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Measurements and 3D reconstruction of antimatter annihilations with the ASACUSA Micromegas Tracker

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The aim of the ASACUSA-CUSP experiment is to form a beam of antihydrogen atoms for in-flight precision spectroscopic measurements. This is performed by trapping and mixing antiprotons and positrons in a common nested-well potential, which is sitting in a double-cusp magnetic field with minimum-B field configuration. We have built a tracking detector, the ASACUSA Micromegas Tracker (AMT) [1], to monitor and resolve annihilations on-axis from annihilations on the trapping electrode walls of the experiment, which latter is a general signature of antihydrogen formation. Data taken during the summer of 2015 is presented in order to demonstrate the first performance of the AMT detector. In particular, data from on- axis trapping and slow extraction of antiprotons is used to illustrate the vertex reconstruction capability of the detector.

KEYWORDS: antihydrogen,micromegas, tracking detector

1. The Asacusa Micromegas Tracker detector

The AMT detector [1] was designed to resolve antihydrogen annihilation vertices with $\sigma_{\mathrm{vx}} \simeq 1$ cm spatial resolution inside the ASACUSA double-cusp trap. It consists of two, half- cylinder, curved micro-strip pattern gaseous detector layers using Micromegas technology [2]. The AMT detector is illustrated on Fig 1.

The detector efficiency at various drift and mesh voltages were measured in a cosmic ray test-bench setup. In particular, the strong magnetic field (B = 3-4 T) of the ASACUSA experiment induces Lorentz-forces on the Micromegas electron avalanche signal which needs to be compensated with appropriate drift fields. The single hit projection efficiency is shown on Fig 2 as a function of the mesh voltage and on Fig 3 as a function of the drift voltage. As a result of the efficiency scan the optimal drift and mesh voltages have been obtained and the AMT is operated at the plateau of the efficiency curve.

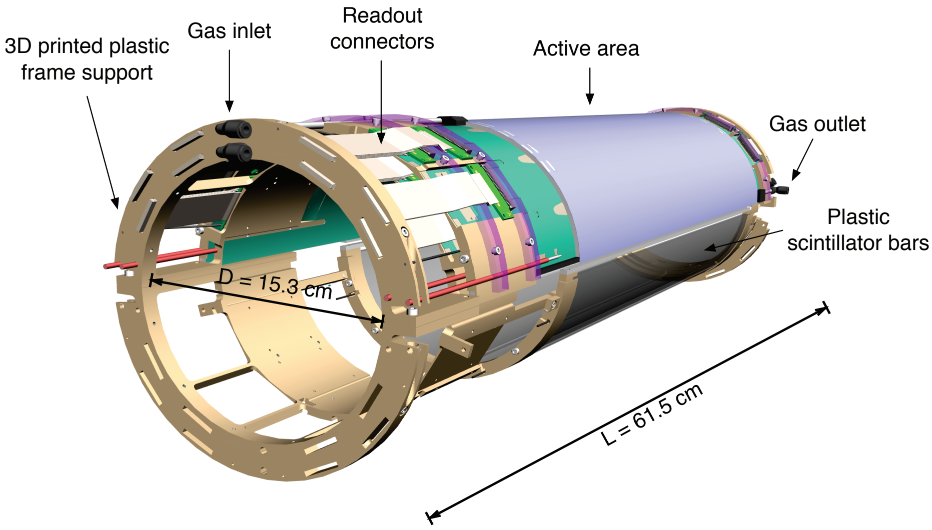

Fig. 1. 3D CAD drawing of the AMT detector.

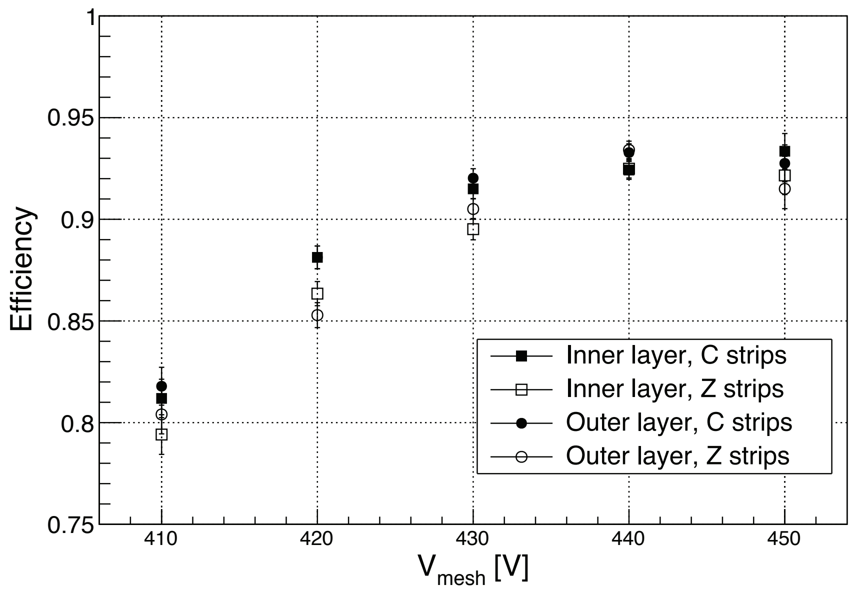

Fig. 2. Single hit projection efficiency of the AMT as a function of the mesh voltage.

2. Annihilation test measurements with antiprotons

Both trapped and in-flight antiprotons were used to test the 3D vertex position reconstruction capability of the AMT. On left in Fig 4 radial distribution of vertices found for trapped antiprotons is shown. On right the same distribution is shown for antiprotons annihilating at the B = 0 T field position on the multi-ring electrode walls. Antihydrogen production is expected to show annihilation signatures similar to the figure on the right for antihydrogen can escape the trapping electric fields due to its neutrality and annihilate on the electrode walls at $R = 4$ cm radius.

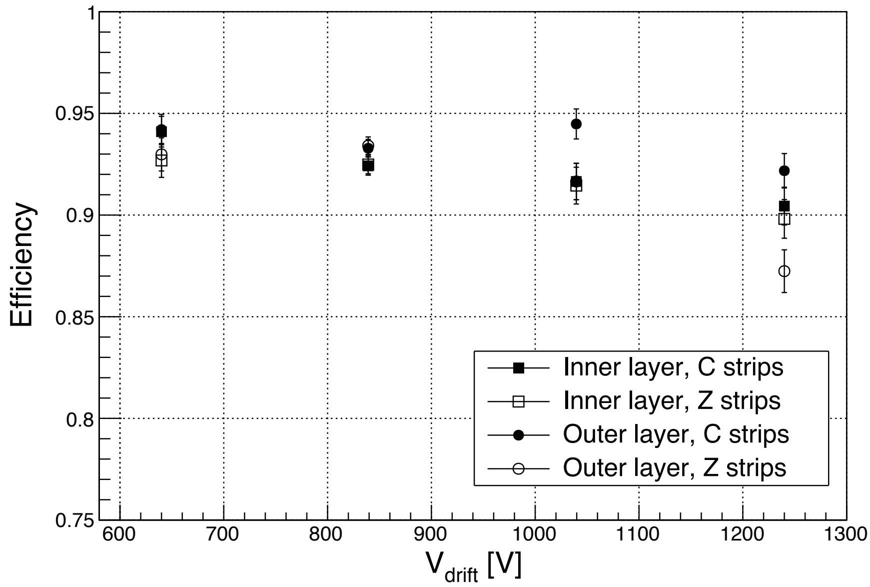

Fig. 3. Single hit projection efficiency of the AMT as a function of the drift voltage.

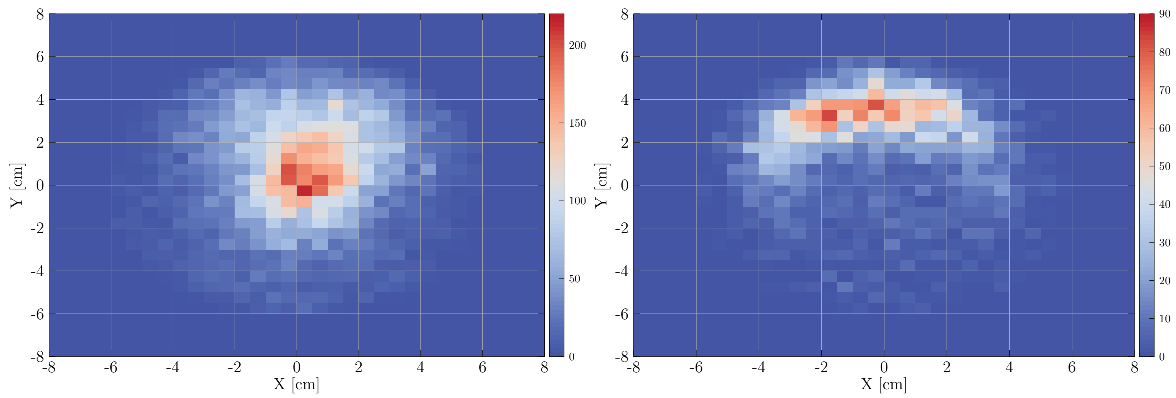

Fig. 4. Reconstructed antiproton annihilation vertex position distribution for antiprotons trapped at the central axis (R = 0 cm radius) of the ASACUSA multi-ring electrode (left) and for antiprotons annihilating on the ASACUSA multi-ring electrode walls at R = 4 cm radius (right).

3. Antihydrogen production observed by the AMT

To produce antihydrogen antiprotons are injected into a nested-well trap where they mix with positrons (see Fig 5). A fraction of the neutral antihydrogen atoms escape the trap potential and either move along the axis or annihilate on the electrode walls used for trapping. The mixing process lasts for a few tens of seconds after which the antiprotons do not overlap with the positron cloud and settle in the two nested well minima.

The AMT detector reconstructed the events during mixing process. The radial and axial vertex position distributions are shown in Fig 6 and Fig 7, respectively, for various time slices during mixing.

In the first 3 seconds the annihilation vertex position is mainly enhanced on the multi-ring elec-

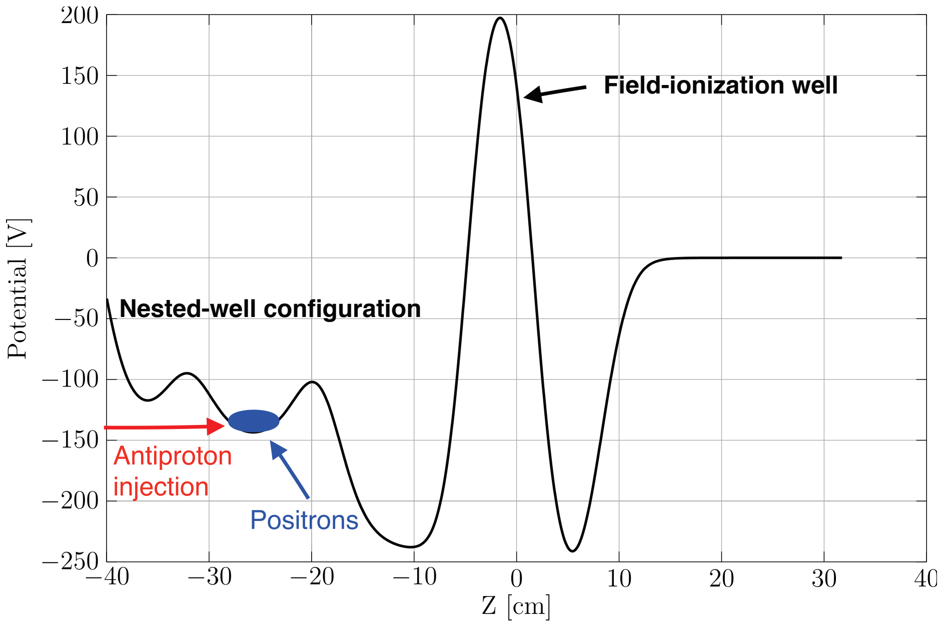

Fig. 5. Electric field configuration used to trap and mix antiprotons and positrons for antihydrogen production.

trode walls indicating that a very efficient antihydrogen production takes place. At the same time the axial annihilation position distribution shows a wide distribution, which also suggest that antihydrogen atoms are formed and emerge from the mixing region significantly to many directions. During the subsequent time slices the radial position of annihilation vertices reduce to the central axis of the trap, and the axial distribution shrinks to a position consistent with one of the nested-well minima. The limited acceptance of the AMT does not allow to recover both nested-well minima.

4. Conclusions

In summary, the Asacusa Micromegas Tracker successfully fulfilled its design goal to detect and discriminate antihydrogen annihilation events from antiproton background events. These first results allow to improve on the discrimination power using more sophisticated analysis techniques.

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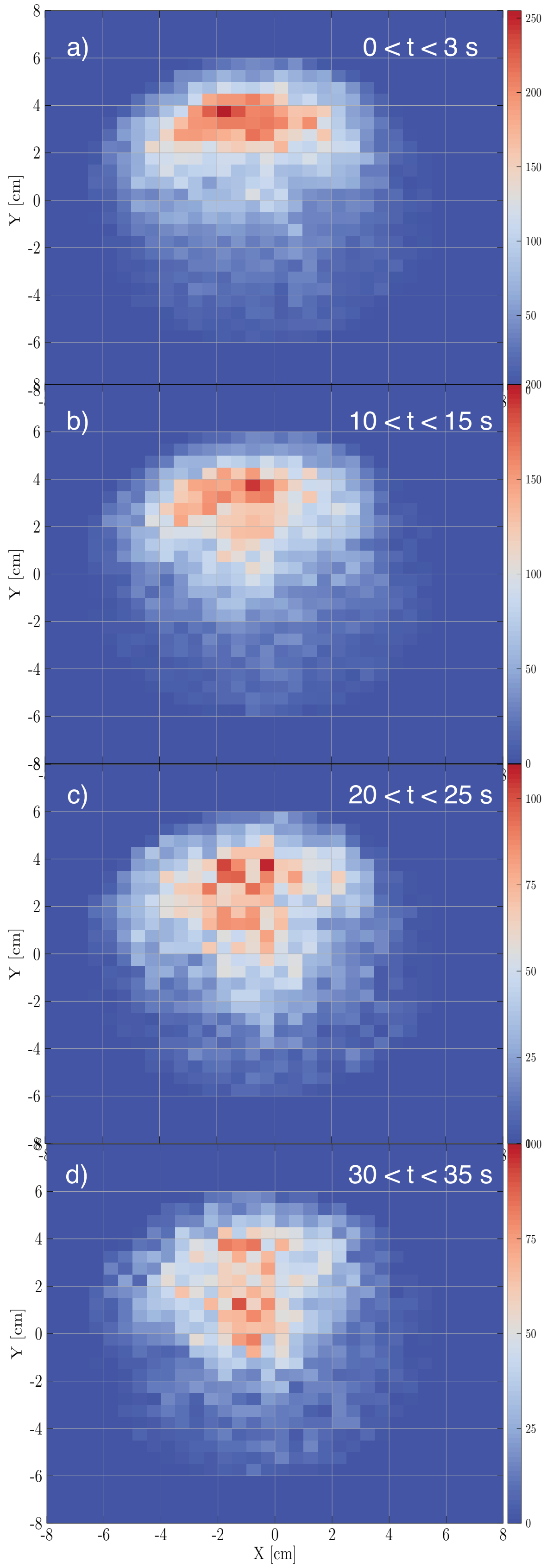

Fig. 6. Radial vertex position distribution, reconstructed by AMT, for various time slices during mixing. The start time of the mixing is $t = 0$ seconds.

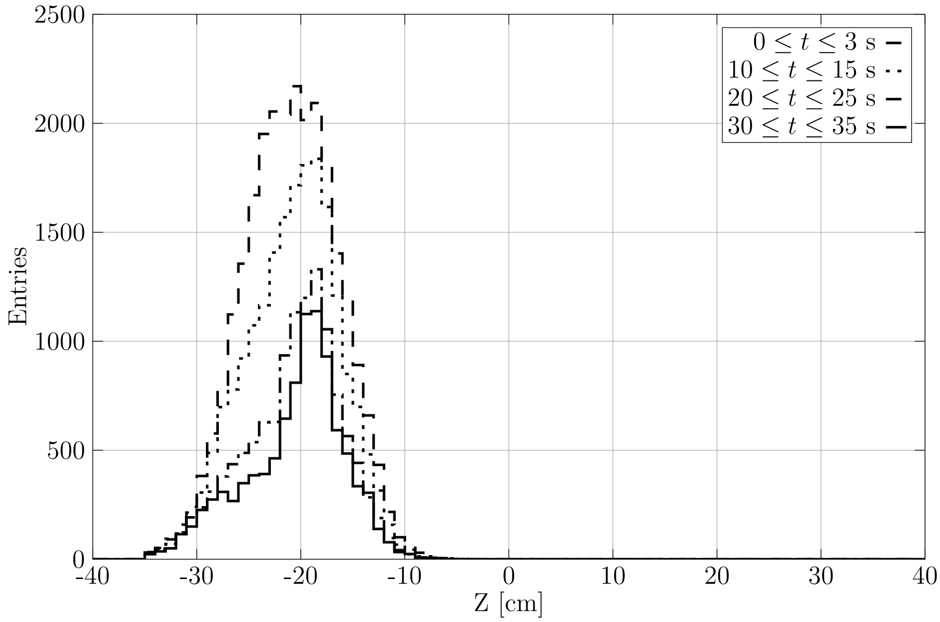

Fig. 7. Axial vertex position distribution, reconstructed by AMT, for various time slices during mixing. The start time of the mixing is $t = 0$ seconds.