THE LOW ENERGY STORAGE RING CRYRING@ESR

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Abstract

The Swedish in-kind contribution to the FAIR facility in Darmstadt, the heavy-ion storage ring CRYRING, has been transported to Darmstadt recently. Instead of warehousing until installation at the Facility for Antiproton and Ion Research, FAIR, the immediate installation behind the existing Experimental Storage Ring, ESR, has been proposed. CRYRING can decelerate, cool and store heavy, highly charged ions that come from the ESR down to a few 100 keV/nucleon. It provides a high performance electron cooler in combination with a gas jet target and thus opens up a very attractive physics program as a natural extension of the ESR, which can only operate down to about 4 MeV/nucleon. CRYRING@ESR also provides beams of low charged ions independently on the GSI accelerator. All this makes CRYRING@ESR the perfect machine for FAIR related tests of diagnostics, software and concepts, and atomic physics experiments with heavy, highly charged ions stored at low energy. Perspectives are also opened up for low-energy nuclear physics investigations. CRYRING@ESR is a first step towards atomic physics with low-energy, highly charged ions at FAIR as planned within the SPARC and APPA collaborations.

INTRODUCTION

In Darmstadt, the facility for antiproton and ion research is being built. Based on the GSI accelerators for injection it will open up new areas of research with heavy ions and, new in Darmstadt, with antiprotons. When it comes to experiments with slow and stored heavy, highly charged ions and antiprotons, two collaborations, the Stored Particles Atomic Physics Research Collaboration - SPARC and the Facility for Low-Energy Antiproton and Ion Research - FLAIR, have been formed to move into one building complex, the FLAIR building.

The low energy storage ring LSR shall provide the highly charged ions and antiprotons at low energy at the FAIR facility for those two collaborations, SPARC and FLAIR. The LSR evolves from the heavy-ion storage ring CRYRING, which has been operated at the Manne Siegbahn Laboratory in Stockholm until 2010 [1]. The main focus is on precision experiments, which requires low energy and well controlled beam properties that is typically achieved by beam cooling. The LSR will be installed as intermediate step between the new experimental storage run NESR and the low energy facilities HITRAP and the ultra low energy storage ring USR. The LSR is a Swedish in-kind contribution to the FAIR facility in Darmstadt, i.e. part of the investment done by the swedish physics community into the FAIR project.

After careful cost evaluation a staged approach was put into place that does not include the NESR in its start version. However, contrary to the original plans the present storage ring at GSI, the ESR, will not be disassembled for component reuse but continue running. Consequently, instead of warehousing the ring components until installation at the Facility for Antiproton and Ion Research, FAIR, the immediate installation behind the existing Experimental Storage Ring, ESR [2, 3], has been proposed and worked out in detail by a Swedish-German working group. The estimated efforts for installation and operation of CRYRING at the ESR have been summarized in a report [4] published by that working group in 2012.

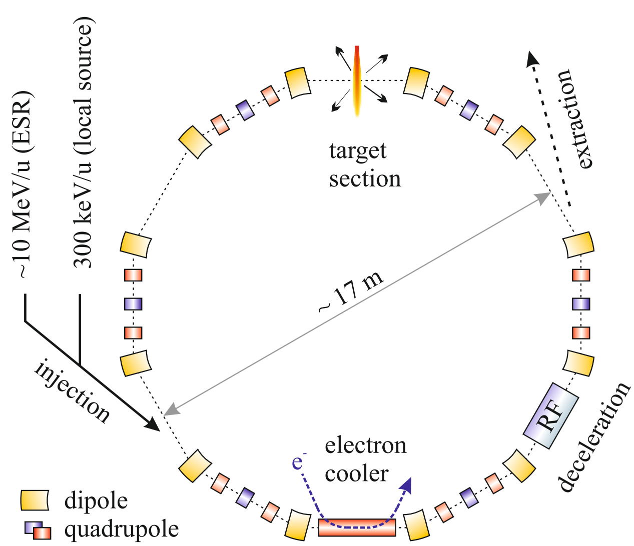

Figure 1: Overview of the storage ring CRYRING as it will be installed at the ESR at GSI in Darmstadt.

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A schematic overview of the storage ring and its facilities is shown in Fig. 1. CRYRING as it will be installed behind the ESR can decelerate, cool and store heavy, highly charged ions from about 10 MeV/nucleon and antiprotons from about 30 MeV/nucleon down to a few 100 keV/nucleon. It provides a high performance electron cooler in combination with a gas jet target. It is equipped with it's own injector and ion source, to allow for standalone commissioning. For more detailed ring parameters see also Table 1.

CRYRING@ESR

As visible in Fig. 1 the ions are kept in orbit by twelve 30° magnetic dipoles and a number of magnetic quadrupoles and sextupoles (not shown in the figure) in six of the twelve straight sections. The other six sections house an injection and an extraction system, the deceleration and acceleration drift, and the electron cooler. One section is used for experimental installations as for instance a gas target. The exact layout of the sections had to be adapted to the new installation place behind the ESR in a modified Cave B. It is hence different from the original layout in Stockholm but also different from the proposed layout for the LSR. The nomenclature was also adapted and starts now with YR01, the injection section including the first ring dipole, and continues to YR12 including the last, the twelfth dipole.

The circumference of CRYRING will be increased slightly from 51.63 m to 54.17 m to match 1/2 of the ESR circumference. This increase is achieved by stretching of the magnet free section about 0.4 m each. Ion optical calculations show that this will not influence the operation of the ring considerably. The horizontal acceptance will be reduced slightly but the ring can be operated at the same tune. Apart from the easier bunch-bucket transfer between ESR and CRYRING@ESR the additional space is very valuable to gain space in the experimental section and to install an additional diagnostic box of FAIR standard. This provides space for tests of FAIR type detectors.

The most important modification is the addition of a new injection system to accept antiprotons at 30 MeV instead of 300 keV, the injection energy for protons when CRYRING was installed in Stockholm. After the decision to move CRYRING behind the ESR, the injection rigidity will even be increased from the required 0.8 Tm for protons or antiprotons to the maximal rigidity that can be stored in the ring, 1.44 Tm, which eases the efficient transfer of heavy, highly charged ions from the ESR to CRYRING.

CRYRING in Stockholm did not have an extraction system. This will be added for installation at GSI. Already in Stockholm the required in-ring optics was successfully tested [5].

The installation of the extraction system forced a new order of the ring components. While the main magnetic elements will of course keep their position minor changes of for instance correction elements are required. Those are described in the technical design report of the LSR [1]. Figure 1 describes the new layout as it will be realized for CRYRING@ESR.

The storage ring is capable of accelerating ions with mass to charge ratio below four injected at only 300 keV/nucleon from the off-line ion source to the maximum rigidity of 1.44 Tm. It also decelerates ions injected at the maximal rigidity down to the lower rigidity limit of 0.054 Tm. The magnets are conceived for fast ramping, such that the whole decelerating (accelerating) process could be done in only 150 ms.

One of the key features is an electron cooler with adiabatic expansion of the electron beam. This yields about 100 times lower transversal electron temperature than in the ESR and yields directly higher resolution in recombination spectroscopy with merged ion-electron beams [6].

Table 1: Parameters for CRYRING Operation at ESR

Description	Value
Circumference	54.17 m
Rigidity at injection	
protons/antiprotons	0.8 Tm
ions	1.44 Tm
Highest possible injection energy	
protons/antiprotons	30 MeV
$^{12}C^{6+}$, *from ESR*	24.7 MeV/nucleon
$^{238}U^{92+}$, *from ESR*	14.8 MeV/nucleon
ions, A/q ≤ 4, *local injector*	300 keV/nucleon
Lowest rigidity	0.054 Tm
Magnet ramping rates	7 T/s, 4 T/s, 1 T/s
Vacuum pressure (N_2 equiv.)	$10^{-11} \dots 10^{-12}$ mbar

Big efforts have been undertaken to ensure the best possible vacuum in CRYRING already during its first life in Sweden. About 10 ion getter pumps and more than 40 non evaporable getter (NEG) pumping modules are installed in the ring. After baking at about 250 degree Celsius, the pressure that has been reached was about $1 \cdot 10^{-11}$ mbar (nitrogen equivalent pressure).

The life time of stored, bare nuclei in a storage ring depends on residual gas pressure, composition, the atomic number of the stored nucleus, and its energy. With the computer code RICODE [8] the life time has been estimated for the vacuum conditions in CRYRING. The results for four different nuclei have been plotted in Fig. 2. For the relevant energy window between 15 MeV/nucleon and 300 keV/nucleon we shall reach a life time between 15 min and 3 s in the ring. This is sufficient for all planned experiments and fits well to the ESR production cycle of about 10 s.

For commissioning and for stand-alone tests of equipment CRYRING got a local injector. This is basically an ion source at 50 kV potential in combination with a Radio-Frequency-Quadrupole accelerator. The ions are first analyzed in a 90 degree dipole magnet and then focussed with electrostatic quadrupoles into the RFQ built in Frank-

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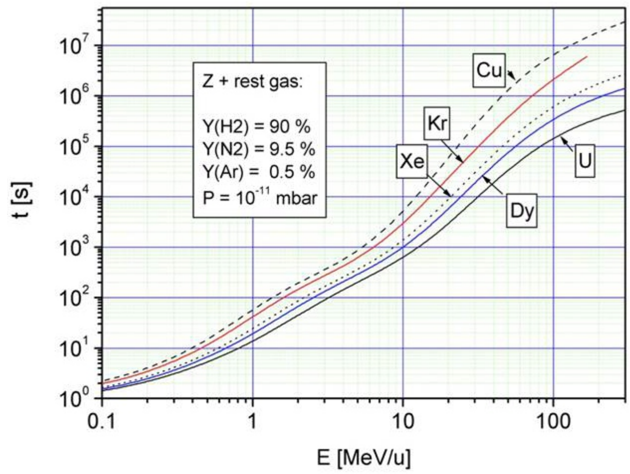

Figure 2: Life time of stored, bare nuclei versus beam energy [7].

furt [9]. The RFQ can accelerate ions with A/q≤4 to 300 keV/nucleon, the injection energy into the ring. To increase the number of ions accepted by the ring, the RFQ is followed by a two-gap debuncher used to decrease the energy spread after acceleration and to ease multi-turn injection into the ring. Both, the RFQ and the debuncher operate at 108.48 MHz.

The beam instrumentation will be a combination of proven hardware and FAIR type front end electronics, controls and data acquisition. This gives the unique opportunity to advance the integration of the new FAIR type soft- and hardware and to test it live.

CONCLUSION

The proposed installation behind the ESR in combination with its own injector makes CRYRING@ESR the perfect machine for FAIR related tests of diagnostics, software and concepts on one side, and atomic physics experiments with heavy, highly charged ions stored at low energy on the other side. The new, FAIR type, control system will be implemented for the first time in a machine that delivers beam and hence will be the perfect occasion to test not only the cooperation of the design concepts but also the stability of the system. Since the ring can be operated any time it is the perfect training ground for operators on the new control system and this allows for valuable feedback on the operational concept well in advance before the commissioning of FAIR's key machines.

Physics applications range from "classical" atomic physics experiments like the determination of the lamb shift using X-ray spectroscopy, but with increased resolution, over measurements at the borderline of atomic and nuclear physics for instance to determine the charge radius, to a yet unexplored energy regime for astrophysical interesting nuclear reactions. The details of planned experiments are laid down in the "Physics book" that is close to completion [10].

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