FIRST EXPERIMENTAL DEMONSTRATION OF THE EXTRACTION OF LOW ENERGY BEAMS FROM THE ESR TO THE CRYRING@ESR

S. Litvinov, Z. Andelkovic, D. Beck, A. Braeuning-Demian, S. Fedotova, W. Geithner, R. Hess, F. Herfurth, C. Kleffner, I. Kraus, M. Lestinsky, F. Nolden, M. Steck, G. Vorobyev
GSI, Darmstadt, Germany

Abstract

The CRYRING@ESR facility [1] will provide the unique possibility for studying properties of highly charged cooled stable and short-lived ions stored at low energy for atomic and nuclear research within the FAIR project [2]. Heavy ion beams will be stored, cooled and decelerated to energies between 10 and 4 MeV/u in the ESR [3] and then delivered to the CRYRING@ESR. There is no dedicated kicker magnet for the fast extraction in this direction. However, a specially developed distorted closed orbit of the beam stored in the ESR in combination with the injection kicker has been suggested for the extraction and experimentally verified in 2014. In the first experiment the ion beam was extracted and transported over a distance of 20 m towards the CRYRING@ESR [4]. In the 2016 machine development run the heavy ion beam was successfully extracted from the ESR and delivered to the first fluorescent screen inside CRYRING@ESR for the first time. Detailed ion-optical simulations as well as the experimental results will be discussed.

CRYRING@ESR FACILITY

The Experimental Storage Ring (ESR) is a symmetric ring with two arcs and two straight sections and a circumference of 108.36 meters. The ESR consists of six 60° dipole magnets, 20 quadrupole and 8 sextupole magnets. The ESR can be operated at a magnetic rigidity in the range of 0.5 – 10 Tm. For reducing transverse and longitudinal emittances of the stored ion beams, the ESR is equipped with an electron cooler which is installed in one of the straight sections of the ring. Another straight section is foreseen for the experiments [3].

The CRYRING@ESR is a magnetic heavy ion storage ring with a circumference of 54.17 m, which corresponds to half of ESR perimeter. The CRYRING@ESR consists of twelve 30° dipole magnets connected by twelve straight sections, each of which is about 3.3 meters long. Every second section is occupied by a quadrupole triplet for the first-order focusing (18 quadrupoles in total) and 2 sextupoles (12 magnets in total) for the second-order corrections. The other straight sections are foreseen for the injection/extraction, electron-cooler, RF cavity, Schottky diagnostic and experiments. The ring will operate at a magnetic rigidity in the range between 0.054 and 1.44 Tm. Highly charged ions decelerated in the ESR to the lowest possible energy of 4 MeV/u then can be stored and decelerated in the CRYRING@ESR down to few 100 keV/u and delivered to the experiments [1].

The CRYRING@ESR is located behind the ESR and they are connected via a transfer line, which has a length of about 90 meters. The layout of the CRYRING@ESR facility is illustrated in Fig. 2.

CALCULATION

High energy ion beams are usually injected from the synchrotron SIS18 [5] into the ESR on the orbit of $\Delta p/p \approx +1\%$, and then stored and cooled with the electron cooler (solid black curve in Fig. 1). In order to keep the beam parallel to the electron beam in the cooler section, 4 horizontal correctors in 2 neighboring main dipole magnets are used. The ESR is equipped with one injection and two extraction septum magnets as can be seen in Fig. 2. The horizontal width of the beam pipe around the septa is 104 mm and in addition, there is the narrow knife of 17 mm width of each septum (see Fig. 1). The injection kicker magnet is placed after the first dipole downstream (see Fig. 2). The stored beam goes after the kick either to the northern extraction septum (towards HITRAP) or to the wall (dotted black curve in Fig. 1). In order to extract the beam properly to the CRYRING@ESR, it is necessary to change the trajectory of the kicked beam, such that it avoids the north extraction septum and the injection septum but reaches the southern extraction septum. This orbit distortion has been performed with a special bumped closed orbit, which has been calculated using 8 horizontal correctors in the 4 main dipoles, which are marked by brown boxes in Fig. 2. The corresponding trajectory is shown by the dashed black curve in Fig. 1. Applying the kick on the distorted orbit the beam can freely be extracted to the CRYRING@ESR (dotted-dashed red curve in Fig. 1).

EXPERIMENT

In August 2014, the calculations has been tested in an experiment at the ESR. Firstly, the proposed extraction scheme was verified with 100 and 400 MeV/u proton and $^{58}Ni^{26+}$ beams. The extracted beam was observed directly after the extraction septum using the TT1DF0 fluorescent screen (see Fig. 2). Later, a $^{14}N^{7+}$ beam at 30 MeV/u was injected, stored and stepwise decelerated to the final energy of 4 MeV/u ($B\rho = 0.58$ Tm), the lowest possible magnetic rigidity usable at the ESR. At each energy, the beam was successfully extracted, changing only the kick angle of the injection kicker by several tenths of a milliradian. The distortion orbit was unchanged.

ISBN 978-3-95450-181-6

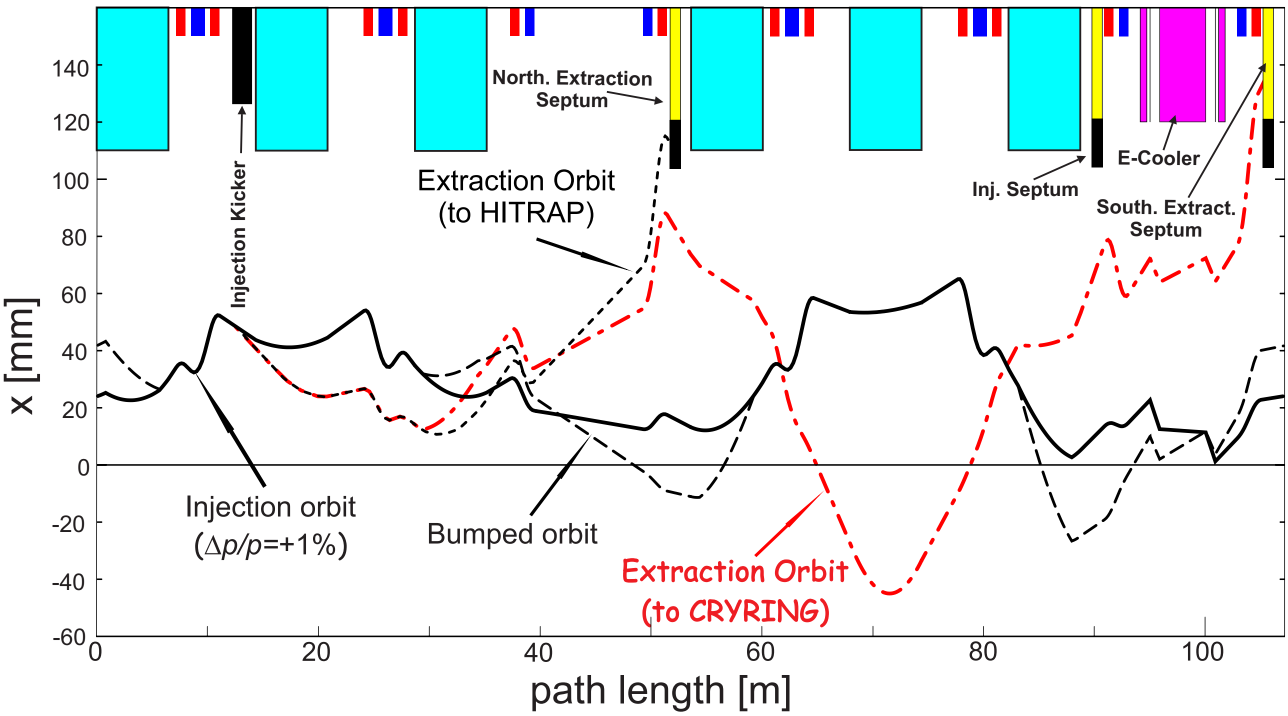

Figure 1: Calculated beam trajectories for one turn in the ESR. The injected stored and cooled orbit of $\Delta p/p = +1\%$ is indicated by the solid black curve. Its kicked orbit (extraction to HITRAP) is shown by the black dotted curve. The distorted bumped orbit is marked by the dashed black curve and its kicked orbit (extraction to CRYRING) is shown by the dotted-dashed red curve. Dipole, horizontal and vertical focusing quadrupole apertures are shown by cyan, red and blue boxes respectively.

In July 2016, during a dedicated experiment, a 6 MeV/u carbon beam using the extraction procedure described above, has been successfully extracted from the ESR. The beam transportation through the transfer channel was performed from stage to stage, observing beam spots at the fluorescent screens installed along the line, until the beam was injected into the CRYRING@ESR and detected at the last screen installed already in the ring. The corresponding beam spot images can be seen in Fig. 2. At least 60% of the ions stored in the ESR before extraction have been transmitted.

OUTLOOK

The primary goal of the experiment is reached, the low energy beam has been successfully delivered to the CRYRING@ESR. However, there is no complete ion-optical setting of the combined CRYRING@ESR structure. The rings are not ion-optically matched with the transfer line, which leads to the lack of transmission. The bottleneck of the matching is that the extraction channel goes through the ESR dipole magnet, whose stray field strongly affects the extracted beam. Its effect has been analyzed in Ref. [6] and has to be included in the matching procedure.

Instabilities of power converters of the transfer line magnets forced us to use during the experiment the ion-optical setting with stronger gradients than optimal, which however caused additional losses and requires therefore, the fine tuning of the linear optics.

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ISBN 978-3-95450-181-6

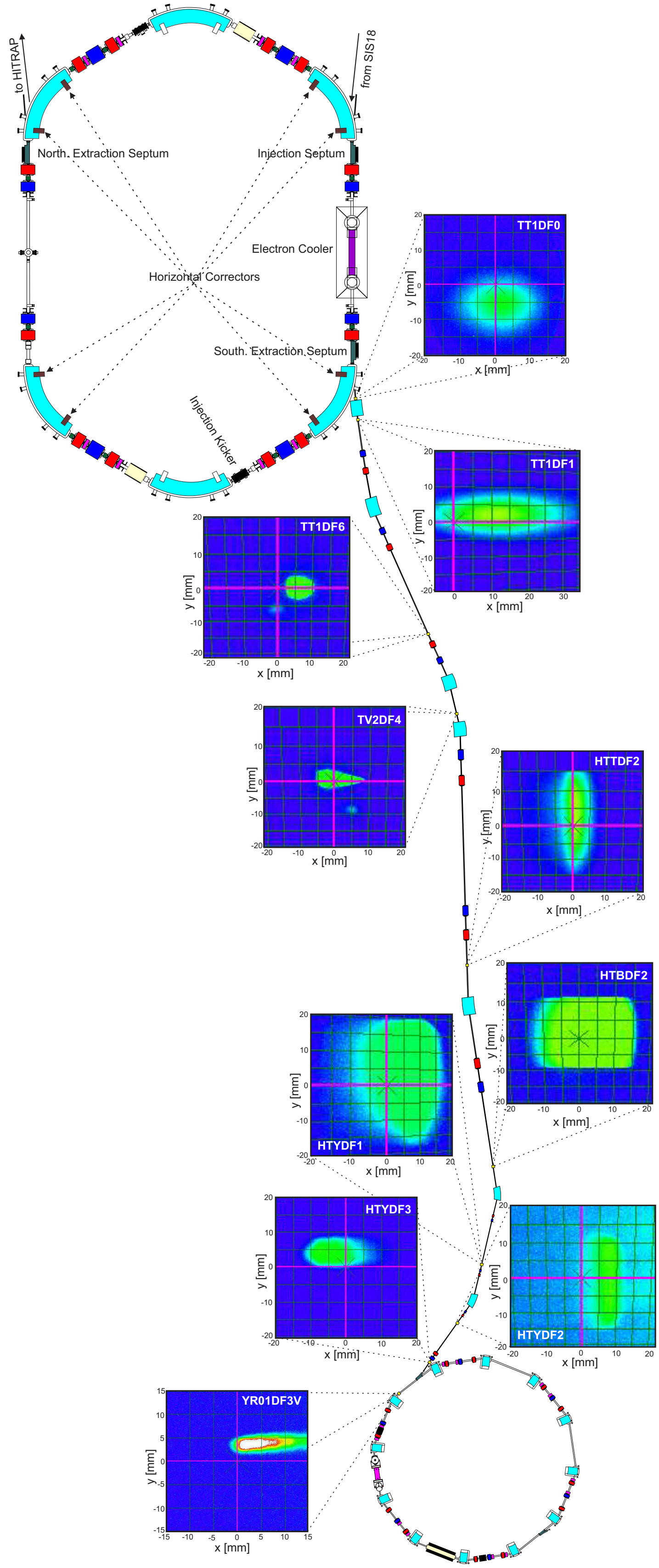

Figure 2: Layout of the CRYRING@ESR facility. The dipole, sextupole, focusing and defocusing quadrupole magnets are marked by cyan, violet, red and blue colors correspondingly. The ESR horizontal correctors used to perform the distortion orbit are indicated by brown boxes.

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