

Antiproton cooling and extraction from an electron-antiproton trap

Balázs Újvári

Department of Experimental Physics of University of Debrecen

Introduction

In ASACUSA [1] project, experiments are planned to investigate initial formation processes of antiprotonic atoms, interaction between antimatter and matter etc., most of which require ultra-low energy antiproton beams. At Antiproton Decelerator (AD, at CERN), 10^7 antiprotons of 5 MeV will be at hands as a pulse of 250 ns with a repetition period of one minute. In our scheme, MeV -energy antiprotons from AD will have several tens of keV after passing through a radio frequency quadropole decelerator (RFQ). Those antiprotons enter a Multi-Ring-Electrode (MRE) trap, then the well-known electron cooling technique will be applied. Dense cloud of antiprotons, together with electrons, are supposed to behave as a nonneutral plasma.

Trap

In designing the trap [2], following two points are especially considered:

- Preparation of 10^{6-7} antiprotons with sub- eV energy within one minute.
- Extraction of cooled antiprotons from the trap which is located in strong magnetic field.

As low energy charged particles tend to follow the field line, it is essential to make the position of the particles as close to the axis as possible for their extraction as a beam. One solution is the application of a rotational electric field.

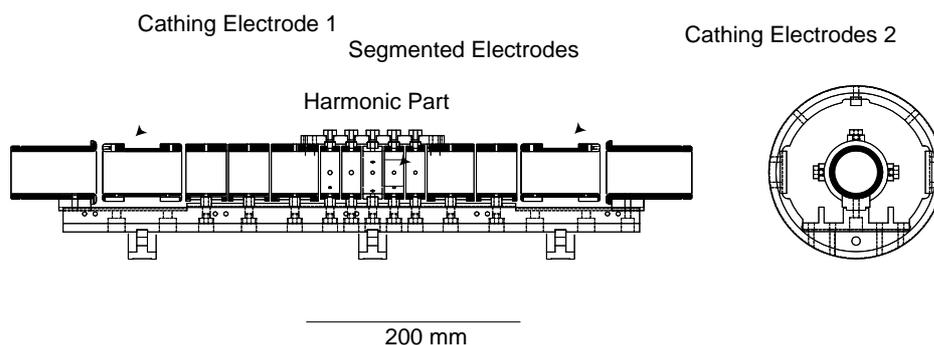


Figure 1: Trap

The trap consists of 14 cylindrical electrodes of 40 mm in inner diameter and total length of 500 mm . It has a long harmonic potential region and will be able to store as many as $\sim 5 \cdot 10^6$ antiprotons and about 100 times more electrons in a prolate spheroid

with a radius ~ 1 mm and its axial length ~ 50 mm with a rather low trapping potential. It is about 5 times larger than that of a traditional Penning-trap.

For application of rotating field, an electrode that is azimuthally segmented into four identical parts is located next to the one at the center. On one end of the trap there is a Faraday-cup which serves as a detector for destructive diagnosis.

Two electrodes marked as cathing electrodes are for the cathing of the several tens keV-energy antiprotons from RFQ, the potential on these is about 50-100 keV.

All the system is installed in a superconducting solenoid. The magnetic field is 5T, the uniformity is better than 0.5% within the trap and considered to be much better in the harmonic region. The magnetic field is scannable at 5T/90sec, which allows to vary the field strength depending on the operational stage, i.e., injection, cooling, or extraction.

Extraction

After cooling we decrease the potential on the right side of the trap, especially on the cathing electrode, the plasma starts to move, but because of its self-electric field increases the field a bit back, we have to compensate continuously during the extraction.

The whole procedures to prepare ultra slow antiprotons are under study with proton and negative hydrogen ion. We have a duoplasmatron ion source, a negative hydrogen ion has a binding energy of 0.74 eV and can be used to simulate an antiproton in the low energy region. For tests like the injection of a high energy beam into the trap, proton will be used.

Calibration

Near the center of the trap the potential can be expressed for a particle of charge q and mass m , as [3]:

$$\Phi(r, z) = \frac{m\omega_z^2}{4q}(2z^2 - r^2),$$

where r and z are cylindrical coordinates, and ω_z is the frequency at which a single trapped particle (or the CM of a cloud of particles) oscillates along the z axis. The equation of motion of a single particle in the z -direction:

$$\ddot{z} = -\omega_z^2 z - \gamma \dot{z} - \frac{qd_1 V}{2mz_0} + \frac{F_{ind}}{m},$$

F_{ind} is the Coulomb attraction force due to the image charge in the electrodes, if we have a cloud of particles:

$$\ddot{Z} = -\Omega_z^2 Z - \Gamma \dot{Z} - \frac{qd_1 V}{2mZ_0},$$

where Ω_z^2 expresses the harmonic restoring strength given by the trapping field modified by the Colulomb attraction force due to the total image charge. This motion indeces a current:

$$I_c = -\frac{qd_1 \dot{z}}{2z_0},$$

The dependences of the voltage V on the induces current I_c can be written as:

$$V = l_n \frac{dI_c}{dt} + \frac{1}{c_n} \int I_c dt + r_n I_c,$$

The parameters l_n , c_n , r_n depend only on the plasma and the trap. This voltage-current relation means that the circuit response of a cloud of particles in a Penning-trap is equivalent to a LRC circuit with a resonant frequency. Using an external “tank” circuit formed by a laboratory inductor L_e and the tank parasitic capacitance C_e coupled to the motion of the CM of a cloud of trapped particles. Using a spectrum analyzer, the measured output of these two circuit:

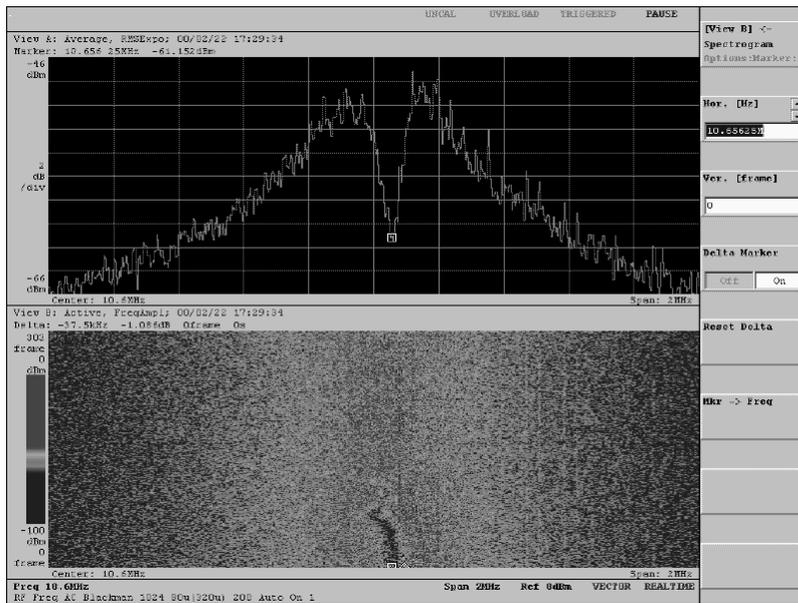


Figure 2: Spectrum

We measured the peak-separation on the oscilloscope and the charge with the Faraday-cup, then we fitted the separation versus charge (using the [3]).

Charge [$10^{-12}C$]	Separation [kHz]
6.6	42
9	102
19.9	178
24.2	253
25.2	238
26.8	268
30.4	291
33.8	305
35.4	269
38.4	333
44	358
46.4	325

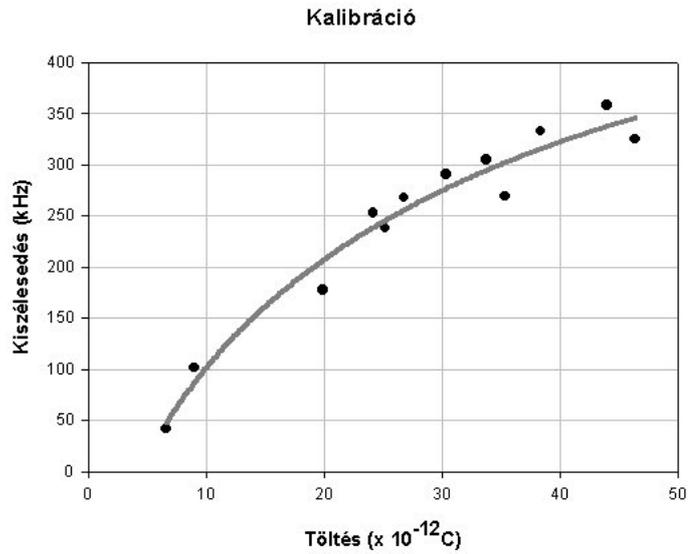


Figure 3: Calibration

References

- [1] R. S. Hayano, ASACUSA Progress report.14.Dec.1999.
- [2] Y. Yamazaki, Multi-ring Trap as a Reservoir of Cooled Antiprotons, CP498, Non-Neutral Plasma Physics III.
- [3] Y. Yamazaki, Tank circuit model applied to particles in a Penning trap, **79**, 1 (1996).