ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-MOZGBF2

STATUS OF THE FAIR PROJECT

P. Spiller, M. Bai, J. Blaurock, O. Boine-Frankenheim, A. Dolinskii,
F. Hagenbuck, C. Kleffner, K. Knie, I. Koop[1], S. Menke, M. Winkler, D. Prasuhn[2],
A. Schuhmann, C. Omet, M. Ossendorf, H. Simon, R. Tölle[2]
GSI GmbH, Darmstadt, Germany [1] BINP, Novosibirsk, Russia [2] FZJ, Jülich, Germany

Abstract

After its completion, the Facility for Antiproton and Ion Research, FAIR GmbH, is supposed to be the leading nuclear physics laboratory in Europe. So far, ten countries have signed the convention and became shareholders of the FAIR GmbH. The central research instrument of FAIR is a new accelerator complex, which is being build east of GSI-Helmholtzzentrum für Schwerionenforschung GmbH in Darmstadt. The FAIR accelerators are served by the existing accelerators of GSI, which are, in parallel to the construction of FAIR, upgraded for operation as injectors and boosters. Four scientific pillars are the foundation of the physics program at FAIR, a) the NUclear STructure and Reactions program (NUSTAR), b) the Atomic, Plasma Physics and Applications (APPA) program, c) the Compressed Baryonic Matter program (CBM) and the hadron structure and dynamics program (PANDA). The APPA program does also involve BIOMAT, comprising research in biophysics, material science and plasma physics. With signing a bilateral agreement with the European Space Agency in 2018, the facilities of FAIR/GSI will also serve as ground laboratory for research relevant for aeronautics and astronautics. The FAIR project has been initiated by GSI in the year 2001. After the preparatory phase, in which the overall facility layout and design has been developed and frozen and major component R&D has been conducted, FAIR has meanwhile approached the main procurement and construction phase. The present reference project schedule is targeted onto a completion of the overall facility in 2025. From 2018, until the commissioning of the new FAIR accelerators with beam, the existing GSI facilities will be operated and serve the requests of the physics communities at GSI. This user operation is called «FAIR phase 0» and will benefit from continuous upgrade measures of the heavy ion accelerators UNILAC and SIS18 for the future booster operation.

THE FAIR ACCELERATOR FACILITY

The accelerator complex of FAIR consists of facilities for primary and secondary beams. The primary beam accelerators, consisting of the heavy ion linac UNILAC, the heavy ion synchrotron SIS18 and the new FAIR heavy ion synchrotron SIS100, are designed for acceleration of all ions from Protons to Uranium. Compared to the presently available beam parameters at GSI, the intensities of Proton and heavy ion beams will be enhanced by a factor of 100. The biggest challenge for the accelerator complex is the generation of world record intensities of Uranium beams. Production targets for secondary beams, such as rare isotope beams or Antiproton beams are followed by a number of separators and storage rings. The Super Fragment Separator (Super-FRS), provides a huge acceptance for rare isotope beams, which together with the enhanced primary beam intensities, leads to an intensity gain factor of 1000 compared to the existing FRS at GSI. A dedicated production target with subsequent large aperture separator, generates secondary Antiproton beams for storage and pre-cooling in the Collector Ring CR and stacking, stochastic cooling and post-acceleration in the High Energy Storage Ring (HESR). The requirements for the Proton beam intensities are determined by the research program with Antiproton beams in the High Energy Storage Ring HESR. This combination of primary and secondary beam facilities has already provided unique conditions for experiments with secondary beams at GSI. Beside of the production of secondary beams, the primary beams are also used for direct fixed target interactions experiments, e.g. in the HADES/CBM and APPA caves.

SIS18–UPGRADE

In order to prepare the existing heavy ion synchrotron SIS18 for the operation as fast cycling SIS100 injector, a technical upgrade has been conducted and almost completed. This upgrade program has been defined in the early project phase of FAIR [1]. It follows a recipe developed by GSI to control the dynamic residual gas pressure, especially at operation with intermediate charge state heavy ions and involves almost all major technical subsystems [2]. The design goals for Proton operation have been set to $5x10^{12}$/cycle and for U^{28+}-ions to $1.5x10^{11}$/cycle. In both cases, SIS18 will be operated with a ramp rate of 10 T/s and a maximum repetition rate of 2.7 Hz. To cope for the operation with significantly increased average beam intensities, beside the machine upgrade, the SIS18 tunnel is presently receiving a major modification. The so-called GAF (GebäudeAnbindung-an-Fair) civil construction project has been launched at the end of 2016 and will be completed in June 2018. The project involves, a) an enhancement of the soil shielding on top of the SIS18 tunnel, requiring a support structure to cover the additional load, b) a radioactive air management system, c) a fire protection system based on Nitrogen flooding, d) a reinforcement wall at the northern arc of SIS18 and e) opening and modification of the eastern wall of the transfer hall, providing the interface to the FAIR tunnel T101.

Status

The preparation for the recommissioning of SIS18 in 2018 has made major progress and is in its final phase. Most of the upgrade program has been successfully implemented through the last decade. The last technical items are presently installed or will be installed after the beam time in 2018. This involves, a) the completion of the new dipole power converter for fast, high precision, ramping, b) the commissioning of

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2018). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-MOZGBF2

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2018). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

two of the three new MA (magnetic alloy) acceleration cavities generating a total acceleration voltage of 50 kV, c) the manufacturing and installation of an IPM (ionization beam profile monitor) system and d) the installation of a new large bipolar dipole magnet as link to the new FAIR beam lines. For the operation with intermediate charge state heavy ions, all magnet chambers have been NEG coated and the bake-out system has been upgraded for temperatures up to 300°C. In March 2018, the final acceptance tests with the new dipole power converter have been conducted with a maximum pulse power of 50 MW. All power tests were performed in the new FAIR control system environment and set-values and device ramps have been generated by the new LSA set-value generation system. Since SIS18 will also be the driver for an important experimental program in the FAIR phase 0 further technical improvements, machine developments and maintenance measures are continuously conducted in parallel to the booster upgrade. E.g. a new high harmonic cavity is under preparation for smoothing the micro spill structure of slowly extracted beams [3]. The civil construction works of the GAF project are progressing well. Only a minor delay of about two months has developed over the execution process, not relevant for the start of the beam time in 2018. About three quarter of the new table construction, carrying the additional soil shielding on top of the accelerator tunnel, has been completed. The construction of the building interface to the FAIR tunnel T101 has been finished, as well as the new escape tunnel east of SIS18.

PROTON LINAC

For the production of Antiproton beams with sufficient intensities, a dedicated high-intensity 325 MHz Proton linac is needed [4]. The Proton linac shall deliver a beam current of 70 mA with an energy of 68 MeV for injection into SIS18. A 2.45 GHz ECR source provides Proton with an energy of 95 keV. The source is designed for the generation of 100 mA beams. The subsequent Low-Energy Beam Transport line (LEBT) contains two magnetic solenoid lenses enclosing a diagnostics chamber, a beam chopper and a beam conus. A ladder 4-Rod RFQ is foreseen as pre-accelerator. Six normal conducting crossbar cavities of CCH and CH type arranged in two sections accelerate the beam to the final energy of 68 MeV [5].

Status

The commissioning of the Proton source takes place at CEA, Saclay. The 100 kV/150 mA high voltage power supply of the source has been commissioned successfully. By means of AC current transformer, fast current transformer FC, Wien filter (beam proportion) and Alison Scanner (emittance measurements) the extracted Proton beam has been characterized. A current of 92 mA (80 mA H^+) with a RMS emittance of 0.3 π mm mrad behind the first solenoid has been produced. The ladder RFQ will be manufactured at the Institute for Applied Physics (IAP), Frankfurt. The production of the RFQ vacuum chambers has been completed. First parts of the chambers have been successfully copper plated at GSI. The production of the ladder structure itself is ongoing. First low-level Rf tests are expected for Q4/2018. The IAP, Frankfurt is also in charge of the design of the CH cavities. With consideration of the requirements from electroplating, specified maximum length of the individual cavity segments and beam dynamics, the design has been completed by now. Seven Klystrons have been delivered to GSI at the beginning of 2018. An eighth Klystron was ordered by the collaboration partner CNRS. With a few interlock modifications, the Klystrons are ready for use. The completion of the setup of the HV modulator is indispensable for the start of the Rf tests. The procurement of major components, e.g. HV switches, transformers, etc. of the modulator has been launched.

HEAVY ION SYNCHROTRON SIS100

The desired operation with high intensity intermediate charge state heavy ions is the driver for significant technical differences between SIS100 and typical Proton synchrotrons. In order to enable such an operation, a new lattice structure had to be introduced. The SIS100 lattice has been optimized with respect to the distribution of projectiles lost after ionization by collisions with residual gas atoms. The so-called charge separator lattice [6] provides 100% efficiency for an implemented ion catcher system. The specially developed, cryogenic ion catchers [7], which are installed at the major loss positions in the middle of the arc quadrupole modules, dump ionized beam particles in a controlled manner. The goal is to minimize gas desorption and to inhibit desorbed gas from interaction with the revolving beam. In order to make use of extensive cryopumping, SIS100 has become a superconducting synchrotron. Besides the magnets itself, all magnet chambers are actively cooled by LHe. In addition, to provide sufficient pumping power for light atoms, e.g. for H and He, a large number of cryosorption pumps is foreseen. The SIS100 fast ramped superconducting dipole magnets are designed for a ramp rate of 4 T/s. The charge separator lattice is a doublet lattice, which provides large flexibility in optical settings. This is assured by three independent quadrupole power circuits. The Rf system consists of different cavity types providing all options for the planned longitudinal manipulations: a) 16 ferrite loaded acceleration cavities, b) 9 MA loaded bunch compression cavities, c) 2 broad band barrier bucket cavities and 2 broad band feed-back cavities.

Status

After the successful manufacturing and cold testing of the First of Series (FOS) superconducting dipole magnet, the series production of the 110 magnets have been released and 24 of them have been manufactured and delivered to GSI (see Fig. 1). The manufacturing of the superconducting quadrupole units at JINR, Dubna has progressed towards two integrated units, consisting of two quadruple magnets, a steerer and a sextupole magnet. With completing a dedicated NICA-FAIR superconducting magnet test facility end of

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-MOZGBF2

November 2016, all preparation for testing the series units are completed.

Figure 1: SIS100 superconducting dipole magnets in storage areas at GSI.

The overall design of the quadruple modules has been conducted together with industrial partners. The tendering of manufacturing and integration, which is one of the biggest technical efforts for the FAIR accelerators, has been successfully finished in February 2018. In parallel, possibilities for cold testing of the integrated modules have been evaluated. At INFN, Salerno a facility has been prepared for the cold testing of future SIS300 magnets. This facility is presently modified for testing of the integrated SIS100 quadrupole modules. The status of design and manufacturing of the Rf systems, for acceleration and compression of the beam has developed well. After successful completion and testing of the FOS bunch compression cavity, the series production of the remaining eight cavities has been launched. Meanwhile, five cavities have been manufactured. In parallel, the design and manufacturing of the FOS acceleration cavity (see Fig. 2) could be completed.

Figure 2: First of Series (FOS) SIS100 acceleration cavity at factory acceptance test.

The ferrite loaded cavity, which provides an acceleration voltage of 20 kV, has successfully passed the factory acceptance tests (FAT) and was shipped in March 2018 to GSI. The procurement of several other SIS100 components has been launched. The goal is to complete the procurement according to functional sections. All major components of the injection system, the injections kicker modules and the injection septum magnets have been tendered, awarded and are in construction. As next large system, the components of the extraction system are procured, starting with the electrostatic extraction septum. The so-called local cryogenics system is one of the most complex and unique technical systems of SIS100. Especially the bypass lines, bridging the warm sections of SIS100, are demanding and differ from conventional cryogenic transfer lines by the integrated superconducting bus bar system. A FOS bypass line has been manufactured and delivered by the Wroclaw University of Technology (WUST) as a Polish in-kind contribution. In parallel to the bypass lines, the design of the overall local cryogenics system, including the end boxes, current feed boxes and feed-in boxes is conducted by WUST.

HIGH ENERGY BEAM TRANSPORT SYSTEM

The High Energy Beam Transport HEBT system provides transfer of ion-, Proton- and Antiproton beams to and from the synchrotrons and storage rings, to and from the Super-FRS, to the Antiproton production target and separator and to the experimental areas (CBM and APPA). It consists of 29 beamline sections with a total length of about 1.5 km. All beam lines are normal conducting with nominal magnetic rigidities of 100 Tm, 18 Tm or 13 Tm. Pulsed operation of sections and fast divider and combiner dipoles for switching between sections will enable a parallel operation of experiments in a time sharing mode.

Status

The key components of the HEBT system are mainly provided by international in-kind partners. Almost all HEBT magnets (331/365) needed are built by Efremov Institute (NIIEFA), St. Petersburg (51 dipole magnets) and Budker Institute (BINP), Novosibirsk (22 dipole, 166 quadrupole and 92 steering magnets).

Figure 3: Dipole magnets (built by NIIEFA) with installed vacuum chambers (built by BINP) shipped to GSI.

Meanwhile, series production is fully running at NIIEFA. Until the end of 2017, fourteen dipole magnets were delivered to GSI/FAIR and passed the Site Acceptance Test (SAT), see Fig. 3. All magnets will be delivered by NIIEFA until end of 2019. In March 2018, the pre-series magnets of the quadrupole series for the 18 Tm sections and the steering magnets for the 100 Tm sections passed the FAT at BINP. Delivery of all magnets made at BINP, is supposed to be completed end of 2020. All related vacuum chambers as

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2018). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-MOZGBF2

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2018). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

well as all general vacuum chambers for the HEBT beam pipe vacuum system are supposed to be built by BINP too. First two series vacuum chambers passed the SAT in February 2018 and were installed in the relevant magnets. Most of the power converters for HEBT quadrupole- and steering magnets will be built by the Indian company ECIL (Electronics Corporation of India Limited). Up to now two in-kind contracts between FAIR, the Indian shareholder BOSE institute and the provider ECIL comprising in total 196 power converters for HEBT (152 for quadrupole and 44 for steering magnets) are closed. The first 6 series quadrupole magnet power converters have recently passed the FAT and will be shipped to GSI/FAIR in April 2018. Another 67 power converters of this type will be manufactured and tested at ECIL until spring 2019. The day zero beam instrumentation of the HEBT lines foresees resonant transformers (RT), fast current transformers (FCT), and particle detector combinations (PDC) for intensity measurements and secondary electron emission grids (SEM-Grid), multi-wire proportional chambers (MWPC) and scintillator screens (SCR) for the determination of the transverse beam profile, furthermore beam position (BPM) and beam loss (BLM) monitors. After prototypes of all these instruments (for BPM only DAQ) were tested successfully in GSI beam transport lines, procurement, production and assembly of many components of the series were started. Several subprojects with the Slovenian in-kind provider Instrumentation Technologies, like HEBT BPM DAQ and BPM pre-amplifier are finished and Final Design Reviews (FDR) took place. Moreover, the Slovenian in-kind partner VacuTech will start the production of the pneumatic drives in this year.

SUPER-FRAGMENT SEPARATOR

The Super-FRS is a high resolution separator for the production of exotic nuclei at relativistic velocities and high rigidity (20 Tm) in flight [8], see Fig. 4. In view of the high expected rates of up $3x10^{11}$ ions/s (from light ions to Uranium), the system contains a pre-separator which acts as a powerful first filter using ion catchers for the suppression of the primary beam. The main separator consists of an ion optical system combined with a detector and slit systems for high rate identification of secondary particles. Three branches are used to serve different experimental areas: (i) the low energy branch for experiments with slowed down or stopped beams, (ii) the high energy branch for reaction studies at almost full beam energy, and (iii) the ring branch for high precision metrology experiments utilizing dedicated techniques for storage rings. The separator with a worldwide outstanding acceptance at high beam energies consists of large acceptance superconducting dipole and multipole magnets and radiation hard normal conducting magnets behind the target area (first half of the pre-separator). A sensitivity with suppression factors of up to $10^{16...17}$ will be achieved and is facilitated by the absence of background ions at the different charge states and the envisaged beam energies. The rotating graphite wheel target will sustain at a few kW and is hosted in an environment of the target chamber where remote handling facilities, including a sophisticated plug system for detectors, slits and other beam instrumentation, are installed. The area is in the vicinity of a hot cell complex where maintenance of the various beam inserts can be performed.

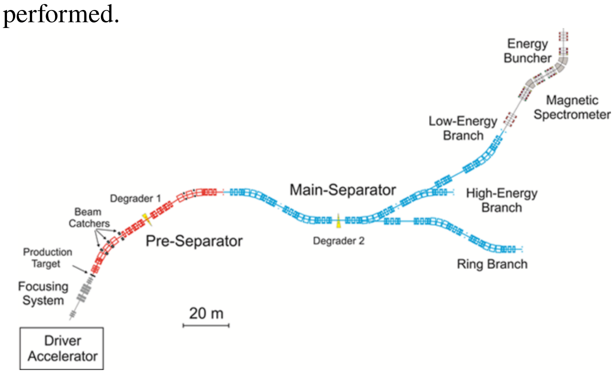

Figure 4: The Super-FRS and its three branches.

Status

All major Super-FRS components are today in their procurement phase. Delivery of First-of-series, FOS prototypes for the superconducting systems are expected this and next year and will be tested in a dedicated test area at CERN. The new test facility will be ready for operation late spring this year. The challenging design for the beam catcher system, especially considering fast extraction from SIS100, with pulse lengths of down to 50 ns, is completed. First mock-up tests for the remote maintenance of catcher components are in preparation for this year at the site of our Indian partners. The conceptual design of the complex target chamber hosting all diagnostics, a beam intensity monitoring system a CCD IR camera system for target monitoring, collimators, the rotating target wheel and further target ladders, all with remote maintenance and control is almost finished. Several handling tests have been successfully carried out at the accelerator laboratory of KVI-CART in the Netherlands. This holds also true for the slit system of the device. For the very demanding detector system, where detectors will be operated at their physical limit with associated rates, many prototype tests have been performed within the last years on site and in different befriended laboratories. These systems are developed in close collaboration with in-kind partners in Finland, France, Poland, Russia, Sweden, and Slovakia.

ANTIPROTON PRODUCTION

Antiprotons are generated in inelastic collisions of high energy Protons with nucleons of a target nucleus at rest. At the future FAIR facility a Proton beam from the SIS100 with a kinetic energy of 29 GeV and a maximal intensity of $2.5x10^{13}$ ppp will be used for pbar production [9,10]. Every 10 seconds $2.5x10^{13}$ protons will be accelerated in SIS100 to 29 GeV and a bunch of 50 ns duration will be formed. Antiprotons will be produced in collision of these Protons with a metal target. The first ion optical element following the Anti-proton production target is a magnetic collector, i.e. a magnetic horn. A magnetic horn similar to that presently operated at CERN [11] will be designed and built for FAIR.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-MOZGBF2

Like at CERN, the horn will be pulsed with 400 kA. The separation of the Antiprotons from primary Protons and other secondary particles will be provided by a dipole magnet with a bending angle of 15 degrees. The beam line starting after the magnetic horn, transfers Antiprotons to the collector ring CR. In this line, transverse and momentum collimation takes place. The Antiprotons within the separator's acceptance (ϵ_x=ϵ_y=240 πmm mrad, $\Delta p/p$=±3%), will be transferred to the CR with nearly 100% transmission. Using a production yield of 1.8x10^{-5} pbar/p after the target [9] we expect an overall yield of 7x10^{-6} cooled antiprotons per primary Proton.

COLLECTOR RING CR

The Collector Ring (CR) [12, 13] is a dedicated storage ring for fast cooling of secondary ion beams generated in the Super-FRS and the Antiproton separator. The accelerator chain, consisting of the p-linac, SIS18, SIS100, the Antiproton separator, CR and HESR generates the Antiprotons for the PANDA experiment [10]. In order to accept hot secondary ions with intensities up to 10^8 and to perform efficient stochastic cooling of these ions, the CR has been designed for a very large acceptance (A=240 mm mrad, dp/p_{max}=6%). For APPA experiments in the HESR, the CR can be used to transport primary beams from SIS18 or SIS100 to the HESR. The CR will be operated at a maximum magnetic rigidity of 13 Tm, which corresponds to an ion energy of 740 MeV/u and 3 GeV for antiprotons. No acceleration or deceleration is foreseen. After injection, a three-step beam manipulation is planned: 1. fast bunch rotation; 2. stochastic cooling; and 3. re-bunching and extraction to the HESR. These steps are relevant for both, Antiproton and rare isotope beams. The CR is planned to be used as a tool for fast mass measurements as well. At FAIR, a variety of new short-lived nuclides will be generated with the Super-FRS by using projectile fragmentation or Uranium fission reactions. For this purpose special optical modes have been developed for generating isochronous condition [14]. The mass measurements in an isochronous system are based on the time-of-flight (TOF) of nuclei with different mass-to-charge ratio. To have a high mass resolving power (more than 106) the isochronous ring must be perfectly adjusted to be operated at the transition point γ_{tr} (characteristic for a storage ring) equal the Lorentz factor γ and the influence of the unwanted effects must be minimized.

Status

Presently the CR ring is constructed in a joint effort of two institutes: GSI in Germany and Budker Institute of Nuclear Physics, BINP in Russia. GSI develops the stochastic cooling system [15]; the broad band RF debuncher system [16]; the control system and components for the beam instrumentation system. As Russian in-kind to FAIR, the BINP will deliver all magnets, power supplies, the vacuum system and major parts of the beam diagnostic devices. The design of the large aperture dipole magnet has been completed and a FOS magnet is presently under construction at BINP. The first of the series RF debuncher MA cavities has been manufactured and delivered to GSI/FAIR in 2017. After successful SAT, the cavity has been accepted and the series production released. Major parts of the stochastic cooling system have been developed and their production will be launched in 2018.

HIGH ENERGY STORAGE RING HESR

The High-Energy Storage Ring (HESR) is planned as an Antiproton storage ring in the momentum range from 1.5 to 15 GeV/c and is primarily used for hadron physics experiments with a pellet target and the PANDA detector. The HESR with a circumference of 576 m consists of a FODO lattice of normal-conducting dipole and quadrupole magnets. To achieve dispersion free straight sections, an option with dispersion suppression at the exit of each arc is foreseen. To cover the whole energy range, a flexible adjustment of the transition energy and the corresponding tr value is foreseen [17]. An important feature of this new facility is the combination of phase-space cooled beams and thick internal targets (e.g. pellet targets) which results in demanding beam parameter requirements for the two operation modes: a) high luminosity mode with peak luminosities of up to $2 \cdot 10^{32}$ $cm^{-2}s^{-1}$ and b) high resolution mode with a relative momentum spread in the order of a few times 10^{-5}. To reach these beam parameters a very powerful phase-space cooling utilizing high-energy electron cooling and high-bandwidth stochastic cooling is required. Special equipment enables this high performance: a) multi harmonic RF cavities [4], b) high sensitivity stochastic cooling pickups for the frequency range 2-4 and 4-6 GHz, c) powerful beam cooling systems to counteract beam heating (from beam target interaction and intra beam scattering).

Staytus

Most of the components of the HESR are produced and accepted. All dipole and quadrupole magnets have been manufactured. The vacuum chambers have been send to GSI for NEG coating and are presently being integrated into the magnets. About 2/3 of the dipole magnets are ready for installation and have been sent to GSI for interims storage. Ten sextupole and steerer magnets were produced at the Romanian in-kind partner and have been shipped to FZJ. All main quadrupole power converters are manufactured and delivered. A prototype barrier bucket cavity is installed for beam tests in COSY. Both the barrier bucket and acceleration cavities with their final design are under construction. FOS kicker and pick-up tanks are installed in the COSY ring for beam tests. The remaining four tanks are in production. After successful FAT of a prototype, the injection kicker system is presently under manufacturing

ACKNOWLEDGEMENTS

The authors would like to thank the GSI work pack-age leaders, the department heads and all in-kind part-ners and other contributors for their tremendous amount of work and engagement for the realization of the FAIR project.

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2018). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-MOZGBF2

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2018). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

REFERENCES

[1] P. Spiller, K. Blasche, P. Hülsmann, A. Krämer, H. Ramakers, and H. R. Sprenger, "High Intensity Uranium Operation in SIS18", in *Proc. EPAC'04*, Lucerne, Switzerland, paper TUPLT020, p.1180 (2004).

[2] P.J. Spiller, R. Balß, A. Bleile, L.H.J. Bozyk, J. Ceballos Velasco, *et al.*, "Status of the FAIR Synchrotron Projects SIS18 Upgrade and SIS100", in *Proc. 5th Int. Particle Accelerator Conf. (IPAC'14)*, Dresden, Germany, pp. 1857–1860, doi: 10.18429/JACoW-IPAC2014-WEOBA01, 2014.

[3] P. Hülsmann, GSI internal note Nr. 20.02.2017.RRF

[4] *Technical Design Report*, (2008), www.edms.cern.ch/document/994418/1

[5] U. Ratzinger, G. Clemente, C. Commenda, H. Liebermann, H. Podlech, R. Tiede, *et al.* "A 70-MeV Proton Linac for the FAIR Facility Based on CH-Cavities", in *Proc. LINAC'06*, Knoxville, TN, USA, paper TH1004, (2006)

[6] P. Spiller *et al.*, "Optimization of SIS100 Lattice and Dedicated Collimation System", ICFA Advanced Beam Dynamics Workshop on High Intensity and High Brightness Hadron Beams, Bensheim, Germany, (2004).

[7] L. Bozyk, "Entwicklung und Test eines Kryokollimator-Prototypen zur Kontrolle des dynamischen Vakuums im SIS100", PhD thesis at TU Darmstadt (2012).

[8] H. Geissel, H. Weick, M. Winkler, G. Münzenberg, V. Chichkine, M. Yavor, *et al.*, "The Super-FRS project at GSI", *Nucl. Instr. Meth. Phys. Res.*, Sect. B 204, 71 (2003). doi: 10.1016/S0168-583X(02)01893-1

[9] K. Knie, B. Franzke, V. Gostishchev, M. Steck, and P. Sievers, "Concept for the Antiproton Production Target at FAIR", in *Proc. IPAC'12*, New Orleans, LA, USA, paper WEPPD030 (2012).

[10] A. Dolinskii. K. Knie, C. Dimopoulou, V. Gostishchev, S. Litvinov, F. Nolden, and M. Steck, "Antiproton complex at the FAIR project", NIM A 629 (2011) 16-24.

[11] D. Boimond, M. Frauchiger, T. Kurtyka, M. Lubrano di Scampamorte, R. Maccaferri, S. Maury, *et al.*, "Design study of the antiproton decelerator: AD", Internal Report CERN/PS 94-02 (AR) (1994).

[12] A. Dolinskii, D. Berkaev, U. Blell, C. Dimopoulou, O. Gorda, H. Leibrock, *et al.*, "Collector ring project at FAIR", *Phys. Scr.* T166, (2015), doi: 10.1088/0031-8949/2015/T166/014040

[13] O.K. Kester, W.A. Barth, A. Dolinskyy, F. Hagenbuck, K. Knie, R. Maier, *et al.*, "Status of the FAIR Accelerator Facility", in *Proc. 5th Int. Particle Accelerator Conf. (IPAC'14)*, Dresden, Germany, June 2014, paper WEPRO060, doi: 10.18429/JACoW-IPAC2014-WEPRO060, 2014.

[14] A. Dolinskii, H. Geissel, S. Litvinov, F. Nolden, M. Steck, H. Weick, "The CR storage ring in an isochronous mode operation with nonlinear optics characteristics", *Nucl. Instr. and Meth.* B 266, 4579(2008), doi: 10.1016/j.nimb.2008.05.082

[15] F. Nolden, K. Beckert, P. Beller, A. Dolinskii, B. Franzke, U. Jandewerth, *et al.*, "Stochastic Cooling Developments at GSI", *AIP Conf. Proc.* Vol. 821, 177(2006), doi: 10.1063/1.2190108

[16] U. Laier *et al.*, "Design and Commissioning of the RF System of the Collector Ring at FAIR", presented at the 9th Int. Particle Accelerator Conf. (IPAC'18), Vancouver, Canada, Apr.-May 2018, paper WEPML034, this conference.

[17] B. Lorentz, T. Katayama, A. Lehrach, R. Maier, D. Prasuhn, R. Stassen, H. Stockhorst, and R. Tölle, "Antiproton Acceleration and Deceleration in the HESR", in *Proc. IPAC'15*, Richmond, VA, USA, paper THPF030, p.3758 (2015).