DESIGN OF A TWO-STAGE ION BEAM COOLER AND BUNCHER FOR LEBIT

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1 Introduction, design goals

The ion accumulator and buncher in the LEBIT project has the task to effectively collect the singly-charged ions delivered from the gas cell and send them to the experimental area as ion pulses with excellent beam properties. It is being designed with the following guidelines in mind:

a) It has to fully accept the 5keV-DC beam from the gas cell which is supposed to have a transverse emittance of 10 π mm mrad and an energy spread of 5 eV or less. These specifications appear conservative given the way the ions are prepared in the gas cell system (see separate report).

b) It has to either provide pulsed beams at alternatively ≈ 2 keV or ≈ 60 keV energy or a DC beam at ≈ 2 keV energy occupying the least phase-space possible (=”cold beam”). The pulsed-mode operation will be the standard operation to feed ions into the experimental area whereas the continuous beam option will ease to find beam-line settings downstream the ion buncher.

c) Because of its application for exotic nuclei it is mandatory to keep the time the ions spend within the system minimum.

Given the recent success of ion coolers/bunchers used in comparable efforts (ISOLTRAP[1] / JYFL[2]) it was decided to adopt the concept of a buffer-gas filled linear radiofrequency quadrupole (RFQ) trap for LEBIT but develop it further in several points.

2 Linear RFQ trap basics

A linear RFQ trap (also called linear Paul trap) is an advanced version of the mass filter, a device widely used in analytical chemistry. The mass filter consists of two pairs of parallel rods that create a two-dimensional quadrupole field. When a suitable high-frequency voltage is applied to the two pairs of electrodes ions with a certain range of charge-to-mass ratios are confined in transverse direction and may pass the structure.

By operating a mass filter in the presence of buffer gas (usually Helium at room temperature) the motion of ions confined in the device will be damped. If the initial energy of the ions is sufficiently low the ions will practically come to rest at some point on the axis of the mass filter. In order to guide the ions to the end of the rod structure an axial drift field is needed in addition to the confining RF field. This drift field can be generated by cutting the rods into many segments which carry an additional DC voltage that decreases along the axis of symmetry. When exiting the mass filter the ions have practically dissipated all their initial energy – except for an axial drift velocity and the additional thermal motion induced by collisions with the buffer gas molecules.

In order to use this beam cooler as a beam accumulator an axial potential depression can be generated by applying a series of suitable voltages to a set of rod segments at the end of the structure that make up the trap. For extraction of the accumulated and cooled ion cloud voltages are applied to the last electrodes of the linear ion trap that quickly guide the ions to the exit of the device.

3 Design

After several design iterations it was decided to use the electrode structure as shown in fig. 1 for the cooler and buncher of LEBIT. The system mainly consists of a cooler and a trap section, linked by a ”micro“-RFQ and a pulsed drifttube.

The cooler section is to quickly dissipate the transverse energy of the ions and most of their axial energy. It is operated at a fairly high pressure of $p_{He} \approx 5 \cdot 10^{-2}$ mbar and long enough (length: 40 cm) to cool ions of mass $A \leq 200$ at room temperature to thermal equilibrium before the end of this section. The trap section is where ions are accumulated in a low pressure ($p_{He} \approx 2 \cdot 10^{-3}$ mbar) environment and ejected as ion pulses.

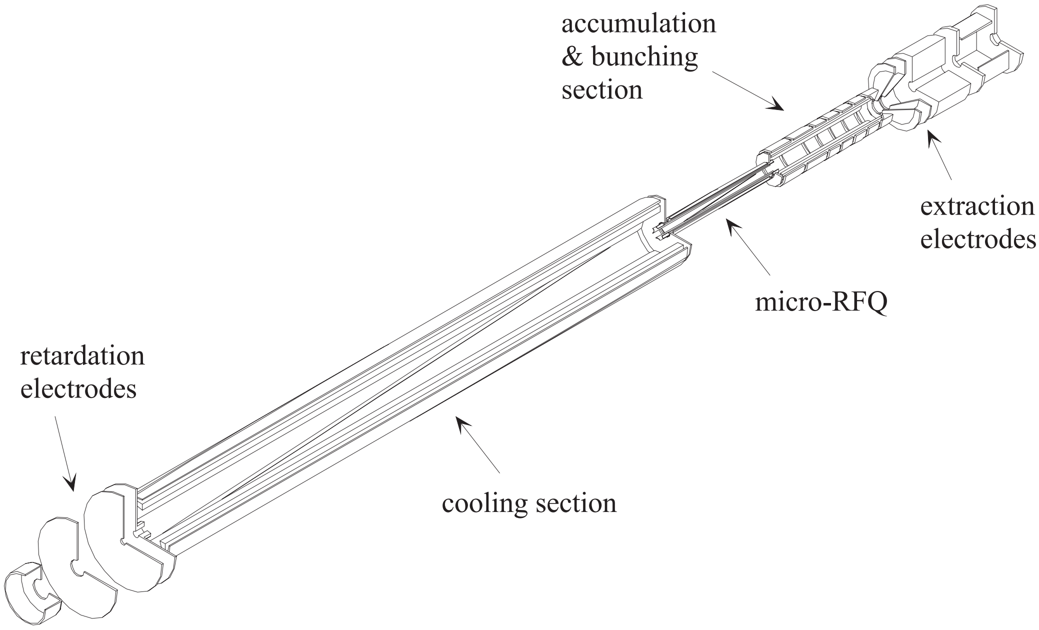

Figure 1: The LEBIT ion accumulator and buncher electrode structure

The separation of the ion accumulator into a high-pressure cooling and a low-pressure trapping stage became necessary to avoid a problem that was observed while simulating the ejection process: If ions are ejected from a trap at high pressure, ($p_{He} \approx 5{\cdot}10^{-2}$ mbar) the ions have a finite probability to make a number of collisions with buffer gas molecules before they enter the high-vacuum region. This series of collisions blows up the energy-spread of the ejected ion pulse to values that are not acceptable. One way around this problem is a very slow extraction of the ions thereby increasing the time spread of the pulse which is contrary to the design goal. By keeping the pressure in the trap section low ($p_{He} \approx 2{\cdot}10^{-3}$ mbar) the collision probability is practically negligible for the trap dimension and operation parameters chosen.

The cooler and the trap sections are connected by a μ-RFQ-guide (Ø 6 mm, length 80 mm) with RF amplitudes scaled such that the confining force is practically constant up to the trap section. The small transverse dimension of the μ-RFQ-guide is needed for the pressure to drop sufficiently between the adjacent sections. Both the cooler section and the μ-RFQ use a novel design with wedge-type cylindrical DC electrodes and RF rods inside. This electrode arrangement creates the required electric fields with considerably less electrodes than a "classical" segmented ion cooler. The trap section is made of seven ring electrodes encompassing the RFQ rods and two acceleration electrodes that allow to shape proper trapping and ejection potentials.

For the production of ions pulses with energies of up to 60 keV a pulsed drift tube has been incorporated the ion optics. The voltage applied to this drift tube may be switched from -2 kV to +58 kV while the ion pulse is in it. This allows the ions to be accelerated to 60 keV when they pass the gap to the next (grounded) electrode ("one-gap LINAC").

Both the cooler section and the trap section will be operated at LN_2-temperature. Besides an increase of the acceptance of the system and a decrease of the cooling time this option will significantly reduce the emittance of the resulting beam/pulse compared to an operation at room temperature.

4 Simulations

The performance of the ion beam cooler and buncher proposed for LEBIT has been checked in detail by simulating the entire ion manipulation process i.e. injection, cooling, trapping and ejection. Injected ions were subjected to the electric field of the electrode structure as calculated with the SIMION v7 software package. The damping

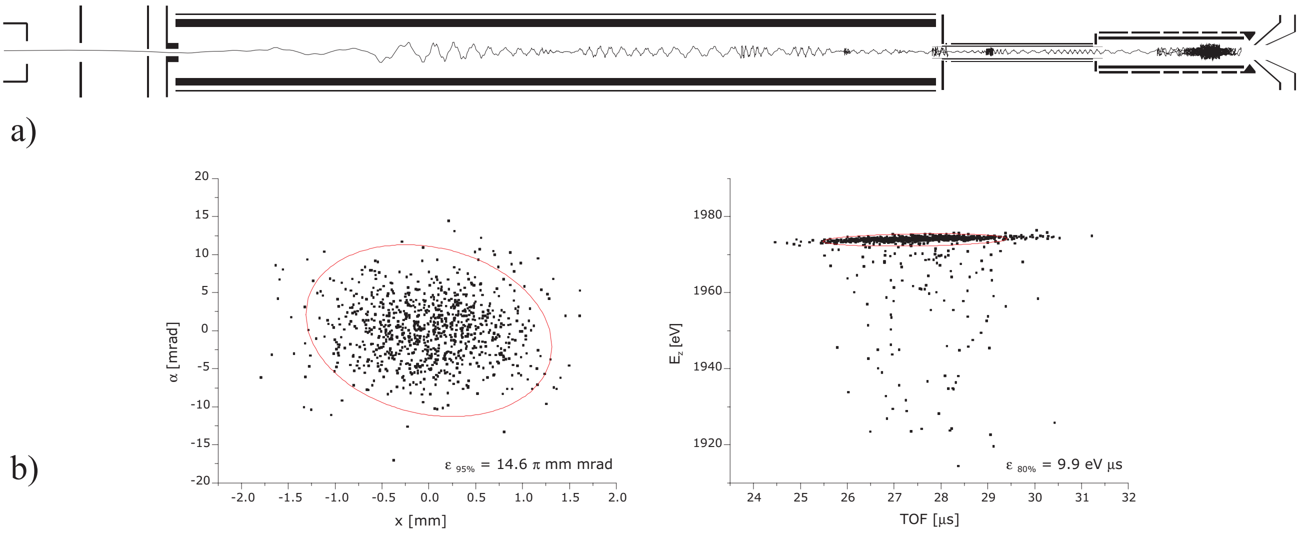

Figure 2: a) Simulated trajectory of a sodium ion getting trapped in the ion accumulator and buncher. b) Calculated transverse and axial phase-space occupied by a 2 keV-energy pulse of ^{133}Cs ions ejected from the buncher system.

force of the Helium gas environment was taken into account by MC-type simulating the scattering processes between ions and Helium atoms. Realistic potentials derived from ion mobility data were used to model the interaction between the collision partners.

As an example fig. 2 a) illustrates the trapping process for a ^{23}Na ion. The trajectory of the ion was recorded for 8 ms after injection into the system. The time chosen is about the average time needed for Na ions to cool to thermal equilibrium at room temperature with the specific operation parameters chosen.

Figure 2 b) shows the calculated phase-space occupied by a 2 keV-energy pulse of ^{133}Cs ions ejected from the buncher system which operates at room temperature. The emittance of the pulse is approximately $14\,\pi$ mm mrad and drops by about a factor of four when the trap is run at LN_2 temperature.

5 Status

With the simulations predicting a satisfying performance of the proposed ion beam cooler and buncher a first draft of the design has been laid out. Detailed design work is about to start now.

References

1. F. Herfurth et al., Nucl. Instr. Meth. A469/2 (2001) 254-275.
2. A. Nieminen et al., Nucl. Instr. Meth. A (2001) in print.