Development of a Simulation Framework for Spherical Proportional Counters

P. Knights, J. Matthews, R. Ward, I. Katsioulas, R. Owen, K. Nikolopoulos - School of Physics and Astronomy, University of Birmingham

Introduction

The spherical proportional counter is a novel gaseous detector [1] with a wide field of application that includes dark matter searches, neutrino searches, and neutron spectroscopy [2]. It comprises a spherical grounded shell containing a spherical anode held in place by a support structure at θ = −1.0. The detector has several key advantages:

- Simple and robust construction
- Flexibility of gas mixtures
- High pressure operation
- Low capacitance independent of detector size
- Determination of interaction properties from pulse-shape analysis

For detector development and deployment in experiments, simulations are a crucial ingredient. Geant4 is a toolkit for the simulation of the passage of particles through matter [4]; Garfield++ is a toolkit for the simulation of gaseous particle detectors [5] and interfaces with dark matter searches, neutrino searches, and neutron spectroscopy. In this work, the strengths of Geant4 and Garfield++ are combined to obtain a predictive simulation framework. Initial interactions in green, electron drift in electric field, and avalanche drift in electric field, and produced 2.38 keV electrons via electron capture to \(^{37}\)Cl.

Detector Response

- \(^{55}\)Fe is a X-ray source producing 5.9 keV X-rays, commonly used in calibration of gaseous detectors
- Study the homogeneity of the detector response by using photons from different angles
- Primary peak arises when all of the photon energy is deposited in the sensitive volume; secondary peak is the Argon escape peak
- Energy resolution deteriorates near the support structure at cos θ = −1.

Interaction Radius

- 37Ar is a gaseous source, uniformly distributed throughout the detector, producing 2.38 keV electrons via electron capture to \(^{37}\)Cl.
- These electrons have a relatively short range.
- Diffusion causes interactions from larger radii to have larger risetimes.
- Risetime selections used to perform fiducialisation

Particle Identification

- Pulse-shape analysis provides particle identification and informs selections to suppress backgrounds
- As an example, cosmic muons may mask the interaction of \(^{55}\)Fe X-ray
- As the ionisation profile for muons and X-rays is different, pulse shape analysis can be used for discrimination

Summary

- Developed a simulation framework that combines Geant4 and Garfield++ and is used to model the spherical proportional counter
- Framework provides a way to investigate detector response in various applications and configurations
- Direct comparison with data is ongoing for validation and further development

References


Figure 1: Principle of operation of the spherical proportional counter [3].

Figure 2: Electron diffusion parameters from Magboltz.

Figure 3: A profile of the electric field near the 2 mm diameter anode in a 30 cm diameter spherical proportional counter, modelled in ANSYS [3].

Figure 4: Flow of an event within the simulation framework: Initial interactions in green, electron drift in red, and avalanche in blue.

Figure 5: Geant4 visualisation of a muon traversing a spherical proportional counter.

Figure 6: Example readout pulses produced by 5 keV electrons from an initial radius of 20 cm for different gas mixtures.

Figure 7: Pulse integral for 5.9 keV photons with an initial radius of 14.5 cm.