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The ATHENA positron accumulator

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Abstract

A positron accumulator has been constructed for use in the ATHENA anti-hydrogen experiment in CERN. Employing a solid neon moderator plated on to a 50 mCi ^{22}Na source, a low energy beam of 7×10^6 positrons/s is guided into a 0.14 T magnetic field where they are trapped and cooled down to room temperature using nitrogen as a buffer gas. Plasmas of up to 2×10^8 positrons in 450 s, with an FWHM of 4 mm after compressing with the rotating electrical wall technique have been observed. In order to transfer the plasma to the main ATHENA (3 T) magnet, where the recombination trap is situated, a transfer section has been constructed consisting of a valve and a pulsed magnet with a pumping restriction inside. This magnet pulses to 1.2 T during the transfer. Preliminary tests have yielded transfer efficiencies in the order of 50%.

Keywords: Positron traps; Moderator; Anti-hydrogen

1. Introduction

The ATHENA anti-hydrogen experiment [1] at CERN, Geneva, aims to produce and trap anti-hydrogen for further studies including tests of CPT and the weak equivalence principle [1–5]. An anti-proton plasma together with a positron plasma in a 3 T magnetic field form the basic elements in the attempt to produce anti-hydrogen. Theory prescribes that the probability of producing anti-hydrogen should increase with increasing positron plasma density. Therefore, a positron accumulator based on the design of the Surko Group at the University of California, San Diego [6–8] was constructed [9,10] as well as a transfer section between the "high" pressure (10^{-9} mbar) accumulator and the "low" pressure ($<10^{-11}$ mbar) recombination region. In this paper we report on the properties of the accumulator as well as give preliminary results for the transfer efficiency.

2. Experimental

Moderated positrons with an energy of 50 eV, emanating from a solid neon moderator plated onto a 50 mCi ^{22}Na source, are guided into the trapping region depicted in Fig. 1. The moderator efficiency is between 0.3 and 0.4% leading to a positron beam with an intensity of up to 7×10^6 positrons/s. The trapping scheme is similar to that developed recently at UCSD [6] and utilizes nitrogen buffer gas to trap and cool the positrons. The axial confinement of the positrons is provided by the application of appropriate electric potentials to the electrode array, while the radial confinement is provided by a 0.14 T axial magnetic field. One of the trapping electrodes is split into six segments, making it possible to compress the

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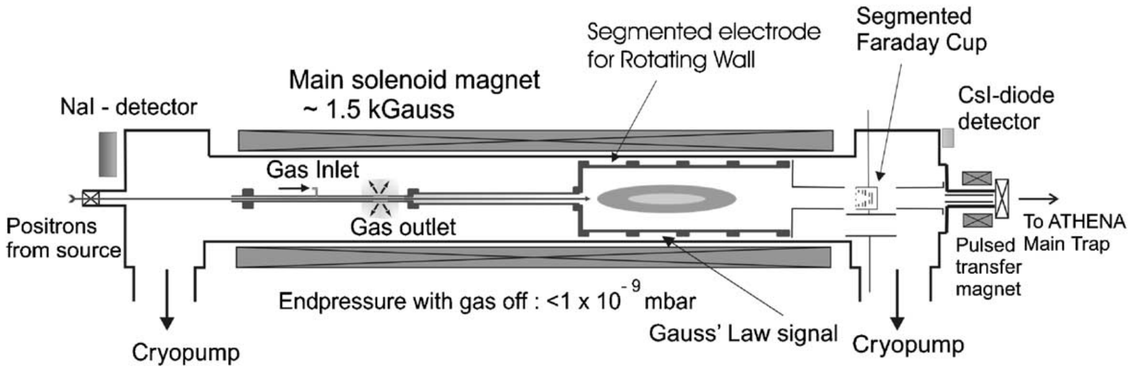

Fig. 1. Schematic overview of the ATHENA positron accumulator.

plasma by applying a rotating electric field ("rotating wall") [11–13]. During compression the plasma is cooled by the nitrogen buffer gas. The size and radial position of the plasma was measured by dumping the positrons on a moveable, segmented Faraday cup detector consisting of nine concentric (semi)-circles. A CsI-photodiode detector, placed outside the vacuum, measures the total number of positrons by monitoring the annihilation of the positrons.

After trapping and cooling the positrons are transferred [1] to the 3 T ATHENA main magnet using a vacuum separation valve, a pumping restriction, a number of transfer electrodes as well as a magnet capable of pulsing to 1.2 T during transfer.

3. Results

In Fig. 2 we show the number of accumulated positrons as a function of time with the buffer gas pressure set to 3×10^{-6} mbar in the first pumping box. The upper and lower curves were measured, respectively, with and without applying a rotating wall during the last half of the accumulation time. The fitted lifetimes are 200 s with and 95 s without rotating wall, respectively. The increase in the lifetime when using the rotating wall shows that, without it the plasma does not appear to be in the limit where annihilation on the buffer gas is the dominant loss. Rather it would indicate that there is still

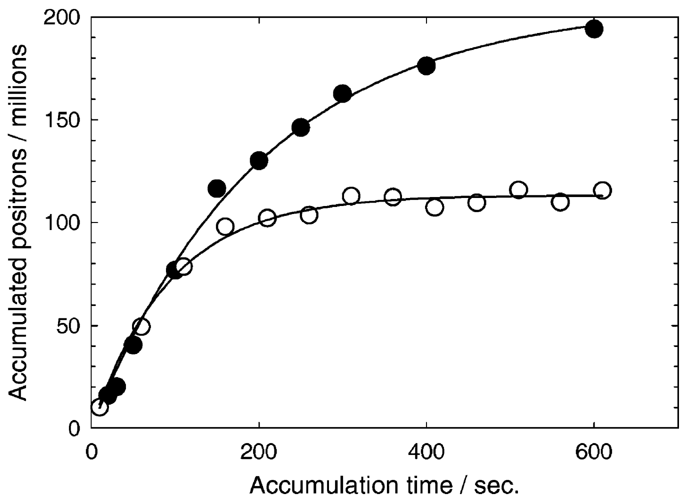

Fig. 2. Accumulation of positrons. The open circles show accumulation of positrons without using the rotating wall technique. The solid circles show accumulation while using the rotating wall technique. The rotating wall was on for the last 50% of the accumulation time. The frequency used was 500 kHz at an amplitude of 0.4 V.

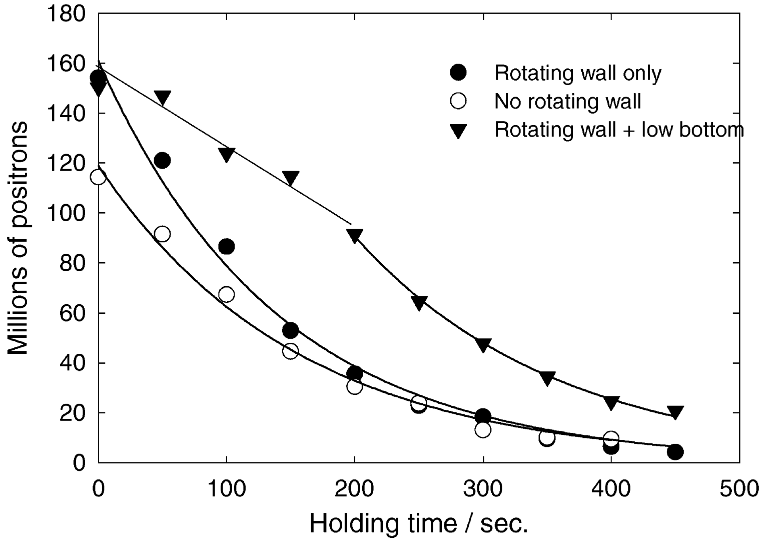

Fig. 3. Decay of the positron plasma after the buffer gas is pumped out and the rotating wall is turned off. The frequency used for the rotating wall was 400 kHz and the amplitude used was 0.2 V. The rotating wall was on for the last 50% of the accumulation time. For the data when the rotating wall was used together with lowering of the bottom of the trap during accumulation, the trap bottom was lowered by 4 V.

a large collisional cross-field drift to the electrode walls.

In order to try to accumulate as many positrons as possible we also lowered the bottom of the trap gradually during accumulation. This has been shown previously [6] to increase the number of accumulated positrons. However, no increase was found, possibly due to the fact that the trap was not filled to the space charge limit.

However, lowering the bottom of the trap during accumulation increased the lifetime of the positrons after the buffer gas was pumped out (see Fig. 3). The lifetime with and without rotating wall is fitted to be both 150 s. When the bottom of the trap was lowered during accumulation the number of positrons exhibits a slow linear fall-off up to about 200 s after which the data follows an exponential fall off that again has a 150 s lifetime.

Fig. 4(a) and (c) shows the ratio between the signal in the central region (20% of the total area) of the Faraday cup while using the rotating wall and the total signal on the Faraday cup with no rotating wall as a function of the applied frequency for different amplitudes. Fig. 4(b) and (d) shows the total number of positrons for the same experiments as observed by the CsI-photodiode detector. The data show how there appears to be a broad peak in the compression in the frequency range 300–600 kHz and that the compression increases with increasing amplitude. Above 600 kHz there is an abrupt fall-off in the signal on the central plate coinciding with a quick drop-off in the total number of positrons. Note that up to 600 kHz the total number of positrons is very stable for all amplitudes and the fact that the ratio for the central region goes above unity must mean that parts of the positron plasma initially missed the Faraday cup altogether, but that the rotating wall has compressed even this outer lying part of the plasma into the central region. The data for the counter-rotating field ((c) and (d)) show a loss of positrons in the center of the plasma coinciding with overall loss of positrons. The loss seems to increase with increasing amplitude of the rotating wall and also with increasing frequency, at least up to around 800–1000 kHz.

Using the Faraday cups we found that the plasma had an FWHM of 15 mm without rotating wall and an FWHM of 3–4 mm when the rotating wall was being used. This implied that the central density increased by a factor up to 20 when using the rotating wall. This compression ratio is much larger than that reported for N_2 previously [13] but this can possibly be attributed to the much larger pressures used.

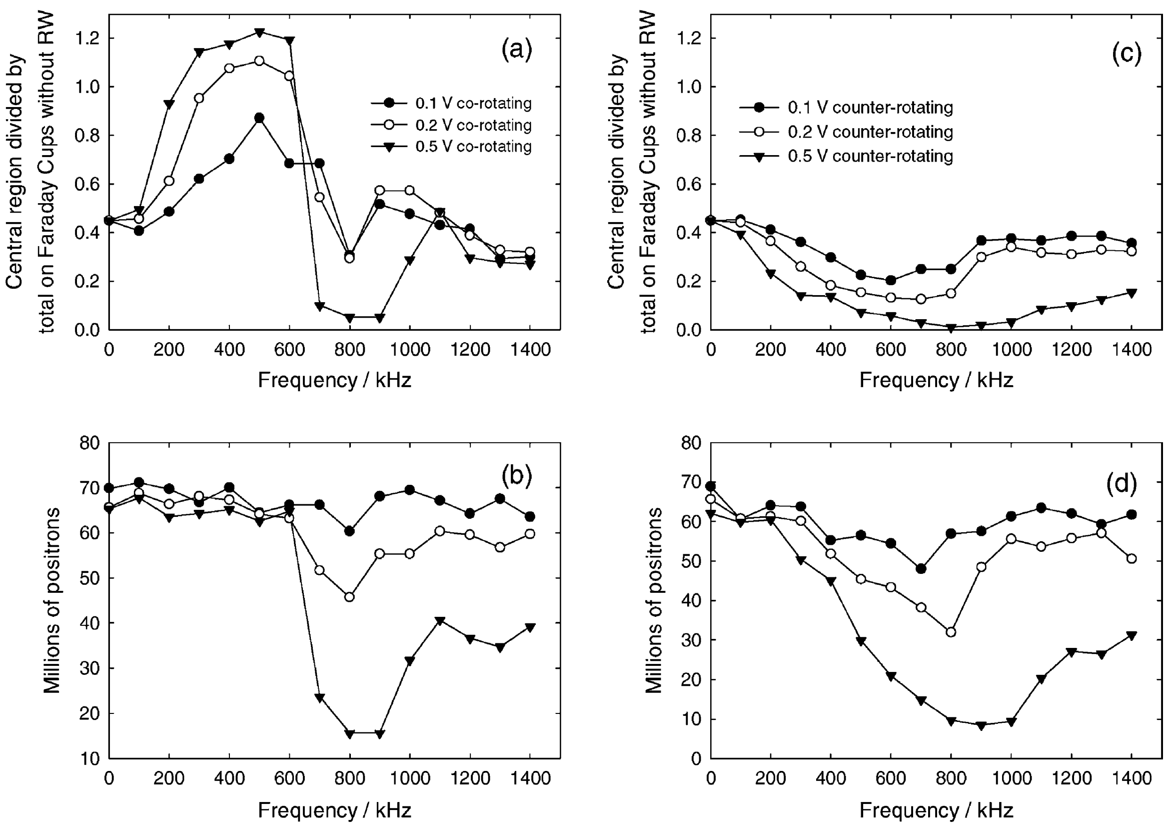

Fig. 4. Optimization of the rotating wall. (a) The number of positrons in the central region compared to the total number with no rotating wall. The data is for accumulation for 60 s and with the rotating wall on for the last 30 s of the accumulation. (b) CsI annihilation data for the same experiments. (a) and (b) are for a co-rotating electric field. (c) and (d) show the corresponding data for a counter-rotating field.

Preliminary measurements were performed on the transfer efficiencies. In order to transfer the positrons into the main ATHENA magnet, the buffer gas was pumped out after accumulation and rotation, the magnet pulsed and the trap in the accumulator opened. The positrons were dumped on a Faraday cup in the main magnet and the annihilation signal was measured with a CsI detector. Preliminary results show that transfer efficiencies of more than 50% can be achieved.

4. Conclusions

We have been able to produce a positron plasma-containing 2×10^8 positrons with an FWHM of 4 mm. Initial transport efficiencies from the accumulator into the main ATHENA magnet are better than 50%. The next steps are introducing CF_4 gas in order to improve compression [13], optimizing the transfer to and trapping and cooling of the positrons in the main ATHENA magnet.

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