Budker Institute of Nuclear Physics

Siberian Branch of Russian Academy of Sciences

The 53th ICFA Advanced Beam Dynamics Workshop on Energy Recovery Linacs "ERL-2013"

9 -13 September, 2013

ABSTRACTS BOOK

Novosibirsk 2013

Dear Colleagues,

ERL 2013 will take place at Budker Institute of Nuclear Physics (Novosibirsk, Russia). Particle accelerators have become one of the main fields of activity of our Institute. In particular, we have an ERL with one-, two- and four-orbit operation modes and a high-power terahertz free electron laser user facility on it. Still, prospective applications of ERLs require far more advanced and challenging installations. Such applications comprise short-duration high-brightness x-ray sources, high-power free electron lasers, nuclear physics facilities with internal target, etc. The new ERL projects for these applications necessitates further development of beam dynamics, electron guns, RF systems and other technological issues. The previous ERL workshops made a significant contribution to this progress. We hope that ERL 2013 will also provide great possibilities for fruitful discussions and important personal contacts of leading scientists in our field.

Sincerely,
Gennady N. Kulipanov, Academician,
International Organizing Committee Chair,
Budker INP, Novosibirsk

Scope

The workshop continues the chain of the ERL workshops (the latest was the 50th ABDW ERL 2011, KEK, Japan). The aim of the workshop is further development of ERL physics, technology and applications. In particular, the issues of beam stability, halo, emittance requirements and limitations, subsystems (RF, injectors, lattices) have to be considered. Also, the ERL applications, operation experience and project statuses have to be discussed.
There will be **six categories** in the workshop as follows:

- Electron Sources
- Beam Dynamics
- Superconducting RF
- Instrumentation and Controls
- Halo and Beam Losses
- Applications of ERL

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Novosibirsk is called the capital of Siberia. It is the biggest city in the area between the Urals and the Pacific Ocean and is the third largest city in Russia after Moscow and St.Petersburg with a population of about 1,4 million people. Novosibirsk was founded in 1893. It is located on both sides of the Siberian river Ob and its history is closely connected with the construction of the Trans-Siberian railroad Moscow-Vladivostok. Today Novosibirsk is an important industrial, agricultural, transport, cultural and scientific center. The city has the biggest Siberian up-to-date airport Tolmachevo, a river port and railway station.

Akademgorodok, which means "Scientific Town" in Russian, is a part of Novosibirsk - is a world-known scientific center. Akademgorodok - the Siberian city of science - is 40 kilometers south of the center of Novosibirsk. It was founded in 1957 and was intended to be an interdisciplinary research center. Physicists, chemists, mathematicians, archaeologists, electronics specialists, philosophers, geologists and geneticists are its residents. Akademgorodok is an agglomeration of a large number of scientific and educational institutions: Novosibirsk State University, one of Russia's three leading universities, Physics-Mathematics School, Higher College of Informatics, fifty scientific research and design institutes of Siberian Branch of Russian Academy of Science are among them. Most of the research Institutes are located along Lavrentiev Prospect - the street was listed in the Guinness Book of World Records as the "most scientific street" in the world.

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Plenary Sessions

Applications of ERL

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Commissioning Status and Further Development of the Novosibirsk Multiturn ERL

Oleg A. Shevchenko, Vladimir Sergeevich Arbuzov, Evgeny Dementyev, Boris Dovzhenko, Yaroslav V. Getmanov, Eduard Iosifovich Gorniker, Boris Aleksandrovich Knyazev, Evegeniy I. Kolobanov, Alexey Anatolyevich Kondakov, Victor Kozak, Evgueni Kozyrev, Sergey Alexandrovich Krutikhin, Vitaly V. Kubarev, Gennady N. Kulipanov, Eduard Kuper, Igor Kuptsov, Grigory Yakovlevich Kurkin, Lev E. Medvedev, Leontii Mironenko, Vladimir Kirillovich Ovchar, Victor Petrov, Andrey Pilan, Vasiliy M. Popik, Vladimir Valeryevich Repkov, Tatiana Vladimirovna Salikova, Mikhail A. Scheglov, Igor Sedlyarov, Stanislav S. Serednyakov, Alexander Skrinsky, Sergey Tararyshkin, Vladimir G. Tcheskidov, Alexey G. Tribendis, Maksim G. Vlasenko, Pavel Vobly, Vladimir Volkov (BINP SB RAS, Novosibirsk), Nikolay Vinokurov (BINP SB RAS, Novosibirsk)

The Novosibirsk ERL is used as a source of electron beams for the powerful Free Electron Laser. It is based on the normal conducting RF structure which operates in CW mode. The third stage of this facility which is the first in the world four-turn ERL has been commissioned recently. More than 90% of electrons were transported to the beam dump, which allowed to increase the average beam current up to 5 mA. The obtained parameters are sufficient to get lasing at the third stage FEL which will be installed at fourth track in the nearest future. In this paper we report the commissioning status and talk about further development of the Novosibirsk ERL and FEL facility.

ERL-based Electron-Ion Collider eRHIC at BNL

Vladimir N. Litvinenko (BNL, Upton, Long Island, New York)

In this paper, we describe our planned future electron-ion collider (EIC), based on the existing Relativistic Heavy Ion Collider (RHIC) hadron facility and the to-be-built electron-beam ERL with up-to six passes through its SRF linacs. Adding a polarized ERL-driven electron-beam with energy tunable within the 5-30 GeV range colliding with variety of species in the existing RHIC-accelerator complex, from polarized protons with a top energy of 250 GeV, to heavy fully striped ions with energies up to 100 GeV/u will turn it into most-advanced electron-ion collider with luminosity ~10E34 cm-2sec-1. We also describe an FFAG-based option for eRHIC recirculating arcs.

A Proposed ERL Test Facility at CERN

Erk Jensen, Oliver Sim Brüning, Rama Calaga, Alessandra Valloni (CERN, Geneva)

An ERL test facility for an energy range of 300 to 400 MeV and beam currents up to 100 mA would be an ideal test bench for superconducting RF cavities and for challenging beam dynamics, it could become an electron-cooler for LHC and could provide high power test beams. The proposed facility operating at 801 MHz would allow validation with beam of a proposed LHC harmonic system, the conceptual operational demonstration of an ERL for LHeC or other future accelerators. An initial concept consists of a 5 MeV injector, 2 antiparallel linacs (as proposed for LHeC) with 75 MV, 4-cavity cryomodules; built-in flexibility would allow different configurations with up to 4 cryomodules.

Overview of the LHeC Design Study at CERN

Oliver Sim Brüning (CERN, Geneva)

The Large Hadron electron Collider (LHeC) at CERN offers the unique possibility of exploring lepton-proton collisions in the TeV Center of Mass (CM) range by further utilizing the existing LHC infrastructure. This paper summarizes two different design options: a Ring-

Ring and a Linac-Ring option using a linac in energy recovery operation mode and outlines the main challenges and next steps for the project.

Radiation Monitoring at Novosibirsk FEL

Tatiana Vladimirovna Salikova, Michael Petrichenkov, Anatoly Repkov, Oleg A. Shevchenko, Nikolay Vinokurov (BINP SB RAS, Novosibirsk)

The system of radiation diagnostics controls levels of radiation in the accelerator hall and in the adjacent rooms where works FEL personnel. The system provides radiation safety of personnel. The software performs data visualization and records the measured data into the database. The special ionization chambers installed in the accelerator hall. They keep track of the beam losses in the vacuum chamber, this information is used for correction of beam orbit. These sensors detect the induced radioactivity. Based on these data, we watch the degradation of the material of construction under the action of radiation.

Novosibirsk ERL-based FEL as User Facility

Gennady N. Kulipanov, Vitaly V. Kubarev, Vasiliy M. Popik, Mikhail A. Scheglov, Oleg A. Shevchenko, Nikolay Vinokurov (BINP SB RAS, Novosibirsk), Boris Aleksandrovich Knyazev (BINP SB RAS, Novosibirsk)

Novosibirsk ERL operates for users with two FELs now. Terahertz FEL, installed on the first orbit, provides radiation in the wavelength range 120 - 240 micron with the average power up to .5 kW and peak power up to 1 MW. The far infrared FEL, installed on the second orbit, generates 40 - 80 micron radiation with the same power. Nitrogen-loaded beamlines transport radiation to user halls. Six stations are in use for biologists, chemists and physicists of several research institutions. Status and results of some user's research are described.

Outline of Beamlines at cERL

Shunsuke Nozawa, Hiroshi Kawata (KEK, Ibaraki), Ryoichi Hajima, Ryoji Nagai (JAEA, Ibaraki-ken), Shin-ichi Adachi (KEK, Tsukuba), Shin-ichi Kimura (Osaka University, Osaka)

In order to demonstrate required accelerator technologies in the 3 GeV ERL light source, cERL, which is now under construction, is starting the commissioning of an injector part from the April of 2013. Along with the operation, the quantum beam obtained from cERL is providing to user experiments. In 2014-15, the construction of beamlines for advanced researches using x- and gamma-rays and terahertz (THz) beam will be starting. Due to an inverse Compton scattering (ICS) of laser pulses on relativistic electron bunches in a ring of the cERL, ultra-short x-ray is produced. The 100 fs x-ray beam from cERL, which is generated by the ICS using high-power and ultra-short laser pulses, is significantly benefit for researches in the field of ultrafast science. On the other hand, high-flux x- and gamma-rays, which is generated by the ICS using an optical build-up cavity and high-frequency laser pulses, is an ideal light source for x-ray imaging and nuclear resonance fluorescence. Furthermore, the coherent synchrotron radiation (CSR) from electronic bunch in cERL can be used as a novel light source for researches of physical properties, because it has high intensity in a THz region. In addition to the hard x-ray beamline, construction of the THz beamline is also being scheduled. At a poster, we will present the outline of the design of these two beamlines and expected applications.

ERL Requirements for X-ray Optics-Free FEL Oscillator

Vladimir N. Litvinenko, Johan Bengtsson, Yue Hao, Yichao Jing, Dmitry Kayran, Dejan Trbojevic (BNL, Upton, Long Island, New York)

We present a comprehensive list of requirements for ERLs required for X-ray FEL oscillator. We discuss both the main ERL driving a high-gain FEL amplifier as well as ERL generating a feed-back electron beam. A scheme where a third ERL is used to generate a TEM-wiggler field used in the feed-back is also presented.

Feasibility Study of Multi-Turn ERL-Based Synchrotron Light Facility

Alexander N. Matveenko, Terry Atkinson, Alexey Vladimirovich Bondarenko, Yuriy Petenev (HZB, Berlin)

Multi-turn energy recovery linac -based light source is a candidate for the future 4th generation synchrotoron light sources. Using the superconducting linac technology, the Femto-Science-Factory (FSF) will provide its users with ultra-bright photon beams of angstrom wavelength at 6 GeV final beam energy. The FSF is intended to be a multi-user facility and offer a variety of operation modes. In this talk an overview of the magnetic optics design will be given. The focus by the design was on the emittance conservation, analysis of the effects of coherent and incoherent synchrotron radiation, bunch compression (short pulse mode), two-stage injection scheme, and beam instabilities.

Multi-Pass, Multi-Bunch Beam Break-up of ERLs with 9-Cell TESLA Cavities

Si Chen, Jia-er Chen, Liwen Feng, Senlin Huang, Kexin Liu (PKU, Beijing)

In this paper, multi-pass, multi-bunch beam break-up effect of some compact Energy Recovery Linac (ERL) configuration using 9-cell Tesla cavity is discussed. The threshold currents of different cases are investigated and some factors that will influence the threshold currents are discussed.

Status of the MESA Project

Kurt Aulenbacher, Jürgen Diefenbach, Robert Gerd Heine, Felix Schlander (IKP, Mainz)

The Mainz Energy recovering Superconducting Accelerator (MESA) is now being set up at the institute fuer Kernphysik, university of Mainz. MESA is intended to serve as a test bed for multi-turn superconducting ERL's. It also has a strong fundamental physics component, since electron scattering from a "pseudo" internal target will provide a new regime of experimental research. On the other hand, MESA may also be operated as a conventional c.w. accelerator with polarized external beam. The latter mode is foreseen to be used for a precision measurement of the Weinberg angle. The project is still in its conceptional phase, different options for r.f.-systems and lattices will be presented.

Beam Performance Measurement at Compact-ERL Injector

Yosuke Honda, Tsukasa Miyajima (KEK, Ibaraki)

A test accelerator for a future ERL based light source has been constructed in KEK. Commissioning of the injector part has started since April 2013. In order to measure beam performance, a diagnostic beam line has been made at the downstream of the injector. We measured emittance, bunch length, energy spread, etc. This presentation reports the measurement setups and the results.

Beam Dynamics Studies on the Injector of the IHEP ERL-TF with Impact-T Code

Yi Jiao (IHEP, Beijing)

We present the beam dynamics studyies with Impact-T code on the injector of the ERL test facility (TF) in the Institute of High Energy Physics (IHEP), Beijing. Vriable parameters, including drive-laser shapes, DC gun voltage, magnetic strengths and RF cavity phase etc, are varied to optimize the beam emittance at the end of the injector.

Optics Design for the Commissioning of the Compact ERL Recirculation Loop

Miho Shimada, Kentaro Harada, Yukinori Kobayashi, Tsukasa Miyajima, Norio Nakamura (KEK, Ibaraki), Ryoichi Hajima (JAEA, Ibaraki-ken)

Optics design and simulation of the beam dynamics are under consideration for the beam commissioning of the compact ERL circular loop scheduled for December. The beam optics from the electron source to dump is optimized by start-to-end simulation to include the effects of space charge and CSR wake, in which the simulation code of 'General Particle Tracer, GPT' and 'elegant' are utilized in the injector and circulator, respectively. The beam loss caused by field emission of the main superconductive accelerator is also evaluated toward the beam commissioning. The compact ERL is planned to be utilized as a user experiment machine in the near future. The optics is also designed for laser-Compton X-ray source and the bunch compression simulation is performed for CSR source in the THz region. In this presentation, we introduced the current status of the optics design.

Beam Dynamics and CSR Suppression in an ERL-driven X-ray FEL

Vladimir N. Litvinenko, Yue Hao, Yichao Jing (BNL, Upton, Long Island, New York)

In this talk we present a self-consistent concept of ERL generated e-beam to drive an array of X-ray FELs. We use eRHIC multi-pass ERL design to explore all relevant beam dynamics. First, we study effects of incoherent and coherent synchrotron radiation on the e-beam parameters and present the set of parameters providing for the emittance preservation. Second, we present a sing bunch compressing scheme (similar to scheme described in *) with large compression ratio, which suppresses emittance growth caused by CSR. Finally, we present simulation result for soft- and hard-X-ray FELs driven by such electron beam. We compare projected performance of such facility with world's existing and proposed FEL facilities.

*Merger Designs for ERLs, V.N. Litvinenko, R.Hajima, D. Kayran, Nuclear Instruments and Methods in Physics Research A 557 (2006) 165

Cornell High-Power Recirculation Loop

Christopher Mayes (Cornell University (CLASSE), Ithaca, New York)

Over the last decade, Cornell has built and tested the high-power, high-brightness photoinjector (consisting of a DC gun, cryomodule, merger, and beam stop), and has separately prototyped a 6 cavity cryomodule for the proposed 5 GeV Cornell ERL. In further preparation for the high energy ERL, Cornell plans to build a 100 mA, 90 MeV recirculation loop using this existing hardware. This talk will present optics and simulations for this design.

Using Chromaticity to Suppress TBBU in High-Energy ERLs

Vladimir N. Litvinenko (BNL, Upton, Long Island, New York)

Energy recovery linacs (ERLs) are an emerging generation of accelerators promising to revolutionize the fields of high-energy physics and photon sciences. These accelerators combine the advantages of linear accelerators with that of storage rings, and hold the promise of delivering electron beams of unprecedented power and quality. Use of superconducting radio-frequency (SRF) cavities converts ERLs into nearly perfect "perpetuum mobile" accelerators, wherein the beam is accelerated to a desirable energy, used, and then gives the energy back to the RF field. One potential weakness of these devices is transverse beam break-up instability that could severely limit the available beam current. In this paper, I propose a novel method of suppressing these dangerous effects using a natural phenomenon in the accelerators, viz., the chromaticity of the transverse motion.

Start-To-End Beam Dynamic Simulations for Femto-Science-Factory Feasibility Study

Terry Atkinson, Alexey Vladimirovich Bondarenko, Alexander N. Matveenko, Yuriy Petenev (HZB, Berlin)

Design studies for a future multi-turn ERL based light source at HZB are being investigated. The Femto-Science-Factory will provide its users with ultra-bright photons of angstrom wavelength at 6 GeV. The FSF is intended to be a multi-user facility and offer a wide variety of operation modes. A low emittance ~0.1 mkm rad mode will operate in conjunction with a short-pulse ~10 fs mode. This paper reports on the first results of the start-to-end beam dynamic simulations for both modes. Higher order geometric and chromatic aberration terms have been suppressed using both multipole magnets and biased off-crest acceleration. The influence of the collective effects (coherent synchrotron radiation) on the transversal emittance is minimised by adjusting the horizontal phase advance.

Analysis of Injection and Recovery Schemes for a Multi-Turn ERL Based Light Source

Yuriy Petenev, Terry Atkinson, Alexey Vladimirovich Bondarenko, Alexander N. Matveenko (HZB, Berlin)

A multi-turn energy recovery linac -based light source is under discussion. Using the superconducting Linac technology, the Femto-Science-Factory (FSF) will provide its users with ultra-bright photon beams of angstrom wavelength. The FSF is intended to be a multi-user facility and offer a variety of operation modes. The driver of the facility is a 6 GeV multiturn energy recovery linac with a split linac. In this talk we discuss designs of the optic in the linac and compare different schemes of beam acceleration: a direct injection scheme with acceleration in a 6 GeV linac, a two-stage injection with acceleration in a 6 GeV linac, and a multi-turn (3-turn) scheme with a two-stage injection and two main 1 GeV linacs. Construction costs and beam break up instability were the key points for comparison.

Longitudinal Stability of Multiturn ERL with Split Accelerating Structure

Yaroslav V. Getmanov, Oleg A. Shevchenko (BINP SB RAS, Novosibirsk), Nikolay Vinokurov (BINP SB RAS, Novosibirsk; KAERI, Daejon)

Some modern projects of the new generation light sources use the conception of multipass energy recovery linac with split (CEBAF-like) accelerating structures. One of the advantages of these light sources is the possibility to obtain a small longitudinal beam size. To help reduce it, the longitudinal dispersion should be non-zero in some arcs of the accelerator. However small deviations in voltages of the accelerating structures can be enhanced by induced fields from circulating bunches due to the dependence of the flight time on the energy spread and the high quality factor of the superconducting radio-frequency cavities. Therefore, instabilities related with interactions of the electron bunches and longitudinal modes of the cavities can develop in the installation. Stability conditions for the interactions with fundamental accelerating mode of the split accelerating system are discussed.

Construction and Commissioning of Compact-ERL Injector at KEK

Shogo Sakanaka (KEK, Ibaraki)

The Compact Energy Recovery Linac (cERL) is under construction at KEK for the future 3-GeV ERL project. During the past year, we have finished key devices, such as a 500-kV DC photocathode electron gun and superconducting (SC) cryomodules for the injector and for the main linac. We installed these devices into a shielding room of the cERL, and carried out high-voltage or high-power tests successfully. In the April of 2013, the 5-MeV injector of the cERL was completed. During April to June in 2013, we commissioned the cERL-injector successfully, and carried out beam tuning and studies. We will present the construction and commissioning of the cERL injector, together with the construction status of a return loop.

Beam Diagnostic Results of RF Gun for the Race-Track Microtron Recuperator of BINP

Vladimir Volkov, Vladimir Sergeevich Arbuzov, Eduard Iosifovich Gorniker, Evegeniy I. Kolobanov, Sergey Alexandrovich Krutikhin, Igor Kuptsov, Grigory Yakovlevich Kurkin, Vadim Nikolaevich Osipov, Victor Petrov, Andrey Pilan, Mikhail A. Scheglov, Igor Sedlyarov, Alexey G. Tribendis, Nikolay Vinokurov (BINP SB RAS, Novosibirsk)

A new electron source for the Race-Track Microtron Recuperator is being developed by BINP SB RAS. It will increase average beam current and brightness of synchrotron radiation. Instead of the static 300kV electron gun operated now we are developing RF gun with the same energy of electrons. This RF gun consists of RF cavity with a gridded thermo cathode mounted on the back wall. RF cavity is driven by a 60 kW generator with last stage equipped by GU101A tetrode tube. Operational frequency of the cavity is 90.2 MHz. It is equal to the second subharmonic of the Microtron RF system frequency. A set of low power electronics controls amplitude of the cavity voltage and its tuner. This system, including a diagnostics beam line, has been installed to serve as a test bench to test the RF cavity and for beam dynamics studies. In continuous regime the designed beam is obtained. This paper summarizes the beam diagnostic results of the cavity in this configuration.

Progress on the Construction of IHEP 500kV Photocathode DC Gun System

Xiaoping Li, Jianshe Cao, Senyu Chen, Yunlong Chi, Yi Jiao, Jintong Liu, Rong Liu, Kun Lv, Shilun Pei, Xiaohua Peng, DaRui Sun, Guangwei Wang, Jiuqing Wang, Shu-hong Wang, Ouzheng Xiao, Jingru Zhang, Tong Zhang, ZuSheng Zhou (IHEP, Beijing), JinQiang Xu (Insititute of High Energy Physics (IHEP))

As one of the most important key technologies for future advanced light source based on the Energy Recovering Linac (ERL), a 500kV photocathode DC gun was supported by IHEP in September of 2011. Up to now, schematic design of all DC gun subsystems including drive laser, photocathode preparation system, electron gun body and ceramic insulator, high voltage power supply and beam diagnosis system has been finished. The detailed parameters of each subsystem are presented in this paper.

The Cornell ERL Injector Project

Bruce Dunham (Cornell University (CLASSE), Ithaca, New York)

Much progress has been made with the Cornell ERL injector, a prototype machine for a future ERL-based light source. We will present recent results on high-average current operation, cathode lifetime, and emittance measurements at 20 and 80 pC.

BNL SRF Gun Commissioning

Wencan Xu, Zeynep Altinbas, Suresh Deonarine, David M Gassner, Harald Hahn, James Jamilkowski, Prerana Kankiya, Dmitry Kayran, Nikolaos Laloudakis, Leonard Masi, Gary McIntyre, David Pate, David Phillips, Thomas Seda, Kevin Smith, Andrew N. Steszyn, Thomas Nicholas Tallerico, Roberto Than, Robert J. Todd, Daniel Weiss, Alex Zaltsman (BNL, Upton, Long Island, New York), Sergey Belomestnykh, Ilan Ben-Zvi, Jin Dai (BNL, Upton, Long Island, New York; Stony Brook University, Stony Brook)

The 704 MHz superconducting RF gun for R&D ERL project is under comissioning at BNL. Since last November, the SRF gun has been conditioned and demonstrated an operational accelerating voltage of 2 MV (an accelerating gradient of 23.5 MV/m). Preparations for the cathode insertion are in final stages and we expect the gun to generate the first electron beam this summer. This paper discusses the BNL SRF gun system, results of the SRF gun commissioning.

Photocathode Drive Laser at IHEP

JinQiang Xu (Insititute of High Energy Physics (IHEP))

It is difficult to find commercial laser products meeting the requirements for ERL photocathode drive laser systems. Therefore Experts at Jefferson Lab, Cornell University and KEK have been making effort to optimize laser configurations and improve performances of their laser systems for many years, and made great progress in laser pulse time jitter, pulse extinction ratio, laser output power and fiber amplifiers design, etc. (*,**,***), but macro-pulse gating and beam current ramping are not solved very well yet because of bulk EO crystals**. Recently, IHEP funded a photocathode test facility project. So we can try our best to set up a drive laser system. The drive laser system comprises two kinds of laser seeds, of which one is ps laser at 1.3 GHz rep rate and another fs one at 100 MHz. At the beginning of this year, the two laser seeds were installed. Fiber amplifiers are being constructed in accordance with the design while an aggressive idea expected to improve beam current ramping method is put forward. We will use fast optic modulators and a spectrum handling method to get flexible

pulses with high extinction ratio. Some optical components with stringent specifications will be crucial. We will optimize our design and then test it at IHEP later.

* S.Zhang, ERL2009;
** Bruce Dunham, ERL2011;
*** Honda Yosuke, ERL2011.

Fabrication and Performance of Cs2Te Photocathode for DC–SRF Gun at Peking University

Huamu Xie, Lin Lin, Kexin Liu, Shengwen Quan, Zhiwen Wang (PKU, Beijing)

DC–SRF photocathode gun is being commissioned in Peking University, which is aimed to produce mA level average current beam. In order to fulfill high quantum efficiency and long life time, the cesium telluride was chosen as the photocathode. The formation and characterization of the photoemissive film is presented. The QE of the fresh photocathode is around 8% and stabilized at 0.5% after weeks' operation (@266nm). After storage in 10-7Pa's vacuum for weeks, the QE showed no decrease. The rejuvenation effect (the reduction of the QE after exposure to residual gas in the chamber) was also investigated by heating and illuminated by the UV light. The pollution was mainly due to the low level vacuum.

Status and Perspectives of SRF Photoinjector Development for BERLinPro

Thorsten Kamps, Wolfgang Anders, Roman Barday, Andrew Burrill, Andreas Jankowiak, Jens Knobloch, Oliver Kugeler, Alexander N. Matveenko, Axel Neumann, Eva Panofski, Martin Anton Helmut Schmeißer, Jens Voelker (HZB, Berlin), Susanne Gundula Schubert (BNL, Upton, Long Island, New York), Alessandro Ferrarotto, Thomas Weis (DELTA, Dortmund), Evgeny Zaplatin (FZJ, Jülich), Jochen Teichert (HZDR, Dresden), Ingo Will (MBI, Berlin), Vasiliy Ivanovich Shvedunov (MSU, Moscow)

The energy recovery linac (ERL) test facility BERLinPro asks for an electron source delivering a beam with low emittance and high average current. The SRF photoinjector concept is a suitable candidate for such an ERL class electron source. After successful running of an SRF photoinjector with superconding Pb cathode we are now concentrating on the next stage of the R&D programme. The talk will present an overview of current and planned activities, related to GunLab, the gun test facility of BERLinPro, high QE photocathodes and additional test setups probing operational limits of photoinjectors.

Construction of the 2nd 500 kV Photocathode DC-gun at KEK

Masahiro Yamamoto, Yosuke Honda, Masanori Kobayashi, Tsukasa Miyajima, Takashi Uchiyama (KEK, Ibaraki), Hajime Yoshida (AIST, Tsukuba), Masao Kuriki (HU/AdSM, Higashi-Hiroshima), Ryoichi Hajima, Shunya Matsuba, Ryoji Nagai, Nobuyuki Nishimori (JAEA, Ibaraki-ken), Makoto Kuwahara (Nagoya University, Nagoya), Hiroki Kurisu (Yamaguchi University, Ube-Shi)

The 2nd 500 kV DC photocathode electron gun for a ERL injector was constructed at KEK. The gun has new functions such as employ new material for ceramic insulator, insulated anode electrode for dark current monitor, repeller electrode for elimination backward ions, extreme high vacuum pumps and so on. A high voltage conditioning is just begun from this summer. In addition, a new cathode preparation system has been developed. It can prepare three cathodes simultaneously and storage many cathodes in a good vacuum condition. The detail design was finished and the construction of all in-vacuum components is progressing.

First Measurements of Photoelectron Transverse Energy Distribution Curve using TESS

Heinrich Ernstovich Scheibler, Dmitry Gorshkov, Aleksandr Sergeevich Terekhov (ISP, Novosibirsk), Ryan Cash, Barry David Fell, Lee Jones, Keith Middleman, Boris Leonidovich Militsyn, Tim Noakes (STFC/DL/ASTeC, Daresbury, Warrington, Cheshire)

Electron injector brightness is limited by the transverse energy spread of the electrons emitted from a photocathode. Knowledge and understanding of the physical mechanisms underpinning this energy spread allows one to predict changes in the beam parameters. Ultimately, this information may help to optimize photocathode design, delivering improvements in photoinjector performance. In order to measure transverse photoelectron energy distribution curves (TEDC) ASTeC, in collaboration with ISP, have developed a Transverse Energy Spread Spectrometer (TESS). This equipment supports photocathode performance measurements both at room and LN2-temperature, under illumination from a range of fixed- and variable-wavelength light sources. TESS also includes a piezo-electric leak valve to allow controllable degradation of the photocathode whilst monitoring the energy spread of emitted electrons. In this work we discuss the principles of TEDC measurements on TESS, and present the first results for a GaAs-photocathode operated at room temperature. The measured TEDCs have exponential shape, and the mean transverse energies were equal to 45 meV for an illumination wavelength of 635 nm, and 102 meV when illuminated at 532 nm.

Studies of NEA-photocathodes

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Photoemission from p-GaAs(Cs,O) and p-GaN(Cs,O) photocathodes with NEA will be discussed. Photoelectron energy analyzers for determination of longitudinal and transverse energy distributions will be compared. By use of these analyzers, the following results were obtained. Domains of validity for actual models of the (Cs,O) - activation layer of GaAs - photocathode were determined. It was revealed, that the maximal value of QE of p-GaAs(Cs,O) - photocathode is achievable with (Cs,O) – activation layer, which fit with dipole layer model. On the other hand, the maximal value of NEA for this photocathode is achievable with (Cs,O) – layer, which correspond to heterojunction model. Two – step photoelectron escape from NEA-photocathode with their transitional capture within near – surface band bending region is proved. Subsequent escape of photoelectron to the vacuum occurs in the ballistic mode, or is accompanied by the elastic and inelastic scattering processes. Elastic scattering is dominated by the random electric field at the semiconductor – vacuum interface and by the surface roughness. Dominant mechanisms of inelastic scattering of photoelectrons include their interaction with surface optical phonons and with surface plasmons. Both processes of inelastic scattering are accompanied by the scattering of photoelectron's direction.

Progress of SRF Gun Development and Operation at the ELBE Accelerator

Jochen Teichert, Andre Arnold, Hartmut Buettig, Ulf Lehnert, Pengnan Lu, Peter Michel, Petr Murcek, Rico Schurig, Hannes Vennekate, Rong Xiang (HZDR, Dresden), Thorsten Kamps, Jeniffa Rudolph (HZB, Berlin), Peter Kneisel (JLAB, Newport News, Virginia), Ingo Will (MBI, Berlin)

Superconducting RF photo guns are suitable candidates for electron injectors in future free electron lasers and energy recovery linacs. For the radiation source ELBE an SRF gun was build and put into operation. During long-term tests, the operation of normal-conducting photocathodes in the superconducting cavity has been successfully demonstrated. At moderate average currents of some hundreds of μA the Cs2Te photocathodes possess excellent lifetime. The gun's acceleration gradient is the key parameters for beam emittance and the maximum achievable bunch charge of the gun. Therefore two new cavities with higher performance were developed, built and treated. The final tests of these cavities are ongoing. An upgraded cryomodule with an integrated superconducting solenoid was built.

Longitudinal Beam Halo in the Photoemission from GaAs-Photocathodes in a 100keV DC Gun

Monika Dehn, Kurt Aulenbacher, Frank Fichtner, Eike Kirsch, Valeri Tioukine (IKP, Mainz)

At Johannes Gutenberg-University Mainz measurements of the time response of photocathodes can be performed routinely at the 'Testquellenlabor' (source testlab) using a deflector cavity. Short electron bunches are generated using a femtosecond tunable laser system operating at 800 nm for best polarization/QE if GaAs is used. In our experiment the laser radiation is also frequency-doubled to 400 nm in order to compare the time response at different wavelengths. First measurements show a strong reduction of the longitudinal beam profile at 400 nm without the trailing electrons which are typically observed at 800 nm.

Dark Current in Superconducting RF Photoinjectors – Measurements and Mitigation

Jochen Teichert, Andre Arnold, Pengnan Lu, Petr Murcek, Gerald Staats, Hannes Vennekate, Rong Xiang (HZDR, Dresden), Roman Barday, Thorsten Kamps (HZB, Berlin)

Unwanted beam can cause beam losses and may produce acute or chronic damages of the accelerator. Furthermore it can considerably disturb experiments or increase its back-ground. The operation of the superconducting RF photo gun at the ELBE accelerator has delivered the first experimental information on that topic. It was found, that dark current is an important issue, similar to that normal conducting RF photo injectors. In the presentation the measurement of dark current, its properties and analysis will be shown and we will discuss ways for mitigation, especially the construction of a dark current kicker.

Field Emission Measurements on Flat Mo-substrates

Roman Barday, Andrew Burrill, Andreas Jankowiak, Thorsten Kamps, Carola Klimm, Jens Knobloch, Frank Siewert (HZB, Berlin), Stefan Lagotzky, Guenter Mueller (Bergische Universitaet Wuppertal, Wuppertal)

Bi-alkali antimonide K2CsSb is a baseline photocathode material for the production of a high brightness electron beam with high average current for future 4th generation multi-user light sources. The low beam emittance required for these projects demands very high field gradient on the photocathode surface, increasing the probability of enhanced field emission (EFE) in the superconducting gun cavity. Molybdenum can be used as a substrate to reduce the lattice mismatch with the cathode crystal. Therefore we have measured the EFE from a flat Mo sample by means of field emission scanning microscopy (FESM) up to 180 MV/m surface field (Es). First EFE (1 nA) was noticed at Es = 60 MV/m, but a strong emitter activation resulted in a finally lower EFE onset at Es = 46 MV/m. Local I(E) measurements have revealed Fowler-Nordheim behavior with enhancement factors of 10-70, however with a wide range of emitting areas (0.1 nm2 - 4300 µm2) which hint for adsorbate or oxide effects. Finally the located emission areas were investigated by SEM/EDX to identify the origin of the EFE.

Upcoming Measurements of Transverse Beam Break-Up at the Superconducting Recirculating Electron Accelerator S-DALINAC

Florian Hug, Thorsten Kuerzeder, Norbert Pietralla (TU Darmstadt, Darmstadt)

Energy-Recovery Linacs are promising tools for providing high-current beams. Potential limitations may occur when the machine design does not sufficiently care for suppressions of the degradation of particle bunches during acceleration and beam transport, so called beam break-up. Opportunities to study these phenomena are rare. The superconducting accelerator S-DALINAC provides electron beams of up to 130 MeV for nuclear physics experiments at the university of Darmstadt since 1991. It consists of a 10 MeV injector and a 40 MeV main linac and reaches its final energy using up to two recirculation paths. The superconducting main linac houses eight 20-cell SRF cavities operated at 3 GHz and 2 K. Due to transverse beam break-up the design beam current of 20 µA could not be reached in recirculating operation mode yet, the highest stable beam current obtained so far accounts for 5 µA, which is sufficient for the nuclear physics experiments carried out at Darmstadt*. On the other hand the very low threshold current for the occurence of beam break-up in addition with the recirculating linac design gives a unique opportunity to the ERL community for testing different strategies of avoiding beam break-up experimentally and to benchmark beam dynamics simulations concerning this topic. We will report on upcoming experiments which will be carried out at the S-DALINAC for that purpose.

* O. Yevetska et al., Nucl. Instr. Meth. A 618 (2010) 160

Experience with Unwanted Beam at Jefferson Lab

Pavel Evtushenko (JLAB, Newport News, Virginia)

We attempt to review operational experience of Jefferson Lab accelerators related to beam halo and beam loss. We divide the beam halo in to four categories based on its origins. These are: 1 – beam halo evolving due to non-linear beam dynamics, 2 – beam due to the field emission in LINAC cavities and in the electron source, 3 – beam due to the drive laser “ghost” pulses, which are the laser pulses present in the system due to finite extinction ration of the electro-optical cells used to reduce the repetition rate of the drive laser, 4 – beam due to the scattering of the drive laser in its transport system and on the cathode as well as due to parasitic light in reaching the cathode. Independent of its source the beam loss can be acute with relatively high intensity, which is sufficient to damage accelerator components within a very short time, and chronic with much lower intensity that does not prevent accelerator operation but can cause damage in a long term. The acute beam loss must be mitigated by the machine protection system. The chronic beam loss is partially mitigated (to acceptable level) by limiting the accelerating gradient of the LINAC and the electron gun, but ultimately can be improved by building accelerator components with onset of the field emission at higher gradient and understanding of the beam dynamic with a very high dynamic range in mind.

Modeling and Optimization of Orbit Correction Using Fuzzy Logic

Tatiana Vladimirovna Salikova (BINP SB RAS, Novosibirsk)

This article describes a fuzzy logic model for beam orbit correction. Step 1. I have created a 'fuzzy logic engine', which works with a soft EPICS database. The EPICS database emulates PVs (Proccess Variable) of the magnetic system and PVs of the diagnostic systems: Beam Position Monitor, integrated beam currents, and radiation doses in the accelerator hall. Step 2. Currently, I am debugging the mechanism of feedback between the 'fuzzy logic engine' and fluctuations of diagnostics PVs. Next step. Adjustment of the time of feedback response of the 'fuzzy logic engine' to information coming from the control systems and FEL diagnostic systems in a hard real time mode.

Optical System with Image Intensifier and Spatial Filters for Large Dynamic Range Transverse Beam Profile Measurements

Pavel Evtushenko (JLAB, Newport News, Virginia)

We have previously reported * on transverse beam profile measurements where dynamic range (DR) was increase by a factor of 100 from typical 500 to about 5.0E+4. It was shown that for non-equilibrium beam with non-Gaussian transverse distribution the RMS beam size can depend significantly on the DR used for calculations. Consequently, measured emittance and Twiss parameters depend on the DR as well. For the optical system used in * diffraction limits the DR at the level slightly above the 5.0E+4 used in measurements. For further increase of the DR spatial filters needs to be used in a way similar to original solar coronagraph ** and its application to the synchrotron radiation measurements ***. To increase overall sensitivity to allow large dynamic range measurements with low duty cycle tune-up beam, our systems includes an image intensifier. On contrary to a coronagraph-like scheme, where central bright part of the distribution is not measured, our systems is intended for simultaneous, complete distribution measurements including the bright core and low amplitude halo, which is needed for proper beam size measurements. Here design considerations for the system are presented.

* P. Evtushenko et al., in Proceedings of FEL2012

** B. F. Lyot, Month. Notice Roy. Ast. Soc, p580, 99 (1939)

*** T. Mitsuhashi, "Beam halo observation by coronagraph", Proceedings of DIPAC05

Monitoring Beam Position in the Multibeam Accelerators

Igor Pinayev (BNL, Upton, Long Island, New York)

Energy recovery linacs have at least two beam co-propagating in the same vacuum vessel, what complicates monitoring orbit of the individual beams. In this paper we present the concept of a beam position monitors for the accelerating structures with multiple beams. Both cases with common and separated nominal orbits orbits are considered. For the first case we utilize the phase information, when for the second case additional pick=up electrodes can be utilized.

The Control System of Novosibirsk Free Electron Laser

Stanislav Sergeevich Serednyakov, Nikolay Vinokurov (BINP SB RAS, Novosibirsk)

Novosibirsk Free electron Laser (FEL) based on multi-turn energy recovery linac is the source of coherent radiation with ability of wavelength tuning. Whole FEL facility is a complex physics installation, controlled by large amount of equipment of different types. Therefore, for effective control and monitor of FEL operation state and its parameters, the particularized control system was developed. In this paper the architecture, hardware, software compound parts of this control system are considered. Also main abilities, characteristics of this system and examples of its usage are presented.

Instrumentation Designs for Beam Distribution Measurements in the ERL Beam Dump at BNL

Toby Allen Miller, Steven Bellavia, Ilan Ben-Zvi, Jesse Matthew Fite, David M Gassner (BNL, Upton, Long Island, New York)

The R&D Energy Recover Linac (ERL) at Brookhaven National Laboratory is undergoing continued development in parallel with piece-wise commissioning efforts as installation of each subsystem is completed. While the machine is planned to be operated at low intensity and short low frequency pulses during the commissioning phases, on going design efforts continue to provide a solution to measure the beam distribution inside the high power electron beam dump using several parallel methods. For low power measurements, this includes a new rad-hard version of long 7/8" heliax ion chambers that encage the dump both in circular and axial directions. For high power measurements, this includes both "pinhole" like multipoint imaging of the dump with ion chambers positioned over an array of holes drilled in the shielding around the beam dump and an Infrared imaging system to peer through an upstream bending magnet in the extraction line to monitor the temperature distribution on the target surface inside the dump. This paper presents the design details of these three systems that work to ensure the proper distribution of the high power electron beam on the target in an effort to avoid reaching the thermal limit of the water cooled beam dump.

Time-Resolving Laser Wire for Large Dynamic Range Measurements - Design Considerations

Pavel Evtushenko, Matt Marchlik (JLAB, Newport News, Virginia)

Better diagnostics and understanding of beam halo are needed for high average current CW SRF electron linacs. Here longitudinal beam halo upstream of the linac evolves in to transverse halo downstream of the linac. A diagnostic for measurements longitudinal phase space distribution with large dynamic range (LDR) is needed for proper setup of an injector and better understanding of beam halo formation. In addition, one of unsolved ERL's diagnostic problems is the transverse beam size monitoring of a high average current, few MeV energy beam. We present our design for a Thomson scattering based CW laser wire system for LDR transverse beam profile measurements. It is designed to be used with CW beam starting with an average current of about 150 mkA, but can, as it is non-destructive and non-intercepting, be use at any average current. When implemented in a dispersive section it can be used for energy distribution measurements. Using a short pulse laser adds

time resolution to the diagnostic. Combining time and energy resolution, the system will allow measurements of the longitudinal phase space distribution while keeping the LDR due to the counting nature of the detection scheme.

Status of the BNL ERL Instrumentation

David M Gassner, Chuyu Liu, Robert Michnoff, Toby Allen Miller, Michiko Minty, Michelle Wilinski (BNL, Upton, Long Island, New York)

The R & D Energy Recovery Linac (ERL) project is currently under development at the Brookhaven National Laboratory. The ERL is expected to demonstrate energy recovery of high intensity beams with a current of up to a few hundred milliamps, while preserving the emittance of bunches with a charge of a few nC produced by a high current SRF gun. To successfully accomplish this task the machine will include beam diagnostics that will be used for accurate characterization of the three dimensional beam phase space at the injection and recirculation energies, transverse and longitudinal beam matching, orbit alignment, beam current measurement, and machine protection. This paper describes the present status of the instrumentation systems that will be used to meet these goals. Unfortunately we have not had any first electron beams yet.

Electron Beam Polarimetry at ERL's

Kurt Aulenbacher (IKP, Mainz)

ERL's which are supposed to be used for particle physics experiments have to be equipped with an electron polarimeter. Such devices must be compatible with ERL-operation, i.e. minimally invasive. The Compton-Laser device may be the method of choice, scattering from trapped completely polarized electrons in an atomic trap could be an alternative. The principles of operation of both methods are discussed.

High Power Diagnostics for an ERL Injector

Bruce Dunham (Cornell University (CLASSE), Ithaca, New York)

Developing diagnostics for characterizing the high-power beams in an ERL injector is a difficult task. Most of the commonly used diagnostics cannot handle the high beam powers. We have developed and tested several methods for measuring beam profiles and beam halo. These will be described, along with a description of the diagnostics used for characterizing the beam at full bunch charge (but low average power).

New Way to Accelerating High Current Beam in ERL

Zhenchao Liu, Jie Gao, Song Jin (IHEP, Beijing), Fang Wang (PKU, Beijing)

High beam current is available for the Energy Recovery Linac (ERL). Different methods are adopted to increase the BBU threshold of the cavity to deliver hundreds of milliampere beam current. The key is to absorbing HOMs more efficiently. The BBU threshold of the slotted cavity is much higher than other high current cavities. However, new tuning method is needed and multipacting should be checked. Here we will present a new way to accelerating the high current beam by a highly HOMs damped cavity, the slotted cavity including the tuning method.

The Development of Cryomodule for c-ERL at MHI

Hiroshi Hara, Katsuya Sennyu (MHI, Kobe)

The design, manufacturing and installing of cryomodule including superconducting cavity for main linac and booster of compact Energy Recovery Linac at KEK will be reported.

Performance of RF System for Compact ERL Injector in KEK

Takako Miura, Mitsuo Akemoto, Dai Arakawa, Shigeki Fukuda, Hiroyuki Honma, Hiroaki Katagiri, Toshihiro Matsumoto, Hideki Matsushita, Shinichiro Michizono, Hiromitsu Nakajima, Katsumi Nakao, Feng Qiu, Tetsuo Shidara, Tateru Takenaka, Yoshiharu Yano (KEK, Ibaraki)

The compact ERL injector has a normal conducting buncher cavity and three superconducting (SC) 2-cell cavities. In particular, two input couplers for each SC cavity are equipped top and bottom side of the cavity, symmetrically. 1.3 GHz RF should be delivered with the same phase to the top and bottom couplers. RF sources of the buncher cavity and the 1-st SC cavity are prepared individually. However, the 2-nd and 3-rd SC cavities are operated by vector sum control using one klystron. LLRF system is based on IQ digital feedback using the FPGA. The beam commissioning was started from April 2013. After the optimum RF feedback gain search was performed, the stabilities of RF fields for especially SC cavities in short time range were achieved 0.01%rms and 0.02 deg. rms. Then we confirmed the correlation of beam energy jitter and RF stability. Finally, very low beam energy jitter of 0.006% was achieved.

Superconducting RF systems in the R&D ERL at BNL

Wencan Xu, Zeynep Altinbas, Ilan Ben-Zvi, Suresh Deonarine, David M Gassner, Harald Hahn, James Jamilkowski, Prerana Kankiya, Dmitry Kayran, Nikolaos Laloudakis, Leonard Masi, Gary McIntyre, Toby Allen Miller, David Pate, David Phillips, Thomas Seda, Kevin Smith, Andrew N. Steszyn, Thomas Nicholas Tallerico, Roberto Than, Robert J. Todd, Daniel Weiss, Alex Zaltsman (BNL, Upton, Long Island, New York), Sergey Belomestnykh, Jin Dai (BNL, Upton, Long Island, New York; Stony Brook University, Stony Brook)

The R&D ERL project at BNL aims to demonstrate a high charge, high current energy recovery linac (ERL). The R&D ERL includes two superconducting RF systems: a half-cell superconducting RF (SRF) gun and a five-cell superconducting linac cryomodule, both operating at 703.7 MHz. A series of tests of the five-cell superconducting linac cavity has been carried out in the ERL cave in the past 4 years. The cavity is able to achieve 20 MV/m with a Q0 exceeding 1010 in pulse mode but only 12 MV/m in CW mode due to a thermal problem. The SRF gun has been conditioned and demonstrated an operational accelerating voltage of 2 MV (an accelerating gradient of 23.5 MV/m). This paper discusses commissioning of the SRF gun and the five-cell superconducting linac cryomodule, and the experience gained during operations of the superconducting RF system for the high current ERL.

SRF Cavity Development for the Cornell ERL Project

Bruce Dunham (Cornell University (CLASSE), Ithaca, New York)

Significant R&D towards achieving the goals for the SRF cavities of an ERL light source has been carried out in the past few years. We will report on the results of a single, 7-cell cavity in a horizontal test cryostat, and on progress towards building a full-scale, 6 cavity prototype for an ERL.

ERL Related SRF Activities at Jlab

Robert Rimmer (JLAB, Newport News, Virginia)

JLab has built and operated two demonstration ERL's, one using a single original CEBAF type cryomodule and an upgraded version using a prototype CEBAF 12 GeV type cryomodule and two original CEBAF modules. Several years ago in preparation for a future upgrade JLab developed cavities capable of even higher current in excess of 100 mA, but that upgrade was never funded. Now two improvements of the existing machine are planned. The first is the refurbishment of the upgrade prototype module to higher energy. The second is to upgrade the injector to be capable of higher current and lower emittance, using cavities developed for the earlier program. The plans and status of these upgrades will be reported.

Progress Report on the International ERL Cryomodule at Daresbury

Shrikant Pattalwar, Rachael Katherine Buckley, Peter Andrew Corlett, Philippe Goudket, Andrew Goulden, Lili Ma, Peter McIntosh, Andrew Moss, Alan Wheelhouse (STFC/DL/ASTeC, Daresbury, Warrington, Cheshire)

Assembly and initial testing of an optimised SRF cryomodule for application on ERL accelerators, which is being developed through an international collaboration, has been successfully completed. The module has been installed on ALICE-ERL (Accelerators and Lasers in Combined Experiments) facility at STFC Daresbury Laboratory, UK. In this paper we report the progress on integration and first experience with the operation of the ERL cryomodule and present some of the initial results.

ASTA Users Facility at Fermilab: Testbed for Superconductying RF Technology

Vladimir Shiltsev (Fermilab, Batavia)

The Advanced Superconducting Test Accelerator (ASTA) currently under commissioning at Fermilab will enable a broad range of beam-based experiments to study fun- damental limitations to beam intensity and to develop transformative approaches to particle-beam generation, acceleration and manipulation. ASTA incorporates a su- perconducting radiofrequency (SRF) linac coupled to a photoinjector and small-circumference storage ring capa- ble of storing electrons or protons. ASTA will establish a unique resource for R&D towards Energy Frontier facilities and a test-bed for SRF accelerators and high- brightness beam applications, including ERLs. The unique features of ASTA include: (1) a high repetition-rate, (2) one of the highest peak and average brightness within the U.S., (3) a GeV-scale beam energy, (4) an extremely stable beam, (5) the availability of SRF and high-quality beams together, and (6) a storage ring capable of supporting a broad range of ring-based advanced beam dynamics experiments. These unique features will foster a broad program in advanced accelerator R&D which cannot be carried out elsewhere.