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A new detection system for very low-energy protons from β-delayed p-decay

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In a collaboration with people from CEA Saclay and IKP Koln, we have developed a gas based detection system called AstroBox, to detect protons from β-delayed p-decay with reduced beta background and improved low-energy resolution. The detector was tested using the β-delayed proton-emitter ^{23}Al previously studied with the Si set-up. The detector and the experimental procedure will be described. The results showed a significantly reduced beta background. There is no background down to about 80 keV, the low energy (206 keV, 267 keV) proton peaks were positively identified, well separated and the resolution was improved. States with β-branchings as low as 0.03% were observed and we are seeking the presence of the isospin forbidden proton-decay branch of the Isobar Analogue State. With the success of this test experiment, the next step is to further improve the detection system and perform more tests and measurements.

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[1] Speaker

1. Introduction

The study of β-delayed proton-decay has been one of the focuses of the nuclear astrophysics group at the Cyclotron Institute, Texas A&M University (see a lecture in these Proceedings [1]). We have been using this particular indirect method to find and determine the properties of resonances dominating proton capture on proton-rich sd-shell nuclei, which in turn help determine the rates of important reactions for H-burning in the stars. The experimental procedure involves separating short-lived proton-rich radioactive nuclei, implanting them in a proton detector and measuring the emitted gamma-rays and protons after beta-decay. In the past we have used very thin Si strip detectors to successfully detect protons with energies as low as~200 keV, but with a large background from positrons [2]. In an effort to lower the beta background and improve the resolution at low-energies, we have recently developed, in collaboration with CEA Saclay and IKP Koln, a new detection system called the AstroBox.

2. The AstroBox detection system

The AstroBox is, basically, a cylindrical gas-filled chamber with a micromegas detector. A schematic drawing can be seen in Figure 1. The chamber itself was made of steel and is about 20 cm tall with a diameter of about 20 cm. It has two entry points, both on different sides of the cyllinder, one for the beam to get into the chamber and the other for the gas flow system. This first will be connected to the rest of the beam line through a flange with a kapton window, in order to contain the gas. The main components inside the chamber are: the detector with the mesh, the grid, the cathode, the equipotential rings and the gas (see Figure 2).

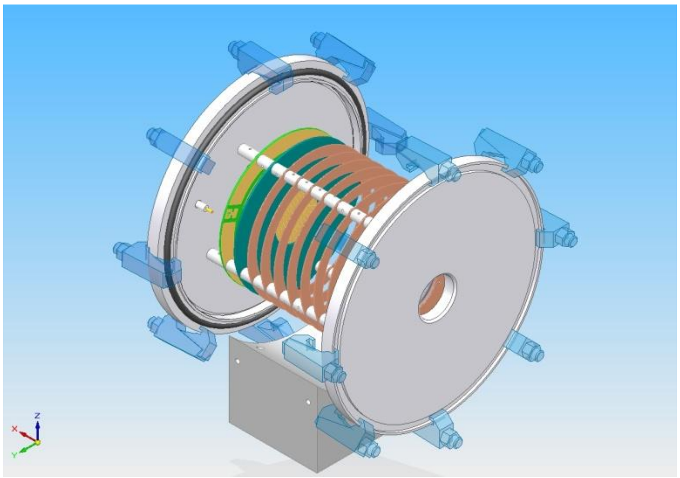

Figure 1 Schematic drawing of AstroBox.

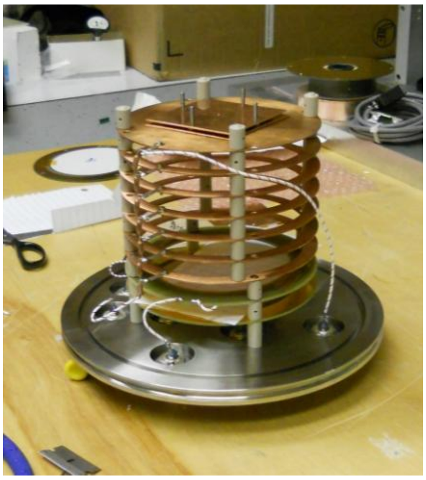

Figure 2 Picture of AstroBox from pre-experiment setup. Beam enters perpendicular on cylinder axis.

MICROMEGAS stands for MICROMEsh GAseous Structure and it is a detector that consists of a two-stage parallel plate avalanche chamber of small amplification gap, combined with a conversion drift region [3]. It was designed and created by people at CERN and Saclay. A PCB frame, 1 mm thick, is printed with anode strips of gold-coated copper on a Kapton substrate (see Figure 3a).

The micromesh is a metallic grid made of nickel (Figure 3c). It has 0.3 mm openings every 3 mm. It stands at 100 µm above the anodes to create a small amplification gap. By applying reasonable voltages, high electric fields can be obtained, about 100 kV/cm [3].

The detector is split into 5 pads (Figure 3b). The central one is circular with a diameter of 50 mm. The outer one has a diameter of 100 mm and it is split into 4 symmetric parts. They can be used individually or connected in different ways.

The gating grid consists of 28 ceramic wires (Figure 3d). Each is 100 um in diameter and the distance between them is 2 mm. The purpose of the grid is to screen the detector from electrons generated while the beam is on (during implantation) when the energy loss is large and the signal can be too large.

The cathode sits at 15 cm above the mesh. The equipotential copper rings are placed below it at 1.5 cm intervals. Their purpose is to ensure that the electric field generated is uniform and stable. The field strength is on the order of 0.1 kV/cm.

The gas used was a standard mixture of Ar and methane in various proportions (P5 or P10). A gas flow system was designed and used to keep the mixing uniform and clear the residues resulting from beam interactions inside the chamber.

Detection efficiency was obtained from GEANT4 simulations.

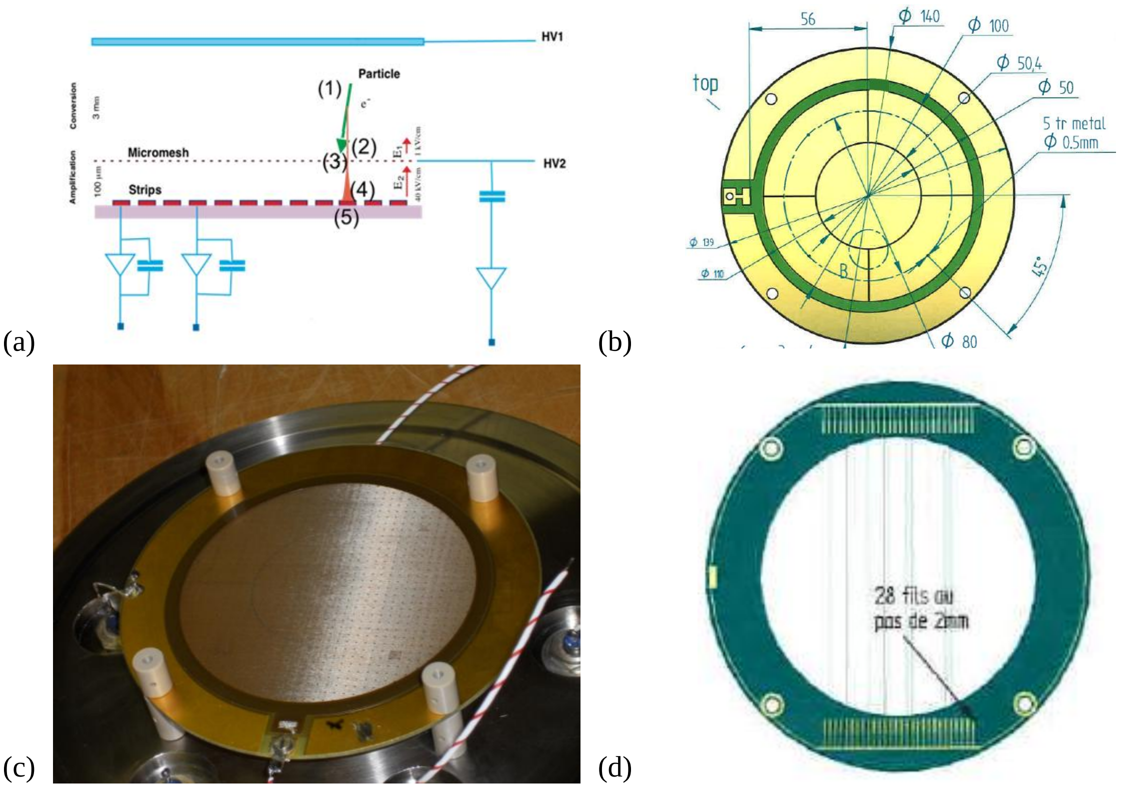

Figure 3 (a) Schematic representation of the MICROMEGAS; (b) Schematic drawing of the anode pads; (c) Picture of the micromesh sitting on top of the anode; (d) Schematic drawing of the grid.

3. The test experiment

3.1 Experimental set-up

The first in-beam test of the AstroBox was done at Texas A&M – Cyclotron Institute. A primary beam of ^{24}Mg at 45 MeV/nucleon was generated from the K500 superconducting cyclotron. It impinged on a hydrogen target at LN_2 temperature. The Momentum Achromat Recoil Spectrometer (MARS) was used to separate a radioactive beam of ^{23}Al with ~4000 pps intensity and 90% purity. We chose this particular nucleus because of its astrophysical significance and we had previously studied it with Si. Following results from that study, there were still particular questions about the low-energy region below E_p=400 keV.

Attached to the MARS backend was a degrader chamber, containing a rotating Al foil, 25 mil thick. The AstroBox was then mounted to this chamber, using the flange containing the Kapton window. For this test, the gas used was P10, 90% Ar and 10% methane, operated at 800 torr pressure. The micromegas anode was set to have 2 detection pads, the central one, and the outer 4 connected together into one outer one. The cathode was biased at a fixed negative voltage of 1.8 kV. The gating grid was biased at 0 V for full transparency (measuring mode) and +750 V for full opacity (implantation mode). The bias on the mesh was also fixed at +260 V, whereas the voltage on the detection pads was varied to determine the optimum value. During the measurement the beam was pulsed.

3.2 Experimental procedure

The procedure was similar to the previous Si-based experiments (see [1,2] for detailed descriptions). There was an "implantation-contro mode" and a "measurement mode". In the implantation–control mode we used the rotating Al energy degrader to 'slow' the beam down until it was stopped in the centre of the detector. We determined when that happened by looking at a plot of energy loss in the centre pad versus energy loss in the outer pad. Figure 4 shows two such plots, specifically for the implantation angles ϑ = 51° and ϑ = 55°. The latter was determined to be the correct one.

In Figure 4a, it is easy to see that the angle is too small and particles do not lose enough energy in the degrader. As such, most punch all the way through the detection volume. This is shown by the diagonal 'line'. Particles are losing energy in both the central and outer regions as they pass through the detector. However there are a few of them that have started stopping in the outer far region, as shown by the blue oval.

In Figure 4b, you can see that most contaminants pass through the detector. A few ^{23}Al particles are stopped in the outer back far region, but most of it is stopped in the central region. So, this is considered the correct implantation angle. In the implantation-control mode the dynamic range was 0-50 MeV.

After determining the degrader angle for central implantation, the measurement was done with a pulsed beam. In the "measuring mode" we only have measured with beam-off and the detector voltages were adjusted to have a dynamic range of 0-5 MeV. During beam on, for 1 sec, we implanted and the gating grid was on, becoming opaque, to protect the detector. During beam off, also for 1 sec, the grid was off allowing full transparency and we measured the decay of ^{23}Al.

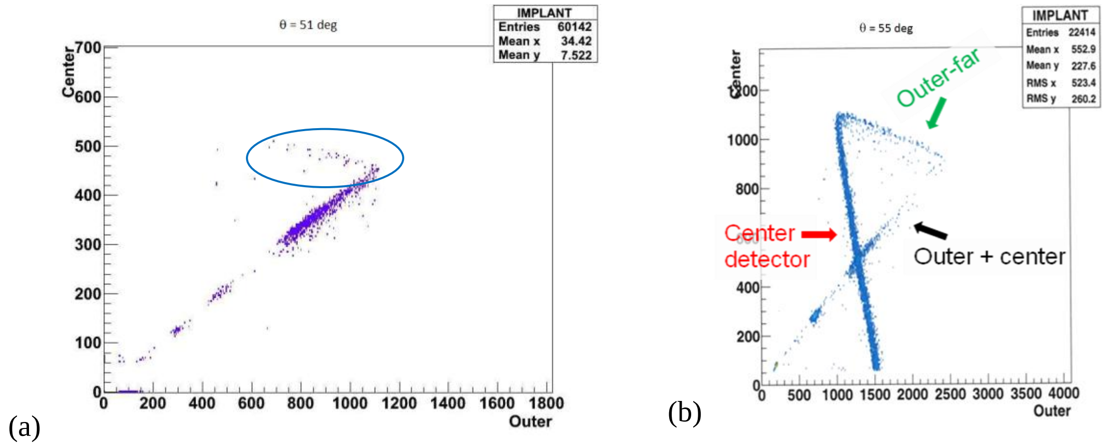

Figure 4 (a) Implantation plot for ϑ = 51° ; (b) Implantation angle for ϑ = 55° .

3.3 Analysis and results

A raw proton spectrum can be seen in Figure 5 as detected by the centre pad after ~2 hours of statistics with an anticoincidence condition with the outer pad. Peak resolution is ~7% and the beta background threshold is down to ~80 keV. Even at low energy the peaks were well separated and we could see some other features that may or may not be other peaks. One issue that came up and complicated the analysis was the implantation distribution. It looked like it was not restricted to the central area. The edges were actually in the outer region. Furthermore, some protons were emitted on a path that had them lose energy in both detection regions. Figure 6 illustrates that. Each line corresponds to one of the energy peaks visible in Figure 5, except that here protons leave part of that energy in one pad and part of it in the other. For a complete analysis, we had to take these protons into account as well.

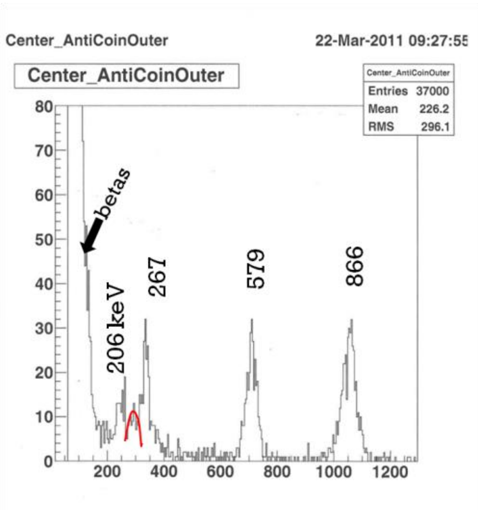

Figure 5 Spectrum obtained from the anticoincidence of the centre with outer pad

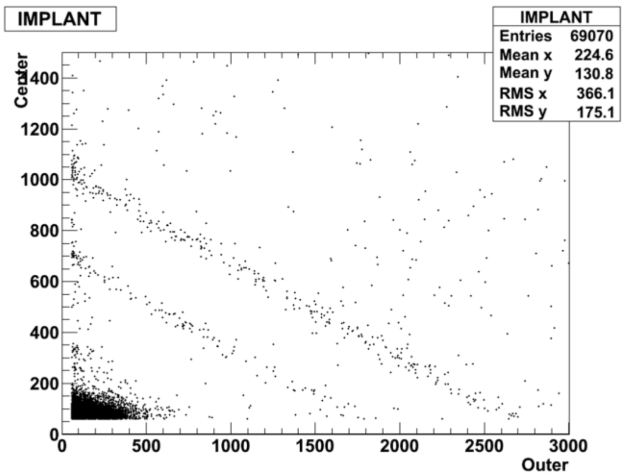

Figure 6 Centre vs Outer histogram

4. Conclusion

We designed a new detector for very low-energy protons from β-delayed p-decay, in cooperation with CEA Saclay and IKP Koln, called AstroBox. The first in-beam test was completed and showed very good results in terms of beta background reduction, energy resolution and sensitivity. We intend to make other adjustments and measure again, to further improve these results.

References

[1] L. Trache, *in these Proceedings, PoS (ENAS 6)033*.

[2] A. Saastamoinen, L. Trache, A. Banu *et al.*, Phys. Rev. C 83, 045808 (2011).

[3] Y. Giomataris *et al*., Nucl. Instr. und Meth. in Phys. Res. A 376 (1996) 29-35