

ESR Operation and Development

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1 Operation for Physics Experiments

The storage ring ESR was operated until August with beam, during the rest of the year 2000 several technical modifications were performed. Experiments in the ESR were devoted to atomic physics, mainly with very highly charged ions, mass measurements with the time-of-flight method, and the observation of the bound beta decay of thallium [1]. Atomic physics experiments mainly used decelerated bare heavy ions in combination with the internal gas jet target. The heavy ions for atomic physics (gold and uranium) were injected after stripping at around 300 MeV/u and decelerated to various energies between 120 and 30 MeV/u. The typical intensities for the decelerated beam were a few times 10^7 ions. The efficiency for deceleration to these energies was 30 - 50 %, typically.

2 Machine Development

A new set of stripper foils was installed in front of the ESR. Additional carbon foils with thicknesses between 10 and 30 mg/cm² allow to inject for heavy ions ($A \geq 200$) charge states with 2-6 bound electrons in sufficient abundance at energies above 200 MeV/u, e.g lithium-like systems will be available at higher energies this way.

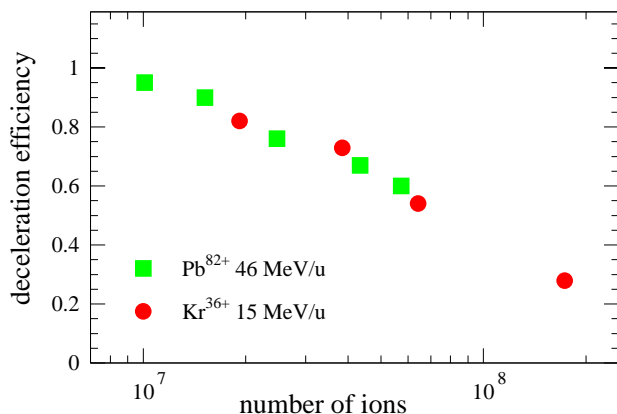


Figure 1: Efficiency for deceleration from 300 MeV/u injection energy to the energy indicated in the legend.

Experiments to decelerate heavy ion beams to even lower energies were continued. For energies below 12 MeV/u the rf frequency has to be changed from harmonic $h=2$ to $h=4$. The debunching and rebunching has been successfully tested at energies between 12 and 30 MeV/u. Supported by continuous electron cooling the de- and rebunching process proved to be free of significant loss. With the beam bunched at harmonic $h=4$ the lowest energy achieved was 9 MeV/u, but still large losses were observed. The intensity of the beam at 9 MeV/u was on the order of a few times 10^5 ions. The ramping speed at the low en-

ergy part of the deceleration procedure (below 15 MeV/u) had to be reduced to 0.01 T/s in order to minimize adverse hysteresis effects. Measurements of tune and of beam position during ramping showed moderate variations, which cannot account for the large losses. The main reason for the losses has not been spotted, but it is likely a combination of the unavoidable adiabatic emittance growth and closed orbit distortions. This is in agreement with measurements of the efficiency for deceleration (Fig. 1). The relative losses increase with beam intensity. It is well known that the emittance of the cooled ion beam, which is always the starting point for deceleration, increases with intensity due to intrabeam scattering [2]. Therefore for higher beam intensity the larger emittance beam is subject to larger losses at aperture limitations.

A first attempt to use the drag force of the electron cooler for deceleration was successful. The rf amplitude was set to zero during deceleration, whereas the accelerating voltage of the electron beam and the magnetic field of the ring magnets were ramped synchronously with a constant electron beam of 0.25 A [3]. The energy of the ion beam was reduced from 15 to 11 MeV/u within 6.7 s, corresponding to a ramp rate of 0.005 T/s, which is only a factor of two slower than what has been achieved with the rf system. However, further studies have to show whether this deceleration mode can provide favorable conditions for routine deceleration to lowest energies.

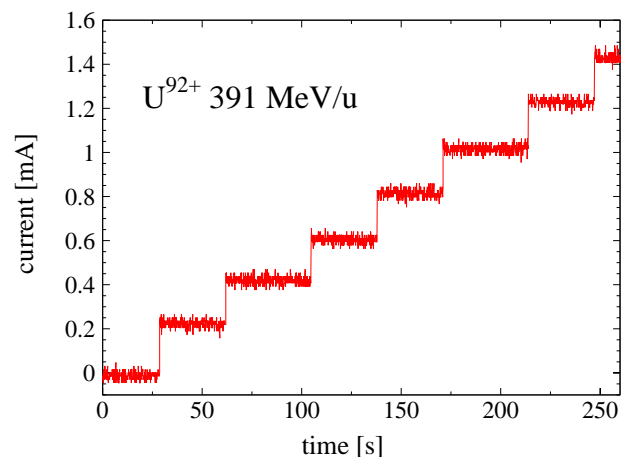


Figure 2: Accumulation of a 391 MeV/u uranium beam by a combination of stochastic precooling, rf stacking and electron cooling of the beam stack.

Stochastic cooling of heavy ions was demonstrated for the first time with a beam of bare uranium ions at an energy of 391 MeV/u [4]. The stochastic cooling system is presently tuned to the corresponding beam velocity ($\beta = 0.71$). Cooling times of about 0.5 s were measured for the longitudinal and vertical cooling. Horizontal cooling was a factor of five slower. The stochastically precooled beam was subsequently stacked by a momentum reduction of 1.8 % with the rf system and contin-

uous electron cooling of the stacked beam at the lower momentum. Figure 2 shows the circulating ion current increase with time. The low and irregular repetition rate of the injections is caused by the availability of the synchrotron SIS for injection into the ESR, as this machine development was performed parasitically to physics experiments served by the synchrotron. The first experience promises that this mode will also be available after some further improvements for fast accumulation of radioactive beams.

The observation of the strong reduction of the momentum spread for electron cooled heavy ion beams of a few thousand ions or less has been explained by an ordered structure of the ions which are confined by their nearest neighbors to their longitudinal position [5]. New experiments have shown that the existence of such an ordered structure can also be indicated by the temporal evolution of the momentum spread after an interruption of cooling. By a fast high voltage switch which stops or starts the extraction of electrons from the cathode within less than 1 ms the cooling was switched on and off alternatingly for time intervals of 6.8 s. The evolution of the momentum spread was monitored by fast Fourier analysis of the longitudinal Schottky noise (Fig. 3).

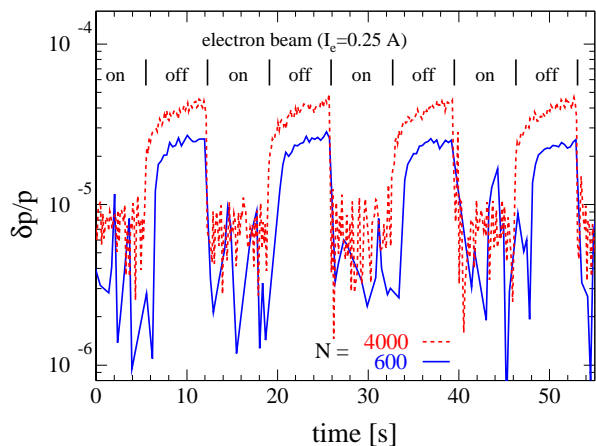


Figure 3: Momentum spread of a U^{92+} beam at 390 MeV/u above (dashed) and below (full line) the transition point to small momentum spread as a function of time. The electron beam is switched on and off for time intervals of 6.8 s. The low intensity cold beam heats up with a delay of about 1 s.

The high intensity beam (particle number $N \simeq 4000$) shows an instantaneous longitudinal heating due to intrabeam scattering. The beam with an intensity below the transition point to small momentum spread ($N \simeq 600$), which is supposed to be in an ordered state, remains in the cold state for nearly 1 s (more than 10^6 revolutions in the storage ring) before the momentum spread starts growing in a manner similar to the higher intensity beam. The ordered structure is obviously not immediately destroyed by intrabeam scattering.

3 Technical Developments

The long shutdown starting in September 2000 was used for several new installations in the ESR. The ramping range of the dipole magnets was hitherto limited by the power supplies for the correction coils sitting in the main dipoles to improve the flatness of the radial field distribution. Replacement by more powerful and bipolar power supplies will allow ramped operation over the full magnetic rigidity range of the ESR. This will be particularly valuable for bare decelerated heavy ions. They can be injected at higher energy with a higher stripping efficiency and then be decelerated to the required energy. It will also ease ESR operation in general.

The internal gas jet target section was completely disassembled. The reconstruction of this area will make room for the installation of new experimental equipment, such as a zero degree electron spectrometer downstream the target, Helmholtz coils to guide electrons produced in the interaction of the beam with target atoms, or a cryogenic bolometer for X-ray detection. The modification of the target section is a prerequisite for a large variety of new experiments which are planned with the internal gas target.

The stepping motors driving the detector pockets for the installation of particle detectors behind the gas target and the electron cooler were replaced by pressurized air actuators. The new actuators can be positioned within 1 s with an accuracy of 0.1 mm for particle detection, compared to times of the order of minutes which were needed to position the detectors with stepping motors. The thickness of the stainless steel entrance windows to the detector volume has been reduced from 50 to 25 μm in order to detect decelerated heavy ions with energies down to 7 MeV/u.

References

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