GEANT4 Simulations for the design of AstroBox2

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During 2011, the "AstroBox2" detector was conceived in order to improve on the results obtained with the original "AstroBox" detector [1]. The purpose of AstroBox2 is to improve the implantation of the source in the active area of the detector and to reduce the background from the energy deposits of β-particles in the gas of the detector by modifying the detector geometry. While the background from the β-particles has already been reduced significantly using AstroBox [1], further reduction of the background is needed in order to carry out future measurements of β-delayed proton decay where the low-energy protons will have energies in the 100-400 keV and have very-low (< 0.01%) relative intensities. AstroBox2 should be able to improve the measurements of the β-delayed proton decay of ^{23}Al, ^{31}Cl and ^{27}P for low proton energies.

A drawing of the design of AstroBox2 is shown in Figure 1. The chamber will be rectangular and will house a micromegas detector of the "Bulk" type [2] with 12 individual pads. Six of the pads will be arranged side-by-side along the beam-axis of the detector, and the remaining six pads will be arranged to surround the central pads on the top and bottom. The pads are configured such that a rare isotope beam produced and separated with the MARS spectrometer is fully stopped and contained, for a given gas pressure, within the four central pads along of the beam axis of the detector. The front and back pads along the beam are used to ensure that the beam implanted was in the center of the detector. In addition, the front pad is employed to count the number of implanted beam particles during the period of the experiment when the beam is on.
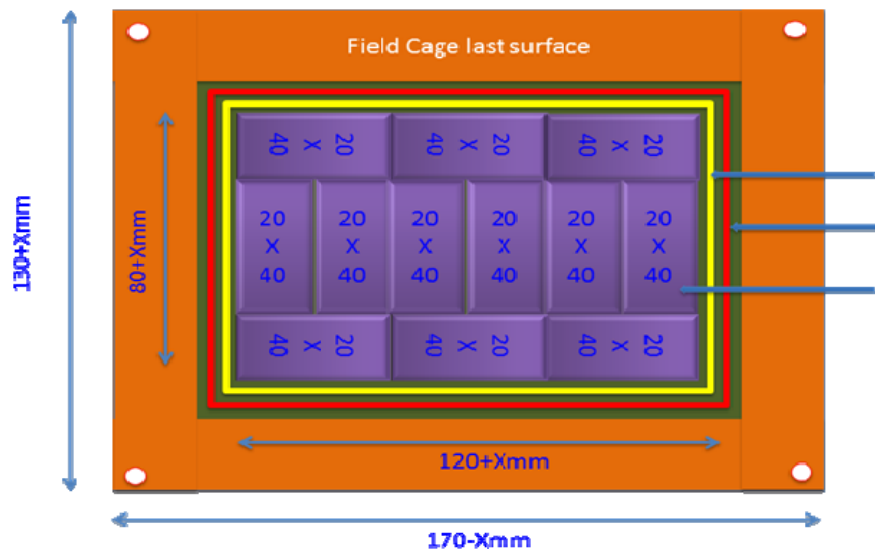

FIG. 1. Proposed design of AstroBox2. The beam enters the chamber from the right side and stops in the central pads. The outer pads are used to reduce the background from the β-particles and high-energy protons.

Once the general layout of the detector was determined, the design of AstroBox2 was simulated with Monte Carlo simulations using the GEANT4 toolkit [3]. A visualization of AstroBox2 simulated with GEANT4 is shown in Fig. 2. To optimize the dimensions and layout of the pads in the chamber, the geometry of AstroBox2 was fully described in GEANT4 and parameters such as the size of the micromegas pads, the gas pressure inside the AstroBox2 chamber and the gaps between the pads were varied. The simulations used the β-delayed proton decay of ^{23}Al [4] to test the response of AstroBox2 with the various detector dimensions and layouts. For most of the simulations, the detector was filled with P5 gas (95% Argon, 5% methane) at 800 torr.
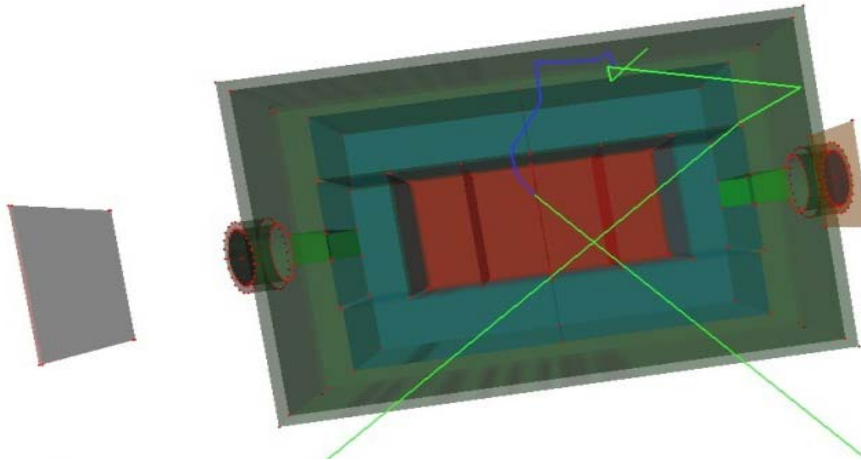

FIG. 2. AstroBox2 setup simulated in GEANT4. The blue and red blocks shown in figure represent the "active volumes" for each micromegas pad. One decay event occurring inside the chamber is also shown.

After testing several different configurations with larger and smaller pad sizes, it was found that a setup with dimensions similar to those in Fig. 1 with pad sizes of 20mm (length) × 40mm (height) × 40 mm (depth) gave the desired result of further reducing the background from the energy deposits from the
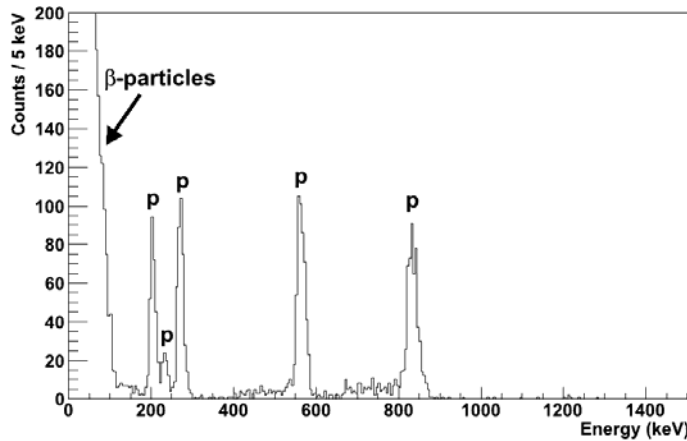

FIG. 3. ^{23}Al β-delayed proton decay as measured in AstroBox2 with the setup shown in Figure 1 simulated with GEANT4. The peaks marked "p" are proton peaks. The proton peaks are well-separated from the β-particle background at the low-energy side of the spectrum. The tail of the β-particle spectrum ends at ~110 keV.

β-particles. The simulated spectrum for ^{23}Al β-delayed proton decay for this setup is shown in Fig. 3. One should note in this figure that the tail of the β-particle distribution at low-energy ends abruptly at about 110 keV. This result is comparable with the one obtained with the original AstroBox detector. However, the advantage of AstroBox2 vs. the original AstroBox is that the ^{23}Al beam is fully implanted inside the central pads of the AstroBox2, even at gas pressures down to 600 torr, according to the simulations. At lower gas pressures, the simulations suggest that the tail of the β-particle distribution can be restricted to even lower energies, allowing for the possibility of observing low-energy protons well below 200 keV.

In conclusion, AstroBox2, a new detector using micromegas, has been designed. The response of the new detector to low-energy protons from ^{23}Al β-delayed proton decay was simulated with the GEANT4 toolkit. It was found that AstroBox2 would give similar results to the original AstroBox detector for the reduction of the background in the proton spectrum from the energy deposits of β-particles. However, the area for the implantation of the incoming beam particles will be larger and better controlled in AstroBox2. This should provide an improvement over the original AstroBox, and perhaps allow the gas pressure to be reduced in the detector which may further reduce the β-particle background.

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