ULTRA-LOW ENERGY ANTIPROTONS AT FLAIR

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Abstract

The Future Accelerator Facility for Beams of Ions and Antiprotons at Darmstadt will produce the highest flux of antiprotons in the world. So far it is foreseen to accelerate the antiprotons to high energies (3-15 GeV) for meson spectroscopy and other nuclear and particle physics experiments in the HESR (High Energy Storage Ring). Within the planned complex of storage rings, it is possible to decelerate the antiprotons to about 30 MeV kinetic energy, opening up the possibility to create low energy antiprotons. In the proposed FLAIR facility [1] the antiprotons shall be slowed down in a last step from 300 keV to 20 keV in an **u**ltra-low energy electrostatic **s**torage **r**ing (USR) for various in-ring experiments as well as for their efficient injection into traps. In this energy range - especially if one thinks about realizing a real multi-purpose facility with not only antiprotons, but also various highly-charged radioactive ions to be stored and investigated - electrostatic storage rings have clear advantages compared to their magnetic counterparts. In case one envisions to even approach the eV range, electrostatic machines are the only possible choice. This contribution presents the layout and design parameters of the USR.

1 INTRODUCTION

The deceleration of the antiprotons from the HESR energy of 30 MeV down to ultra-low energies of only a few keV has to be realized in a two steps.

First, energy variation down to 300 keV is done in a magnetic storage ring (LSR), before the final deceleration in the USR. Aiming to be a true multi user facility, the ring should provide an antiproton beam that can be used by various in-ring and external experiments "at the same time", i.e. from bunch to bunch, the different experiments may be served at different energies of the antiprotons, different intensities and beam characteristics (bunched, slowly extracted quasi-dc operation).

High luminosity, low emittance and low momentum spread are some of the main characteristics of the electron-cooled antiproton beam that shall be achieved and that the various experiments may take advantage of. Some experience is available on the international scene and electrostatic storage rings in Denmark [2] and Japan [3] could already prove the benefits of these machines for a variety of research areas. Various geometrical shapes can be realized [4], where the size of the machine is mainly determined by the size of the electron cooler and the experimental sections.

2 RING LATTICE

The declared design goal for a machine dedicated to the cooling, deceleration and storage of antiprotons was to keep the lattice as simple as possible, while still enabling in-ring experiments as well as experiments with extracted beams.

A compact machine with an overall size of only 6 x 6m can fulfill these requirements.

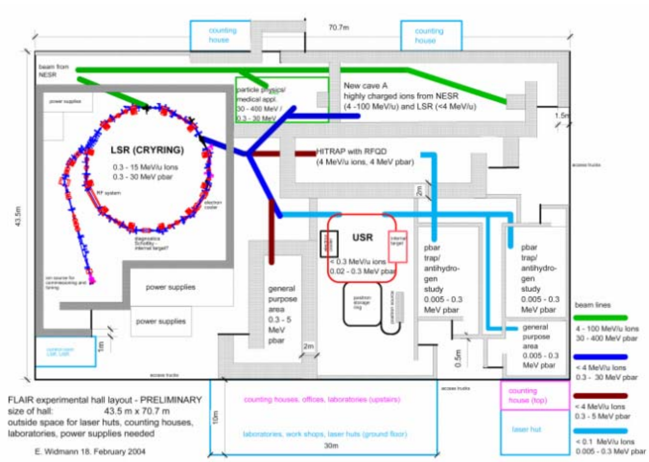

Figure 1: Overview of the FLAIR facility.

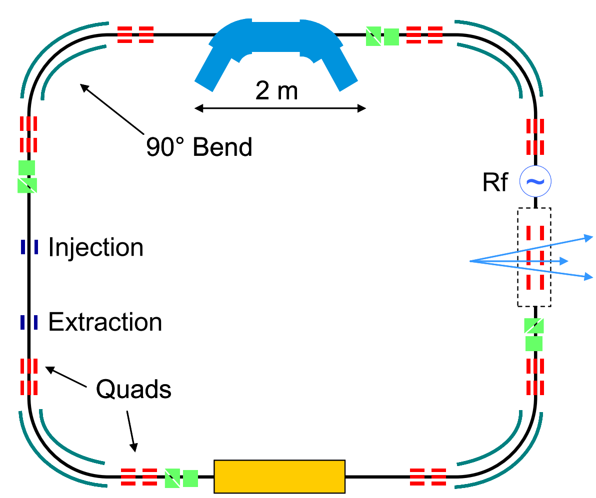

Figure 2: Overview of the ultra-low energy storage ring (USR) of the proposed FLAIR facility.

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Injection is done with an additional fast inflector where the ions are bent towards the design orbit. In each of the corner sections, a 90° cylinder deflector guides the particles with a waist in the centre, Fig. 3. Comparable to other machines [5], control of the transverse dimensions is done with electrostatic quadrupole doublets placed in front of and after each bending section. In addition, a deflector for beam extraction is integrated into the lattice, two experimental sections, where e.g. a reaction microscope and an electron cooler can be integrated – the latter determining the size of the storage ring.

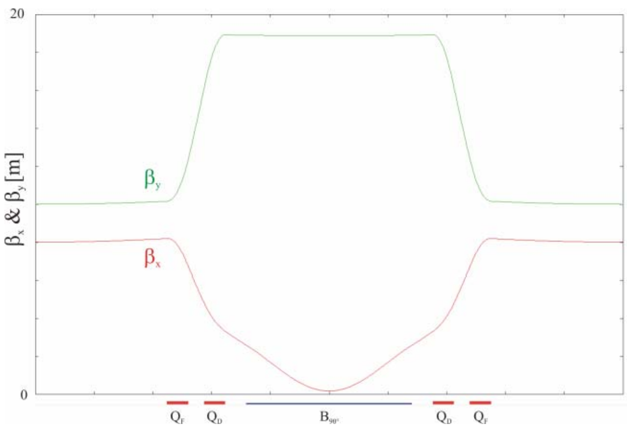

Figure 3: Calculated beta functions in the horizontal and vertical direction for a quarter ring section.

At low energies, the incoherent tune shift limits the maximum number of antiprotons that can be stored in the machine. Assuming a tolerable tune shift of ΔQ=0.1, 10^7 antiprotons shall be stored in the USR, leading to an effective rate for in-ring experiments of $1 \cdot 10^{12}$ 1/s. For external experiments, like ion traps, a small emittance and a small momentum spread beam of $5 \cdot 10^5$ antiprotons/s at the lowest energy of 20 keV can be extracted from the machine.

The design parameters are summarized in table 1.

3 BEAM COOLING

Electron cooling reduces the diameter and the divergence of the stored ion beam and, in connection with rf bunching of the stored beam, can produce short ion pulses as desirable for measurements with the in-beam reaction microscope. The electron cooling technique employs an electron beam moving at the same average velocity as the ion beam over a part of the closed ion orbit to damp the ion motion in the storage ring.

At the 300-keV maximum ion energy of the USR, electron cooling of a stored antiproton beam requires an electron beam energy of about 165 eV. Low electron energies of only a few eV will be required for cooling antiproton beams at the desired lower energy limit around 20 keV.

Establishing efficient phase-space cooling with electron beams of few-eV energies is one of the challenges in the USR project. In contrast to electron cooling in the magnetic storage rings operating at higher beam velocities, the electrical power transported by the electron beam will be extremely low (ranging from ~1 W at the highest electron energy down to <1mW at 5 eV); moreover, only a low magnetic guiding field (<10 mT) is required. The design of the cooler is done at MPI-K and based on the experience with the TSR cooler [6, 7].

Table 1: Summary of the ring parameters

General Parameters	
Energy range	20 keV – 300 keV
Circumference	22.28 m
Base pressure	$< 5 \cdot 10^{-11}$ mbar
90° deflectors	
Height	160 mm
Radii	970 mm and 1030 mm
Shield Distance	15 mm
Voltage |U|	< 20 kV
Quadrupoles	
Length	200 mm
Distance between lenses	150 mm
Aperture Radius	50 mm
Shield Distance	10 mm
Voltage	+/- 6 kV
Steerer Length	100 mm
Steerer Plate Distance	120 mm
antiproton rates	
space charge limit (20 keV)	$1 \cdot 10^7$
effective rate (20 keV)	$1 \cdot 10^{12}$ 1/s
extracted rate (20 keV)	$5 \cdot 10^5$ 1/s

Ultimate cooling times in both transverse and longitudinal direction were estimated based on existing measurements. However, a large uncertainty remained since especially at the lowest energies, where one is in the linear region of the cooling force, theoretical predictions seem to be less reliable.

Therefore, systematic measurements with protons at low energies started recently at the TSR. Fig. 4 shows the measured transverse cooling times of 480 keV protons averaged over 20 injections. The magnetic rigidity in the storage ring was 0.1 Tm and thus only one third of the lowest rigidity ever used in the TSR before !

The measured cooling time of τ=1s fits nicely into the estimated values. More measurements will be done within 2004.

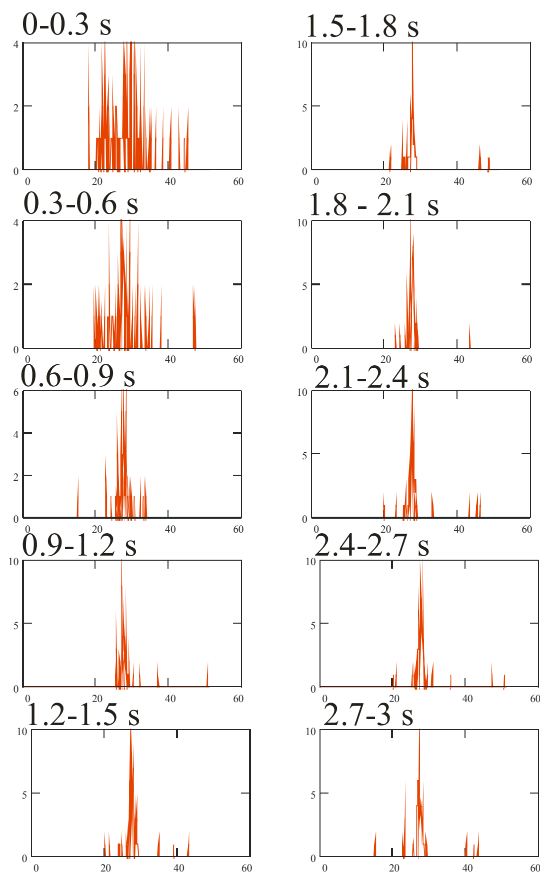

Figure 4: Measured transverse cooling times for a 480 keV proton beam. The signal is averaged over 20 injections.

4 OPTIONS

The future GSI facility offers not only a fascinating environment for physics with low-energy antiprotons, but also great possibilities in the field of highly charged radioactive ions. Without needing to change the lattice of the machine, highly charged ions could be stored and decelerated in the USR as well.

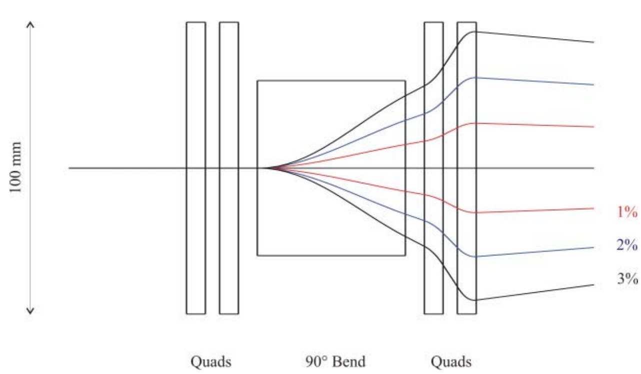

Figure 5: $|\Delta q|/q$=1%...3% separation in the cryogenic storage ring as calculated with COSY infinity.

In this case, the life time is limited by electron capture and in order to achieve reasonable life times in the order of several seconds, vacuum pressures below 10^{-13} mbar have to be realized, bringing the technical demands of the USR close to the cryogenic storage ring at MPI-K [5].

Another option foresees in-flight production of anti-hydrogen by merging the low-energy antiproton beam with a positron beam. The neutral particle could leave the machine through small openings in the deflectors at the end of the straight sections and thus no major changes in the ring design would be necessary. Both options are at present subject to further analysis.

5 OUTLOOK

The ultra-low energy storage ring marks a significant evolution step from existing electrostatic storage rings. Being an energy variable machine for antiprotons and possibly for highly charged radioactive ions, requiring nanosecond pulse lengths for in-ring experiments, a number of new technical challenges have to be solved, making the machine conditional on the success of the cryogenic storage ring at MPI-K, where these topics will be approached for the first time.

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