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Toward the production of antihydrogen at rest in ATHENA[☆]

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Abstract

Preliminary results about the handling of charged plasma in ATHENA are shown describing both the destructive and the non-destructive methods. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

The production of antihydrogen atoms at rest, that is having energies of a few tenth of μeV, and their confinement inside magnetic traps for high-resolution spectroscopy are the goals of the ATHENA [1,2] experiment at CERN. Another experiment having the same scientific goal is ATRAP [3]. The cold antihydrogen atoms will be formed in ATHENA by merging two cold charged plasmas: one made by positrons and one by antiprotons and allowing for the spontaneous or stimulated radiative recombination or the three body recombination to take place. The actual antiproton source is the Antiproton Decelerator (AD) at CERN delivering 100 MeV/c particles. The achievement of lower energies requires the use of electromagnetic traps. About 1% of the AD antiprotons will be caught inside a cylindrical multisector trap (40 cm length and 2.4 cm diameter) and cooled up to criogenic temperature by the electron cooling method using the experience accumulated during the LEAR operation [4]. The handling of the charged plasma (the electron plasma used to cool the antiprotons, the antiproton plasma and the positron one) and the control of their parameters (density, dimensions, temperature, number of particles) are of primary importance for

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the optimization of the recombination process. Here we will focus our attention on the antiproton cooling process and we will discuss some of the techniques used for the plasma diagnostic and optimization of the electron cooling strategy. Some preliminary results obtained storing electrons inside the ATHENA catching trap are shown.

2. Electron cooling of antiprotons

About 10^5 antiprotons having energy below 15 KeV are expected to be caught in ATHENA. In these conditions we note that total cooling times of a few tenths of seconds require about 10^8–10^9 electrons with density 10^7–$10^8\,\mathrm{cm}^{-3}$ and that practically all the cooling time is spent for reaching an energy in the eV range. Achieving lower energies increases the cooling time by a very negligible factor. The radial extent of the electron plasma is important because the antiproton radial orbits must cross the electron cloud and the axial superposition between the two clouds has also to be taken into account. Moreover, the space charge due to the electrons plays an important role in the definition of the antiproton final energy. This is because the electrons have to be removed before moving antiprotons inside the recombination region and this operation transforms the potential energy due to the space charge into antiproton kinetic energy. Considering that the electrons space charge potentials are of the order of tenths of eV, this can spoil the effect of the cooling. Taking into account all these considerations, a proper electron cooling strategy requires: loading the catching trap with a sufficient electron number; reaching an electron storage time long enough; knowing the density and the radial cloud dimensions; reducing the electron number during the cooling process and let the system go into equilibrium with a smaller number of electrons; monitor the electrons and antiproton number in non destructive way; measure the antiproton temperature.

3. Electron plasma tests in the ATHENA catching trap

Various experimental tests are in progress using electrons in the ATHENA catching trap. Here only a few results are reported. The catching trap is mounted inside a cryostat placed in a 3 T magnetic field and in an ultrahigh vacuum region. Electrons can be loaded inside the trap using a filament. The potentials applied to each trap electrode can be separately chosen in order to shape a trap region of proper length (Penning type or Malmberg type) and to control the electron current. We tested many loading procedures leading to different initial plasma conditions. The required number of electrons and density have been achieved.

A fast pulse having a few ns risetime and falltime and programmable width and amplitude (0–50 V) can be applied to one trap electrode. Because of the mass ratio between antiprotons and electrons, choosing a pulse of 50–100 ns width and a proper amplitude we expect that during the pulse duration the antiprotons only travel a fraction of mm while most of the electrons can escape. The measurements have shown that this controlled reduction of the electron number works also when we wish to remove the most part of the electrons. As a reference, a couple of 100 ns, 50 V pulse applied to a trap having 35 V depth and 4 cm length, leaves inside the trap a few percent of the electrons.

Two diagnostic methods have been implemented: the first one is destructive and it consists in lowering the potential well and dumping the electrons on one of the end electrodes. The induced signal is measured using a high-impedance, low-noise amplifier and it furnishes the number of extracted electrons and informations about the electron plasma radius. The sensitivity is about 10^5 electrons. The second is non destructive.

The method developed by us for measuring the radial extent of the plasma is based on the hypothesis that we deal with a plasma in equilibrium with uniform density n_0 and negligible temperature. As long as the applied confining potentials are higher than the space charge potential, the plasma stays confined. If we suddenly lower the potential well from V_i to $V_\mathrm{i} - \Delta V_\mathrm{i}$ then some particles eventually escape reducing the space charge potential until the confining condition is again satisfied. Because the space charge potential is maximum on the axis, the number N_{esc} of particles escaping the trap is the number necessary to leave a hollow cylinder (r_e is the external radius and r_i the internal one) charge distribution having on the axis a space charge potential $V(r_e, r_i, n_0)$ equal to $V_i - \Delta V_i$. The measurement procedure consists in lowering the trap depth from V_i to $V_i - \Delta V_i$ by the described fast pulses and measuring N_{esc} by the destructive method, then applying two or three pulses in order to completely dump the plasma and measure the remaining number of particles. Combining the measurements and using the analytical expression for $V(r_e, r_i, n_0)$ it is very easy to obtain r_e and the density. As expected, the measurements showed that the electrons are lost by processes leading to radial transport across the magnetic field. These are due to neutral gas collisions and asymmetries in the confining system [5].

Non-destructive diagnostic of plasma confined in Penning and Malmberg traps is a wide field including methods related to the detection of the frequency of the plasma oscillation modes [5] or generally to the induced signal on the trap electrodes due to some particular motion of the particles inside the trap [6]. Our method is the detection of a plasma mode corresponding to the motion of the plasma center of mass inside a Penning trap that is a displacement (along the z-axis in our present situation) of the cloud without a charge of its shape. This mode has the frequency ω_z of z motion of a single particle. The oscillation is excited by applying to one trap electrode a drive potential having frequency close to ω_z and detecting, by a resonant circuit, the induced signal. This method has been applied with success to electrons and it will be applied also to antiprotons. The amplitude of the induced voltage signal is proportional to the number of stored particles and its decay time is related to the coherence time of the oscillation under examination. In case of electrons, the decay time is dominated by the dissipation of center of mass energy on the tuned circuit resistor and it is expected to be inversely proportional to the particle number. Two independent measurements of the particle number are then obtained. Interesting informations are also contained in the frequency of the induced signal because a frequency shift has been detected while the particle number decreases due to the radial transport. The analysis of signals of this type allows to follows the evolution of the number of particles while they are stored inside the trap. The measured sensitivity corresponds to about 10^3 electrons.

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