

Slow Extraction at the Heidelberg Heavy Ion Storage Ring TSR

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Abstract

At the Heidelberg heavy ion cooler storage ring a slow beam extraction system using the third order resonance $Q_x = 8/3$ has been installed using the same electrostatic septum for extraction and injection. Different extraction methods have been investigated: In the first method the beam was injected close to the third integer resonance and electron cooled. By variation of the cathode potential of the electron cooler gun by -0.4% the tune was shifted to the third integer resonance due to the chromaticity of the ring. With this method an extraction efficiency of about 30% was achieved. Beam extraction using emittance growth due to multiple scattering on the residual gas was done by setting the betatron tune just above the third order resonance. The beam could also be extracted by applying a transverse rf field with a frequency corresponding to the betatron tune of the beam. By adjusting the transverse rf voltage and frequency the spill of the extracted beam and its intensity could be controlled.

1 INTRODUCTION

The Test Storage Ring TSR [1] installed at the Max Planck Institut für Kernphysik is used for accelerator, atomic and nuclear physics experiments. The ring has a circumference of 55.4 m and a maximum rigidity of 1.5 Tm and can receive heavy ions up to iodine from a 12 MV tandem van de Graaff and a normal conducting RF linac combination. Electron cooling is used to reduce the phase space of the stored beam and for the accumulation [2] of ions.

In the last years the TSR became an important tool in molecular physics. Only a storage ring offers the opportunity to get vibrational cold molecules just by storing them and waiting until they are relaxed. Together with the new installed extraction system the TSR is now a source for cold molecular ion beams.

2 THE EXTRACTION SYSTEM

In 1995 the slow extraction system consisting of a new vacuum chamber and two septum magnets (see table 1) was installed in the TSR. It was placed right after the injection,

so that the electrostatic septum of the injection could also be used for the extraction. Further more it is possible to transport the beam directly from injection to the extraction channel without accumulating.

septum	MS3	MS4	ES
deflect. angle [mrad]	160	350	60
gap [mm]	25	40	30
max. field	0.5 T	0.75 T	5 MV/m
max. current/voltage	2850 A	1500 A	150 kV
length [mm]	429	850	619

Table 1: Parameters of the two septum magnets and the electrostatic septum.

3 MEASUREMENTS

During two beam times several extraction methods were investigated using a $^{12}\text{C}^{6+}$ beam ($E=73.3$ MeV).

To measure the current in the ring the countrate of the horizontal beam profile monitor and the current transformer were used. At the provisional end of the extraction a multi-channel-plate counted the number of the extracted particles.

The third order resonance $Q_{res} = 8/3$ driven by one sextupole magnet was used to extract the stored beam. The tune was shifted to cross the resonant value by different methods. The efficiency for all methods was in the range of 25 %. The time structure (spill) of the extracted beam ranged from 100 ms up to several hundreds of seconds.

3.1 Extraction by variation of the longitudinal momentum

In order to shift the tune over the resonance the dependency on the longitudinal momentum due to the horizontal chromaticity $\xi_x \approx 10$ was used. The longitudinal momentum of the cooled beam was decreased (about -0.4%) by changing the cathode potential of the electron cooler.

The following scheme for this extraction method was applied: After injection the stored beam was cooled until the equilibrium emittance of $\epsilon_x = 0.1 \pi$ mm mrad was

reached. The sextupole strength was increased to $m = B''L/B\rho = 0.3\text{ m}^{-2}$ and then the cathode potential of the cooler was switched to another value corresponding to a tune of $Q_x = 2.661$. Figure 1 shows the spill of the extracted beam. The extraction time depends on the time necessary for the ion beam to follow the velocity change of the electron beam. For the 73.3 MeV carbon beam it takes about 1 s for a change of the electron momentum of $\Delta p/p \approx -0.4\%$ at an electron current of 200 mA.

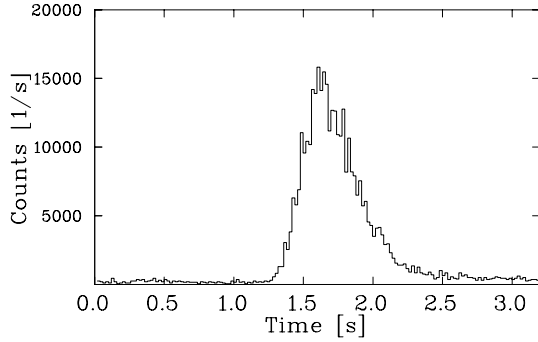


Figure 1: *Spill of the beam extracted by changing the longitudinal momentum with the electron cooler.*

3.2 Extraction using emittance growth by residual gas

The emittance of the circulating beam is increased by multiple scattering which is caused by Coulomb interaction between the beam and residual gas in the ring. The average vacuum pressure in the TSR was 5×10^{-11} torr. For a carbon beam the average emittance growth per second is estimated to be 0.006π mm mrad/s. This emittance growth was used to extract the beam. For the resonant excitation of the beam the sextupole strength was $m = 2.2\text{ m}^{-2}$ and for the tune a value of $Q_x = 2.6773$ was chosen. After injection of the beam no parameters of the ring were changed. Figure 2 shows the spill of the extracted beam. The time constant is $\tau = 165 \pm 2$ s. This is also the lifetime of the stored ions determined by the third order resonance. This method leads to very long spills of the extracted beam and is easy to control by variation of tune and sextupole strength.

3.3 Extraction using transverse RF-field

The emittance of the stored beam can also be increased by applying a transverse RF-field, that fulfills the following condition:

$$f_{RF} = f_0(n \pm q) \quad , \quad (1)$$

where f_0 is the revolution frequency, n an integer number and q the non integer part of the tune. The spill of the extracted beam can be controlled by the RF-frequency and the RF-Amplitude. Figure 3 shows the time structure of the extracted beam current by applying a pulsed

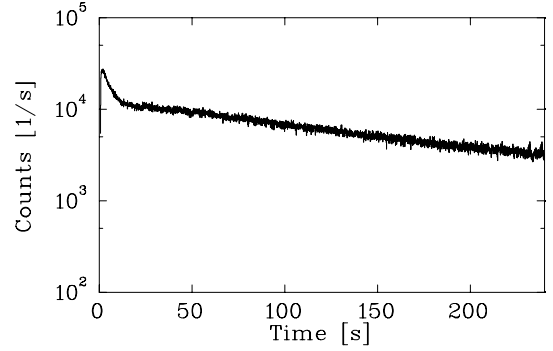


Figure 2: *Spill of the extracted particles by utilizing the emittance growth due to multiple scattering with the residual gas.*

modulated RF-field. The amplitude of the transverse RF-Voltage of about 100 V was switched on and off every few seconds. The frequency dependency of the beam extraction rate is shown in figure 4, where the frequency was changed between 0.802 MHz and 0.808 MHz. The Measurement indicates a resonance structure with a maximum at $f_{RF}=0.8059$ MHz which is given by equation 1. The dashed line in figure 4 is the counting rate caused by emittance growth due to multiple scattering.

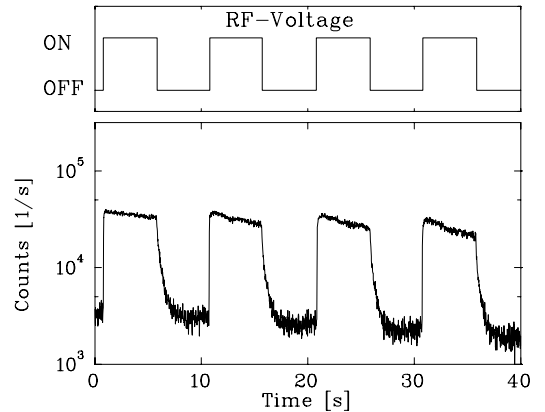


Figure 3: *Count rate of the extracted particles as a function of time. The RF-voltage of the kicker was switched on and off.*

4 PROFILE OF THE EXTRACTED BEAM

The horizontal profile of the extracted beam was measured with a 1 mm slit in front of the Multi Channel Plate. The beam was moved over the slit with the septum magnet. Figure 5 shows the measured profiles for two different extraction methods. The methods using an emittance growth of the beam are expected to lead to a very small emittance of the extracted beam [4]. Changing the longitudinal momentum of the beam results in larger horizontal emittance due to changing separatrix size during extraction.

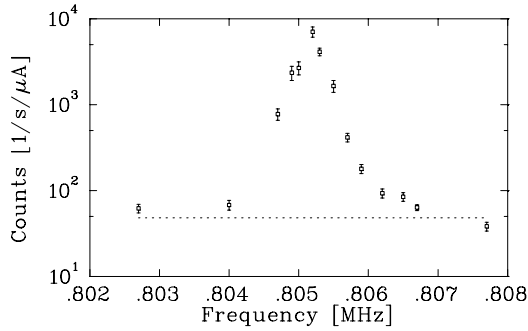


Figure 4: The number of extracted particles normalized on the ion-current in the ring as a function of the RF-frequency

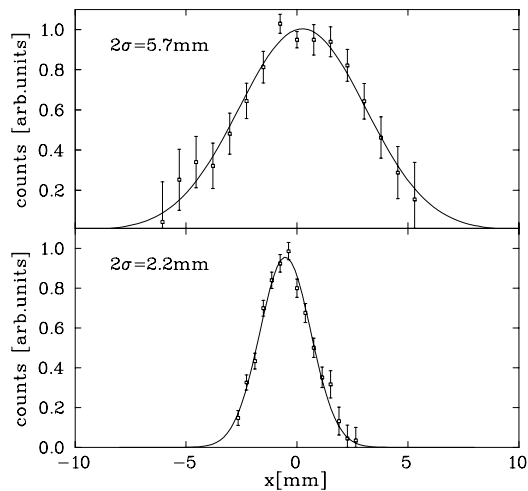


Figure 5: Horizontal profiles of the beam extracted by changing the longitudinal momentum with the electron cooler (top) and by the emittance growth due to multiple scattering (bottom).

5 FIRST COULOMB EXPLOSION IMAGING EXPERIMENT

The knock out extraction method was used for a Coulomb Explosion Imaging (CEI) experiment [3]. CEI is a method to directly measure molecular structure by analyzing the fragments of rapidly dissociating (exploding) molecules where their binding electrons have been stripped off. The molecule chosen for this experiment was HD^+ . After being stored for a few seconds the molecules are vibrational cold. Then the beam was slowly extracted and collimated by a 1 mm pinhole. The coulomb explosion takes place in a thin (≈ 10 nm) FORMVAR foil. The proton was separated from the deuteron by using a magnetic dipole field. A CCD camera records the image on a phosphor screen. Figure 6 shows the coulomb explosion image consisting of the deuteron and proton fragments. If the final velocities of all the molecular constituents are known which can be measured with a time and position sensitive detector the structure of each molecule and thus the nuclear density distribution can be obtained.

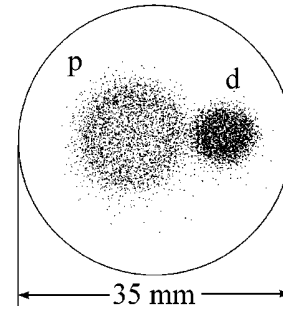


Figure 6: Image on the phosphor screen of the protons and the deuterons which are separated by a magnetic dipole field.

6 ACKNOWLEDGEMENT

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7 REFERENCES

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