FLAIR: A FACILITY FOR LOW-ENERGY ANTIPROTON AND ION RESEARCH

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Abstract

To exploit the unique possibilities that will become available at the Facility for Antiproton and Ion Research (FAIR), a collaboration of about 50 institutes from 15 countries was formed to efficiently enable an innovative research program towards low-energy antimatter-physics. In the Facility for Low-energy Antiproton and Ion Research (FLAIR) antiprotons and heavy ions are slowed down from 30 MeV to energies as low as 20 keV by a magnetic low-energy storage ring (LSR) and an electro-static ultra-low energy storage ring (USR).

In this contribution, the facility and the research program covered are described with an emphasis on the accelerator chain and the expected particle numbers.

INTRODUCTION

Currently, the Antiproton Decelerator (AD) at CERN [1] is the only place in the world where physics with low-energy antiprotons is done.

This facility has been in operation since 2000, and although the experiments at the AD have produced some widely published and recognized results, such as the first formation of anti hydrogen at rest, they are limited by the relatively low intensity of antiprotons from the AD, approximately 10^5 particles per second, and by the availability of pulsed extraction only. In addition, the particles are delivered from the AD at a kinetic energy of 5 MeV, which is significantly higher than the 100 keV or less which is best suited for these experiments.

At AD, the reduction in kinetic energy from 5 MeV to a few keV is made by degrading in a foil, which causes a rather large increase of the beam divergence and momentum spread, and there is also a high loss of antiprotons in the degrader foil. These effects limit the capture efficiency to about 10^{-4}.

An improvement was achieved by the installation of the RFQ–D used by the ASACUSA collaboration [2] that today provides beams at 100 keV energy. However, the

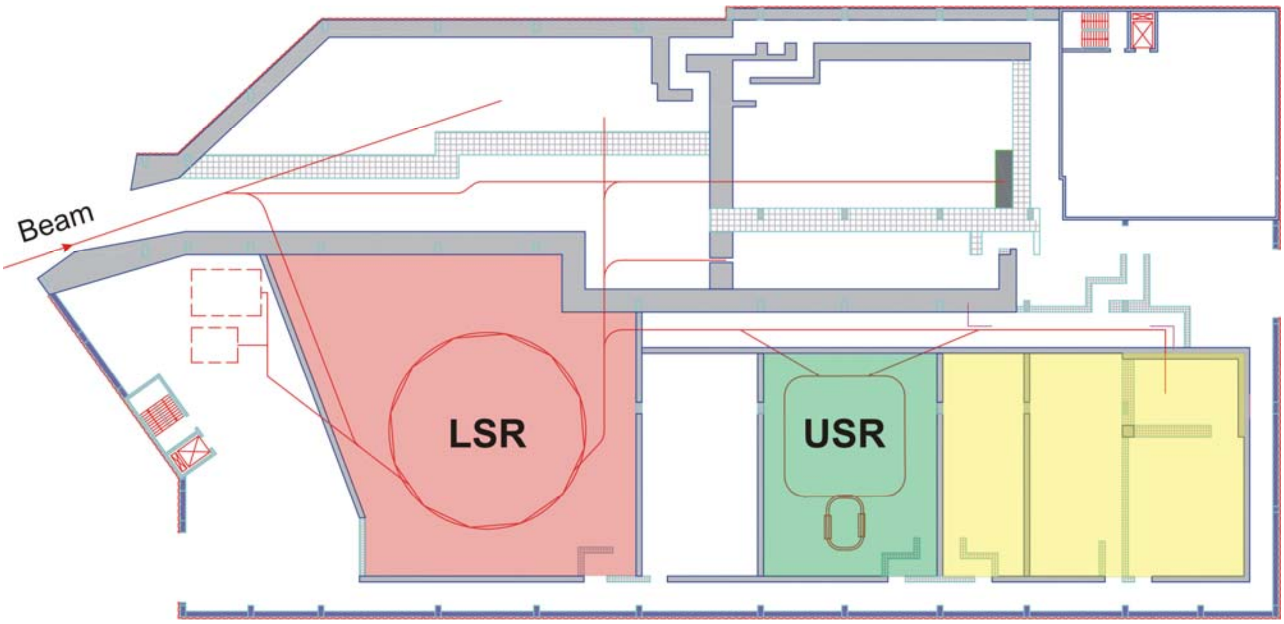

Figure 1: Layout of the FLAIR building. The low energy region can be divided into areas with beam energies between 30 MeV → 300 keV (red line), 300 keV → 20 keV (green line) and 20 keV → rest (yellow line).

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rather large emittance ε = 100 mm mrad and energy spread $\Delta E/E$ = 10% of the output antiproton beam require a large stopping volume and a high-power pulsed laser to induce transition for high precision spectroscopy. The laser bandwidth today limits the precision of the experiments.

A next generation facility clearly needs to overcome the present limitations and must also pave the way for experiments not possible at the AD by providing slow extracted, quasi-DC beams for nuclear physics type experiments and ultra-show bunches of only a few nanoseconds duration for internal collision experiments.

CONCEPT OF FLAIR

The future FAIR [3] facility on the site of the current GSI laboratory will be an international facility mainly for nuclear and hadron physics, but also for atomic physics, plasma research, biophysics and materials research. This will include physics with antiprotons, and the production rate of antiprotons will be at least 10 times higher than what is achieved at the AD today. This is due to the installation of three cooling and decelerating rings, similar to what CERN had at the time of proton-antiproton collisions at the SPS. In the case of FAIR, the antiprotons will be delivered from these rings at 30 MeV kinetic energy. The important new feature at FAIR is that the deceleration from 30 MeV is made at a dedicated facility, FLAIR (Facility for Low-energy Antiproton and Ion Physics), consisting of another two cooling and deceleration rings. In addition to antiprotons, also exotic unstable and highly charged ions will become available at FLAIR.

FLAIR will thus offer the unique possibility for low-energy antiproton and ion research and thus benefit from maximum synergies between the fields. Details about the proposed research program can be found in the submitted letter of intent [4].

The layout of the facility is shown in Fig. 1. The building is designed as a complex which includes the experimental areas requested by the experiments presented in the technical proposals submitted by the FLAIR and SPARC [5] collaborations, the hall for the **l**ow-energy **s**torage **r**ing (LSR) and the additional areas needed for off-line mounting and testing of setups, control and data acquisition rooms, laser labs, power supplies storage rooms, a small workshop and social rooms.

The accelerator structure to decelerate antiprotons and highly charged ions consists of the above mentioned LSR, an electrostatic **u**ltra-low energy **s**torage **r**ing (USR), and finally a universal trap facility (HITRAP) [6]. These components of the facility can provide stored as well as fast and slow extracted cooled beams at energies between 30 MeV and 300 keV (LSR), between 300 keV and 20 keV (USR), and cooled particles at rest or at ultra-low eV energies (HITRAP).

Since one main focus of the FLAIR collaboration is the exploitation of physics with low-energy antiprotons, the deceleration cycle within the facility and maximum particle numbers will be given here in this paper for this particular case.

The particles are injected from the NESR and are slowed down in a first step from 30 MeV to 300 keV in the LSR. Electron cooling will then be applied before transferring the antiprotons to the USR. Here, they are decelerated again to energies as low as 20 keV and can then be used either for in-ring experiments or be transferred via fast or slow extraction to external setups.

Since all the main parameters of the CRYRING facility at the Manne Siegbahn Laboratory are a perfect match with the requirements of the LSR and it was decided to discontinue its funding, a very attractive idea is to move the whole storage ring together with its integrated cooler and a low-energy injector to FLAIR. This would not only provide the LSR as one of the central installations of FLAIR, but would also allow off-line commissioning of the whole FLAIR facility and its experiments without the need of antiprotons or ions from the NESR. Furthermore, training of operators, as well as continuous development of the facility and experiments with ions of other species than those provided from the NESR would become feasible. Details about the storage ring as well as first dedicated experiments towards the machine performance in the FLAIR context can be found elsewhere at this conference [7].

The USR is a new development and will be the first energy-variable electrostatic cooler synchrotron installed within a large accelerator facility. It will not only decelerate the antiprotons and exotic ions to lowest energies of 20 keV/q, which will allow e.g. direct injection into traps, but will also enable in-ring experiments with at least six orders of magnitude higher event rates than in single pass setups and also pave the way for nuclear physics type experiments with slow extracted, quasi DC beams. Details about the USR lattice, its optical elements and the envisaged experiments are given in [8].

PARTICLE RATES

In the LSR, the space-charge limit for a coasting beam of protons at 300 keV is $N = 5\times10^8$, assuming a maximum tune shift $\Delta Q = -0.1$ and an emittance of $\varepsilon = 1\ \pi$ *mm mrad*, see Fig. 2. However, the electron cooling at 300 keV is probably not strong enough to reach this emittance, but it is estimated that at least 1×10^8 antiprotons can be delivered within 1 π mm mrad once every NESR cycle of perhaps 20 s, losses during extraction not counted. Since the space-charge limit is proportional to energy (non-relativistically) while equilibrium emittances in our case shrink with energy, one can expect that the number of antiprotons per unit time and emittance increases at least linearly with energy.

Some improvement could be obtained if the NESR beam is bunched at the 4th harmonic before extraction, and the four bunches are transferred to the LSR and decelerated in four consecutive machine cycles. Each cycle taking about 5 s, LSR could then be able to deliver four batches of 1×10^8 antiprotons, minus extraction losses, within approximately $1\,\pi$ mm mrad emittance every 20 s.

For highly charged ions, the space-charge limit scales with A/Z^2. The rates for intra beam scattering and electron cooling also change, such that one can expect that the equilibrium emittance, at the space-charge limit, does not depend strongly on the ion species for a given particle velocity. Again, the emittance shrinks with increasing energy. From this scaling, we can find, for example, that the limit of 1×10^8 antiprotons at 300 keV corresponds to 4×10^7 U^{92+} at 4 MeV/u.

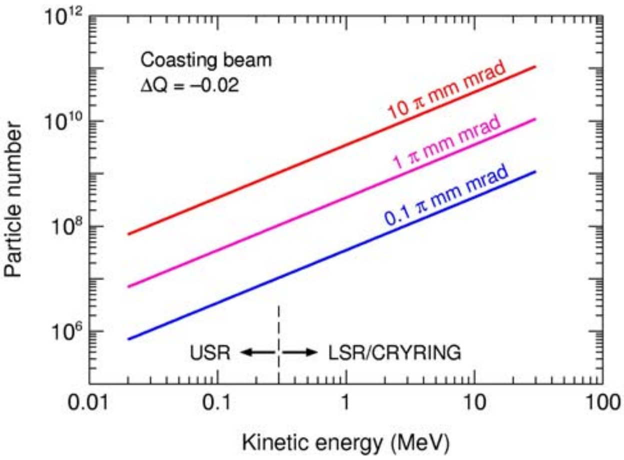

Fig 2: Antiproton space-charge limit for a coasting beam with an assumed Laslett tune shift of -0.02.

The resulting antiproton rates per unit time, averaged over the duration of a deceleration cycle starting from injection are listed in the following Fig 3.

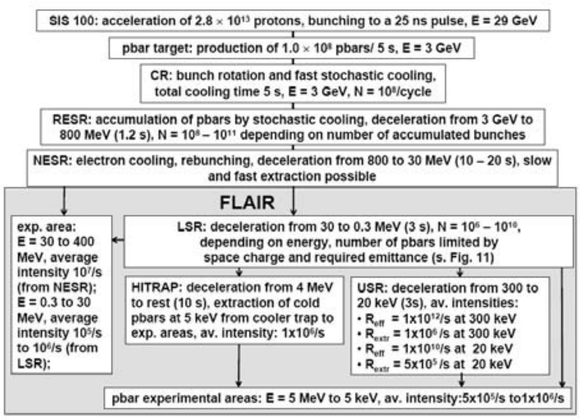

Fig. 3: Estimated antiproton intensities at FLAIR. R_{eff} is the effective antiproton rate in ring and R_{extr} the average rate of extracted antiprotons, assuming 90% losses throughout the overall deceleration cycle from the NESR.

This scheme gives about a factor 100 more antiprotons per unit time stopped in gas targets or trapped in ion traps as compared to the present AD at CERN where no dedicated accumulation and multi-stage deceleration rings are utilized. The availability of such beams, especially with the additional possibilities of performing in-ring experiments and measurements with slow extracted beams, will tremendously increase the number of experiments possible at this facility.

CONCLUSION

FLAIR is part of the FAIR joint core program and will be a world wide unique next-generation low-energy antiproton and ion facility. Cooled antiprotons down to 20 keV both in storage rings and extracted ions at lowest energies from ion sources will revolutionize low energy antiproton physics. Continuously extracted beams at these energies will enable nuclear and particle physics type experiments currently not possible at the AD of CERN. Furthermore, the availability of short-lived exotic nuclei at the future facility at Darmstadt creates utmost synergies by using antiprotons as hadronic probes for nuclear structure.

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