Development of a Simulation Framework for Spherical Proportional Counters

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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.

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

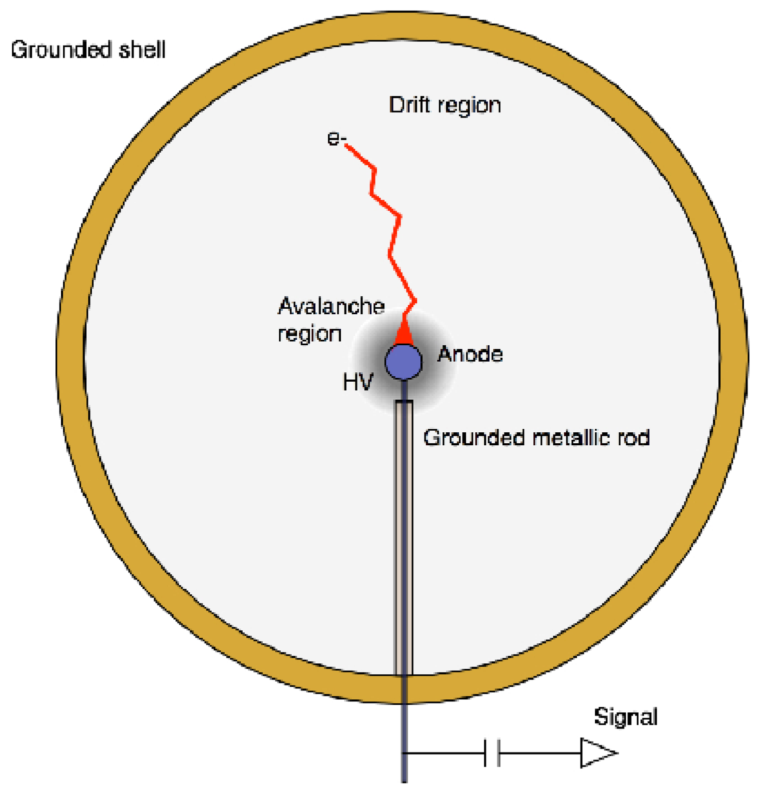

Figure 1: Principle of operation of the spherical proportional counter [3].

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 to Heed for particle interactions [6], ANSYS (a finite element method software) electric field modelling [7], and Magboltz for gas transport parameter modelling [8]. In this work, the strengths of Geant4 and Garfield++ are combined to obtain a predictive simulation framework.

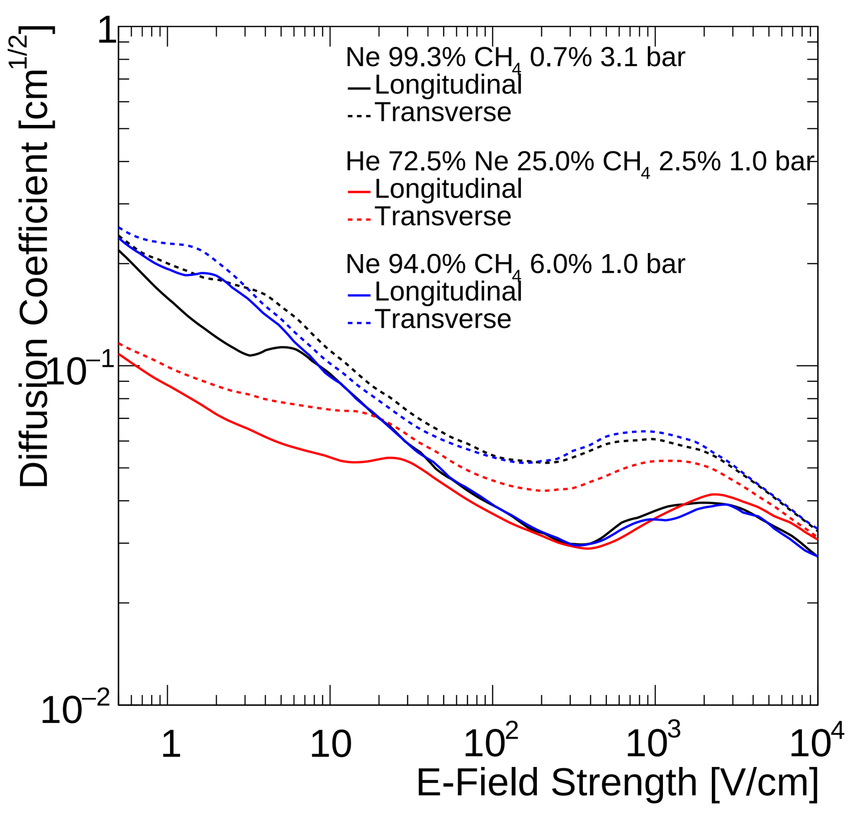

Figure 2: Electron diffusion parameters from Magboltz.

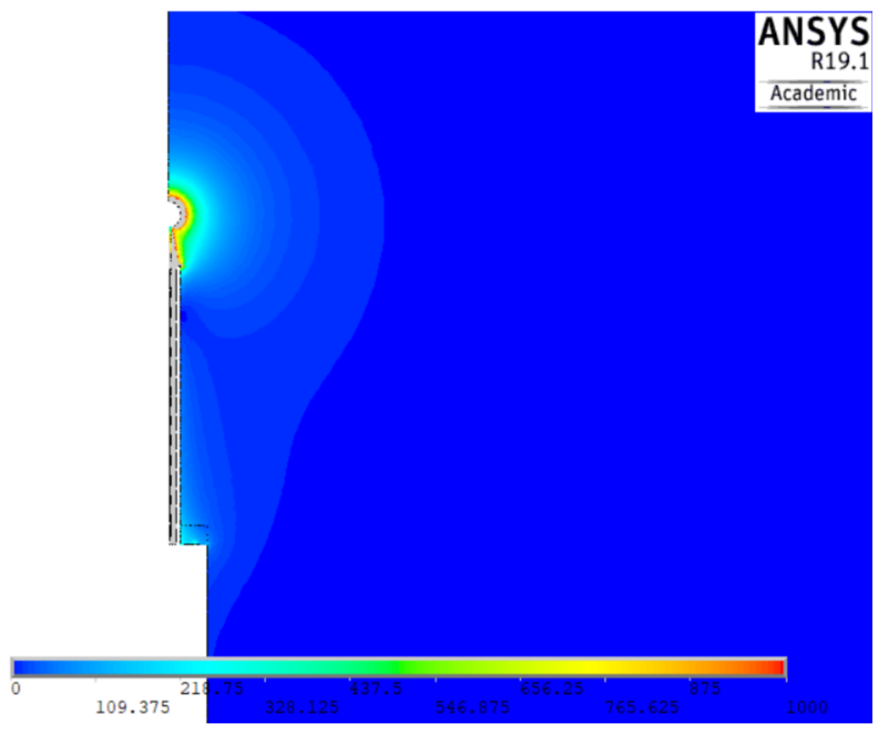

Figure 3: A profile of the electric field near the 2 mm diameter anode in a 30 cm diameter spherical proportional counter, modelled in ANSYS [3].

Simulation Framework

The detector is simulated using a Geant4 application, which includes Garfield++ as a custom physics model via the physics parameterisation feature [9].

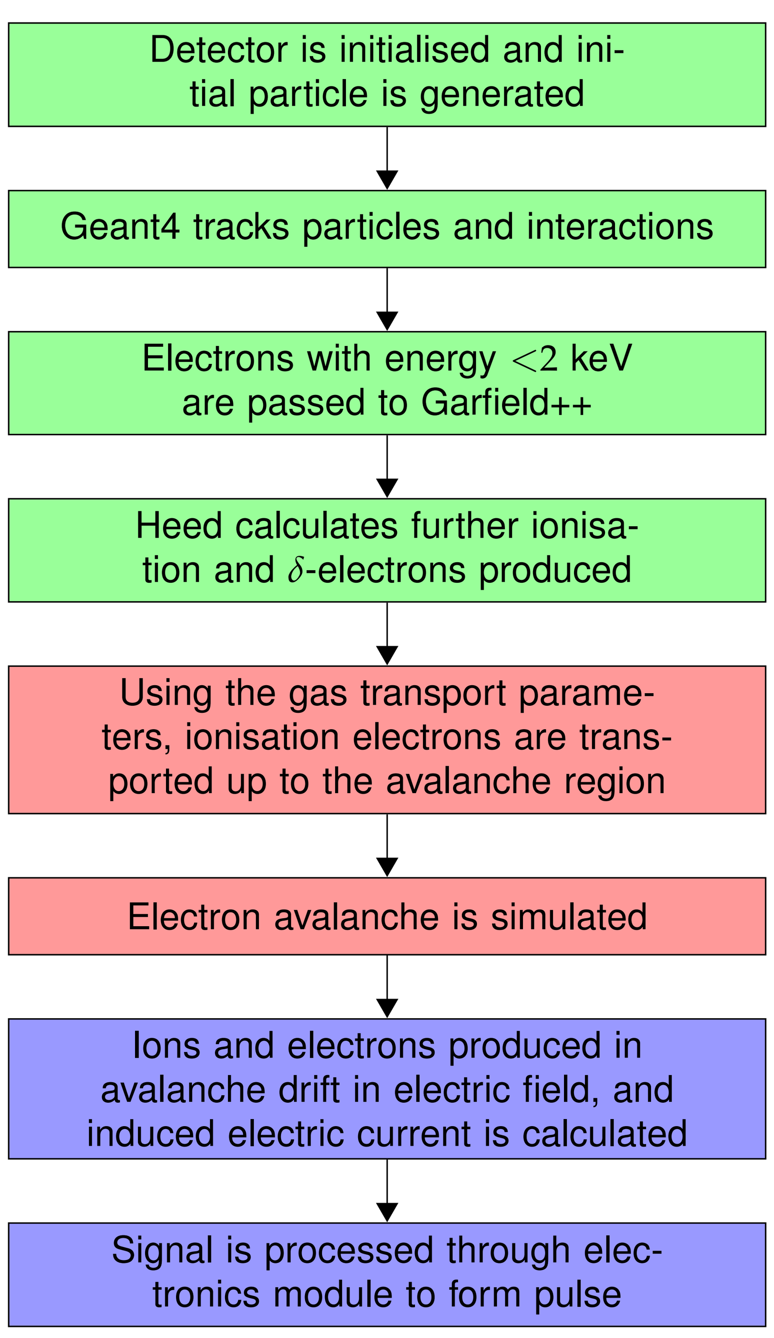

Figure 4: Flow of an event within the simulation framework: Initial interactions in green, electron drift and avalanches in red, and signal calculation in blue.

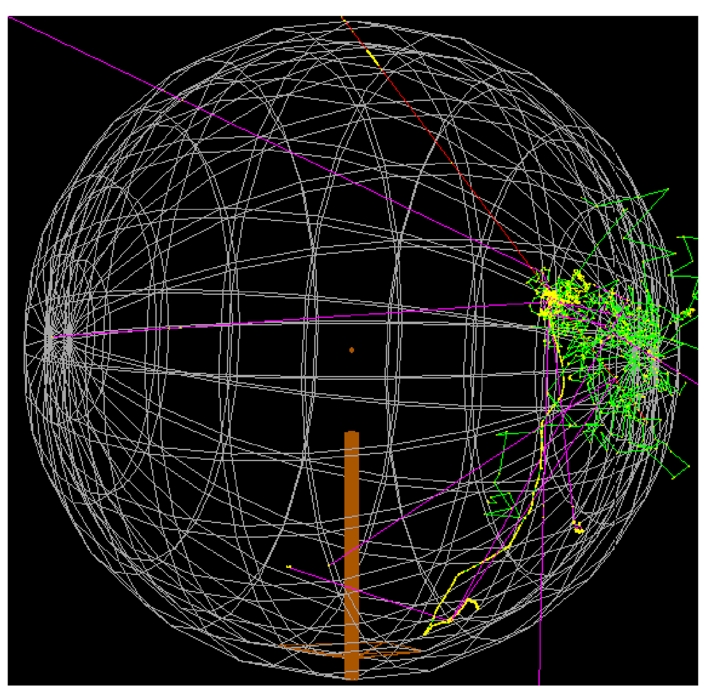

Figure 5: Geant4 visualisation of a muon traversing a spherical proportional counter.

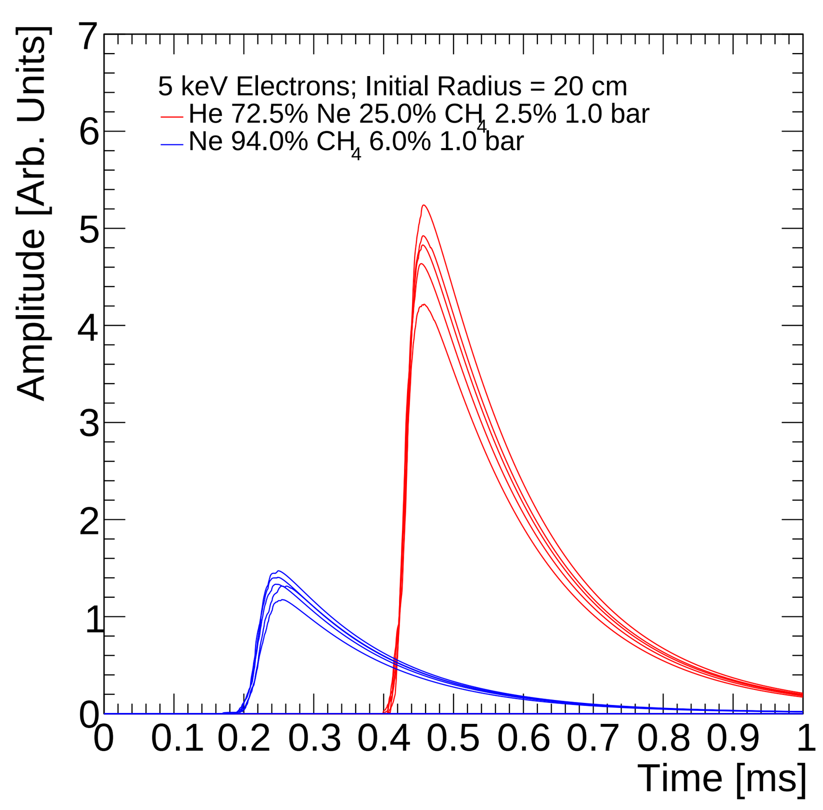

Figure 6: Example readout pulses produced by 5 keV electrons from an initial radius of 20 cm for different gas mixtures.

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Detector Response

- ^{55}Fe is a X-ray source producing 5.9 keV X-rays, commonly used in calibration of gaseous detectors
- Study the homogenity 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 $\cos\theta = -1$

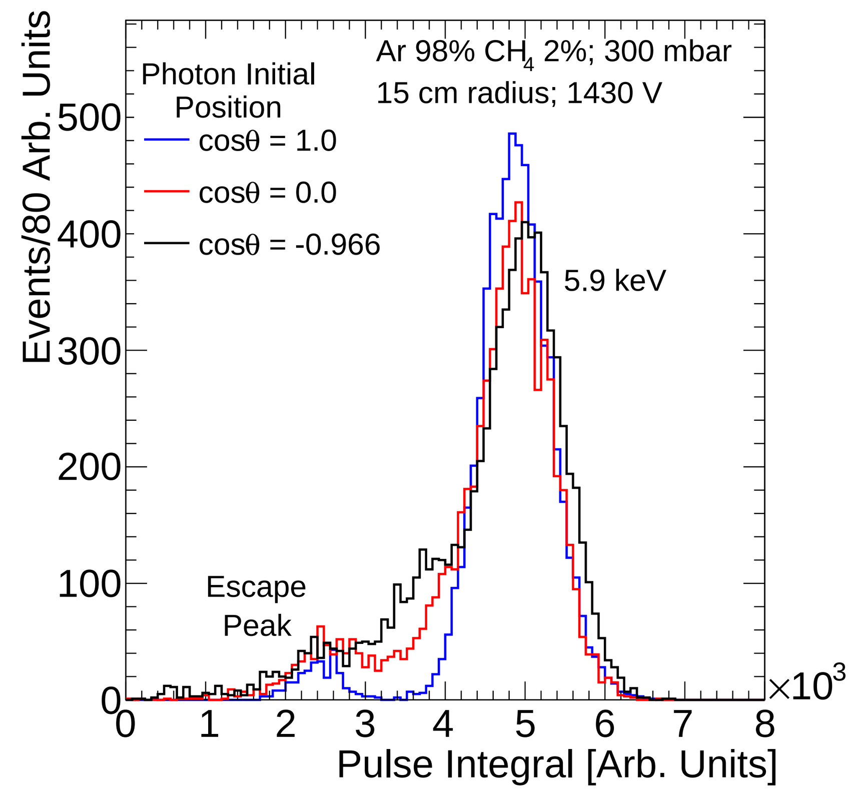

Figure 7: Pulse integral for 5.9 keV photons with an initial radius of 14.5 cm.

Interaction Radius

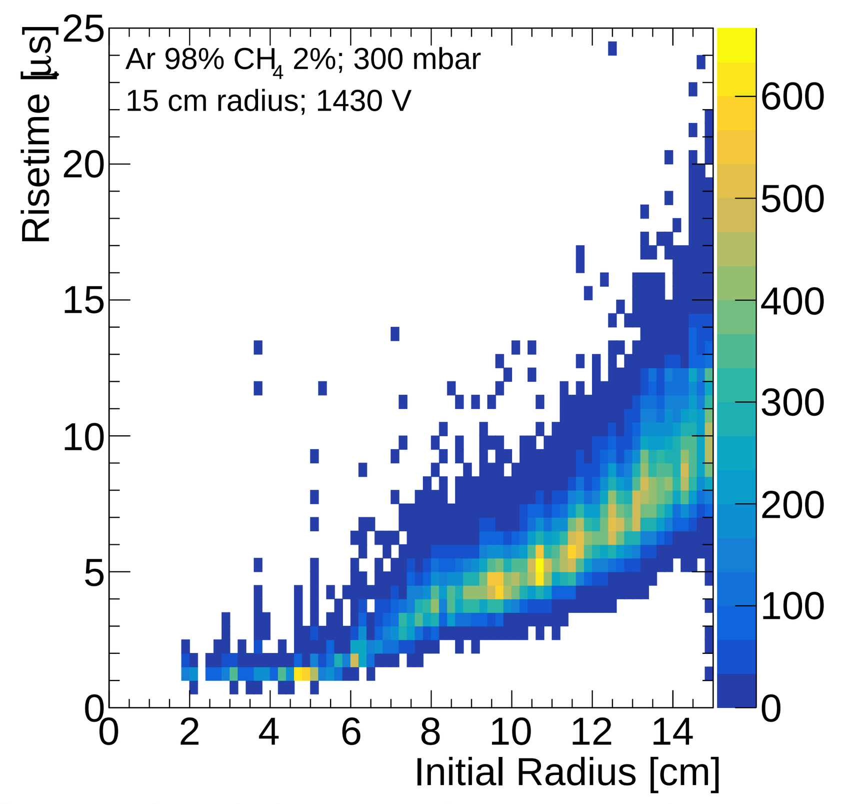

Figure 8: Initial electron radius versus pulse risetime for 2.38 keV electrons with an initial $\cos\theta > -0.8$.

- ^{37}Ar 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

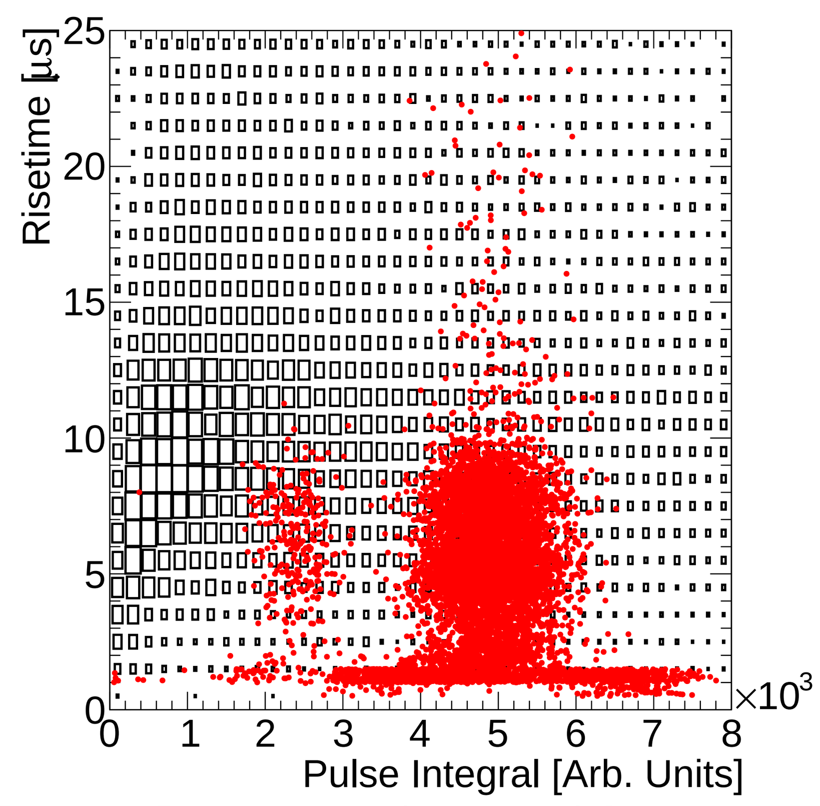

Figure 9: Risetime vs pulse integral for muons incident from a plane above the detector (black) and 5.9 keV photons (red).

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

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