THE FUTURE GSI FACILITY: BEAMS OF IONS AND ANTIPROTONS

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Abstract

A brief description is given of the conceptual layout, technical aspects and overall performance characteristics, some R&D, and the main research areas of the future international facility for beams of ions and antiprotons to be constructed at the GSI Laboratory.

INTRODUCTION

With strong participation from its users and the international science community, GSI over the past few years has developed plans [1] for a major new international accelerator facility, using the present GSI system as an injector (Figure 1). Following an evaluation of the proposal by the Wissenschaftsrat, the science advisory committee to the German federal government, and its recommendation to construct the facility [2], the government has recently given approval for construction under two conditions: that a technical plan be developed for staged construction, and that 25% of the total cost come from international partners [3].

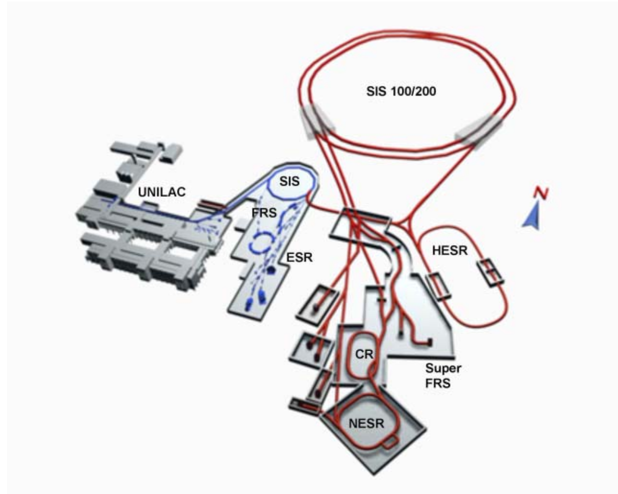
The central goals for the new facility are to substantially increase the intensities of ion beams, their energy, and to provide secondary beams with unique characteristics: intense beams of short-lived nuclei up to 1-2 GeV per nucleon and energetic, high-quality beams of antiprotons, both with the options for storage, beam cooling and in-ring experimentation.

FACILITY DESCRIPTION

The intensity of 'low-energy' ion beams, i.e. beams around 1-2 GeV per nucleon, will be increased by two to three orders of magnitude over present (two orders in space charge limit, up to three orders over actual present performance). This will be achieved by increasing the cycling rate of the injector, the present synchrotron SIS18, by a factor ten. A second factor arises from reducing the charge state of, for example, uranium beams from 73 to around 25. Since the space charge limit enters quadratically with charge state, this gives close to a second factor of ten.

The most important consequence of this will be the increase in secondary beam intensities, i.e. beams of short-lived nuclei ('radioactive beams') by three to four orders of magnitude. This comes from the fact that in addition to the primary intensity increase, collection efficiency and storage of secondary beams will be substantially improved.

Ion beams of high charge-state and thus higher energy, up to 30-35 GeV per nucleon for medium to heavy masses, will also become available at substantially increased intensities over present facilities.



Primary Beams

- 10^{12}/s; 1.5 – 2 GeV/u; $^{238}U^{28+}$
- Factor 100-1000 over present in intensity
- $4x10^{13}$/s 30 GeV protons
- 10^{10}/s $^{238}U^{73+}$ up to 25 (- 35) GeV/u

Storage and Cooler Rings

- Cooled radioactive beams
- e – A collider
- 10^{11} stored and cooled 3(0) - 15 GeV antiprotons

Secondary Beams

- Broad range of radioactive beams up to 1.5 - 2 GeV/u; up to factor 10 000 in intensity over present
- Antiprotons 3(0) - 30 GeV

Key Technical Features

- Cooled beams
- Rapidly cycling superconducting magnets

Figure 1: The existing GSI facility (left) with the linear accelerator UNILAC, the heavy-ion synchrotron SIS18, the fragment separator FRS and the experiment storage ring ESR; and the new project (right) with the double-ring synchrotron SIS100/200, the high-energy storage ring HESR, the collector ring CR, the new experiment storage ring NESR, the super-conducting fragment separator Super-FRS and several experimental stations. The present UNILAC/SIS18 complex serves as injector for the new double-ring synchrotron.

An important new development at GSI will be the availability of high-energy, high-quality antiproton beams over a broad range of beam energies, from thermal energies up to 15 GeV.

A characteristic feature of the new facility is the broad usage of storage and beam-cooler rings (see Figure 1). Stochastic and electron-beam cooling are widely used, together with internal targets, which open a range of new opportunities for high-resolution and precision experiments. In particular electron-beam cooling, originally developed to raise luminosities in proton-proton [4] and proton-antiproton collider rings [5] (but never really used at colliders pushing the energy frontier simply because the needed electron-beam energies and powers were out of reach) have proven to be superb tools for beam handling and beam improvements at the low-energy antiproton and proton rings, and most recently at ion storage rings in particular the high-energy ion storage ring ESR at GSI [6].

Beam cooling, storage-ring beam handling schemes, and in-ring experimentation are key features of the new facility. Some of these aspects, and in addition research and development into rapidly-cycling superconducting magnets and vacuum issues at very high beam currents, are discussed in other presentations to this conference [7,8].

The research program proposed for the future facility is broad and covers several areas of study into the structure of matter. It emphasizes the regime of the strong force (quarks, nucleons, nuclei, and quark and nuclear matter), but also has strong components into matter-ion interactions at the material science level, in particular in plasma physics and in atomic physics with highly stripped relativistic ions.

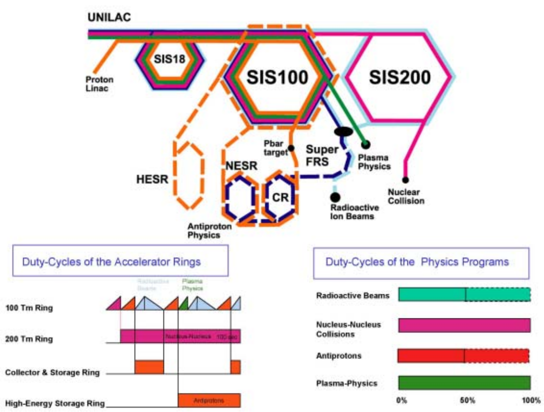


Figure 2: Schematic illustration of the highly efficient parallel operation at the new facility. In the example shown, all four different scientific programs are served in parallel: A proton beam (orange), accelerated in SIS100, produces antiprotons (orange dashed) in the antiproton target-station, which are then collected, accumulated and cooled in the CR/NESR storage-ring combination, injected and accelerated in SIS100, and then transferred to the HESR for in-ring experiments. In parallel, i.e. during the fraction of the SIS100 super-cycle not needed for the protons, a primary ion beam (blue) is accelerated in SIS100 and slowly extracted to the Super-FRS to produce radioactive secondary beams (blue dashed) for fixed target experiments. (Alternatively the radioactive beams could be sent to the CR and NESR instead of the antiprotons after fast extraction from SIS 100). In addition, every 10-100 seconds a high-energy heavy-ion beam (red) is accelerated in SIS100/200 and slowly extracted for nuclear collision experiments; these experiments require a lower beam intensity than the maximum possible from the accelerator. Moreover, intense beam pulses (green) are provided every few minutes for plasma physics experiments that require very low repetition rates.

The reasons for the broad research program are basically twofold: first, the methods and goals of the science exploring the (microscopic) structure of matter are often similar at the different levels of the hierarchy, and thus relate to each other in a synergetic way.

Second, though, to achieve the challenging goals in beam intensity and overall accelerator performance asked for by today's research programs, large (and very costly) facilities need to be built (including the present project). It seems prudent simply from considerations of the cost/benefit ratio that such major facilities can serve several science fields or research communities simultaneously. The present facility, due to the wide use of rings and the resulting intrinsic cycling times and storing possibilities, leans itself well to a highly parallel and multiple use. This is illustrated in Figure 2.

THE RESEARCH PROGRAM

An overview of the various research programs, grouped into five categories, is listed in Table 1. It is discussed in detail in the Conceptual Design Report [1] and at various workshops. Here we only repeat some overarching aspects that, to a certain extent, connect the different research areas.

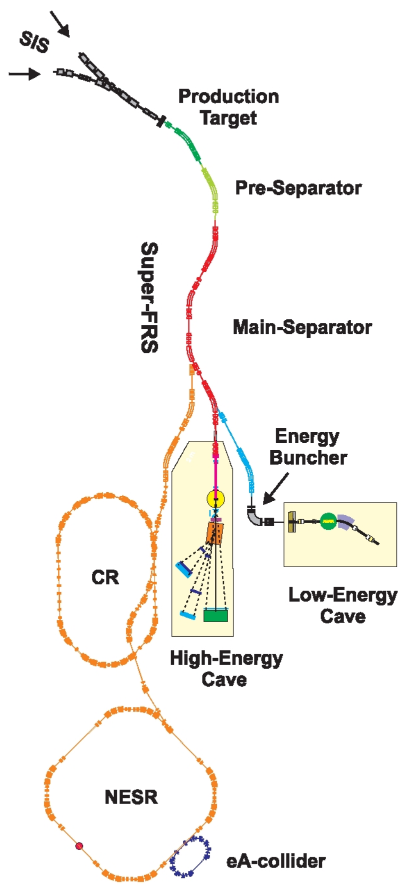


Figure 3: Schematic layout of the proposed Super-FRS exotic nuclear beams facility shown to scale. The three main branches of experimental areas are indicated.

The first goal is to achieve a comprehensive and quantitative understanding of all aspects of matter that are governed by the strong force. Matter at the level of nuclei, nucleons, quarks and gluons is governed by the strong interaction and is often referred to as hadronic matter.

The research goal of the present facility thus encompasses all aspects of hadronic matter, including the investigation of fundamental symmetries and interactions that are relevant for this regime.

The second goal addresses many-body aspects of matter. The many-body aspects play an important and often decisive role at all levels of the hierarchical structure of matter. They govern the behavior of matter as it appears in our physical world.

These two broad science aspects, the structure and dynamics of hadronic matter and the complexity of the physical many-body system, transcend and determine the more specific research programs listed in Table 1.

Table 1: Summary of research areas at the GSI future facility

Research Areas	**Exemplary Topics**	**Facility Aspects**
Structure and Dynamics of Nuclei	Nucleonic matter Nuclear astrophysics Fundamental symmetries	Radioactive Beams
Hadron Structure and Quark-Gluon Dynamics	Non-perturbative QCD Quark-gluon degrees of freedom Confinement and chiral symmetry	Antiprotons
Nuclear Matter and the Quark-Gluon Plasma	Nuclear phase diagram Compressed nuclear/strange matter Deconfinement and chiral symmetry	Relativistic Heavy-Ion Beams
Physics of Dense Plasmas and Bulk Matter	Properties of high-density plasmas Phase transitions and equation of state Laser - ion interaction with and in plasmas	Bunch Compression
Ultra High EM-Fields and Appli-cations	QED and critical fields Ion - laser interaction Ion - matter interaction	Highly-stripped rela-tivistic ions/ Petawatt Laser

The program summarized in Table I builds on the accelerator parameters but also forefront experimental equipment. Examples are shown in Figure 3 for the research with beams of short-lived nuclei (radioactive beams); and in Figure 4 for the High Energy Storage Ring (HESR) and the internal-target PANDA detector, for in-ring experimentation with cooled, high-quality energetic antiproton beams at energies covering the charmed quark region. More information is again found in [1].

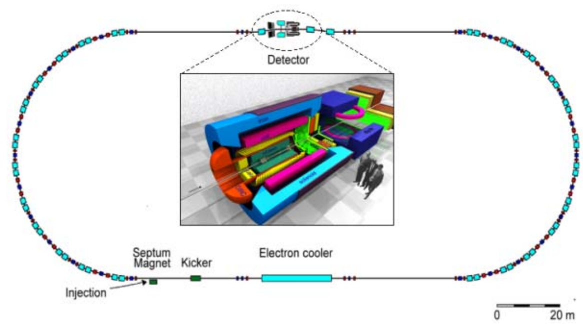


Figure 4: View of the HESR and the PANDA Detector.

REFERENCES

[1] An International Accelerator Facility for Beams of Ions and Antiprotons; Conceptual Design Report, 11/2001; http://www.gsi.de/GSI-Future/cdr/; this report is also available on CD. Mail to press@gsi.de to request a copy.

[2] Press release 24/2002, www.wissenschaftsrat.de/

[3] Press release, 5.2.03, www.bmbf.de/presse01/799

[4] G.I. Budker, Atomnaja Energia, 22, p. 346, 1967

[5] G.I. Budker, Ya.S. Derbenev, N.S. Dikansky , V.I. Kudelainen, I.N. Meshkov, V.V. Parkhomchuk, D.V. Pestrikov, B.N. Sukhina, A.N. Skrinsky, IEEE Trans. Nucl. Sci. NS-22,2093-7(1975)

[6] Contributions to the “11th International Advanced ICFA Beam Dynamics Workshop on Beam Cooling and Instability Damping”, Moscow, 1997, Nucl. Instr. Meth. 391,1 (1997). For a recent review on present and future applications of beam cooling see: Contributions to “Rare Isotope Physics at Storage Rings” - An International Workshop Organized by GSI and RIKEN, Hirschegg, Austria, 2002; the presentations given at that Workshop are available on CD. Mail to press@gsi.de to request a copy.

[7] P. Spiller, contribution to this conference.

[8] B. Franzke, contribution to this conference.