BASELINE DESIGN FOR THE FACILITY FOR ANTIPROTON AND ION RESEACH (FAIR) FINALIZED*

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Abstract

In 2001, GSI, together with a large international science community, presented the Conceptual Design Report (CDR) for a new accelerator facility for beams of ions and antiprotons in Darmstadt [1]. This unique facility, now named FAIR Facility for Antiproton and Ion Research, is based on extensive discussions and a broad range of workshops and working group reports, organized by GSI and by the international user communities over a period of several years. Following an in-depth evaluation of the proposal by the German Wissenschaftsrat and its recommendation to realize the facility, the Federal Government gave conditional approval for construction of FAIR in February 2003.

Since then the project has gone through major steps of development and significant progress has been achieved with regard to the scientific-technical and political preparation of the project. The FAIR Baseline Technical Report [2] is the latest result of the process.

INTRODUCTION

To coordinate all preparatory activities for FAIR, an international committee structure, led by the International Steering Committee (ISC) was established with representatives of 13 countries so far: China, Finland, France, Germany, Greece, India, Italy, Poland, Russia, Rumania, Spain, Sweden, and United Kingdom. These countries signed a Memorandum of Understanding for FAIR, which provides the framework for scientific-technical cooperation and expresses the explicit intent to participate in the construction and science use of FAIR.

ISC formed two working groups, the Working Group for Scientific and Technical Issues (STI) and the Working Group on Administrative and Funding Issues (AFI). These groups formed sub-groups: scientific, technical and administrative advisory committees to scrutinize the research programs, the facility design, cost and legal issue, etc.

STI, with the help of the Program Advisory Committee, evaluated and rated the proposed research programs and experimental facilities. Thus a detailed plan was worked out to define the experiments of the base program, which are included in the core facility funding.

In parallel the proposed accelerator facility was technically evaluated with the help of a technical advisory committee (TAC) and various expert sub-groups. From this evaluation process, beam specifications were refined and the topological layout of the facility was determined.

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After setting up a costing scheme by AFI, STI, assisted by two cost review expert panels, evaluated the costs for the accelerators and experimental facilities, as well as for civil construction. First estimates of the operation costs of the facility where derived as well. The results on costs and schedule were specified and handed to ISC, together with the 3500 pages FAIR Baseline Technical Report, in April 2006.

The AFI working and its sub-committees are preparing legal contracts for contributions to be made by the partner countries. According to present considerations, a limited liability company, FAIR GmbH, will be take project ownership. Cooperating closely with GSI during construction and operation, optimal use will be made of the know-how and expertise of the hosting laboratory. Further organisational details will be stipulated in the Convention, Articles of Association and the By-Laws und which FAIR will be set up.

LAYOUT AND KEY PROPERTIES

The concept of the FAIR Accelerator Facility has been developed by the international science community and the GSI laboratory. Its goal is to provide stable beams and radioactive nuclei as well as antiprotons in a wide range of intensities and energies with optimum beam qualities for a multifaceted forefront science program.

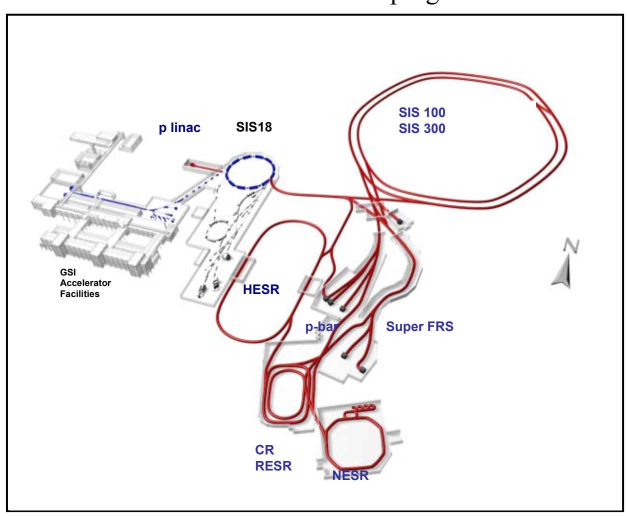

Figure 1: Layout of the existing accelerators at GSI (UNILAC, SIS18, ESR) and the new FAIR facilities: the superconducting synchrotrons SIS100 and SIS300, the collector ring CR, the accumulator ring RESR, the new experimental storage ring NESR, the superconducting fragment separator Super-FRS, the proton linac, and the high energy antiproton storage ring HESR.

Table 1: Key parameters and features of the synchrotrons and cooler/storage rings

Ring	Circumference [m]	Beam rigidity [Tm]	Beam energy [GeV/u]	Specific Features
Synchrotron SIS100	1083.6	100	2.7 for U^{28+} 29 for p	**Fast pulsed superferric magnets up to B=2 T, dB/dt=4 T/s, bunch compression to ~60 ns of $5 \cdot 10^{11}$ U ions, fast and slow extraction, $5 \cdot 10^{-12}$ mbar operating vacuum**
Synchrotron SIS300	1083.6	300	34 GeV/u for U^{92+}	**Pulsed superconducting cosθ-magnets up to B=6 T, dB/dt=1 T/s, slow extraction of ~ $3 \cdot 10^{11}$ U-ions per sec. with high duty cycle, $5 \cdot 10^{-12}$ mbar operating vacuum**
Collector Ring CR	212	13	0.740 for A/q=2.7 3 for antiprotons	**Acceptance for antiprotons: 240 x 240 mm mrad, $\Delta p/p = \pm 3 \times 10^{-2}$, fast stochastic cooling of radioactive ions and antiprotons, isochronous mass spectrometer for short-lived nuclei**
Accumulator Ring RESR	245	13	0.740 for A/q=2.7 3 for antiprotons	**Accumulation of antiprotons after pre-cooling in the CR, fast deceleration of short-lived nuclei, ramp rate 1T/s**
New Experimental Storage Ring NESR	222	13	0.740 for A/q=2.7 3 for antiprotons	**Electron cooling of radioactive ions and antiprotons with up to 450 keV electron-beam energy, precision mass spectrometer, internal target experiments with atoms and electrons, electron-nucleus scattering facility, deceleration of ions and antiprotons, ramp rate 1 T/s**
High-Energy Storage Ring HESR	574	50	14	**Stochastic cooling of antiprotons up to 14 GeV, electron cooling of antiprotons up to 9 GeV; internal gas jet or pellet target**

The concepts of FAIR substantially are built on seminal developments made over the last 15 years at GSI and at other laboratories worldwide in acceleration, accumulation and phase-space cooling of high-energy proton and heavy-ion beams. Adopting new results, e.g. in fast-pulsed superconducting (sc) magnet design, in phase-space cooling by stochastic and electron cooling of ion beams, and in ultra-high vacuum technology, the FAIR Baseline Technical Report was derived. Figure 1 depicts a schematic layout of the new facility. The double-synchrotron SIS100/300 is the heart of the FAIR accelerator facility. Adjacent to the synchrotrons is a complex of storage ring-cooler rings and experiment stations, including a superconducting nuclear fragment separator (Super-FRS) and an antiproton production target. Key parameters and features of the individual rings are listed in table 1.

FAIR will supply radioactive ion beams (RIBs), antiprotons and the full spectrum of stable ion beams with unprecedented intensities and beam quality for precision experiments.

An important feature of the facility is truly parallel operation, i.e. running up to four research programs in parallel due to the intrinsic cycle times of the accelerator and cooler-storage rings. This allows an effective and cost-effective multidisciplinary research program, covering the fields of QCD, nucleus-nucleus collision at high baryon density, nuclear structure and nuclear astrophysics research with nuclei far off stability, high-density plasma physics, atomic and material sciences, radio-biological studies and other application-oriented research.

THE FAIR SYNCHROTRONS

The 'working horse' of the FAIR complex is a superconducting double-synchrotron, named SIS100 and SIS300, with a circumference of 1084 m and magnetic rigidities of 100 and 300 Tm, respectively. The two synchrotrons will be built on top of each other in a underground tunnel. Figure 3 depicts a cross section of the SIS100/300 tunnel.

The synchrotron magnetic lattice will be constructed from fast-pulsed superconducting magnets to allow for a compact design to minimize both construction and operating costs.

For the highest intensities the 100 Tm synchrotron will operate at a repetition frequency of 1 Hz with ramp rate of up to 4 T/s in the bending magnets. SIS100 will deliver pulses of heavy ions and intense proton beams with $5 \cdot 10^{13}$ particles per spill at an energy of up to 30 GeV, allowing for efficient antiproton production.

The 300 Tm machine will operate at bending fields of 6 T at ramp rates of up to 1 T/s. Using high charge states (e.g. U^{92+}), heavy ion beams will be accelerated in SIS300 to energies of 35-45 GeV/u. The maximum intensity of 2×10^{10} per cycle for these beams allows a long spill of up to 100 s, while keeping a sufficient average intensity. Furthermore, SIS300 can be operated as a stretcher. Both, primary and secondary (radioactive and antiproton) beams are then injected, cooled and stored in a system of storage rings with internal targets and in-ring experiments. Based on the phase-space cooling techniques applied in the storage rings, the future program will broadly take advantage of the small emittance and low momentum spread of beams in high precision experiments.

The FAIR synchrotrons will compress heavy-ion and proton beams down to very short bunch lengths required for the production and subsequent storage and efficient cooling of exotic nuclei (~60 ns) and antiprotons (~25 ns).

With the double-synchrotron facility, continuous beams with high average intensities of up to $3{\cdot}10^{11}$ ions per second are provided at energies of 1 GeV/u for heavy ions, either directly from the SIS100 or by transfer to, and slow extraction from the 300 Tm ring. The SIS300 will provide ion beams of maximum energies around 45 GeV/u for Ne^{10+} beams and close to 35 GeV/u for fully stripped U^{92+} beams, respectively.

The maximum intensities in this mode are close to $1.5{\cdot}10^{10}$ ions per spill. For nucleus-nucleus collisions, intensities between 10^8 and 10^9 per second are provided. The high-charge state, high-energy beams can be extracted over extended periods, e.g. over a time interval of 10 - 100 seconds, as continuous beam. Slow extraction from the SIS100 is an option for extending the flexibility of parallel operation for experiments.

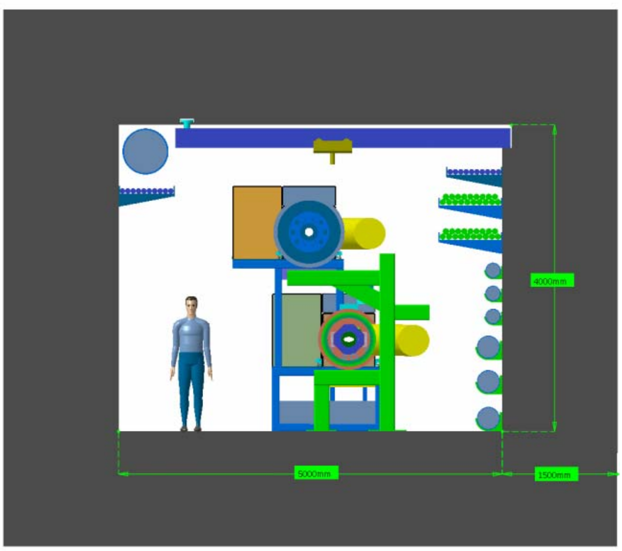

Figure 2: Cross-section to the double-synchrotron tunnel, with both machines on top of each other. The tunnel dimensions are 5 m in width and 4 m in height.

THE FAIR STORAGE RINGS

The accelerator facility is complemented by a system of cooler-storage rings:

The collector ring (CR) for stochastic cooling of radioactive ion or antiproton beams from the production targets. In addition, this ring offers the possibility for mass measurements of short-lived ions, by operating in isochronous mode.

The accumulator ring (RESR) for accumulation of antiprotons after pre-cooling in the CR, and for the fast deceleration of short-lived nuclei.

A new experimental storage ring (NESR) for experiments with ions and antiprotons. Equipped with stochastic and electron cooling will house also a variety of experimental devices, including a precision mass spectrometer, internal target experiments with atoms and electrons, and an electron-nucleus scattering facility. The NESR will be capable to decelerate ions and antiprotons and to extract them for the low-energy antiproton and heavy ion research area (FLAIR).

The high-energy storage ring (HESR) is optimized for antiprotons of energy up to 14 GeV. This ring will operate with an internal target and associated detector set-up. It will be equipped with a high-energy electron cooler (electron energies up to 4.5 MeV) and a stochastic cooling system to compensate for beam degradation due to target interaction and intra-beam scattering.

This unprecedented combination of accelerators and storage rings aims for 100-fold higher primary ion beam intensities than the present GSI-system and, in combination with the superconducting fragment separator (Super-FRS), an increase of radioactive beam intensities by up to 4 orders in magnitude will be reached. FAIR will provide high-luminosity antiproton beams, high-energy proton and ion beams (about 20 times higher than available at GSI presently), and short ion pulses with energies up to 100 kJ.

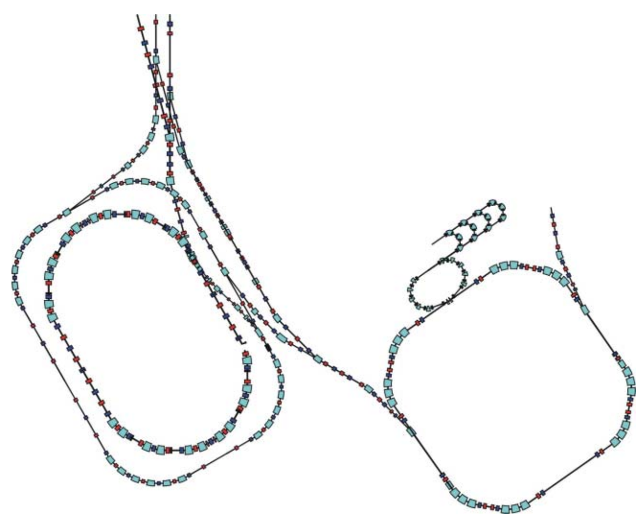

Figure 3: Top view of the CR/RESR and NESR accumulator and experimental storage rings with the electron ring ER equipped with an independent injector.

REFERENCES

[1] An International Accelerator Facility for Beams of Ions and Antiprotons, CDR, GSI 2001.

[2] FAIR Baseline Technical Report (FBTR), GSI 2006.