LAYOUT OF THE USR AT FLAIR

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Abstract

The **F**acility for **L**ow-energy **A**ntiproton and **I**on **R**esearch (FLAIR) and a large part of the wide physics program decisively rely on new experimental techniques to cool and slow down antiprotons to 20 keV, in particular on the development of an **u**ltra-low energy electrostatic **s**torage **r**ing (USR). The whole research program connected with anti-matter/matter interactions is only feasible if such a machine will be realized.

For the USR to fulfil its key role in the FLAIR project, the development of novel and challenging methods and technologies is necessary: the combination of the electrostatic storage mode with a deceleration of the stored ions from 300 keV to 20 keV, electron cooling at all energies in both longitudinal and transverse phase-space, bunching of the stored beam to ultra-short pulses in the nanosecond regime and the development of an in-ring reaction microscope for antiproton-matter rearrangement experiments. In this contribution, the layout and the expected beam parameters of the USR are presented and its role within FLAIR described.

INTRODUCTION

Electrostatic storage rings have proven to be a valuable tool for molecular and atomic physics in the low energy regime. Around some tens of keV, they allow avoiding problems related to hysteresis effects and remanence of magnetic fields.

Today only three such machines exist, all of them having a comparable, compact racetrack-shape layout and working at a fixed energy of 20 keV [1, 2] or 30 keV [3] with a continuous beam. Two of the rings [1, 3] can be operated at liquid nitrogen temperature and only one of them [2] is equipped with an electron merged beam device, which works at the required low energies but with a rather limited resolution.

A double electrostatic ring, operating in a merged beam configuration and at temperatures below 10 K, has been approved at MSL in Stockholm [4], a fixed energy storage ring for energies up to 50 keV is planned at the University of Frankfurt [5] and a **c**ryogenic **s**torage **r**ing (CSR) shall be built up at the Max-Planck institute for nuclear physics (MPI-K) in Heidelberg [6].

For an ultra-low energy storage ring installed at a next-generation antiproton and ion facility, new and challenging techniques need to be developed to ensure multi-user operation and pave the way for a true multi-purpose facility:

- Combination of the electrostatic storage mode with beam deceleration from 300 keV to 20 keV
- Availability of fast and slow extraction to enable both trap experiments with pulsed beams and nuclear physics type experiments requiring extracted quasi-DC beams
- Electron cooling at all covered energies for a variety of different ions ranging from antiprotons to bare uranium
- A cryogenic vacuum system to ensure residual gas pressures below $1 \cdot 10^{-13}$ mbar for reasonable life times even for highly charged ions
- Particle detection techniques and beam diagnostic elements, operating at cryogenic temperatures and designed for lowest beam energies and currents.

The USR will combine these features for the first time and will be one of the essential tools for low-energy physics at FLAIR.

RING LAYOUT

As pointed out before, the symmetric machine consists of electrostatic elements only. A schematic overview of the 9m x 9m ring is given in the following Fig. 1.

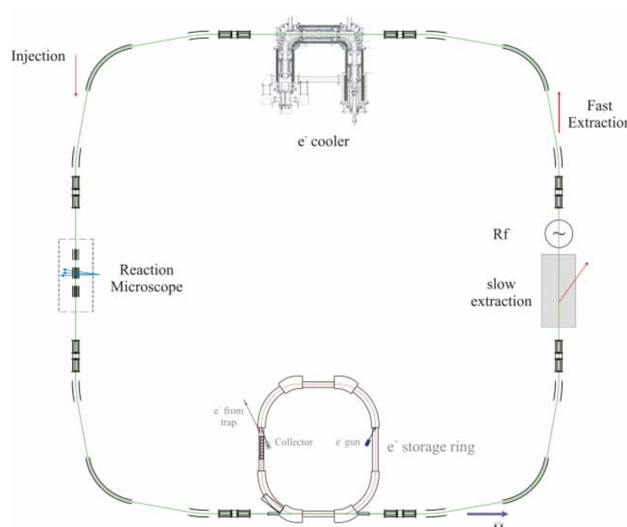

Fig. 1: Overview of the ultra-low energy storage ring with the optional merged positron ring.

The overall 90° bend in the corner sections is split up into one 70° and two smaller 10° cylinder deflectors to allow easy injection along one of the straight sections as well as fast extraction of the beam and detection of

*Present address: CERN, Geneva, Switzerland neutral particles generated by e.g. collisions with the residual gas. Transverse modulation of the beam is realized by pairs of electrostatic quadrupole doublets which also house small steerers for closed orbit correction [7]. All electrostatic elements are limited by grounded shields placed at a distance of 15 mm on both sides of the respective element. This efficiently reduces the effect of fringe fields on the stored beam and higher order effects.

This layout allows experiments with merged laser or neutral atom beams along the straight sections. In the present layout, the internal experimental regions are equipped with the following installations:

First, the elements necessary for the slow extraction as well as an rf decelerating and bunching unit are integrated into the straight section located opposite of the beam injection. While the requirements for the length of the circulating bunches are around a few hundreds of nanoseconds for external trap experiments and thus fairly relaxed, ultra-short bunches of only a few nanoseconds are required for the internal experiments that would then use the bunch itself as a trigger signal for the measurements.

Second, an electron cooler with an effective cooler length of ~ *1 m*, a field homogeneity of $B_x/B_s < 1 \cdot 10^{-3}$ and a maximum solenoid field of $B_{max}=300$ *G*. The overall size of the storage ring is basically determined by the dimensions of the electron cooler and its correction elements.

Electron cooling in this regime, where the electron energy needs to be as low as 10 eV is a new challenge that is presently addressed at the MPI-K [8,9].

With a luminosity, or in other words, effective collision rates, that are at least six orders of magnitude higher than for a single-pass experiment, the USR provides the ideal tool for studies of the dynamics in ion- (antiproton-) atom (molecule) collisions occurring on the sub-femtosecond timescale. For that purpose, a novel in-ring reaction microscope will be developed for the USR and integrated into the third experimental section.

Such a spectrometer consists of a set of position sensitive recoil ion and electron detectors where the fragments created during the collision process are guided towards the detector by a combination of electrostatic and magnetic fields [10]. An in-ring reaction microscope will give direct access to total, differential and finally also to fully differential cross sections for a large number of collision systems. Antiprotons and also exotic radioactive and highly charged ions at FLAIR will serve as projectile particles in combination with all different kind of gas jets as targets. Fully differential measurements will then be realizable with highest resolution, and with expected rates that are many orders of magnitude larger than what is available today.

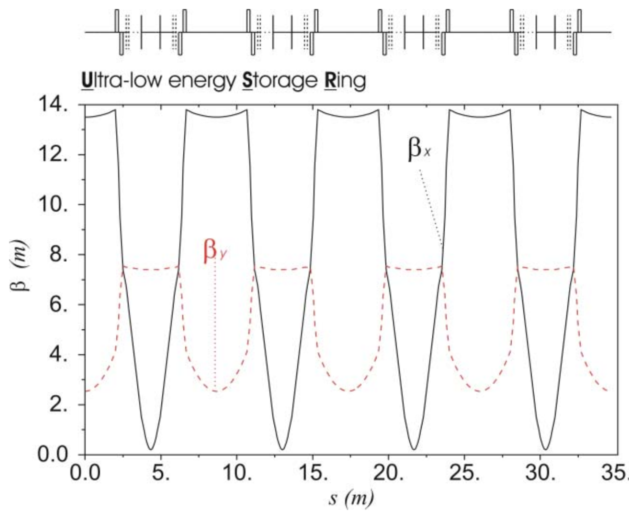

Fig. 2: Calculated beta functions of the USR.

Depending on the experimental requirements, the machine can be set to a variety of different working points with one example given in Fig. 2. Here, the horizontal beam size is minimized in the 70° bends, where the mechanical aperture is relatively small, while the vertical beam size is at its maximum at this position. An overview of the machine and element parameters is given in table 1.

Table 1: Main parameters of the USR.

General Parameters	
Energy range	20 keV – 300 keV
Circumference	34.7 m
Base pressure	$< 5 \cdot 10^{-13}$ mbar
Operating Temperature	4 K
10° deflectors	
Height	240 mm
Radii	1940 mm and 2060 mm
Voltage |U|	< 20 kV
70° deflectors	
Height	160 mm
Radii	970 mm and 1030 mm
Voltage |U|	< 20 kV
Quadrupoles	
Length	200 mm
Distance between lenses	150 mm
Aperture Radius	50 mm
Voltage	+/- 6 kV
Steerer Length	100 mm
Steerer Plate Distance	120 mm
Machine Parameters	
space charge limit (20 keV)	$2 \cdot 10^7$
Q_x	2.38
Q_y	1.14

At FAIR, both antiprotons and exotic, highly charged ions will be available. The USR shall take maximum benefit of these unique possibilities and ideally allows decelerating all different kinds of ions to lowest energies of 20 keV/q. Due to the large capture cross sections at such low energies, a cryogenic vacuum system, needed to realize ultimate pressures below 10^{-13} mbar has be used. Such low pressures guarantee sufficiently long beam life times in the order of seconds even for bare uranium ions.

Since outgasing from the wall is negligible at temperatures of a few Kelvin, only gas inflow due to leaks and from external lines has to be taken into consideration. In principle, the cold surface of the innermost vacuum chamber is acting as a large cryo pump, condensing all gases with the exception of hydrogen and helium. Thus the partial pressure of hydrogen will limit the ultimate pressure. By binding the latter via charcoal distributed around the machine and thus ensuring to cover the inner surface with less than one monolayer of the gas, lowest pressures should become reachable.

MERGED POSITRON BEAM

An interesting option for the USR is its possible combination with a special positron cooler storage ring (PCSR) for storage and electron cooling of positrons analogous to the LEPTA ring [11]. This combined facility could then be used for exploring the following unique research topics:

- Storage and cooling of positrons
- Positron cooling of antiprotons at ultra low energy
- Generation of antihydrogen in-flight
- Antihydrogen-hydrogen or in general antihydrogen-atom, -molecule collisions
- Generation of ortho-positronium in-flight

The antihydrogen generation is realized in one of the straight sections of the USR where the antiproton and positron beams are overlapped and have equal velocities. The stored antiproton energy will determine the kinetic energy of the produced antihydrogen atoms and should be in the range of ~20 keV for studies of antihydrogen-hydrogen collisions (positron beam energy ~10 eV). Since the LEPTA scheme presently works at much higher energies, the development of suitable techniques for obtaining an intense merged positron beam at the given low energy represents a particular challenge. It is likely that the positron storage ring should use a cryogenic vacuum system in order to ensure reasonably long lifetimes. The development of low-energy electron beams for the CSR will be of particular advantage also for this application.

CONCLUSION

The ultra-low energy storage ring marks a significant evolution step forward compared to existing electrostatic storage rings. Being an energy variable machine for antiprotons and highly charged radioactive ions, requiring nanosecond pulse lengths for in-ring experiments as well as an integrated electron cooler operating down to lowest energies, a number of new technical challenges have to be solved. Its installation within a next-generation antiproton and ion facility will make the storage ring a true multi-user facility able to cover a wide physics field.

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