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INVESTIGATIONS INTO EFFICIENT EXTRACTION AND ACCELERATION OF BEAMS FROM ION TRAPS

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Abstract

A number of exotic ion species, such as for example radioactive isotopes or antiprotons, are highly desirable at very low energies of some tens of keV for fundamental studies. In order to obtain cooled beams with low emittance and low momentum spread, these particles are often first captured in an ion trap, cooled and then extracted and accelerated before being used in experiments. The extraction mechanism and subsequent beam handling impacts critically on the final beam quality. In this contribution, the beam energyis optimized for efficient beam extraction and acceleration from a specific ion traps. For this purpose, field maps from the MUSASHI trap at CERN are used as a basis for simulation studies into the beam dynamics and output beam quality.

INTRODUCTION

A small antiproton recycling ring [1] in the energy range between 3 and 30 keV has been designed for use at the CERN Antiproton Decelerator (AD). An injection beamline has been designed to transport the antiprotons from the MUSASHItrapand inject them into the ring. Both the ring and injection line are presented in detail elsewhere at this conference [2,3]. For the investigations into possible injection beam line designsafixed energy of 150 eV was assumed for the particles. In MUSASHI it is, however, possible to change the energy of the extracted antiprotons in the range between 150-1,000eV. Assuming a given extraction scheme, this opens an opportunity for optimizing the beam extraction by studying the beam quality as a function of extraction energy.

The magnetic field of the trap, including its fringe and stray fields, has significant influence on the particle motion. In particular, it leads to a rotation of the whole beam around the longitudinal axis inside the trap. As a consequence, the beam that is extractedfrom the trap out of the magnetic field is highly divergent. The beam angular momentum defines the value of the beam emittance.A decreasing magnetic field leads to an increase of the beam emittance in the transverse directions and to a strong coupling between them. This may potentially worsen the conditions for proper beam transport.

With the aim to identify possibilities for reducing this coupling the motion of the beam was analyzed as a function of beam energy. Therefore a dedicated code was programmed to solve the system of differential equations of motion in cylinder coordinates in a magnetic field.

PARTICLE TRACKING

In order to represent the antiproton beam coming from MUSASHI, the fringe magnetic field (Fig.1) of the trap solenoid was taken into account in full 3D simulations. These were performed from the centre of the trap using the core of the compressed beam only [4]. The magnetic field inside the trap solenoid was assumed to be 2.5 T for nextsimulations.

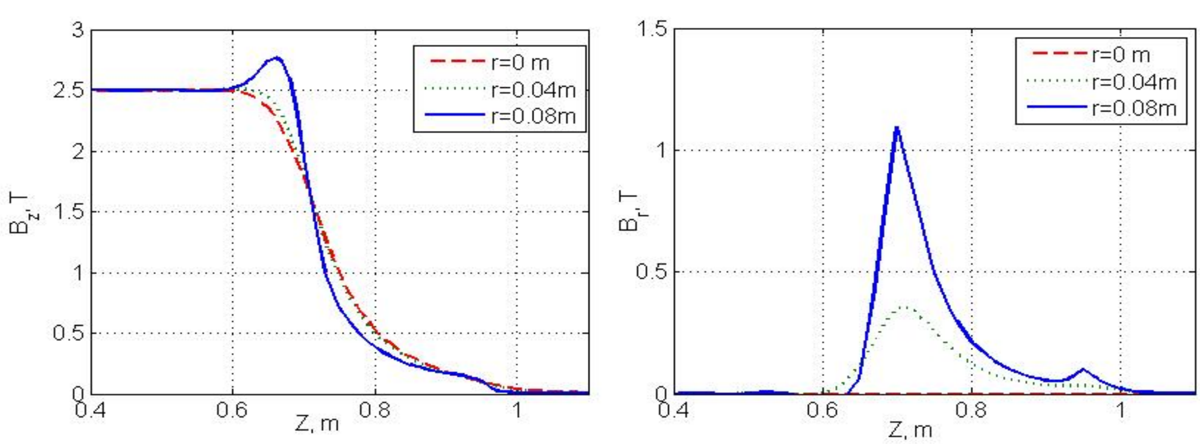

Figure 1: Longitudinal and radial components of the magnetic field of the MUSASHI solenoid.

The system of equations of motion in an axially symmetric magnetic field (Bφ=0) is given by:

$$\begin{cases} \dfrac{\partial(m\dot{r})}{\partial t} - mr\dot{\varphi} = q\left\{r\dot{\varphi}B_z\right\} \\ \dfrac{\partial(mr\dot{\varphi})}{\partial t} + m\dot{r}\dot{\varphi} = q\left\{-\dot{r}B_z + \dot{z}B_r\right\} \cdots(1) \\ \dfrac{\partial(m\dot{z})}{\partial t} = q\left\{-r\dot{\varphi}B_r\right\} \end{cases}$$

It was found that with increasing energy of the extracted antiprotons the divergence of the beam decreases. Fig. 2 shows example particle trajectories for different energies.

The divergence of the beam is, however, not the only process that one can observe during beam extraction The whole beam rotates around the longitudinal axis. The sign of the azimuthal component of the velocity is determined by the balance between $-\dot{r}B_z$ and $\dot{z}B_r$ as can be seen from (1).

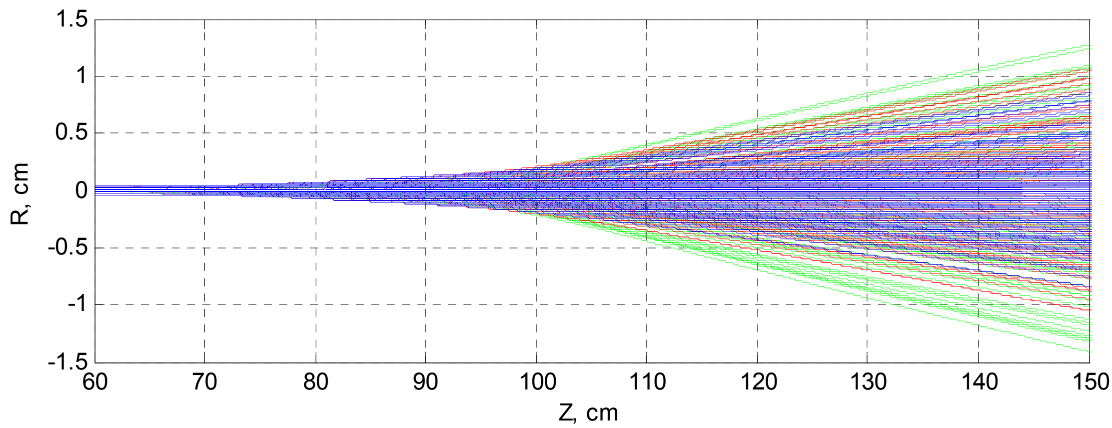

Figure 2: Particle trajectories. Blue lines correspond to an energy of E=150eV, green lines, E=1,000 eV, red lines, E=2,000 eV.

In Fig. 3 the azimuthal components of the velocity for the extracted antiprotonsat different energies are shown. In this study, three different energies were used: 150 eV (green lines), 1,000eV (red lines) and 2,000eV(blue lines). The magnetic field inside the trap was always assumed to be B=2.5 T

One can see thatthe azimuthal component of the velocityincreasesfor z up to 100cm and then slowly decreases to zero (for E>1,000eV) oreven to negative values for E<1,000eV. It should be pointed out that when $V_\varphi$is zerothe motion is uncoupled.

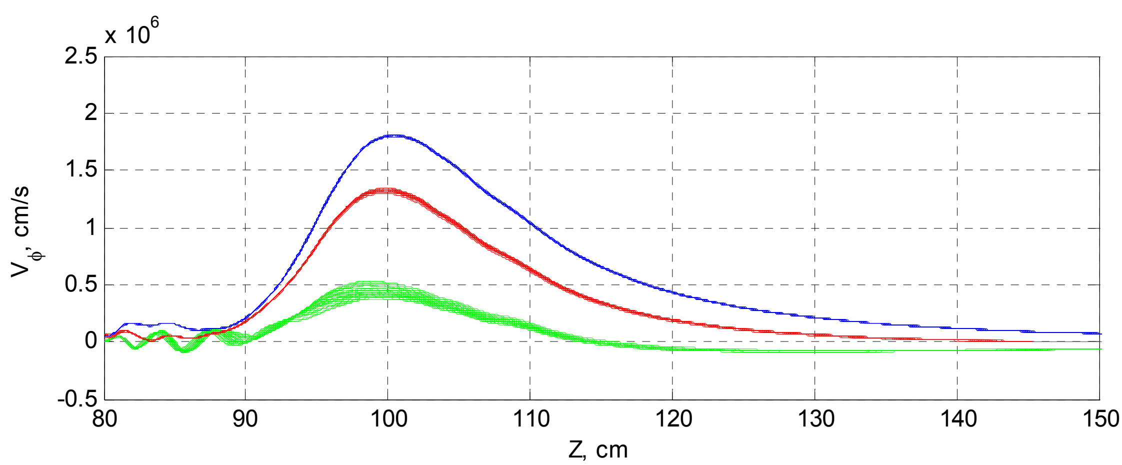

Figure 3: Azimuthal velocity of the antiprotons as a function of longitudinal position and at three different beam energies.

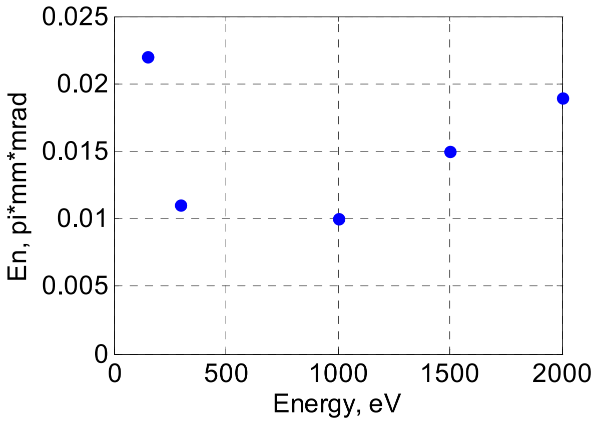

Figure 4: Normalized RMS emittance of the beam against the extracted energy

An optimum energy of 1,000 eV was found for beam extraction with the previously described trap parameters. The larger theazimuthal velocity of the beam, the larger the value of the resulting beam emittance. Fig. 4 shows the dependence of the normalized emittance on the energy of the extracted particles in the point where the beam transport line to the antiproton recycler ring is beginning, i.e. at z=128.6 cm.

In addition to the above simulation, the magnetic field strength was increased to 5 T. Fig. 5 shows the azimuthal velocity of the antiprotons at an extraction energy of 150eV,1,000eV, 2,000 eV and 3,000 eV. It can be seen that the optimumextraction energy for a field level of 5 T is substantially higher than for 2.5 T and is equal to about 3,000eV.

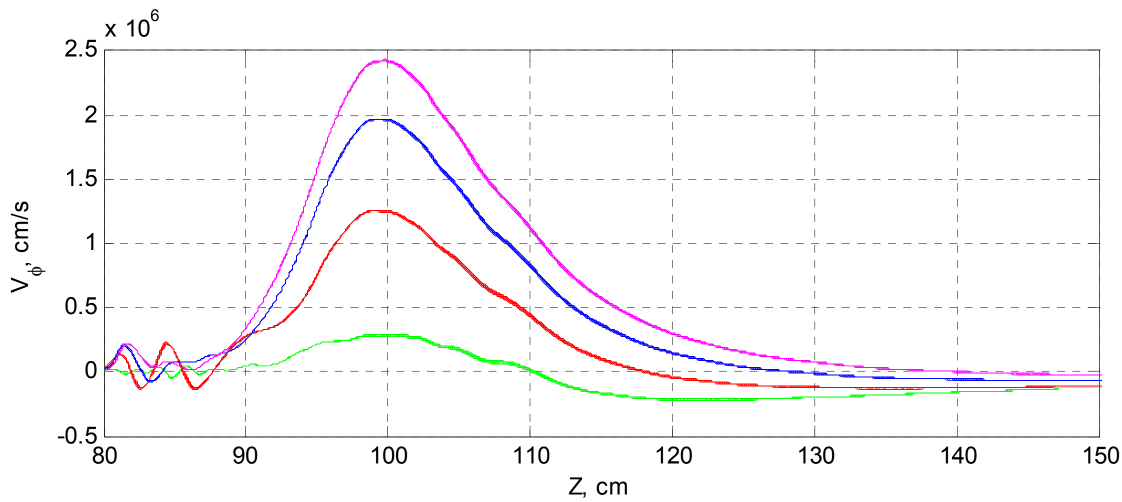

Figure 5:Azimuthal velocity of the antiprotons as function of the longitudinal position at different extraction energies: Green lines correspond to E=150 eV, red lines, 1,000eV, blue lines, 2,000eV, magenta, 3,000 eV. Magnetic field inside the trap B=5 T.

SUMMARY AND OUTLOOK

It was found that the optimum energy of the beam extracted from the MUSASHI trap is about 1,000 eV. The beam of this energy passed the region of the decreasing magnetic field with close to zero azimuthal velocity. The optimum energy depends also on the level of the magnetic field of the trap. For a field level of 5 T it is substantially higher than for 2.5 T and is equal to about 3,000 eV.

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