfy the Maxwell equations and are relatively insensitive to numerical noise in the data. These techniques can be used to compute, in Lie-algebraic form, realistic transfer maps for LHC final-focus quadrupoles and for the proposed ILC Damping Ring wigglers. An exactly-soluble but numerically challenging model field is used to provide a rigorous collection of performance benchmarks.

## TH6RE — Afternoon Poster INSTRUM T03, T05, T23

### Development of Screen Beam-Profile-Monitor System for High Energy Beam-Transport Line at the HIMAC

The screen monitor system is an important tool for beam diagnostic of the high-energy-beam transport line at the Heavy-Ion Medical Accelerator in Chiba (HIMAC). We have developed a very thin fluorescent film and high speed charge-coupled-device camera. Because the fluorescent film is very thin ( $\text{ZnS:Ag } 2\text{mg/cm}^3$ ), the beam is measured with semi-non-destructively. Consequently we can use more than two monitors at the same time and multiple locations. Moreover we employ a high-speed three-processor for image processing, the system can be applied for online monitoring and interlock system (100Hz). When the beam profile measured by this system is inevitably changed over the setting tolerance during therapeutic irradiation for the patient, the beam is immediately turned off. The design and measurement result by irradiation test are discussed.

N. Saotome, T. Furukawa, T. Inaniwa, Y. Iwata, T. Kanai, A. Nagano, K. Noda, S. Sato, T. Shirai (NIRS)

TH6REP001

### Independent Component Analysis Applied for Turn by Turn Beam Position Analysis in the TLS

After commissioning of new BPM system in the TLS, it would support functionality of turn by turn data which can be applied in independent component analysis (ICA). This data analysis method is a special case of blind source separation to separate multivariable signal and additive noise and shown to be a useful diagnostic tool in acceleration application. In this paper, we use the ICA method to analyze experimental BPM turn by turn data of the TLS storage ring, measure betatron tunes, and identify abnormal BPM signals. Other possible applications have been also further studied continuously.

P. C. Chiu, K. T. Hsu (NSRRC)

TH6REP002

### Orbit Stability Observation of the Taiwan Light Source

Since the diagnostic system built with the new BPM system upgrade in TLS, we can observe and analyze the orbit stability more clearly and systematically. The disturbances to cause orbit fluctuation mainly come from power supply ripple, ground vibration, ID effects and etc. Removing the disturbed source is a straight, effective but inactive solution. Orbit feedback system is therefore adopted to suppress the remaining noise. In this report, we will evaluate the orbit stability in TLS and present the efforts we have done to improve the orbit stability.

P. C. Chiu, K. T. Hsu, K. H. Hu, C. H. Kuo (NSRRC)

TH6REP003

TH6REP004

**The Unstable of Light Beam Line is Diagnosed by the Mask Hardware Design**

E.-T. Chung (NSRRC)

I0 luminous intensity is the most important reference in the light source. The variation of  $d(I/I_0)$  % more than large, will cause user's experiment be difficult. In TLS (Taiwan Light Source), there are three pieces of important I0 that examine and click for the consulting value, the dragon beam line (BL11) is the main viewpoint for us test. We analyze the unstable factor of the beam by FFT, which will offer important somehow to improve the system. We need a lot of to prove it in order to judge the main reason and then revise the mistake when unstable in the light beam of tracking is producing. How the signals which we pick and fetch correct information? This paper will show us by using the design hardware. The first is mask time designed, used the digit circuit adjustably mask time, the second is trigger signal to recorder, via the circuit fast reaction of the digit, can provide data to far oscillate graph, in reflecting time, pick and fetch to the state wave form and record time clicking. The intact signal can be into database using analysis, cooperate with history can double check correction, and using the machine can diagnose question and find the solution.

TH6REP005

**The Design of Beam Diagnostic Components Installed in TPS Vacuum System**

H. P. Hsueh, C.-C. Chang, Y.-B. Chen, P. J. Chou, G.-Y. Hsiung, S.-N. Hsu (NSRRC) J.-R. Chen (National Tsing Hua University)

The main beam diagnostic components that will be installed are the BPM system. The feedthrough button has been decided to have 6mm diameter and its design has been optimized to have lower broadband impedance and better impedance matching for both good signal transmission quality and low power reflection to interfere with electron beam itself. All detailed sizes and engineering requirement will be described in this poster presentation. All these detailed considerations are required since short bunch operation will be considered in the future operation of TPS. Other diagnostic components including DCCT and longitudinal feedback kicker will also be shown in this poster.

TH6REP006

**Correlation Study between Beam Stability Observed by Electron BPMs and Photon Monitors**

K. H. Hu, J. Chen, K. T. Hsu, C. H. Kuo (NSRRC)

Beam qualities include orbit stability and multi-bunch instability plays a crucial role for the operation of a synchrotron light source. To improve and to keep high beam quality, intensive correlation analysis is performed between data taken by electron BPMs and photon monitors. Efforts of this study will be summary in this report.

TH6REP007

**X-Ray Beam-Position Monitor for the IASW Beamline**

C. K. Kuan, C. L. Chen, G.-Y. Hsiung, I. C. Sheng (NSRRC) J.-R. Chen (National Tsing Hua University)

The IASW beamline is sensitive to the stability of photon beam. The X-ray beam-position monitor (XBPM) is designed to be an online feedback control for an overall beam position stability. This photoemission-type XBPM uses the metallic blades to obtain the photon current. The beam position is calculated by the summation and difference of the blade currents of the blade pair. The gap between the blade pair is import to the performance of the XBPM. We use the SRW and Spectra program to calculate the



distribution of the photon beam and then to analyze the optimized gap. The photon beam in the IASW beamline is flat. The horizontal blade gap is difficult to design, but the resolution of the vertical beam position is less than 1 $\mu$ m, and the beam stability is less than 1 $\mu$ m between the two injections of Top-Up mode. The design, fabrication and measurement results are presented here.

### New BPM System and its Related Diagnostic Tools for the Taiwan Light Source

Commissioning of new digital BPM system for TLS is done recently. The new BPM system could support functionalities of turn by turn data, post-mortem and 10Hz slow data acquisition. 10 kHz fast data translation through Liberas grouping mechanism also succeeded to acquire all bpm data and integrate into the orbit feedback system. Various tests are performed systematically to confirm its performance and reliability and will be discussed in this report. We also present the functionalities and infrastructure of the related diagnostic tools. It could record 10 sec orbit data simultaneously via hardware and software event trigger at 10 kHz. Turn by turn and post mortem are also supported through embedded EPICS IOC. More integrated software tools and environment will continue to be developed for future operation.

C. H. Kuo, P. C. Chiu, K. T. Hsu, K. H. Hu (NSRRC)

### Fast Orbit Feedback System Commissioning of the Taiwan Light Source

The orbit feedback system of the TLS has been deployed for a decade to stabilize electron closed orbit. As the upgrades of digital bpm electronics and switching power supply, the infrastructure of orbit feedback system has also been dramatically modified and rebuilt. The most primary works for the upgrade plan have been done including installation of new bpm and power supply since it was first proposed. After the ordered computer blade ready and the current updated rate raised from 1 kHz to 5 kHz or even 10 kHz, the system will evolve to a newly fast orbit feedback system. It is new scheduled to be commissioned in 2009 spring and can be expected to achieve a submicron stability of the electron beam at a bandwidth of at least 60 Hz.

C. H. Kuo, P. C. Chiu, K. T. Hsu, K. H. Hu (NSRRC)

### Proposal for a Non-Interceptive Spatio-Temporal Correlation Monitor

Designs for developing TeV-range electron-positron linear colliders include a non-zero crossing angle colliding scheme at the interaction point to mitigate instabilities and possible background. Maximizing the luminosity when operating with non-zero crossing angles requires the use of "crab" cavities to impart a well-defined spatio-temporal correlation. In this paper we propose a novel non-interceptive diagnostic capable of measuring and monitoring the spatio-temporal correlation, i.e. the transverse position of sub-picosecond time slices, within bunch. An analysis of the proposed scheme, its spatio-temporal resolution and its limitations are quantified. Finally, the design of a proof-of-principle experiment in preparation for the Fermilab's A0 photoinjector is presented.

T. J. Maxwell (Northern Illinois University)

TH6REP008

TH6REP009

TH6REP010

TH6REP011

**Longitudinal Beam Diagnostics for the ILC Injectors and Bunch Compressors**

P. Piot, V. Demir, T. J. Maxwell, M. M. Rihaoui (Northern Illinois University) C.-J. Jing (Euclid TechLabs, LLC) J. G. Power (ANL)

We present a diagnostics suite and analyze techniques for setting up the longitudinal beam dynamics in ILC  $e^-$  injectors and  $e^+$  and  $e^-$  bunch compressors. Techniques to measure the first order moments and recover the first order longitudinal transfer map of the injector's intricate bunching scheme are presented. Coherent transition radiation diagnostics needed to measure and monitor the bunch length downstream of the  $\sim 5$  GeV bunch compressor are investigated using a vector diffraction model.

TH6REP012

**Low-Energy Emittance Studies with the New SNS Allison Scanner**

M. P. Stockli, S. Assadi, W. Blokland, T. V. Gorlov, B. Han, C. D. Long, T. R. Pennisi (ORNL)

The new SNS Allison emittance scanner measures emittances of 65 kV ion beams over a range of  $\pm 116$  mrad. Its versatile control system allows for time-dependent emittance measurements synchronized by an external trigger, and therefore is suited for studying pulsed systems. After a programmable delay the system acquires a variable array of beam current measurements, each averaged over a changeable time span. The baseline of the current measurements are determined by averaging a fraction of 1 ms shortly before the start of the ion beam pulse. This paper presents the time evolution of emittance ellipses during the 1 ms  $H^-$  beam pulses emerging from the SNS test LEBT, which is important for loss considerations. In addition it presents the time evolution of emittance ellipses during the 3 week active lifetime of an SNS  $H^-$  source, which is an operational issue. Additional emittance data characterize the dependence on the electron-dump voltage, the extractor voltage, and the LEBT lens voltages, all of which were critical for reaching the 38 mA baseline  $H^-$  beam current. Emittance data for the dependence on the beam current highlight the challenges for the SNS power upgrade.

TH6REP013

**Measurement and Detailed Simulation of Beam Losses Caused by Thin Interception Devices (Wire Scanners, Scrapers) at SNS**

A. P. Zhukov (ORNL)

Conversion of BLM readings between in- to number of lost particles is a challenging task. Any insertion device is a good mean to obtain a localized loss and obtain such conversion factor with direct measurement. Such a measurement serves as a good benchmark for Monte-Carlo simulation of radiation transport. We used wire scanners and scraper induced losses to perform analysis of BLM response to local loss. The paper also provides a technique to measure 0.1% of full beam charge being intercepted by scraper during 650kW production run extracting the useful signal from high noise (20 times higher than signal) environment

TH6REP014

**A Simulation Based Thermal Design of a New Current Monitor for the Beam Current Upgrade at the PSI Proton Accelerator**

Y. Lee, P.-A. Duperrex, D. C. Kiselev, U. Muller (PSI)

The Paul Scherrer Institute (PSI) operates a high power proton accelerator for the research projects in physical and medical sciences. Currently, a proton beam current of 2mA with a beam power of 1.2MW is routinely used. In the future, the

ring cyclotron with new cavities will make a proton beam current of 3mA possible. The enhanced beam power will generate higher thermal and mechanical loads to different accelerator components. In this paper, a simulation based study of a new current monitor designed to sustain the 3mA beam operation is presented. The monitor is located behind the second graphite target and exposed to scattered particles and their secondaries. The thermal energy deposition in the current monitor has been calculated by the Monte-Carlo particle transport code MARS. The calculated power source has been used for the the coupled flow, heat and radiation simulations, for the prediction of the operating temperature. The effect of the newly introduced water cooling system and the surface blackening has been analyzed by using CFX. The thermal properties of the monitor system have been measured by laboratory experiments, and a simulation validation study is presented.

### Visual Monitor for Near-Target Beam Diagnostics

With increasing beam powers and current densities in current neutron spallation sources one approaches materials' limits.

**K. Thomsen (PSI)**

The importance of near-target beam monitoring rises accordingly. At the Paul Scherrer Institute (PSI), the liquid metal target of MEGAPIE set especially stringent requirements for the reliable interruption of the proton beam in case of an anomaly in the incident current density distribution. A completely novel device called VIMOS based on the optical monitoring of a glowing mesh has been devised. By now, the system has been operating successfully for five years. Starting from the initial goal of reliably detecting beam anomalies in a timely manner the scope of the system has been extended to serve as a standard device for beam monitoring and fine tuning of the settings of the beam transport lines. In parallel to the expansion of the use of VIMOS over time, requirements for improving the maintainability of the system while also reducing concurrent cost have become more urgent. A summary of the operational experience of VIMOS will be reported as well as steps taken in order to deliver more quantitative data on the beam profile in the future.

### Analysis of Contribution from Edge Radiation to Optical Diffraction Radiation

Beam size measurement with near-field optical diffraction radiation (ODR) has been carried out successfully at CEBAF. The ODR station is installed on the Hall-A beam line after eight bending magnets. The ODR images were affected by an unexpected radiation. Some calculations for analyzing the source of the radiation will be presented. Furthermore, two schemes will be proposed to alleviate the contamination.

**C. Liu (PKU/IHIP) P. Evtushenko, A. Freyberger (JLAB) C. Liu (CASA) A. H. Lumpkin (Fermilab)**

### Beam Energy Diagnostic and Feedback System for the Top-Up Operation at the PLS Linear Accelerator

Electron beam energy measurement system has been developed by using image processing of the beam image obtained from a beam profile monitor, beam position monitor and current of the analyzing magnet power supply at PLS 2.5GeV Linac. An accurate beam energy measurement system is necessary and the energy of the beam has to be stabilized for the top-up operation of the PLS. The beam energy measurement system consists of a beam profile monitor, a beam position monitor, an analyzing magnet, a beam

**S.-C. Kim, Y. J. Han, W. H. Hwang, K. R. Kim, S. H. Kim, S. H. Nam, C. D. Park, S. S. Park, S. J. Park (PAL)**

current monitor, and an image processing system. We investigated various factors related to the energy fluctuations such as klystron RF output jitter and the effect of cooling and air temperature variations in the Linac. In this article we will also present on the beam energy measurement system and its applications for the performance analyses and feedback for the energy stabilization systems.

### Blade-Type Photon-Beam-Position-Monitor in PLS

C. Kim, H. J. Choi, Y. J. Han, J. Y. Huang, S. N. Kim (PAL)

A photon-beam-position-monitor (PBPM) is installed in a diagnostic beamline of the Pohang Light Source (PLS). From experience of existing PBPMs, we enriched our understanding of the synchrotron radiation and this understanding is fully considered for physical design of the new PBPM. The newly built PBPM is tested by using a high-power ultraviolet laser and its performance is checked before installation. Measurement results of beam position shows that the current (thermal) effect is reduced significantly and they also shows good agreement with results from a beam position monitor inside the PLS storage ring.

### A Real-Time Fill-Pattern Measurement System at the Pohang Light Source

J. W. Lee, E.-H. Lee, S. J. Park, J. C. Yoon (PAL)

PLS(Pohang Light Source) is 2.5 GeV synchrotron radiation facility in Pohang, Korea. A real-time fill-pattern measurement system that measures the real-time intensity distribution of the electron bunches in the storage ring is designed and being developed at the PLS. An ultra-fast photo-diode with 30 pico-second rise time and a high-speed digitizer with 8 GS/s are used for real-time measurement of the fill-pattern at bunch-by-bunch resolution. The fill-pattern measurement system is fully integrated into the CompactPCI/Linux-based EPICS control system. This paper describes the design and development progress of a fill-pattern measurement system for the PLS.

### A Single-Shot, Bunch Length Diagnostic Using Coherent Terahertz Radiation Interferometry

G. Andonian, S. Boucher, A. Y. Murokh, M. Ruelas (RadiaBeam)  
G. Travish (UCLA)

The generation of high peak current, high brightness beams routinely requires compression methods (e.g. four-bend chicane), which produce coherent radiation as a by-product. The sensing of this radiation, coupled with interferometric methods, yields crucial longitudinal bunch length and bunch profile information. This paper discusses the progress of the development of a real-time terahertz interferometer used for longitudinal beam profile diagnosis.

### A Practical Method to Reduce COTR Background in OTR Beam Profile Measurements

A. Y. Murokh (RadiaBeam) E. Hemsing, J. B. Rosenzweig (UCLA)

A Coherent Optical Transition Radiation (COTR) arising from the photo-injector electron beams spontaneous microbunching at optical frequencies has been recently observed in a number of experiments. This effect can lead to an undesirable optical background for OTR beam profile measurements at these facilities. A method to resolve this problem is

proposed, based on selectively suppressing the back-scattered COTR using multiple scattering in the insertion foil. An analytical treatment of COTR dependence on the angular divergence in the radiating beam is presented, and the efficacy of the approach is illustrated with the numerical examples, using LCLS injection beam parameters.

### Beam Orbit Tilt Monitor Studies at ATF2

We have designed a beam orbit tilt monitor for stabilizing a beam orbit in ATF2. Once we can measure a beam orbit tilt angle with high precision at one point, we can relate this data with the beam position profile at the focal point. This monitor is composed of a single rectangular cavity and waveguides to extract the signal. This monitor can measure the beam orbit tilt with a single cavity. We extract the signal of one basic resonance mode from the cavity. This electric field mode is perpendicular to the nominal beam axis, and is excited by beam tilt. The magnitude of extracted signal gives us the beam tilt data. According to our simulation, the expected sensitivity is about 80 nrad. in the vertical direction and 300 nrad. in the horizontal direction.

**D. Okamoto** (RCNS) Y. Honda (KEK) T. Sanuki (Tohoku University, School of Science)

TH6REP022

### Micron Size Laser-Wire System at the ATF Extraction Line, Recent Results and ATF-II Upgrade

The KEK Accelerator Test Facility (ATF) extraction line laser-wire system has been upgraded, enabling the measurement of micron scale transverse size electron beams. The most recent measurements using the upgraded system are presented, including the major hardware upgrades to the laser transport, the laser beam diagnostics line, and the mechanical control systems.

**A. S. Aryshev**, V. Karataev (JAI) G. A. Blair, S. T. Boogert, G. E. Boorman, A. Bosco, L. Deacon (Royal Holloway, University of London) L. Corner, N. Delerue, B. Foster, F. Gannaway, D. F. Howell, L. J. Nevay, M. Newman, R. Senanayake, R. Walczak (OXFORD-physics) H. Hayano, K. Kubo, N. Terunuma, J. Urakawa (KEK)

TH6REP023

### A Proposal of a Single Coupler Cavity Beam Position Monitor

Cavity beam position monitors (CBPM) made a significant progress in the last 10 years with an entire nano-beamline relying on them being currently commissioned at ATF2 (KEK). The major improvement was the introduction of the mode selective coupling allowing for efficient rejection of unwanted monopole modes. We propose another step towards creating a simple and cost effective CBPM - a cavity using just one coupler (instead of 2 or even 4) to couple out both polarisations of the dipole mode. The x and y signals are then split in the mixing stage of the electronics, so that only one expensive high-frequency electronics front-end is used for both x and y. A very good separation of the x and y signals can be achieved with a reasonable performance mixer assembly. In this paper we present the concept and provide some simulation results proving this processing scheme.

**A. Lyapin** (UCL) S. T. Boogert (Royal Holloway, University of London)

TH6REP024

**Development of the S-Band BPM System for ATF2**

A. Lyapin, B. Maiheu, M. Wing (UCL) R. C.D. Ainsworth, S. T. Boogert, G. E. Boorman, S. Molloy (Royal Holloway, University of London) A. Heo, E.-S. Kim, H.-S. Kim (Kyungpook National University) Y. Honda, T. Tauchi, N. Terunuma (KEK) D. J. McCormick, J. Nelson, G. R. White (SLAC) S. Shin (Fermilab) D. R. Ward (University of Cambridge)

The ATF2 international collaboration is intending to demonstrate nanometre beam sizes required for the future Linear Colliders. An essential part of the beam diagnostics needed to achieve this goal is the high resolution cavity beam position monitors (BPMs). In this paper we report on the S-band system installed in the final focus re-

gion of the new ATF2 extraction beamline. It only includes 4 BPMs, but they are mounted on the most critical final focus magnets squeezing the beam down to 35 nm. We discuss both the design and the first operational experience with the system.

**An Ultra-Fast Laserwire Scanner Based on Electro-Optics**

A. Bosco, G. A. Blair, S. T. Boogert, G. E. Boorman (Royal Holloway, University of London)

The design of an electro-optic deflector to be used for fast laserwire electron beam profilers is presented. A complete optical characterization of the device, performed using a

130 kHz repetition rate modelocked laser with external RF synchronization capabilities, is illustrated. The implementation into the existing two-dimensional laserwire scanner at PETRA III is discussed.

**Development of the C-Band BPM System for ATF2**

S. Molloy, S. T. Boogert (Royal Holloway, University of London) Y. Honda, T. Tauchi, N. Terunuma (KEK) J. Y. Huang, W. H. Hwang, S. H. Kim, S. J. Park, Y. J. Park (PAL) A. Lyapin (UCL) J. May, D. J. McCormick, J. Nelson, T. J. Smith, G. R. White (SLAC)

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tors (BPMs). In this paper we report on the C-band system consisting of 32 BPMs spread over the whole length of the new ATF2 extraction beamline. We discuss the design of the BPMs and electronics, main features of the DAQ system, and the first operational experience with these BPMs.

**Accelerator Physics Activity at the VEPP-4M Collider**

E. B. Levichev, V. E. Blinov, A. V. Bogomyagkov, S. E. Karnae, G. V. Karpov, V. A. Kiselev, O. I. Meshkov, S. A. Nikitin, I. B. Nikolaev, E. A. Simonov, V. V. Smaluk, A. N. Zhuravlev (BINP SB RAS)

The VEPP-4M electron-positron collider is now operating with the KEDR detector for high-energy physics experiments. Parallel with these experiments, the VEPP-4M scientific team carries out a number of accelerator physics investigations. Suppression of

the guide field ripples using the NMR probe signal from the reference magnet has been tested. A DC component of the main field drift is decreased to 1 keV/day. With the modernized Touschek polarimeter and the ripple suppression system, an absolute record resolution of 0.001 ppm in determination the depolarization frequency is

achieved. Dependence of Touschek particle counting rate on the beam energy (1.8-4 GeV) have been measured. Results of the last experiment can be claimed at the planned super B and C-Tau factories. For measurement of the particle beam position and angle, an X-ray multi-pinhole camera has been installed at the VEPP-4M. Design of this new beam diagnostic instrument and first measurement results are presented. In order to suppress the longitudinal instability caused by high-order modes of the RF cavities, a feedback system has been developed. The system layout and first results of its operation are described.

### Beam Measurement System for VEPP-2000

This paper describes several beam instruments for VEPP-2000 complex. These beam instruments include: a secondary emission monitors and a image current monitors to measure beam position and tuning beam transport, installed into injection channels; a tuning measurement system to measure the beam tune; a DCCT measurement system to measure the beam DC current and beam life; a closed orbit measurement system and a transverse beam profile measurement system includes several button-type electromagnetic beam position monitors (BPM), optics, acquisition tools and high resolution CCD cameras distributed around the storage ring to measure the beam profile and its position. Some applications of these measurement systems and their measurement results are presented.

Yu. A. Rogovsky (BINP SB RAS)

TH6REP030

### Calibration of the Beam Position Monitors for VEPP-2000

The basic requirement for the VEPP-2000 beam position monitor (BPM) is the measurement of the beam orbit with 0.1 mm precision. To improve the measurement accuracy, the re-sponse of the beam position monitors was mapped in the laboratory before they were installed in the VEPP-2000 ring. The wire method is used for the sensitivity calibration and position-to-signal mapping. The test stand consists of high frequency coaxial switches to select each pickup electrode, movable antenna to simulate the beam, signal source, spectrum analyzer to measure the pickup signals, and analysis software. This calibration measurement showed possibility of required accuracy. During calibration the electrical center of the different BPM was measured with respect to the mechanical center. Conversion between the BPM signal and the actual beam position is done by using polynomial expansions fit to the mapping data within  $\pm 6$  mm square. Results for these portions of the calibration are presented.

Yu. A. Rogovsky (BINP SB RAS)

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TH6REP031

### Fast-Gated Camera Measurements in SPEAR3

An intensified, fast-gated CCD camera was recently installed on the visible diagnostic beam line in SPEAR3. The  $\sim 2$ nS electronic gate capability, ability to make multiple-exposure images and to acquire sequences of images provides good diagnostic potential. Furthermore, the addition of a rotating mirror just upstream of the photocathode provides the ability to optically 'streak' multiple images across the photocathode. In this paper, we report on several fast-gated camera studies including (1) resonant excitation of vertical bunch motion, (2) imaging of the injected beam with and without emittance-spoiling windows in the upstream transfer line, (3) injection kicker tuning to minimize perturbations to the stored beam and (4) images of short-bunch 'bursting' in the low momentum-compaction mode of operation.

W. X. Cheng, W. J. Corbett, A. S. Fisher (SLAC) W. Y. Mok (Life Imaging Technology)

TH6REP032

TH6REP033

**Interferometer for Beam Size Measurements in SPEAR3**

W. J. Corbett, W. X. Cheng, A. S. Fisher, E. Irish (SLAC) T. M. Mitsuhashi (KEK) W. Y. Mok (Life Imaging Technology)

A two-slit interferometer has been installed in the SPEAR3 diagnostic beam line to measure vertical beam size at a dipole source point. The diagnostic beam line accepts unfocused, visible light in a  $3.5 \times 6.0$  mrad aperture so that at the slit location 17 m from the source, the vertical extent of the beam is 100mm. For typical source sizes of  $\sigma_y \sim 15$   $\mu\text{m}$  (0.1% emittance coupling) a slit separation of 80 mm produces fringe visibility of order  $V=0.5$ . Hence a significant plot of fringe visibility vs. slit separation can be generated to infer source size via Fourier transformation. In this paper we report on the interferometer construction, beam size measurement and potential deficiencies of the system, and compare with theoretical results.

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TH6REP034

**Evaluation of Bergoz Instrumentation NPCT at SPEAR3**

D. J. Martin, R. O. Hettel, J. J. Sebek (SLAC)

The Bergoz Instrumentation NPCT (New Parametric Current Transformer) has been evaluated at the SPEAR3 synchrotron light source. The device was tested for UHV performance and residual gas analysis (RGA), and was found suitable for installation in the storage ring. The NPCT was installed during August 2008 and has measured beam currents to 500 mA. Performance is compared to the earlier PCT design. The device has been instrumented with RTD and thermocouple sensors for a complete characterization of the internal operating temperature.

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TH6REP035

**Beam Diagnostic by Outside Beam Chamber Fields**

A. Novokhatski, S. A. Heifets (SLAC) A. V. Aleksandrov (ORNL)

Fields induced by a beam and penetrated outside the beam pipe can be used for a beam diagnostic. Wires placed in longitudinal slots in the outside wall of the beam pipe can work as a beam pickup. This has a very small beam-coupling impedance and avoids complications of having a feed-through. The signal can be reasonably high at low frequencies. We calculate the beam-coupling impedance due to a long longitudinal slot in the resistive wall and the signal induced in a wire placed in such a slot and shielded by a thin screen from the beam. We present a field waveform at the outer side of a beam pipe, obtained as a result of calculations and measurements. Such kind of diagnostic can be used in storage rings, synchrotron light sources, and free electron lasers, like LINAC coherent light source.

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TH6REP036

**LCLS Stripline BPM System Commissioning**

S. R. Smith, R. G. Johnson, E. A. Medvedko (SLAC)

The Linac Coherent Light Source (LCLS) begins operation this year with 83 new stripline beam position monitor (BPM) processors. System requirements include several-micron position resolution for single-bunch beam charge of 200 pC. We describe the processing scheme, system specifications, commissioning experience, and performance measurements.

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### Radiation of a Charge Crossing the Left-Handed Medium Boundary and Prospect of its Application to Beam Diagnostics

Radiation of a charge crossing the boundary between vacuum and left-handed medium is analyzed. The medium is characterized by permittivity and permeability with frequency dispersion of "plasmatic" type. Such properties can be realized in some modern metamaterials with a relatively simple structure. Both the case of unbounded medium and the case of circular waveguide are considered. Analytical expressions for field components are obtained and algorithm of their computation is developed. The main attention is given to the analysis of radiation in vacuum region. In particular, it is shown that two types of radiation can be generated in this region. One of them is an ordinary transition radiation having relatively large magnitude. Another type of radiation can be named the "Cherenkov-transition" radiation. Conditions of generating this type of radiation are obtained. This effect and some another properties of radiation can be used for diagnostics of beams. For example, the detector with two energy thresholds can be designed.

A. V. Tyukhtin, T. Yu. Alekhina, E. G. Doil'nitsina, S. N. Galyamin (Saint-Petersburg State University)

### High Precision Beam Energy Measurement with Cherenkov Radiation in an Anisotropic Dispersive Metamaterial Loaded Waveguide

We consider microwave Cherenkov radiation in a waveguide containing an engineered medium, and show that the properties of the radiation can be used to determine the energy of charged particle beams. These properties can form the basis of a new technique for bunch diagnostics in accelerators. We propose to use a material characterized by a diagonal permittivity tensor with components depending on frequency as in the case of a plasma but with the constant terms not equal to unity. These properties can be realized in a metamaterial with a relatively simple structure. In contrast to previous work in the present paper a vacuum channel in the waveguide is taken into account. The particle energy can be determined by measurement of mode frequencies. It is shown that a strong dependence of mode frequencies on particle energy for some predetermined narrow range can be obtained by appropriate choice of the metamaterial parameters and radius of the channel. It is also possible to obtain energy measurements over a wider range at the cost of a weaker frequency dependence.

A. V. Tyukhtin (Saint-Petersburg State University) S. P. Antipov (ANL) A. Kanareykin, P. Schoessow (Euclid TechLabs, LLC)

\*A. V. Tyukhtin, S. P. Antipov, A. Kanareykin, P. Schoessow, PAC07, p.4156.

\*\*A. V. Tyukhtin, EPAC08, p.1302.

\*\*\*A. V. Tyukhtin, Technical Physics Letters, v.34, p.884 (2008); v.35 (2009), in press.

### OTR Monitors for the IFUSP Microtron

In this work we describe the design of the OTR monitors that will be used to measure beam parameters of the IFUSP Microtron electron beam. The OTR monitor design must allow for efficiency in the entire energy range (from 5 MeV up to 38 MeV in steps of 0.9 MeV), and the devices are planned to monitor charge distribution, beam energy and divergence. An exception is made for the OTR monitor to the 1.7 MeV beam line, which is to be used to monitor only the beam charge distribution at the exit of the linac injector. The image acquisition system is also presented.

T. F. Silva, R. Lima, A. A. Malafronte, M. N. Martins, A. J. Silva, V. R. Vanin (USP/LAL)

**Electron Beam Profile Determination: The Influence of Charge Saturation in Phosphor Screens**

T. F. Silva, Z. O. Guimarães-Filho, C. Jahnke, M. N. Martins (USP/LAL)

In this work we describe a model to study the effect of charge saturation in phosphor screens in the determination of electron beam profiles. It is shown that the charge saturation introduces systematic errors in the beam diameter determination, since it tends to increase the observed beam diameter. The study is made supposing a Gaussian beam profile and a saturation model to the charge response of the phosphor material. The induced errors increase for higher currents and/or narrow beams. A possible correction algorithm that can be applied to some measurements is presented, together with a brief discussion about the consequences of these systematic errors in emittance measurements.

In this work we describe a model to study the effect of charge saturation in phosphor screens in the determination of electron beam profiles. It is shown that the charge

**Maximum-Entropy-Based Tomographic Reconstruction of Beam Density Distribution**

Y.-N. Rao, R. A. Baartman (TRIUMF) G. Goh (SFU)

For ISAC at TRIUMF, radioactive isotopes are generated with a 500MeV proton beam. The beam power is up to 40kW and can easily melt the delicate target if too tightly focused. We protect this target by closely monitoring the distribution of the incident proton beam. There is a 3-wire scanner monitor installed near the target; these give the vertical profile and the +45 and -45 degree profiles. Our objective is to use these 3 measured projections to find the 2-D density distribution. By implementing the maximum entropy (MENT) algorithm, we have developed a computer program to realize tomographic reconstruction of the beam density distribution. Of particular concern is to make the calculation sufficiently efficient that an operator can obtain the distribution within a few seconds of the scan. As well, we have developed the technique to perform phase space reconstruction, using many wire scans and the calculated transfer matrices between them. In this paper we present details of the computer code and the techniques used to improve noise tolerance and compute efficiency.

For ISAC at TRIUMF, radioactive isotopes are generated with a 500MeV proton beam. The beam power is up to 40kW and can easily

**Development Status of a Beam Monitor System at XFEL/SPring-8**

Y. Otake (RIKEN Spring-8 Harima) H. Ego, H. Tomizawa, K. Yanagida (JASRI/SPring-8) A. Higashiya, S. I. Inoue, H. Maesaka, S. M. Matsubara, T. Ohshima, T. Shintake, M. Yabashi (RIKEN/SPring-8)

In XFEL/SPring-8, it is very important to generate an electron beam, having a low slice emittance of 0.7 pimm-mrad, a pulse width of 30 fs, and a peak current of 3 kA at an X ray lasing part. For tuning such beam to guarantee stable X ray laser generation, beam and laser monitors to diagnose the temporal structure of them are an indispensable function. The monitors, such as a beam position monitor (BPM), a TM11-mode rf beam deflector and a screen monitor (SCM), have been developed to satisfy the function. The BPM has a position resolution of less than 1  $\mu\text{m}$ . The SCM to observe the beam deflecting image has a position resolution of 2.5  $\mu\text{m}$ . The design of a longitudinal beam diagnosis system using the monitors showed that it can measure a temporal structure with a resolution of 0.5 fs along the beam pulse. The experiment to check feasibility of the BPM showed that it can work as a beam arrival timing monitor with a temporal resolution of 46 fs. A monitor system using an in-vacuum photo diode was also developed to measure the laser arrival timing, and showed ability to resolve a 2 ps time jitter. These temporal resolutions allow us fine beam tuning required for the XFEL.

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### Beam Diagnostics for the USR

The novel electrostatic Ultra-low energy Storage Ring (USR), planned to be installed at the future Facility for Low-energy Antiproton and Ion Research (FLAIR), will slow down antiprotons and possibly highly charged ions down to 20 keV/q. This multipurpose machine puts challenging demands on the necessary beam instrumentation. Ultra-short bunches (1-2 ns) on the one hand and a quasi-DC beam structure on the other, together with a variable very low beam energies (20-300 keV/q), ultra-low currents (down to 1 nA or even less for a non-circulating beam) and few particles ( $< 2 \times 10^7$ ), require the development of new diagnostic devices as most of the standard techniques are not suitable. Several solutions, like resonant capacitive pick-ups, beam profile monitors, Faraday cups or cryogenic current comparators, are under consideration. This contribution presents the beam instrumentation foreseen for the USR.

**J. Harasimowicz**, M. Putignano (The University of Liverpool) **J. Harasimowicz**, C. P. Welsch (Cockcroft Institute) K.-U. Kuehnel (MPI-K)

TH6REP043

### DITANET – An Overview of the First Year Achievements

Beam diagnostics is a rich field in which a great variety of physical effects are made use of and consequently provides a wide and solid base for the training of young researchers. Moreover, the principles that are used in any beam monitor or detector enter readily into industrial applications or the medical sector which guarantees that training of young researchers in this field is of relevance far beyond the pure field of particle accelerators. DITANET- "Diagnostic Techniques for particle Accelerators – a European Network" - covers the development of advanced beam diagnostic methods for a wide range of existing or future accelerators, both for electrons and ions. DITANET is the largest ever coordinated EU education action for PhD students in the field of beam diagnostic techniques for future particle accelerators with a total budget of 4.2 M€. This contribution gives an overview of the network's activities and outlines selected research results from the consortium.

**C. P. Welsch** (The University of Liverpool) **C. P. Welsch** (Cockcroft Institute)

TH6REP044

### Developments of 3-D EO Bunch Shape Monitor for XFEL/SPring-8

In XFEL/SPring-8, it requires ultra high-brightness electron bunches with ultralow slice emittance and bunch duration of 30 fs (FWHM) in a lasing part. In order to measure such bunches, we are developing a single-shot, non-destructive, real-time 3-D bunch shape monitor based on EO sampling with a manner of spectral decoding. It consists of a radially polarized probe laser and 8 EO-crystals, which surround a beam axis azimuthally and their crystal-axes are radially distributed as well as Coulomb fields of electron bunches. The probe laser has a linear-chirped broad bandwidth ( $> 400$  nm at 800 nm of a central wavelength) for higher temporal resolution, and a hollow shape to avoid interacting with electron bunches. As an EO crystal, we investigate the feasibility of an organic crystal such as a DAST for 20-fs temporal response. This monitor can measure not only longitudinal but also transverse charge distribution at the same time. These real-time 3-D bunch shape measurements are very important to optimize electron bunches for XFEL operation. We present the scheme of this monitor with its estimation in detail and report the developing status for probe laser and organic-EO-crystals.

**A. Maekawa**, M. Uesaka (The University of Tokyo, Nuclear Professional School) H. Tomizawa (JASRI/SPring-8)

TH6REP045

### Reduction of Systematic Errors in Diagnostic Receivers through the Use of Balanced Dicke-Switching and Y-Factor Noise Calibrations

J. Musson, T. L. Allison, R. J. Flood (JLAB)

Receivers designed for diagnostic applications range from those having moderate sensitivity to those possessing large dynamic range. Digital receivers have a dynamic range which are a function of the number of bits represented by the ADC and subsequent processing. If some of this range is sacrificed for extreme sensitivity, noise power can then be used to perform two-point load calibrations. Since load temperatures can be precisely determined, the receiver can be quickly and accurately characterized; minute changes in system gain can then be detected, and systematic errors corrected. In addition, using receiver pairs in a balanced approach to measuring  $X_+$ ,  $X_-$ ,  $Y_+$ ,  $Y_-$ , eliminates systematic offset errors from non-identical system gains, and changes in system performance. This paper describes and demonstrates a balanced BPM-style diagnostic receiver, employing Dicke-switching to establish and maintain real-time system calibration. Benefits of such a receiver include wide bandwidth, solid absolute accuracy, improved position accuracy, and phase-sensitive measurements. System description, static and dynamic modeling, and measurement data are presented.

Receivers designed for diagnostic applications range from those having moderate sensitivity to those possessing large dynamic

### Application of Goubau Surface Wave Transmission Line for Improved Bench Testing of Diagnostic Beamline Elements

J. Musson, K. E. Cole (JLAB)

In-air test fixtures for beamline elements typically utilize an X-Y positioning stage, and a wire antenna excited by an RF source. In most cases, the antenna contains a standing wave, and is useful only for coarse alignment measurements in CW mode. A surface-wave (SW) based transmission line permits RF energy to be launched on the wire, travel through the beamline component, and then be absorbed in a load. Since SW transmission lines employ traveling waves, the RF energy can be made to resemble the electron beam, limited only by ohmic losses and dispersion. Although lossy coaxial systems are also a consideration, the diameter of the coax introduces large uncertainties in centroid location. A SW wire is easily constructed out of 200 micron magnet wire, which more accurately approximates the physical profile of the electron beam. Benefits of this test fixture include accurate field mapping, absolute calibration for given beam currents, Z-axis independence, and temporal response measurements of sub-nanosecond pulse structures. Descriptions of the surface wave launching technique, transmission line, and receiver electronics are presented, along with measurement data.

In-air test fixtures for beamline elements typically utilize an X-Y positioning stage, and a wire antenna excited by an RF source.

### A Real-Time System For Measuring Beam Spot Size of Linac Using Thick Pinhole Imaging

D. T. Bin (TUB)

In order to easily measure the beam spot size of linac with internal target enclosed, a real-time system, based on thick pinhole imaging technique, is employed. The principle of thick pinhole imaging and the processing of data are introduced in this paper. The experimental result on a 15MeV electron linear accelerator is also presented. Comparing with the usual "sandwich" method which needs to develop X-ray films and take a long time when conditioning the accelerator working parameters, the X-ray pinhole imaging method can make a real-time measuring and conditioning. As the linac working parameters change, the beam profile's variation is observed on screen immediately which makes it more efficiently to condition the linac. Key words: linac, X-ray, thick pinhole imaging, beam spot

In order to easily measure the beam spot size of linac with internal target enclosed, a real-time system, based on thick pinhole

**Advanced Longitudinal Diagnostic for Single-Spike SASE Operation at the SPARC FEL**

It has been suggested that an ultra-short, very low charge beam be used to drive short wavelength single-spike operation at the SPARC FEL. This paper explores the development and construction of a longitudinal diagnostic capable of completely characterizing the radiation based on the Frequency-Resolved Optical Gating (FROG) technique. In particular, this paper explores a new geometry based on a Transient-Grating (TG) nonlinear interaction and includes studies of start to end simulations for pulses at the SPARC facility using GENESIS and reconstructed using the FROG algorithm. The experimental design, construction and initial testing of the diagnostic are also discussed.

**G. Marcus**, G. Andonian, S. Reiche, J. B. Rosenzweig (UCLA) M. Ferrario, L. Palumbo (INFN/LNF) L. Giannessi (ENEA C. R. Frascati)

TH6REP049

**Studies of Aerogel Optical Properties for CCR Diagnostics**

The use of coherent Cherenkov radiation produced in an aerogel is studied in this paper. An aerogel is a material with an index of refraction close to unity and it could be used as a diagnostic tool for longitudinal distribution of an electron beam. An aerogel spectral properties are experimentally studied and analyzed. This method will be employed for the helical IFEL bunching experiments at Neptune linear accelerator facility at UCLA.

**R. Tikhoplav**, A. Knyazik, J. B. Rosenzweig (UCLA) G. Andonian, M. Ruelas (RadiaBeam)

TH6REP050

**Status of the MICE Tracker System**

The Muon Ionization Cooling Experiment (MICE) is being built at the Rutherford Appleton Laboratory (RAL) to test ionization cooling of a muon beam. Successful demonstration of cooling is a necessary step along the path toward creating future high intensity muon beams in either a neutrino factory or muon collider. MICE will reduce the transverse emittance of the beam by 10%, and spectrometers using particle physics techniques will measure the emittance reduction with an absolute precision of 0.1%. This measurement will be done with scintillating fiber tracking detectors nested inside solenoid magnets on either side of the cooling channel. Each fiber tracker contains five stations with 3 layers of fibers rotated 120 degrees with respect to each other, thereby allowing reconstruction of hit points along the path of the muons. Light is carried from the active fiber volume by clear waveguide fibers where it is detected using VLPCs (Visible Light Photon Counters). The details of the tracker commissioning using cosmic rays will be discussed in addition to the status and performance of the readout electronics\*.  
\*Submitted on behalf of the MICE collaboration.

**L. Coney** (UCR)

TH6REP051

**MICE Beamline Instrumentation**

The Muon Ionization Cooling Experiment (MICE) is being built at the Rutherford Appleton Laboratory (RAL) to test ionization cooling of a muon beam. This is a crucial step along the way toward future high intensity muon beams in either a neutrino factory or muon collider. The MICE muon beam is designed to have a momentum of 140-240 MeV/c

**L. Coney** (UCR) A. D. Bross, G. W. Sellberg, M. J. Utes (Fermilab)

TH6REP052

with a variety of beam optics. In order to better understand the beam and to aid in commissioning the experiment, two beam profile monitors have been installed in the MICE beamline. These are scintillating fiber detectors made of 0.9 mm diameter fibers in doublet planes with a 1.08 mm pitch and read out with Burle multi-anode PMTs. The active area of the two detectors covers 20x20 cm and 45x45 cm with doublets in both x and y giving a two dimensional profile of the MICE beam. In this paper, the details of these beam profile monitors will be discussed, and data taken with them in the MICE beamline will be shown. Submitted on behalf of the MICE collaboration.

### Determination of True RMS Emittance from OTR Measurements

C. F. Papadopoulos, R. B. Fiorito, P. G. O'Shea, A. G. Shkvarunets (UMD) M. E. Conde, W. Gai, J. G. Power (ANL)

Single foil OTR and two foil OTR interferometry have been successfully used to measure the size and divergence of electron beams with a wide range of energies. To

measure rms emittance, two cameras are employed: one focused on the foil to obtain the spatial distribution of the beam, the other focused to infinity to obtain the angular distribution. The beam is first magnetically focused to a minimum size in directions which are orthogonal to the propagation axis, using a pair of quadrupoles. Then simultaneous measurements of the rms size ( $x,y$ ) and divergence ( $x',y'$ ) of the beam are made. However, in the process of a quadrupole scan, the beam can go through a spot size minimum, a divergence minimum and a waist, i.e. the position where the cross-correlation term is zero. In general, the beam size, divergence and focusing strength for each of these conditions are different. We present new algorithms that relate the beam and magnetic parameters to the rms emittance for each of these three cases. We also compare the emittances, obtained using our algorithms and measurements made at the ANL AWA facility, with those produced by computer simulation.

### Calibration of Quadrupole Component of Beam Position Monitor at HLS LINAC

J. Fang, P. Li, P. Lu, Q. Luo, B. Sun, X. H. Wang (USTC/NSRL)

The strip-line beam position monitor can be used as a non-intercepting emittance measurement monitor. The most important part

of emittance measurement is to pick up the quadrupole component. To improve the accuracy of measurement, the response of the strip-line BPM pickups will be mapped before it's installed in the HLS LINAC. This paper introduce the calibration system of the BPM, which consists of a movable antenna and a RF signal source, simulating the beam, a BPM moving bench with its control system, and an electronics system. When the position calibration is done first, the offset between electronic center and mechanical one of the BPM and the position sensitivity are gotten. There are two methods for quadrupole component calibration: one is indirect evaluation method that estimates the sensitivity of quadrupole component by the factor of position second moment; the other is direct method by simulation of a Gaussian beam through together many Gaussian weighted grid points. The results of two methods are given and compared. The effect of antenna's diameter upon the fitting size of simulate beam has also been analyzed.

### Signal Processing Methods for the Staggered Pair Photon Beam Position Monitor

L. M. Gu, S. F. Lin, P. Lu, C. B. Shen, B. Sun (USTC/NSRL)

The stability of synchrotron radiation source is of great significance for users, and an accurate and reliable photon beam position

monitor (PBPM) is essential for success of synchrotron radiation experiments. Recently, we development a new

PBPM called staggered pair photon beam position monitor for photon beam position measurement in Hefei Light Source (HLS). Its main advantage is to reduce the influence of bunch size. Usually, difference over sum ( $\Delta/\Sigma$ ) method is used to process the photon beam signal. Two new methods are put forward, which are a ratio method and a log-ratio method. For photon beam with Gaussian distribution, differences among methods of  $\Delta/\Sigma$ , ratio and log-ratio are introduced. Some calculating results are given for three signal processing methods. Comparing those three methods of position signal processing, log-ratio method is found to have the widest range of linearity, and can obtain identical beam position with different bunch size. Based on that, we also compare staggered pair monitor with double-blade monitor. The staggered pair monitor is found to have higher sensitivity, as well it can ignore the influence of bunch size.

### Study on Depolarization Time of Resonant Depolarization Experiment

Radial alternating magnetic field is generated to act on polarized beam to give rise to resonant depolarization and calibrate the energy of electron by feeding power to a pair of vertical installed striplines in HLS. In the paper, the relationship between depolarization time and power fed into the striplines is investigated, and spin frequency spread is considered too. As a result, a depolarization time of 60s is acquired with an amplifier power of 15W fed into the striplines.

J. Q. Lan, H. Xu (USTC/NSRL)

TH6REP056

### Measurement of BPM Chamber Motion in HLS

Significant drifts in the horizontal beam orbit in the storage ring of HLS (Hefei Light Source) have been seen over many years.

J. W. Li, Y. Cao, C. Li, P. Lu, B. Sun (USTC/NSRL)

The horizontal BPM chamber motion is about 210  $\mu\text{m}$  for one period of user time. What leads to the drift of BPM chamber is thermal expansion mainly caused by the synchrotron light. To monitor the BPM chamber motion for all BPMs, a BPM chamber motion measurement system is built in real-time. The raster gauges are used to measure the displacement, and the displacement data are transmitted by RS485 serial network to a IPC which processes the data and sends them to HLS control system. The used raster gauge holds a sensitivity of 0.5  $\mu\text{m}$  and a precision of 1.5  $\mu\text{m}$ . The results distinctly show the relation between the BPM chamber motion and the beam current. The air condition is also a minor factor to the motion, but not important. To suppress the effect of the BPM chamber motion, a compensation strategy is implemented at HLS. The results of experiment are given.

TH6REP057

### DESIGN OF RACETRACK CAVITY BEAM POSITION MONITOR

A new high brightness injector is planned to be installed at HLS, NSRL. It is based on a new photocathode RF electron gun. To steer the beam along the optimal trajectory, higher precision controlling of beam position is required. The positional resolution of the BPM system designed for the new RF gun should be higher than 10  $\mu\text{m}$ . A new cavity BPM design is then given instead of old stripline one because of its higher positional resolution. In a normal symmetrical pill-box BPM design, machining tolerance will result in x-y coupling, which will cause cross-talk problem. A novel design is then presented here. To solve the problem before, a position cavity which has a racetrack cross section is used instead of a pill-box one. The ideal resolution of this design could be less than 3 nm.

Q. Luo, D. H. He, B. Sun (USTC/NSRL)

TH6REP058

**Single Bunch Longitudinal Measurement at HLS**

B. Y. Wang, P. Lu, T. J. Ma, B. Sun, J. G. Wang (USTC/NSRL)

Measurements of the bunch length and Longitudinal profile in single bunch mode in Hefei Light Source (HLS) have been made using oscilloscope and streak camera. The streak camera uses visible synchrotron radiation produced by the beam to measure its longitudinal distribution and the oscilloscope uses near IR light to measure its bunch length. A description of HLS and experimental system setup are described in this paper. The dependence of the bunch length on beam current and RF voltage for a single bunch was measured using oscilloscope and the dependence of the bunch distribution on beam current was measured using streak camera. The energy spread was measured using beam life to analyze the reason of the bunch lengthening. The HLS vacuum chamber impedance is estimated from the measurement results.

**Beam Parameters Measurement with a Streak Camera in HLS**

J. G. Wang, B. Sun, B. Y. Wang, H. Xu (USTC/NSRL)

In HLS streak camera system has been built. The system is used to measure some parameters of bunch like bunch length, longitudinal bunch profile and synchrotron frequency and so on, as it may report a direct derivation of fundamental machine characteristics. The system mainly consists of the synchrotron light extracting optics setup, the OPTOSCOPE streak camera and PC with a frame grabber interface card. The light extracting optics setup is used to extract synchrotron light at the bending magnet and the setup consists of the light extracting path and the optics imaging system. The streak camera realizes the functions of acquiring light and imaging. PC with a frame grabber interface card and ARP-Optoscope software package is used to monitor the light in real-time, acquire the image of light and analyze the data. The streak camera system operates with either synchroscan sweep mode or dual time base sweep mode. At present, some results are given, which include the bunch lengthening, the longitudinal bunch profile and the synchrotron frequency. These results are compared with the results acquired by using oscilloscope.

**Design of Beam Measurement System for High Brightness Injector in HLS**

X. H. Wang, J. Fang, P. Lu, Q. Luo, B. Sun, J. G. Wang (USTC/NSRL)

A high brightness injector has been developing in HLS (Hefei Light Source), and the design of beam parameter measurement system is presented in this paper. The whole system will measure beam position, beam current, emittance of beam, bunch length, beam energy and energy spread. For the beam position, we have designed three types of BPMs: stripline BPM, with the resolution of 20  $\mu\text{m}$ ; cavity BPM, with the resolution of 10  $\mu\text{m}$ , and resonant stripline BPM\*. The beam position processor Libera will be used. The beam current will be measured using the ICT and FCT. When going out of the gun, the energy of the beam is about 4MeV -- 5MeV, and the emittance of the beam is charge-dominated, so we use a set of slits with the width of 90  $\mu\text{m}$  to split the beam to beamlets. The bunch length is measured using OTR and streak camera. Before entering the bending magnet, the beam will go pass a very narrow slit, with the width of 90  $\mu\text{m}$ , and the resolution of energy spread will be improved.

\*M. Dehler, "Resonant Strip line BPM for Ultra Low Current Measurements", Proceedings of DIPAC 2005, Lyon, France, p.286-288



### Status of the First Commissioning of the Shintake Monitor for ATF2

Commissioning of the ATF/ATF2 project will start in the winter of 2008 to 2009, with the aim of studying beam optics, diagnostic instrumentations, and tuning processes for around 35 nm beam size. The project is the

realistic scaled down model of the ILC final focus system, and also, studies in the project offered important findings for future accelerator physics. In this presentation, we will present about the status of the first commissioning of the Shintake monitor for ATF2. The monitor is located at the virtual interaction point of the ATF2 (the focus point) to measure beam size. A measurable ranges as a design are from 6 micron down to 20 nm in vertical and down to several microns in horizontal. That wide range allows us to used the detector from the beginning of the beam tuning process. The monitor scheme was originally proposed by T. Shintake and verified using around 60 nm beam at FFTB project. We upgraded the detector system for ATF2 of smaller beam size and implemented a laser wire scheme for horizontal beam size measurement. These additional capabilities are also presented.

**T. Yamanaka**, S. Komamiya, M. Orouku, T. S. Suehara (University of Tokyo) Y. Honda, T. Kume, T. Tauchi, N. Terunuma (KEK) Y. Kamiya (ICEPP)

TH6REP062

### Deflecting Mode Optimization for a High Energy Beam Diagnostic Tool

Travelling wave and standing wave deflectors are well known RF devices that nowadays are used in particle accelerators as a

beam diagnostic tool. They will also be implemented in FERMI@Elettra project, a soft X-ray fourth-generation light source under development at the ELETTRA laboratory, and used to completely characterize the beam phase space by means of measurements of bunch length and transverse slices emittance. In particular, one deflector will be placed at low energy (250MeV) and another at high energy (1.2GeV), just before the FEL process starts. In this note we collect our experience and simulation on this last device, making a comparison between the most relevant options we have considered to satisfy our RF and space constraints. Basic cell design is discussed for both the travelling and standing wave choice. In particular, two different modes, the  $2/3\pi$  and the  $5/6\pi$ , are analyzed for the travelling wave option while an 11 cells design in  $\pi$  mode is presented for the standing wave case. For both cases sensitivity analysis and other relevant RF parameters are given.

**P. Craievich** (ELETTRA) M. Petronio (DEEI)

TH6REP063

### Measuring Betatron Tunes with Driven Oscillations

The betatron tunes of an electron storage ring may be measured by driving transverse oscillations with an excitation electrode and measuring the resonant beam response with a pickup electrode. We model the damping of coherent betatron oscillations from the tune spread and radiation damping, finding that the tune signal is proportional to the square root of the product of the betatron functions at the excitation and pickup locations. The signal is independent of the betatron phase advance between the two locations. Our results are applied to the Aladdin 800-MeV electron storage ring.

**R. A. Bosch** (UW-Madison/SRC)

TH6REP064

**Commissioning of the Bunch-to-Bunch Feedback System at the Advanced Photon Source**

C. Yao, N. P. Di Monte, W. E. Norum (ANL)

The Advanced Photon Source storage ring has several bunch fill patterns for user operation. In some fill patterns the single-bunch beam charge is as high as 16 mA. We installed a bunch-to-bunch feedback system that aims to overcome high-charge beam instability and reduce the required chromatic correction. Due to the drive strength limitation, we decided to first commission the feedback system in the vertical plane. We present our preliminary results, some of the issues that we have experienced and resolved, and our plan to expand the system to the horizontal plane.

The Advanced Photon Source storage ring has several bunch fill patterns for user operation. In some fill patterns the single-bunch

**Growth/Damp Measurements and Bunch-by-Bunch Diagnostics on the Australian Synchrotron Storage Ring**

D. J. Peake, R. P. Rassool (Melbourne) M. J. Boland, G. LeBlanc (ASCo)

Recently a transverse bunch-by-bunch feedback system was commissioned to combat the resistive-wall instability in the storage ring. The system successfully controls the vertical beam motion so 200 mA can be stored with all in-vacuum undulators at minimum gap and a slightly positive chromaticity setting. The FPGA that comes with the feedback system also provides powerful possibilities for diagnostic measurements. Results will be presented for a) growth/damp measurements to quantitatively characterise the resistive-wall instability, b) bunch-by-bunch diagnostics such as tune chromaticity and c) initial bunch-cleaning attempts in conjunction with a APD bunch purity measurement system.

Recently a transverse bunch-by-bunch feedback system was commissioned to combat the resistive-wall instability in the storage ring. The system successfully controls the

**Design of the Brazilian Synchrotron Light Source Digital Multi-Bunch Feedback System**

S. R. Marques, R. H.A. Farias, L. Sanfelici, P. F. Tavares (LNLS)

The main facility of the Brazilian Synchrotron Light Laboratory is a 1.37 GeV Synchrotron Light Source. The accelerator ring can be filled with up to 148 electron bunches and the initial current of 250 mA decreases down to 150 mA at the end of the user's shifts. The beam energy is ramped down to 500 MeV, the current is refilled and the energy is ramped up again to 1.37 GeV for a new shift. Coupled-bunch instabilities excited by different sources can negatively impact the light source performance either lowering the brilliance of the beam or causing beam losses in the energy ramps. The upcoming new insertion devices and beamlines are pushing up the beam stability requirements even more. We present the current status of a digital feedback system that is being designed for controlling transversal and longitudinal beam instabilities.

The main facility of the Brazilian Synchrotron Light Laboratory is a 1.37 GeV Synchrotron Light Source. The accelerator ring can

**Bunch Cleaning at the Canadian Light Source**

J. M. Vogt, J. C. Bergstrom, S. Hu (CLS) P. L. Lemut, V. Poucki (Instrumentation Technologies)

A high-purity single-bunch operating mode, required for time-resolved experiments, has been introduced into the CLS Storage Ring. The newly deployed Transverse Feedback System, which uses the Libera Bunch-by-Bunch system as the feedback processor, has added features that inherently enable bunch cleaning. The bunch purification mechanism is based on a frequency modulated signal that drives the unwanted bunches into betatron oscillations to remove them from the Storage Ring. Bunch purities of  $1 \cdot 10^{-6}$  are achieved, limited only by the leakage rate from adjacent bunches.

A high-purity single-bunch operating mode, required for time-resolved experiments, has been introduced into the CLS Storage Ring. The newly deployed Transverse Feedback

### Measurements of Coupled-Bunch Instabilities in BEPC-II

BEPC-II is a two ring electron-positron collider designed to operate at 1 A beam currents. Longitudinal and transverse coupled-bunch instabilities have been observed in both electron and positron rings. In this paper we present measurements of both transverse and longitudinal instabilities with the identification of active eigenmodes, measurements of growth and damping rates, as well as of the residual beam motion levels. The measurements will then be used to estimate the growth rates at the design beam currents (yet to be achieved). We will also demonstrate how such data is used for specifying power amplifier and kicker parameters.

**D. Teytelman** (Dimtel) J. M. Byrd (LBNL) J. Cao, J. Yue (IHEP Beijing)

### Development and Commissioning of Bunch-by-Bunch Longitudinal Feedback System for Duke Storage Ring

The coupled bunch mode instabilities (CBMIs) caused by vacuum chamber impedance limit and degrade the performance of the storage ring based light sources. A bunch-by-bunch longitudinal feedback (LFB) system has been developed to stabilize beams for the operation of a storage ring based Free Electron Laser (FEL) and the High Intensity Gamma-ray Source (HIGS) at the Duke storage ring. Employing a Giga-sample FPGA based processor (iGP), the LFB is capable of damping out the dipole mode oscillation for all 64 bunches. As a critical subsystem of the LFB system, kicker cavity is developed with a center frequency of 938 MHz, a wide bandwidth ( $> 90$  MHz), and a high shunt impedance ( $> -10-00 \Omega$ ). First commissioned in summer 2008, the LFB has been operated to stabilize high current multi-bunch operation. More recently, the LFB system is demonstrated as a critical instrument to ensure stable operation of the HIGS with a high intensity gamma beam above 20 MeV with a frequent top-off injection to compensate for the substantial and continuous electron beam loss in the Compton scattering process. In the future, we will perform detailed studies of the impedance effects using the LFB system.

**W. Wu**, M. D. Busch, J. Li, G. Swift, P. Wang, Y. K. Wu (FEL/Duke University) Y. Kim (PSI) I. S. Ko, I. S. Park (PAL) D. Teytelman (SLAC)

### SuperB Fast Feedback Systems

The SuperB project consists of an asymmetric ( $4 \times 7$  GeV), very high luminosity, B-Factory to be built at Roma-II University campus in Italy, with the ambitious luminosity goal of  $10^{36} \text{ cm}^{-2} \text{ s}^{-1}$ . To achieve the very challenging performances, robust and powerful bunch-by-bunch feedback systems are necessary to cope with fast coupled bunch instabilities in rings with high beam currents and very low emittances. The SuperB bunch by bunch feedback should consider the rich legacy of previous systems, the longitudinal (DSP-based) feedback built in 1993-97 and the recent "iGp" feedback system designed in 2002-06. Both were designed by large collaborations between Research Institute (SLAC, DAFNE@LNF/INFN, ALS@LBNL, KEK). The core of the new system will be the digital processing module, based on powerful FPGA components, to be used in longitudinal and transverse planes. Off-line analysis programs, as well real-time diagnostic tools, will be included. The feedback impact on very low emittance beams have to be carefully considered. A MATLAB simulator based on a beam/feedback model is also foreseen for performance checks and fast downloads of firmware/gateway code and parameters.

**A. Drago** (INFN/LNF)

**DAFNE Horizontal Feedback Upgrade**

A. Drago (INFN/LNF)

In this paper the horizontal feedback upgrade for the positron DAFNE ring is presented. After having completed the analysis of the  $e^+$  current limit behavior, a feedback upgrade has been turned out necessary. For the success of the crab waist experiment in the 2008 year, a fast solution to implement the upgrade has been necessary. It has been considered if a simple power increase would be the best solution. The lack of power combiners and of space for other two power amplifiers has brought to a different approach, doubling the entire feedback system. The advantages of this implementation respect to a more traditional power amplifier doubling are evident: two feedback kicks every revolution turns, better use of the power amplifiers, greater reliability, and less coherent noise in the system. Measurements of the two feedbacks have shown a perfect equivalence of the new and the old system: in fact the resulting damping rate is exactly the double of each system taken individually. A description of the implementation is presented together with the performance of the system.

In this paper the horizontal feedback upgrade for the positron DAFNE ring is presented. After having completed the analysis

**Tune Locked Bunch Cleaning with Bunch-by-Bunch Feedback at the SPring-8 Booster Synchrotron**

T. Nakamura, T. Aoki, K. Fukami, K. Kobayashi, M. Shoji, H. Yonehara (JASRI/SPring-8)

The bunch cleaning for the SPring-8 storage ring is performed at the booster synchrotron. The booster is currently running at 1 Hz rate to keep the machine parameters stable. Currently, we intend to operate the booster on demand for energy saving, however the large drift of the tune was observed in such operation mode and this drift drives the tune to off-resonance of the RFKO frequency. To overcome this tune drift, we are testing the tune locked bunch cleaning system with transverse bunch-by-bunch feedback. In this system, the main bunch is excited by positive feedback and the signal from the feedback is used to excite the RFKO system, thus the frequency of the RFKO system is locked to the tune. The system and preliminary results are presented.

The bunch cleaning for the SPring-8 storage ring is performed at the booster synchrotron. The booster is currently running at 1 Hz rate to keep the machine parameters stable.

**Development of a Fast Micron-Resolution Beam Position Monitor Signal Processor for Linear Collider Beam-Based Feedback Systems**

P. Burrows, R. Apsimon, C. I. Clarke, B. Constance, H. Dabiri Khah, A. F. Hartin, C. Perry, J. Resta-López, C. Swinson (JAI) G. B. Christian (ATOMKI) A. Kalinin (STFC/DL/ASTeC)

We present the design of prototype fast beam position monitor (BPM) signal processors for use in inter-bunch beam-based feedbacks for linear colliders and electron linacs. We describe the FONT4 intra-train beam-based digital position feedback system prototype deployed at the Accelerator test facility (ATF) extraction line at KEK, Japan. The system incorporates a fast analogue beam position monitor front-end signal processor, a digital feedback board, and a fast kicker-driver amplifier. The total feedback system latency is less than 150ns, of which less than 10ns is used for the BPM processor. We report preliminary results of beam tests using electron bunches separated by c. 150ns. Position resolution of order 1 micron is obtained.

We present the design of prototype fast beam position monitor (BPM) signal processors for use in inter-bunch beam-based feedbacks for linear colliders and electron linacs. We describe the FONT4 intra-train beam-based

### Design and Performance of Intra-Train Feedback Systems at ATF2

The major goals of the final focus test beam line facility ATF2 are to provide electron beams with a few tens nanometer beam sizes and beam stability control at the nanometer level.

J. Resta-López, P. Burrows (JAI)

In order to achieve such a level of stability beam based feedback systems are necessary at different timescales to correct static and dynamic effects. In particular, we present the design of intra-train feedback systems to correct the impact of fast jitter sources. We study a bunch-to-bunch feedback system to be installed at the extraction line to combat the ring extraction transverse jitters. In addition, we design a bunch-to-bunch feedback system at the interaction point for correction of position jitter due to the fast vibration of the magnets in the final focus. Optimum feedback software algorithms are discussed and simulation results are presented.

TH6REP075

### Hardware-Based Fast Communications for Feedback Systems

The performance of feedback control systems is limited by latency. The hardware-based fast communication system described here offers means for deterministic, fault-tolerant data transmission for feedback systems requiring low-latency communications, such as orbit feedback and Radio Frequency (RF) controls.

L. R. Doolittle, A. Ratti, C. Serrano, A. Vaccaro (LBNL)

TH6REP076

### Radiation Hardness Testing of PMD Scientific Inc. Electrochemical Seismometer for Linear Colliders

A prototype PMD seismometer with electrochemical seismic sensors immune to high magnetic fields, was tested for radiation hardness at SLAC National Accelerator Laboratory.

J. W. Amann, T. V.M. Maruyama, A. Seryi, C. M. Spencer (SLAC)  
I. A. Abramovich (PMD SCIENTIFIC, INC.)

The seismometer was exposed multiple times of increasing duration to the radiation field of a Co60 calibration source. Results of this testing, including changes in the sensitivity curve of the seismometer, are reported. Additionally the challenges and difficulties in performing radiation hardness testing are discussed. We also compare the accumulated dose with the radiation environment typical for the interaction region of a linear collider, where such a sensor could be located.

TH6REP077

### Feedback Techniques and SPS Ecloud Instabilities - Design Estimates

The SPS at high intensities exhibits transverse single-bunch instabilities with signatures consistent with an Ecloud driven instability. While the SPS has a coupled-bunch transverse feedback system, control of Ecloud-driven motion requires a much wider control bandwidth capable of sensing and controlling motion within each bunched beam.

J. D. Fox, T. Mastorides, C. H. Rivetta, D. Van Winkle, J. Xu (SLAC)  
J. M. Byrd (LBNL) W. Höfle, G. Rumolo (CERN) R. de Maria (BNL)

This paper draws beam dynamics data from the measurements and simulations of this SPS instability, and develops initial performance requirements for a feedback system with 2-4 GS/sec sampling rates to damp Ecloud-driven transverse motion in the SPS at intensities desired for high-current LHC operation. Requirements for pickups, kickers and signal processing architectures are

TH6REP078

presented. Initial lab measurements of proof-of-principle lab model prototypes are presented for the wideband kicker driver signal functions.

### Development and Status of Transverse Bunch by Bunch Feedback System at SOLEIL

R. Nagaoka, J.-M. Filhol, M.-P. Level, C. Mariette, R. Sreedharan (SOLEIL)

Ever since the first user operation, the digital transverse bunch by bunch feedback system developed at SOLEIL has successfully been operated, achieving a stable multi-

bunch beam at the highest intensity in the two planes at zero chromaticity with a single chain working in a diagonal mode. Since then a vertical stripline, optimised to generate large deflections to combat the strong single bunch headtail instability, was installed to construct another chain. The combined use of the two chains allowed enhancing the feedback performance. In particular, by differentiating the feedback gain between high and low intensity bunches, the system is capable of working in hybrid filling modes. In parallel, online applications were integrated into the control system to allow measuring the tunes by selectively exciting a single bunch, damping and growth rates, and analysing the bunch by bunch data in frequency or time domain for post-mortem purposes. Future plans including installation of a horizontal stripline and a noise reduction by avoiding the baseband conversion of the beam signal are also discussed.

### Beam Position Orbit Stability Improvement at SOLEIL

L. S. Nadolski, L. Cassinari, J. P. Daguere, J. Denard, J.-M. Filhol, N. Hubert, N. Leclercq, A. Nadji (SOLEIL)

SOLEIL is the French 2.75 GeV high brilliance third generation synchrotron light source delivering photons to beam-lines since January 2007. Reaching micrometer

to sub-micrometer level stability for the photon beams is then necessary but very challenging. Since September 2008, a fast orbit feedback has been running in daily operation. The performances of the system will be presented together with comparison with the ones previously achieved with the slow orbit feedback system. Status of the interaction of both feedback systems will be discussed. Moreover new X-BPMs have been installed on dipole and undulator based beam-lines; a total number of 9 vibration sensors (velocimeters) are now installed in the storage ring tunnel, on the experimental slab and outside the building in order to help to locate the different noise sources. Detailed results will be presented and debated.

### Calculation and Simulation of the Stripline Kicker Used in HLS

Y. B. Chen (USTC/NSRL)

A bunch-by-bunch analogue transverse feedback system at the Hefei Light Source (HLS) is to cure the resistive wall instability

and the transverse coupled bunch instabilities. The kicker of the feedback system has four 21-cm-long electrodes of stripline type mounted in a skew  $45^\circ$ . Calculation and Simulation of the transverse kicker are shown.

### Experiment of Transverse Feedback System at HLS

In this paper, we introduce the BxB transverse feedback systems at Hefei Light Source (HLS), which employ an analog system and a digital system. The construction and commissioning for two feedback systems, as well as the instability analysis of beam and the experiment result of the feedback system in HLS are also presented in this paper.

**J. H. Wang**, Y. B. Chen, W. Li, L. Liu, M. Meng, B. Sun, L. Wang, Y. L. Yang, Z. R. Zhou (USTC/NSRL) J. Cao, J. Yue (IHEP Beijing) D. K. Liu (SINAP) L. Ma (IHEP Beijing) K. R. Ye (SSRF)

TH6REP082

### Commissioning of the HLS Analog TFB System

As low injection energy and multi-turn injection at HLS, the task of diagnosing and curing coupled-bunch instabilities becomes ever harder. The transverse analog feedback system has been redeveloped to improve effect, recently. In this paper, the new improved designs are described and new system's commissioning results are discussed. The transverse coupled bunch instability at 200MeV injection status is also experimentally studied.

**Y. L. Yang**, Y. B. Chen, G. Cheng, W. Li, L. Liu, M. Meng, J. H. Wang, L. Wang, Z. R. Zhou (USTC/NSRL)

TH6REP083

### Commissioning of the Digital Transverse Bunch-by-Bunch Feedback System for the HLS

Hefei Light Source (HLS) is an 800MeV storage ring with bunch rate of 204 MHz, the harmonics of 45, and circumference of 66 meters. HLS injection works at 200MeV, where the multi-bunch instabilities limit the maximum stored current. A digital transverse bunch-by-bunch feedback system has recently been commissioned at HLS to suppress the multi-bunch instabilities during injection. We employ the SPring-8 FPGA based feedback processor and modified it at NSRL to process horizontal and vertical oscillation signals, independently and simultaneously by one single processor. The design of the digital transverse feedback system and the experiment results are presented in this paper.

**Z. R. Zhou**, Y. B. Chen, M. Meng, B. Sun, J. H. Wang, L. Wang, Y. L. Yang (USTC/NSRL) K. Kobayashi, T. Nakamura (JASRI/SPring-8)

TH6REP084

### Design and Analysis of a Mixed-Signal Feedback Damper System for Controlling Electron-Proton Instabilities

An electron-proton (e-p) instability is observed with increased beam intensity at the Spallation Neutron Source (SNS) in Oak Ridge National Laboratory (ORNL). This paper presents a wide-band, mixed-signal system for active dampening of the e-p instability. It describes techniques used for feedback damping, data acquisition, and analysis. The paper also describes analysis tools to monitor system performance, and presents preliminary results for expected system performance. The mixed-feedback damper system includes anti-aliasing low-pass filters, analog-to-digital converters (ADCs), reconfigurable field programmable gate array (FPGA) hardware, digital-to-analog converters (DACs), and power amplifiers. The system will provide feedback damping, system monitoring, and offline analysis capabilities. The digital portion of the system features programmable gains and delays, and equalizers that are

**Z. P. Xie**, M. J. Schulte (UW-Madison) C. Deibele (ORNL)

TH6REP085

implemented using parallel comb filters and finite impulse response (FIR) filters. These components perform timing adjustments, compensate for gain mismatches, correct for ring harmonics, and equalize magnitude and phase dispersions from cables and amplifiers.

### A Stable Phase Reference for the APS Short-Pulse X-Ray Project

F. Lenkszus, R. Laird (ANL)

The Argonne Advanced Photon Source is in the process of developing a short-pulse x-ray (SPX) beamline capable of producing picosecond-scale x-ray pulses for use in time-resolved studies. To accomplish this, transverse deflecting cavities (crab cavities) operating at eight times the storage ring rf will be installed to enable production of short x-ray pulses at a selected beamline. Analysis reveals demanding phase and amplitude stability requirements for the cavity fields. The common-mode cavity field phase error relative to bunch arrival time is  $\pm 10$  degrees at the 2815-MHz cavity frequency while the cavity-to-cavity phase difference must be held to  $\pm 0.07$  degrees. The phase differential between the cavity phase and beamline timing must be held to  $\pm 1$  picosecond. A phase stabilized link\* is being developed to transport a phase stable 351.9-MHz reference to the LLRF located at the beamline end. The delivered phase-stable reference will be used to develop rf references for the cavity LLRF, beamline laser, and streak camera. This paper will discuss the details of the design and report measured performance of the prototype.

\* J. Frisch, D. Bernstein, D. Brown, E. Cisneros, "A High Stability, Low Noise RF Distribution System," Proceedings of PAC2001, pp 816-818.

### Firmware Development for SNS New Timing Master

R. Stefanic, J. Dedic (Cosylab) D. Curry (ORNL RAD) D. H. Thompson (ORNL)

Implementation of a timing system master device is a complicated task, since a lot of details have to be taken into account even once the architecture decisions have been laid down. At SNS/ORNL timing master controller is being upgraded in collaboration with Cosylab and this paper focuses on some details of its implementation. New timing system master device is based on agile FPGA circuitry and the main focus of this paper is its firmware implementation. Provided are implementation details for event distribution supporting multiple event sources and priorities. Discussed are mechanisms, ensuring deterministic behavior, different methods of encoding that have been employed, and host-independent distribution of time stamp frames. The concept of the super-cycle is explained and its implementation is laid down. Taken into account that implementation for such a complex device involves extensive testing, paper provides insight into verification it was applied. Advantages of the SystemC based test-benches over traditional VHDL-only verification are discussed.

### Different Methods for Long-term Femtosecond Stable RF Signal Generation from Optical Pulse Trains

M. Felber, V. R. Arsov, P. Gessler, K. E. Hacker, F. Loehl, F. Ludwig, K.-H. Matthiesen, H. Schlarb, B. Schmidt, A. Winter (DESY) S. Schulz, J. Zemella (Uni HH)

Next generation FEL light sources like the European XFEL require timing stability between different subsystems on a 10 fs level. In the optical synchronization scheme, the timing information is distributed across the facility via sub-ps laser pulses traveling on length stabilized optical fibers. Different methods are available for RF



extraction from the pulse train: direct conversion of a higher harmonic of the pulse repetition frequency, a PLL using a Sagnac-Loop as balanced optical-microwave phase detector, and a PLL using a Mach-Zehnder interferometer. We characterize the short- and long-term phase stability of these optical to radio frequency converters as well as the amplitude stability of the extracted RF signal and demonstrate their capability of meeting the stringent requirements.

### A Pico-Second Stable and Drift Compensated High-Precision and Low-Jitter Clock and Trigger Distribution System for the European XFEL Project

For the operation of the European X-Ray Free Electron Laser (XFEL), a system wide synchronous low-jitter clock and precise, adjustable triggers must be generated and

**P. Gessler**, K. Rehlich (DESY) C. Bohm, A. Hidvegi (Stockholm University)

distributed throughout the approximately 3.5 km long facility. They are needed by numerous diagnostics, controls, and experiments. Fast ADCs require the jitter of the distributed 1.3GHz clock to be in the order of a few pico seconds (RMS) and that it is synchronized to the accelerating RF. The phase of the 1.3GHz clock must therefore be adjustable at every endpoint. Due to cable lengths, and the temperature dependence of the propagation speed, temperature drifts are a serious issue. Therefore a complex monitoring and compensation mechanism has been developed to minimize these effects. Triggers must also be distributed throughout the system to synchronize different control or measurement tasks. The triggers must be adjustable in time in order to compensate for different cable lengths and should have a resolution of one ns but with ps stability. A prototype of this clock and trigger system has been developed and first measurements have shown, that the strong requirements can be fulfilled.

### Laser Timing Jitter Measurements Using a Dual-Sweep Streak Camera at the A0 Photoinjector

Excellent phase stability of the drive laser is a critical performance specification of photoinjectors such as Fermilab's A0 photoinjector (A0PI). Previous efforts based on the measurement of the power spectrum of the signal of a fast photodiode

**J. Ruan**, A. H. Lumpkin, J. K. Santucci (Fermilab)

illuminated by the mode locked infra-red laser pulse component indicated a phase jitter of less than 1.4 ps (technique limited). A recently procured dual-sweep plugin unit and existing Hamamatsu C5680 streak camera were used to study the phase stability of the UV laser pulse component. Initial measurements with the synchroscan vertical sweep unit locked to 81.25 MHz showed that the phase slew through the micropulse train and the phase jitter micropulse to micropulse were two key aspects that could be evaluated. The phase slew was much less than 100 fs per micropulse, and the total phase jitter (camera, trigger, and laser) was approximately 300 fs RMS for measurements of 20-micropulse trains. Data on the macropulse phase stability were also obtained. A possible upgrade to achieve better phase stability will be also discussed.

**All-Optical Synchronization of Distributed Laser Systems at FLASH**

S. Schulz, L.-G. Wissmann, J. Zemella (Uni HH) V. R. Arsov, M. Felber, P. Gessler, K. E. Hacker, F. Loehl, F. Ludwig, K.-H. Matthiesen, H. Schlarb, B. Schmidt, A. Winter (DESY)

The free-electron laser FLASH and the planned European XFEL generate X-ray light pulses on the femtosecond time-scale. The feasibility of time-resolved pump-probe experiments, special diagnostic measure-

ments and future operation modes by means of laser seeding crucially depend on the long-term stability of the synchronization of various laser systems across the facility. For this purpose an optical synchronization system is being installed and tested at FLASH. In this paper, we report on the development and the performance of a background-free optical cross-correlation scheme to synchronize two individual mode-locked lasers of different center wavelengths and repetition rates with an accuracy of better than 10 fs. The scheme has been tested by linking a Ti:sapphire oscillator, used for electro-optical diagnostics at FLASH, to both a locally installed erbium-doped fiber laser and the end-point of an actively length-stabilized fiber link distributing the pulses from a master laser oscillator. In the latter case, the diagnostics laser is then synchronized to the electron beam and first accelerator based measurements on the performance of the system could be carried out.

**Remote Synchronization of Laser Systems for the LCLS**

J. M. Byrd, L. R. Doolittle, G. Huang, A. Ratti, J. W. Staples, R. B. Wilcox (LBNL) J. C. Frisch, G. R. Hays, W. E. White (SLAC)

The Linac Coherent Light Source presently under construction at SLAC requires relative jitter of several remote lasers of <100 fsec. We present a conceptual design of a timing

system to distribute a master timing signal on 16 channels with <100 fsec relative jitter and drift over a 24 hour period. The system is based on interferometrically stabilized optical fiber links over which RF and timing signals are distributed as modulations on the optical carrier. We also present results of tests of a prototype system installed at SLAC which compare the performance of fibers installed in the linac tunnel and klystron gallery.

**ALS Top Off Injection User Gating System**

J. M. Weber, B. J. Bailey, M. J. Chin, F. Sannibale, M. Vinco (LBNL)

The Advanced Light Source (ALS) is a third generation synchrotron light source that has been operating since 1993 at Berkeley Lab.

Recently, the ALS was upgraded to achieve Top-Off Mode, which allows injection of 1.9GeV electron beam into the Storage Ring approximately every 30 seconds. Several beam lines are sensitive to the transient beam motion caused by injection into the Storage Ring. For these users, a pre-trigger preceding injection by about 500ms is distributed to each beam line. Each beam line is provided independent delay and pulse width control to create a unique gating pulse used to ignore data during injection. This paper will describe the details of the ALS Top Off Injection User Gating System.

### Laser Jitter Measurement for the NSRRC Photoinjector System

The 266 nm UV drive laser for the NSRRC 2998 MHz photoinjector system is generated from a nonlinear optical crystal which is driven by a 798 nm, 3.5 mJ infrared Ti:Sapphire laser. Electronics has been implemented in the NSRRC 2998 MHz photoinjector system to synchronize those IR laser pulses with the master oscillator signal of the high power microwave system. A 74.95MHz signal derived from the master oscillator is used as the reference for the Coherent Mira seed laser cavity. Through the Synchrolock module of the system, this reference signal is locked to the clock with jitter less than 0.25ps (rms). The arrival time jitter of laser pulses on photoinjector cathode surface is measured by comparing the phase of a 2998 MHz pulse train with the master clock signal with a I/Q demodulator. The pulse train is generated from an ultrafast photodiode output signal by a 10 pulse, 2998 MHz stripline comb filter. This pulse train signal is further filtered by a narrow-band 2998MHz cavity for phase comparison. Timing and synchronization electronics for this system as well as the laser jitter measurement results will be reported.

**C. C. Liang**, J. H. Chen, C. S. Chou, K. T. Hsu, W. K. Lau, A. P. Lee, S. H. Lee (NSRRC)

TH6REP094

### Status and Upgrade for Top-Up Operation of Timing System at the PLS

The timing system for Pohang Light Source(PLS) consists of a synchronous universal counter, AND gates, delay generators and other commercial modules of NIM type for increasing of a reliability, easy maintenance, low timing jitters, and all types of filling pattern. That was upgraded in 2003 from the old timing system based on the VXI create such as a trigger synchronize module, a fine delay module, a repetition rate pulse generator module, and so on. The new timing system has been operated very well for PLS decay operation mode. But the timing system should be upgraded for the top-up operation to increase the beam injection efficiency to decrease the beam loss, and to supply the injection timing signals for beam line users. This paper describes the present operation status and upgrade progress of timing system for top-up operation at the PLS.

**M.-H. Chun**, K. M. Ha, J. H. Kim, B. R. Park (PAL)

TH6REP095

### Timing System for the FIR Linac

PAL is constructing a coherent FIR (Far-Infrared Radiation) source using a 60-MeV S-band electron linac which includes a photocathode RF-Gun. The Spectra-Physics "Tsunami" laser system for the RF-gun which has an oscillation frequency of 79.3333 MHz should be synchronized to the 2.856 GHz RF system which consists of a solid-state amplifier and a 60 MW klystron. The timing system for the linac will use a 36th harmonics of photo-diode signal obtained at the output of the laser oscillator to generate the minimum jitter 2.856 GHz RF signal. The timing system will provide trigger signals for the laser amplifier at -10-20 Hz, the laser pulse slicer at 30 Hz, and the modulator and solid-state amplifier at 30 Hz. The reference clock and trigger signals in the timing system must have low jitter to provide a very stable synchronization of smaller than 150fs jitter between the laser system and the RF system. In this paper the performance of the timing system will be discussed.

**B. R. Park**, H.-S. Kang, C. Kim, C. D. Park, I. H. Yu (PAL)

TH6REP096

**Low Phase-Noise, Low Jitter Master Oscillator for the LCLS Cavity BPM System**

A. Young (SLAC)

The Linac Coherent Light Source (LCLS) project at SLAC uses a dense 15 GeV electron beam passing through a 131m undulator to generate extremely bright xrays. The project requires electron bunches with a bunch charge of 20pC to 1nC and bunch lengths of 0.020mm (70fs). To measure the beam resolution to 1 micron (rms) for bunch charge > 20 pC in the undulator, a cavity BPM system was chosen. This system can measure the beam position to within a micron. The LCLS Cavity BPM local oscillator subsystem consists of a second order phase-locked loop (PLL) to synchronize with LCLS timing system and injector system. The output of the PLL is distributed to 36 Cavity BPM receivers and 36 high speed digitizers while maintaining good phase noise and low jitter. This paper describes the design of the PLL and how it met the design specifications of 0.1 degree of phase noise at 119MHz and 1 ns of rms jitter.

**Preinjector Gun Upgrade, Timing and Synchronization and Preparation for the Top-Up Injection in Elettra**

A. Carniel, S. Bassanese, E. Karantzoulis, C. Scafuri, A. Vascotto (ELETTRA)

Elettra is the third generation light source in operation in Trieste since 1993, upgraded with a full energy booster injector last year. Top-up operation is on schedule in the near future but already the new timing system and gun are ready to operate in this mode. The paper describes all tasks and requirements needed to satisfy top-up injection include custom made hardware, interaction with controls and radiation protection system.

**The Beam Pick-Up Based Timing System in ATLAS**

C. Ohm (Stockholm University) T. Pauly (CERN)

The ATLAS BPTX system utilizes dedicated electrostatic button pick-ups, installed 175 m away along the LHC beam pipe on both sides of ATLAS. The usage of the BPTX signals in ATLAS is twofold; they are used both in the trigger system and for LHC beam monitoring. The ATLAS Trigger System is designed in three levels, sequentially refining the event selection. The discriminated BPTX signals provide a Level-1 trigger when a bunch passes through ATLAS. Furthermore, the BPTX detectors are used by a stand-alone monitoring system for the LHC bunches and timing signals. The BPTX monitoring system measures the phase between collisions and clock with high accuracy in order to guarantee a stable phase relationship for optimal signal sampling in the sub-detectors. In addition, the properties of the individual bunches are measured and the structure of the beams is determined. On September 10th, 2008, the first LHC beams reached the ATLAS experiment. During this period with single beam, the ATLAS BPTX system was used extensively to time in the read-out of the sub-detectors. We present the performance of the BPTX system and its measurements of the first LHC beams.

### The CEBAF Master Oscillator and Distribution Remodeling

Jefferson Lab's CEBAF accelerator operation requires various frequency signals to be distributed along the site. Three signals: 10 MHz, 70 MHz and 499 MHz are synthesized in the Machine Control Center (MCC) while 1427 MHz and 429 MHz are derived from 499 MHz and 70 MHz signals in four separate locations. We are replacing our obsolete 10 MHz, 70 MHz and 499 MHz sources with new sources that will incorporate a GPS receiver to discipline a 10 MHz reference. In addition the MO (Master Oscillator) system will be redundant (duplicate MO) and a third signal source will be used as a system diagnostic. Moreover the 12 GeV Energy Upgrade for CEBAF accelerator will be adding 80 new RF systems. To support them the distribution of 1427 MHz and 70 MHz signals has to be extended and be able to deliver enough LO (Local Oscillator) and IF (Intermediate Frequency) power to 320 old and 80 new RF systems. This paper discusses the new MO and the drive line extension.

T. E. Plawski, C. Hovater, J. Musson (JLAB)

TH6REP100

### Experimental Characterization of Timing Jitter at the NSLS SDL

Synchronization between a laser system and an electron beam plays a critical role in photoinjector operation, pump-probe experiments and many other applications. Here we report two novel experimental techniques for measuring the laser to RF timing jitter in a photoinjector, and e-beam arrival timing jitter after a magnetic chicane bunch compressor. The laser to RF timing jitter was characterized by observing the electron beam charge fluctuation through the Schottky effect. This technique was used to characterize the SDL photoinjector laser to RF timing jitter as a function of the temperature fluctuation in the laser room, and we have shown the resolution of this technique is  $\sim 100$  fs. A stripline beam position monitor (BPM) located down stream of the compressor will be used to investigate the e-beam arrival timing jitter after a magnetic chicane bunch compressor; the outputs of the stripline BPM can be used to measure the arrival timing jitter by mixing them with a RF reference signal. The effect of the chicane on the arrival time jitters will be studied for the first time using this technique.

H. J. Qian (TUB) Y. Hidaka, J. B. Murphy, B. Podobedov, H. J. Qian, S. Seletskiy, Y. Shen, X. J. Wang, X. Yang (BNL)

TH6REP101

### Electro-Optic Synchronization for the UCLA Pegasus Ultrafast Electron Diffraction Experiment

Electro-optic sampling (EOS) employing a spatially-encoding single-shot geometry is used to non-destructively monitor timing fluctuations in a time resolved pump-probe electron diffraction experiment [1]. A single ultrashort laser source is used three times per shot: once to generate a photoelectron bunch, once to pump a thin metal foil diffraction target, and once to measure the relative time-of-arrival of the electron beam at the target through EOS. Spatially decoded EOS results using  $< 20$  pC moderately relativistic (3.5 MeV) electron bunches from the Pegasus Laboratory [2] are presented and compared to calculations of the propagation of terahertz electric fields in zinc telluride crystals.  
[1] P. Musumeci, et al., *Ultramicroscopy*, 108 (2008)  
[2] P. Musumeci, et al., *Phys. Rev. Lett.*, 100, 244801 (2008)

C. M. Scoby, M. S. Gutierrez, J. T. Moody, P. Musumeci (UCLA)

TH6REP102

## FR5PF — Morning Poster BDEMF D01, D03, D05

### PAMELA Lattice Design and Performance

S. L. Sheehy, K. J. Peach, H. Witte, T. Yokoi (JAI) D. J. Kelliher, S. Machida (STFC/RAL/ASTeC)

PAMELA (Particle Accelerator for Medical Applications) is a design for a non-scaling Fixed Field Alternating Gradient accelerator facility for Charged Particle Therapy, using

protons and light ions such as carbon to treat certain types of cancer. A lattice has been designed with tune stabilisation, to constrain the variation of betatron tunes through acceleration and thus avoid integer resonance crossing and beam blow-up. This paper outlines the design and performance of this proposed PAMELA lattice.

### Straight Section in Scaling FFAG Accelerator

Y. Mori (KEK) J.-B. Lagrange (KURRI)

Straight section in scaling FFAG accelerator has been explored and scaling law for straight section has been investigated. Under

these studies, dispersion suppressed straight section, which could be useful for efficient RF acceleration, can be designed in ordinary scaling FFAG ring accelerator.

### Harmonic Number Jump Acceleration in Scaling FFAG Accelerator

Y. Mori (KEK) T. Planche (KURRI)

Harmonic number jump (HNJ) acceleration in scaling FFAG accelerator, especially for muon acceleration in neutrino factory, has

been studied. Criteria for HNJ acceleration were clarified and beam tracking simulations have been carried out.

### Orbit Reconstruction, Correction, Stabilization and Monitoring in the ATF2 Extraction Line

Y. Renier, P. Bambade (LAL) K. Kubo (KEK) J. Resta-López (JAI) A. Scarfe (UMAN) G. R. White (SLAC)

The orbit in the ATF2 extraction line has to be accurately controlled to allow orbit and optics corrections to work well downstream.

The Final Focus section contains points with

large beta function values which amplify incoming beam jitter, and few correctors since the steering is performed using quadrupole movers, and so good orbit stability is required. It is also essential because some magnets are non-linear and can introduce position-dependent coupling of the motion between the two transverse planes. To check the long-term evolution, the orbit is monitored and reconstructed, allowing comparisons with simulations to identify sources of variations.

### Coupling Correction in ATF2 Extraction Line

The purpose of ATF2 is to deliver a beam with stable very small spotsizes as required for future linear colliders such as ILC or CLIC. To achieve that, precise controls of aberrations such as dispersion and coupling are necessary. Initially, coupling correction upstream of the final focus line of the ATF2 will be performed with only two skew quadrupoles (SQ) in the extraction line (EXT). We thus first examine the feasibility of coupling correction in the EXT with those two SQ, considering several possible coupling error sources. The correction is first based on an algorithm of minimisation of vertical emittance with successive skew scans, implemented in the Flight Simulator code\*. We will then investigate new methods to measure and extract the first order four coupling parameters of the beam matrix in order to perform a more direct and accurate coupling correction.

**C. Rimbault**, P. Bambade (LAL) S. Kuroda (KEK) G. R. White, M. Woodley (SLAC)

\*G. White et al., "A flight simulator for ATF2...", TUPP016 EPAC08

### Linear Optics Calculations and Measurements in Cornell ERL Injector

Commissioning of a new high brightness electron source for the Energy Recovery Linac at Cornell University is currently underway. Despite the fact that the beam dynamics in this portion of the accelerator is space-charge dominated, a fundamental understanding of the machine linear optics is crucial in that it determines the effectiveness of space-charge emittance compensation methods, as well as provides the means to achieving various beam parameters such as beam length and energy spread. We present a comparison between numerically obtained transfer matrices using computed field maps of the various beam line elements in the injector and experimentally measured response matrices. A procedure for performing beam-based alignment of the machine is also presented.

**C. M. Gulliford** (CESR-LEPP) I. V. Bazarov (CLASSE) A. K. Kim (Cornell University, Laboratory for Elementary-Particle Physics)

### Analytic Solution of the Envelope Equations for an Undepressed Matched Beam in a Quadrupole Doublet Channel

In 1958, Courant and Snyder analyzed the problem of alternating-gradient beam transport and treated a model without focusing gaps or space charge.\* We extend their work to include the effect of gaps (still neglecting space charge) and obtain exact solutions for the matched envelopes.\*\* We assume a periodic lattice of quadrupole doublets. The focus sections have piecewise-constant field strength and equal lengths, but the zero-field drift sections have arbitrary length ratio. We obtain and show the exact envelope results as functions of  $z$  for various field strengths, occupancies ( $\eta$ ), and gap-length ratios. We show the peak envelope excursion as a function of field strength or phase advance ( $\sigma$ ) for various cases. There is a broad  $\sigma$  range over which the minimum peak varies less than  $\pm 1\%$ . For  $\eta = 1$ , this range is 64 to 98 degrees; for  $\eta = 0.5$ , it is 62 to 96 degrees. In the lowest stable band, the optimum field strength rises by 37.6% when  $\eta$  is reduced from 1.0 to 0.5 and rises by 76.0% if also one gap has zero length. In the second stable band, the higher field strength accentuates the remarkable compression effect predicted for the FD (gapless) model.\*\*

**O. A. Anderson** (LBNL) L. L. LoDestro (LLNL)

\*E. D. Courant and H. S. Snyder, Ann. Phys. 3, 1 (1958).

FR5PFP005

FR5PFP006

FR5PFP007

\*\*The present work extends a recent envelope analysis carried out without gaps (O. A. Anderson and L. L. LoDestro, submitted to Phys. Rev. ST-AB).

### Beam Centroid Oscillations in Solenoidal Transport Channels

S. M. Lund, J. E. Coleman, S. M. Lidia, P. A. Seidl, C. J. Wootton (LBNL)

A recent theory in Ref. \* analyzes small-amplitude oscillations of the transverse beam centroid (center of mass) in solenoidal transport channels. This theory employs a trans-

formation to a rotating Larmor frame to simply express the centroid response to mechanical misalignments (transverse center displacements and tilts about the of the longitudinal axis of symmetry) of the solenoid and initial centroid errors. The centroid evolution is expressed in terms of a superposition of the centroid evolving in the ideal aligned system plus an expansion in terms of "alignment functions" that are functions of only the ideal lattice with corresponding amplitudes set by the solenoid misalignment parameters. This formulation is applied to analyze statistical properties of beam centroid oscillations induced by solenoid misalignments. Results are compared to experiments at the NDCX experiment at the LBNL. It is found that contributions to oscillation amplitudes from tilts are significantly larger than contributions from offsets for expected parameters. Use of the formulation to optimally steer the centroid back on-axis with limited diagnostic measurements is also discussed.

\* S. M. Lund, C. J. Wootton, and E. P. Lee, "Transverse centroid oscillations in solenoidally focused beam transport lattices," accepted for publication, Nuc. Inst. Meth. A.

### Finding the Center of Sextupole Magnets Empirically

G. J. Portmann, C. Steier (LBNL)

In a storage ring it is beneficial to have the beam orbit pass as close as possible to the center of the sextupole magnets to avoid the

feeddown errors. This paper will examine a method of measuring the location of the sextupole center using the electron beam. Measuring the center of an individually powered quadrupole is commonly done by using the dipole feeddown error. This sextupole center method is based on the ability to accurately measure quadrupole and skew-quadrupole feed-down errors. It also works on sextupole magnets connected in a series on one power supply.

### Using Novel Injection Schemes for Enhanced Storage Ring Performance

D. Robin (LBNL)

Recently there has been a proposal to use pulsed high order multipole elements for injection. One of the advantages of this pro-

posed injection scheme would be that it would be less disruptive to the stored beam and thus advantageous for Top-off operation. In addition to Top-off, such novel injectors might open the door to operating storage rings in more desirable lattice settings. In this paper we will explore some of the possibilities for taking advantage of high order multipole pulsed kick injection.



**Linear Optics of a Solenoid with Off-Axis Orbit**

Analytical formula of the 6X6 transfer matrix of a magnetic solenoid is derived. As an example, analytical and numerical study of a bunch compressor consists of such solenoids is presented.

W. Wan, A. Zholents (LBNL)

**Orbit Response Matrix Measurements in the Los Alamos Proton Storage Ring**

Orbit response matrix techniques have been used in numerous electron storage rings to elucidate various optical properties of the machines. Such measurements in a long-pulse accumulator ring have unique complications. We present here the techniques and results of such a measurement at the Los Alamos Proton Storage Ring\*. We also show the deficiencies in previous models of the ring and a comparison of the beta-functions as fit by the orbit response method to direct measurements by quadrupole magnet variations.

\*LA-UR- 08-07694

J. S. Kolski, R. J. Macek, R. C. McCrady, T. Spickermann (LANL)  
J. S. Kolski (IUCF)

**An Update of the USR Lattice: Towards a True Multi-User Experimental Facility**

In the future Facility for Low-energy Antiproton and Ion Research (FLAIR) at GSI, the Ultra-low energy electrostatic Storage Ring (USR) will provide cooled beams of antiprotons and possibly also highly charged ions down to energies of 20 keV/q. A large variety of the envisaged experiments demands a very flexible ring lattice to provide a beam with variable cross section, shape and time structure, ranging from ultra-short pulses to coasting beams. The preliminary design of the USR worked out in 2005 was not optimized in this respect and had to be reconsidered. In this contribution we present the final layout of the USR with a focus on its "split-achromat" geometry, the combined fast/slow extraction, and show the different modes of operation required for electron cooling, internal experiments, or beam extraction. We finally give a summary of the machine parameters and the layout of the optical elements.

A. I. Papash (MPI-K) C. P. Welsch (Cockcroft Institute)

**Errors in Beam Emittance Measurement in a Transport Channel**

Determination of exact values of beam emittance is important for future linear collider. Beam emittance measurements technique is based on measurement of beam sizes at several beam profile stations in a quadrupole channel shifted between each other by a specific value of phase advance of betatron oscillations. Four-dimensional beam emittance measurement requires determination of ten values of the beam sigma-matrix, while two-dimensional beam emittance measurements scheme requires determination of six values of sigma-matrix. Measurement procedure is sensitive to variation of beam sizes at the beam profile stations, which might result in unstable determination of beam emittance. Paper discusses errors of beam emittance measurements as a function of errors in beam size measurement. Regions of stable and unstable beam emittance measurements are determined.

Y. K. Batygin (NSCL) M. Woodley (SLAC)

FR5PFP011

FR5PFP012

FR5PFP013

FR5PFP014

**An Achromatic Mass Separator Design for Ions from the NSCL EBIT Charge Breeder**

M. Portillo, G. Bollen, S. Chouhan, O. K. Kester, G. Machicoane, J. Ottarson, S. Schwarz, A. Zeller (NSCL)

The NSCL at Michigan State University (MSU) is implementing a system called the ReA3 to reaccelerate rare isotope beams from projectile fragmentation to energies of about 3 MeV/u. The re-acceleration system uses an Electron Beam Ion Trap (EBIT) to provide a compact and cost efficient system. We discuss the design parameters for a  $m/q$  separator that is to be used to separate highly charged ions from an EBIT type charge breeder. The separator is designed to accept ions at 12 keV/u with mass to charge ratios in the range of  $m/q = 2.5$  to 5 amu. The goal is to separate selected rare isotope species from any residual ions before injecting them into the ReA3 linear accelerator system. Using ray tracing simulations with SIMION\*, as well as higher order map calculations with COSY INFINITY\*\*, the performance of the separator has been evaluated in terms of the expected mass resolution and overall acceptance. The separator consists of a magnetic sector and a series of electrostatic devices to obtain a first order achromatic tune. For comparison, similar performance values will be derived as those for a similar separator constructed at REX-ISOLDE\*\*\*.

\*D. A. Dahl, Int. J. Mass Spectrom. Ion Processes 200, 3 (2000) .

\*\*K. Makino and M. Berz, Nucl. Instr. and Meth. A 558, 346 (2005)

\*\*\*R. Rao et. al., EPAC-98, Stockholm, Sweden, 2132-2134 (1998).

The NSCL at Michigan State University (MSU) is implementing a system called the ReA3 to reaccelerate rare isotope beams from projectile fragmentation to energies of about 3 MeV/u. The re-acceleration system uses an Electron Beam Ion Trap (EBIT) to provide a compact and cost efficient system. We discuss the design parameters for a  $m/q$  separator that is to be used to separate highly charged ions from an EBIT type charge breeder. The separator is designed to accept ions at 12 keV/u with mass to charge ratios in the range of  $m/q = 2.5$  to 5 amu. The goal is to separate selected rare isotope species from any residual ions before injecting them into the ReA3 linear accelerator system. Using ray tracing simulations with SIMION\*, as well as higher order map calculations with COSY INFINITY\*\*, the performance of the separator has been evaluated in terms of the expected mass resolution and overall acceptance. The separator consists of a magnetic sector and a series of electrostatic devices to obtain a first order achromatic tune. For comparison, similar performance values will be derived as those for a similar separator constructed at REX-ISOLDE\*\*\*.

**Parametric Channeling and Collapse of Charged Particles Beams in Focusing Fields**

M. V. Vysotskyy, V. I. Vysotskii (National Taras Shevchenko University of Kyiv, Radiophysical Faculty)

A new type of self-organized orientational motion of different types of charged particles with internal energy structure in strong focusing fields, i.e., parametric channeling, is proposed and studied in details. Features of this mode of motion are associated with the strong parametric coupling of orientational oscillations in focusing fields and vibrations caused by intraparticle processes. During the channeling of molecular diatomic ions this effect can cause "parametric collapse", i.e., beam self-cooling, compression, and a periodic or aperiodic (irreversible) decrease in its phase-space volume. It was also shown that during motion of atomic ions and nuclei in crystals parametric coupling between ion channeling states in the field of crystal axes and planes and electronic states in the ion volume leads to the possibility of periodic decrease in the oscillation amplitude of the atomic ion in the channel. Parametric cooling of beams with a transverse energy decrease can also occur during axial channeling of relativistic electron beams. This process results from the parametric coupling between channeling states, and electron spin states in effective magnetic field in moving system.

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**Dispersion-Leak Lattice for PLS**

H.-S. Kang, J. Choi, D. E. Kim, K. R. Kim, M. Kim, T.-Y. Lee (PAL)

The PLS is a TBA lattice with an emittance of 18 nm-rad which doesn't use dispersion leakage in straight section. Allowing dispersion in straight section can reduce the emittance to 10nm-rad. Dynamic aperture is investigated using MAD including the effect of insertion devices such as multipole wiggler and elliptically polarized undulator. The possibility of further reduction of emittance is also investigated by using dispersion leakage. In this paper, we will describe the simulation results of the dispersion leak lattice and the operation test results in PLS.

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### Experimental Studies of Random Error Effects in High-Intensity Accelerators Using the Paul Trap Simulator Experiment (PTSX)

Understanding the effects of random errors in machine components such as quadrupole magnets and RF cavities is essential for the optimum design and stable operation of high-intensity accelerators. The effects of random errors have been studied theoretically, but systematic experimental studies have been somewhat limited due to the lack of dedicated experimental facilities. In this paper, based on the compelling physics analogy between intense beam propagation through a periodic focusing quadrupole magnet system and pure ion plasma confined in a linear Paul trap, experimental studies of random error effects have been performed using the Paul Trap Simulator Experiment (PTSX). It is shown that random errors in the quadrupole focusing strength continuously produce a non-thermal tail of trapped ions, and increases the rms radius and the transverse emittance almost linearly with the amplitude and duration of the noise. This result is consistent with 2D WARP PIC simulations. In particular, it is observed that random error effect can be further enhanced in the presence of beam mismatch.

**M. Chung** (Fermilab) **M. Chung**, R. C. Davidson, P. Efthimion, E. P. Gilson, R. M. Majeski (PPPL)

FR5PFP018

### Envelope-like Equations for Wobbling and Tumbling Beams

For applications of high intensity beams in heavy ion fusion and high energy density physics, introducing wobbling and tumbling dynamics for the driver beam is an effective technique to reduce plasma and hydrodynamic instabilities in the beam-target interaction region. The wobbling dynamics is introduced by applying transverse deflection of the beam centroid by use of RF fields, and the tumbling dynamics can be imposed by a solenoidal focusing lattice. A set of five envelope-like equations are derived to describe the transverse dynamics of a high intensity beam with wobbling and tumbling motion under the combined transverse focusing and deflection imposed by the quadrupole focusing lattice, the solenoidal focusing lattice, and the deflecting RF fields. Two of equations are for the transverse dimensions of the beam as in the standard envelope equations. Two more of the equations describe the wobbling dynamics of the beam centroid, and the fifth equation describes the tumbling of the beam.

**H. Qin**, R. C. Davidson (PPPL)

FR5PFP019

### Emittance Exchange at the A0 Photoinjector

A transverse to longitudinal emittance exchange experiment is installed at the Fermilab A0 Photoinjector. We report on the completed measurement of emittance exchange transport matrix as well as the ongoing program to directly measure the emittance exchange. Both the transverse and longitudinal input beam parameters are being explored in order to achieve direct emittance exchange with minimal dilution effects

**T. W. Koeth** (Rutgers University, The State University of New Jersey) H. T. Edwards, A. S. Johnson, A. H. Lumpkin, J. Ruan, R. Thurman-Keup (Fermilab) R. P. Fliller (BNL)

FR5PFP020

## Plans and Progress towards Tuning the ATF2 Final Focus System to Obtain a 35nm IP Waist

G. R. White (SLAC) J. K. Jones (STFC/DL/ASTeC) K. Kubo, S. Kuroda (KEK) Y. Renier (LAL) A. Scarfe (UMAN) R. Tomas (CERN)

Using a new extraction line currently being commissioned, the ATF2 experiment plans to test a novel compact final focus optics design using a local chromaticity correction scheme, such as could be used in future linear colliders\*. Using a 1.3 GeV beam of  $\sim 30$ nm normalised vertical emittance extracted from the ATF damping ring, the primary goal is to achieve a vertical IP waist of 35nm. We discuss our planned strategy, implementation details and early experimental results for tuning the ATF2 beam to meet the primary goal. These optics require uniquely tight tolerances on some magnet strengths and positions, we discuss efforts to re-match the optics to meet these requirements using high-precision measurements of key magnet elements. We simulated in detail the tuning procedure using several algorithms and different code implementations for comparison from initial orbit establishment to final IP spot-size tuning. Through a Monte Carlo study of 100's of simulation seeds we find we can achieve a spot-size within 10% of the design optics value in at least 90% of cases. We also ran a simulation to study the long-term performance with the use of beam-based feedbacks.

\*"ATF2 Proposal", ATF2 Collaboration (Boris Ivanovich Grishanov et al.), KEK-REPORT-2005-2, Aug 23, 2005.

## Proton Storage Ring Optics Modeling with ac-Driven Betatron Motion

Y. T. Yan, A. Chao (SLAC) M. Bai (BNL)

Unlike an electron storage ring with radiation damping, resonance excitation is unsuitable to a proton storage ring for turn-by-turn betatron orbit data. However, one may consider modified betatron motion driven by ac dipoles oscillating at frequencies near the betatron tunes. With a matrix formulation for adding ac-dipole effects on 2-D coupled one-turn map, we concatenate the ac-dipole effects and the one-turn map to obtain a modified linear map. The ac-dipole effects are equivalent to inserted symplectic linear maps at the ac-dipole locations. If the maps are normalized through decoupling similarity transformation, the decoupled maps for the ac-dipole effects are equivalent to 1-D thin quads inserted at the corresponding locations, the same conclusion for the 1-D driven oscillation\*. For optics modeling with MIA technique\*\*, one must make sure that there are, simultaneously, two transverse ac-dipole driven betatron oscillations along with one longitudinal synchrotron oscillation. Once the optics model for the modified betatron motion is obtained, one can then obtain the proton storage ring model by de-concatenating the inserted ac-dipole linear maps.

\* R. Miyamoto, S. E. Kopp, A. Jansson, and M. J. Syphers, PRSTAB 11, 084002 (2008).

\*\* Y. T. Yan, ICFA Beam Dynamics Newsletter, No. 42, pp. 71-87 (2007), Y. Cai, W. Chou, Eds.

## Quantum Aspects of Accelerator Optics

S. A. Khan (SCOT)

Charged-particle optics, or the theory of transport of charged-particle beams through electromagnetic systems, is traditionally dealt with using classical mechanics. Though the classical treatment has been very successful, in designing and working of numerous charged-particle optical devices, it is natural to look for a prescription based on the quantum theory, since any system is quantum mechanical at the fundamental level. With this motivation the quantum theory of charged-particle beam optics, is being developed by Jagannathan et al. It is found that the quantum theory gives

rise to interesting additional contributions to the classical paraxial and aberrating behaviour. In the classical limit the quantum formalism reproduces the well-known Lie algebraic formalism. This formalism is further applied to the study of the spin-dynamics of a Dirac particle with anomalous magnetic moment being transported through magnetic optical element. This naturally leads to a unified treatment of both the orbital (the Lorentz and Stern-Gerlach forces) and the spin (Thomas-Bargmann-Michel-Telegdi equation). <http://www.geocities.com/rohelaakhan/>, <http://rohelaakhan.googlepages.com/>

### Quantum Methodologies in Light Beam Optics

A unified treatment of light beam optics and polarization, using the standard mathematical machinery of quantum mechanics is presented. Dirac-like form of the Maxwell equations is well known in literature. Starting with the Dirac-like form of the Maxwell's equations a unified treatment of light beam optics and polarization has been obtained. The traditional results (including aberrations) of the scalar optics are modified by the wavelength-dependent contributions. Some of the well-known results in polarization studies are realized as the leading-order limit of a more general framework of our formalism. <http://www.geocities.com/rohelaakhan/>, <http://rohelaakhan.googlepages.com/>

S. A. Khan (SCOT)

FR5PFP024

### Extending the Energy Range of 50Hz Proton FFAGs

Using an FFAG for rapid-cycling proton acceleration has the advantage that the acceleration cycle is no longer subject to constraints from the main magnet power supply used in an RCS. The RF can be used to its maximum potential to increase the energy range in a short 50Hz cycle as proposed for multi-MW proton driver projects. The challenge becomes an optical one of maintaining a stable lattice across a wide range of beam momenta without magnet sizes or the ring circumference making the machine prohibitively expensive for its purpose. Investigations of stable energy ranges for proton FFAG lattices in the few GeV regime (relativistic but not ultra-relativistic) are presented here.

S. J. Brooks (STFC/RAL/ASTeC)

FR5PFP025

### Beam Transport Line with a Scaling FFAG Type Magnet

A scaling fixed field alternating gradient (FFAG) accelerator provides large momentum acceptance despite of constant field in time. Optical functions are nearly the same for large momentum range. We have designed a straight beam transport (BT) line using a scaling FFAG type magnet which has a field profile of  $xk$ , where  $x$  is the horizontal coordinate and  $k$  is the field index. This BT line has very large momentum acceptance as well, for example  $\pm 50\%$ , and optical functions do not practically depends on momentum. We also designed a dispersion suppressor at the end by the combination of a unit cell with different field index  $k$  so that the momentum dependence of orbits should be eliminated at the exit. An obvious application of this design is the BT line between FFAG accelerator and gantry of a particle therapy facility. However, we also consider it for the transport of muon beams, which have large emittance and momentum spread. This could be an alternative to the conventional BT line with solenoid or quadrupole because of the strong focusing nature of quadrupole and the large momentum acceptance like solenoid.

S. Machida (STFC/RAL/ASTeC)

FR5PFP026

**Extended ALICE Injector**

B. D. Muratori, J. W. McKenzie, Y. M. Saveliev (STFC/DL/ASTeC)

Results of designing of the extended ALICE injector with the aim to include a special dedicated diagnostic line are presented. The purpose of the diagnostic line is to characterise the low energy beam, before it enters the booster, as much as possible. A key component of the ALICE is the high brightness injector. The ALICE injector consists of a DC photocathode gun generating  $\sim 80$  pC electron bunches at 350 keV. These bunches are then matched into a booster cavity which accelerates them to an energy of 8.35 MeV. In order to do this, three solenoids and a single-cell buncher cavity are used, together with the off-crest of the first booster cavity where the beam is still far from being relativistic. The performance of the injector has been studied using the particle tracking code ASTRA.

**Linear Optics Calibrations for the SSRF Storage Ring Based on COD**

L. G. Liu (SSRF)

The ssrf is a 3rd generation light source under commissioning. The commissioning of the storage ring has progressed very well so far. The periodicity and symmetry of the linear optics in a real storage ring is important, however maybe be broken by various errors, such as field errors, manufactured errors. A distorted linear optics can excite more and stronger nonlinear resonances, which will reduce the storage ring dynamic aperture and make the ring suffer from low injection efficiency and short beam lifetime. Therefore, it is necessary to restore the designed periodicity and the symmetry of the linear optics based on measured closed orbit distortion. The calibration procedure can be done by using LOCO (the Linear Optics from Closed Orbit). After fitting the measured response matrix by the model one, the linear optics of the storage ring is calibrated. And different operation modes have been also measured and verified.

**Storage Ring Beam Dynamics Modeling with Limited Instrumentation**

C. Kwankasem, S. Chunjarean (SLRI) H. Wiedemann (SLAC)

For the SIAM Photon Source, we propose to establish a storage ring model based on quadrupole fitting of the measured betatron functions. By fitting of quadrupole field strength parameters to measured values of the betatron function, a series of problems at the SIAM Photon Source could be determined. For example, the problem of turn-to turn electrical coil shorts was detected and solved by replacing the new quadrupole coils. Subsequently, we could identify a quadrupole calibration error due to conflicting information on the number of turns per coil. Other causes regarding the beam dynamics model such as high field saturation effects, power supply calibration error, and proximity to nearby magnets have been taken into account to establish accurate quadrupole calibration factors. The establishment of an accurate model is essential for beam dynamics predictions, closed orbit correction, response matrix determination for LOCO, low emittance operation, and optics correction for high field insertion devices.

**Cyclotron Matching Injection Optics Optimization**

R. A. Baartman (TRIUMF)

Injection from an external ion source into a cyclotron results in unavoidable emittance growth when the cyclotron's pole gap is not small compared with the first turn radius. In such a congested geometry, the injected beam first has the two

transverse directions coupled on entering the axial magnetic field of the cyclotron, then transverse and longitudinal phase spaces are coupled by the inflector. Generally, to avoid loss, the beam is focused tightly through the inflector. It thus arrives at the first turn strongly mismatched because the vertical focusing in such a cyclotron is rather weak (vertical tune  $< 0.3$ ). Space charge exacerbates the mismatch because it depresses the vertical tune further. Emittance growth from all these effects can be calculated using the full Sacherer 6D envelope formalism. We develop the technique to include cyclotrons and in particular the transverse optics of the rf gaps, and apply it in particular to the re-design of the TRIUMF 300 keV vertical injection line.

### Possible Limitations in Coupling Correction Using Orbit Response Matrix Analysis

The specified vertical emittance for the ILC damping rings is 2 pm. A major objective for the Accelerator Test Facility (ATF) at KEK is to demonstrate reliable operation in this low emittance regime. LOCO is a tool for identifying optics errors in storage rings, based on fitting a lattice model to the measured closed orbit response matrix. This technique can be used to determine corrections to minimise vertical dispersion and betatron coupling, and hence reduce the vertical emittance. So far, efforts to apply LOCO to the ATF to achieve 2 pm vertical emittance have met with limited success. This paper presents the results of simulations aiming to identify possible limitations in the technique. We consider the effects of varying parameters controlling the fit of the lattice model to the measured data, and investigate possible degeneracies (e.g. between skew quadrupole strengths and tilts of the corrector magnets) that may limit the quality of the correction achievable using this technique.

**K. G. Panagiotidis** (The University of Liverpool) **K. G. Panagiotidis**, **A. Wolski** (Cockcroft Institute)

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### Beam Transportation and Diagnostics of Mini-LIA

A miniature linear induction accelerator (Mini-LIA) was designed and manufactured by China Academy of Engineering Physics and Tsinghua University. The device consists of an electron gun with thermionic cathode, pulsed power system, two accelerator cells, beam transportation systems and diagnosis systems etc. Double-pulsed beam with each beam current more than 1.0A and beam energy more than 200keV was obtained on Mini-LIA. Transportation of the beam by numerical simulation and PARMELA code is presented and with the results the beam line is optimally designed. Furthermore, several diagnostics methods and experimental results to measure the beam characteristics are presented on this paper.

**C. Cheng** (TUB)

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### The Simulation Study of the Fringing Field Effect on a Compact Storage Ring

In compact storage ring design, fringing field can significantly influence the tune and twiss function of the ring lattice. Furthermore, the fringing field of the quadrupoles and dipoles can significantly influence the beam stability of injection. In this paper, we present the simulation study of the fringing field effect on particle motion in a compact storage ring proposed for the TTX light source. We likewise present the algorithm for the fringing field simulation as well as the influence of the fringing field on beam dynamics in this paper.

**D. D. Yang**, **W.-H. Huang** (TUB)

We likewise present the algorithm for the fringing field simulation as well as the influence of the fringing field on beam dynamics in this paper.

**Optical Stochastic Cooling in a Compact Storage Ring**

P.-CH. Yu, W.-H. Huang, X. Shen (TUB)

the general layout of the scheme, as well as the lattice design of the storage ring. The results of beam dynamics simulation are likewise presented.

The feasibility study of optical stochastic cooling (OSC) utilizing a compact storage ring is presented in this paper. We present

**6D Cooling Simulations for the Muon Collider**

P. Snopok (UCR)

laser. It has a number of advantages over other cooling channels, but it also has certain drawbacks. The injection and extraction, the absorber overheating, and the bunch train length are among main issues. A number of simulations of a possible solution to these problems, the RFOFO helix, commonly referred to as the Guggenheim channel, were carried out and their results are summarized. The details of the tracking studies of both the idealized and realistic lattices are presented and compared.

The RFOFO ring is considered to be one of the most promising six-dimensional cooling channels proposed for the future Muon Collider.

**Close Orbit Correction of Hefei Advanced Light Source (HALS) Storage Ring**

G. Feng (USTC/NSRL)

Hefei Advanced Light Source (HALS), is brought forward by National Synchrotron Radiation Laboratory (NSRL). This 1.5GeV storage ring with ultra low emittance about 0.2nmrad consists 18 combined FBA cells and the Circumference is 388m. Strong enough quadrupoles and sextupoles must be needed for getting such low emittance lattice which will lead beam close orbit distortions' (COD) sensitivity to the field and alignment errors in the magnets. Estimation of the COD from various error sources are investigated. Using orbit response matrix and singular value decomposition method, The distribution of beam position monitors and the location of slow and fast correctors are reported in the paper. Simulation proves that COD can be corrected down to 50 microns level. In the same time the corrector strengths are smaller enough in the correction scheme.

In order to meet the increasing requirements of synchrotron radiation users, a new plan of VUV and soft X-ray light source, named

**Adiabatic Thermal Beam Equilibrium in an Alternating-Gradient Focusing Field**

J. Z. Zhou, C. Chen, K. R. Samokhvalova (MIT/PSFC)

presented. Warm-fluid equilibrium equations are solved in the paraxial approximation and the rms beam envelope equations and the self-consistent Poisson equation, governing the beam density and potential distributions, are derived. The theory predicts that the 4D rms thermal emittance of the beam is conserved, but the 2D rms thermal emittances are not constant. Although the presented rms beam envelope equations have the same form as the previously known rms beam envelope equations, the evolution of the rms emittances in the present theory is given by analytical expressions. The beam density is calculated numerically, and it does not have the simplest elliptical symmetry, but the constant density contours are ellipses whose aspect ratio decreases as the density decreases along the transverse displacement from the beam axis. For high-intensity beams, the beam density profile is flat

An adiabatic warm-fluid equilibrium theory for a thermal charged-particle beam in an alternating gradient (AG) focusing field is



in the center of the beam and falls off rapidly within a few Debye lengths, and the rate at which the density falls is approximately isotropic in the transverse directions.

### Possible Emittance Growth due to Nonuniform Particle Distribution in Beams with Thermal Equilibrium Condition

Possible emittance growth due to a nonuniform particle distribution can be analyzed with a thermal equilibrium state in various space-charge potential beams. The possible emittance growth is given by a function of a space-charge tune depression and a nonlinear field energy factor. The nonlinear field energy factor, which is determined by nonuniformity of a charge distribution, is estimated in the thermal equilibrium distribution on a cross-section in a beam. The nonlinear field energy factor changes with space-charge potential for the thermal equilibrium distribution. It is expected that the possible emittance growth will be decreased effectively to consider in the thermal equilibrium condition.

T. Kikuchi (Nagaoka University of Technology) K. Horioka (TIT)

FR5PFP038

### Verification of the AWA Photoinjector Beam Parameters Required for a Transverse-to-Longitudinal Emittance Exchange Experiment

A transverse-to-longitudinal emittance exchange experiment is in preparation at the Argonne Wakefield Accelerator (AWA). The experiment aims at exchanging a low ( $< 5$  mm-mrad) longitudinal emittance with a large ( $>15$  mm-mrad) transverse horizontal emittance for a bunch charge of 100 pC. Achieving such emittance partitioning, though demonstrated via numerical simulations, is a challenging task and need to be experimentally verified. In this paper, we report emittance measurements of the beam in the transverse and longitudinal planes performed at 12 MeV. The measurements are compared with numerical simulations using Impact-T.

M. M. Rihaoui, P. Piot (Northern Illinois University) W. Gai, J. G. Power (ANL)

FR5PFP039

### Measurement and Simulation of Space Charge Effects in a Multi-Beam Electron Bunch from an RF Photoinjector

We report on a new experimental study of the space charge effect in a space-charge-dominated multi-beam electron bunch. A 5 MeV electron bunch, consisting of a variable number of beamlets separated transversely, was generated in a photoinjector and propagated in a drift space. The collective interaction of these beamlets was studied for different experimental conditions. The experiment allowed the exploration of space charge effects and its comparison with three-dimensional particle-in-cell simulations. Our observations also suggest the possible use of a multi-beam configuration to tailor the transverse distribution of an electron beam.

M. M. Rihaoui, P. Piot (Northern Illinois University) W. Gai, J. G. Power, Z. M. Yusof (ANL)

FR5PFP040

**ORBIT Benchmark of Extraction Kicker Instability Observed in SNS**

J. A. Holmes, S. M. Cousineau, V. V. Danilov (ORNL) Z. Liu (IUCF)

During one of the high beam intensity runs in SNS, a coasting beam instability was observed in the ring when the beam was stored for 10000 turns. This instability was observed at an intensity of about 12 microcoulombs and was characterized by a frequency spectrum peaking at about 6 MHz. A likely cause of the instability is the impedance of the ring extraction kickers. We carry out here a detailed benchmark of the observed instability, uniting an analysis of the experimental data, a precise ORBIT Code tracking simulation, and a theoretical estimate of the observed beam instability.

**Approximate Matched Solution of Intense Charged Particle Beam Propagating through Periodic Quadrupole Focusing Lattice**

E. Startsev, R. C. Davidson, M. Dorf (PPPL)

The transverse dynamics of an intense charged particle beam propagating through a periodic quadrupole focusing lattice is described by the nonlinear Vlasov-Maxwell system of equations where the propagating distance plays the role of time. To find matched-beam quasi-equilibrium distribution functions one need to determine a dynamical invariant for the beam particle moving in the combined external and self-fields. The standard approach for sufficiently small phase advance is to use the smooth focusing approximation, where particle dynamics is determined iteratively using the small parameter (vacuum phase advance)/(360 degrees) < 1 accurate to cubic order. In this paper, we present a perturbative Hamiltonian transformation method which is used to transform away the fast particle oscillations and obtain the average Hamiltonian accurate to 5th order in the expansion parameter. This average Hamiltonian, expressed in the original phase-space variables, is an approximate invariant of the original system, and can be used to determine self-consistent beam equilibria that are matched to the focusing channel.

**Matching with Space Charge #2**

S. B. van der Geer (Pulsar Physics) D. J. Holder, B. D. Muratori (STFC/DL/ASTeC) M. J. de Loos, S. B. van der Geer (TUE)

The required strengths of quadrupoles in a phase-space tomography section are significantly affected by the total charge per bunch. Finding settings at a high charge is challenging because of the non-linear nature of Coulomb interactions. This is further hindered by the inability to use thin-lens approximations and dependence on numerical simulations. Finally, one faces the problem that at some charge there simply is no solution at all. In this contribution we describe a simple procedure, implemented in the General Particle Tracer (GPT) code, which can be used to find optimal beamline settings in the presence of space-charge forces. The recipe 'transports' the settings for a zero-charge solution to those of the desired charge and it gives an indication what the maximum tolerable charge is.

**Studies of Space Charge Loss Mechanisms Associated with Half Integer Resonance on the ISIS RCS**

C. M. Warsop, D. J. Adams, B. G. Pine (STFC/RAL/ISIS)

ISIS is the spallation neutron source at the Rutherford Appleton Laboratory in the UK.

Operation centres on a 50 Hz proton synchrotron, which accelerates  $\sim 3 \cdot 10^{13}$  ppp from 70 to 800 MeV, corresponding to beam powers of 0.2 MW. Beam loss imposes limits on operational intensity, and a main contributing mechanism is the action of half integer resonance under high space charge. The same loss mechanism is also a potential problem in ISIS upgrade scenarios involving either higher energy injection into the existing ring, or the addition of a new 3 GeV, high intensity RCS. Progress on particle in cell simulation studies investigating the effects of the driven coherent envelope motion, the associated parametric halo, along with implications of momentum spread, dispersion and longitudinal motion, is reported. Where possible, comparisons are made with relevant theoretical models. Closely related benchmarking work, experimental studies and plans are also summarised.

### Code Development and Space Charge Studies for ISIS Upgrades

There are several upgrade ideas being actively researched at ISIS, which collectively would boost beam power to target to more than 1 MW. Underpinning the programme of upgrades is a study of high intensity effects that impose limitations on beam power, and the development of codes to investigate these effects. A core aim of the work is to validate simulations and theory. A new 2D space charge code, *Set*, has been developed to study high intensity beam behaviour. *Set* has been successfully parallelized this year, leading to a significant improvement in simulation time. Work has begun extending the code to 2.5D. Benchmarks including the CERN Montague resonance, and modeling of the half integer resonance at GSI SIS rings are reported.

**B. G. Pine**, D. J. Adams, C. M. Warsop, R. E. Williamson (STFC/RAL/ISIS)

FR5PFP045

### Longitudinal Dynamics Studies for ISIS Upgrades

ISIS is the pulsed neutron and muon source based at the Rutherford Appleton Laboratory in the UK. Operation is centred on a loss-limited 50 Hz proton synchrotron which accelerates  $\sim 3 \cdot 10^{13}$  protons per pulse from 70 MeV to 800 MeV, corresponding to mean beam powers of 0.2 MW. A number of ISIS upgrades are currently under study. One option replaces the linac for higher energy injection into the existing ring, potentially increasing beam current through reduction in space charge. The other main option adds a new 3 GeV RCS, boosting the energy of the beam to provide higher beam power. For both these upgrade routes, longitudinal dynamics of the existing and proposed new rings play a crucial role in achieving high intensity with low loss. This paper outlines longitudinal beam dynamics studies in the rings for both these cases, including development of a new longitudinal space charge code, comparison of different algorithms and codes and treatment of the key beam dynamics issues for each case. The influence of non-space charge impedances is also considered.

**R. E. Williamson**, C. M. Warsop (STFC/RAL/ISIS)

FR5PFP046

### Thermal Control of the Fermi@Elettra Accelerating Sections

FERMI@Elettra is a FEL user facility under construction at Sincrotrone Trieste, Italy. It will use the existing normal conducting S-band Linac and seven accelerating sections received from CERN after the LIL decommissioning. Two additional new sections are also foreseen. The Linac repetition rate will be 10 Hz during the initial stage of operation, but it will be ramped up from 10 Hz to 50 Hz. Due to the higher RF power dissipation, the temperature distribution

**C. Serpico**, G. D'Auria, P. Delgiusto (ELETTRA)

FR5PFP047

on the copper structure will reach higher values. RF heating will imply a thermal deformation of the accelerating cavities, both in the transversal and in the longitudinal direction. Since FERMI@Elettra has stringent requirements on phase stability, the length of the section must be kept as constant as possible. In this paper the thermo-mechanic behaviour of the accelerating sections is investigated and the results of the simulations are presented. Furthermore an algorithm has been developed to control the longitudinal deformation of the sections.

### Analysis of the CSR Interaction for a 2D Energy-Chirped Bunch on a General Orbit

R. Li (JLAB)

When an electron bunch with initial linear energy chirp traversing a bunch compression chicane, the bunch interacts with itself via coherent synchrotron radiation (CSR) and space charge force. The effective longitudinal CSR force for a 2D energy-chirped gaussian bunch on a circular orbit has been analyzed earlier\*. In this paper, we present our analytical results of the effective longitudinal CSR force for such a bunch going through a general orbit, which includes the entrance and exit of a circular orbit. In particular, we will show the behavior of the force in the last bend of a chicane when the bunch is under extreme compression.

\*R. Li, Phys. Rev. ST Accel. Beams 11, 024401 (2008).

### Effects of Transverse Physics on Nonlinear Evolution of Longitudinal Space-Charge Waves in Beams

K. Tian (JLAB) I. Haber, R. A. Kishek, P. G. O'Shea, M. Reiser (UMD) D. Stratakis (BNL)

Longitudinal space-charge waves can introduce energy perturbations into charge particle beams and degrade the beam quality, which is critical to many modern applications of particle accelerators. Although many longitudinal phenomena arising from small perturbations can be explained by a one-dimensional cold fluid theory, nonlinear behavior of space-charge waves observed in experiments has not been well understood. In this paper, we summarize our recent investigation by means of more detailed measurements and self-consistent simulations. Combining the numerical capability of a PIC code, WARP, with the detailed initial conditions measured by our newly developed time resolved 6-D phase space mapping technique, we are able to construct a self consistent model for studying the complex physics of longitudinal dynamics of space-charge dominated beams. Results from simulation studies suggest that the unexplained nonlinear behavior of space-charge waves may be due to transverse mismatch or misalignment of beams.

### An Analytical Characterization of Initially Non-Homogeneous Matched Beams at Equilibrium

R. P. Nunes, F. B. Rizzato (IF-UFRGS)

Non-homogeneity is a characteristic naturally present in non-neutral beams. Recently, a set of works has been developed by us for beams initially homogeneous, making possible that relevant beam macroscopic quantities such as the RMS radius and emittance could be determined at equilibrium as functions of characteristic parameters of its phase-space topology. The present work intends to investigate the influences of the initial inhomogeneity in the beam route to equilibrium. For that, the system here is described by an initially cold, azimuthally symmetric, and non-homogeneous beam, focused by a constant magnetic field. Through the same methodology introduced in the studies for the homogeneous beams, both emittance and beam envelope have been obtained as a function of the magnitude

of the inhomogeneity and some additional phase-space parameters. The results obtained with this investigation have proven to be useful not only to better understand the effects of inhomogeneity over beam dynamics but also to provide physical background to the investigations previously carried out for homogeneous beams.

### The Influences of Initially Induced Inhomogeneity over the Dynamics of Mismatched Intense Charged Beams

Although undesired in many applications, the intrinsic spurious spatial inhomogeneity that permeates real systems is the forerunner instability which leads high-intensity charged particle beams to its equilibrium. In general, this equilibrium is reached in a particular way, by the development of a tenuous particle population around the original beam, conventionally known as the halo. In this way, the purpose of this work is to analyze the influence of the magnitude of initial inhomogeneity over the dynamics and over the equilibrium characteristics of initially quasi-homogeneous mismatched beams. For that, all beam constituent particles, which are initially disposed in an equidistant form, suffer a progressive perturbation through random noise with a variable amplitude. Dynamical and equilibrium quantities are quantified as functions of the noise amplitude, which indirectly is a consistent measure of the initial beam inhomogeneity. The results have been obtained by the means of full self-consistent N-particle beam numerical simulations and seem to be an important complement to the investigations already carried out in prior works.

R. P. Nunes, L. C. Martins (IF-UFRGS)

### On the Time Scale of Halo Formation in Homogeneous Mismatched Beams

Experiments and numerical simulations show that high-intensity beams composed by charged particles usually reach their final stationary state while progressively populating of a spatial region external to its original border. This populating process occurs in such terms the beam spatial limits at equilibrium increases by an amount of two or three times its initial nominal size. This is known as halo in Beam Physics. In this way, this work intends to better understand the time scale of halo formation as a function of the initial beam mismatch. The system here consists of an initially cold, mismatched, azimuthally symmetric, and homogeneous beam, focused by a constant magnetic field. The carried out investigation has shown that the time scale of halo formation, in fact, can be segmented in two different quantities, each one associated to distinct physical mechanisms. One is related with the initial non-homogeneity naturally present in such systems, and the other is a result of the initial beam mismatch. This investigation seems to be useful to design more efficient collimation systems and/or non-linear control systems for the next high-power accelerators.

R. P. Nunes, F. B. Rizzato (IF-UFRGS)

### Centroid Dynamics of Magnetically Focused Intense Relativistic Charged Beams Surrounded by a Conducting Wall

In this paper, we investigate the combined envelope-centroid dynamics of relativistic continuous charged beams transported through a uniform focusing field and surrounded by a conducting wall. For such beams, the conducting wall screens the electric field but allows magnetic field penetration, enhancing the induced charges effect on the beam transport. As a consequence, in contrast to the case of nonrelativistic beams where the walls are shown to have little effect\*, relativistic beams may have their centroid motion severely affected, leading to limitations in the total

R. Pakter, L. C. Martins, F. B. Rizzato (IF-UFRGS)

current and area occupied by the beam inside the conductor. Self-consistent simulation are used to verify the findings.

\*K. Fiuza, F. B. Rizzato, and R. Pakter, Phys. Plasmas, 13, 02310<sup>1</sup> (2006).

### Relaxation of Intense Inhomogeneous Mismatched Charged Beams

F. B. Rizzato, A. Endler, R. P. Nunes, R. Pakter, E. G. Souza (IF-UFRGS)

In this work we analyze the dynamics of mismatched inhomogeneous beams of charged particles. Initial inhomogeneities lead to propagating density waves across the beam core, and the presence of density waves eventually results in density build up and particle scattering. Particle scattering off waves in the beam core and the presence of resonances due to envelope mismatches ultimately generate a halo of particles with concomitant emittance growth. Emittance growth directly indicates when the beam relaxes to its final stationary state, and the purpose of the present paper is to describe halo and emittance in terms of test particles moving under the action of the mismatched inhomogeneous beam. To this end we develop an average Lagrangian approach for the beam where both density and envelope mismatches are incorporated. Test particle results compare well with full simulations.

In this work we analyze the dynamics of mismatched inhomogeneous beams of charged particles. Initial inhomogeneities lead to propagating density waves across

### Anisotropic Kinetic and Dynamics Processes in Equipartitioned Beams

W. Simeoni (IF-UFRGS)

The question is whether an anisotropic system of collisionless particles coupled by long-range space-charge forces will equipartition and, if so, how. Results show that collective effects tend to cause an initial beam with strongly nonuniform density to relax, rapidly, to a state that is equilibrium-like. In order to understand the initial dynamical behavior of an anisotropic beams, in particular, to study possible mechanisms of equipartition connected with phase space we have to know how we can compute the variables (volume, area of surface, and area projected) that characterize the anisotropic beam in phase space. The purpose of this paper is to propose one definition of the anisotropic equipartition. In the state of anisotropic equipartition, the temperature is stationary, the entropy grows in the cascade form, there is a coupling of transversal emittance, the beam develops an elliptical shape with a increase in its size along one direction and there is halo formation along one direction preferential.

The question is whether an anisotropic system of collisionless particles coupled by long-range space-charge forces will equipar-

### Beam Dynamics and RF Cavity Design of a Standing/Traveling-Wave Hybrid Photoinjector for High Brightness Beam Generation

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D. Alesini, L. Ficcadenti, B. Spataro (INFN/LNF) L. Palumbo  
(Rome University La Sapienza)

A hybrid photoinjector, which we present here, consists of a 6-cell traveling wave structure with a standard 1.6-cell RF gun attached to the one end and a 3-m long linac following for further acceleration. With this structure, no reflection observed at the input port. This enables to build the accelerator without a circulator which limits the power and the frequency of RF. From the beam dynamics point of view, the beam is produced as the normal RF guns and gets short by velocity bunching in the traveling wave section right after the gun. The peak current can reach more than 1 kA, with about 2 mm.mrad of the emittance at 20 MeV. We discuss more details about the beam dynamics as well as the RF structure.

A hybrid photoinjector, which we present here, consists of a 6-cell traveling wave structure with a standard 1.6-cell RF gun attached to the one end and a 3-m long linac following for further acceleration. With this

### Beam Dynamics Simulations of the Velocity Bunching in a Superconducting Linac

The velocity bunching is a hot topic in normal conducting photoinjectors to generate high-brightness beams instead of magnetic chicanes in the low energy region. We apply this technique to the superconducting photoinjectors. The linac considered here consists of several 9-cell TESLA cavities, the standard 1.6-cell normal conducting RF gun is assumed, though. In the case of 1.1 nC injection, the peak current increases to 1 kA with 2.6 mm.mrad of the emittance. The peak current can be higher but the emittance becomes worse in that case, and vice versa. We discuss more details on the spot.

**A. Fukasawa, B. D. O'Shea, J. B. Rosenzweig (UCLA)**

FR5PFP057

### Longitudinal Beam Bucket Studies for a Space-Charge Dominated Beam

The stability of beams in the longitudinal direction is fundamental to the operation of accelerators that circulate high intensity beams such as the University of Maryland

Electron Ring (UMER), a scaled accelerator using low-energy electrons to model space charge dynamics. The space charge forces in the beam are responsible for the expansion of the beam ends, creating a change in energy from beam head/tail to the main base energy flat-top part of the beam. This paper presents the first experimental results on using an induction cell to longitudinally focus the bunch circulating within the UMER lattice and on how the beam responds to the time-dependant impulses applied by the cell.

Keywords: electron ring, focusing, induction cell.

**B. L. Beaudoin, S. Bernal, K. Fiuza, I. Haber, R. A. Kishek, P. G. O'Shea, M. Reiser, D. F. Sutter, C. Wu (UMD)**

FR5PFP058

### Resonance Phenomena over a Broad Range of Beam Intensities in an Electron Storage Ring

The University of Maryland Electron Ring (UMER) can operate over a broader range of beam intensities than other circular machines. Naturally, transverse and longitudinal

space charge effects limit the ability to store beams. In UMER, the resonance properties of the machine in the two regimes of operation, emittance- and space charge-dominated transport, differ significantly. We report on studies of linear betatron resonances in UMER from 0.6 mA to 80 mA beam current, corresponding to theoretical space charge incoherent tune shifts well over the Lasslet limit. The observations are related to existing theories as well as to computer simulations. We also describe the instrumentation and techniques used for tune measurements.

**S. Bernal, B. L. Beaudoin, M. Cornacchia, K. Fiuza, I. Haber, R. A. Kishek, P. G. O'Shea, M. Reiser, D. F. Sutter, C. Wu (UMD)**

FR5PFP059

### Modeling Longitudinal Dynamics of High Intensity Beams

Understanding the longitudinal dynamics of high intensity (space-charge-dominated) electron and ion beams is important. The longitudinal dynamics of space-charge-

dominated beams can be fundamentally different from beams at lower intensities, because at sufficiently high beam intensities the beam response to a longitudinal perturbation is the launching of space charge waves. This work analyses the beam longitudinal dynamics for the University of Maryland Electron Ring (UMER) beam, i.e., high

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FR5PFP060

current, low-energy and space-charge-dominated electron beam which is applicable, on a scaled basis, to a large class of other beam systems. We use the WARP particle-in-cell code to perform simulations that are compared with theoretical predictions and experimental results.

### Matching and Injection of Beams with Space Charge into the University of Maryland Electron Ring (UMER)

R. A. Kishek, B. L. Beaudoin, S. Bernal, K. Fiuza, I. Haber, P. G. O'Shea, C. F. Papadopoulos, M. Reiser, D. F. Sutter, C. Wu (UMD)  
D. Stratakis (BNL)

Beam matching is critical for avoiding envelope mismatch oscillations that can lead to emittance growth and halo formation, especially if the beam has significant space charge. The University of Maryland Electron

Ring (UMER) is a research storage ring that is designed for scaled studies that are applicable to many larger machines. Using 10 keV electron beams at relatively high current (0.6 -- 100 mA), space charge forces are relatively strong. Matching of the UMER beam is rendered difficult by the space charge, the crowdedness of the lattice, and especially the unique injection scheme where an offset oversized quadrupole is shared between the ring and the injector. In this paper we discuss several schemes for optimizing the matching at injection, both analytical and beam-based, which we test using particle-in-cell simulations with the code, WARP. Comparison to UMER experimental data is provided where available.

### Halo Regeneration in Intense Charged Particle Beams

C. F. Papadopoulos, I. Haber, R. A. Kishek, P. G. O'Shea, M. Reiser (UMD)

Halo is one important limiting factor for the continuous and reliable operation of intense electron or ion beam facilities, such as FELs and spallation neutron sources. A halo population

outside the core of the beam can lead to uncontrolled beam loss, electron cloud effects and activation of the beam pipe, as well as beam quality degradation. In this study, we focus on the issue of halo removal, by means of beam collimation, and subsequent halo regeneration. We compare the particle-core model of halo creation to accurate, self consistent particle-in-cell (PIC) simulations. We show that under certain conditions the halo is regenerated even after collimation. This can only be understood within the context of collective effects, particularly in the case of intense beams.

### Coherent Phenomena over a Broad Range of Beam Intensities in the Electron Storage Ring UMER

D. F. Sutter, B. L. Beaudoin, S. Bernal, M. Cornacchia, K. Fiuza, I. Haber, R. A. Kishek, P. G. O'Shea, M. Reiser, C. Wu (UMD)

The University of Maryland Electron Ring (UMER) is designed for operation over a broad range of beam intensities, including those normally achieved only in linacs. This

is possible thanks to a combination of low-energy (10 keV) electrons and a high density of magnetic quadrupoles (72 over an 11.5 m circumference) that allow operation from 0.5 mA to 100 mA; that is, from the emittance dominated to the highly space charge dominated regimes. We present results of basic centroid-motion characterization, including measurements of closed-orbit distortion, momentum compaction factor, and natural chromaticity and



dispersion. These are compared with results from computer simulations employing the code ELEGANT. We discuss the techniques and challenges behind the measurements with fast beam-position and wall-current monitors, and also the special role of the background ambient magnetic field for beam steering.

### Analysis of Decoherence Signals at the SLS Storage Ring

An online measurement of the beam energy spread is based on the analysis of the decoherence/recoherence signals obtained from the beam position monitors after a single turn beam excitation by a pinger magnet. Furthermore the analysis allows calibration of the model in terms of higher order chromaticities and amplitude dependant tune shifts. Analytical models and experimental results will be presented.

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FR5PFP064

### The Object Oriented Parallel Accelerator Library (OPAL)

OPAL (Object Oriented Parallel Accelerator Library) is a tool for charged-particle optics in accelerator structures and beam lines including 3D space charge, short range wake-fields and a 1D coherent synchrotron radiation. Built from first principles as a parallel application, OPAL admits simulations of any scale, from the laptop to the largest HPC clusters available today. Simulations, in particular HPC (High Performance Computing) simulations, form the third pillar of science, complementing theory and experiment. In this paper we present numerical and HPC capabilities such as fast direct and iterative solvers together with timings up to several thousands of processors. The application of OPAL to our PSI-XFEL project as well as to the ongoing high power cyclotron upgrade will demonstrate OPAL's capabilities applied to ongoing projects at PSI. Plans for future developments will be discussed.

**A. Adelman**, Y. Ineichen, C. Kraus, T. Schietinger, M. Wittberger (PSI) S. J. Russell (LANL) J. J. Yang (CIAE)

FR5PFP065

### A User-Friendly Code to Model Radiation of High Brightness Beams

The accelerator community has many codes that model beams and emitted radiation. Many of these codes are specialized and often, as in start-to-end simulations, multiple codes are employed in subsequent fashion. One of the most important goals of simulations is to accurately model beam parameters and compare results to those obtained from real laboratory diagnostics. This paper describes the development of a user-friendly code that models the coherent radiation of high brightness beams, with a heavy emphasis on simulation of observables via laboratory diagnostics.

**G. Andonian**, M. Ruelas (RadiaBeam) S. Reiche (UCLA)

FR5PFP066

### Acceleraticum: Computer Code for Tracking of Charge Particles in Storage Rings

We describe a computer code for general design of the accelerator magnetic lattice and 6D particle tracking under rather realistic circumstances. The tracking module provides symplectic simulation of the particles motion in almost all existing magnetic elements. Any kinds of the multipole field errors are available. To track the beam through the

**P. A. Piminov**, E. B. Levichev (BINP SB RAS)

FR5PFP067

wiggler and undulator field (measured or obtained by the magnet design code) a special symplectic algorithm is developed. The effects of the radiation damping and excitation, beam-beam collision and space charge are included in the code. An original approach to optimize the dynamic aperture is developed and described in the report.

### Wakefield Simulation of CLIC PETS Structure Using Parallel 3D Finite Element Time-Domain Solver T3P

A. E. Candel, A. C. Kabel, K. Ko, L. Lee, Z. Li, C.-K. Ng, G. L. Schussman (SLAC) I. Syratchev (CERN)

In recent years, SLAC's Advanced Computations Department (ACD) has developed the parallel 3D Finite Element electromagnetic time-domain code T3P. Higher-order Finite

Element methods on conformal unstructured meshes and massively parallel processing allow unprecedented simulation accuracy for wakefield computations and simulations of transient effects in realistic accelerator structures including two-beam concepts. Applications include simulation of wakefield damping and power extraction of the transfer structure (PETS) and an analysis of the CLIC beam loading compensation scheme.

### Parallel 3D Finite Element Particle-in-Cell Simulations with Pic3P

A. E. Candel, A. C. Kabel, K. Ko, L. Lee, Z. Li, C.-K. Ng, G. L. Schussman (SLAC) I. Ben-Zvi, J. Kewisch (BNL)

SLAC's Advanced Computations Department (ACD) has developed the parallel 3D Finite Element electromagnetic Particle-In-Cell code Pic3P. Designed for simulations of

beam-cavity interactions dominated by space charge effects, Pic3P solves the complete set of Maxwell's equations self-consistently and includes space-charge, retardation and boundary effects from first principles. Higher-order Finite Element methods with adaptive refinement on conformal unstructured meshes lead to highly efficient use of computational resources. Massively parallel processing with dynamic load balancing enables large-scale modeling of photoinjectors with unprecedented accuracy, aiding the design and operation of next-generation accelerator facilities. Applications include the LCLS photoinjector and the ILC Polarized SRF Gun.

### Using Commodity Graphic Processing Units (GPUs) for High-Speed Storage Ring Simulations

A. C. Kabel (SLAC) D. S. Yershov (University of Illinois)

Parallel floating-point processors for graphics rendering (GPUs) are an attractive option for some computational problems usually

requiring supercomputing. We show that single-particle dynamics maps well onto GPU hardware. We present an algorithm that makes optimal use of the caching mechanisms of NVidia 8xxx-series GPUs, leading to a near-ideal speedup of tracking studies on this platform. The algorithm is sufficiently general to allow treatment of general non-linear magnetic lattices, using arbitrary-order symplectic integrators. We describe the 'gputrack' library which provides a high-level language API, making the algorithm easily embeddable into traditional codes. Using the LHC lattice and the 'PLIBB' tracking code as a host, we show typical long-term tracking results. We address the issue of long-term stability in the presence of non-hamiltonian terms due to round-off errors of the GPU's single-precision arithmetic. An extended algorithm, using rational symplectic lattices, achieves exact symplecticity while sacrificing some speed and accuracy. We benchmark speed and long-term stability of the two algorithms.

**Thermal Analysis of SCRF Cavity Couplers Using Parallel Multi-Physics Tools TEM3P**

SLAC has developed a multi-physics simulation code TEM3P for simulating integrated effects of electromagnetic, thermal and structural effects. TEM3P shares the same finite element infrastructure with EM finite elements codes developed at SLAC. This enables simulations within a single framework. Parallel implementation allows large scale computation, and high fidelity and high accuracy simulations can be performed in faster time. In this paper, TEM3P is used to analyze thermal loading in the coupler end-groups of the JLAB SCRF cavity. The results are benchmarked against measurements.

**V. Akcelik**, K. Ko, L. Lee, Z. Li, C.-K. Ng (SLAC) G. Cheng, R. A. Rimmer, H. Wang (JLAB)

FR5PFP071

**Command Line Interface to Tracy Library**

We describe a set of tools that interface to the Tracy particle tracking library. The state of the machine including misalignments, multipole errors and corrector settings is captured in a “flat” file, or “machine” file. There are three types of tools designed around this flat file: 1) flat file creation tools. 2) flat file manipulation tools. 3) tracking tools. We describe the status of these tools, and discuss how they have been used in the design process for NSLS-II.

**B. Nash** (SLAC)

FR5PFP072

**2D Potential for an Elliptical Charge Distribution**

We have employed the method of images and linear superposition to develop a computational method for calculating electric potential for two dimensional elliptical surface and three dimensional ellipsoid uniform charge distributions Shell inside a perfect long cylindrical conductor\*. We consider charge distribution as set of point charges. For each point charge, we calculate the image charge and coordinate. The potential in each point is assumed to be a linear superposition of potentials of all point charges including original and images.

**K. Haghighi mood** (PPRC) M. Aslaninejad (IPM)

\*Miguel A. Furman Phys. Rev. ST Accel. Beam 10, 081001(2007)

FR5PFP073

**Self-Consistent Parallel Multi Bunch Beam-Beam Simulation Using a Grid-Multipole Method**

The simulation code COMBI has been developed to enable the study of coherent beam-beam effects in the full collision scenario of the LHC, with multiple bunches interacting at multiple crossing points over many turns. The parallel version of COMBI was first implemented using a soft-Gaussian collision model which entails minimal communication between worker processes. Recently we have extended the code to a fully self-consistent collision model using a Grid-Multipole method, which allows worker processes to exchange charge and field information in a compact form which minimizes communication overhead. In this paper we describe the Grid-Multipole technique used and its adaptation to the parallel environment through pre- and post-processing of charge and grid data. Performance measurements in multi-core and Myrinet-cluster environments will be given. We will also present our estimates of the potential for very large-scale simulations on massively-parallel hardware, in which the number of simulated bunches ultimately approaches the actual LHC bunch population.

**F. W. Jones** (TRIUMF) W. Herr, T. Pieloni (CERN)

FR5PFP074

FR5PFP075

**Benchmarking TRACK against PARMELA in the Design of the TRIUMF e-Linac**

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V. Naik (DAE/VECC)

The TRIUMF ARIEL Project plans to build a 50MeV electron linac at 10mA to produce radioactive ion beams through photofission. Beam dynamics studies of the accelerator are on-going. The TRACK code originally written to simulate proton and heavy ion linacs has been used in e-linac modeling studies. This paper will summarize the TRACK simulation studies and the simulation results will be compared with other codes like PARMELA and ASTRA.

The TRIUMF ARIEL Project plans to build a 50MeV electron linac at 10mA to produce radioactive ion beams through photofission. Beam dynamics studies of the accelerator

FR5PFP076

**Multipacting Simulation in ISAC-II Superconducting Cavities**

M. Gusarova, N. P. Sobenin (MEPhI) V. Zvyagintsev (TRIUMF)

ISAC-II are presented. The multipacting simulation was done using MultP-M code. Dangerous areas of structure and levels of an accelerating field are revealed. Examples of electrons resonant trajectories are presented. Simulation results are compared with experimental results obtained during several superconducting cavities processing.

The results of 3D multipacting simulation in coaxial superconducting quarter wave cavities of the linear accelerator of heavy ions

FR5PFP077

**Realistic Models for RF Cavities**

D. T. Abell, I. V. Pogorelov, P. Stoltz (Tech-X)

accelerating mode and a TM-110 (crab) mode. They are useful for the accurate computation of transfer maps\* as well as for constructing model fields that can be used for testing and comparing a variety of rf cavity codes.

\*D. T. Abell, "Numerical computation of high-order transfer maps for rf cavities", Phys. Rev. ST Accel. Beams 9, 052001, (2006).

We present realistic models, including fringes, for several standing-wave modes in rf cavities. These models include a simple

FR5PFP078

**Fringe-Field Effects in Simulations of Non-Scaling FFAGs**

D. T. Abell, G. I. Bell (Tech-X) E. Forest (KEK) A. G. Ruggiero, D. Trbojevic (BNL)

els for the fringes. In particular, we study how fringe extent and other parameters affect important measures of machine performance.

\*E. Forest, Y. Nogiwa, F. Schmidt, "The FPP and PTC Libraries", ICAP'2006.

Recent simulations of non-scaling FFAGs suggest that the effects of magnet fringe fields are of signal importance. We present PTC\* simulations that include realistic mod-

FR5PFP079

**Highly Accurate Frequency Calculations of Crab Cavities Using the VORPAL Computational Framework**

T. M. Austin (Tech-X) L. Bellantoni (Fermilab) J. R. Cary (CIPS)

We have applied the Werner-Cary method\* for extracting modes and mode frequencies

from time-domain simulations of crab cavities, as are needed for the ILC and the beam delivery system of the LHC. This method for frequency extraction relies on a small number of simulations and post-processing using the SVD algorithm with Tikhonov regularization. The time domain simulations were carried out using the VORPAL computational framework, which is based on the eminently scalable finite-difference time-domain algorithm. A validation study was performed on an aluminum model of the 3.9 GHz RF separators built originally at Fermi National Accelerator Laboratory in the US. Comparisons with measurements of the A15 cavity show that this method can provide accuracy to within 0.01% of experimental results after accounting for manufacturing imperfections. To capture the near degeneracies two simulations requiring in total a few hours on 600 processors were employed. This method has applications across many areas including obtaining MHD spectra from time-domain simulations.

\*J. Comp. Phys. 227, 5200-5214 (2008)

### Reduction of the Friction Force in Electron Cooling Systems due to Magnetic Field Errors

Magnetic field errors can limit the dynamical friction force on co-propagating ions and, hence, increase the cooling time. We present theoretical and numerical results for

A. V. Sobol, G. I. Bell, D. L. Bruhwiler (Tech-X) A. V. Fedotov, V. Litvinenko (BNL)

reduction of the friction force due to bounded transverse magnetic field errors, as a function of wavelength. VORPAL \* simulations using a binary collision algorithm \*\* show that small-wavelength field errors affect the friction logarithmically, via the Coulomb log, while long-wavelength errors reduce the friction by effectively increasing the transverse electron temperature. A complete understanding of finite-time effects and the role of small impact parameter collisions is required to correctly interpret the simulation results. We show that the distribution of electron impact parameters is similar to a Pareto distribution, for which the central limit theorem does not apply. A new code has been developed to calculate the cumulative distribution function of electron-ion impact parameters and thus correctly estimate the expectation value and uncertainty of the friction force.

\* C. Nieter and J. Cary, J. Comp. Phys. 196 (2004), p. 448.

\*\* G. Bell et al., J. Comp. Phys. 227 (2008), p. 8714.

### 3D Simulations of Secondary Electron Generation and Transport in a Diamond Electron Beam Amplifier

The Relativistic Heavy Ion Collider (RHIC) contributes fundamental advances to nuclear physics by colliding a wide range of ions. A novel electron cooling section,

R. Busby, J. R. Cary, D. A. Dimitrov (Tech-X) I. Ben-Zvi, X. Chang, T. Rao, J. Smedley, Q. Wu (BNL)

which is a key component of the proposed luminosity upgrade for RHIC, requires the acceleration of high-charge electron bunches with low emittance and energy spread. A promising candidate for the electron source is the recently developed concept of a high quantum efficiency photoinjector with a diamond amplifier. To assist in the development of such an electron source, we have implemented algorithms within the VORPAL particle-in-cell framework for modeling secondary electron and hole generation, and for charge transport in diamond. The algorithms include elastic, phonon, and impurity scattering processes over a wide range of charge carrier energies. Results from simulations using the implemented capabilities will be presented and discussed.

**Investigation of Charge Gain in Diamond Electron Beam Amplifiers via 3D Simulations**

D. A. Dimitrov, R. Busby, J. R. Cary (Tech-X) I. Ben-Zvi, X. Chang, T. Rao, J. Smedley, Q. Wu (BNL)

A promising new concept of a diamond amplified photocathode for generation of high-current, high-brightness, and low thermal emittance electron beams was recently proposed\* and is currently under active development. To better understand the different effects involved in the generation of electron beams from diamond, we have been developing models (within the VORPAL computational framework) to simulate secondary electron generation and charge transport. The currently implemented models include inelastic scattering of electrons and holes for generation of electron-hole pairs, elastic, phonon, and charge impurity scattering. We will present results from 3D VORPAL simulations with these capabilities on charge gain as a function of primary electron energy and applied electric field. Moreover, we consider effects of electron and hole cloud expansion (initiated by primary electrons) and separation in a surface domain of diamond.

\*I. Ben-Zvi et al., Secondary emission enhanced photoinjector, C-AD Accel. Phys. Rep. C-A/AP/149, BNL (2004).

**Accurate and Efficient Study of RF Cavities by Using a Conformal FDTD Method**

M. C. Lin, C. Nieter, D. S. Smithe, P. Stoltz (Tech-X)

This work introduces a conformal finite difference time domain (CFDTD) method as implemented in VORPAL to accurately and efficiently study RF cavities. For illustration, an A6 magnetron cavity has been employed and the corresponding dispersion relation has been carried out. The accuracy of the CFDTD method is measured by comparing with SUPERFISH calculations. To verify the accuracy of the CFDTD simulations, a geometric model has been constructed in VORPAL and simulated with different mesh numbers as 10,000, 40,000, 90,000, 160,000, and 250,000 for three DM<sub>F</sub>RAC values equal to 0.75, 0.5 and 0.25, respectively. The results show an accuracy of 99.4% can be achieved by using only 10,000 meshes with Dey-Mitra algorithm. By comparison, a mesh number of 360,000 need be used to preserve an accuracy of 99% in the conventional FDTD method. One should be careful using conventional FDTD to study systems with complicated geometry as the staircased meshes fail to conform the boundary correctly. The simulation time of studying the interaction of particles with fields inside cavities can be dramatically reduced by using CFDTD particle-in-cell simulation without losing accuracy.

\* C. Nieter, J. R. Cary, J. Comput. Phys. 196, 448-473 (2004).

\*\* S. Dey, R. Mitra, and S. Chebolu, Microwave and Opt. Technol. Lett. 14, 213-215 (1997).

**Fast Electromagnetic Solver for Cavity Optimization Problems**

P. Messmer, T. M. Austin, J. R. Cary (Tech-X)

In order to meet the design and budget constraints of next generation particle accelerators, individual components have to be optimized using numerical simulations. Among the optimizations are the geometric shape of RF cavities and the placement of coupler and dampers, requiring large numbers of simulations. It is therefore desirable to accelerate individual cavity simulations. Finite-Difference Time-Domain (FDTD) is a widely used algorithm for modeling electromagnetic fields. While being a time-domain algorithm, it can also be used to determine cavity modes and their frequencies. Weak scaling of parallel FDTD yields good results due to the algorithm locality, but the maximum speedup is determined by the usually small problem size. Graphics Processing Units (GPUs) offer a huge amount of processing power and memory bandwidth, well suited for accelerating FDTD simulations. We therefore developed an FDTD solver on GPUs and incorporated it into the plasma simulation code VORPAL. We will present

GPU accelerated VORPAL simulations, provide speedup figures and address the effect of running these simulations in single precision.

### Benchmarking Multipacting Simulations in VORPAL

We will present the results of benchmarking simulations run to test the ability of VORPAL to model multipacting processes in Superconducting Radio Frequency structures.

VORPAL is an electromagnetic (FDTD) particle-in-cell simulation code originally developed for applications in plasma and beam physics. The addition of conformal boundaries and algorithms for secondary electron emission allow VORPAL to be applied to multipacting processes. We start with simulations of multipacting between parallel plates where there are well understood theoretical predictions for the frequency bands where multipacting is expected to occur. We reproduce the predicted multipacting bands and demonstrate departures from the theoretical predictions when a more sophisticated model of secondary emission is used. Simulations of existing cavity structures developed at Jefferson National Laboratories will also be presented where we compare results from VORPAL to experimental data.

C. Nieter, C. Roark, P. Stoltz (Tech-X) G. Ciovati, K. Tian, H. Wang (JLAB)

FR5PFP085

### HOM Maps of RF Cavities for Particle Tracking Codes

We present our recently developed capability for generating High-Order Mode (HOM) maps of rf cavity fields for use in particle

tracking code-based simulations. We use VORPAL field data as a starting point, and follow the approach of\* to produce the maps that are subsequently incorporated into the MaryLie/IMPACT and Synergia frameworks. We present and discuss the results of applying this new modeling tool to crab cavity simulations.

\*D. T. Abell, "Numerical computation of high-order transfer maps for rf cavities", Phys. Rev. ST Accel. Beams 9, 052001, (2006).

I. V. Pogorelov, D. T. Abell, P. Stoltz (Tech-X)

FR5PFP086

### Bend-Induced Phase Space Dilution due to Collective Effects in Medium Energy Electron Accelerators

Envisioned MW-class free-electron lasers based on energy recovery linac, as well as other low energy electron accelerators for industrial applications, often incorporate

bends, e.g. to longitudinally compress the beam. In this low energy regime (typically 50-100 MeV), collective effects have an especially strong influence on the system dynamics, requiring in particular a robust, high-accuracy computational CSR modeling capability. We compare and discuss the results of simulations using filter-based and newly designed adaptive approximation-based CSR algorithms. Our simulations use the Fermilab Test Accelerator facility photoinjector as a benchmark example.

I. V. Pogorelov (Tech-X) D. Mihalcea (Northern Illinois University)  
P. Piot (Fermilab)

FR5PFP087

### New Diffusion Analysis Tools for Beam Beam Simulations

V. H. Ranjbar, A. V. Sobol (Tech-X) H. J. Kim, T. Sen (Fermilab)

A new set of tools for BBSIM has recently been developed to analyze the nature of the diffusion in multi-particle simulations. The diffusion subroutines are currently used to accelerate beam lifetime calculations by estimating the diffusion coefficient at various actions and integrating the diffusion equation. However it is possible that there may be regimes where anomalous diffusion dominates and normal diffusion estimates are incorrect. The tools we have developed estimate the deviation from normal diffusion and can fit the coefficients of a jump diffusion model in the event that this type of diffusion dominates.

### Modeling Microwave Transmission in Electron Clouds

S. A. Veitzer, P. Stoltz (Tech-X) J. M. Byrd (LBNL) K. G. Sonnad (FZK)

Microwave transmission in accelerator beam pipes is providing a unique method for determining electron cloud characteristics, such as density, plasma temperature, and potentially the efficacy of electron cloud mitigation techniques. Physically-based numerical modeling is currently providing a way to interpret the experimental data, and understand the plasma-induced effects on rf signals. We report here recent applications of numerical simulation of microwave transmission in the presence of electron clouds. We examine the differences in phase shift induced by  $T_{10}^{11}$  and  $TM_{01}$  modes in circular cross section beam pipes for uniform density electron clouds. We also detail numerical simulation of the cyclotron resonance and examine how the width of the resonance changes with applied dipole magnetic fields strength and cloud temperature.

### Handling Overlapping Fields within the V-Code Beam Dynamics Simulation Tool

S. Franke, W. Ackermann, T. Weiland (TEMF, TU Darmstadt)

Based on the moment approach a fast tracking code named V-Code has been implemented at TEMF. Instead of using the particle distribution itself this method applies a discrete set of moments of the particle distribution. The time evolution of each moment can be deduced from the Vlasov equation when all essential external forces are known. These forces are given by the Lorentz equation in combination with the distribution of electric and magnetic fields. For efficiency reasons the 3D fields in the vicinity of the bunch trajectory are reconstructed in V-Code from one-dimensional field components by means of proper multipole expansions for the individual beam line elements. The entire beam line is represented in the code as a successive alignment of separate independent beam line elements. The proximity of some beam forming elements may lead to overlapping fringe fields between consecutive elements. In order to simulate even such beam lines with the V-Code, its database of disjunctive beam line elements has to be enhanced to deal also with superposed fields. In this paper a summary of issues regarding the implementation complemented with simulation results will be provided.



**Wakefield Computations with the PBCI Code Using a Non-Split Finite Volume Technique**

We report on a new numerical technique for the computation of geometrical wakes in three-dimensional LINAC structures. The method utilises an explicit Finite Volume Time Domain formulation. The numerical dispersion in all three axial directions is completely eliminated by choice of an appropriate staggering of the field components on the grid. Thus, contrary to most of the previously reported techniques no splitting of the time-evolution operator is necessary. This results in large savings in computational time as well as in an improved numerical accuracy. We have implemented this new technique in the PBCI code. Furthermore, using this approach we have performed an extended study on the self-induced transverse kicks due to the cavity couplers for ultra-short electron bunches in the TESLA accelerating modules.

E. Gjonaj, T. Lau, T. Weiland (TEMF, TU Darmstadt)

FR5PFP091

**Spacecharge Models in the General Particle Tracer (GPT) Code**

The General Particle Tracer (GPT) code is a well established package for the design of charged particle accelerators and beam lines. A crucial component of this code is the calculation of Coulomb interactions. In this contribution we present two different numerical algorithms for the calculation of these particle-particle effects: The standard Particle-In-Cell (PIC) method and a Barnes-Hut (B&H) treecode approach. The PIC method is fast and reliable, but it does not include binary interactions. The method is therefore inapplicable when disorder induced heating plays a role, for example in electron microscopes and focused ion beams. The Barnes-Hut method, borrowed from the astrophysics community, calculates all pair wise interactions in an efficient manner. This approach covers all Coulomb effects, but it is potentially much slower. A realistic test case is presented highlighting the strengths and weaknesses of both approaches.

M. J. de Loos, O. J. Luiten (TUE) M. J. de Loos, S. B. van der Geer (Pulsar Physics)

FR5PFP092

**Applications of a New Code to Compute Transfer Maps and Describe Synchrotron Radiation in Arbitrary Magnetic Fields**

An analytic tracking code has been developed to describe an arbitrary magnetic field in terms of its generalised gradients\* and multipole expansion, which is used with a 2nd-order symplectic integrator\*\* to calculate dynamical maps for particle tracking. The modular nature of the code permits a high degree of flexibility and allows customised modules to be integrated within the code framework. Several different applications are presented, and the speed, accuracy and flexibility of the algorithms are demonstrated. A module to simulate synchrotron emission is described and its application to an 'ILC-type' undulator system is demonstrated.

D. Newton (The University of Liverpool) D. Newton, A. Wolski (Cockcroft Institute)

FR5PFP093

\*Venturini M. and Dragt A., NIM Phys. Res. Sect. A, 427, 387 (1999)

\*\*Wu Y., Forest E., Robin D. S., Physical Review E, 68, 4, Part 2, 046502 (2003)

**Enhanced Methods for Cavity Impedance Calculations**

F. Marhauser, R. A. Rimmer, K. Tian, H. Wang (JLAB)

With the proposal of medium to high average current accelerator facilities the demand for cavities with extremely low HOM impedances is increasing. Modern numerical tools are still under development to more thoroughly predict impedances that need to take into account complex absorbing boundaries and lossy materials. With the usually large problem size it is preferable to utilize massive parallel computing when applicable and available. Apart from such computational issues, we have developed methods using available computer resources to enhance the information that can be extracted from a cavity's wake potential computed in time domain. In particular this is helpful for a careful assessment of the extracted RF power and the mitigation of potential beam breakup or emittance diluting effects, a figure of merit for the cavity performance. The methods are described as well as examples of their implementation.

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**Simulation of Electron Beam Polarization by Multiple Compton Scattering**

P.-CH. Yu, W.-H. Huang, Y. Wang (TUB)

Based upon the analytical results in G. L. Kotkin, V. G. Serbo, and V. I. Telnov\*, we simulate the final polarization of electron beam by multiple Compton scattering utilizing a Monte-Carlo macro-particle code. The changes in polarization of the unscattered electrons passing through the laser pulse are taken into consideration.

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\*Phys. Rev. ST – Acc. Beams 6, 011001

**Updates to QUINDI: A Code to Simulate Coherent Emission from Bending Systems**

D. Schiller (UCLA)

QUINDI has been developed to address the numerical challenge of calculating the radiation spectra from electron bunches in bending magnet systems. Since the introduction of QUINDI, many improvements and features have been added, including three dimensional magnetic fields. A more modular approach has been achieved which allows better interoperability with other codes and allows the use of previous QUINDI output files as tracking input files for future runs.

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**Implementation of Coupler's RF Kick and Coupler's Wake Field in Lucretia**

A. Saini (University of Delhi)

It is well known that Insertion of a coupler into a RF cavity breaks the rotational symmetry of the cavity, resulting in an asymmetric field in a cavity. This asymmetric field results in a transverse RF Kick. RF kick due to coupler transversely offsets the bunch from the nominal axis & depends on the longitudinal position of the particle in the bunch. Also, insertion of coupler generates short range transverse wake field which is independent from the transverse offset of the particle. These effects causes emittance dilution & it is thus, important to study their behavior & possible correction mechanisms. Emittance dilution tolerances in proposed Collider ILC are very stringent, both in Bunch Compressor & Main Linac, so in order to confirm the analytical results & PLACET results of emittance dilution due

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to coupler's effect, coupler's RF kick & coupler's wake field are implemented in a beam dynamics program, Lucretia. Calculations are done for Main Linac & Bunch Compressor. Results are compared with previous analytical results & Placet results. The good agreement has been achieved.

### Self-Consistent Non-Stationary Model for Multipactor Analysis in Dielectric-Loaded Accelerator Structures

Multipactor (MP) may occur in many situations: one- and two-surface MP, resonant and poly-phase-MP, on the surface of metals and dielectrics etc. We consider this phenomenon in dielectric loaded accelerator (DLA) structures. The starting point for our work is experimental and theoretical studies of such structures jointly done by Argonne National Lab and Naval Research Lab\*. In the theoretical model developed during those studies, the space charge field due to the accumulated charged particles is taken into account as a parameter. We offer a non-stationary 2D cylindrical model where the DC field is taken into account self-consistently. We have improved our previous model\*\* and demonstrated that its predictions are in good agreement with the results of other studies\*\*\*. We also demonstrate some recent results where the effects of axial particle motion are taken into account.

\*J. G. Power et al., PRL, 92, 164801, 2004

\*\*O. V. Sinitsyn et. al., AIP Proc. 13th Advanced Accelerator Concepts, 2008

\*\*\*J. G. Power, S. H. Gold, AIP Proc.12th Advanced Accelerator Concepts, 2006

O. V. Sinitsyn, T. M. Antonsen, R. A. Kishek, G. S. Nusinovich (UMD)

## FR5RF — Morning Poster ADVCON A13, BDEMF D04

### Microwave PASER Experiment at the AWA

S. P. Antipov, W. Gai, O. Poluektov, J. G. Power (ANL) C.-J. Jing, A. Kanareykin, P. Schoessow (Euclid TechLabs, LLC) L. Schächter (Technion)

Particle Acceleration by Stimulated Emission of Radiation (PASER) is method of particle acceleration in which a beam gains energy from an active medium through stimulated emission. To obtain the required sit-

ulated emission for the PASER effect the particle beam intensity is modulated at the frequency corresponding to the energy difference between the levels in which population inversion is achieved in the active medium. We propose to use solid-state active medium based on the Zeeman effect (triplet systems) for the PASER. Modulation of the beam at the frequency of the transition to obtain stimulated emission can be produced by means of a deflecting cavity. A transverse "beamlet" pattern will be produced on the AWA photocathode gun by using a laser mask. The transverse beam distribution will be transformed into a longitudinal beam modulation as the beam passes through the deflecting cavity. Two designs are being considered: X-band and a 100 GHz design. The 100 GHz design yields a higher total energy gain (26 MeV for 1 pc beam charge) but requires Tesla-level magnetic fields.

### Design of a 20.8/35.1 GHz Higher-Order-Mode Dielectric-Loaded Power Extraction Set

F. Gao, W. Gai, W. Liu (ANL) F. Gao, T. Wong (Illinois Institute of Technology) C.-J. Jing (Euclid TechLabs, LLC)

We report on the design of a dual-frequency higher-order-mode dielectric-loaded power extraction set. This power extraction set consists of a dual-frequency dielectric-

loaded decelerating structure (decelerator) and two changeable output couplers. In the decelerator, the TM<sub>02</sub> mode synchronizes with an ultra-relativistic electron beam at 20.8GHz, and the TM<sub>03</sub> mode synchronizes with the beam at 35.1GHz. These frequencies are both harmonics of 1.3GHz, the operating frequency of the electron gun and linac at the Argonne Wakefield Accelerator. The power generated in the unwanted TM<sub>01</sub> mode is effectively suppressed for bunch train operation with a novel mode suppression technique. To extract power from the decelerator to standard rectangular waveguides, a TM<sub>02</sub>-T<sub>10</sub><sup>10</sup> output coupler was designed with S<sub>21</sub> = -0.26dB at 20.8GHz, and a TM<sub>03</sub>-T<sub>10</sub><sup>10</sup> output coupler with S<sub>21</sub> = -0.66dB at 35.1GHz. 90.4MW and 8.68MW rf power are expected to be extracted from a drive beam with charge of 50nC per bunch, at 20.8GHz and 35.1GHz respectively.

### Optimization of a Truncated Photonic Crystal Cavity for Particle Acceleration

C. A. Bauer, J. R. Cary, G. R. Werner (CIPS)

Through computer simulation, a 2D photonic crystal (PhC) cavity formed from a truncated triangular lattice of dielectric rods is

optimized to confine a single accelerating mode efficiently. Photonic crystals have the ability to reflect radiation within only certain frequency ranges, called bandgaps; the bandgaps are determined by the geometry and material of the PhC and so are tunable. For truncated PhCs, reflection is incomplete. Therefore, the confinement of bandgap frequencies to a cavity within a truncated PhC is weakened by the severity of the truncation. For a cavity made of 18 dielectric rods in a truncated triangular lattice arrangement, the desired accelerating cavity mode is weakly

confined. Adjusting the positions and sizes of the dielectric rods away from the best lattice configuration within an optimization procedure gives unintuitive structures, ultimately increasing the confinement of the accelerating mode by a factor of 100. Confinement of higher-order modes is also dramatically reduced by the optimization. Similar increases in confinement of the fundamental accelerating mode are found for a 24-rod structure.

### Generation of Short Proton Bunches in the CERN Accelerator Complex

Short high-energy proton bunches have been proposed as efficient drivers for future single-stage electron-beam plasma accelerators. We discuss if and how the desired proton bunches could be obtained in the CERN accelerator complex, considering various compression schemes, such as a fast non-adiabatic lattice change prior to extraction from a storage ring or the use of transversely deflecting cavities.

**F. Zimmermann**, Y. Papaphilippou (CERN)

FR5RFP004

### Renovation of the KEK PS-Booster as a Digital Accelerator

An induction acceleration system in a circular ring has been developed and proved to be feasible\*. Since such an acceleration system has not a limit of a frequency band-width, any ion species are expected to be accelerated without any tuning of the acceleration device. Especially, no limit of the lowest frequency may allow direct injection of an ion beam from the ion source to a synchrotron. We call such an accelerator as "Digital Accelerator". The KEK PS-Booster has shut down in March, 2006, after 28 years operation as an injector of the KEK 12-GeV PS, a neutron source and a medical machine for cancer therapy. We are now renovating the PS-Booster as the first Digital Accelerator. An ion beam injected from an ECR ion source is accelerated by the Digital Accelerator with a repetition of 10 Hz. An argon ion is prepared at first. Then, a laser ablation ion source will be employed to deliver a wide variety of metal ion species. This paper describes the outline of this project and the present status.

**T. Adachi**, Y. Arakida, T. Iwashita, E. Kadokura, M. Kawai, T. Kawakubo, T. Kono, T. Kubo, T. Kubo, H. Nakanishi, K. O. Okamura, H. Someya, K. Takayama, M. Wake (KEK) M. Okamura (BNL) K. Okazaki (Nippon Advanced Technology Co. Ltd.)

FR5RFP005

\*K. Takayama et al., "Experimental Demonstration of the Induction Synchrotron", Phys. Rev. Lett. 98, 054801-4 (2007).

### Transition Radiation Measurement of Channel Guided Laser Plasma Accelerator Electron Beams

The 100 TW capillary-discharge-guided laser plasma accelerator at LBNL has created stable, collimated, ultra short (less than 50fs) electron bunches with energies up to 1 GeV\*. Transition radiation (TR) will happen when such electron bunches pass through an aluminum foil\*\*. TR has very wide wavelength range extending from X-rays to far-infrared and can provide information about the electron beam divergence, spot size, energy and energy spread\*\*\*. For high intensity, few femtosecond long electron beams, coherent TR in the optical regime (OTR) can be produced, which also gives temporal bunch information. Because of the low beam charge (tens of pC) and the presence of intense spectrally broadened laser radiation caused by interaction with the plasma, it is challenging to extract the OTR signal from the intense laser background. Several

**C. Lin**, A. J. Gonsalves, K. Nakamura, D. Panasenko, C. B. Schroeder (LBNL) W. Leemans (University of Nevada, Reno)

FR5RFP006

implementations have been developed and tested. Results from TR experiments will be shown and the use of the transition radiation based on-line diagnostic for laser plasma accelerators will be discussed.

\*W. P. Leemans et al., Nature Vol 2, 696 (2006)

\*\*L. Wartski et al., J. Appl. Phys. 46, pp. 3644-3653 (1975)

\*\*\*C. B. Schroeder et al., Phys. Rev. E 69, 016501 (2004)

## Capture and Control of Laser-Accelerated Proton Beams: Experiment and Simulation

F. Nürnberg, B. G. Logan (LBNL) I. Alber, K. Harres, M. Roth, M. Schollmeier (TU Darmstadt) W. Barth, H. Eickhoff, I. Hofmann (GSI) A. Blazevic (GSI Plasma) A. Friedman, D. P. Grote (LLNL)

Ion acceleration from high-intensity, short-pulse laser irradiated thin foils has attracted much attention during the past decade. The emitted ion and, in particular, proton pulses contain large particle numbers (exceeding a trillion particles) with energies in the multi-MeV range and are tightly confined in time ( $< \text{ps}$ ) and space (source radius a few micrometers). The generation of these high-current beams is a promising new area of research and has motivated pursuit of applications such as tabletop proton sources or pre-accelerators. Requirements for an injector are controllability, reproducibility and a narrow (quasi-monoenergetic) energy. However, the source provides a divergent beam with an exponential energy spectrum that exhibits a sharp cutoff at its maximum energy. The laser and plasma physics group of the TU Darmstadt, in collaboration with GSI and LBNL, is studying possibilities for transport and RF capture in conventional accelerator structures. First results on controlling laser-accelerated proton beams are presented, supported by WARP simulations.

Ion acceleration from high-intensity, short-pulse laser irradiated thin foils has attracted much attention during the past decade. The emitted ion and, in particular, proton pulses contain large particle numbers (exceeding a

## Optimization and Single-Shot Characterization of Ultrashort THz Pulses from a Laser Wakefield Accelerator

G. R.D. Plateau, E. Esarey, C. G.R. Geddes, W. Leemans, N. H. Matlis, C. B. Schroeder, C. Toth (LBNL) O. Albert (LOA)

Ultrashort terahertz pulses with energies in the  $\mu\text{J}$  range can be generated with laser wakefield accelerators (LWFA), which produce ultrashort electron bunches with energies up to 1 GeV\* and energy spreads of a few-percent. At the plasma-vacuum interface these ultrashort bunches emit coherent transition radiation (CTR) in a wide bandwidth ( $\sim 1 - 10 \text{ THz}$ ) yielding terahertz pulses of high intensity\*\*,\*\*\*. In addition to providing a non-invasive bunch-length diagnostic\*\*\*\* and thus feedback for the LWFA, these high peak power THz pulses are suitable for high field (MV/cm) pump-probe experiments. Maximizing the radiated energy was done by controlling the THz mode quality and by optimizing both the energy and the charge of the electron bunches via pre-pulse control on the driver beam. Here we present the study of three different techniques for pre-pulse control and we demonstrate the production of  $\mu\text{J}$ -class THz pulses using energy-based and single-shot electro-optic measurements.

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\*W. P. Leemans et al., Nature Physics 2, 696 (2006)

\*\*W. P. Leemans et al., PRL 91, 074802 (2003)

\*\*\*C. B. Schroeder et al., PRE 69, 016501 (2004)

\*\*\*\* J. van Tilborg et al., PRL 96, 014801 (2006)

### Spectral Analysis of Betatron Radiation from a Laser Wakefield Accelerator

Electrons being trapped and accelerated in plasma wakefield accelerators are subject to a transverse oscillatory motion in the electrostatic fields of the plasma, leading to synchrotron radiation in the propagation direction of the electron beam. The radiation is

typically in the hard x-ray domain with a very broad spectrum and a collimated emission. These x-ray beams have a great potential for applications, but their spectral features are very difficult to measure due to their intrinsically broadband emission and the noisy environment of laser wakefield experiments. Furthermore, despite some great progress in the field in the last few years, shot-to-shot reproducibility of the electron beam is still challenging, which makes a single-shot x-ray spectrum measurement very appealing. We will present a new design for a single shot, hard x-ray spectrometer based on Ross filters. The design allows for compensation of the x-ray beam spatial inhomogeneity and has been implemented on recent wakefield experiments at the Jupiter Laser Facility, Lawrence Livermore National Laboratory.

**P. Michel**, J. Bonlie, L. Divol, D. H. Froula, S. H. Glenzer, J. Palastro, D. Price, J. E. Ralph, J. S. Ross, C. Siders (LLNL) C. E. Clayton, C. Joshi, K. A. Marsh, A. E. Pak (UCLA) B. B. Pollock, G. R. Tynan (UCSD)

FR5RFP009

### Micro-Fabricated Nanostructured Accelerator Based Neutron Gun

Currently, the most commonly used neutron source is a  $^{252}\text{Cf}$  sample. These sources are highly radioactive and toxic and would be a perfect ingredient in a dirty bomb. Deuterium/Deuterium acceleration based sources are commercially available, but are expensive and fragile. Our micro-

fabricated neutron gun uses an inexpensive ceramic injection micro-molding and metallizing paste process for the batch fabrication of many essentially disposable neutron guns with standard industrial fabrication processes. A nano-structured deuteriated target, MEMS based penning trap and acceleration column provide pulsed neutron production in an insulating and durable ceramic/metal package.

**C. M. Whitney**, S. M. Pellegrin, C. G. Wilson (Louisiana Tech University)

FR5RFP010

### Preliminary Study of Proton Driven Plasma Wakefield Acceleration

The idea of proton bunch driven plasma wakefield acceleration was recently proposed. The motivation is to use an existing high energy proton beam to drive a large amplitude accelerating electric field, and then accelerate the electrons to the energy frontier. Simulations of the plasma wakefield production and acceleration process from a PIC code are given in this paper. In order to get high accelerating field, the required proton bunch length is extremely small. The preliminary design parameters for bunch compression are also presented.

**A. Caldwell**, F. Simon, G. X. Xia (MPI-P) K. V. Lotov (BINP SB RAS) A. M. Pukhov (HHUD)

FR5RFP011

## Epicyclic Helical Channels for Parametric Resonance Ionization Cooling

A. Afanasev, V. Ivanov, R. P. Johnson, G. M. Wang (Muons, Inc)  
S. A. Bogacz, Y. S. Derbenev (JLAB)

Muon beam ionization cooling is a key element in the design of next-generation low-emittance and high-luminosity muon colliders. Present designs, however, have limitations that need to be addressed with new approaches. To obtain low-emittance muon beams, a new concept is being developed that combines ionization cooling in a Helical Cooling Channel (HCC) with a parametric resonance, where the excellent field homogeneity of the HCC allows the beam to be controlled near strong resonances. An essential novelty is that the z-dependent dispersion function required for this cooling is created in a HCC by imposing an additional helical field with opposite helicity. Thus the dispersion is small at the wedge-shaped absorbers to allow emittance exchange and control of momentum spread and the dispersion is large at the positions of the chromatic aberration correction elements. In this project we develop a theoretical description of a muon transport line that includes a solenoid with superimposed transverse helical dipole fields that vary with two characteristic periods. An analytical theory for parametric resonance ionization cooling in such a transport line is described.

## Fabrication of Micro-Scale Metallic and Dielectric Accelerator Structures with Sub-Wavelength Features

E. R. Arab (PBPL) G. Travish, N. Vartanian, J. Xu (UCLA) R. B. Yoder (Manhattanville College)

The millimeter-scale  $\mu$ Accelerator Platform (MAP)—essentially a “particle accelerator on a chip”—will ultimately allow for revolutionary medical and industrial applications due to its manageable size and reproducibility. The MAP consists of an electron source and an all-dielectric, laser powered, particle accelerator. The dielectric structure has two slab-symmetric reflecting mirrors with a vacuum gap between them. A periodic coupling mechanism allows laser power to enter transversely through one mirror. This mechanism is analogous to the slots of an optical diffraction grating, with coupling period and vacuum gap equal to the wavelength of the laser (800nm in this study). Work to date has included designing, fabricating and testing a prototype relativistic structure using a patterned gold layer. To go further, we have studied the fabrication techniques and electromagnetic designs of an all-dielectric (non-metallic) structure. Fabrication of the final structure is modeled after Vertical-Cavity Surface-Emitting Lasers (VCSEL) and Distributed Bragg Reflector (DBR) techniques. Preliminary numerical studies of the sub-relativistic structure are also presented.

## Testing of Laser-Driven Resonant Accelerating-Structures Possessing Sub-Wavelength Periodic Features

N. Vartanian, G. Travish, J. Xu (UCLA) E. R. Arab (PBPL) R. B. Yoder (Manhattanville College)

The Micro-Accelerator Platform, a laser-driven accelerating device measuring less than a millimeter in each dimension, has a variety of applications in industry and medicine. The structure consists of two parallel slabs, with each possessing reflective surfaces and with one having periodic slots which allows transversely incident laser light to enter the gap between the two planes. The resonance of the electric field created in the gap can be measured indirectly through the spectral response of the device. Using a combination of an interferometer and a fiber coupled spectrometer, prototype structures are aligned and measured. With the aid of a nanometer-accuracy positioning device, the bottom slab (a mirror) is aligned with the top slotted-structure. The interferometer and a low power laser are used to position the slabs. A 800nm Titanium-



Sapphire oscillator with a bandwidth of greater than 100nm is used for the spectral measurements. The spectra of both transmitted and reflected beams have been measured for a number of structures and are compared to simulation results. Various improvements to the initial measurement system as well as alternative future approaches are discussed.

### Testing of a Laser-Powered, Slab-Symmetric Dielectric Structure for Medical and Industrial Applications

Laser-powered dielectric accelerating structures, which have attracted attention in recent years, trade fabrication challenges and extremely small beam apertures for the promise of high gradients and new bunch formats. The slab-symmetric, periodically-coupled  $\mu$ Accelerator Platform (MAP) is one such dielectric accelerator, and has been under development through a RadiaBeam-UCLA collaboration for several years. Intended applications of the structure include the production of radiation for medical treatments, imaging, and industrial uses. Prototype MAP structures are now being fabricated, and a program has been undertaken to test this device using externally injected electron beams. Plans are underway to install structures in the E163 facility at SLAC. In this paper we describe the testing methods, diagnostics and expectations. Progress and results to date are also presented.

**S. Boucher** (RadiaBeam) E. R. Arab, G. Travish, N. Vartanian (UCLA) R. B. Yoder (Manhattanville College)

FR5RFP015

### Scaling and Transformer Ratio in a Plasma Wakefield Accelerator

High gradient acceleration of electrons has recently been achieved in meter scale plasmas at SLAC. Results from these experiments show that the wakefield is sensitive to parameters in the electron beam which drives it. In the experiment the bunch lengths were varied systematically at constant charge. Here we investigate the correlation of peak beam current to the wake amplitude. The effect of beam head erosion will be discussed and an experimental limit on the transformer ratio set. The results are compared to simulation.

**I. Blumenfeld**, F.-J. Decker, M. J. Hogan, R. Ischebeck, R. H. Iversen, N. A. Kirby, R. Siemann, D. R. Walz (SLAC) C. E. Clayton, C. Huang, C. Joshi, W. Lu, K. A. Marsh, W. B. Mori, M. Zhou (UCLA) T. C. Katsouleas, P. Muggli, E. Oz (USC)

FR5RFP016

### Investigation of a Gas Jet Produced Hollow Plasma Wakefield Accelerator

The effect of ion motion and the need for practical positron propagation have incited interest in hollow plasma channels. These channels are typically assumed to be cylindrically symmetric; however, a different geometry could be easier to achieve. The introduction of a filament across the outlet of a high mach number gas jet can produce two parallel slabs of gas separated by a hollow channel. Here, the propagation and acceleration properties of a wakefield accelerator driven between these slabs is investigated.

**N. A. Kirby**, I. Blumenfeld, M. J. Hogan, R. Siemann, D. R. Walz (SLAC) A. W. Davidson, C. Huang (UCLA)

FR5RFP017

### Laser Wakefield Simulation Using a Speed-of-Light Frame Envelope Model

B. M. Cowan, D. L. Bruhwiler, P. Messmer, K. Paul (Tech-X) E. Cormier-Michel, E. Esarey, C. G.R. Geddes (LBNL)

Simulation of laser wakefield accelerator (LWFA) experiments is computationally highly intensive due to the disparate length scales involved. Current experiments extend hundreds of laser wavelengths transversely and many thousands in the propagation direction, making explicit PIC simulations enormously expensive. We can substantially improve the performance of LWFA simulations by modeling the envelope modulation of the laser field rather than the field itself. This allows for much coarser grids, since we need only resolve the plasma wavelength and not the laser wavelength, and this also allows larger timesteps. Thus an envelope model can result in savings of several orders of magnitude in computational resources. By propagating the laser envelope in a Galilean frame moving at the speed of light, dispersive errors can be avoided and simulations over long distances become possible. Here we describe the model and its implementation. We show rigorous studies of convergence and discretization error, as well as benchmarks against explicit PIC. We also demonstrate efficient, fully 3D simulations of downramp injection and meter-scale acceleration stages.

### Nonlinear Envelope Dynamics of Intense Laser Pulses Propagating in Underdense Plasmas

A. Bonatto, R. Pakter, F. B. Rizzato (IF-UFRGS)

In the present analysis we study the self consistent propagation of intense laser pulses in a cold ideal-fluid underdense plasma, with particular interest in how the envelope dynamics is affected by the plasma frequency. Using the Hamiltonian formalism and nonlinear dynamics tools we show that a series of Hamiltonian bifurcations give rise to intense electric fields, leading us to a relevant regime for wakefield acceleration schemes. Nonlinear coupling of plasma waves and electromagnetic pulses triggers chaotic dynamics which may detrap the plasma wave from the pulse, leading to wavebreaking. At this point, we investigate the multidimensional effects of this phenomena.

### Proton Acceleration in CO<sub>2</sub> Laser-Plasma Interactions at Critical Density

D. J. Haberberger, C. Joshi, K. A. Marsh, A. E. Pak, S. Tochitsky (UCLA)

Over the last several years, the Target Normal Sheath Acceleration (TNSA) mechanism in solid density plasmas produced by a laser pulse has achieved proton energies up to 10's of MeV and quasi-monoenergetic beams at lower energies. Although solid-target experiments have demonstrated high-charge and low-emittance proton beams, little work has been done with gaseous targets which in principle can be operated at a very high repetition frequency. At the Neptune Laboratory, there is an ongoing experiment on CO<sub>2</sub> laser driven proton acceleration using a rectangular (0.5x2mm) H<sub>2</sub> gas jet as a target. The main goal is to study the coupling of the laser pulse into a plasma with a well defined density in the range of 0.5 to 2 times critical density and characterize the corresponding spectra of accelerated protons. Towards this end, the Neptune TW CO<sub>2</sub> laser system is being upgraded to produce shorter 1-3ps pulses. These high-power pulses will allow us to investigate acceleration of protons via the TNSA and Direct Ponderomotive Pressure mechanisms as well as their combination. The current status of the proton source experiment will be presented.

### Acceleration of an Electron Bunch with Narrow Energy Spread in a PWFA

One of the challenges for plasma wakefield accelerators (PWFAs) is to accelerate a trailing bunch with a narrow energy spread. The real challenge is to produce a bunch

train with a least one drive bunch and one trailing bunch. We have demonstrated experimentally at the BNL-ATF a mask technique that can produce trains of bunches with variable spacing in the sub-picosecond range\*. This 60 MeV train with one to five drive bunches and a trailing bunch propagates in a 1 to 2 cm long plasma capillary discharge with a variable plasma density. When the plasma density is tuned such that the plasma wavelength is equal to the drive bunches spacing the plasma wakefield is resonantly excited. The distance between the last drive bunch and the trailing bunch is one and a half time that between the drive bunches, putting the trailing bunch in the accelerating phase of the wakefield. The resonance is characterized by a maximum energy loss by all the drive bunches and maximum energy gain by the trailing bunch. Experimental results will be presented.

\*P. Muggli et al., Phys. Rev. Lett. 101, 054801, 2008

P. Muggli (UCLA) B. A. Allen (USC) M. Babzien, K. Kusche, J. H. Park, V. Yakimenko (BNL)

FR5RFP021

### Generation of Bunch Trains for Plasma Wakefield Accelerator Applications

At the BNL-ATF we have recently demonstrated the generation of trains of electron with sub-picosecond spacing\*. These trains of equidistant bunches can be used to reso-

nantly excite large amplitude wakefields in plasmas. The resonance is reached when the plasma wavelength is equal to the drive bunch train spacing. However, in order to accelerate an electron bunch with a narrow energy spread, a trailing witness bunch must be generated. The witness bunch must be separated from the last drive bunch by one and a half times the distance between drive bunches. We show that such a drive/witness bunch train can be generated. The mask can also be designed to produce witness bunches trailing the drive bunch train by 2.5, 3, 5, ... times the drive bunch spacing in order to probe the coherence of the plasma wake in subsequent wave bucket. Resonantly driving plasma wakes with trains of bunches could lead to multiplication of the trailing bunch energy by up to the number of bunches in the drive train with high efficiency in a single stage. Experimental results will be presented.

\* P. Muggli et al., Phys. Rev. Lett. 101, 054801, 2008

P. Muggli (UCLA) B. A. Allen (USC) M. Babzien, K. Kusche, J. H. Park, V. Yakimenko (BNL)

FR5RFP022

### Design of Photonic Crystal Gap Fiber Accelerator Structures

Photonic crystals have been suggested for use as laser driven particle accelerator structures with higher accelerating gradients and effective damping of unwanted higher order modes. Here we selected Photonic band gap (PBG) fibers with hollow

core defects to design such an accelerator structure. To achieve this design, Out-plane-wave mode in photonic crystal fiber was selected for longitudinal electric field. The out-plane-wave plane wave expansion method was deduced for confinement and the dispersive curve versus variation of  $k_z$  and speed of light for synchronization. Then super cell approximation was also introduced for calculating the defected photonic crystal structure. After the selection of appropriate geometry and the dimensions of photonic crystal fiber accelerators, The field distribution was simulated and calculated with RSOFT Bandsolve software for this structure.

H. Z. Zhang, C.-F. Wu (USTC/NSRL) Z. P. Li (USTC)

FR5RFP023

## FR5RFP024 Preservation of Ultra Low Emittances in Future High Energy Plasma Wakefield-Based Colliders

R. Gholizadeh, P. Muggli (USC) C. Huang, W. B. Mori (UCLA)  
T. C. Katsouleas (Duke University)

Plasma Wakefield Accelerator has been proven to be a promising technique to lower the cost of the future high energy colliders by offering orders of magnitude higher gradients than the conventional accelerators. However, it has been shown that ion motion is an important issue to account for in the extreme regime of ultra high intensities and ultra low emittances, characteristics of future high energy colliders. In this regime, the transverse electric field of the beam is so high that the plasma ions cannot be considered immobile at the time scale of electron plasma oscillations, thereby leading to a nonlinear focusing force. Therefore, the transverse emittance of a beam matched to the initial linear focusing will not be preserved under these circumstances. However, Vlasov equation predicts a matching profile even in the nonlinear regime. Furthermore, we extend the idea and introduce a plasma section that can match the entire beam to the mobile-ion regime of plasma. We also find the analytic solution for the optimal matching section. Simulation results will be presented.

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## FR5RFP025 Simulations of Positron Beams Propagation in Plasmas

X. Li, P. Muggli (USC)

Studies on propagation of electron beams in plasmas have shown that in the blowout regime of the plasma wakefield accelerator (PWFA), the emittance of the incoming beam is preserved because of the linear focusing force exerted by a uniform ion column. However, for positron beams the focusing force is nonlinear and they suffer emittance growth. We simulate the propagation of positron beams in uniform plasmas with different densities. We determine the beam transverse sizes at the plasma exit and on a screen located one meter downstream from the plasma exit to compare them with experimental results obtained at the Stanford Linear Accelerator Center. We calculate the beam emittance from the simulation results and observe the beam size and emittance grow with increasing plasma density. We also investigate the possibility of using hollow plasma channels to preserve the beam incoming emittance. Preliminary simulation results will be presented.

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## FR5RFP026 All-Optical Compton Gamma-Ray Source

K. Koyama, A. Yamazaki (UTNL) T. Hosokai (RLNR) A. Maekawa,  
M. Uesaka (The University of Tokyo, Nuclear Professional School)  
M. Miyashita (SUT)

An all-optical inverse Compton gamma-ray source is enable us to make a tabletop monochromatic gamma-ray source that might be applied to measure an amount of nuclear material, etc. An intense laser pulse excites a very nonlinear plasma wave and accelerate electron bunch up to several-hundreds MeV within a length of a few millimeters. The key to success is stabilization of the laser-plasma accelerators. We are developing the artificial injection technique of initial electrons in to the plasma wave and guiding of the intense laser pulse by the preformed plasma channel.

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### The Impact of Beam Spreads on the Acceleration Process at the Electrons "Reflection" from a Supershort Laser Pulse in a Wiggler

Nonlinear scheme of electrons acceleration in the fields of a supershort laser pulse with actual form of envelope and a strong mag-

Kh. V. Sedrakian (YSU)

netic wiggler is investigated by means of numerical integration of classical relativistic equations of motion for electron beams with diverse structure and setups. It is shown that the threshold phenomenon of particles "Reflection" from a plane electromagnetic wave in a wiggler\* takes place for laser pulses with confined transversal space-temporal structures as well, and the electron beam distribution function after the interaction was explored which reveals the impact of the beam spreads in this nonlinear regime of interaction. After the inelastic "reflection" electrons are essentially accelerated - the above-threshold acceleration rate is nonlinearly increasing at the increase of the threshold value of "Reflection" phenomenon and at the values approaching to the relativistic intensities of the current supershort laser pulses becomes significant. The impact of angular and energetic divergences of electron beams of high brightness on the acceleration process has been explored numerically.

\*H. K. Avetissian et al., Phys. Lett. A 66, 161 (1978); H. K. Avetissian, Relativistic Nonlinear Electrodynamics, Springer, New York, (2006).

### Measurement of the RHIC Abort Kicker Longitudinal Impedance

In face of the new upgrades for RHIC the longitudinal impedance of the machine plays an important role in setting the thresh-

N. P. Abreu, E. M. Choi, H. Hahn (BNL)

old for instabilities and the efficacy of some systems. In this paper we describe the measurement the longitudinal impedance of the abort kicker for RHIC as well as simulations of the structure. The impedance measurement was done by the S21wire method covering the frequency range from 9 kHz to 2.5 GHz. A model was constructed for simulations in the CST MWS program. Results for the magnet input and the also the beam impedance are compared to the measurements .We observed a sharp resonance peak around 10 MHz and a broader peak around 20 MHz in both, the real and imaginary parte, of the  $Z/n$  These two peaks account for a maximum imaginary longitudinal impedance of  $j15 \Omega$ , value 2 orders of magnitude larger than the theoretical value of  $j0.2 \Omega$ , which indicates that the kicker is one of the main sources of longitudinal impedance in the machine. More detail study of the system properties and possible changes to reduce the coupling impedance will be presented.

### Landau Damping with High Frequency Impedance

Couples bunch longitudinal instability in the presence of high frequency impedance is considered. A frequency domain technique

M. Blaskiewicz (BNL)

is developed and compared with simulations. The frequency domain technique allows for absolute stability tests and is applied to the problem of longitudinal stability in RHIC with the proposed 56 MHz rf system.

### Impedance Calculations for the NSLS-II Storage Ring

A. Blednykh, S. Krinsky (BNL)

In this note, we provide an update on our efforts to characterize the impedance of the NSLS-II storage ring. In particular, we discuss the contribution of the individual components to the total longitudinal and transverse impedance. For a 3mm Gaussian driving bunch, we present the longitudinal loss factors and the transverse kick factors. We also discuss efforts to optimize the impedance of certain critical components.

### Infra-red Extraction Chamber for the NSLS-II Storage Ring

A. Blednykh, G. L. Carr, D. S. Coburn, S. Krinsky (BNL)

The short- and long-range wakepotentials have been studied for the design of the infrared (IR) extraction chamber with large full aperture: 67mm vertical and 134mm horizontal. The IR-chamber will be installed within a 2.6m long wide-gap bending magnet with 25m bend radius. Due to the large bend radius it is difficult to separate the light from the electron trajectory. The required parameters of the collected IR radiation in location of the extraction mirror are ~50mrad horizontal and ~25mrad vertical (full radiation opening angles). If the extraction mirror is seen by the beam, resonant modes are generated in the chamber. In this paper, we present the detailed calculated impedance for the design of the far-IR chamber, and show that placing the extraction mirror in the proper position eliminates the resonances. In this case, the impedance reduces to that of a simple tapered structure, which is acceptable in regard to its impact on the electron beam.

### Microwave Instability Threshold Simulations for NSLS-II

A. Blednykh, S. Krinsky, B. Nash, L.-H. Yu (BNL)

For the NSLS-II storage ring with damping wigglers but without a Landau cavity, the low-current bunch length is 4.5mm. We have studied bunch lengthening and estimated the microwave instability threshold using the multi-particle tracking code TRANFT. An estimate of the pseudo-Green's function for a 0.5mm driving bunch was obtained for most components of the vacuum system by using the 3D code GdfidL. With our present computer resources, certain components were too large and had too complex geometry to allow the wake for such a short bunch to be computed using GdFidL. In these cases, the actual 3D geometry was approximated by a structure having circular cross-section, and the pseudo-Green's function was computed using the 2D code ABCI. It was found that the dominant geometric wake is due to the tapers for the in-vacuum undulators. The resistive wall wake is also important. The effect of pseudo-Green's functions corresponding to an even shorter driving bunch (0.05mm) was investigated using the program ECHO to compute the wake of tapers with circular cross-section. Our results suggest that the microwave threshold will occur at an average single-bunch current greater than 5mA.

### Transverse Impedance Localization Using Intensity Dependent Optics

R. Calaga (BNL) G. Arduini, E. Métral, G. Papotti, D. Quattraro, G. Rumolo, B. Salvant, R. Tomas (CERN)

Measurements of transverse impedance in the SPS to track the evolution over the last few years show discrepancies compared to the analytical estimates of the major contributors. Recent measurements to localize the major sources of the transverse impedance using intensity dependent

optics are presented. Some simulations using HEADTAIL to understand the limitations of the reconstruction and related numerical aspects are also discussed.

### Equilibrium Tail Distribution due to Touschek Scattering

Single large-angle Coulomb scattering is referred to as Touschek scattering. In addition to causing particle loss when particles are scattered outside the momentum aperture, the process also results in a non-Gaussian tail, which is determined by an equilibrium between the Touschek scattering and radiation damping. Here we present an analytic calculation for this equilibrium distribution. A motivation for this calculation is the observation that the top-up injection process involves frequent beam orbit shifts close to the septum. This will result in the scraping of halo particles. We use our calculation to estimate the particle loss rate due to this process.

**B. Nash, S. Krinsky (BNL)**

FR5RFP035

### Longitudinal Space Charge Effects near Transition

Studies of space charge effects in the Small Isochronous Ring (SIR) at Michigan State University revealed a fast longitudinal instability at and below the transition that could not be explained by the conventional negative mass instability. The observed beam behavior can be explained by the effect of the radial component of the coherent space charge force on the longitudinal motion. The transverse coherent space charge force effectively modifies the slip factor shifting the isochronous point and enhancing the negative mass instability. This paper presents results of numerical and experimental studies of the longitudinal beam dynamics in SIR and proposes an analytical model explaining the results.

**E. Pozdeyev (BNL) F. Marti, R. C. York (NSCL) J. A. Rodriguez (CERN)**

FR5RFP036

### Impedance of CPMU in SLS Storage Ring

The longitudinal and transverse impedances of CPMU (cryogenic permanent magnet undulators) of the SLS storage ring are evaluated. The study takes into account the walls frequency dependent conductivity and the electrical and magnetic properties of the material at low temperature.

**M. Ivanyan, V. M. Tsakanov, A. Vardanyan (CANDLE) M. M. Dehler, A. Streun (PSI)**

FR5RFP037

### Longitudinal and Transverse Resistive Wake Fields in PSI-XFEL Undulator

The resistive longitudinal and transverse wakefields, longitudinal loss and transverse kick factors excited by the electron bunch in undulator section of the PSI-XFEL are given. The ordinary and in vacuum undulators are considered. For in vacuum undulator the modified technique for impedance calculation is developed.

**M. Ivanyan, V. M. Tsakanov (CANDLE) M. M. Dehler (PSI) A. Grigoryan (YSU)**

FR5RFP038

### Resonance Behaviour in the Multilayer Resistive Wall Wake Field

K. M. Hock, A. Wolski (Cockcroft Institute)

The multilayer structure of the resistive wall beam pipe is shown to affect the long range wake fields in a way that is consistent with resonance behaviour of waves that undergo multiple scattering among the layers. In the frequency domain, the transverse impedance of a single layer wall is found to peak at a frequency where the half wavelength in the wall is equal to the wall thickness. In the spatial domain, this is manifested as a clear increase in wake field strength at the corresponding distance. For two layers, one thick and one thin, the impedance shows two distinct peaks whose half wavelengths are again equal to the corresponding layer thicknesses. This behaviour provides a simple way to estimate the impedance and wake function of the multilayer resistive wall.

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### Wake Field Simulations for the Vacuum Chamber Transitions of the ILC Damping Rings

M. Korostelev, A. Wolski (Cockcroft Institute)

Vacuum chamber transitions of the ILC damping rings associated with BPM insertions, vacuum ports, antechamber tapers etc, may make a significant contribution to the overall machine impedance. Since most transitions are not azimuthally symmetric, commercial 3D codes based on the finite element method have been used to compute their wake fields. The results for selected vacuum chamber components are presented in this paper, together with some estimates of the impact of the wake fields on the beam dynamics in the damping rings.

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### Full Structure Simulations of ILC Collimators

J. D.A. Smith (Cockcroft Institute)

The prototype collimator of the ILC is simulated, to address potential issues with trapped modes and heating. A number of codes are benchmarked, and the interplay between resistive and geometric wakefields is carefully considered.

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### Effect of Wake Fields in an Energy Recovery Linac

M. G. Billing, H. A. Williams (CLASSE)

Wake fields arising from the discontinuities in the vacuum chamber produce energy spread. In an energy recovery linac (ERL), a spent beam is decelerated before it is dumped in order to use its energy for the acceleration of new beam. While the energy spread accumulated from wakes before deceleration does not increase during deceleration, it becomes more important relative to the beam's decreasing energy. Therefore, in an ERL, wakes can produce very significant energy spread in the beam as it is decelerated to the energy of the beam dump so that beam transport to the dump may become impractical. This effect can place a limit either on the maximum charge per bunch or on the wake field-budget for the ERL. As an example of these wake field effects, this paper discusses their impact for the present design of the Cornell ERL and estimates the effects for typical vacuum chamber components being considered.

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### Simulations of Electron-Cloud Current Density Measurements in Dipoles, Drifts and Wigglers at CEsrTA

CESR at Cornell has been operating as a damping ring test accelerator (CesrTA) with beam parameters approaching those anticipated for the ILC damping rings. A core component of the research program is to fully understand electron cloud effects in CesrTA. As a local probe of the electron cloud, several segmented retarding field analyzers (RFAs) have been installed in CesrTA in dipole, drift and wiggler regions. Using these RFAs, the energy spectrum of the time-average electron cloud current density striking the walls has been measured for a variety of bunch train patterns; with bunch populations up to  $2 \times 10^{10}$  per bunch, beam energies from 2 to 5 GeV, horizontal geometric emittances from roughly 10 to 133 nm, and bunch lengths of about 1 cm; and for both positron and electron beams. The effect of mitigation measures, such as coatings, has also been studied. This paper will compare these measurements with the predictions of simulation programs, and discuss the implications of these comparisons for our understanding of the physics of electron cloud generation and mitigation in ILC-like damping rings.

**J. R. Calvey**, J. A. Crittenden, G. Dugan, S. Greenwald, J. A. Livezey, M. A. Palmer, D. L. Rubin (CLASSE) C. M. Celata, M. A. Furman (LBNL) H. Fukuma, P. Jain, K. Kanazawa, Y. Suetsugu (KEK) K. C. Harkay (ANL) R. Holtzapple (CalPoly) M. T.F. Pivi, L. Wang (SLAC)

FR5RFP043

### Studies of the Effects of Electron Cloud Formation on Beam Dynamics at CesrTA

The Cornell Electron Storage Ring Test Accelerator (CesrTA) has commenced operation as a linear collider damping ring test bed following its conversion from an  $e^+e^-$  collider in 2008. A core component of the research program is the measurement of effects of synchrotron-radiation-induced electron cloud formation on beam dynamics. We have studied the interaction of the beam with the cloud in a number of experiments, including measurements of coherent tune shifts and emittance growth in various bunch train configurations, with different bunch currents, beam energies, beam emittance, and bunch lengths, for both positron and electron beams. This paper compares these measurements to modeling results from several advanced cloud simulation algorithms and discusses the implications of these comparisons for our understanding of the physics of electron cloud formation and decay in damping rings of the type proposed for future high-energy linear colliders.

**J. A. Crittenden** (Cornell University, Department of Physics) J. R. Calvey, G. Dugan, J. A. Livezey, M. A. Palmer, D. L. Rubin (CLASSE) M. A. Furman, G. Penn, M. Venturini (LBNL) K. C. Harkay (ANL) R. Holtzapple (CalPoly) K. Ohmi (KEK) M. T.F. Pivi, L. Wang (SLAC)

FR5RFP044

### Wake and Higher Order Mode Computations for CMS Experimental Chamber at the LHC

Wakefields and trapped Higher Order Modes in the CMS experimental chamber at the LHC are investigated using a geometrical model which closely reflects the presently installed vacuum chamber. The basic rf-parameters of the higher order modes (HOMs) including the frequency, loss parameter, and the Q-value are provided. To cover also transient effects the short range wakefields and the total loss parameter has been calculated, too. Most numerical calculations are performed with the computer code MAFIA. The calculations of the Modes is complemented with an analysis of the multi-bunch instabilities due to the longitudinal and dipole modes in the CMS vacuum chamber.

**R. Wanzenberg** (DESY) E. Métral (CERN)

FR5RFP045

### Studies of Collective Effects in SOLEIL and DIAMOND Using the Multiparticle Tracking Codes SBTRACK and MBTRACK

R. Nagaoka (SOLEIL) R. Bartolini, J. Rowland (Diamond)

Good understanding of instabilities is of great importance in light source rings that provide high current beams. The inherently large machine impedance, which often evolves with continuous changes of insertion devices, enhances collective effects that need to be well controlled to assure the machine performance. The problem is usually not straightforward, as one must quantify short and long range wakes that excite single and multi bunch instabilities, the coupling between instabilities and different planes, as well as Landau effects in arbitrary filling modes. The paper presents the study made on DIAMOND and SOLEIL using the multiparticle tracking codes sbtrack and mbtrack. While sbtrack performs a 6-dimensional single bunch tracking, mbtrack does its direct extension to multibunches. The most recent code development includes a MATLAB version and a high precision Fourier analysis of collective modes. The study emphasises the use of realistic impedance models, either empirically or numerically constructed, and aims to elucidate the relative importance of different physical effects by closely comparing with experimental observations.

Good understanding of instabilities is of great importance in light source rings that provide high current beams. The inherently

### Analysis of the Transverse SPS Beam Coupling Impedance with Short and Long Bunches

B. Salvant (EPFL) G. Arduini, H. Burkhardt, H. Damerou, W. Höfle, E. Métral, G. Papotti, G. Rumolo, B. Salvant, E. N. Shaposhnikova, R. Tomas, S. M. White (CERN) R. Calaga, R. de Maria (BNL)

knowledge of the sources of SPS beam coupling impedance, so that longitudinal and transverse impedance reduction campaigns can be planned and performed effectively if needed. In this paper, the transverse impedance of the SPS is studied by injecting a single long bunch into the SPS, and observing its decay without RF. This particular setup enhances the resolution of the frequency analysis of the longitudinal and transverse bunch signals acquired with strip line couplers connected to a fast data acquisition. It also gives access to the frequency content of the transverse impedance. Results from measurements with short and long bunches in the SPS performed in 2008 are compared with simulations and theoretical predictions.

The upgrade of the CERN Large Hadron Collider (LHC) would require a four- to five-fold increase of the single bunch intensity presently obtained in the Super Proton Synchrotron (SPS). Operating at such high single bunch intensities requires a detailed

### An Update of ZBASE, the CERN Beam Coupling Impedance Database

B. Salvant (EPFL) H. Medina, E. Métral, G. Rumolo, B. Salvant (CERN)

beam parameters, as well as additions, removal or modifications of hardware. To this end, an update of the impedance database was performed, so that impedance results from theoretical calculations using new multilayer models, impedance results from electromagnetic field simulations and impedance results from bench measurements can be compiled. In particular, the impedance database is now set to separately produce the dipolar and quadrupolar transverse impedance and wakes that the HEADTAIL simulation code needs to accurately simulate the effect of the impedance on the beam dynamics.

A detailed knowledge of the beam coupling impedance of the CERN synchrotrons is required in order to identify the impact on instability thresholds of potential changes of

### Coupling Impedance of the CERN SPS Beam Position Monitors

A detailed knowledge of the beam coupling impedance of the CERN Super Proton Synchrotron (SPS) is required in order to operate this machine with a higher intensity for the foreseen Large Hadron Collider (LHC) luminosity upgrade. A large number of Beam Position Monitors (BPM) is currently installed in the SPS, and this is why their contribution to the SPS impedance has to be assessed. This paper focuses on electromagnetic simulations and bench measurements of the longitudinal and transverse impedance generated by the horizontal and vertical BPMs installed in the SPS machine.

**B. Salvant** (EPFL) D. Alesini, M. Migliorati, B. Spataro (INFN/LNF) G. Arduini, C. Boccard, F. Caspers, A. Grudiev, O. R. Jones, E. Métral, G. Rumolo, **B. Salvant**, C. Zannini (CERN) R. Calaga (BNL) F. Roncarolo (UMAN)

FR5RFP049

### Beam Instability Studies at Transition Crossing in the CERN PS

The CERN PS crosses transition energy at about 6 GeV by using a second order gamma jump performed with special quadrupoles. However, for high-intensity beams, and in particular the single bunch beam for the neutron Time-of-Flight facility, a controlled longitudinal emittance blow-up is still needed to prevent a fast single-bunch vertical instability from developing near transition. A series of studies have been done in the PS in 2008 to measure the beam behaviour near transition energy for different settings of the gamma transition jump. The purpose of this paper is to compare those measurements with simulations results from the HEADTAIL code, which should allow to understand better the different mechanisms involved and maybe improve the transition crossing.

**S. Aumon**, W. Bartmann, S. S. Gilardoni, E. Métral, G. Rumolo, R. R. Steerenberg (CERN) **B. Salvant** (EPFL)

FR5RFP050

### Comparison of Enamel and Stainless Steel Electron Cloud Clearing Electrodes Tested in the CERN Proton Synchrotron

During the 2007 run with the nominal LHC proton beam, electron cloud has been clearly identified and characterized in the PS using a dedicated setup with shielded button-type pickups. Efficient electron cloud suppression could be achieved with a stainless steel stripline-type electrode biased to negative and positive voltages up to  $\pm 1$  kV. For the 2008 run, a second setup was installed in straight section 84 of the PS where the stainless steel was replaced by a stripline composed of an enamel insulator with a resistive coating. In contrast to ordinary stripline electrodes this setup presents a very low beam coupling impedance and could thus be envisaged for long sections of high-intensity machines. Here, we present first comparative measurements with this new type of enamel clearing electrode using the nominal LHC beam with 72 bunches and 25 ns bunch spacing.

**E. Mahner**, F. Caspers, T. Kroyer (CERN)

FR5RFP051

### Impedance Studies for the Phase II LHC Collimators

E. Métral, F. Caspers, A. Grudiev, T. Kroyer (CERN) F. Roncarolo (UMAN) B. Salvant (EPFL) B. Zotter (Honorary CERN Staff Member)

The LHC phase 2 collimation project aims at gaining a factor ten in cleaning efficiency, robustness and impedance reduction. From the impedance point of view, several ideas emerged during the last year, such as using dielectric collimators, slots or rods in copper plates, or Litz wires. The purpose of this paper is to discuss the possible choices, showing analytical estimates, electro-magnetic simulations performed using Maxwell, HFSS and GdFidL, and preliminary bench measurements. The corresponding complex tune shifts are computed for the different cases and compared on the stability diagram defined by the settings of the Landau octupoles available in the LHC at 7 TeV.

The LHC phase 2 collimation project aims at gaining a factor ten in cleaning efficiency, robustness and impedance reduction. From the impedance point of view, several ideas emerged during the last year, such as using

### Update on Fast Ion Instability Simulations for the CLIC Main Linac

G. Rumolo, D. Schulte (CERN)

The specification for vacuum pressure in the CLIC electron Main Linac critically depends on the fast ion instability. In fact, the maximum tolerable pressure value in the pipe of the Main Linac is dictated by the threshold above which the fast ion instability sets in over a CLIC bunch train. Previous calculation based on ion generation from residual gas ionization alone showed that, due to the loss of the trapping along the linac caused by the beam size shrinking from acceleration, a pressure as high as 10 nTorr could be accepted, higher than the tolerable value in the long transfer line. However, since the accelerated beam becomes transversely very small, its electric field can reach values above the field ionization threshold. When this happens, the whole space region with a sufficiently high electric field gets instantly fully ionized by the first bunch and the effect on the bunch train could be severe. We have modeled field ionization in our simulation code FASTION and re-evaluated the onset of fast ion instability in the Main Linac.

The specification for vacuum pressure in the CLIC electron Main Linac critically depends on the fast ion instability. In fact, the maximum

### Multi-Bunch Simulations with HEADTAIL

G. Rumolo, E. Métral (CERN)

The HEADTAIL code has been used for many years to study the interaction of a single bunch with a localized or lumped source of electromagnetic perturbation, usually self-induced (impedance, electron cloud or space charge). It models the bunch as macroparticles and at each turn slices up the bunch into several adjacent charged disks, which are made to subsequently interact with the perturbing agent. A first step toward the extension of HEADTAIL to multi-bunch simulations is presented in this paper. In this case, the bunches themselves are modeled as charged disks and are not sliced, which makes us lose information on the intra-bunch motion but can describe a zero mode interaction between different bunches in a train. The interaction of an SPS bunch train of 72 bunches with the resistive wall or a narrow-band impedance is studied as an example.

The HEADTAIL code has been used for many years to study the interaction of a single bunch with a localized or lumped source

### Multi-Bunch Calculations in the CLIC Main Linac

In the main linac of the compact linear collider (CLIC), wakefield induced multi-bunch effects are important. They have a strong impact on the choice of accelerating structure design. The paper presents the limit for the wakefield that one bunch exerts on the next. It also gives estimates for the allowed level of persistent wake fields and on the resistive wall wakefield.

**D. Schulte** (CERN)

FR5RFP055

### Reference Measurements of the Longitudinal Impedance in the CERN SPS

First reference measurements of the longitudinal impedance were made with beam in the SPS machine in 1999 to quantify the results of the impedance reduction programme, completed in 2001. The 2001 data showed that the low-frequency inductive impedance had been reduced by a factor 2.5 and that bunch lengthening due to the microwave instability was absent up to the ultimate LHC bunch intensity. Measurements of the quadrupole frequency shift with intensity in the following years suggest a significant increase in impedance (which nevertheless remains below the 1999 level) due to the installation of eight extraction kickers for beam transfer to the LHC. Microwave instability is still not observed up to the maximum bunch intensities available from injector. The experimental results are compared with expectations based on the known longitudinal impedance of the different machine elements in the SPS.

**E. N. Shaposhnikova**, T. Bohl, H. Damerau, K. Hanke, T. P.R. Linnekar, B. Mikulec, J. Tan, J. Tuckmantel (CERN)

FR5RFP056

### Studies of Beam Instability in a Double RF System in the CERN SPS

Studies of beam stability in a double RF system are motivated by both the use of the 4th harmonic RF system in the SPS and possible applications in the LHC. The results of measurements in the SPS with four high intensity bunches in bunch-lengthening and bunch-shortening operation modes and at different RF voltages during a coast at 270 GeV/c are presented. The role of the phase loop in the observed slow-growing bunch instability has also been investigated.

**E. N. Shaposhnikova**, T. Bohl, T. P.R. Linnekar (CERN) **C. M. Bhat** (Fermilab)

FR5RFP057

### Stabilizing Effect of a Double-Harmonic RF System in the CERN PS

Motivated by the discussions on scenarios for LHC upgrades, beam studies on the stability of flat bunches in a double-harmonic RF system have been conducted in the CERN Proton Synchrotron (PS). Injecting nearly nominal LHC beam intensity per cycle, 18 bunches are accelerated on harmonic  $h=21$  to 26 GeV with the 10 MHz RF system. On the flat-top, all bunches are then transformed to flat bunches by adiabatically adding RF voltage at  $h=42$  from a 20 MHz cavity in anti-phase to the  $h=21$  system. The voltage ratio  $V(h42)/V(h21)$  of about 0.5 was set according to simulations. For the next 140 ms, longitudinal profiles show stable bunches in the double harmonic RF bucket until extraction. Without the second harmonic component, coupled-bunch oscillations are observed. The flatness of the bunches along the batch is analyzed as a measure of the relative phase error between the RF systems due to beam loading. Measurements of electron cloud

**C. M. Bhat** (Fermilab) F. Caspers, H. Damerau, S. Hancock, E. Mahner, F. Zimmermann (CERN)

FR5RFP058

effects induced by the beam are also discussed. The results of beam dynamics simulations and their comparison with the measured data are presented.

### Emittance Dilution Caused by the Couplers in the Main Linac and Bunch Compressor of ILC

A. Latina, I. G. Gonin, A. Lunin, K. Ranjan, N. Solyak, V. P. Yakovlev (Fermilab)

In the paper the results are presented for calculation of the transverse wake and RF kick from the power and HOM couplers of the acceleration structure. The beam emittance dilution caused by the couplers is calculated for the main linac and bunch compressor of ILC. It is shown that for the bunch compressor this effect may constitute a problem, and modification of the coupler unit may be necessary in order to preserve the cavity axial symmetry.

### Stability Issues of the mu2e Proton Beam

K. Y. Ng (Fermilab)

Stability issues of the mu2e proton beam are discussed. These include space-charge distortions, head-tail instabilities, as well as electron cloud effects.

Stability issues of the mu2e proton beam are discussed. These include space-charge distortion of bunch shape, microwave instabilities, head-tail instabilities, as well as electron cloud effects.

### Stability of Bunches in Barrier Buckets

T. Sen, C. M. Bhat, J.-F. Ostiguy (Fermilab)

We examine the stability of intense flat bunches in barrier buckets. We consider a class of stationary distributions and derive analytical expressions for the threshold intensity at which Landau damping is lost against rigid dipole oscillations in the presence of impedances and space charge forces. Particle simulations are used to follow the dynamics in a barrier bucket and compare with the analytic expressions. These studies are related to experimental observations in the Recycler ring at Fermilab.

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### Investigation of Single Bunch Instabilities due to Electron Cloud Effects

K. G. Sonnad (FZK) G. Franchetti (GSI) M. A. Furman, J.-L. Vay (LBNL) K. Ohmi (KEK) M. T.F. Pivi, T. O. Raubenheimer (SLAC) G. Rumolo, F. Zimmermann (CERN) K. G. Sonnad (University of Karlsruhe)

The dynamics of single bunch transport in the presence of electron clouds is investigated using various simulation programs and methods for the purpose of benchmarking, and a better understanding of electron cloud effects. Calculations will include the effects of varying bunch charge, electron cloud densities and beam energies. Instabilities triggered by an initial beam offset will also be investigated. The beam particles will be tracked through an alternating gradient quadrupole focusing system, where the quad strength is adjusted to match the tune of the particular machine. Additional effects coming from the discrete as opposed to smooth focusing will also be discussed.

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### Investigation of the Temporal Structure of CSR-Bursts at BESSY II

Bursts of coherent synchrotron radiation (CSR) in the far IR and down to the  $\mu$ -wave region have been observed in many synchrotron light sources. At BESSY II the temporal

**P. Kuske** (Helmholtz-Zentrum Berlin für Materialien und Energie GmbH)

structure of these pulses in the THz-region was observed as a function of the bunch length which was varied by changing the momentum compaction factor and as a function of the number of electrons in the single bunch. It was found, that for a bunch length between 3 and 15 ps the first signs of time dependent CSR occur at a frequency which is a multiple of the zero current synchrotron frequency. This frequency increases with the bunch length and indicates that higher azimuthal modes become unstable first. Slower bursts, with repetition rates on the time scale of mill seconds and much slower than the synchrotron period, show up slightly above this threshold. These bursts possess the much faster initial temporal structure and are probably the result of longitudinal mode mixing. The experimental observations are presented and compared to calculations.

### Streak Camera Observations of Bunches Undergoing Head-Tail Instability due to Electron Clouds

Beam blow-up due to electron clouds has been observed in the KEKB LER and other machines around the world. A synchro-be-

**J. W. Flanagan**, H. Fukuma, H. Ikeda, K. Ohmi (KEK)

atron sideband signature in the bunch position spectra, which appears at the onset of transverse bunch size blow-up, has confirmed a head-tail instability as being the mechanism of emittance growth\*. Previous observation via streak camera of the bunch shape in the fully blown-up state, well above threshold, were not successful in imaging the head-tail motion directly. Simulations show that the maximum amplitude of the head-tail coherent motion occurs just at the onset of the instability, with excursion amplitudes comparable to the beam size. This motion eventually deconheres as the emittance of the bunch increases, becoming much smaller than the beam size in the fully-blown up state. Using a streak camera we study the variations in the shape and size of LER bunches above, below and around the beam blow-up and instability threshold, and compare the amplitudes of the head-tail distortions observed to those predicted by simulation.

\* J. W. Flanagan et al., Phys. Rev. Lett. 94, 054801 (2005).

### Simulation for the Measurement of Near-Bunch Electron Cloud Density at KEKB LER

Electron cloud deteriorates the performance of particle accelerators and storage rings. It is therefore of considerable importance to understand the electron cloud buildup in a

**P. Jain** (GUAS/AS) H. Fukuma, K. Kanazawa, S.-I. Kurokawa (KEK)

given accelerator. In past, the data taken by a retarded field analyzer (RFA) with a multi channel plate showed that the signal had the peaks which coincided with the positron bunch pattern if the high voltage of -2kV was applied to the retarded grid. It suggests that the high energy electrons are generated near the beam-bunch. At Low Energy Ring (LER) of KEK B-factory (KEKB), experiments have been performed to measure the near-bunch electron cloud density in the drift space by observing the high energy electrons. In order to analyze the measurement in detail, a 3-D computer program is being developed. A comparison of the simulation with the experimental data shall be presented in this paper.

**Higher Order Modes in a String of Multi-Cell Accelerating Structures**

Y. Morozumi (KEK)

The International Linear Collider will employ tens of thousands of superconducting 9-cell accelerating structures for its main linacs. Damping of higher order modes is crucial to beam stability. Study of higher order modes, however, tends to focus on trapped modes in a single 9-cell structure model alone both in simulation and measurement. Propagating modes above cut-off frequencies are left untouched because of difficulty of a realistic model of multiple 9-cell structures. We have simulated a full spectrum of higher order modes in a long string of 9-cell structures.

**Electron Cloud Instability under the Presence of the Dispersion**

K. Ohmi (KEK) J. Hyunchang (POSTECH)

Electron cloud causes a transverse single bunch instability above a threshold of the cloud density. The threshold is determined by the strength of the beam-electron cloud interaction and Landau damping due to the synchrotron oscillation and/or momentum compaction. We discuss that the threshold is remarkably degraded due to the dispersion, one of the parameter of the circular accelerator optics. The single bunch instability is more serious than previous predictions without considering the dispersion, especially in the case that the horizontal beam size due to the dispersion dominates compare than that due to the emittance.

**Demonstration of Electron Clearing Effect by Means of Clearing Electrodes and Groove Insertions in High-Intensity Positron Ring**

Y. Suetsugu, H. Fukuma (KEK) M. T.F. Pivi, L. Wang (SLAC)

Beam instability caused by the electron cloud is expected to be a limiting factor in the performance of future advanced positron and proton storage rings. In a wiggler section of the positron ring of the KEK B-factory (KEKB), we have installed a vacuum chamber with an insertion that can be replaced and including different techniques to study the mitigation of the electron-cloud effect in a high magnetic field region. We have installed an insertion with strip-line clearing electrode, an insertion with triangular grooves and an insertion with a smooth surface, and compared them each other under the same conditions. The electrode insertion is composed of a thin tungsten layer formed on a thin alumina ceramic layer. The groove insertion is composed of TiN-coated triangular grooves running longitudinally. In this paper, we report about the tests in the KEKB and about the large reduction in the measured electron cloud density when the clearing electrode and groove sections are installed with respect to the smooth insertion. These experiments are the first ones demonstrating the principle of the clearing electrode and groove insertions in a magnetic field.

**Intensity Dependent Beam Dynamics Studies in the Fermilab Booster**

L. K. Spentzouris (Illinois Institute of Technology) J. F. Amundson, W. Pellico, P. Spentzouris, E. G. Stern, R. E. Tomlin (Fermilab) D. O. McCarron (IIT)

The FNAL Booster is a combined-function proton synchrotron with a bunch intensity of  $\sim 6 \cdot 10^{10}$  protons; significantly greater than expected in the original design. The injection energy is 400 MeV (gamma factor 1.4), low enough for space charge forces to play a role in beam dynamics. The magnets are used directly as vacuum



tanks, so the laminated pole surfaces contribute significantly to impedance. A study of the transverse coupling dependence on beam intensity is presented here. Experimental results are being analyzed using Synergia, a high-fidelity, parallel, fully 3D modeling code that includes both space charge and impedance dynamics. Previously, Synergia has always shown good agreement with experimental data. Our initial studies show that the direct space charge contribution to beam dynamics is too small to account for the increase in the coupling seen experimentally, corroborating analytic results. Parametric studies of the impedance needed to match the measured coupling are being done. Agreement between simulation and experiment should provide an independent measure of the Booster impedance, which has been analytically modeled and calculated elsewhere.

### A Simulation Study of the Electron Cloud Induced Instability at DAFNE

A strong horizontal instability has been observed in the DAFNE positron ring since 2003. Experimental observations suggest an electron cloud induced coupled bunch instability as a possible explanation. In this communication we present a simulation study of the electron cloud coupled bunch instability for the DAFNE positron ring, performed with the code PEI-M, and compare the numerical results with experimental observations.

**T. Demma**, A. Drago, S. Guiducci, M. Zobov (INFN/LNF) K. Ohmi (KEK)

FR5RFP070

### Maps for Electron Clouds: Application to LHC Conditioning

The electron cloud driven effects can limit the ability of recently build or planned accelerators to reach their design parameters.

**T. Demma**, R. Cimino (INFN/LNF) S. Petracca (U. Sannio)

The secondary emission yield reduction (called "scrubbing") due to the fact that the electrons of the cloud hit the vacuum chamber wall, modifying its surface properties, may minimize any disturbing effects of the cloud to the beam. The dependence of "scrubbing" efficiency on beam and chamber parameters can be deduced from e-cloud simulation codes modeling the involved physics in full detail. In this communication we present a generalization of the map formalism, introduced in<sup>\*,\*\*</sup>, for the analysis of electron flux at the chamber wall with particular reference to the exploration of LHC conditioning scenarios. Simulations based on this formalism are orders of magnitude faster compared to those based on standard particle tracking codes.

\*U. Iriso and S. Peggs, "Maps for Electron Clouds", Phys. Rev. ST-AB 8, 024403, 2005.

\*\*T. Demma et al., "Maps for Electron Clouds: Application To LHC", Phys. Rev. ST-AB 10, 114401 (2007).

FR5RFP071

### Stabilization of Beam Instability due to Space Charge Effect at J-PARC

The kicker magnet is one of dominant sources of impedances with 3 GeV RCS at J-PARC. It has been considered that this impedance gives us the significant constraint to increase the beam intensity. Recently, the 300 kW beam was accomplished at 3 GeV RCS, while no instability is found. We discuss the space charge effect to stabilize the beam instability.

**Y. Shobuda** (JAEA/J-PARC) Y. H. Chin (KEK)

FR5RFP072

**Estimation of the Electron Emission from the RCS Collimator**

K. Yamamoto (JAEA/J-PARC)

The RCS of J-PARC accelerator complex has been commissioned since September 2007. By a study of one year, we were able to demonstrate more than 200kW operation. In such high intensity operation, the electron cloud effect may have an important roll for the accelerator limitation. we estimated the electron emission from the collimator surface of RCS by a simulation.

**Observation of Longitudinal Microbunch Instabilities in Diamond Storage Ring**

R. Bartolini, V. Karataev (JAI) R. Bartolini, G. Rehm (Diamond)

Diamond is a third generation synchrotron light source built to generate infra-red, ultra-violet and X-ray synchrotron radiation (SR) of exceptional brightness. The operation of the Diamond storage ring with short electron bunches for generation of Coherent THz radiation and short X-ray pulses for time-resolved experiments is limited by the onset of microbunch instabilities. We have started a project to investigate the longitudinal electron beam dynamics and microbunch instabilities in the Diamond storage ring. In the first experiment we used an ultra-fast (time response is about 250 ps) Schottky Barrier Diode sensitive to the radiation within the 3.33-5 mm wavelength range. When the single bunch current exceeded 1.9 mA we observed a set of sub-THz bursts appearing quasi-periodically while the beam was circulating in the ring. The fast response allowed us to detect the signal turn-by-turn, which gives us an opportunity to study the bursts' structure and evolution. It also allows us to study the effect in a multi-bunch mode when bunches are only 2 ns apart. In this report we will present our first preliminary results and also discuss future plans.

**Effects of Transverse Periodic Beam Loading in a Storage Ring**

J. R. Thompson, J. M. Byrd (LBNL)

Uneven beam fill patterns in storage rings, such as gaps in the fill patterns, leads to periodic, or transient loading of the modes of the RF cavities. We show that an analogous effect can occur in the loading of a dipole cavity mode when the beam passes off the electrical center of the cavity mode. Although this effect is small, it results in a variation of the transverse offset of the beam along the bunch train. For ultralow emittance beams, such as optimized third generation light sources and damping rings, this effect results in a larger projected emittance of the beam compared with the single bunch emittance. The effect is particularly strong for the case when a strong dipole mode has been purposely added to the ring, such as a deflecting, or "crab" cavity. We derive an approximate analytic solution for the variation of the beam-induced deflecting voltage along the bunch train. We also show via a tracking simulation the combined effect of the periodic loading of the fundamental and dipole modes.

**Initial Results of Simulation of a Damping System for Electron Cloud-Driven Instabilities in the CERN SPS**

J. R. Thompson, J. M. Byrd (LBNL) W. Höfle, G. Rumolo (CERN)

Single and multi-bunch instabilities on bunch trains driven by electron clouds have been observed in the CERN SPS for some years. In this paper, we present initial results to implement a damping system in a computer simulation of a

single bunch vertical instability using the HEADTAIL code. The code simulates the interaction between a proton bunch and a uniform electron cloud that has built up inside of the beam pipe. In all simulations we use typical SPS parameter sets for three different values of the beam momentum : 26 GeV/c, 55 GeV/c and 120 GeV/c. The feedback is implemented as a corrective kick calculated from the vertical centroid of each slice of the electron bunch with a one turn delay. The bandwidth of the feedback is varied by filtering the slice information along the bunch. Initial results indicate that the instability can be damped with a minimum bandwidth of 300 MHz with a relatively high gain.

### Simulation of a Feedback System for the Attenuation of E-Cloud Driven Instability

Electron clouds impose limitations on current accelerators that may be more severe for future machines, unless adequate measures of mitigation are taken. Recently, it has been proposed to use feedback systems operating at high frequency (in the GHz range) to damp single-bunch transverse coherent oscillations that may otherwise be amplified during the interaction of the beam with ambient electron clouds. We have used the simulation package WARP-POSINST to study the growth rate and frequency patterns in space-time of the electron cloud driven beam breakup instability in the CERN SPS accelerator with, or without, an idealized feedback model for damping the instability. We will present our latest results and discuss their implications for the design of the actual feedback system.

**J.-L. Vay**, J. M. Byrd, M. A. Furman, M. Venturini (LBNL) J. D. Fox (SLAC)

FR5RFP077

### Update on Electron-Cloud Simulations Using the Package WARP-POSINST

At PAC05, we presented the package WARP-POSINST for the modeling of the effect of electron clouds on high-energy beams. We present here the latest developments in the package. Three new modes of operations were implemented: 1) "build-up mode" where, similarly to Posinst (LBNL) or Ecloud (CERN), the build-up of electron clouds is modeled in one region of an accelerator driven by a legislated bunch train; 2) "quasi-static mode" where, similarly to Headtail (CERN) or Quickpic (USC/UCLA), the "frozen beam" approximation is used to split the modeling of the beam and the electrons into two components evolving on their respective time scales; and 3) "Lorentz boosted mode" where the simulation is performed into a moving frame where the space and time scales related to the beam and electron dynamics fall in the same range. The implementation of modes (1) and (2) was primary motivated by the need for benchmarking with other codes, while the implementation of mode (3) fulfills the drive toward fully self-consistent simulations of e-cloud effect on the beam including the build-up phase. We also present benchmarking with other codes and selected results from its application to e-cloud effects.

**J.-L. Vay**, C. M. Celata, M. A. Furman, M. Venturini (LBNL) K. G. Sonnad (FZK)

FR5RFP078

### Recent Experiments and Simulations of Electron Cloud Buildup in Drift Spaces and Quadrupole Magnets at the Los Alamos PSR

Recent beam studies have focused on understanding the main sources and locations of electron clouds (EC) which drive the observed e-p instability at the Los Alamos Proton Storage Ring (PSR). Strong EC signals are observed in drift spaces and quadrupole magnets at PSR which

**R. J. Macek**, L. Rybarcyk, T. Zaugg (LANL) A. A. Browman (Tech-Source)

FR5RFP079

together cover ~65% of the ring circumference. New results making use of two longitudinal barriers to isolate the drift space electron diagnostic provide definitive evidence that most of the drift space EC signal is “seeded” by electrons ejected longitudinally by ExB drifts from adjacent quadrupole magnets. This result can explain why weak solenoids and TiN coatings in several drifts spaces had no effect on the e-p instability threshold. Modeling of EC generation in 3D quadrupoles using a modified version of the POSINST code shows that a sizeable fraction of the electrons generated in the quadrupoles are ejected longitudinally into the adjacent drifts. The experimental findings and simulation results will be presented.

### Studies of the Stability of Modified-Distribution-Function Beams on the Princeton Paul Trap Simulator Experiment (PTSX)

E. P. Gilson, R. C. Davidson, M. Dorf, P. Efthimion, R. M. Majeski, E. Startsev, H. Wang (PPPL) A. Arora (Cornell University) M. Chung (Fermilab) N. Thomas (MIT)

The Paul Trap Simulator Experiment (PTSX) is a compact laboratory Paul trap that simulates a long, thin charged-particle bunch coasting through a kilometers-long magnetic alternating-gradient (AG) transport system by putting the physicist in the frame-of-reference of the beam.

Results are presented from experiments in which the ion source is masked in order to create a variety of initial distribution functions. The stability of hollow beams, off-axis beams, and multiple beamlets is explored. Measurements of the transverse density profile are taken after approximately 100 lattice periods of equivalent beam propagation in order to allow ample time for evolution of the beam distribution function. Using the masked ion source with beams that have an initial depressed-tune of 0.9, the resultant transverse density profiles are strongly affected by the initial distribution function modifications. The experimental data are compared with results of particle-in-cell (PIC) simulations performed with the WARP code.

### Higher Mode Heating Analysis for Superconducting ILC Linacs

K. L.F. Bane, C. Adolphsen, Z. Li, L. Xiao (SLAC)

The superconducting cavities and interconnects in the 12 km long linacs of the International Linear Collider (ILC) are designed to

operate at 2K where cooling costs are very expensive. Thus it is important to ensure that any additional cryogenic heat loads are small in comparison to those from static losses and the fundamental 1.3 GHz accelerator mode. One potential heat source is the higher order modes (HOM) excited by the beam. Such modes will be damped by specially designed HOM couplers that are attached to the cavities (for trapped modes), and by 70K ceramic dampers that are located in each of the eight or nine cavity cryomodules (for propagating modes). Brute force calculations of the higher frequency, non-trapped modes excited in a string of cryomodules is limited by computing capacity. We present, instead, an approach that combines scattering matrix and wakefield calculations to study the effectiveness of the dampers in limiting the heat deposited in the 2K cryogenic system.

### Sheet Beam Klystron Instability Analysis

K. L.F. Bane, C. Adolphsen, A. Jensen, Z. Li, G. V. Stupakov (SLAC)

An L-band (1.3 GHz) sheet beam klystron that will nominally produce 10 MW, 1.6 ms pulses is being developed at SLAC for the ILC program. In recent particle-in-cell

transport simulations of the 115 kV DC beam through the klystron buncher section without rf drive, a hose-type

instability has been observed that is the result of beam noise excitation of transverse modes trapped between the rf cells. In this paper we describe analytical calculations and numerical simulations that were done to study the nature of this instability and explore the required mode damping and changes in the beam focusing to suppress it.

### Measurements, Analysis, and Simulation of Microwave Instability in the Low Energy Ring of KEKB

Using a streak camera, we measured the longitudinal profiles of a positron bunch in the Low Energy Ring (LER) of KEKB at various currents. The measured charge densities were used to construct a simple  $Q=1$  broadband impedance model. The model with three parameters not only gave an excellent description of longitudinal dynamics for a positive momentum compaction factor but also for the negative ones, including bunch shortening below a threshold and bursting modes beyond the threshold. Furthermore, our study indicated that the threshold of microwave instability was about 0.5 mA in bunch current in the LER. At the nominal operating current 1.0 mA, there was a 20% increase of the energy spread. The results of measurement, analysis, and simulations will be presented in this paper.

Y. Cai (SLAC) J. W. Flanagan, H. Fukuma, Y. Funakoshi, T. Ieiri, K. Ohmi, K. Oide, Y. Suetsugu (KEK)

### Simulations of Jitter Coupling due to Wakefields in the FACET Linac

Facilities for Accelerator Science and Experimental Test Beams (FACET) is a proposed facility at SLAC that would use the initial two-thirds of the linac to transport  $e^+$  and  $e^-$  beams to an experimental region. A principal use of this facility is to identify the optimum method for accelerating positrons in a beam driven plasma wakefield accelerator. To study this, a positron bunch, followed  $\frac{1}{2}$  an rf cycle later by an electron bunch, will be accelerated to an asymmetric chicane designed to move the positrons behind the electrons, and then on to the plasma wakefield test stand. A major focus of study was the coupling of jitter of the positron bunch to the electron bunch via linac wakes. Lucretia is a Matlab toolbox for the simulation of electron beam transport systems, capable of multi-bunch tracking and wakefield calculations. With the exception of the lack of support for tracking of electrons and positrons within a single bunch train, it was well suited to the jitter coupling studies. This paper describes the jitter studies, including modifications made to Lucretia to correctly simulate tracking of mixed-species bunch trains through a lattice of magnetic elements and em wakes.

S. Molloy, M. J. Hogan, Y. Nosochkov, A. Seryi, P. Tenenbaum (SLAC)

### Longitudinal Beam Stability in the Super B-Factory

We give an overview of wake fields and impedances in a proposed Super B project, which is based on extremely low emittance beams colliding at a large angle with a crab waist transformation. Understanding the effect wake fields have on the beam is critical for a successful machine operation. We use our combined experience from the operation of the SLAC B-factory and DAFNE Phi-factory to eliminate strong HOM sources and minimize the chamber impedance in the Super B design. Based on a detailed study of the wake fields in this design we have developed a quasi-Green's function for the entire ring that is used to study bunch lengthening and beam stability. In particular, we check the stability threshold using numerical solutions of the Fokker-Plank equation. We also make a comparison of numerical simulations with the bunch lengthening data in the B-factory.

A. Novokhatski (SLAC) M. Zobov (INFN/LNF)

FR5RFP083

FR5RFP084

FR5RFP085

**Analysis of the Wake Field Effects in the PEP-II SLAC B-Factory**

A. Novokhatski, J. Seeman, M. K. Sullivan, U. Wienands (SLAC)

Although the impedance of the high and low energy rings is small, the high current intense beams generated a lot of power. These wake field effects are: heating and damage of vacuum beam chamber elements like RF seals, vacuum valves, shielded bellows, BPM buttons and ceramic tiles; vacuum spikes, vacuum instabilities and high detector background; beam longitudinal and transverse instabilities. We also discuss the methods used to eliminate these effects. Results of this analysis and the PEP-II experience may be very useful in the design of new storage rings and light sources.

We present the history and analysis of different wake field effects throughout the operational life of the PEP-II SLAC B-factory.

**The Effect of an Oxide Layer on Resistive-Wall Wake Fields**

A. Novokhatski (SLAC)

plays more noticeable role in the wake field generation. Additionally to the resistance and roughness, the wall may have an oxide layer, which is usually a dielectric. It is important for aluminum pipe, which have Al<sub>2</sub>O<sub>3</sub> layer. The thickness of this layer may vary in a large range: 1-100 nm. We study this effect for the very short (20-1000 nm) ultra relativistic bunches in an infinite round pipe. We solved numerically the Maxwell equations for the fields in the metal and ceramics. Results showed that the oxide layer may considerably increase the wavelength and the decay time of the resistive-wall wake fields, however the loss factor of the very short bunches does not change much.

Shorter and shorter electron bunches are now used in the FEL designs. The fine structure of the wall of a beam vacuum pipe

**Double RF System for PEP-X Light Source - Topology, Longitudinal Beam Stability and Performance**

C. H. Rivetta, J. D. Fox, T. Mastorides, D. Van Winkle (SLAC)

The baseline PEP-X design has identified the short Touschek-scattering limited lifetime of the beam as a serious concern. The RF system with a nominal gap voltage of 10MV, leads to an unacceptable bunch length and lifetime for the PEP-X purpose. The PEP-X initial design includes a third harmonic RF system to increase the bunch length from 2.5 mm to 5 mm. This paper analyzes possible topologies for the Double RF system including super-conducting cavities and normal-conducting cavities reused from PEP-II facility. Overall parameters for the RF station are defined based on power limits of its main components. The studies focus on the impact of different control strategies for the RF station feedback in the beam stability and performance. The paper overviews the analysis of beam loading and beam instabilities induced by the Double RF system impedance for a nominal beam current of 1.5A. The effect on the accelerating voltage profile due to the ion clearing gap in the beam pattern has been studied and is determined to be critical for the achievement of a uniform bunch length along the revolution period.

The baseline PEP-X design has identified the short Touschek-scattering limited lifetime of the beam as a serious concern. The RF system

### Transverse Single Bunch Instability in PEP-X

Transverse mode coupling instability (TMCI) is one of the major limitations of a single bunch current in storage rings. PEP-X, unlike PEP-II, is characterized by a low synchrotron frequency and a small aperture of the insertion devices. Therefore, the threshold of the instability in PEP-X is expected to be much lower. We estimate the threshold of TMCI using both analytical and numerical approaches and the impedance model of the ring.

L. Wang, G. V. Stupakov (SLAC)

FR5RFP089

### Effects of Beam Filling Pattern on Beam Ion Instability and Beam Loading in PEP-X

There is an ultra small emittance and high beam current in PEP-X, the beam ion instability can be fast. A harmonic cavity is proposed in order to lengthen the bunch from 2.5mm to 5mm. However, the beam loading causes the variation of the bunch length due to the non-uniform beam filling. Multi-bunch-train filling pattern is proposed to reduce the number of trapped ions. Meanwhile, the beam loading can also be mitigated. The effects of beam filling patterns on the beam-ion instability and beam loading are investigated using numerical and analytical methods.

L. Wang, Y. Cai, M.-H. Wang (SLAC)

FR5RFP090

### Understanding of Electron Resonance in a Dipole Magnet

In a dipole magnet, the electron cloud varies with the field strength. When the field is strong enough, the electrons are confined to move along the field line. In a strong magnet, the energy gain of electrons changes periodically with magnetic field, and has maximum when the bunch spacing is multiple times of the gyration period. A 2D Simulation shows an enhancement of electron cloud at resonance. Meanwhile, the beam test in the chicane magnet of PEP-II electron ring shows a minimum of electron flux at the resonance with an alumina surface. In this paper, the electron cloud with 3D field is investigated with 3D code CLOUDLAND and the effects of the magnetic field are summarized.

L. Wang (SLAC)

FR5RFP091

### Measurements of the Complex Conductivity of Vacuum Vessels at THz Frequencies

Accurate determination of the wakefield effects for high intensity, short electron bunches is an area of active research in accelerator design. Of particular interest is the resistive wall wakefield which depends upon the complex conductivity of the vacuum vessel. This conductivity depends on factors such as the frequency of the applied field, the temperature of the vessel and the level of impurities in the vessel material and so is generally difficult to characterise for real vessels. We present an experiment for determining the complex conductivity properties of a cylindrical vessel at frequencies in the THz regime, through the sub-picosecond time-resolved measurement of pulsed THz radiation transmitted through the structure. These results are compared to theoretical calculations.

D. J. Scott, S. P. Jamison (STFC/DL/ASTeC)

FR5RFP092

**BTF Simulations for Tevatron and RHIC with Resistive Wall Wake Field**

V. H. Ranjbar, A. V. Sobol (Tech-X) H. J. Kim, T. Sen, C.-Y. Tan (Fermilab)

Recent improvements to BBSIM permit detailed simulations of collective effects due to resistive wall wake fields. We compare results of beam transfer measurements (BTF) in the Tevatron and RHIC with and without the effects of resistive wall wake fields. These are then compared to actual BTF measurements made in both machines and the impact of intensity on our measurements. We also investigate the impact of resistive wall wake fields on various chromaticity measurement approaches.

**Development of a 1.5+0.5 Cell Photoinjector**

B. D. O'Shea, A. Fukasawa, J. B. Rosenzweig (UCLA) L. Faillace (Rome University La Sapienza)

We present the status of development of a 1.5+0.5 cell photoinjector run in the blowout regime. LANL Parmela simulation results indicate a near uniform beam of slice energy spread on the order of 500 eV when neglecting thermal effects. We examine the use of an extra half cell to control longitudinal beam growth and compare the system in development with previous 1.6 cell photoinjector designs.

**Studies of Bunch Distortion and Bursting Threshold in the Generation of Coherent THz-Radiation at the ANKA Storage Ring**

M. Klein, T. Bueckle, M. Fitterer, A. Hofmann, A.-S. Muller, K. G. Sonnad (University of Karlsruhe) I. Birkel, E. Huttel, Y.-L. Mathis (FZK)

In synchrotron light sources, coherent synchrotron radiation (CSR) is emitted at wavelengths comparable to and longer than the bunch length. One effect of the CSR wake field is the distortion of the bunch distribution, which increases with higher currents. In the theoretical calculations, a threshold exists beyond which the solutions begin to diverge. On the other hand, the CSR wake can also excite a microrbunching instability which prevents stable emission of CSR for high currents and leads to highly intense bursts of radiation. In this paper the development of the calculated bunch shapes and the corresponding moments of the current distribution for varying bunch currents are studied. It can be shown that the numerical threshold beyond which the solutions diverge, does not coincide with the observed bursting-stable-threshold at the ANKA storage ring, which agrees well with theory.

**Simulation Results of Current Filamentation Instability Generated from PWFA Electron Beam**

B. A. Allen, B. Feng, P. Muggli (USC) C. Huang (UCLA) T. C. Katsouleas (Duke University) V. Yakimenko (BNL)

Current Filamentation Instability, CFI, (or Weibel instability) is of central importance for relativistic beams in plasmas for the laboratory, ex. fast-igniter concept for inertial confinement fusion, and astrophysics, ex. cosmic jets. Simulations, with the particle-in-cell code QuickPic, with a beam produced by an RF accelerator show the appearance and effects of CFI. The instability is investigated as a function of electron beam parameters (including charge, transverse size and length) and plasma parameters (density and length) by evaluating the filament currents and magnetic fields. We present simulation results, discuss



further simulation refinements, suggest criteria and threshold parameters for observing the presence of CFI and outline a potential future experiment.

### Four Regimes of the IFR Ion Hose Instability

An electron beam focused by an ion channel without a magnetic field, in the so-called ion focus regime (IFR), may be disrupted by the transverse ion hose instability. We describe the growth in four regimes.

**R. A. Bosch** (UW-Madison/SRC)

## FR5RE — Morning Poster CONTOPS, LAMEAR

### High Availability On-Line Relational Databases for Accelerator Control and Operation

D. Dohan, G. Carcassi, L. R. Dalesio (BNL)

The role of relational database (RDB) technology plays in accelerator control and operation continues to grow in such areas as electronic log books, machine parameter definitions, and facility infrastructure management. RDBs are increasingly relied upon to provide the official 'master' copy of these data. The services provided by the RDB have traditionally not been 'mission critical'. The availability of modern RDB management systems is now equivalent to that of standard computer file-systems, and thus RDBs can be relied on to supply (pseudo-)realtime response to operator and machine physicist requests. This paper describes recent developments in the IRMIS RDB (1) project. Generic lattice support has been added, serving as the driver for model-based machine control. Abstract physics name service, with introspection has been added. Specific emphasis has been placed both on providing fast response time to accelerator operators and modeling code requests, as well as high (24/7) availability of the RDB service.

### EPICS-DDS

N. Malitsky (BNL)

This paper presents a new extension to EPICS, approaching the Data Distributed Service (DDS) interface based on the Channel Access protocol. DDS is the next generation of the middleware industrial standards, bringing a data-centric publish-subscribe paradigm to distributed control systems. In comparison with existing middleware technologies, the data-centric approach is able to provide a consistent consolidated model supporting different data dissemination scenarios and integrating many important issues, such as quality of service, user-specific data structures, and others. The paper considers different features of the EPICS-DDS layer in the context of the accelerator high-level environment and introduces a generic interface addressing various types of accelerator toolkits and use cases.

### RHIC Injector Complex Online Model Status and Plans

V. Schoefer, L. Ahrens, K. A. Brown, J. Morris, S. Nemesure (BNL)

An online modeling system is being developed for the RHIC injector complex, which consists of the Booster, the AGS and the transfer lines connecting the Booster to the AGS and the AGS to RHIC. Historically the injectors have been operated using static values from design specifications or offline model runs, but tighter beam optics constraints required by polarized proton running (e.g. accelerating with near-integer tunes) have necessitated a more dynamic system. An online model server for the AGS has been implemented using MAD-X as the model engine, with plans to extend the system to the Booster and the injector transfer lines and to add the option of calculating optics using the Polymorphic Tracking Code (PTC) as the model engine.

### A Software Architecture for High Level Applications

A distributed software architecture for high level applications is under development at the NSLS-II (National Synchrotron Light Source II) project. One of the important issues is to make accelerator simulation model run on a standalone model server. To enhance the capacity of the model server, it is required to have a set of narrow and general API to accommodate various existing tracking codes. A preliminary study for the API development has been started at NSLS-II based on The MMLT (Matlab Middle Layer Toolkit). A new interface is developed for the MMLT to support another simulation engine known as Tracy. A virtual accelerator is also built for the NSLS-II storage ring based on the Tracy code and the EPICS framework. Although we don't have a real machine, we can evaluate and develop our high level application with the support of virtual accelerator. This paper describes the current status of the software architecture for high level applications.

**G. B. Shen**, L. R. Dalesio, D. Dohan, N. Malitsky (BNL)

FR5REP004

### Synchronous Device Interface

A new approach in embedded device control is developed by Lawrence Berkeley National Laboratory (LBNL) and Brookhaven National Laboratory (BNL). The system will be implemented in BNL's NSLS-II project. The new embedded device control system consists of two tier control: cell controller tier (EPICS IOC) connected by Gbit/s fiber link, and device control tier connected by 100Mbit/s link. A new fast communication protocol has been developed and applied for the data distribution. This paper will discuss the two tier embedded controller system and its applications in NSLS-II power supply control.

**Y. Tian**, L. R. Dalesio (BNL) L. R. Doolittle (LBNL)

FR5REP005

### Equipment/Cyclotron Operation Simulation Based on Creator/Vega Visual Scenery Simulation Technology

Under the influence of applications using virtual reality in cyclotron R&D, this paper discusses a complete process for developing Equipment/Cyclotron Operation Simulation based on Creator/Vega Visual Scenery Simulation Technology, operating rules modeling and solutions to its key problem. The virtual scene model for Equipment/Cyclotron is designed with 3D modeling software Multi-Gen Creator, especially its DOF technology and Switch node. The basic graphs such as wires were represented through OpenGL callback functions. By the Vega virtual scene drive, simulation for Equipment/Cyclotron Operation comes practicable. A set of molding data as well as operation rules has been carried out and tested, targeting with communication equipment. The next step is to extend modeling data to the CRM cyclotron.

**S. Luo**, D. B. Liao, S. Liu (Commanding Communications Academy) F. Yang, Z. G. Yin, T. J. Zhang (CIAE)

FR5REP006

### Final Implementation and Performance of the LHC Collimator Control System

The 2008 collimation system of the CERN Large Hadron Collider (LHC) included 80 movable collimators for a total of 316 degrees of freedom. Before beam operation, the final controls implementation was deployed and commissioned. The control system enabled remote control and appropriate diagnostics of the relevant parameters. The collimator

**S. Redaelli**, R. W. Assmann, R. Losito, A. Masi (CERN)

FR5REP007

motion is driven with time-functions, synchronized with other accelerator systems, which allows controlling the collimator jaw positions with a micrometer accuracy during all machine phases. The machine protection functionality of the system, which also relies on function-based tolerance windows, was also fully validated. The collimator control challenges are reviewed and the final system architecture is presented. The results of the remote system commissioning and the operational experience are discussed. The system tests performed for the 2009 beam operation are also reviewed.

### Information Management within the LHC Hardware Commissioning Project

A. Vergara-Fernández, B. Bellesia, C. Fernandez-Robles, M. Koratzinos, A. Marqueta Barbero, M. Pojer, R. I. Saban, R. Schmidt, M. Solfaroli Camillocci, J. Szkutnik, M. Zerlauth (CERN)

The core task of the commissioning of the LHC technical systems was the individual test of the 1572 superconducting circuits of the collider, the powering tests. The two objectives of these tests were the validation

of the different sub-systems making each superconducting circuit as well as the validation of the superconducting elements of the circuits in their final configuration in the tunnel. A wide set of software applications were developed by the team in charge of coordinating the powering activities (Hardware Commissioning Coordination) in order to manage the amount of information required for the preparation, execution and traceability of the tests. In all the cases special care was taken in order to keep the tools consistent with the LHC quality assurance policy, avoid redundancies between applications, ensure integrity and coherence of the test results and optimise their usability within an accelerator operation environment. This paper describes the main characteristics of these tools; it details their positive impact on the completion on time of the LHC Hardware Commissioning Project and presents usage being envisaged during the coming years of operation of the LHC.

### FESA at FAIR - The Front-End Software Architecture

T. Hoffmann, M. Schwickert (GSI) G. Jansa (Cosylab)

One of the main challenges of the planned Facility for Antiproton and Ion Research (FAIR) at GSI in Darmstadt is to handle its

complex parallel and multiplexed beam operation. In addition, the size of the FAIR project demands for tailor-made but yet extendible solutions with respect to all technical subsystems, especially for the control system. In order to operate and maintain the large amount of front-end equipment standardized solutions are an absolute must. Moreover, to give guidelines and interface specifications to the international collaborators and external partners for so-called "in-kind contributions" facility-wide standards have to be defined. For that purpose, GSI decided to use the Front-end Software Architecture (FESA) at the lowest level of the control system. FESA was developed by CERN and is already operational at LHC and its injectors. This report presents a framework overview and summarizes the status of the FESA test installation at GSI. Additionally, first experiences with the SIS18 BPM system controlled via FESA are presented.

### Event-Based Timing and Control System for Fast Beam-Mode Switching at KEK 8 GeV Linac

K. Furukawa, M. Satoh, T. Suwada (KEK)

The 8-GeV linac at KEK provides electrons and positrons to several accelerator facilities. The 50-Hz beam-mode switching system

has been constructed in order to realize the simultaneous top-up injections for Photon Factory, KEKB high-

energy and low-energy rings. Those three rings require different beam characteristics. Event-based timing and control system was built, and it changes parameters for various accelerator components in 20ms. We describe the present status of the accelerator operation with this new and improved control system.

### Using LabVIEW to Improve the Operation of a Particle Accelerator

The Ion Beam Laboratory of the Technological Nuclear Institute (ITN) in Lisbon has a particle accelerator based on the Van de Graaff machine which is used for research in the area of material characterization. The Van de Graaff particle accelerator\* in the ITN is an horizontal electrostatic accelerator capable of producing Helium and Hydrogen ion beams with energies up to 3 MeV. The developed system comprises the accelerator turn-on and turn-off procedures during a normal run, which includes the set of terminal voltage, ion source, beam focusing and control of ion beam current and energy during operation. In addition, the computer monitors the vacuum and is able to make a detail register of the most important events during a normal run, allowing the use of the machine by less qualified technicians in safe conditions. The data acquisition system consists in PC, a data acquisition I/O board compose by with two multifunction input/output boards from National Instruments and five electronic modules. The computer control system uses a LabVIEW synoptic for interaction with the operator and an I/O board that interfaces the computer and the accelerator system.

**J. G. Lopes**, F. A. Alegria (IST) L. M. Redondo (ISEL)

\*Rosenblatt, J. "Particle Acceleration". London, Methuen and Co LTD., 1968.

### Timing Delay Management Database for J-PARC Linac and RCS

J-PARC Timing System is defined two kinds of timing, scheduled timing and synchronization timing. The scheduled timing is defined by a delay determined in advance from the 25 Hz trigger clock sent from the central timing control. Most devices and power supplies run with the scheduled timing. The scheduled timing system is configured one transmitter module in central control room and many receiver modules in device installed rooms (in total more than one hundred modules). Three signals which are the 12MHz master clock, the 25Hz trigger clock and the type, and LUT (Look-up Table) are distributed to the all receiver modules from transmitter module. An LUT is delay data block which is 256 \* 8 array (the "256" is the number of "type", the "8" is the number of "trigger fan-out" per one receiver module). Then, a great number of "delay data" have to be managed for accelerator operation. The paper presents about the database to manage the timing delay for Linac and RCS (Rapid Cycling Synchrotron).

**H. Takahashi** (JAEA/J-PARC) H. Sakaki (JAEA) M. Sugimoto (Mitsubishi Electric Control Software Corp)

### High-Frequency Waves Optimizing Control for Linear Accelerators

Maximum utilization of high-frequency power sources for accelerating waveguides is one of the problems of electron beam accelerators control. It is necessary to maintain the optimal phase of the field relative to the accelerated particles, what is not always performed with high accuracy in manual mode. High-frequency waves optimizing control for linear accelerators based on information from the directional coupler detecting head is described in the work. The coupler is located on the waveguide what leads unused part of energy to load. Amplitude of the signal is inversely to energy delivered to accelerated beam and can be used as input parameter for the control. An integrator

**A. V. Derevianko**, M. Styervoyedov (KhNU)

measures square under the signal enveloping curve. After analog-to-digital conversion information is handled by microcontroller regulator, which determines the direction and magnitude of accelerating field phase change and produces the control signal. Control signal is transmitted to the phase changer, setting it to the optimal lagging angle. At start time the control signal sets phase changer to middle or a priori well-known position. All electronic nodes are synchronized by the accelerator sync pulse.

### The Accelerator Control Systems

A. V. Derevianko, S. Styervoyedov (KhNU)

The problem of upgrading or integrating old particle accelerators control systems facilities with new architectures can be solved with the aid of new software and hardware products development. The designing of a new architecture is a search of the most reliable and cheapest solutions at any level of system. Our idea is to design the control system for the new facilities under development and, at the same time, to upgrade the old accelerators control systems. The control system was divided into several layers as OSI model is. The lower-layer functions are performed by the set of microcontroller devices and RS-485 and Ethernet communication lines. On the highest level a personal computer running Windows system works. The popularity of this system, its features oriented to network applications, wide choice of programming languages and instruments and the high level of administration and security management are the most important reasons of this choice. Software and hardware flexibility allow to adjust system according to specific requirements. The developed architecture of the system, the specific control system applications are presented in the report.

### ALS Control System Upgrade in C#

H. Nishimura, M. J. Beaudrow, W. E. Byrne, C. M. Ikami, G. J. Portmann, CA. Timossi, M. E. Urashka (LBNL)

The high-level software for the ALS injector control system is being rewritten synchronizing with the low-level hardware migration to the EPICS system\*. New programs are all written in C# for the use on the new operator consoles that are Windows Vista PCs. We use SCA. NET for the channel access, WCF for IPC, and XML for configurations. GUI is currently in WinForm but moving to WPF. We will be reporting the result of the first release of the system from the aspect of the software development.

\*The progress was reported at PCaPAC 2008 as <http://users.cosylab.com/~mpelko/PCaPAC08/papers/mow02.pdf>, and

<http://users.cosylab.com/~mpelko/PCaPAC08/papers/tup018.pdf>

### ALS Injector High Level Controls Upgrade

G. J. Portmann, C. M. Ikami, H. Nishimura, CA. Timossi, M. E. Urashka (LBNL)

The ALS started operations in 1993. From the perspective of the injector very little has change in the last 15 years. An effort started in 2008 to replace all the high level controls applications. This effort combines three very different programming methods: C#, Matlab, and EPICS. The backbone of the high level controls is C# on the .NET framework on Windows Vista. This paper will describe the upgrade plan and commissioning results.

### Beam Test with a DDS of Arbitrary Waveform

In the present acceleration system in HIMAC, an acceleration frequency of a direct digital synthesizer is controlled with B-clock of B+ and B- signals that correspond to the 0.2 Gauss increment and decrement on dipole magnetic field. In the tested new control system, we have used only clock pulse whose clock rate is locked to the power line frequency. With this control of acceleration frequency, acceleration tests were performed. With this control system, it is easy to build up the acceleration control system for multiple flattop patterns. Other merit of a pattern generation with this synchronous clock pulse is easy manipulation of an RF waveform during acceleration period. Beam test with multi-harmonic acceleration was also performed, which can be used to improve the bunching factor. In this presentation, the used RF system and results of its beam tests will be presented.

M. Kanazawa (NIRS)

FR5REP017

### Timing System Upgrade for SNS

A timing system is a crucial subsystem of every accelerator, responsible for orchestrating the entire machine. By the use of it, devices are notified about the present activities and are coordinated accordingly. The current SNS timing system is based on the modified BNL solution. Its implementation technology is backdated, making it complicated and also hard to maintain. At SNS we chose a roadmap which would allow a gradual upgrade of the timing system without having to redesign everything at once and yet provide a path for future modernization of the infrastructure. This paper presents requirements and implementation for the new timing master, which will provide us with more flexible control and greater reliability by tremendously reducing the component count while still retaining back compatibility with existing timing receiver units. The design is based on FPGA technology in a way that simplifies the required interaction with the VME processor. Low level signal generation is table driven with host supervision while critical events and data can be completely controlled by the VME host. The design of the system is a collaboration effort of SNS and Cosylab.

D. H. Thompson (ORNL) J. Dedic (Cosylab)

FR5REP018

### Developing of PBPM Data Acquisition Control System for the PLS

The prototypes of PBPM of the four blade types were installed in front-ends 1C1 diagnostic beam line. The four-blade PBPM measure both the horizontal and the vertical positions of the photon beam. Keithley<sup>TM</sup> picoammeters are used to record the blade current. The position in both vertical and horizontal directions is calibrated by driving the stepping motors of the PBPM through an Industrial computer. PBPM Data Acquisition Control System (DACS) is based on Window XP platform. The DACS is equipped with an Ethernet-to-GPIB controller (GPIB-ENET/00). Using the GPIB-ENET/100, networked computers can communicate with and control IEEE 488 devices from anywhere on an Ethernet-based TCP/IP network. This is GPIB interfaces four picoammeters and Ethernet-based TCP/IP communicates by Industrial Computer. Developing with LabVIEW for Windows XP, the interface to EPICS is accomplished by means of Win32 channel Access DLL's. Our LabVIEW application program incorporates EPICS-based motor control and PC-based data acquisition, using a National Instruments I/O board, and saves position data to txt files. This paper presents the PBPM DACS for PLS Control System.

J. C. Yoon, K. M. Ha, C. Kim, S. J. Park (PAL)

FR5REP019

**An Overview of JFreeChart Library for Plotting Scientific Data**

S. Chevtsov (SLAC)

At SLAC, we are developing physics applications using Java. Specifically, we are using the open-source JFreeChart library for plotting scientific data. Based on Java2D, this flexible library provides many robust features that we successfully integrated in our software. However, there are many user requirements that resulted in a SLAC-specific customization of JFreeChart and even in reimplementing some of its core parts. In this paper, we give a general overview of JFreechart's suitability in the accelerator world.

At SLAC, we are developing physics applications using Java. Specifically, we are using the open-source JFreeChart library for plotting scientific data. Based on Java2D, this flexible library provides many robust features that we successfully integrated in our software. However, there are many user requirements that resulted in a SLAC-specific customization of JFreeChart and even in reimplementing some of its core parts. In this paper, we give a general overview of JFreechart's suitability in the accelerator world.

**XAL-Based Applications and Online Model for LCLS**

P. Chu, R. H. Iverson, P. Krejcik, G. R. White, M. Woodley, J. Wu (SLAC) Q. Gan (IHEP Beijing)

work includes proper relational database schema modification to better suit XAL configuration data requirements, addition of new device types for LCLS online modeling purposes, longitudinal coordinate system change to better represent the LCLS electron beam rather than proton or ion beam in the original SNS XAL design, intensive benchmarking with MAD and present SLC modeling system for the online model, and various new features to the XAL framework. Storing online model data in a relational database and providing universal access methods for other applications is also described here.

XAL, a high-level application framework originally developed by Spallation Neutron Source (SNS), has been adopted by the Linac Coherent Light Source (LCLS) project. The

**Interfacing of Third-Party Accelerator Code with the Lucretia Flight Simulator**

S. Molloy, M. T.F. Pivi, G. R. White (SLAC) Y. Renier (LAL)

Written as an add-on to the Lucretia tracking software, it allows simulation of a beamline in a control system environment identical to that in the control room. This allows the testing and development of monitoring and correction tools by an international collaboration by making the control system transparent to the user. The native beamline representations are those adopted by Lucretia, so, in order to allow third party software to interface with this system, it was necessary to develop functionality to convert the lattice to a universal representation. Accelerator Markup Language (AML), and its associated Universal Accelerator Parser (UAP), were used for this purpose. This paper describes the use of the UAP to convert the internal beamline representation to AML, and the testing of this conversion routine using the lattice description of the ATF2 final focus experiment at KEK, Japan. Also described are the inclusion of PLACET and SAD based algorithms using appropriate converters, and tests of these on the ATF2 extraction line.

The Flight Simulator is a tool used for international collaboration in the writing and deployment of online beam dynamics algorithms.

**A Flight Simulator Based Beam Based Alignment Package for ATF2**

S. Molloy, G. R. White, M. Woodley (SLAC)

The Flight Simulator is a Matlab middleware layer which uses the Lucretia beam tracking engine and a lower level EPICS control system to allow the development of beam control and monitoring algorithms in a simulation environment that appears identical to that of the control room. The goal of ATF2 is to test a novel compact final focus

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optics design intended for use in future linear colliders. The newly designed extraction line and final focus system will be used to produce a 37nm vertical waist from the extracted beam. Alignment of the magnetic elements is of vital importance for this goal and it is expected that beam-based alignment (BBA) techniques will be necessary to achieve the necessary tolerances. This paper describes a package for the beam-based alignment of quadrupole and sextupole magnets in the ATF2 damping ring, extraction line, and final focus system. It brings together several common techniques for the alignment of magnetic elements, and has been implemented as a GUI-based tool that may be used on its own, or integrated with other routines. The design of this package is described, and simulation and beam results are shown.

### Device and Accelerator Modelling Relational Database

We describe an integrated relational database for beamline element configuration and online accelerator modelling for LCLS. It is hosted in Oracle, from which online controls

**G. R. White**, A. Chan, S. Chevtsov, P. Chu, E. Grunhaus, K. Luchini, M. Woodley (SLAC)

software, optimization applications and feedback, use a programming interface to acquire the element data and model. Database population is by an automated process starting with a MAD deck, which is processed in Matlab to derive text files that describe the beamline elements whose data are uploaded using Oracle Loader, and the resulting Oracle APEX applications and reports are used for survey, cabling, metrology and other facilities. An automated facility for online model generation creates an XAL online model beamline description file using a database query; the resulting model is then tracked, and results can be loaded back into the database. As such, both the design or extant machine model, of the present and all previous model runs are available, and linked to the relevant element configuration. We present the process flow from the MAD design to the database, the database schema, the database applications, the process of generating a machine model, and some scientific software which uses the database.

### Control of Electron Beam Parameters and Machine Setting with Model Independent Global Analysis

An x-ray Free-Electron Laser (FEL) calls for a high brightness electron beam. Generally, such a beam needs to be accelerated to

**M. J. Lee**, J. Wu (SLAC)

high energy on the GeV level and compressed down to tens of microns, if not a few microns. The very bright electron beam required for the FEL has to be stable and the high quality of the electron beam has to be preserved during the acceleration and bunch compression. With a newly developed model independent global optimizer\*, here we report study for the control and error diagnostics of such a generic machine: magnetic elements, and RF cavities, and the electron beam parameters: the peak current, centroid energy, and trajectory. Collective effects, such as coherent synchrotron radiation, space charge, and various wakefields are incorporated in a parametric approach. Applicability and verification are detailed for the LINAC Coherent Light Source, an x-ray FEL project being commissioned at SLAC.

\*M. J. Lee, SLAC Report in press (2009).

**Orbit Display's Use of the Physics Application Framework for LCLS**

S. Zelazny, S. Chevtsov, P. Chu, D. Fairley, P. Krejcik, D. Rogind, G. R. White, M. Woodley (SLAC)

At SLAC (SLAC National Accelerator Laboratory) the CD (Controls Department) is developing a physics application framework based on the Java(tm) programming language developed by Sun Microsystems. This paper will discuss the first application developed using this approach: a new Orbit Display. The software is being developed by several individuals in reusable Java packages. It relies on EPICS \* (Experimental Physics and Industrial Control System) toolkit for data collection and XAL \*\* (A Java based Hierarchy for Application Programming) for model parameters. The Orbit Display tracks and displays electron paths through the LCLS (Linac Coherent Light Source) in both a graphical, beam line plot, and tabular format. It contains many features that may be unique to SLAC and is meant to be used both in the control room and by individuals in their offices or at home. Unique features include BSA (Beam Synchronous Acquisition), Orbit Fitting, and Buffered Acquisition.

\* <http://www.aps.anl.gov/epics>

\*\* <http://neutrons.ornl.gov/APGroup/appProg/xal/xal.htm>

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**High-Level ALICE Software Development**

B. J.A. Shepherd, J. K. Jones (STFC/DL/ASTeC)

The ALICE accelerator is a 35MeV energy recovery linac prototype at Daresbury in the U. K. Due to the highly experimental nature of the accelerator, there has been a strong influence of accelerator physicists in the high-level control software for the machine. Starting from the underlying EPICS-based control system, a suite of interactive commissioning software has been built using traditional software approaches, such as LabVIEW, as well as experimenting with interactive, rapid prototyping programming languages, such as Mathematica. Using the EPICS Channel Access protocols, the control system is flexible and extensible. A wide range of tools can be used to develop and debug high-level software, allowing machine physicists to use the most appropriate and familiar tools for software development.

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**A Novel Beam Control Algorithm with Orbit Response Matrix**

C. Wu, E. H. Abed, B. L. Beaudoin, S. Bernal, I. Haber, R. A. Kishek, P. G. O'Shea, M. Reiser, D. F. Sutter (UMD)

Beam centroid control is an important method for optimizing the performance for accelerators, including the University of Maryland Electron Ring (UMER), which is a scaled low-energy (10KeV) storage ring. The conventional response matrix and singular value decomposition approach do not work well on the UMER because of the unique ring structure. One of the purposes of this work is to verify that the beam centroid could be controlled in the presence of very strong space charge. In this paper, we present a novel algorithm which is based on the singular value decomposition, but uses a different response matrix, which is computed from the closed equilibrium orbit and beam positions up to the first four turns in the multi-turn beam circulation. Other issues like strong coupling between the horizontal steering dipoles and vertical steering dipoles in the beam injection section will be addressed. Implementation of this algorithm leads to significant improvement on the beam positions and multi-turn operation.

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## Operating Procedure Changes to Improve Antiproton Production at the Fermilab Tevatron Collider

Since the start of Fermilab Collider Run II in 2001, the maximum weekly antiproton accumulation rate has increased from  $400 \cdot 10^{10}$

**B. E. Drendel, J. P. Morgan, D. Vander Meulen (Fermilab)**

Pbars/week to approximately  $3,700 \cdot 10^{10}$  Pbars/week. There are many factors contributing to this increase, one of which involves changes to operational procedures that have streamlined and automated antiproton source production. Automation has been added to our beam line orbit control, stochastic cooling power level management, and RF settings. In addition, daily tuning efforts have been streamlined by implementing sequencer driven aggregates.

FR5REP030

## ALS FPGA-Based Extraction Trigger Inhibit Interlock System for Top-Off Mode

The Advanced Light Source (ALS) is a third generation synchrotron light source that has been operating since 1993 at Berkeley Lab.

**J. M. Weber, K. M. Baptiste, R. S. Mueller (LBNL)**

Recently, the ALS was upgraded to achieve Top-Off Mode, which allows injection of 1.9GeV electron beam into the Storage Ring approximately every 30 seconds. The ALS Top-Off Mode Beam Current Interlock System was installed to prevent the potential hazard of injected electrons propagating down user beam lines. One of the requirements of this interlock system is a fast response time from detected event to injection trigger inhibit. Therefore, solid state devices, not electro-mechanical relays typically used in accelerator safety systems, must be used to implement the trigger inhibit logic. An FPGA-based solution was selected for this function. Since commercial FPGAs are not rated for high reliability or fail-safe operation, some of the logic resources were used to perform system self-checking to reduce the time to detect system failures and increase reliability. The implementation and self-checking functions of the Extraction Trigger Inhibit Interlock System will be discussed.

FR5REP031

## Diagnostic Systems for the TLS SRF System

The Taiwan Light Source (TLS) is a 1.5GeV third generation synchrotron accelerator. A 500MHz superconducting cavity operated at

**Y.-H. Lin (NSRRC)**

gap voltage of 1600KV for storing 300mA beam current has been adopted in 2005. And maximum beam current of 400mA had been achieved in 2006. The superconducting RF technology greatly improve both the flux intensity and beam stability. However, the system reliability is always the challenge for the system operations. Therefore, the diagnostic systems are crucial to identify the system fault and fixed it in the operational phase. In this paper, the diagnostic systems for the TLS SRF module are reported. The system consists of hardwares, home-made software and database servers. These developments are also presented in this paper.

FR5REP032

## Next Generation Fast RF Interlock Module and VME-ATCA Adapter for ILC High Availability RF Test Station Demonstration

The ILC R&D electronics program at SLAC includes development of key technologies aimed at improving reliability and availability and reducing cost. This paper discusses

**R. S. Larsen, C. Adolphsen, D. J. McCormick, W. C. Ross, Z. M. Szalata (SLAC) R. W. Downing (R. W. Downing Inc.)**

FR5REP033

the development of high availability interlocks and controls for the L-Band high power RF stations. A new Fast Fault Finder (F3) VME module has been developed to process both slow interlocks using FPGA logic to detect the interlock trip excursions. This combination eliminates the need for separate PLC control of slow interlocks with modules chained together to accommodate as many inputs as needed. Next a high availability platform demonstration will port the F3's via a specially designed VME adapter module into the new industry standard ATCA[1] crate (shelf). This high-availability platform features an Intelligent Platform Management (IPMI) system to control and monitor the health of the entire system, provide redundancy as needed for the application, and demonstrate auto-failover and hot-swap to minimize MTTR. The goal is to demonstrate "five nines" (0.99999) system availability at the shelf level. A new international initiative, the xTCA for Physics Standards Working Group, will be briefly mentioned.

[1] Advanced Telecom Computing Architecture

### Reliability of Operation at SLAC in the LCLS Era

U. Wienands, B. Allen, W. S. Colocho, R. A. Erickson, M. Stanek (SLAC)

For LCLS, an uptime of 95% of the scheduled beam time is aimed for. This is a challenging goal for a linac-driven facility, exceeding typical up time during PEP-II run-

ning by a significant amount. During the 2008 and the 2009 LCLS beam-commissioning runs we have been gathering and analysing statistics to identify the worst offenders as far as downtime is concerned. In 2008, an overall hardware uptime of 90% was achieved, indicating the need to decrease our downtime by a factor of two. One approach to focus the effort has been to identify those faults that cause the worst performance for a system in a given time period and focus on these. Another one is to compare our MTTR performance with that of other facilities thus identifying where our processes might be improved. In this paper we will show how we track our performance and examples of the benefit of addressing identified reliability issues.

### Reliability Analysis of the LHC Machine Protection System: Analytical Model Description

S. Wagner, R. Nibali (ETH) R. Schmidt, J. Wenninger (CERN)

The design and operation of the LHC Machine Protection System (MPS) implicates the trade-off between machine safety and

beam availability, defined by MPS reliability in terms of missed emergency beam dumps and false dumps. A generic methodology, including almost 5000 MPS components modeled as individual objects and Monte Carlo simulation, has proved feasible and useful to address that trade-off\*. The resulting MPS reliability numbers allow for the comparison of different system configurations with regard to safety and availability. In search of a solution to reduce the simulation time needed for addressing the rare events involved, an analytical description of the model has been developed. Its numerical solution provides an advanced verification of the simulation results and the basis for a rare event approach. The paper introduces the analytical description and the verification of the reliability numbers resulting from the simulations. It specifies to which extent the simulations can be replaced by the analytical model description and where the latter reaches its limits. Furthermore, the meaning of the analytical description as a basis for simulation time reduction is discussed.

\*S. Wagner, Balancing Safety and Availability for an Electronic Protection System, ESREL08; S. Wagner, Reliability Analysis of the LHC Machine Protection System: Terminology and Methodology, EPAC08

**Interaction of the Large Hadron Collider 7 TeV/c Proton Beam with a Solid Copper Target**

When the LHC will work at full capacity, two counter rotating beams of 7 TeV/c protons will be generated. Each beam will consist of 2808 bunches while each bunch will comprise of  $1.15 \times 10^{11}$  protons. Bunch

length will be 0.5 ns whereas two neighboring bunches will be separated by 25 ns. Intensity in the transverse direction will be Gaussian with  $\sigma = 0.2$  mm. Each beam will carry 362 MJ energy, sufficient to melt 500 kg of Cu. Safety is an extremely important issue in case of such powerful beams. We report two-dimensional numerical simulations of hydrodynamic and thermodynamic response of a solid copper cylinder that is facially irradiated by one of the LHC beams in axial direction. The energy loss of protons in copper is calculated employing the FLUKA code and this data is used as input to a hydrodynamic code, BIG2. Our simulations show that the beam will penetrate up to 35 m into the solid copper target. Since the target is strongly heated by the beam, a sample of High Energy Density (HED) matter is generated. An additional application of the LHC, therefore will be, to study HED matter. This is an improvement of our previous work [Tahir et al., PRL 94 (2005) 135004].

N. A. Tahir (GSI) V. E. Fortov, I. Lomonosov, A. Shutov (IPCP)  
D. Hoffmann (TU Darmstadt) R. Piriz (Universidad de Castilla-La Mancha) R. Schmidt (CERN)

FR5REP036

**SNS BLM System Evolution: Detectors, Electronics and Software**

SNS is a high intensity hadron beam facility; so the Beam Loss Monitor (BLM) system is a crucial part of Machine Protection System

and an important tool for beam tuning. The paper presents the current status of installed detectors and experimental data obtained during SNS operations. We compare several different types of BLMs and show advantages and disadvantages of each type. The electronic parts obsolescence became a real issue since the original electronics was designed about 10 years ago. The first test of our next generation BLM system is expected to be done by summer 2009. The new system will contribute to significant noise reduction and will follow a modular concept of Smart Device to achieve a higher degree of reliability and maintainability.

A. P. Zhukov, S. Assadi, J. Pogge (ORNL)

FR5REP038

**The Machine Protection System for the Linac Coherent Light Source**

A state-of-the-art Machine Protection System for the SLAC Linac Coherent Light Source has been designed and built to shut off the beam within one pulse during 120

Hz operation to protect the facility from damage due to beam losses. Inputs from beam loss monitors, BPMs, toroids and position switches of insertable beam line devices are connected to a number of Link Node chassis placed along the beam line. Link Nodes are connected with a central Link Processor in a star topology on a dedicated gigabit Ethernet fiber network. The Link Processor, a Motorola MVME 6100, processes fault data at 360 Hz. After processing, rate limit commands are sent to mitigation devices at the injector and just upstream of the entrance of the sensitive undulator beam line. The beam's repetition rate is lowered according to the fault severity. The SLAC designed Link Nodes support up to 96 digital inputs and 8 digital outputs each. Analog signals are handled via standard IndustryPack (IP) cards placed on the Link Node motherboards with optional transition boards for signal conditioning. A database driven algorithm running on the Link Processor provides runtime loadable and swappable machine protection logic.

S. N. Norum, S. Allison, S. Chevtsov, J. E. Dusatko, K. D. Kotturi,  
P. Krejcik, J. Olsen, T. Straumann, A. J. Tilghman (SLAC)

FR5REP039

## Performance Evaluation of EPICS Oscilloscopes for Real-Time Waveform Monitoring

L. Shaw (ZTEC Instruments) J. Y. Tang (ORNL)

The EPICS oscilloscopes are remotely controlled and monitored via LAN. Operators can control and query all instrument functions and settings, and monitor captured waveforms via EPICS PVs, an EDM panel, or via a "virtual front panel" application running in Linux or Windows. Upper and lower waveform masks used for pass-fail testing are automatically generated by the oscilloscope from a captured "golden waveform". A variable-width output pulse is generated upon every captured waveform that passes (falls within the masks) or fails (falls outside the masks), depending on the operator's requirements. Real-time pass-fail monitoring has been demonstrated on the teststand for the Spallation Neutron Source (SNS) injection and extraction kicker waveforms occurring both at 60Hz and 120Hz. We believe that the same instruments will also support SNS's future requirements for real-time monitoring of waveforms at 120Hz.

The EPICS Oscilloscopes have been evaluated to perform simultaneous real-time pass-fail monitoring of two or four waveforms.

## Current Status and Final Design of the Cryogenic Storage Ring in Heidelberg, Germany

M. W. Froese, K. Blaum, J. R. Crespo Lopez-Urrutia, F. Fellenberger, M. Grieser, D. Kaiser, M. Lange, F. Laux, S. Menk, D. Orlov, R. Repnow, C. D. Schroeter, D. Schwalm, T. Sieber, J. Ullrich, J. Varju, A. Wolf, R. von Hahn (MPI-K) O. Heber, M. L. Rappaport, Y. Toker, D. Zajfman (Weizmann Institute of Science, Physics)

be presented. This ring will allow long storage times of ion beams with energies in the range of keV per charge for highly charged ions and polyatomic molecules. Combined with vacuum chamber temperatures approaching 2K, infrared-active molecular ions will be radiatively cooled to their rotational ground states. Many aspects of this concept were experimentally tested with a cryogenic trap for fast ion beams (CTF), which has already demonstrated the storage of fast ion beams in a large cryogenic device. An upcoming test will investigate the effect of pre-baking the cryogenic vacuum chambers to 600K on the cryogenic vacuum and the ion beam storage.

An electrostatic Cryogenic Storage Ring (CSR) is currently being built in Heidelberg, Germany. The current status and final design of this ring, with a focus on the precision chamber suspension, optimized 2K chamber cooling, and the cryogenic pumping down to extremely low pressures will

## Investigations of the USR "Short Pulse" Operation Mode

A. I. Papash (MPI-K) C. P. Welsch (Cockcroft Institute)

ton and Ion Research (FLAIR) is to provide very short bunches in the 1-2 nanosecond regime to pave the way for kinematically complete measurements of the collision dynamics of fundamental few-body quantum systems -- for the first time on the level of differential cross sections. The "short pulse" operation mode may be split up in two steps: First, the cooled coasting beam of low energy ions will be adiabatically captured by a high harmonic RF cavity (20 MHz) into ~50 ns buckets. Second, the beam will be compressed to very short pulses with a desired width of only 1-2 ns by an RF buncher located 2 m in front of the so-called reaction microscope. To efficiently limit the beam energy spread, RF decompression is then done at after the experiment to avoid beam losses. In this contribution, we present numerical investigations of this very particular operation mode.

One of the central goals of the Ultra-Low energy Storage Ring (USR) project within the future Facility for Low-energy Antiproton

### Simulations of Space Charge Effects in Low Energy Electrostatic Storage Rings

Electrostatic storage rings have proven to be invaluable tools for atomic and molecular physics. Due to the mass independence of the electrostatic rigidity, these machines are able to store a wide range of different particles, from light ions to heavy singly charged bio-molecules. However, earlier measurements showed strong space charge limitations; probably linked to non-linear fields that cannot be completely avoided in such machines. The nature of these effects is not fully understood. In this contribution, we present the results from simulating an electrostatic fixed-energy storage ring under consideration of non-linear fields as well as space charge effects using the computer code SCALA.

C. P. Welsch (The University of Liverpool) M. H. Al-Malki (KACST) A. I. Papash (MPI-K) C. P. Welsch (Cockcroft Institute)

FR5REP043

### Layout of an Electrostatic Storage Ring at KACST

A state-of-the-art fixed energy electrostatic storage ring that will allow for precision experiments with most different kinds of ions in the energy range of up to 30 keV will be constructed and operated at the National Center for Mathematic and Physics (NCMP) at the King Abdulaziz City for Science and Technology (KACST). The ring is planned to be the central machine of a unique and highly flexible experimental platform. The lattice design therefore has to cover the different experimental techniques that the ring will be equipped with, such as e.g. electron-ion crossed-beams and ion-laser/ion-ion/ion-neutral merged-beams techniques. This paper presents the technical and particle optical design of this novel machine, explains the particular challenges in its layout, and reports on the general project status.

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FR5REP044

### Energy Upgrade of the ATLAS SC Heavy-Ion Linac

An energy upgrade project of the ATLAS heavy ion linac at ANL includes a new cryomodule containing seven  $-10^{-9}$  MHz  $\beta=0.15$  quarter-wave superconducting cavities to provide an additional 15 MV voltage to the existing linac. Several new features have been incorporated into both the cavity and cryomodule design. For example, the primary feature of the cryomodule is a separation of the cavity vacuum space from the insulating vacuum. The cavities are designed in order to cancel the beam steering effect due to the RF field. The cryomodule was designed and built as a prototype for the driver linac of the Facility for Rare Isotope Beams (FRIB). Similar design can be effectively used in the SC proton linac for the Project X at FNAL. Currently, we are working on cryomodule assembly and final preparation of cryogenics, RF, vacuum and other subsystems for off-line tests. The initial commissioning results will be reported.

P. N. Ostroumov, J. D. Fuerst, S. M. Gerbick, M. Kedzie, M. P. Kelly, S. W.T. MacDonald, R. C. Pardo, S. I. Sharamentov, K. W. Shepard, G. P. Zinkann (ANL)

FR5REP045

FR5REP046

**Beam Commissioning of the RFQ for the RHIC-EBIS Project**

M. Okamura, J. G. Alessi, E. N. Beebe, V. Lo Destro, A. I. Pikin, D. Raparia, J. Ritter (BNL) T. Kanesue (Kyushu University, Department of Applied Quantum Physics and Nuclear Engineering) A. Schempp, J. S. Schmidt, M. Vossberg (IAP) J. Tamura (Department of Energy Sciences, Tokyo Institute of Technology)

A new 4 rod RFQ fabricated by IAP, Frankfurt, is being commissioned at Brookhaven National Laboratory. The RFQ will accelerate intense heavy ion beams provided by an Electron Beam Ion Source (EBIS) up to 300 keV/u. The RFQ will accelerate a range of Q/M from 1 to 1/6, and the accelerated

beam will be finally delivered to RHIC and NSRL. The first beam test is planned to use beams from the BNL Test EBIS. The detailed test results will be presented.

FR5REP047

**Studies of Microbunching at BNL NSLS Source Development Laboratory**

S. Seletskiy, Y. Hidaka, J. B. Murphy, B. Podobedov, H. J. Qian, Y. Shen, X. J. Wang, X. Yang (BNL)

We observe a phenomenon of microbunching at NSLS Source Development Laboratory (SDL). We observe the substructures inside 70MeV bunch even for subpicosecond

beams of 10pC charge. Additional substructures are formed when the beam is compressed in the bunch compressor utilizing 4-magnet chicane. We study the mechanisms for beam substructures development on example of 100fs pulse. It allows reducing possibility of having beam structures induced by photo-injector laser, eliminating effects of RF curvature, and enhancing LSC and CSR effects. We also study microbunching in the beams with controlled laser induces substructures by implementing laser pulse shaping.

FR5REP048

**Optimization of the Bunch Compressor at BNL NSLS Source Development Laboratory**

S. Seletskiy, Y. Hidaka, J. B. Murphy, B. Podobedov, H. J. Qian, Y. Shen, X. J. Wang, X. Yang (BNL)

At BNL NSLS Source Development Laboratory (SDL) 70MeV electron bunches are compressed by the bunch compressor (BC) consisting of a linac section followed by 4-

magnet chicane. The achievable beam compression is limited by nonlinear beam dynamics in the BC and by the CSR. In this report we present the novel beam-based technique of chicane calibration, describe the measurements of CSR effect on the beam in the chicane, and discuss the possible scenarios of the BC optimization.

FR5REP049

**Optimization of the Beam Transmission Efficiency in NSLS Linac**

X. Yang, A. Goel, T. V. Shaftan (BNL)

NSLS linear accelerator is a part of the injector system that services two NSLS rings daily. Only half of the charge coming out of

the gun is captured and accelerated in NSLS linac to the energy of 120MeV. Another half of the charge is lost in the linac-to-booster transport line due to high energy spread of the beam. In this paper we discuss the results of our studies on optimization of the NSLS linac front-end performance. We developed a 1D model which agreed with the experimental observation. Afterwards, it has been applied to optimize the beam transmission efficiency in NSLS linac.



### Development of 132 MeV DTL for CSNS

In the China Spallation Neutron Source (CSNS) projects, the conventional 324 MHz Alvarez DTL accelerating structures will be used to accelerate H-beam from 3MeV to 132MeV. The R&D for the Alvarez DTL linacs has been carried out at IHEP in Beijing. The first 2.8 m tank containing 28 drift tubes is under fabricated and will be presented in this paper.

X. Yin, S. Fu, K. Y. Gong, Z. R. Sun (IHEP Beijing)

FR5REP050

### Design of the Pi-Mode Structure (PIMS) for Linac4

The PIMS will accelerate an  $H^{+}$  beam from 100 MeV to 160 MeV, the output energy of Linac4. The cell length is constant within each of the 12 seven-cell cavities, but increases from cavity to cavity according to the increasing beam velocity. Its mechanical design is derived from the five-cell normal conducting LEP cavities, which were in operation at CERN for approximately 15 years. Even though the shunt impedance is around 10% lower than for a Side-Coupled Linac (SCL) operating at 704 MHz, the PIMS has the advantage of using the same RF frequency (352 MHz) as all the other accelerating structures in Linac4, thus simplifying and standardising the linac RF system. Furthermore, the simplified mechanical construction of the PIMS, which uses only 84 cells instead of over 400 for the SCL, also reduces construction costs and tuning effort. In this paper we present the electromagnetic design of the PIMS, including the arguments for the choice of a 5% cell-to-cell coupling factor, the shape of the coupling cells, the dimensioning of the wave-guide ports, and the expected field errors during operation.

F. Gerigk, R. Wegner (CERN)

FR5REP051

### Construction Status of Linac4

The civil engineering works of the Linac4 linear accelerator at CERN started in October 2008 and regular machine operation is foreseen for 2013. Linac4 will accelerate  $H^{-}$  ions to an energy of 160 MeV for injection into the PS Booster (PSB). It will thus replace the ageing Linac2, which presently injects at 50 MeV into the PSB, and it will also represents the first step in the injector upgrade for the LHC aiming at increasing its luminosity. This paper reports on the status of the design and construction of the main machine elements, which will be installed in the linac tunnel from the beginning of 2012 onwards, on the progress of the civil engineering and on the ongoing activities at the Linac4 test stand.

F. Gerigk, C. Carli, R. Garoby, K. Hanke, A. M. Lombardi, R. Maccaferri, S. Maury, C. Rossi, M. Vretenar (CERN)

FR5REP052

### Higher Order Modes in the Superconducting Cavities of the SPL

In this paper is analysed the influence of Higher Order Modes (HOM) on the operation of the superconducting linac section of the SPL, the Superconducting Proton Linac being designed at CERN. For this purpose, the characteristics of the HOMs in the 2 different beta families (0.65, 0.92 both at 704 MHz) of the SPL are calculated to estimate their effect on the cryogenic system and on the beam stability. For both criteria the maximum external Q of the HOMs is defined.

F. Gerigk, M. Schuh, J. Tuckmantel (CERN) C. P. Welsch (KIP)

FR5REP053

**Linac4 DTL Prototype: Theoretical Model, Simulation and Low Energy Measurements**

F. Grespan, G. De Michele, F. Gerigk, S. Ramberger (CERN)

A one meter long hot prototype of the LINAC4 DTL, built in a collaboration with INFN Legnaro, was delivered to CERN in 2008. It was then copper plated at CERN and is presently prepared for high-power testing at the CERN test stand in SM18. In this paper we present 2D/3D simulations and the first RF low-power measurements to verify the electromagnetic properties of the cavity and to tune it before the high-power RF tests. In particular, the influence of the post couplers was studied in order to guarantee stabilization of the accelerating field during operation. We present an equivalent circuit model of the DTL, together with a comparison of 3D simulations and measurement results for the hot model.

**Linac4 Beam Characterization before Injection into the CERN PS Booster**

B. Mikulec, G. Bellodi, M. Eshraqi, K. Hanke, T. Hermanns, A. M. Lombardi, U. Raich (CERN)

Construction work for the new CERN linear accelerator, Linac4, started in October 2008. Linac4 will replace the existing Linac2 and provide an  $H^-$  beam at 160 MeV (as opposed to the present 50 MeV proton beam) for injection into the CERN PS Booster (PSB). The charge-exchange  $H^-$  injection combined with the higher beam energy will allow for an increase in beam brightness required for reaching the ultimate LHC luminosity. Commissioning of Linac4 and of the transfer line to the PSB is planned for the last quarter of 2012. Appropriate beam instrumentation is foreseen to provide transverse and longitudinal beam characterization at the exit of Linac4 and in two dedicated measurement lines located before injection into the PSB. A detailed description of the diagnostics set, especially of spectrometer and emittance meter, and the upgrade of the measurement lines for Linac4 commissioning and operation is presented.

**Proposed FNAL 750-keV Linac Injector Upgrade**

C.-Y. Tan, D. S. Bollinger, W. Pellico, C. W. Schmidt (Fermilab)

The present FNAL Linac  $H^-$  injector has been operational since 1978 and consists of a magnetron  $H^-$  source and a 750-keV Cockcroft-Walton Accelerator. The proposed upgrade to this injector is to replace the present magnetron source having a rectangular aperture with a circular aperture, and to replace the Cockcroft-Walton with a 200-MHz RFQ. Operational experience at other laboratories has shown that the upgraded source and RFQ will be more reliable and require less manpower than the present system.

**Multi-Cell Reduced-Beta Elliptical Cavities for a Proton Linac**

J.-P. Carneiro, N. Solyak, V. P. Yakovlev (Fermilab) W. Hartung (NSCL) P. N. Ostroumov (ANL)

A superconducting cavity has been designed for acceleration of particles traveling at 81% the speed of light ( $\beta = 0.81$ ). The application of interest is an 8 GeV proton linac proposed for a Fermilab upgrade; at present, the cavity is to be used from 420 MeV to 1.3 GeV. The cavity is similar to the 805 MHz high-beta cavity developed for the SNS Linac, but the resonant frequency (1.3 GHz) and beam tube diameter (78 mm) are the same as for the  $\beta = 1$  cavities developed for the TESLA Test Facility. Four single-cell prototype cavities have been fabricated and tested. Two multi-cell prototypes have also been fabricated,

but they have not yet been tested. The original concept was for an 8-cell cavity, but the final design and prototyping was done for 7 cells. An 11-cell cavity was proposed recently to allow the cryomodules for the  $\beta = 0.81$  cavity and downstream 9-cell  $\beta = 1$  cavities to be identical. The choice of number of cells per cavity affects the linac design in several ways. The impact of the number of cells in the 8 GeV linac design will be explored in this paper. Beam dynamics simulations from the ANL code TRACK will be presented.

### Overview and Status Update of the Fermilab HINS Linac R&D Program

The High Intensity Neutrino Source (HINS) linac R&D program at Fermilab is constructing a first-of-a-kind superconducting H<sup>1-1</sup>

**R. C. Webber** (Fermilab)

linac. The machine will demonstrate acceleration of high intensity beam using superconducting spoke cavities, solenoidal focusing optics throughout for control of halo growth, and operation of many cavities from a single high power rf source for acceleration of non-relativistic particles. The ion source and RFQ are operational with beam and the 10 MeV room temperature cavity section is being assembled. Superconducting spoke cavity testing is proceeding. The overall status and outlook of the HINS program is presented.

### A New High Energy UNILAC as a High Current Heavy Ion Injector for the FAIR-Synchrotrons

The GSI UNILAC serving as a high duty factor heavy ion linac is in operation since nearly 35 years. An upgrade program dedicated to FAIR will be finished until 2011.

**W. Barth, L. A. Dahl, H. Eickhoff, L. Groening** (GSI)

For the FAIR project the synchrotron SIS 18 has to be filled up to the space charge limit. After re-commissioning of the UNILAC the replacement of the main DTL is foreseen. A new 4 MV/m 108 MHz IH-LINAC provides a high intensity 5 MeV/u U<sup>4+</sup>-beam. The existing gas stripper section is reused to perform a beam intensity of 24 emA in charge state 42+. The existing UNLAC-tunnel may house a high efficient linac structure. A superconducting or normal conducting 324 MHz-CH-linac (crossbar H-structure) is under consideration as well as rf-resonators of half wave or quarter wave type. The new high energy linac should be able to boost the beam energy up to 30 MeV/u. A further upgrade option is a second 100 m-linac (324 MHz) to enhance the beam energy to up to 100 MeV/u (U<sup>41+</sup>), sufficient to feed the FAIR 100 Tm synchrotron in direct line. The paper will report on the ongoing conceptual layout of a new UNILAC-concept.

### Prototype Construction of a Coupled CH-DTL Proton Linac for FAIR

For the research program with cooled antiprotons at FAIR a dedicated 70MeV, 70mA proton injector is needed. The main acceleration of this room temperature injector will

**R. B. Brodhage, S. Minaev, H. Podlech, U. Ratzinger, R. Tiede** (IAP) G. Clemente, L. Groening (GSI)

be provided by six coupled CH-cavities operated at 325MHz. Each cavity will be powered by a 3 MW klystron (6 in total). For the second acceleration unit from 11.7 to 24.3 MeV measurements on a 1:2 scaled model are performed. This tank is now ready for construction and will be used for RF power tests at GSI. The RF power test installations are underway. This paper presents the CH-DTL design and especially the status of the first power cavity.

FR5REP058

FR5REP059

FR5REP060

### Recent Superconducting CH-Cavity Development

M. Busch, A. Bechtold, H. Podlech, U. Ratzinger (IAP)

The superconducting CH-cavity is the first multi-cell drift tube cavity for the low and medium energy range of proton and ion linacs. A 19 cell,  $\beta=0.1$  cavity has been developed and tested successfully with gradients of up to 7 MV/m. A piezo based fast tuner system has been developed. First horizontal tests of the cavity in a cryo-module with tuner are presented. Additionally, the construction of a new superconducting 325 MHz 7-gap CH-cavity has started. This cavity has an optimized geometry with respect to tuning possibilities, high power RF coupling and minimized end cell lengths. After low power tests it is planned to test this cavity with a 11.4 MeV/u beam delivered by the Unilac at GSI.

The superconducting CH-cavity is the first multi-cell drift tube cavity for the low and medium energy range of proton and ion

### A Beam Transport System for the Frankfurt Funneling Experiment

P. Kolb, N. Mueller, A. Schempp (IAP)

The goal of the Frankfurt Funneling Experiment is to multiply beam currents by merging two low energy ion beams. In an ideal case this would be done without any emittance growth. Our setup consists of two ion sources, a Two-Beam-RFQ accelerator and a multi cell deflector which bends the beams to one common beam axis. Current work is the design of a new beam transport system between RFQ accelerator and deflector. With extended RFQ-electrodes the drift between the Two-Beam-RFQ and the rf-deflector will be minimized and therefor unwanted emittance growth prohibited. First rf measurements with a scaled experiment will be presented.

The goal of the Frankfurt Funneling Experiment is to multiply beam currents by merging two low energy ion beams. In an ideal

### Funneling with a Two-Beam RFQ Accelerator

N. Mueller, U. Bartz, D. Ficek, P. Kolb, J. M. Maus, A. Schempp, M. Vossberg (IAP)

Funneling is a method to increase low energy beam currents in multiple stages. The Frankfurt Funneling Experiment is a model of such a stage. The experiment is built up of two ion sources with a electrostatic lens systems, a Two-Beam RFQ accelerator, a funneling deflector and a beam diagnostic system. The two beams are bunched and accelerated in a Two-Beam RFQ and the last parts of the RFQ electrodes achieve a 3d focus at the crossing point of the two beam axis. A funneling deflector combines the bunches to a common beam axis. The optimized ion sources are adapted to the front end bunching section. Recent funneling measurements with the one-gap and the multi-gap deflector will be presented.

Funneling is a method to increase low energy beam currents in multiple stages. The Frankfurt Funneling Experiment is a model of such a stage. The experiment is built up

### The New GSI HLI-RFQ for cw Operation

M. Vossberg, N. Mueller, A. Schempp (IAP) L. A. Dahl (GSI) J. Haeuser (NTG Neue Technologien GmbH & Co KG)

A new CW-RFQ will be built for the upgrade of the HLI (High Charge State Injector) of GSI for operating with a 28 GHz-ECR-Ion source and simultaneous increase of the beam duty cycle from 25% to 100 %. The new HLI 4-rod RFQ will accelerate charged ions from 4 keV/u to 300 keV/u for the injection into the IH-structure The design had been optimized to get a rather short structure with LRFQ=2m to match the available RF-power of max. 60 kW in cw. High beam transmission, a small energy spread and small transverse emittance growth and good input matching were design goals. Properties of this CW-RFQ and status of project will be presented.

A new CW-RFQ will be built for the upgrade of the HLI (High Charge State Injector) of GSI for operating with a 28 GHz-ECR-Ion source and simultaneous increase

### Mechanical Design of the IFMIF-EVEDA RFQ

The IFMIF-EVEDA RFQ is a 9.8 m long cavity, whose working frequency is equal to 175 MHz. In the base line design the accelerator tank is composed of 9 modules flanged together and a pattern of lateral CF100 flanges

allows to host the dummy tuners and the couplers, and a pattern of CF 150 flanges the apertures for vacuum pumping manifolds as well. The construction procedure of each module foresees the horizontal brazing of four half -- module length electrodes and then the vertical brazing of two brazed assembly. The progresses in the design and engineering phase, as well the description of all the fabrication phases are reported.

**A. Pepato** (INFN- Sez. di Padova) M. Comunian, A. Palmieri, A. Pisent, C. Roncolato (INFN/LNL) E. Fagotti (Consorzio RFX, Associazione Euratom-ENEA sulla Fusione)

FR5REP065

### RFQ Design Optimisation for PAMELA Injector

The PAMELA project aims to design an ns-FFAG accelerator for cancer therapy using protons and carbon ions. For the injection system for carbon ions, an RFQ is one option

for the first stage of acceleration. An integrated RFQ design process has been developed using various software packages to take the design parameters for the RFQ, convert this automatically to a CAD model using Autodesk Inventor, and calculate the electric field map for the CAD model using CST EM STUDIO. Particles can then be tracked through this field map using Pulsar Physics' General Particle Tracer (GPT). Our software uses Visual Basic for Applications and MATLAB to automate this process and allow for optimisation of the RFQ design parameters based on particle dynamical considerations. Initial particle tracking simulations based on modifying the field map from the Front-End Test Stand (FETS) RFQ design have determined the best operating frequency for the PAMELA RFQ to be close to 200 MHz and the length approximately 2.3 m. The status of the injector design with an emphasis on the RFQ will be presented, together with the results of the particle tracking.

**M. J. Easton**, M. Aslaninejad, S. Jolly, J. K. Pozimski (Imperial College of Science and Technology, Department of Physics)

FR5REP066

### Novel Integrated Design Method and Beam Dynamics Simulations for the FETS RFQ

A 4m-long, 324MHz four-vane RFQ, consisting of four resonantly coupled sections, is currently being designed for the Front End Test Stand (FETS) at RAL in the UK. Previous beam dynamics simulations, based on

field maps produced with a field approximation code, provide a baseline for the new design. A novel design method is presented that combines the CAD and electromagnetic modelling of both the RFQ tank and the vane modulations with more sophisticated beam dynamics simulations using the General Particle Tracer code (GPT). This approach allows the full integration of the optimisation of the RFQ, based on beam dynamics simulations using a 3D EM-field map of the CAD model, with the design and manufacture of the RFQ vane modulations and RFQ tank. The design process within the Autodesk Inventor CAD software is outlined and details of the EM modelling of the RFQ in MicroWave Studio are given. Results of beam dynamics simulations in GPT are presented and compared to previous results with field approximation codes. Finally, possible methods of manufacture based on this design process are discussed.

**S. Jolly**, M. J. Easton, P. Savage (Imperial College of Science and Technology, Department of Physics) A. P. Letchford, J. K. Pozimski (STFC/RAL)

FR5REP067

**LENS Proton Linac: 6 Kilowatt Operation**

T. Rinckel, D. V. Baxter, A. Bogdanov, V. P. Derenchuk, P. E. Sokol (IUCF) W. Reass (LANL)

The Indiana University Cyclotron Facility is operating a Low Energy Neutron Source which provides cold neutrons for material research and neutron physics as well as neutrons in the MeV energy range for neutron radiation effects studies. Neutrons are being produced by a 13 MeV proton beam incident on a Beryllium target. The LENS Proton Delivery System (PDS) is routinely operating at 13 MeV and 25 mA at 1.8% duty factor. The RF system, consisting of three Litton 5773 klystron RF tubes at 425 MHz and 1 MW each, power the AccSys Technology PL-13 Linac. The proton beam delivers 6 kilowatts of power to the Beryllium target. Details of the beam spreading system, target cooling system, and accelerator operations will be discussed.

**100 MeV DTL Development for PEPF Proton Linac**

H. S. Kim, Y.-S. Cho, J.-H. Jang, D. I. Kim, H.-J. Kwon, B.-S. Park (KAERI)

A 100 MeV DTL as a main accelerating section of the PEPF proton linac is under development. The PEPF proton linac consists of a 50 keV proton injector based on a duoplasmatron ion source, 3 MeV four-vane RFQ, 20 MeV DTL and 100 MeV DTL. The 100 MeV DTL is composed of 7 tanks and each tank is an assembly of 3 sections. The tank is made of seamless carbon steel and inside surface is electroplated with copper. Each drift tube contains an electroquadrupole magnet which is made of hollow conductor and iron yoke with epoxy molding. Following the fabrication of tanks and drift tubes, a precise alignment of drift tubes and field flatness tuning procedure are performed. Currently four DTL tanks out of seven are completed and the rest are under fabrication. The status of development and test results of the fabricated parts are reported in this paper.

**Development of IH Accelerating Structures with PMQ Focusing for Low-Beta Ion Beams**

S. S. Kurennoy, J. F. O'Hara, L. Rybarczyk (LANL)

We are developing high-efficiency room-temperature RF accelerating structures based on inter-digital H-mode (IH) cavities and the transverse beam focusing with permanent-magnet quadrupoles (PMQ), for beam velocities in the range of a few percent of the speed of light. Such IH-PMQ accelerating structures following a short RFQ can be used in the front end of ion linacs or in stand-alone applications such as a compact deuteron-beam accelerator up to the energy of several MeV. New results from our detailed electromagnetic 3-D modeling combined with beam dynamics simulations and thermal-stress analysis for a complete IH-PMQ accelerator tank, including the end-cell design, will be presented.

**Simulation of Large Acceptance Linac for Muon**

H. M. Miyadera, A. J. Jason, S. S. Kurennoy (LANL)

Muon accelerators are proposed world wide for future neutrino factory, muon colliders and other applications. One of the problem on accelerating muons is their large emittance as well as huge energy preads. We carried out some simulation works on large acceptance muon linear accelerator that operates at mixed buncher / acceleration mode. The designed

linac has following features: iris structure of 12 cm diameter, inject  $\sim 100$  MeV muon beam and accelerates to several 100 MeV, 700 MHz and 25 MV/m peak field. Further acceleration of the muon beam can be easily done by extending the muon linear accelerator. According to the simulation, our linac can accelerates DC muon beam of 20 - 100 MeV range with 20 % phase acceptance.

### Use of a Debuncher Cavity for Improving Multi-Beam Operations at LANSCE

The Los Alamos Neutron Science Center simultaneously provides both  $H^-$  and  $H^+$  beams to several user facilities. Opposite polarity beams are usually accelerated in the linac during the same macropulse when beam-loading limitations are not exceeded. Presently, the Weapons Neutron Research (WNR)  $H^-$  and Isotope Production Facility (IPF)  $H^+$  beams are accelerated simultaneously during the same macropulse. The amplitude of the cavity field in the last 201-MHz buncher, located in the common transport just upstream of the DTL, is a compromise between the optimal values for each beam. Recent beam dynamics studies have shown that implementing a debuncher cavity in the  $H^-$  low-energy beam transport would allow for more optimal operation of both beams. For this application where space is limited, a compact 201-MHz quarter-wave cavity will be used. This paper will report on the beam dynamics simulations performed and the quarter-wave cavity design being developed to address this issue.

L. Rybarcyk, S. S. Kurennoy (LANL)

### The Superconducting Driver Linac for the Proposed MSU FRIB Project

The superconducting (SC) driver linac developed for the proposed Facility for Rare Isotope Beams (FRIB) at Michigan State University (MSU) will be able to accelerate stable beams of heavy ions to  $> 200$  MeV/u with beam powers up to 400 kW. The driver linac front-end will include ECR ion sources, a bunching system for multi-charge state beams and a radio frequency quadrupole (RFQ). The superconducting linac will have a base frequency of 80.5 MHz primarily using SC cavities and cryomodules developed for the Rare Isotope Accelerator (RIA), the FRIB predecessor. A charge-stripping chicane and multiple-charge state acceleration will be used for the heavier ions in the driver linac. A beam delivery system will transport beam to the in-flight particle fragmentation target station. The paper will discuss recent progress in the accelerator system design for the superconducting driver linac.

X. Wu, C. Compton, M. Doleans, W. Hartung, D. Lawton, F. Marti, R. C. York, Q. Zhao (NSCL)

### Ion Beam Dynamics in Superconducting Drift Tube Linac

Ion superconducting linac is based on periodic system from short identical niobium cavities. This linac supplies typically 1 MV of accelerating potential per cavity. By specific phasing of the RF cavities one can provide a stable particle motion in the whole accelerator. The longitudinal and transverse ion beam dynamics are studied in this linac. The 3D equation of motion in the Hamiltonian form is devised by the smooth approximation. This equation is used for analysis of the nonlinear ion beam dynamics in superconducting linac. It was shown that the connection between the phase acceptance and the transverse emittance can be found by means of the effective potential function. The focusing methods by the solenoid field and RF field are studied. The results of this investigation are compared with the numerical simulation of ion beam dynamics in superconducting linac.

E. S. Masunov, A. V. Samoshin (MEPhI)

### Final Tests on the First Module of the ACLIP Linac

V. G. Vaccaro, M. R. Masullo (Naples University Federico II and INFN) C. De Martinis (Universita' degli Studi di Milano & INFN) D. Giove (Istituto Nazionale di Fisica Nucleare) S. J. Mathot (CERN) A. C. Raino (Bari University, Science Faculty) R. J. Rush (e2v) V. Variale (INFN-Bari)

ACLIP is a proton 3 GHz SCL linac designed as a booster for a 30 MeV commercial cyclotron. The final energy is 60 MeV well suitable for the therapy of ocular tumours or for further acceleration (up to 230 MeV) by a second linac in order to treat deep seated tumours. ACLIP has a 5 modules structure

coupled together. The first one (able to accelerate proton from 30 to 35 MeV) has been completely assembled. High power tests are in progress at e2v in Chelmsford, UK, where the possibility of using magnetrons as the source of RF power is under investigation. Acceleration tests are foreseen for Spring 2009. In this paper we will review the main features of the linac and discuss the results of RF measurements, high power RF tests and possibly acceleration tests.

### Low Energy High Power Side Coupled Linac Optimization

V. G. Vaccaro, F. Galluccio (Naples University Federico II and INFN) A. Renzi (Naples University Federico II)

The use of BBAC (Back-to-Back Accelerating Cavity) tiles in proton Side Coupled Linacs can be extended down to energies of the order of 20 MeV, keeping more than suitable

shunt impedances and energy gradients. However, the considerable energy absorption from the cavity noses may induce a remarkable increase in their temperature. This may cause both a strong duty-cycle-dependent detuning of the modules, and dangerous thermo-mechanical stress due to the non-uniform temperature distribution. An innovative shape of the BBAC tile is proposed, which allows to limit the temperature rise within a safe range, without introducing detrimental effects neither on the shunt impedance nor on the working frequency. A protocol for the design of such a cavity will be presented.

### Performance Analysis and Improvement of the 50 MeV Linac for the Taiwan Light Source

C. Y. Wu, J. Chen, K. T. Hsu, K. H. Hu, J.-Y. Hwang, A. P. Lee, D. Lee, K.-K. Lin (NSRRC)

Operation performance of the linear accelerator is crucial to satisfy stringent requirements for the top-up operation of the Taiwan Light Source. The performance of linear

accelerator affects injector stability directly. Efforts to improve diagnostics and develop control applications for performance characterization are on going. Enhance operation performance of 50 MeV linac is also under way. Efforts for the improvement of the linac to provide better top-up injection performance will be summary in this report.

### A Fourth Order Resonance of a High Intensity Linac

D.-O. Jeon (ORNL) G. Franchetti, L. Groening (GSI)

The  $4\nu=1$  resonance of a linac is demonstrated when the depressed tune is around 90 deg. It is observed that this fourth order

resonance is dominating over the better known envelope instability and practically replacing it. Simulation study shows a clear emittance growth by this resonance and its stopband. One of the authors [DJ] made a proposal to



GSI to measure the stopband of this resonance. The experiment was conducted successfully and the experiment data will be presented separately in the conference.

### Design of a -10-4 MHz Trapezoidal Type IH-RFQ

A trapezoidal IH-RFQ (T-IH-RFQ) is being built to accelerate  $^{14}\text{C}^+$  from 40 keV to 500 keV, motivated by RFQ based  $^{14}\text{C}$  AMS application at Peking University. The last design of beam dynamics and the optimized results of RF structure will be presented in this paper. The length of the cavity is about 1.1m operating at -10-4MHz, with a designed transmission efficiency of more than 97%. A special feature is that the RFQ output beam energy spread is as low as 0.6% approached by the method of internal discrete bunching. On the other hand, the new RF cavity structure T-IH-RFQ was proposed for the beam dynamics design, which has higher resonant frequency than traditional four rods RFQ and IH-RFQ at the same transverse dimension. Microwave Studio (MWS) simulations have been performed to study the field distribution and power consumption characteristic of this T-IH-RFQ. The specific shunt impedance and the quality factor have been optimized. Those details will be given.

Y. C. Nie, J. E. Chen, J. X. Fang, S. L. Gao, Z. Y. Guo, Y. R. Lu, X. Q. Yan, K. Zhu (PKU/IHIP)

FR5REP079

### Commissioning Status of 10-MeV Intense Electron Linac

An intense L-band electron linac is now being commissioned at ACEP (Advanced Center for Electron-beam Processing in Cheorwon, Korea) for irradiation applications. It is capable of producing 10-MeV electron beams with the 30-kW average beam power. For a high-power capability, we adopted the traveling-wave structure operated with the  $2\pi/3$ -mode at 1.3 GHz. The structure is powered by a 25-MW pulsed klystron with 60-kW average RF power. The RF pulse length is 8  $\mu\text{s}$  while the beam pulse length is 7  $\mu\text{s}$  due to the filling time in the accelerating structure. The accelerating gradient is 4.2 MV/m at the beam current of 1.45 A which is the fully beam-loaded condition. In this paper, we present details of the accelerator system and commissioning status.

S. H. Kim, M.-H. Cho, W. Namkung, H. R. Yang (POSTECH) S. D. Jang, S. J. Park, Y. G. Son (PAL) J.-S. Oh (NFRI)

FR5REP080

### Characteristics of Shaped Traveling-Wave Structure and Combined Accelerating System

The shaped traveling-wave (STW) structure contains periodic structure of cavities with optimal shape and magnetic coupling operating in forward traveling-wave mode\*. Phase shift per cavity in the direction of moving particles is more than  $\pi$ . Choice of the phase shift determines the structure efficiency, achievable accelerating gradient, and sensitivity of accelerating field to instabilities and errors. Choice of values of coupling between cavities determines distribution of accelerating field along the structure. Relevant dependences and recommendations are presented. The structure ensures high efficiency of acceleration and gives a possibility to vary energy of particles in wide range. The combined system including standing-wave bunching section and STW accelerating section in common design makes it possible to operate without application of magnetic focusing devices and special devices for matching with microwave generator. It is well suited for compact variable-energy electron accelerators used for radiation technologies. Calculated characteristics of variable-energy combined electron accelerator with maximum energy of 10 MeV are given.

V. M. Pirozhenko (Private Address)

FR5REP081

\*V. M. Pirozhenko, "Efficient Traveling-Wave Accelerating Structure for Linear Accelerators", EPAC'08, Genoa, June 2008, pp. 2746-2748.

### Study of IH Linear Accelerator with Higher Order Mode

N. Hayashizaki, T. Hattori (RLNR)

An Interdigital-H (IH) linac has been used for ion acceleration in low beta range. It can realize a resonant cavity of a convenient size at low frequencies and higher shunt impedance at low energy range. These characteristics are advantageous especially for heavy ion acceleration. Since the shunt impedance of the IH linac reduces according to the increasing of beam energy, the linacs operated by the TM<sub>010</sub> mode such as an Alvarez type and a coupling cavity type are adopted for medium and high energy range. However, we propose the new IH linac using the TE<sub>11n</sub> mode, the higher order mode IH (HOM-IH) linac. By using the higher order mode, the resonance frequency is higher than that of the IH linac. This property is suitable for middle and high beta linacs, and a proton linac as well. The design of the cavity structure and the possibility are presented.

### 'S' Band Linac Tube Developmental Work in SAMEER, India

R. Krishnan, A. Deshpande, T. S. Dixit, C. S. Nainwad (SAMEER)

The developmental work on linear electron accelerators in SAMEER, India is briefed in this paper. The technology to develop 'S' band compact side coupled standing wave electron linear accelerator is very well established at SAMEER, Mumbai center. 6 MV to 15 MV linacs are developed with the desired specifications. Indigenous 6 MV linac machines for radiotherapy applications have been developed successfully and these machines are in use at premier cancer hospitals in the country. SAMEER is presently working on the development of the dual mode-electron and photon and dual photon energy linear accelerator for radiotherapy application. The 6 MeV linac tube development and its test results are discussed.

### Commissioning of the Injector Linac of the IFUSP Microtron

T. F. Silva, A. L. Bonini, C. Jahnke, R. Lima, M. Lucena, A. A. Malafrente, M. N. Martins, L. Portante, A. J. Silva, V. R. Vanin (USP/LAL)

The Instituto de Física da Universidade de São Paulo (IFUSP) is building a two-stage 38 MeV continuous wave racetrack microtron. This accelerator consists of a linac injector that delivers a 1.7 MeV beam to a microtron (booster) with 5 MeV exit energy. A transport line guides the beam to the main microtron to be accelerated to energies up to 38 MeV in steps of 0.9 MeV. This work describes the commissioning of the linac injector that comprises the first two accelerating structures of the IFUSP Microtron. A provisional beam line was built at the end of the linac to provide energy and current measurements. We also present results concerning RF power, RF phase, and temperature control of the accelerating structures. The first results of the chopper and buncher systems are also presented.

### Front End Studies for a High Power Proton Driver

Future projects like a neutrino factory or an advanced spallation neutron source require high power proton accelerators capable of producing beams in the multi-MW range. The quality of the beam delivered to the target is very much dictated by the accelerator front end and by the lower energy linac. Prompted by the Front End Test Stand (FETS) under construction at RAL, a new 800 MeV  $H^+ - H^-$  linac is being considered as part of a possible MW upgrade for ISIS. Preliminary simulations of high intensity beam dynamics and beam transport in the new linac suggest that a re-evaluation of the front end Medium Energy Beam Transport (MEBT) line is necessary. In this paper different optical designs for the 3 MeV MEBT line are presented and their impact on the subsequent Drift Tube Linac (DTL) section is being analyzed.

**D. C. Plostinar** (STFC/RAL/ASTeC)

FR5REP085

### Outline Linac and Ring Designs for Potential ISIS Upgrades

Features of a linac and ring for potential ISIS upgrades are outlined. Maximum parameters are 0.8 GeV, 0.5 MW for the  $H^-$  linac and 3.2 GeV, 2 MW for the ring, both at 30 or 50 Hz. The linac is based on a 324 MHz frequency at low energies, having an ion source, LEBT, 3 MeV RFQ and MEBT, with a 74.8 MeV drift tube linac (DTL) and intermediate energy beam transport (IEBT). The MEBT chopper stage uses solenoid and triplet focusing, and both MEBT and IEBT have long sections for beam collimation. There are three options for the higher energies, a 648 MHz superconducting linac (ScL1, ScL2 and ScL3), a 648 MHz (CCL, ScL2 and ScL3), and a 324 MHz (ScLa) with a two-stage 972 MHz (ScLb and ScLc). The ScL1, CCL and ScLa are designed to accelerate the  $H^-$  beam from 74.8 to  $\sim 200$  MeV. The proton synchrotron design is based on a five superperiod lattice of doublet and triplet cells, and has a circumference of  $\sim 370$  m.

**G. H. Rees** (STFC/RAL/ASTeC)

FR5REP086

### Status of the SARAF CW 40 MeV Proton/Deuteron Accelerator

The Soreq Applied Research Accelerator Facility, SARAF, is currently under construction at Soreq NRC. SARAF is based on a continuous wave (CW), proton/deuteron RF superconducting linear accelerator with variable energy (5–40 MeV) and current (0.04–2 mA). SARAF is designed to enable hands-on maintenance, which implies beam loss below  $10^{-5}$  for the entire accelerator. Phase I of SARAF consists of a 20 keV/u ECR ion source, a low energy beam transport section, a 4-rod RFQ, a medium energy (1.5 MeV/u) transport section, a superconducting module housing 6 half-wave resonators and 3 superconducting solenoids, a diagnostic plate and a beam dump. Phase II will include 5 additional superconducting modules. The ECR source is in routine operation since 2006, the RFQ is in routine operation with protons since 2008 and has been further operated with molecular hydrogen and deuterons. The superconducting module is being operated and characterized with protons. Phase I commissioning results, their comparison to beam dynamics simulations and Phase II plans will be presented.

**I. Mardor**, D. Berkovits, I. Gertz, J. Rodnizki, L. Weissman (Soreq NRC) K. Dunkel, F. Kremer, M. Pekeler, C. Piel, P. vom Stein (ACCEL)

FR5REP087

**Commissioning of the 100 MeV Preinjector for the Spanish Synchrotron ALBA**

A. S. Setty, D. Jousse, J.-L. Pastre, F. Rodriguez (THALES) G. Benedetti, D. Einfeld, A. Falone, U. Iriso, M. Munoz, A. Olmos, F. Perez, M. Pont, P. Sanchez (ALBA) A. Sacharidis (EuroMev)

A turn key 100 MeV linac was provided by THALES Communications in order to inject electrons into the booster synchrotron of ALBA\*. The linac was commissioned in October 2008. This paper will remind the

main features of the linac\*\* and will give results obtained during the commissioning tests. The energy and emittance measurements have been done on the transfer line conceived and realized by CELLS. Specified and measured beam parameters will be compared to show the performance of the entire system.

\* D. Einfeld "Progress of ALBA", EPAC08, Genoa, Italy, June 2008.

\*\* A. Falone et al, "Status of the 100 MeV preinjector for the ALBA synchrotron", EPAC08, Genoa, Italy, June 2008.

**Physical Design and Microwave Measurements of 4MeV X-Band SW Accelerator**

Hua,,J. F. Hua, H. Chen, Q. X. Jin, J. Shi, D. C. Tong (TUB)

On the basis of an X-band 2MeV on-axis standing wave electron linear accelerator, a 4MeV X-band accelerator is designed for

non-destructive testing. With the coupler cell located in the middle of the accelerating tube, the circuit model is applied to analyze the RF characteristic and the particle dynamic is then checked using PARMELA. The cold measurements and RF adjusting are also described in this paper.

**Development of a 4 MeV X-Band SW Accelerator**

Q. X. Jin, H. Chen, Hua,,J. F. Hua, D. C. Tong (TUB)

A compact X-band accelerator for non-destructive testing is being developed at Tsinghua University. Based on the X-band

(9.3GHz) tunable coaxial magnetron of 1.0 MW, which is commercially available in china, an 320mm-long on-axis coupled SW accelerating tube has been optimized. The structure is operated on the  $\pi/2$  mode with average effective shunt impedance more than 125 M $\Omega$ /m. The total length of the structure, including a Pierce electron gun and a target, is less than 400mm. The diameter of the tube with the cooling water jacket is only 60mm, which can significantly reduce the shielding volume and weight. The single tube can produce two kinds of x-rays: energy of 4MeV with dose rate of 150cGy/min@m or 2MeV with dose rate of 50cGy/min@m. This paper presents the design performance characteristics of the structure and the results of the high-power tests.

**The Primary Experiment of Multipactor Electron Gun Based Accelerator**

M. Zhong, C.-X. Tang, S. Zheng (TUB)

The Multipactor Electron Gun (MEG) can produce high current self-bunching electron beams. In this paper, the primary experi-

mental results of an S-band MEG based accelerator are presented. The accelerator was modified from a 6MeV standing wave accelerator to integrate the MEG, which has an adjusting structure to control both the cathode-grid distance and frequency tuner. The designed output energy is 5MeV and average current is 100mA. The experiment included low power microwave parameter measurement and high power beam test. In the microwave parameter measurement, the relationship between tuner position and E-field distribution was investigated. Platinum was used

as the secondary electron emitters of the MEG. The multipacting process was observed and an average current of 40mA was collected by an aluminum target.

### Optics Study on the Extraction Region for a High Intensity Compact Cyclotron

As a high intensity compact cyclotron, CYCIAE-100 is designed to provide proton beams in two directions simultaneously. At the extraction region, the fringe field of the main and the field of the combination magnet will influence the beam optics. The fringe field may become critical by comparison with the separated sector machine because of the compact structure. The dispersion during the beam extraction should not be ignored, which may make the beam envelop become evidently bigger. Then the beam loss and residual radiation increase. To study the beam optics at the extraction region of CYCIAE-100, the orbit tracking and transfer matrix calculation and symplectic by function extension of the code GOBLIN and modification of STRIPUBC have been implemented. The characteristics of the extracted beam have been investigated based on the main field from a FEM code and overlapping with the field generated from the combination magnet at each extraction port. The results are also compared with those from the CIAE's code CYCTRS to confirm this precise prediction. The transfer matrix from this simulation is analyzed and used for the down stream beam line design.

S. M. Wei, S. An, M. Li, T. J. Zhang (CIAE) Y.-N. Rao (TRIUMF)

### Coupled Particle Motion in the CIAE CRM Injection Line

The 40 keV  $H^{-}$  injection line for the 10 MeV CRM cyclotron at CIAE has two main operation modes: delivering bunched 5 mA CW beam or pulsed beam with more than 50uA, again being bunched. The focusing structure for CRM injection is adopted with ESQQ and the final focusing is done by quadruple doublet with 2.5 cm aperture radius. Pulsed bunch is achieved by placing 2.2 MHz sinusoidal transverse chopper after the 70 MHz bunching cavity. Particles outside the wanted  $\pm 3^{\circ}$  phase width @ 2.2 MHz, corresponding to  $\pm 90^{\circ}$  @ 70 MHz, are absorbed in 50cm drift length between chopper and round slit with 1cm aperture. Time dependence of sinusoidal chopping field causes rms emittance increase by a factor 3 and changes twiss parameter alpha by a factor 2 before the slit. Solenoid couples radial phase space planes, but equalizes both rms emittances. Final focusing is done by quadrupole doublet with almost unchanged field strength. Particle tracking results are presented for the chopped pulse, showing equalization of rms emittances in solenoid and radial-axial coupling at CRM injection in both planes. Transmission efficiency is greater than 50 % for the unchopped bunch and 1 % for the chopped bunch.

S. An, T. J. Zhang (CIAE) K. Bongardt (FZJ)

### Periodic Parameter Tracking Using the Measured Magnetic Field Maps of the RACCAM Spiral FFAG Magnet

A prototype of a spiral lattice FFAG magnet has been constructed in the frame of the RACCAM project\*. This magnet is subject to extensive field measurements and 3-dimensional field map measurements. The properties and qualities of the magnet are assessed directly from ray-tracing, using stepwise integration, for deriving lattice parameters as tunes, chromaticities, dynamic apertures, etc. Reporting on this is the subject of the poster.

F. Meot (CEA) F. Forest, M. J. Leray (Sigmaphi) J. Pasternak (Imperial College of Science and Technology, Department of Physics)

\*<http://lpsc.in2p3.fr/serviceaccelerateurs/raccam.htm>

**An Alternative Design for the RACCAM Magnet with Distributed Conductors**

D. Neuvéglise (SIGMAPHI S. A.) F. Meot (CEA)

This paper presents an alternative design of the magnet for the RACCAM project. The aim of this collaboration is to study and build a prototype of a scaling spiral FFAG as a possible medical machine for hadron therapy. The magnet was first designed with a variable gap to produce the desired field law  $B=B_0(r/r_0)k$ . The key feature in the "scaling" behavior of the magnet is in getting the fringe field extent to be proportional to the radius. Although the fringe field is increasing with gap dimension, we have obtained quite constant tunes in both horizontal and vertical by using a variable chamfer. An alternative magnet design was then proposed with parallel gap and distributed conductors on the pole to create the required field variation. This solution requires about 40 conductors along the pole and much more power than the gap shaping solution. We expect a much better tune constancy even without variable chamfer. We can think about an "hybrid" magnet with parallel gap at small radii and gap shaping afterward. Such a solution could take advantages of both solutions.

This paper presents an alternative design of the magnet for the RACCAM project. The aim of this collaboration is to study and

**Accelerating a Cyclotron 18 MeV Proton Beam by a SCDTL Linac**

L. Picardi, C. Ronsivalle (ENEA C. R. Frascati) P. Panichelli, G. Prete, F. Romano, G. Valentini (SPARKLE S.r.l.)

SPARKLE company is setting up in the south of Italy (Casarano) a new cyclotron facility based on a 18 MeV, 150 uA IBA Cyclone 18/9. The aim is to create a multidisciplinary research site for the medical applications of accelerators. The main activity will be the production of standard and new radionuclides, by internal targets and one external beam line. Another opposite beam line has been reserved for low current proton irradiations for radiotherapy studies, and a linac booster between 18 and 24 MeV was designed and built to this end. The beam line, which focuses and matches the beam to the linac, includes a chopping system to synchronize the beam to the pulsed linac and to collect 99% of the beam not synchronous to the linac. The linac uses a 3 GHz SCDTL structure powered by a magnetron modulator system. In the paper we report an overview of the beam line, component design, and tests.

SPARKLE company is setting up in the south of Italy (Casarano) a new cyclotron facility based on a 18 MeV, 150 uA IBA Cyclone 18/9. The aim is to create a multidisciplinary

**Lifetime Studies for Polarized and Unpolarized Protons in COSY**

S. A. Martin, B. Lorentz, D. Prasuhn, F. Rathmann, R. Schleichert, H. Stockhorst (FZJ) A. Garishvili, A. N. Nass, E. Steffens (University of Erlangen-Nurnberg, Physikalisches Institut II) P. Lenisa, M. Statera (INFN-Ferrara)

The PAX Collaboration is planning experiments using polarized Antiprotons. The only experimentally proven method so far which could lead to the production of polarized antiprotons is the spin-filtering. In particular, spin-filtering has been used to generate polarized protons in an experiment at the Heidelberg TSR\*. In order to optimize spin-filtering for the production of polarized antiprotons dedicated experiments are planned at COSY with protons and AD (CERN) with antiprotons. The experimentation at COSY has already started in 2007. A decisive experiment has been performed to settle a long controversy about the role of electrons in the polarization buildup by spin-filtering. Instead of studying the polarization buildup in an initially unpolarized beam, the inverse situation was investigated by observation of depolarization of an initially polarized beam. For the first time the electrons of the electron cooler have been used as a target to study their depolarizing effects on the stored beam. At the same time a series of machine experiments have been performed to study the beam lifetime at different energies.

The PAX Collaboration is planning experiments using polarized Antiprotons. The only experimentally proven method so far which could lead to the production of polarized antiprotons is the spin-filtering. In particular, spin-filtering has been used to

\*F. Rathmann et al., Phys. Rev. Lett. 71, 1993, p.1379

### Tune Stabilized Non-Scaling FFAG Lattices

Tune stabilized non-scaling FFAG lattices can be an interesting solution for various applications. They allow to obtain small orbit excursion and to simplify the magnet geometry with respect to scaling FFAG machines. The chromaticity close to zero al-

lows to avoid integer resonance crossing to minimize emittance increase during acceleration. Various lattice designs are compared and chromaticity correction and its effect on dynamical aperture is shown. Prospects for application in hadrontherapy in the framework of PAMELA project are discussed.

**J. Pasternak**, M. Aslaninejad (Imperial College of Science and Technology, Department of Physics) D. J. Kelliher, S. Machida (STFC/RAL/ASTeC) **J. Pasternak**, J. K. Pozimski (STFC/RAL) K. J. Peach, S. L. Sheehy, H. Witte, T. Yokoi (JAI)

FR5REP098

### Status of the JINR FLNR Cyclotrons

The current status of the JINR FLNR cyclotrons and plans of their modernization are reported. At present time, four isochro-

nous cyclotrons: U400, U400M, U200 and IC100 are under operation at the JINR FLNR. The U400 and the U400M are the basic cyclotrons that are under operation about 6000 and 3000 hours per year correspondingly. Both the accelerators are used in DRIBS experiments to produce and accelerate exotic very neutron-rich isotopes of light elements such as  $^6\text{He}$  and  $^8\text{He}$ . The U400 (pole diameter of  $D=4$  m) is designed to accelerate ion beams of atomic masses from 4 to 209 to maximum energy of 26 MeV/u for synthesis of the new super heavy elements and other physical experiments. The U400M cyclotron ( $D=4$  m) is used to accelerate ions of elements from Li to Ar up to 50 MeV/u and heavier ions such as  $^{48}\text{Ca}$ ,  $^{86}\text{Kr}$ ,  $^{136}\text{Xe}$ , up to 6 MeV/u after recent modernization. The U200 cyclotron ( $D=2$  m) is used to produce isotopes by using He ions with energies about 9 MeV/u, modernization of the cyclotron injection is planned. Modernized IC100 accelerator ( $D=1$ m) is used to produce track membranes and carrying out experiments in solid-state physics by using Ar, Kr and Xe ions at energies of 1.2 MeV/u.

**I. V. Kalagin**, S. N. Dmitriev, B. Gikal, G. Gulbekyan (JINR)

FR5REP099

### Coupling Resonance $Q_x-Q_y=0$ and Its Correction in Axial Injection Channel of the Cyclotron

In axial injection channels of FLNR JINR cyclotrons the axial symmetric ion beam is formed just after the analyzing bending

magnet. This gives an opportunity to use for beam focusing at vertical part of the channel solenoidal magnetic lenses only. During the motion of intense axial symmetric beam in the longitudinal magnetic field of solenoids and cyclotron the transverse tunes  $Q_x$ ,  $Q_y$  coincide. In this case the small disturbance of beam axial symmetry leads to excitation of coupling resonance  $Q_x-Q_y=0$  due to beam self-fields. The influence of the resonance results in significant asymmetry of the transverse beam emittances. The magnitude of this asymmetry is evaluated within the framework of moments method and is in a good agreement with one obtained in the macro-particles simulation. The correction of resonance by means of the normal quadrupole lens is proposed.

**N. Yu. Kazarinov** (JINR)

FR5REP100

### Screening of Optical Elements in C400 Axial Injection Beam Line

N. Yu. Kazarinov, V. Aleksandrov, V. Shevtsov, A. Tuzikov (JINR)  
Y. Jongen (IBA)

C400 is compact superconducting cyclotron for hadron therapy. The permissible level of the transverse magnetic field at the horizontal part of axial injection beam line of a cyclotron is about 10 Gauss. At the same time the C400 magnetic field is about 500 Gauss in magnitude at the places of the ion sources, vertical bending magnet and quadrupole lens location. Thereby the screening of these beam-line elements is needed. The 3D OPERA model of the cyclotron and channel elements is used for this purpose.

### Axial Injection Beam Line of C400 Superconducting Cyclotron for Carbon Therapy

N. Yu. Kazarinov, V. Aleksandrov, V. Shevtsov, A. Tuzikov (JINR)  
Y. Jongen (IBA)

The cyclotron can accelerate all ions with charge to mass ratio 0.5. Protons are accelerated as single charge  $2H^+$  molecules and extracted by stripping at 270 MeV. All other ions are extracted by an electrostatic deflector at 400 MeV/u. The final layout of the axial injection beam line of C400 cyclotron is given. Two ion sources for production of  $^{12}C^{6+}$  ions and Alphas beams are located at the horizontal part of the channel before both side of the combination vertical magnet. The third ion source for the production of  $2H^+$  is placed in straight line on the vertical axis. The rotational symmetry of the beam is reestablished with the help of one quadrupole lens placed just after analyzing magnet. The beam focusing at the vertical part of the channel is provided by three solenoidal lenses instead of four quadrupoles used in the previous version of beam line. The results of simulation of ion beams transport in the axial injection channel are presented.

### Developments for High Intensity Proton Beam Acceleration at RCNP Cyclotron Facility

M. Fukuda, K. Hatanaka, H. N. Kawamata, M. Kibayashi, T. Saito,  
H. Tamura, T. Yorita (RCNP)

In order to meet requirements from research in nuclear physics and industrial applications using secondarily produced particles such as neutrons and muons, an upgrade program of the RCNP cyclotron facility for increase of 392 MeV primary proton beam intensity is in progress. A 2.45 GHz ECR ion source using a set of permanent magnets was designed for high intensity proton beam production. Arrangement of the magnets and extraction electrodes was optimized by using magnetic field and particle orbit simulation codes of TOSCA and IGUN. Performance test of the ion source has been started recently. A flat-top acceleration system was developed for the K140 AVF cyclotron to improve the intensity and quality of the pre-accelerated beam for the K400 ring cyclotron. Further modification of the AVF cyclotron RF system is proceeding to achieve the flat-top acceleration of 65 MeV protons, injected into the ring cyclotron for acceleration up to 392 MeV. The center region of the AVF cyclotron was also improved to increase beam transmission. In this paper, present status of the developments for high intensity proton beam acceleration will be presented.



**Muon Cooling in a Racetrack FFAG Using Superfluid Helium Wedge Absorbers**

An FFAG lattice with racetrack-shape has been designed to cool muon beams. The ring has straight sections with FFAG magnets. Wedge absorbers using superfluid helium and RF cavities are installed to the straight section. This paper describe the first result of simulation study.

**A. Sato** (Osaka University) S. Ishimoto (KEK)

FR5REP104

**Phase Rotation in the Six-Sector PRISM-FFAG**

An (Fixed Field Alternating Gradient) ring which consists of six PRISM-FFAG magnets was constructed at RCNP, Osaka University. The technique of phase rotation to make a mono-energetic beam has been studied by using this ring and alpha particles. This paper reports the final results of this project.

**A. Sato**, M. Aoki, Y. Arimoto, T. Itahashi, Y. Kuno, Y. Nakanishi, M. Y. Yoshida (Osaka University) Y. Iwashita (Kyoto ICR) Y. Kuriyama, Y. Mori (KURRI) A. Kurup (Imperial College of Science and Technology, Department of Physics) C. Ohmori (KEK/JAEA)

FR5REP105

**Sawtooth RF System with High Field Gradient for PRISM-FFAG**

PRISM is on the way to build a future intense low energy muon source, which combines mono chromaticity and high purity. In the PRISM project, an FFAG is used as the phase rotator to achieve the monochromatic muon beams. In order to achieve required energy spread after the phase rotation, a sawtooth RF is necessary. This paper describes sawtooth RF studies with a high field-gradient RF using a Magnetic Alloy (MA) cavity for the PRISM project.

**A. Sato**, M. Aoki, Y. Arimoto, T. Itahashi, Y. Kuno, Y. Nakanishi, M. Y. Yoshida (Osaka University) Y. Iwashita (Kyoto ICR) Y. Kuriyama, Y. Mori (KURRI) C. Ohmori (KEK/JAEA)

FR5REP106

**Modelling the ALICE Electron Beam Properties through the EMMA Injection Line Tomography Section**

EMMA (Electron Machine with Many Applications) is a prototype non-scaling electron FFAG currently under construction at Daresbury Laboratory. The energy recovery linac prototype ALICE will operate as its injector, at a reduced the energy of 10 to 20 MeV, compared to its nominal energy of 35 MeV. An injection line has been designed which consists of a dogleg to extract the beam from ALICE, a matching section, a tomography section and some additional dipoles and quadrupoles to transport and match the beam to the entrance of EMMA. This injection line serves both as a diagnostic to measure the properties of the beam being injected into EMMA and also a useful diagnostic tool for ALICE operation. This paper details the simulations undertaken of the electron beam passing through the matching and tomography sections of the EMMA injection line, including the effect of space charge. This will be an issue in the energy range at which this diagnostic is being operated when combined with high bunch charge. A number of different scenarios have been modelled and an attempt made to compensate for the effects of space charge in the matching and tomography sections.

**D. J. Holder** (Cockcroft Institute) B. D. Muratori (STFC/DL/ASTeC)

FR5REP107

FR5REP108

**EMMA Diagnostic Line**

**B. D. Muratori**, J. K. Jones, S. L. Smith, S. I. Tzenov (STFC/DL/ASTeC)

EMMA (Electron Machine with Many Applications) is a prototype non-scaling electron FFAG to be hosted at Daresbury Laboratory. NS-FFAGs related to EMMA have an unprecedented potential for medical accelerators for carbon and proton hadron therapy. It also represents a possible active element for an ADSR (Accelerator Driven Sub-critical Reactor). This paper will summarize the design of the extraction / diagnostic transfer line of the NS-FFAG. In order to operate EMMA, the energy recovery linac ALICE shall be used as injector and the energy will range from 10 to 20 MeV. Because this would be the first non-scaling FFAG, it is important that as many of the bunch properties are studied as feasible, both at injection and at extraction. To do this, a complete diagnostic line was designed consisting of a tomography module together with several other diagnostic devices including the possibility of using a transverse deflecting cavity. Details of the diagnostics are also presented.

EMMA (Electron Machine with Many Applications) is a prototype non-scaling electron FFAG to be hosted at Daresbury Laboratory. NS-FFAGs related to EMMA have an

FR5REP109

**EMMA Commissioning**

**B. D. Muratori**, S. L. Smith, S. I. Tzenov (STFC/DL/ASTeC) J. S. Berg (BNL)

EMMA (Electron Machine with Many Applications) is a prototype non-scaling electron FFAG to be hosted at Daresbury Laboratory. NS-FFAGs related to EMMA have an unprecedented potential for medical accelerators for carbon and proton hadron therapy. It also represents a possible active element for an ADSR (Accelerator Driven Sub-critical Reactor). This paper summarises the commissioning plans for this machine together with the major steps and experiments involved along the way. A description of how the 10 to 20 MeV beam is achieved within ALICE is also given, as well as extraction from the EMMA ring to the diagnostics line and then dump.

EMMA (Electron Machine with Many Applications) is a prototype non-scaling electron FFAG to be hosted at Daresbury Laboratory. NS-FFAGs related to EMMA have an

FR5REP110

**Magnetic Measurements of the RACCAM Prototype FFAG Dipole**

**M. J. Leray**, F. Forest (Sigmaphi) F. Meot (CEA) J. Pasternak (LPSC)

The paper presents the magnetic measurements of the RACCAM prototype FFAG dipole, manufactured by SIGMAPHI for the Raccam ANR Medical FFAG project. This magnet prototyping work, started early 2006, is being performed in collaboration between the IN2P3/LPSC Laboratory team and SIGMAPHI. This paper describes the magnetic measurement results and comparison with Tosca simulation.

The paper presents the magnetic measurements of the RACCAM prototype FFAG dipole, manufactured by SIGMAPHI for the

FR5REP111

**Beam Loss by Lorentz Stripping and Vacuum Dissociation for the CIAE 100 MeV H<sup>-</sup> Compact Cyclotron**

**T. J. Zhang**, F. P. Guan, X. L. Jia, S. M. Wei, J. Q. Zhong (CIAE) Y. J. Bi (TUB) G. Dutto, G. H. Mackenzie, L. W. Root (TRIUMF) J. Z. Wang (Department of Physics, Central China Normal University)

There is increasing interest in high current compact H<sup>-</sup> cyclotrons for RIB, isotope production or as injectors for sub-critical reactor testing facilities. For compact cyclotrons, a practical limit on the output energy, to prevent significant Lorentz stripping and resulting activation, is ~100 MeV. Vacuum dissociation is another critical problem, because a compact structure and small parts inside the tank make high vacuum challenging. This paper

There is increasing interest in high current compact H<sup>-</sup> cyclotrons for RIB, isotope production or as injectors for sub-critical reactor testing facilities. For compact cyclotrons, a practical limit on the output energy, to prevent significant Lorentz stripping and resulting activation, is ~100 MeV. Vacuum dissociation is another critical

describes how Lorentz stripping and vacuum dissociation were calculated for our "CYCIAE-100" under construction. In order to take into account non uniform magnetic fields and vacuum, losses were calculated by numerically integrating loss equations along tracked orbits, as these were being calculated by the beam dynamics code. To verify the code, losses derived with field and vacuum data from the TRIUMF 500 MeV cyclotron were compared with measurements. For the CYCIAE-100 cyclotron we predict that electromagnetic losses will account for less than 0.3% of total beam, vacuum losses for less than 0.58%, with peak magnetic fields up to 1.35T and average vacuum up to  $5 \cdot 10^{-8}$  Torr.

### Analysis of Orbits in Combined Function Magnets

Fixed-Field Alternating-Gradient (FFAG) accelerators span a large range of momenta and have markedly different reference orbits

S. R. Koscielniak (TRIUMF)

for each momentum. In the non-scaling (NS) versions proposed for rapid acceleration, the orbits are geometrically dissimilar. In particular, none of the orbits within bending magnets are arcs of circles and this complicates tune calculation. One approach to NS-FFAG design is to employ alternating combined-function magnets. Second generation NS-FFAGs designs attempt to mitigate the variation of betatron tunes; and careful calculation of orbits and tunes is essential. Starting from an analytic magnetic potential for the combined-function magnet, we elucidate expressions for orbit calculation which are second order in the cyclotron motion and arbitrary order in the momentum (no expansion is used).

### AG Focusing in the Thomas Cyclotron of 1938

It is sometimes asserted that Thomas's proposal to provide additional axial focusing in cyclotrons (to enable them to operate

M. K. Craddock (UBC & TRIUMF)

isochronously at relativistic energies) by introducing an azimuthal variation in the magnetic field was an early example of alternating-gradient focusing. While Thomas cyclotrons certainly exhibit alternating field gradients, it is shown that the alternating focusing produced is very much weaker than the edge focusing (everywhere positive) arising from orbit scalloping.

### FFAGs and Cyclotrons with Reverse Bends

This paper describes tracking studies of FFAGs and radial-sector cyclotrons with reverse bends using the cyclotron equilibrium

M. K. Craddock (UBC & TRIUMF) Y.-N. Rao (TRIUMF)

orbit code CYCLOPS. The results for FFAGs confirm those obtained with lumped-element codes, and suggest that cyclotron codes will prove to be important tools for evaluating the measured fields of FFAG magnets. The results for radial-sector cyclotrons show that the use of negative valley fields would allow axial focusing to be maintained, and hence allow intense cw beams to be accelerated, to energies of the order of 10 GeV.

**Recent Beam Studies of the FFAG-ERIT System for BNCT**

K. Okabe (University of Fukui, Faculty of Engineering) Y. Mori (KURRI) M. Muto (FFAG DDS Research Organization)

Institute). And the first beam test was successfully completed in March 2008. In this poster, recent status of beam studies will be presented.

The accelerator-based neutron source using ERIT (Energy/emittance Recovery Internal Target) scheme has been constructed at KURRI (Kyoto University Research Reactor

**A Compact High-Resolution Isobar Separator for the CARIBU Project**

C. N. Davids, D. Peterson (ANL)

Laboratory. Fission fragments from a  $^{252}\text{Cf}$  source are thermalized, cooled, and accelerated to 50 keV. The small longitudinal emittance of this cooled beam allows the use of pure magnetic dispersion for mass analysis. Using two  $60^\circ$  bending magnets, two electrostatic quadrupole doublets, and two electrostatic quadrupole singlets in a symmetric combination, a first-order mass resolution of 22,400 is calculated. Aberration correction up to 5th order is accomplished by means of two electrostatic hexapole singlets and a 48-rod electrostatic multipole lens with hexapole, octupole, decapole, and dodecapole components. The fields with critical tolerances are the quadrupole singlets ( $\pm 1 \times 10^{-3}$ ) and the hexapole component of the multipole ( $\pm 2 \times 10^{-3}$ ). Ion-optics calculations were performed using the program COSY INFINITY\*\*. The resulting ion trajectories and mass spectra will be presented. All electrostatic elements have been constructed, and delivery of the magnets is expected in early 2009. A progress report on installation and commissioning will be presented.

\*See invited talk by R. Pardo at this conference.

\*\*Version 8.1, M. Berz et al., (2002).

We have designed a compact high-resolution isobar separator for CARIBU\* at the ATLAS accelerator facility at Argonne National

**Rare Ion Beam Facility at Kolkata – Present State of Development**

A. Bandyopadhyay, S. Basak, D. Bhowmick, A. Chakrabarti, P. S. Chauhan, S. Dechoudhury, J. S. Kainth, P. Karmakar, T. Kundu Roy, T. K. Mandi, M. Mondal, V. Naik, H. K. Pandey, D. Sanyal (DAE/VECC)

initiated with an eye to produce RIBs using the photo-fission route. The RIBs will be ionized, mass separated and the RIB of interest will be accelerated using a four rod Radio Frequency Quadrupole from 1.7 to 98 keV/u. The posts, vanes and base plate of the RFQ have been machined from OFC copper and the cavity is made from steel with its inner surface plated with copper. Oxygen beam of charge state  $5+$  has already been accelerated with an efficiency of around 90% through the RFQ. The first IH LINAC will accelerate RIBs up to about 186 keV/u. The octagonal shape LINAC cavity is made from explosively bonded copper clad steel. Low power tests of the LINAC is encouraging - the beam test is scheduled for January 2009 and the results of which will be reported. The R&D efforts in various areas of this project will be discussed in this paper. Special emphasis will be given to the development of the RFQ and LINAC.

An ISOL post-accelerator type of Rare Ion Beam (RIB) facility is being developed at our centre. The facility will use light ion beams from the K=130 cyclotron for producing RIBs using suitable thick targets. Also, development of an electron LINAC has been

**An Alternative Ion-Optical Mode of the Recuperated Experimental Storage Ring (RESR)**

The main purpose of the Recuperated Experimental Storage Ring (RESR) in the FAIR project is the accumulation of antiprotons coming from the Collector Ring (CR), where they are stochastically pre-cooled. The accumulation scheme in the RESR foresees longitudinal stacking in combination with stochastic cooling. The stochastic cooling process strongly depends on the slip factor  $\eta$  of the ring. Presently, the RESR is designed to operate with small slip factor of 0.03. In order to increase the flexibility for optimized stochastic cooling a new alternative ion-optical mode with higher slip factor of 0.11 has been calculated in such a way, that the RESR can be operated with a fixed magnetic structure in both modes. The influence of the high-order chromaticity on the particle motion has been investigated and a chromaticity correction scheme is applied. The variation of the transition energy over the momentum acceptance was examined and the possibility of its correction is described.

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FR5REP118

**REX-ISOLDE Facility and the Importance of Beam Time Structure to Data Acquisition and Processing - the Experimentalist's View**

The REX-ISOLDE radioactive ion beam facility at CERN makes great demands also on the experimentalists due to its specific duty cycle, the time structure with short beam pulses, intensities and so on. This paper describes the experimentalist's point of view, focusing on the special circumstances arising from the beam time structure and considerations in data acquisition of how to obtain sufficient and correct statistics. In particular, the case of Coulomb excitation experiments, where a large total cross section is ultimately desired, is studied in greater detail.

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FR5REP119

**Beam Funneling in the Facility for Rare Isotope Beams**

The Facility for Rare Isotope Beams (FRIB) will provide intense beams of short-lived isotopes for fundamental research in nuclear structure and nuclear astrophysics. Operation of the facility requires intense uranium primary beams. At the present time acceleration of two simultaneous charge states of uranium from a single ion source is needed to achieve the required intensity. Three schemes are considered for funneling the beams from two sources as an alternate solution. One is the traveling wave RF kicker for merging of bunched beams extracted from ECR ion sources. Another one implements the idea of utilizing an RFQ for beam merging\*, which can be used after preliminary acceleration of both beams. The third approach assumes usage of a conventional standing-wave RF kicker. Parameters of all three schemes are compared and analyzed.

**Y. K. Batygin**, F. Marti (NSCL)

\*R. H. Stokes and G. N. Minerbo, AIP Conference Proceedings 139 (1985), p.79.

FR5REP120

**Effect of Space Charge on Extraction Efficiency of Ions in Cyclotron Gas Stopper**

Cyclotron gas stopper is a newly proposed device to stop energetic ions in a high pressure helium gas and to transport them in a singly charged state with a gas jet to a vacuum region. Radioactive ions are slowed down by gas collisions inside the field of a weakly focusing cyclotron-

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FR5REP121

type magnet and extracted via interaction with the Radio Frequency field of sequence of concentric electrodes (RF carpet). The present study focuses on a detailed understanding of space charge effects in the central ion extraction region. Such space charge effects originate from the ionization of the helium gas during the stopping of the ions and are the cause for beam rate limitations. Particle-in-cell simulation of two-component (electron-helium) plasma interacting via Coulomb forces were performed in a field created by ionized ions. Simulation results indicate beam rate capabilities and efficiencies far beyond those achieved with linear gas cells presently used to stop projectile fragments.

### Holifield Radioactive Ion Beam Facility (HRIBF) Development Status

D. W. Stracener, J. R. Beene, D. Dowling, R. C. Juras, Y. Liu, M. J. Meigs, A. J. Mendez, P. E. Mueller, J. W. Sinclair, B. A. Tatum (ORNL)

HRIBF produces high-quality beams of short-lived radioactive isotopes for nuclear science research, and is currently unique worldwide in the ability to provide neutron-rich fission fragment beams post-accelerated

to energies above the Coulomb barrier. HRIBF is undergoing a multi-phase upgrade. Phase I (completed 2005) was construction of the High Power Target Laboratory to provide the on-going Isotope Separator On-Line development program with a venue for testing new targets, ion sources, and radioactive ion beam (RIB) production techniques with high-power ORIC beams. Presently under way is Phase II, the Injector for Radioactive Ion Species 2, a second RIB production station that will improve facility reliability and accommodate new ion sources, RIB production, and RIB purification techniques, including laser applications. The Phase III goal is to substantially improve facility performance by replacing or supplementing the Oak Ridge Isochronous Cyclotron production accelerator with either a high-power 25-50 MeV electron accelerator or a high-current multi-beam commercial cyclotron. Either upgrade is applicable to R&D on isotope production for medical or other applications.

### Beam Commissioning of Separated Function RFQ Accelerator

J. E. Chen, J. X. Fang, Z. Y. Guo, Y. R. Lu, Z. Wang, K. Zhu (PKU/IHIP)

The beam commissioning of Separated Function RFQ(SFRFQ) accelerator, which can gain high accelerating efficiency and enough focusing strength for low energy high current beam, is presented.

In order to demonstrate the feasibilities of this novel accelerator, a prototype cavity was designed and constructed. The O<sup>+</sup> beam was accelerated from 1MeV to 1.7MeV by SFRFQ cavity. A triplet was used to match the transverse beam emittance from 1MeV ISR-RFQ -10-00 to SFRFQ acceptance. A capacitance frequency tuning system was designed to keep SFRFQ cavity work at the same frequency of ISR RFQ. The whole accelerator system and the beam test result are presented in this paper.

### Beam Delivery and Future Initiatives at the ISAC Radioactive Ion Beam Facility

M. Trinczek, F. Ames, R. A. Baartman, P. G. Bricault, M. Dombisky, K. Jayamanna, J. Lassen, R. E. Laxdal, M. Marchetto, L. Meringa, A. C. Morton, V. A. Verzilov, F. Yan (TRIUMF)

The ISAC facility, located at TRIUMF, first began delivering radioactive ion beams (RIBs) in 1998, added post-accelerated beam capability in 2001, and is regarded as one of the premiere RIB facilities in the world. The

existing constraints on RIBs of  $Z < 83$  and accelerated beams of  $A/q < 30$  with energies limited to 5MeV/u are being

addressed. A charge-state booster for RIBs has been commissioned to alleviate the  $A/q < 30$  restriction and has successfully delivered multi-charge beams through the ISAC accelerators. The 5MeV/u license limit will be removed once an on-line beam monitor is commissioned, allowing beams of up to 11MeV/u to be delivered presently, and increased to over 20MeV/u when the next accelerator phase is installed. In 2008, an actinide target was used to produce RIBs of  $Z > 82$ ; this successful test was performed on a uranium target with yields measured and radiation safety monitored. A new Beam Delivery group has been formed to integrate all aspects of RIB production, which has led to improved efficiency and greater experimental results. These new capabilities will be presented, showing how 2009 promises to be both an exciting and productive year at ISAC.

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