CHARGE EXCHANGE EXTRACTION AT THE EXPERIMENTAL STORAGE RING ESR AT GSI

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Abstract

At the storage ring ESR at GSI the charge exchange extraction of an electron cooled beam of highly charged heavy ions was successfully established. Fully stripped heavy ions are injected with an energy above 300 MeV/u, decelerated to 50-80 MeV/u and cooled with the electron cooler. Due to electron capture inside the cooler, hydrogen-like ions are produced continuously. These ions are of higher rigidity and therefore circulating on a different orbit inside the storage ring. This well separated orbit offers the opportunity to deflect specifically the secondary ions with a small movable septum magnet and afterwards extract them out of the storage ring. This method allows a slow extraction whereby the rate can be controlled over a wide range by varying the electron current in the cooler.

1 INTRODUCTION

Ion storage rings have proved to be versatile tools also for atomic physics. Investigations of atomic structure, charge exchange reactions and electron ion recombinations are performed at several institutes. The ESR storage ring (Fig. 1) at GSI [1] offers unique possibilities for experiments in this field. Electron cooled heavy ion beams ranging from Carbon to fully stripped Uranium are available and beside the electron cooler an internal gasjet target can be used for investigations.

To improve the experimental conditions especially for highly charged heavy ions, the ion beam can be decelerated in the storage ring. An injection energy between 300 and 400 MeV/u is necessary to obtain high charge states after stripping, whereas high precision spectroscopy requires low ion energies to reduce the uncertainty caused by the relativistic Doppler Effect.

So far only internal experiments could take full advantage from the high quality and variable energy of electron cooled beams in the ESR. To extend the field of applications also to external fixed target experiments, a slow extraction method is necessary which preserves the beam quality and allows a variation of the extraction rate and time. The novel method of charge exchange extraction fulfills all these requirements.

2 EXTRACTION SCHEME

The large momentum acceptance of the ESR of ±1.5 % in the standard operation setting serves as a basis for the

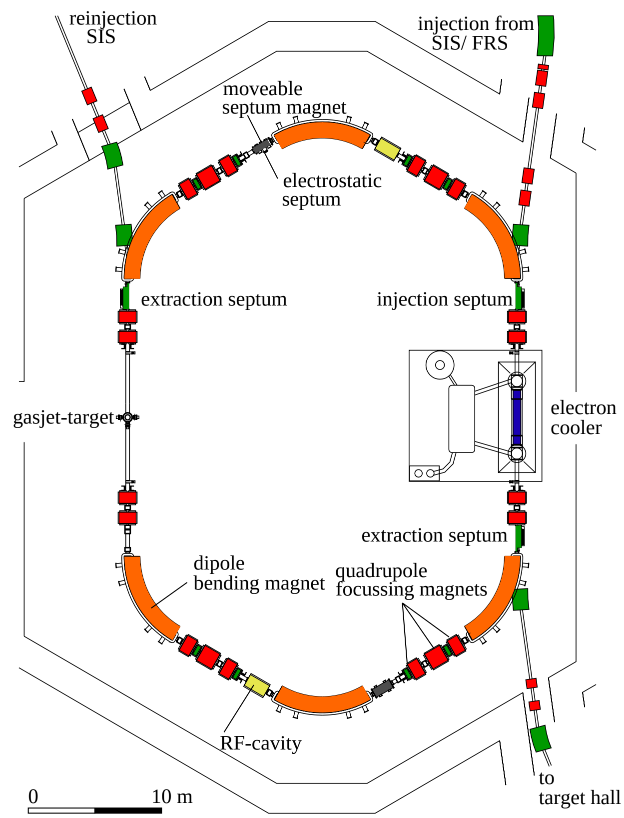

Figure 1: Storage ring ESR with its main components.

charge exchange extraction. Up to three different charge states of heavy ions can be stored simultaneously. In normal operation the injected beam is stored and accumulated by a rf-stacking scheme supported by electron cooling which defines the stack energy. The momentum of the stacked ions is normally 1-1.5 % lower than the value at injection.

By capturing an electron in the cooler the ions experience a rigidity jump and are circulating on an more outward orbit [2]. These down-charged secondary ions are produced continuously and constitute the lifetime determining loss mechanism for the primary electron cooled beam. For the charge exchange extraction these secondary ions are the source of the extracted beam.

The separation of the primary and secondary beam is illustrated in Fig. 2 for Au^{79+} as primary ions. Shown is the horizontal separation between the primary (solid black

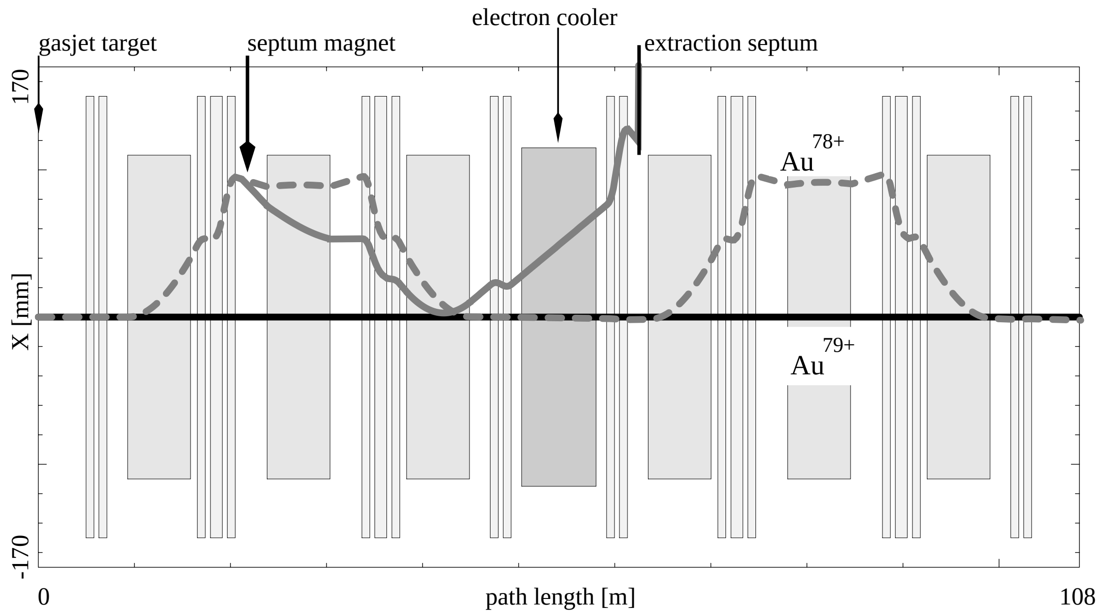

Figure 2: Horizontal separation of the orbits of a primary and secondary Gold-beam along one revolution in the storage ring. The extracted secondary beam is deflected into the extraction septum by a small kick in the north bend of the ESR.

line) and the down-charged ions (dashed grey line) along the orbit length over one revolution in the ESR. In addition the main magnetic elements are shown as well as the electron cooler in the center of the plot. In the bends the two beams are well separated and therefore a selective deflection of the secondary beam is possible.

For the ESR lattice an inward kick of 5 mrad near the maximum separation is sufficient to deflect the secondary beam into the extraction septum. The deflected orbit is shown as a solid grey line in Fig. 2 together with the positions of the deflection and extraction septa. This method of beam extraction preserves the small emittances and momentum spread obtained by electron cooling.

Due to the scheme described above, the highest charge state which can be extracted is hydrogen-like. To extract also fully stripped ions, a hydrogen-like primary beam can be stripped using the internal gasjet target. In that case the secondary fully stripped ions are now on an more inward orbit and can be deflected by an electrostatic septum, located at the same azimuthal position as the magnetic septum for the down-charged ions (see Fig. 1). Since the latter method works only at high ion energies and has not been applied yet to an experiment, this contribution concentrates on the extraction of down-charged ions at low energies.

3 MOVABLE SEPTUM MAGNET

The required kick of the down-charged ions is done with a small dipole magnet, installed inside the vacuum chamber on a movable vacuum feed-through. Its basic parameters are collected in Table 1. The magnet has to be moved in the horizontal plane because the position of the down-charged beam varies for different ion species. It is located in front of the central dipole magnet in the north bend of the ESR (Fig. 1).

The comfortable separation of the primary and secondary beams of 60-70 mm at the septum position allows a compact and magnetically well shielded mechanical design of the magnet. A side view in beam direction is given in Fig. 3. In addition the direction of the magnetic field in the gap and the positions and typical sizes for a decelerated primary and secondary Gold-beam are shown. By applying a suitable local orbit bump, the septum magnet will not influence the injection orbit at high energy. So that it can stay at its position during injection and accumulation. This allows the setup of an fully computer controlled operational cycle without moving the septum magnet.

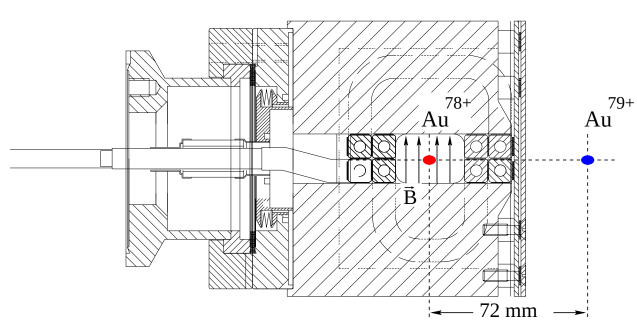

Figure 3: Side view of the movable magnetic septum. Also shown are the primary Au^{79+} and the down-charged Au^{78+} beam which are separated about 72 mm at the septum.

Table 1: Parameters of the movable septum magnet.

effective length	22 cm
gap aperture	30 x 21 mm^2
number of windings	4
maximum current	1000 A
deflection angle	5 mrad

4 OPERATIONAL CYCLE

The delivery of a decelerated slowly extracted heavy ion beam to an experiment outside the ESR requires a complex operational cycle. Nevertheless an automated scheme could be established for extraction times of 40-60 s. A sketch of one of these repeated cycles is displayed in Fig. 4. The magnetic field strength of the main dipoles (dashed graph) is used as a measure for the ion energy and the solid curve shows the stored ion beam current in the ESR, measured with a current transformer.

A cycle starts with injection and accumulation at high energy. When the storage ring is filled, the cooling is stopped and the beam is decelerated. At extraction energy the ions are cooled again and the charge exchange extraction starts immediately. The beam current in the ESR now decays with a lifetime determined by the electron capture rate of the ions. Even at low energies of 50-70 MeV/u the recombination is dominated by electron capture in the electron cooler. Therefore the extraction rate and time can be adjusted over a wide range simply by varying the electron current in the cooler. Some typical beam parameters for decelerated and electron cooled beams are shown in Table 2.

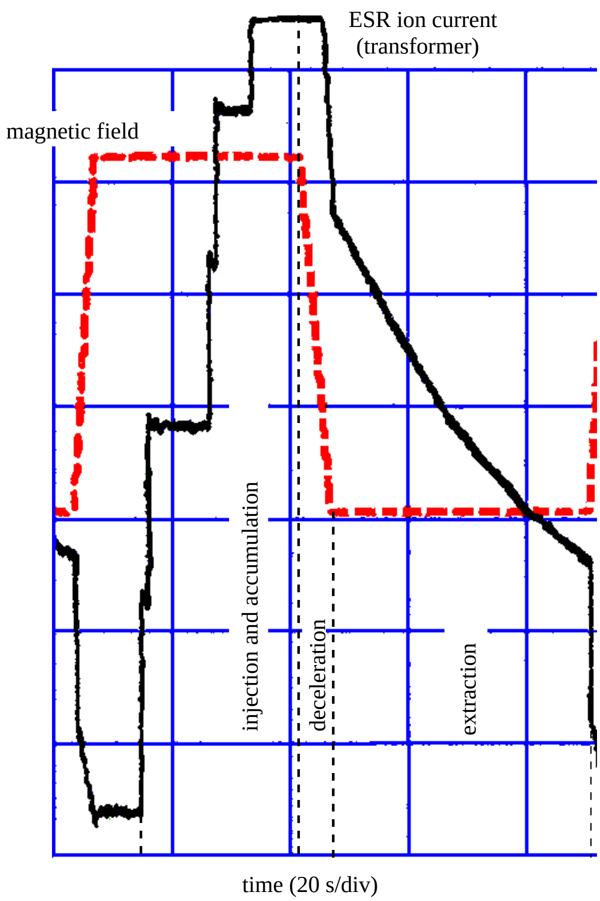

Figure 4: Typical ESR cycle for experiments with decelerated beams and charge exchange extraction.

Table 2: Ion beam parameters for decelerated Au^{78+} beams.

ion energy	50 MeV/u
number of stored ions	2×10^7
momentum spread $\Delta p/p$	1.4×10^{-4}
emittances ε_x, ε_y (1σ)	0.1 π mm mrad

5 EXPERIMENTAL APPLICATIONS

A channeling experiment [3] profited from the small beam divergence, whereby a maximum rate of 10^5 ions/s was extracted at 53 MeV/u. The upper bound of the extracted beam emittance (1σ) was proved to be 0.8 π mm mrad. This is one order of magnitude smaller than the typical beam emittance for slow extraction from the synchrotron SIS. In addition it is not possible to get high charge states at this low ion energy directly from the synchrotron.

In a second experiment, a cryodetector test [4], the small momentum spread of the extracted beam was below the intrinsic energy resolution of the detector and could therefore be used for calibration. In this particular case a very small extraction rate was required. An Uranium beam was extracted at two energies of 360 and 75 MeV/u over several hours with a rate of only 10^2-10^3 ions/s.

6 REFERENCES

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