The Future GSI Facility

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I. Introduction

Over the past few years GSI, with strong participation from the European science community, has developed plans for a major new accelerator facility [1]. The conceptual layout, using the present GSI system as injector, is shown in Figure 1. The proposal was evaluated in 2001/2002 by the Wissenschaftsrat, the science advisory committee to the German federal government, which recommended its realization [2]. Based on this recommendation, the German government has recently given approval for construction of the facility, contingent upon two conditions: that a technical plan be developed for staged construction, and that funding for 25% of the total cost come from international partners [3].

II. Facility Characteristics

The central goals for the new facility are to substantially increase the intensities of ion beams, their energy, and to provide energetic beams of antiprotons.

Specifically, 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 intensity). The most important consequence of this will be the increase in secondary ion 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 higher energy, up to 25 - 30(35) GeV per nucleon for medium to heavy masses, will become available at substantially increased intensities over present facilities.

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

A characteristic feature of the new facility (see Figure 1) is the broad usage of storage and beam cooler rings. Stochastic and electron-beam cooling are widely applied and, together with internal targets, open a range of new opportunities in high-resolution and precision experiments. In particular electron-beam cooling, originally developed to increase luminosities in proton-proton [4] and proton-antiproton collider rings [5] (but never really used at colliders that pushed the energy frontier, simply because the necessary 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 also 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 aspects are discussed below and in other presentations to this conference. This presentation will first briefly summarize the overall research program and the technical facility, and then describe the research opportunities with antiproton beams, the theme of this conference.

III. Research Programs

In most general terms, the scientific thrusts of the facility can be summarized by the following broad research goals. 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 that will be pursued at the future facility:

i. investigations with beams of short-lived radioactive nuclei, addressing important questions about nuclei far from stability; areas of astrophysics and nucleosynthesis in supernovae and other stellar processes, and tests of fundamental symmetries;
ii. the study of hadronic matter at the sub-nuclear level with beams of antiprotons, including two key aspects: confinement of quarks and the generation of the hadron masses. They are intimately related to the

existence (and spontaneous breaking) of chiral symmetry, a fundamental property of the strong interaction;

iii. the study of compressed, dense hadronic matter in nucleus-nucleus collisions at high energies;
iv. the study of bulk matter in the high-density plasma state, a state of matter of interest for inertial confinement fusion and astrophysical settings;
v. studies of Quantum Electrodynamics (QED), of extremely strong (electromagnetic) fields , and of ion-matter interactions.

IV. Outline of the Facility

The concept and layout of the new facility (Figure 1) has evolved from the science requirements as follows: substantially higher intensities are achieved, compared to the present system, through faster cycling and, for heavy ions, lower charge state which enters quadratically into the space charge limit. The reduced charge state, and still a desired energy of up to 1.5 AGeV for radioactive beam production, requires a larger magnetic bending power. These aspects are fulfilled by the SIS100 synchrotron.

It also generates intense beams of energetic protons, up to 30 GeV, and from these antiprotons. Heavy ion beams of high energy, i.e. 25-30(35) AGeV, are generated using ions in a high charge state plus the additional, somewhat slower but still rapidly cycling SIS200 synchrotron ring. The intensity required for these beams allows for long spills. Similarly, the SIS200 can be used as a stretcher for radioactive beams.

Both, primary and secondary beams can be injected, cooled and stored in a system of rings with internal targets and in-ring experimentation. Rings may be shared for uses with different beams. Based on the developments and excellent experiences with cooled beams at the present GSI facility, the future program will broadly take advantage of this aspect of beam handling. More details about the beam characteristics can be found in the CDR [1].

V. Antiprotons at the new Facility

The new facility to be constructed at GSI is based on various workshops and discussions that explored a wide range of rather diverse options and technical schemes. From these the consolidated scheme of the facility and its research program was built, as summarized above and described in more detail in the Conceptual Design Report [1].

One of the important inputs was a letter of intent [7] and subsequent forums and discussions that proposed the physics program with antiprotons. The core activity is centred at the High Energy Storage Ring (HESR) (see Figures 1 and 2), where electron-beam cooled antiproton beams of highest quality are available over the full momentum range from 3 to 15 GeV/c for in-ring experimentation. An overview of the associated research goals, technical issues, and the challenging in-ring PANDA detector system is given in the talk by J. Ritman to this conference [8].

Beyond the central HESR antiproton program several other interesting areas of study with antiproton beams are under discussion, some of which were newly presented at this conference (Figure 2). These additional opportunities arise from the fact that the antiprotons will be generated in a system of production target and a subsequent collector and storage ring system that provide for efficient and high intensity cooled low-energy antiprotons. These antiproton beams will have about 3 GeV/c momentum. However, the rings can also decelerate stored ions (foreseen for the radioactive beams, but this can as well be applied to the antiproton beam).

Secondly, there are plans to slow down radioactive ions, extract, then decelerate them further to thermal energies, and then store them in ion traps. Again, this system can also be adopted to prepare antiprotons at rest in a trap. This is discussed in more detail in the talk to this conference by W. Quint [9].

Further, there is a an experimental ring planned for electron scattering from radioactive nuclei in a collider mode, with the ions circulating in the NESR storage ring (see Figure 1). This would allow, in principle, antiproton scattering on nuclei to determine neutron and proton radii from annihilation cross sections. This was discussed in the talk by P. Kienle to this conference [10].

Finally, I want to mention another opportunity that would use leptons to scatter from antiprotons. Using the electron scattering ring to collide positrons with antiprotons stored in the NESR, provides an opportunity to study form factors and some aspects of structure functions around 1 GeV center-of-mass energy in the CPT-mirrored system of electron-proton collisions. This would extend CPT tests beyond the presently conceived tests involving system-integrated observables (such as energy states or magnetic moments etc) to more detailed (differential) structure functions that might open interesting new opportunities for CPT tests. Of course, the sensitivity of these structural tests is much lower than the one involving integrated observables from precision spectroscopy.

In any case, the future GSI facility will provide new opportunities in antiproton physics, with parameters that open interesting prospects in several areas of research. This can be done in a highly parallel mode with the other programs because of the highly modular system of storage/cooler and experimentation rings. This leads to a synergy with regard to cost-effectiveness but also with respect to possible intellectual overlaps and interconnections between the different areas of research. The details of the highly parallel operation and its consequences are described in detail in the Conceptual Design Report [1].

Many have contributed to the project, from within GSI and from the international science community, as listed in [1]. I want to take also this opportunity to express special thanks to everyone involved.

References

[1] An International Accelerator Facility for Beams of Ions and Antiprotons; Conceptual Design Report, November 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] Wissenschaftsrat, Press Release 24/2002, November 18, 2002, http://www.wissenschaftsrat.de/

[3] BMBF, Press Release from February 5, 2003; http://www.bmbf.de/presse01/

[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] H. Koch et al., Letter-of-Intent "Construction of a GLUE/CHARM Factory at GSI", GSI Informal Report 1999

[8] Ritman et al., contribution to this Conference

[9] W. Quint, contribution to this Conference.

[10] P. Kienle, contribution to this Conference

Figure Captions

Figure 1: Facility layout and characteristics

Figure 2: Antiproton research opportunities at the future facility