UNIVERSITY OF BIRMINGHAM

Birmingham Gaseous Detectors Laboratory

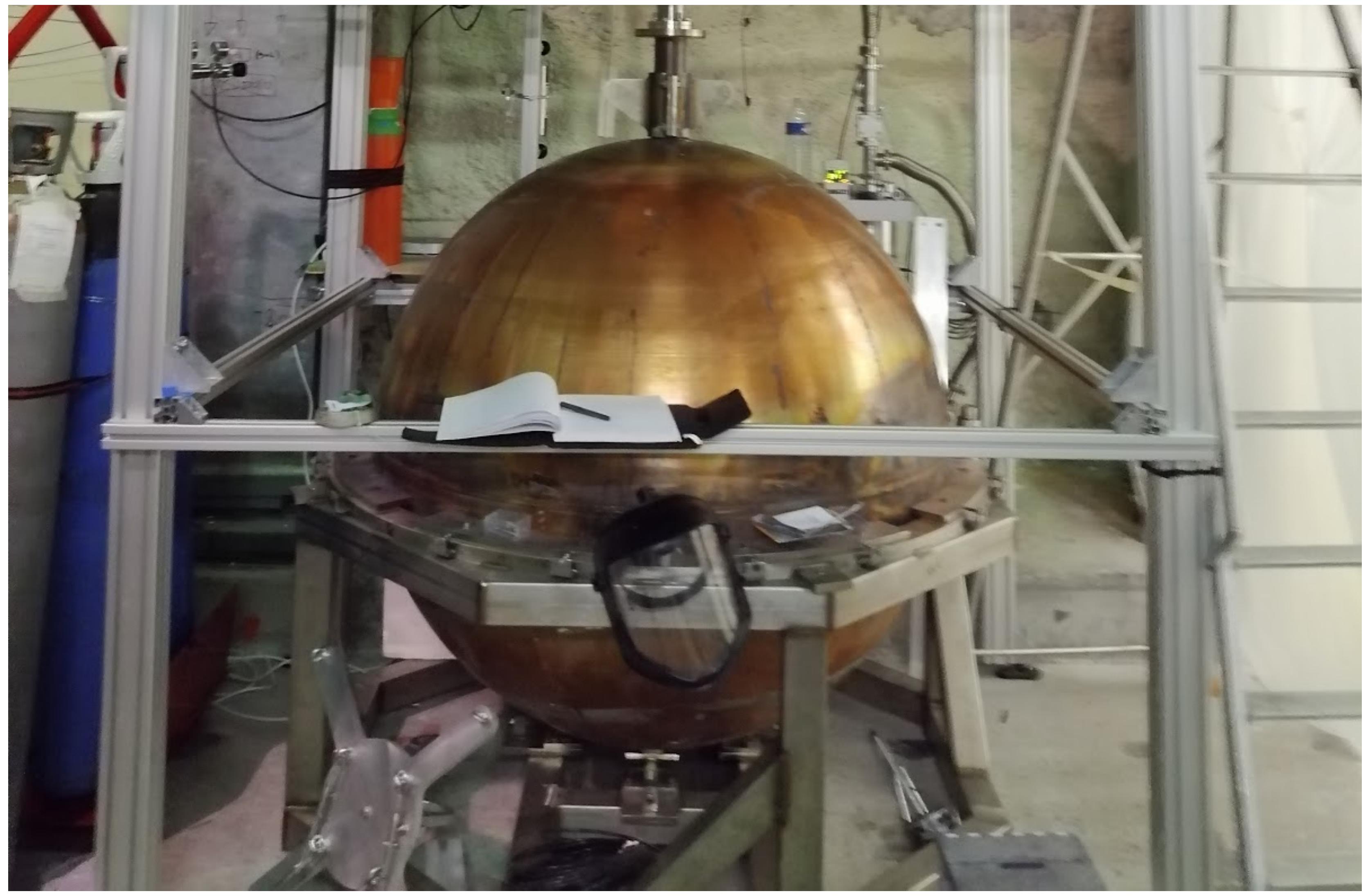
A Simulation Framework for Spherical Proportional Counters

I. Katsioulas, P. Knights, I. Manthos, J. Matthews, K. Nikolopoulos, T. Neep, M. Slater, R. Ward

University of Birmingham, UK

Spherical Proportional Counters

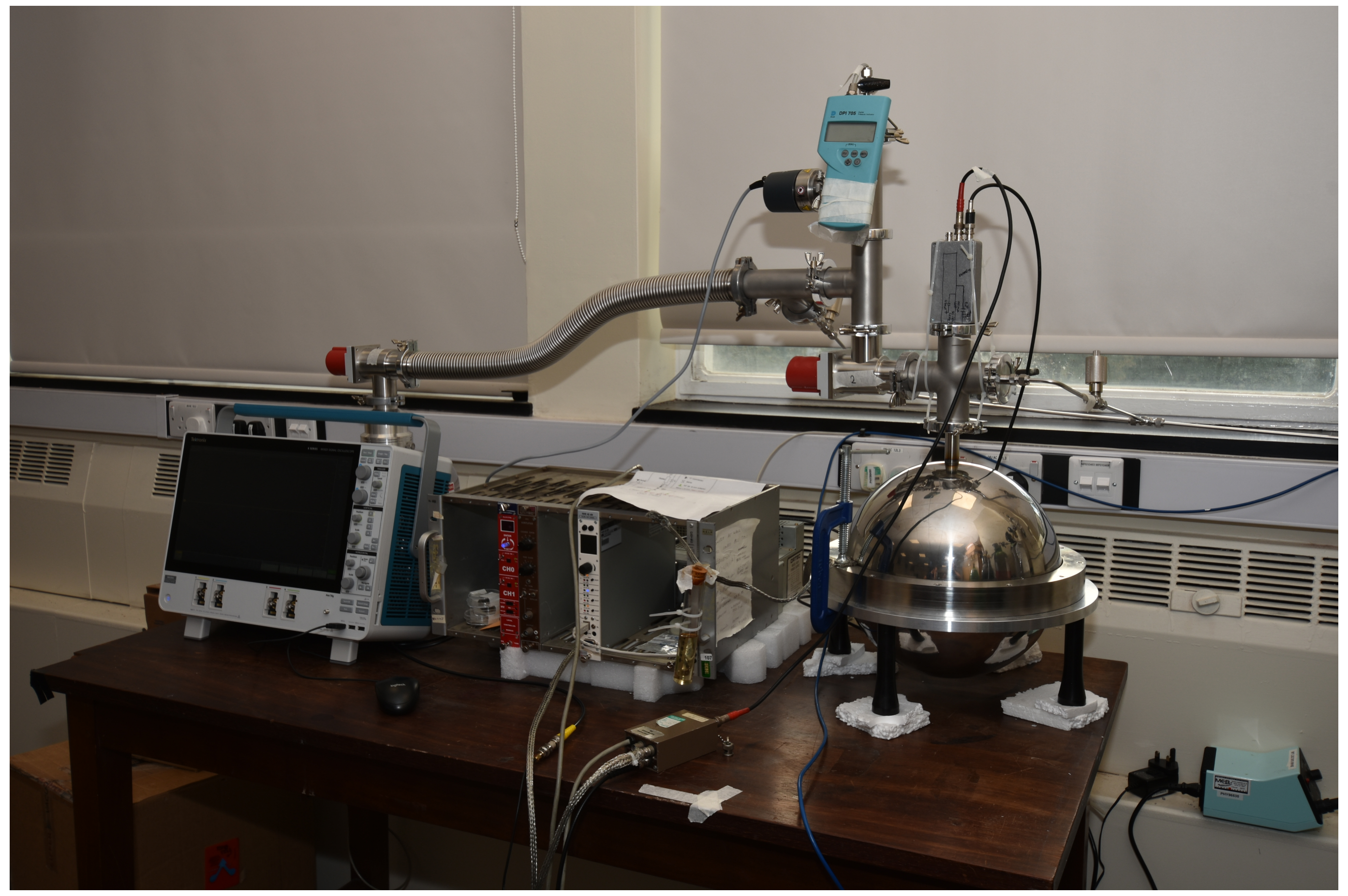
- A spherical gaseous detector with multiple applications
  - Direct DM searches (NEWS-G) — Astropart.Phys. 97 (2018) 54-62
  - Neutron spectroscopy — IEEE NSS/MIC 2019 9060052
  - 0νββ decay (R2D2) — JINST 16 (2021) 03, P03012
  - Neutrino physics — Phys.Lett.B 634 (2006) 23-29



NEWS-G: SNOGLOBE (LSM and SNOLAB, Canada)

See T. Neep's talk (Tues. 14:15) for more on NEWS-G &
See I. Manthos's poster for more on neutron spectroscopy

G. Charpak and I. Giomataris in CEA Saclay, France
(sphere was previously a LEP RF cavity)



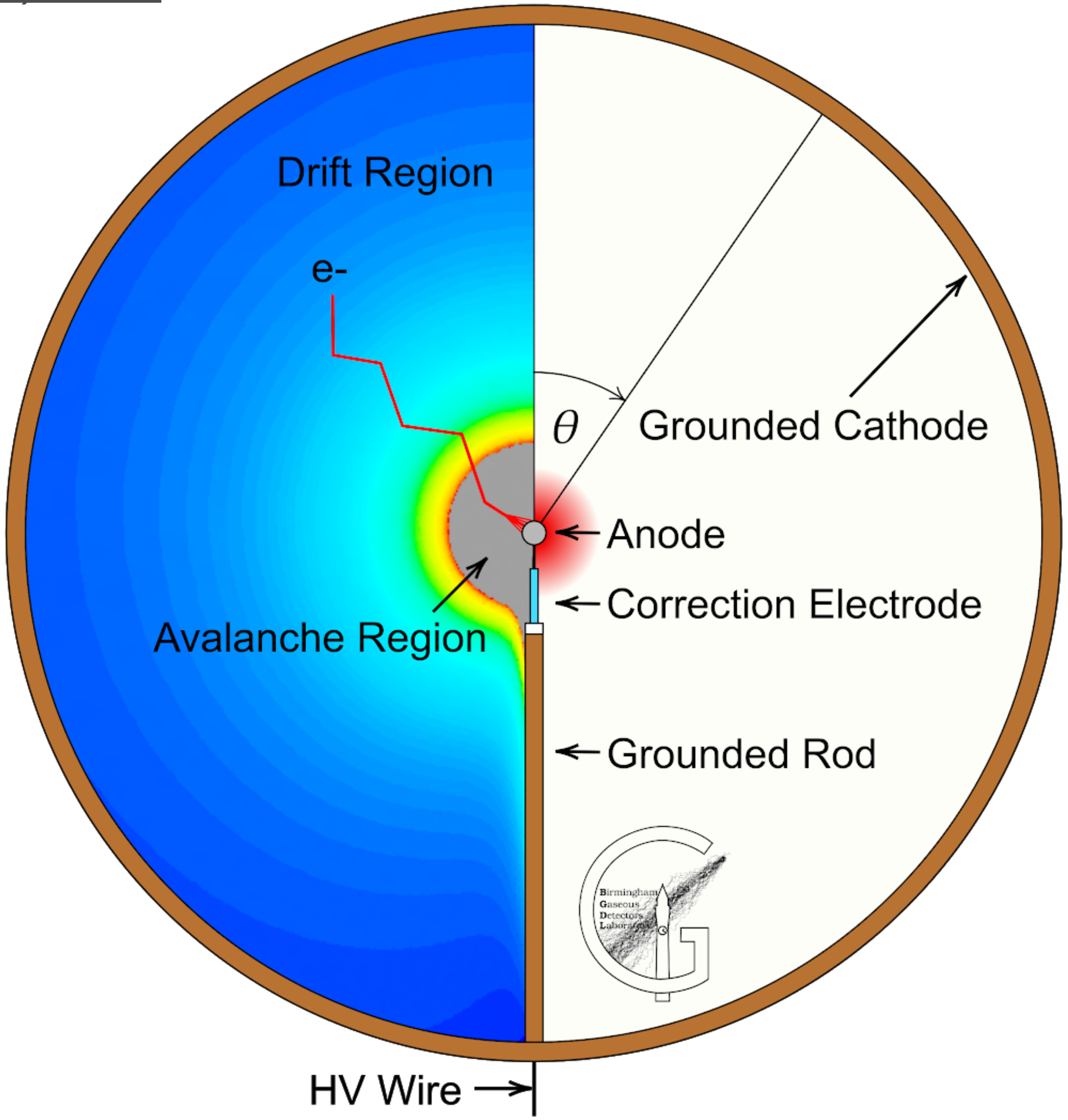
University of Birmingham
Gaseous Detector Laboratory

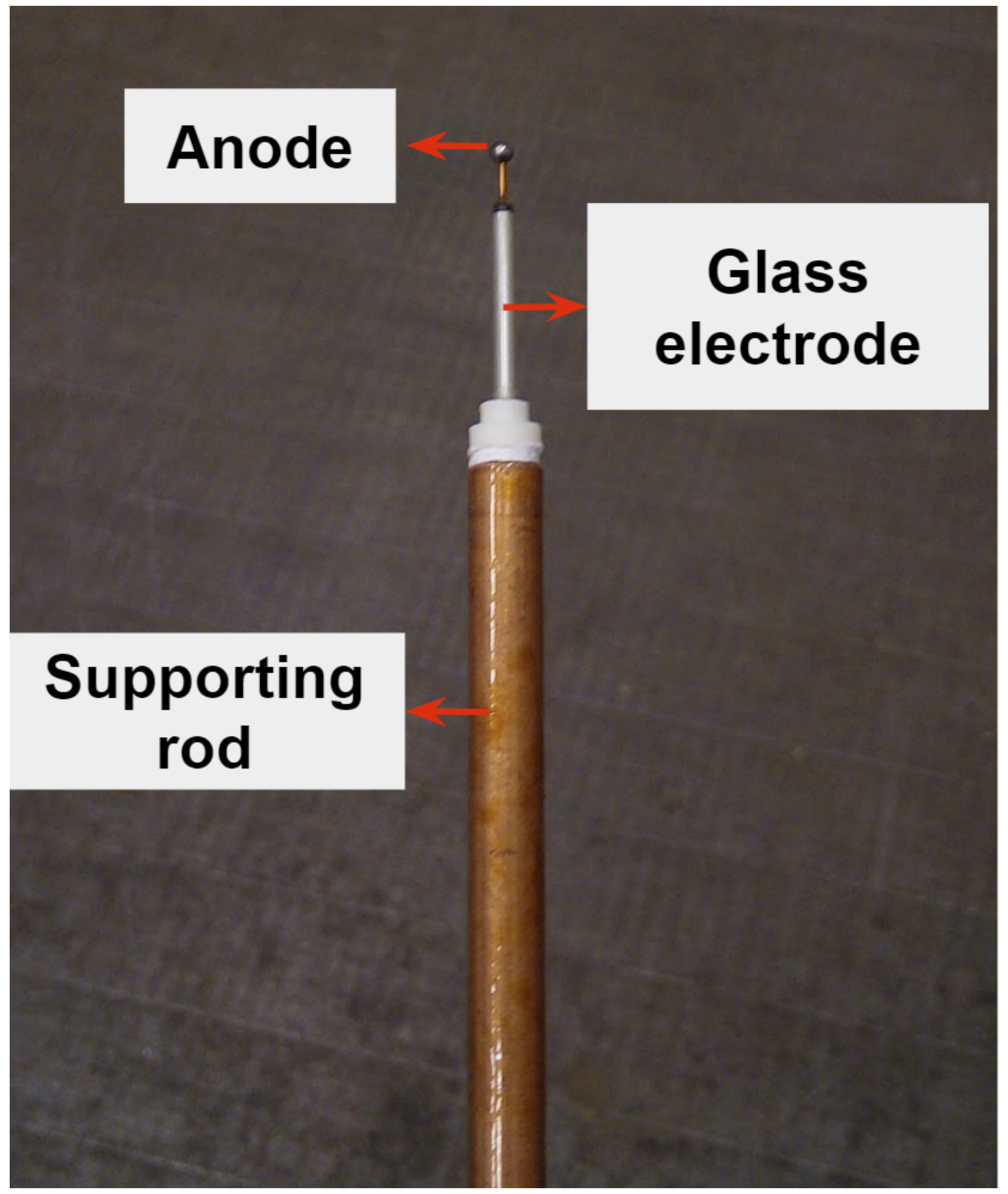
Boulby Underground Laboratory

How it Works

- ⌀O(0.1-1 m) sphere with ⌀O(1 mm) sphere in centre
- Voltage applied to inner sphere - anode
  - $E \sim 1/r^2$
  - Naturally divides detector into drift and avalanche region
- Simulation is a critical ingredient in detector R&D and interpretation of measurements

JINST 3 (2008) P09007





JINST 13 (2018) 11, P11006

Simulation Framework

- Many packages available for detector simulation:
  - Geant4: for simulation particle interactions with matter
  - ANSYS: finite-element methods software for electric field calculations
  - Garfield++: For simulating electron-ion drift and signal calculations
    - Interfaces with Magboltz, SRIM and HEED
- Simulation framework combines these with custom calculations to form complete simulation

Development of a simulation framework for spherical proportional counters

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Abstract: The spherical proportional counter is a novel gaseous detector with numerous applications, including direct dark matter searches and neutron spectroscopy. The strengths of the Geant4 and Garfield++ toolkits are combined to create a simulation framework for spherical proportional counters. The interface is implemented by introducing Garfield++ classes within a Geant4 application. Simulated muon, electron, and photon signals are presented, and the effects of gas mixture composition and anode support structure on detector response are discussed.

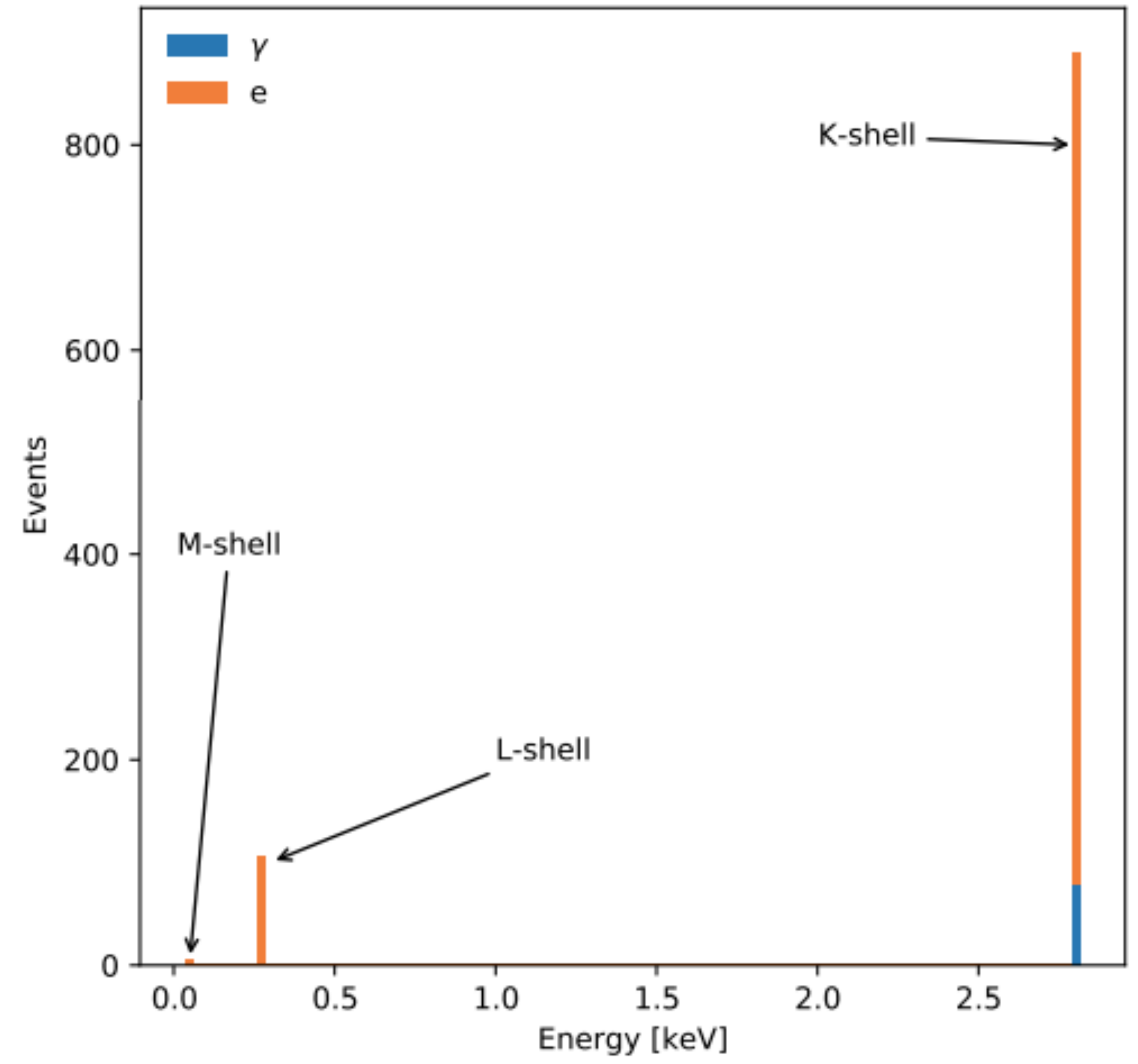
Keywords: Detector modelling and simulations I (interaction of radiation with matter, interaction of photons with matter, interaction of hadrons with matter, etc); Detector modelling and simulations II (electric fields, charge transport, multiplication and induction, pulse formation, electron emission, etc); Gaseous detectors; Simulation methods and programs

2020 JINST 15 C06013

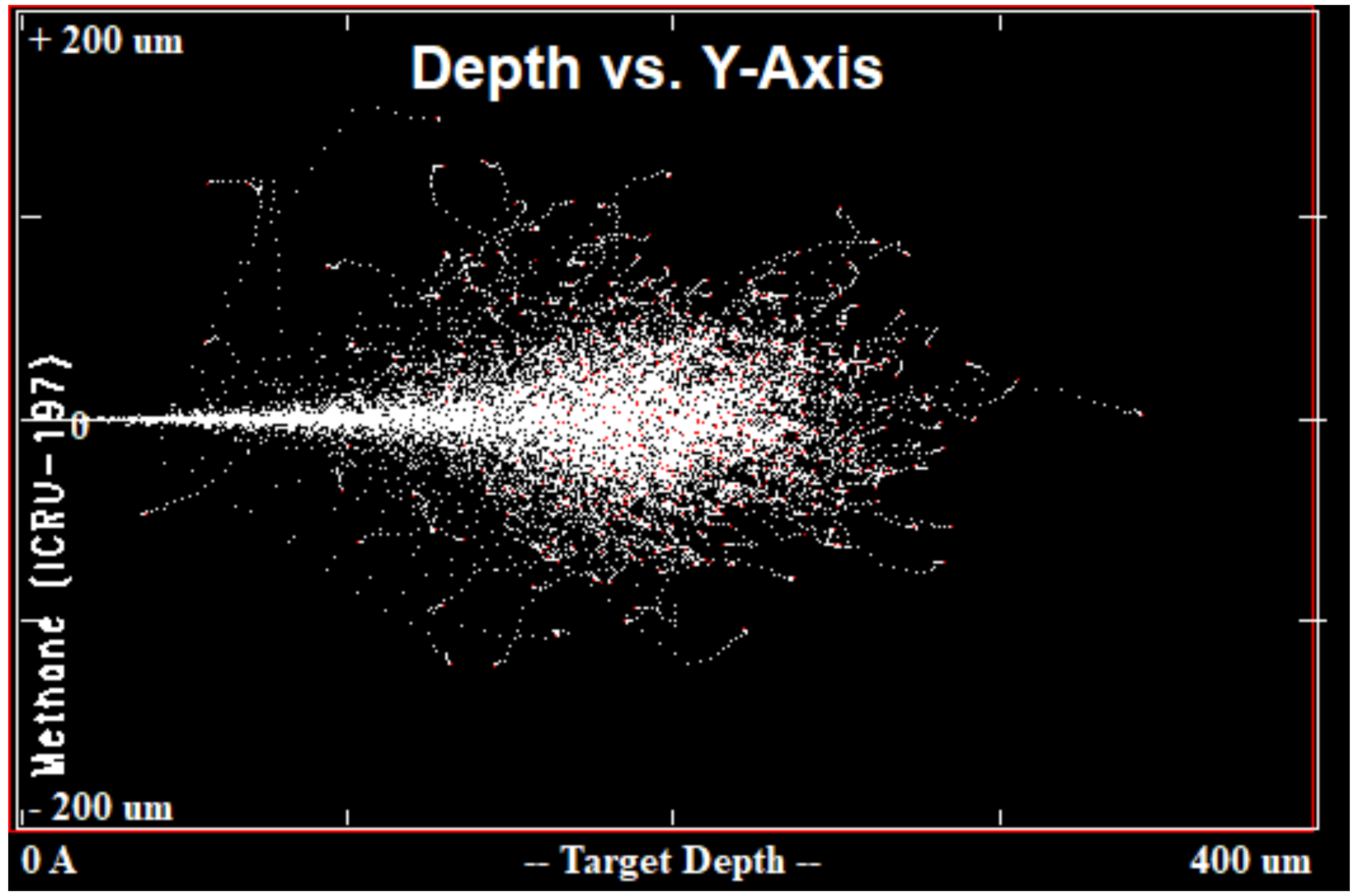
JINST 15 (2020) 06, C06013

Initial Particle Generation and Tracking

- Detector initialised: can include cathode material, shielding etc.…
- Primary particle generated by `G4ParticleGun`
  - Choose particle type, energy, position and direction
  - Initial particle could be calibration source, experimental background isotope decay, dark matter nuclear recoils, …
- Particle transported and interacted with gas, cathode, etc.
- Electrons with E<2 keV passed to Garfield++



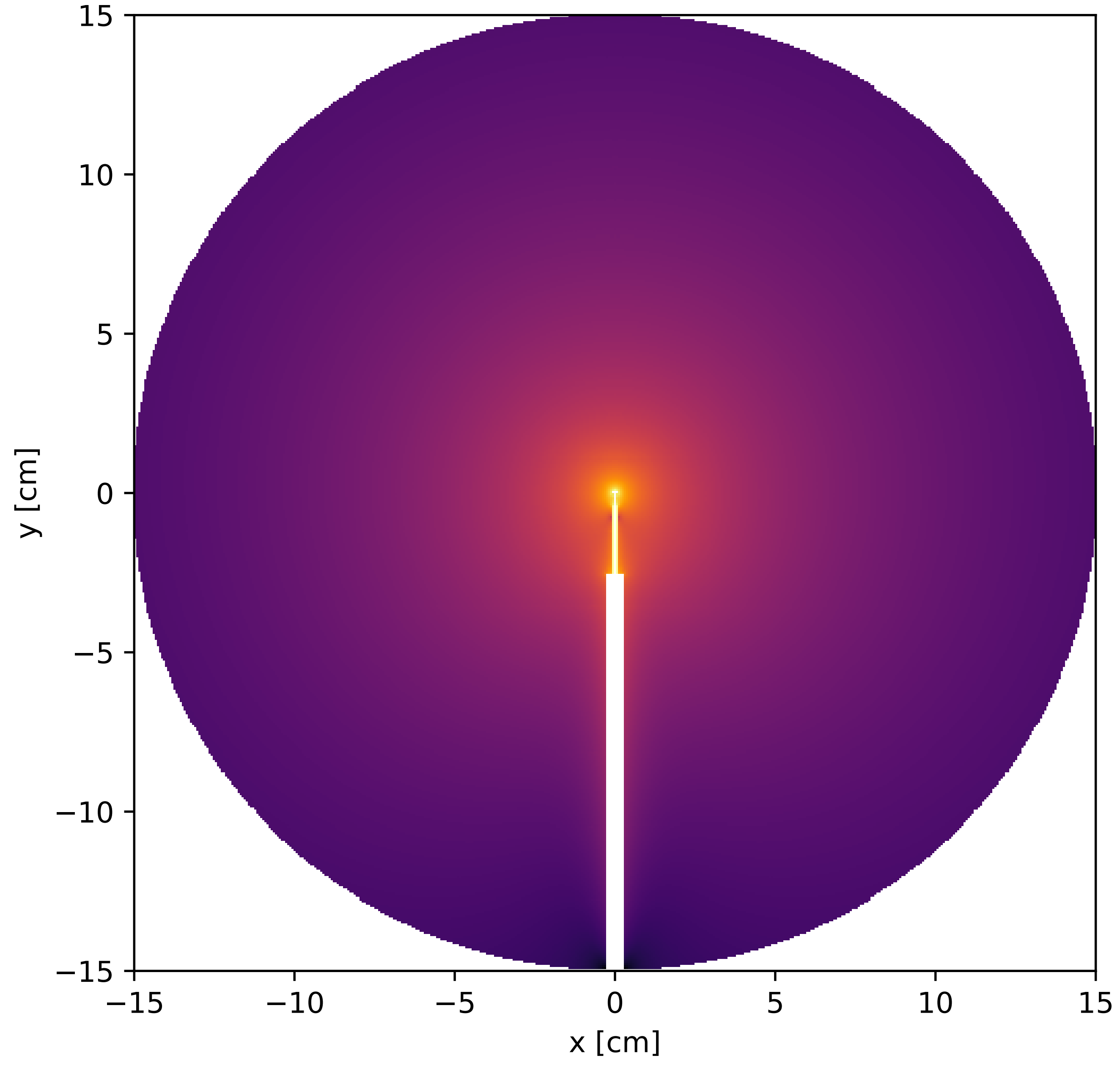
Example:1000 ^{37}Ar decays (typical calibration source) using GEANT4's `G4RadioactiveDecayPhysics` model



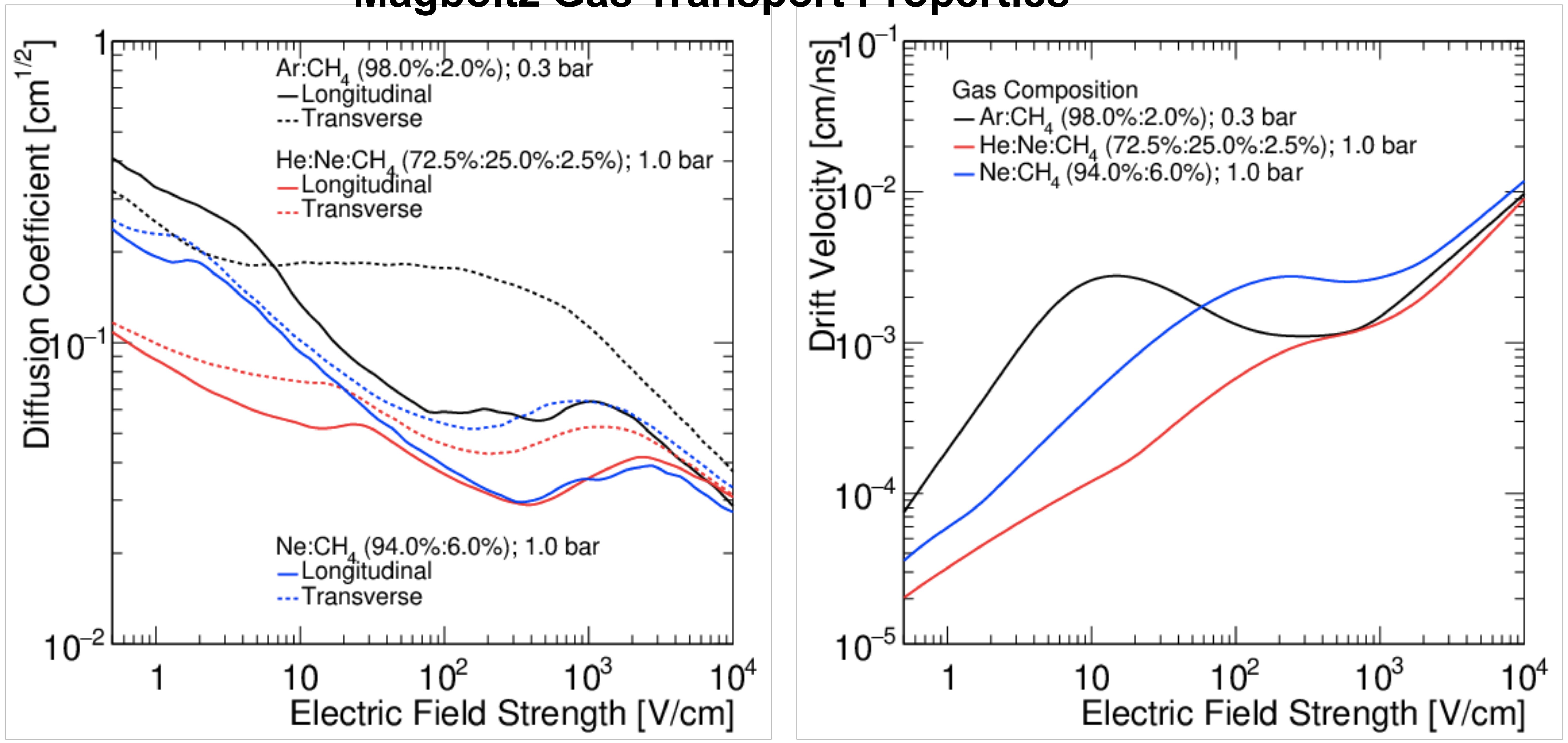
10 keV Protons interacting in CH_4 in SRIM simulation - SRIM can be used to compute energy losses in the simulation

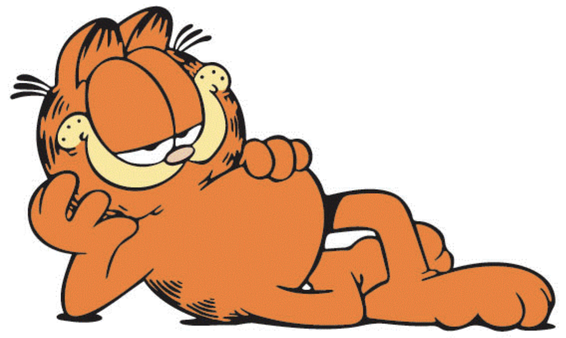
Electron Transport

Electric Field Magnitude Map



Magboltz Gas Transport Properties

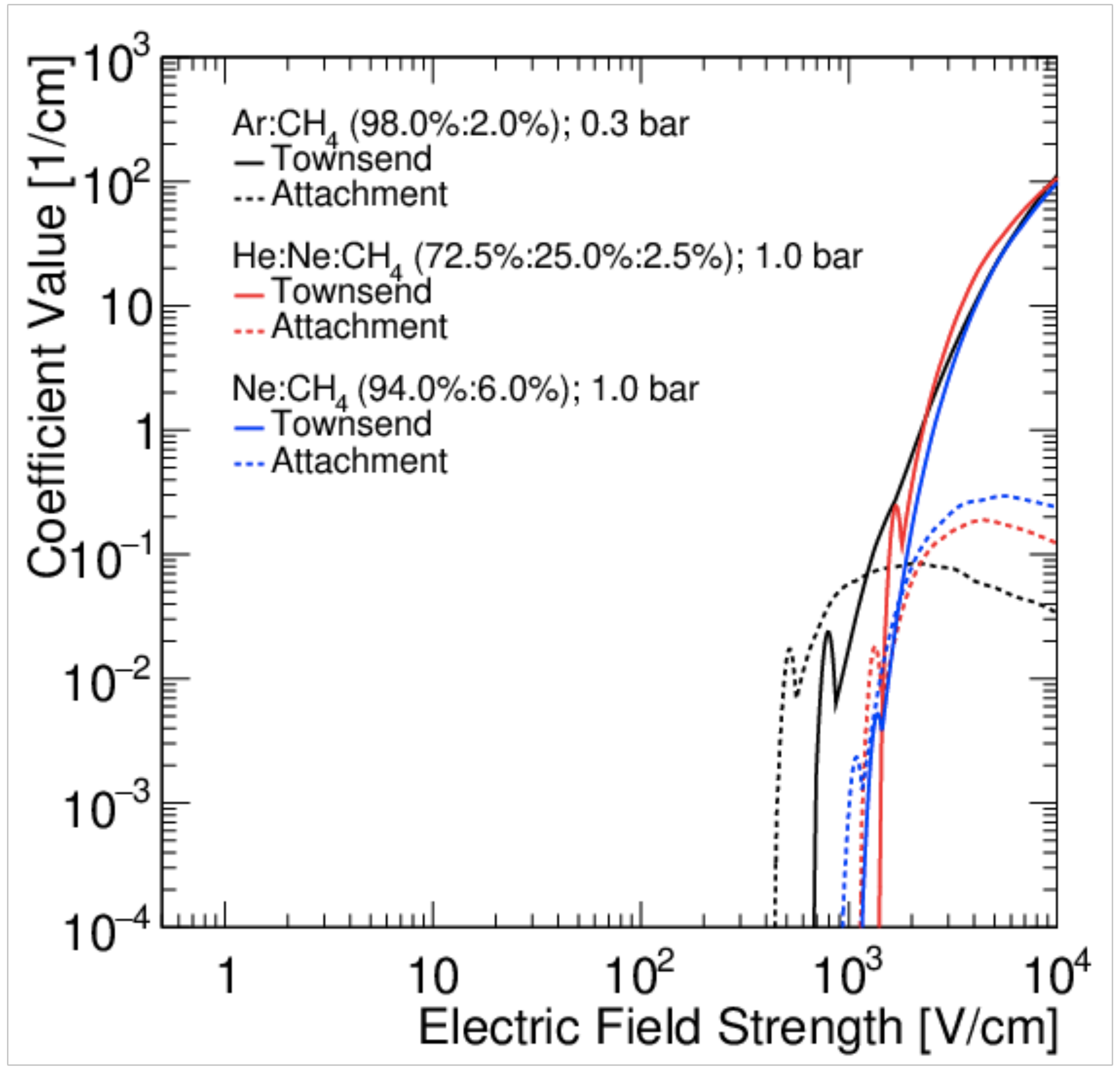


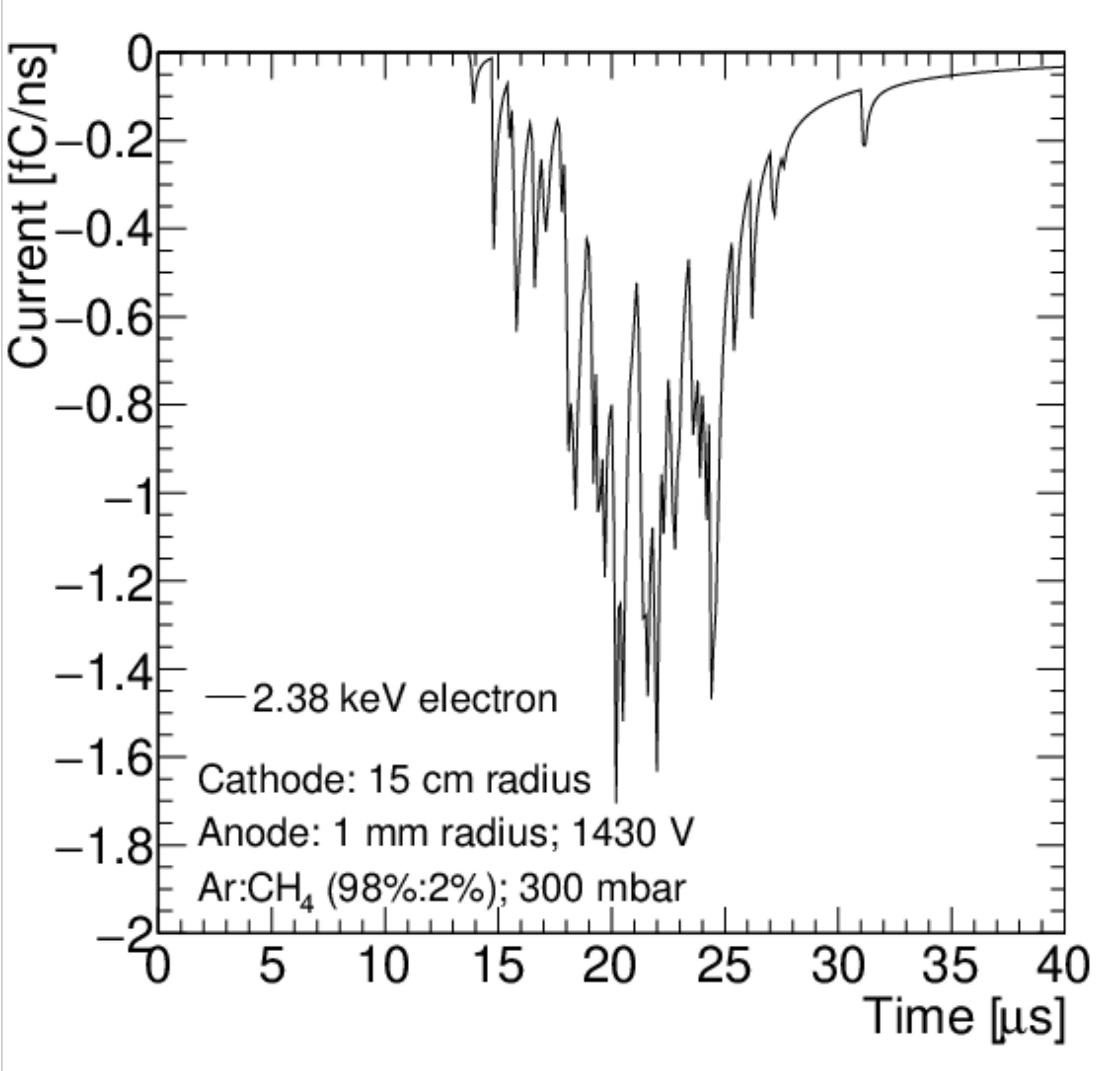


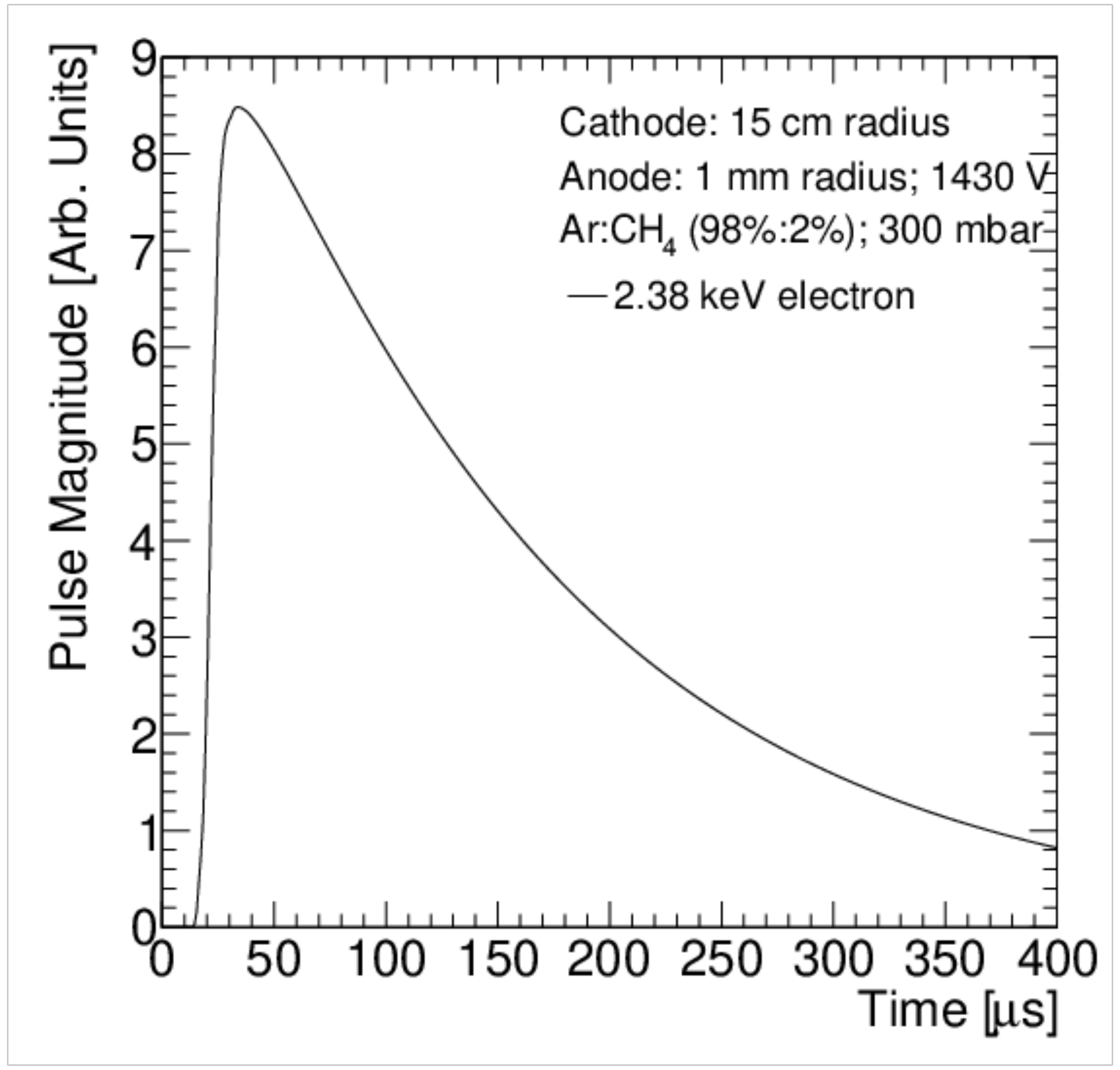
- HEED compute further ionisation (δ-electrons)
- Electrons transported (drift and diffusion) to avalanche region
  - ANSYS used to calculate electric field map
  - Magboltz used to compute gas transport parameters

ANSYS

Charge Amplification and Signal Formation







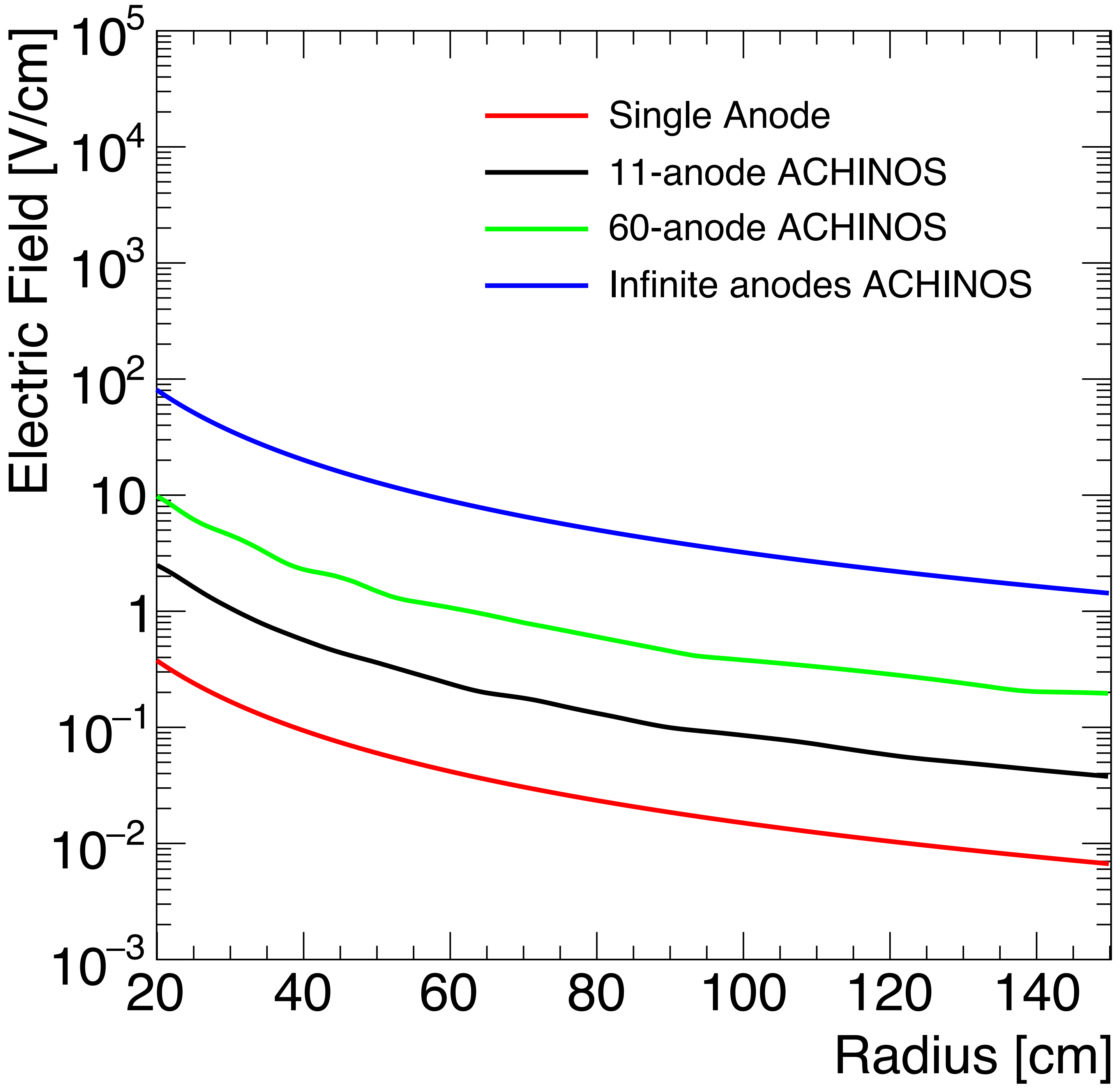
- Electron avalanche simulated when electrons approach anode
- Avalanche gain parameterised to save computational time
  - Gain follows Polya distribution
- Generated ions transported and induced current calculated
- Signal passed through simulated electronics chain
  - Directly comparable to experimental results

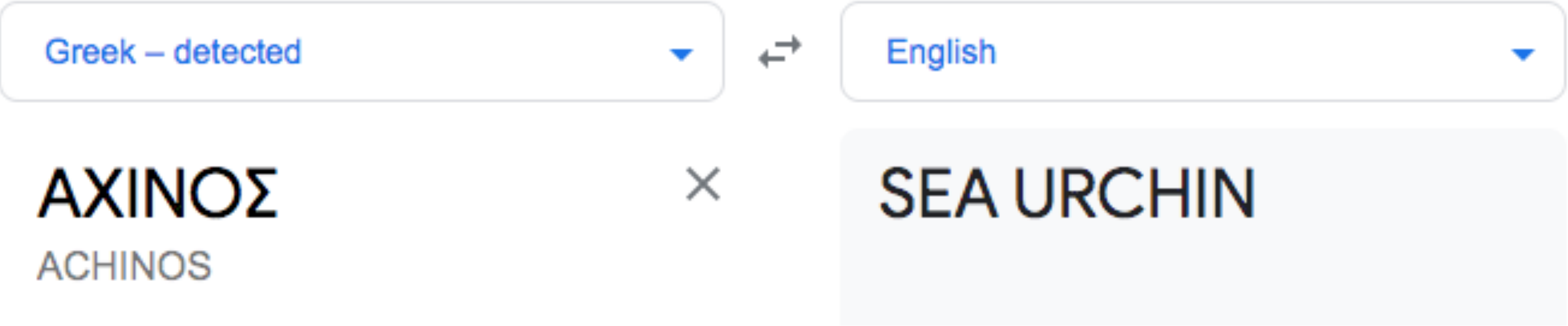
ACHINOS

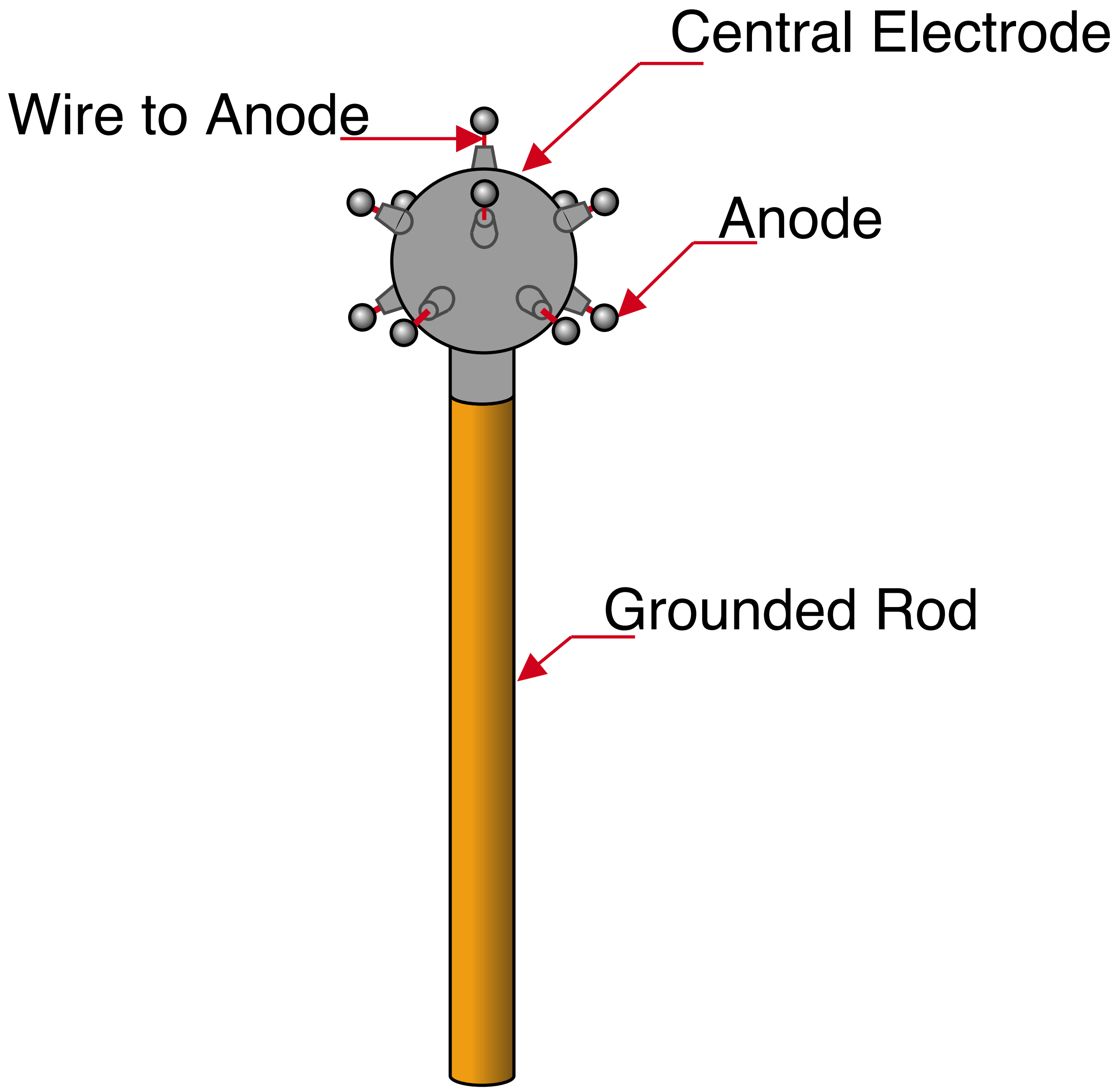
- Gain and drift fields are coupled with single anode
  - Challenge in producing larger radii and higher pressure detectors
- Idea: A multi-anode readout
  - Gain and drift decoupled

JINST 12 (2017) 12, P12031

JINST 15 (2020) 11, 11



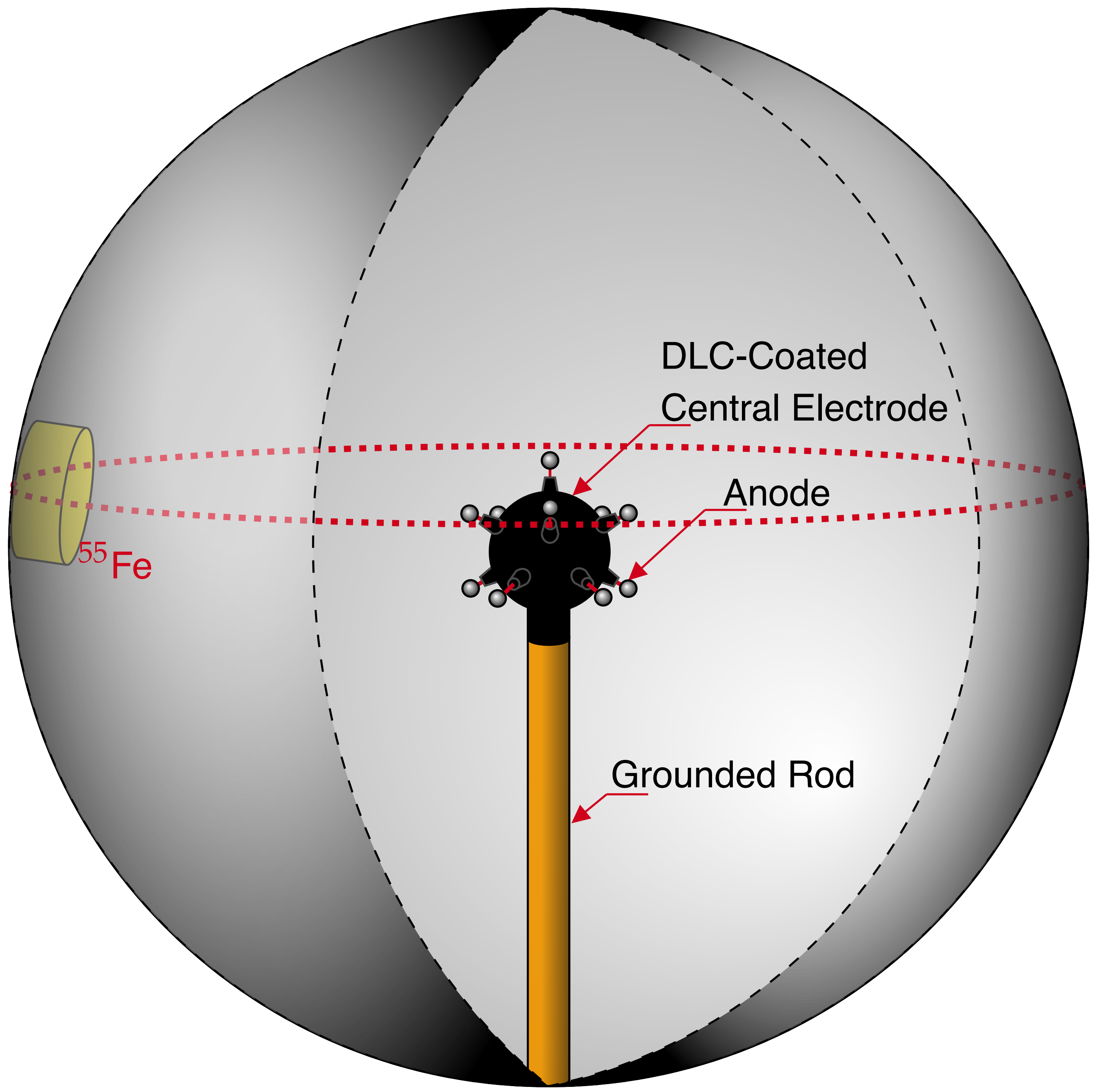


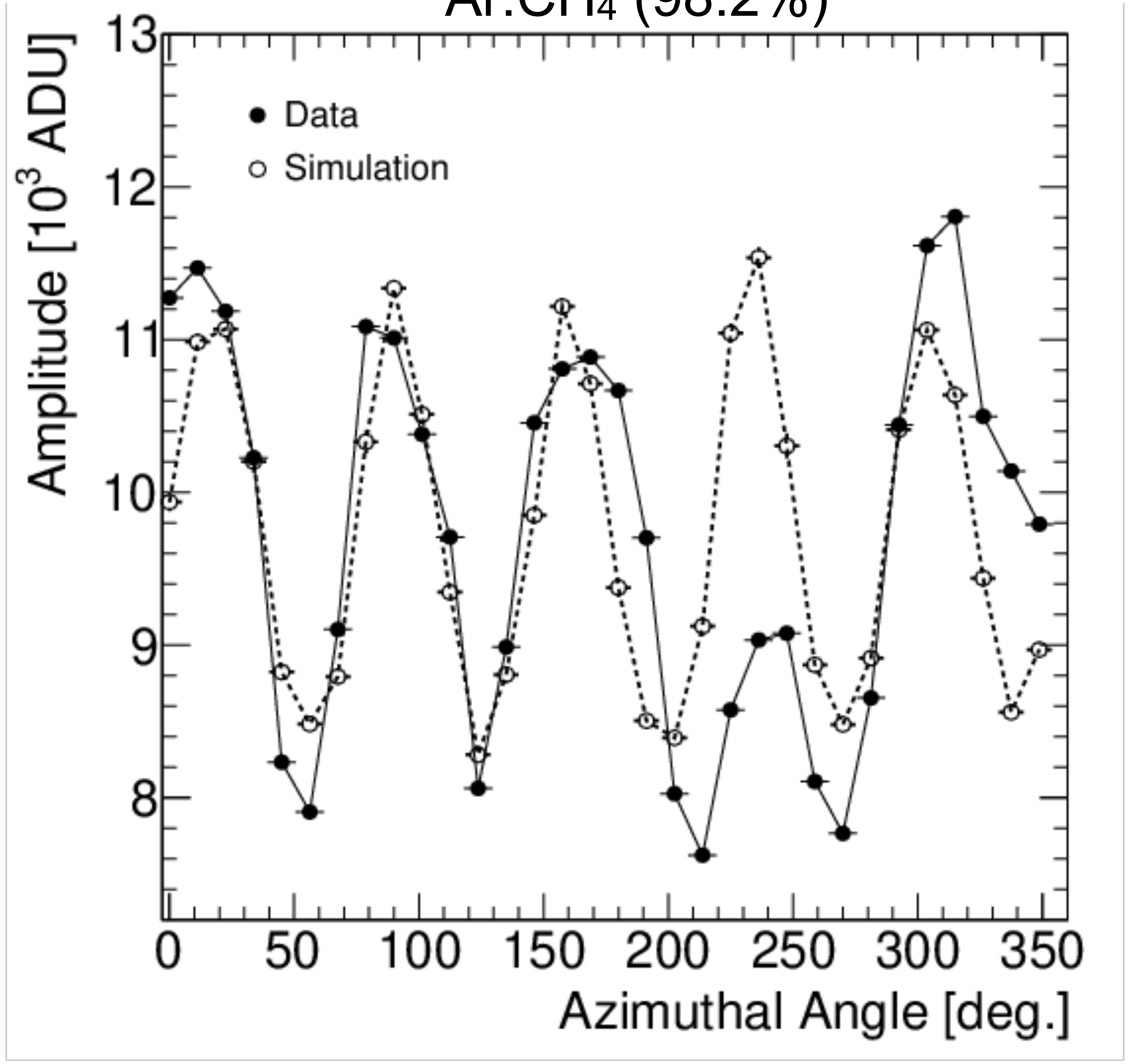


ACHINOS Testing

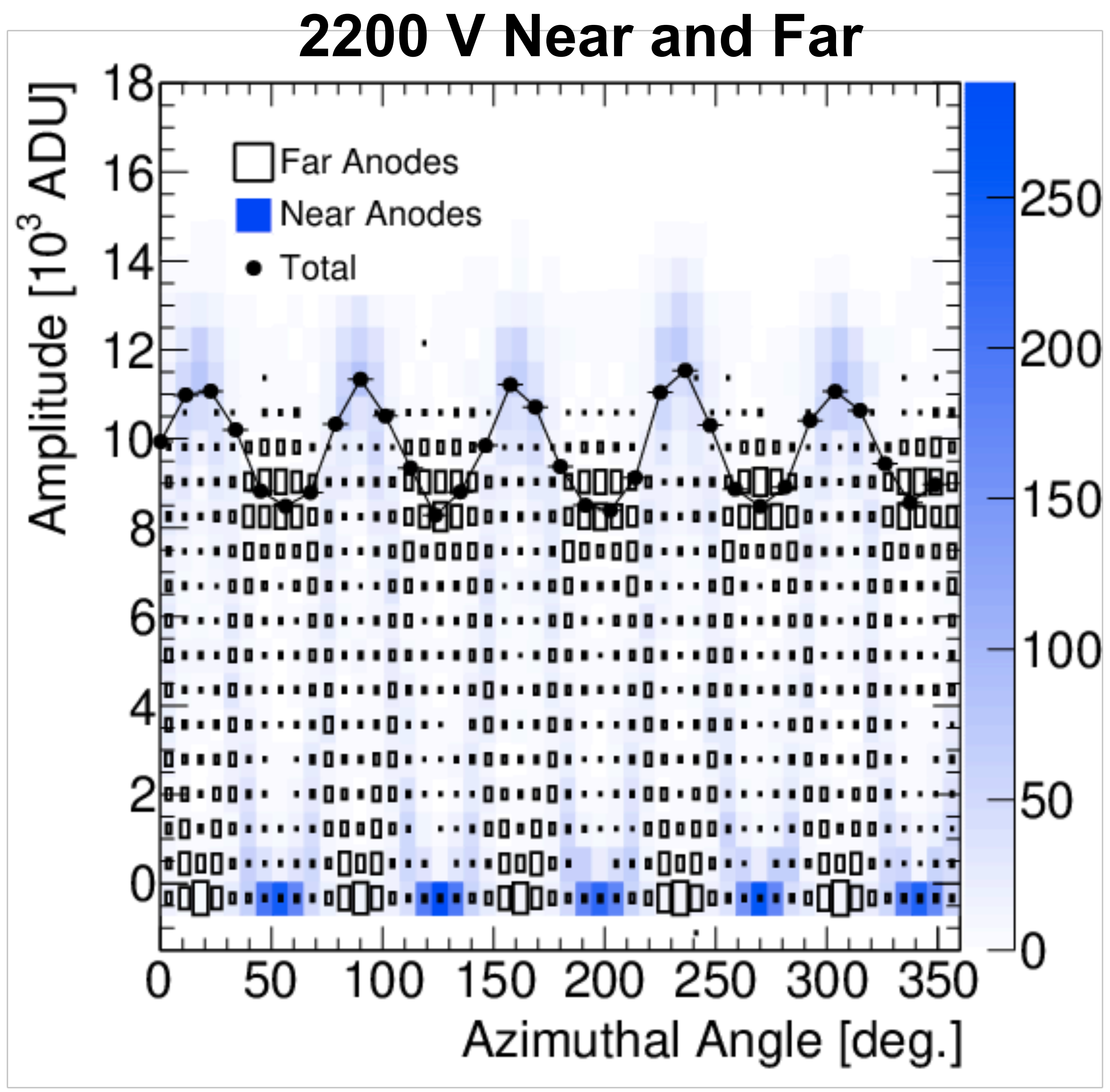
- Recent R&D for ACHINOS *JINST 15 (2020) 11, 11*
  - 11 anodes, DLC-coated central electrode
- Directed ^{55}Fe source at multiple parts of the ACHINOS to study uniformity of response
  - Source gives 5.9 keV photons
- Observed sinusoidal-like pulse amplitude variations with position

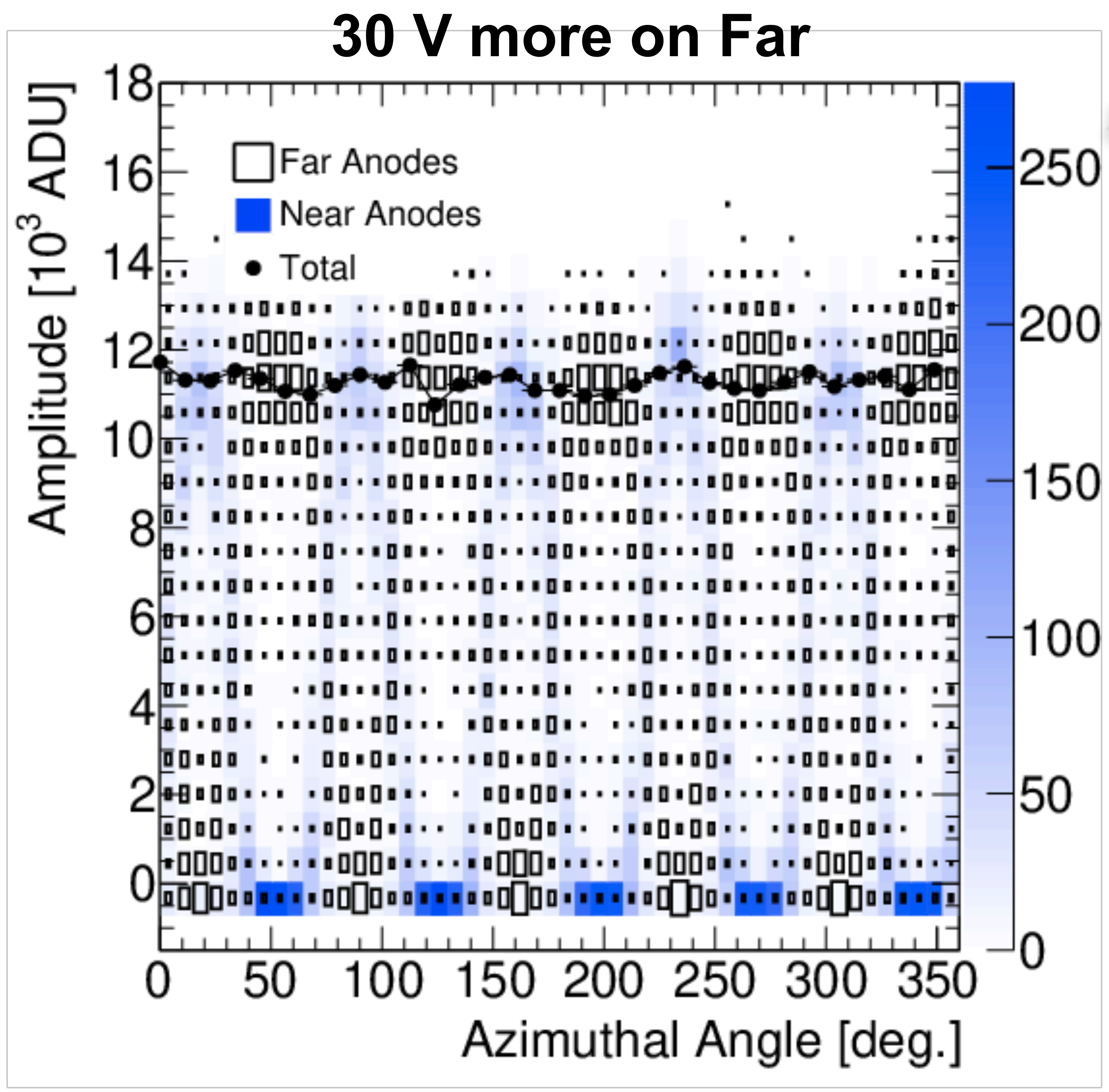
⌀30 cm detector, 1 bar
$Ar:CH_4$ (98:2%)

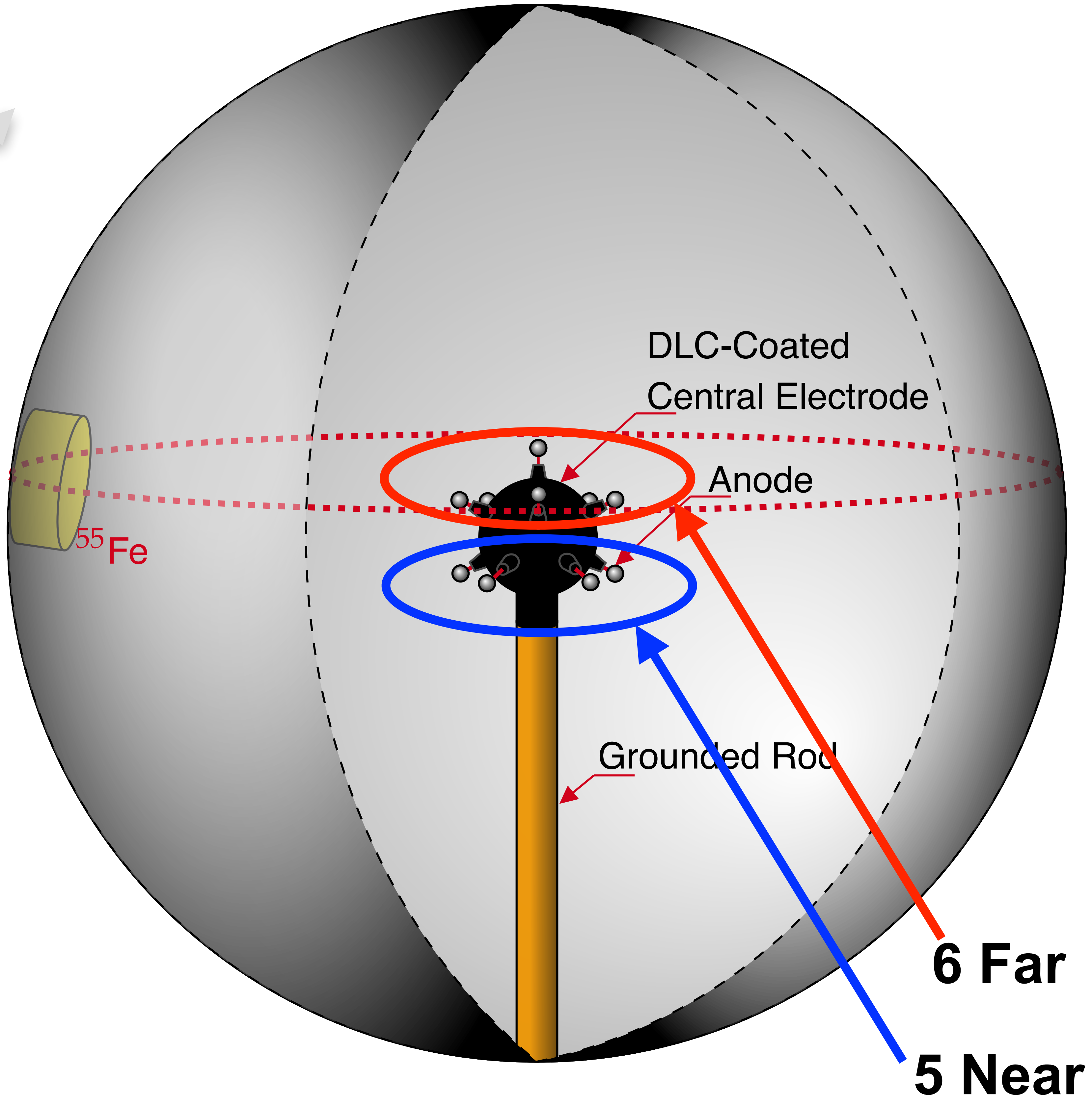




ACHINOS Simulations



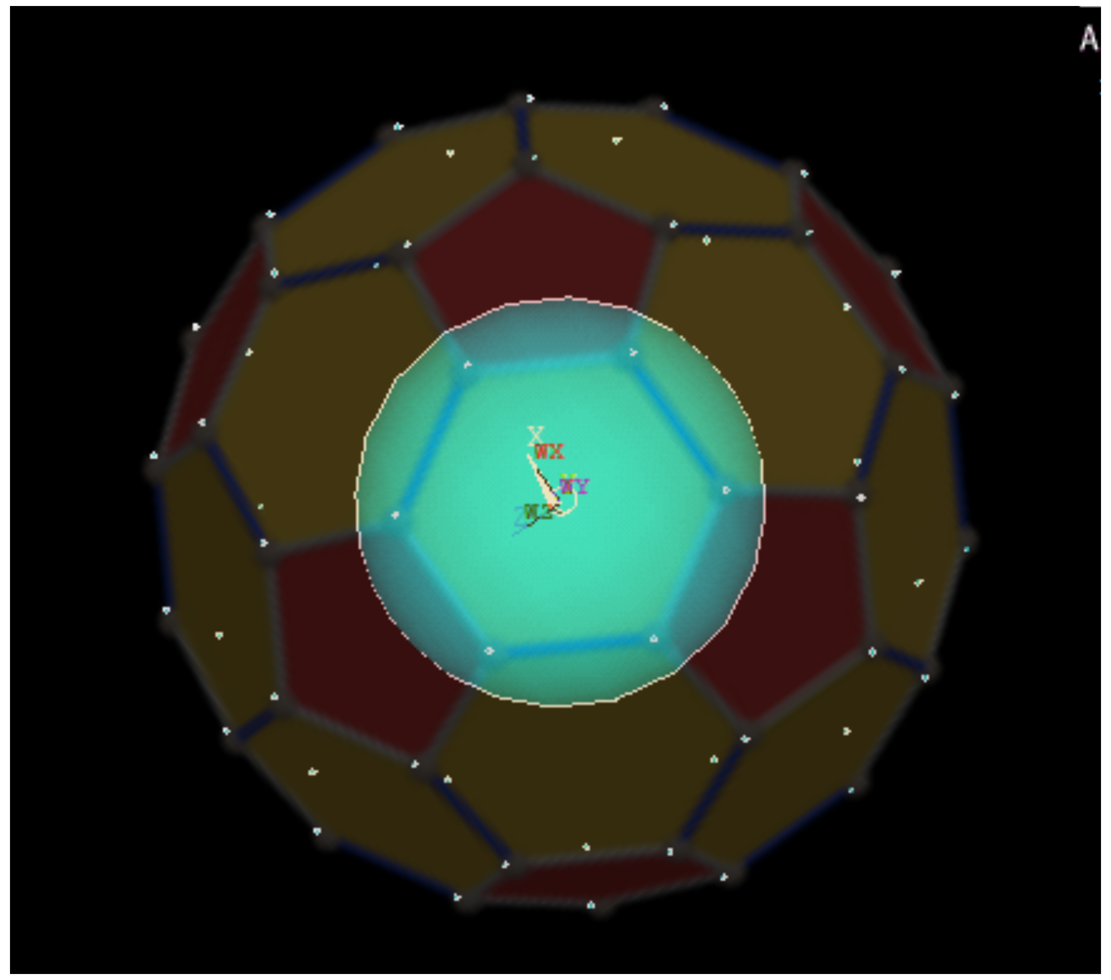


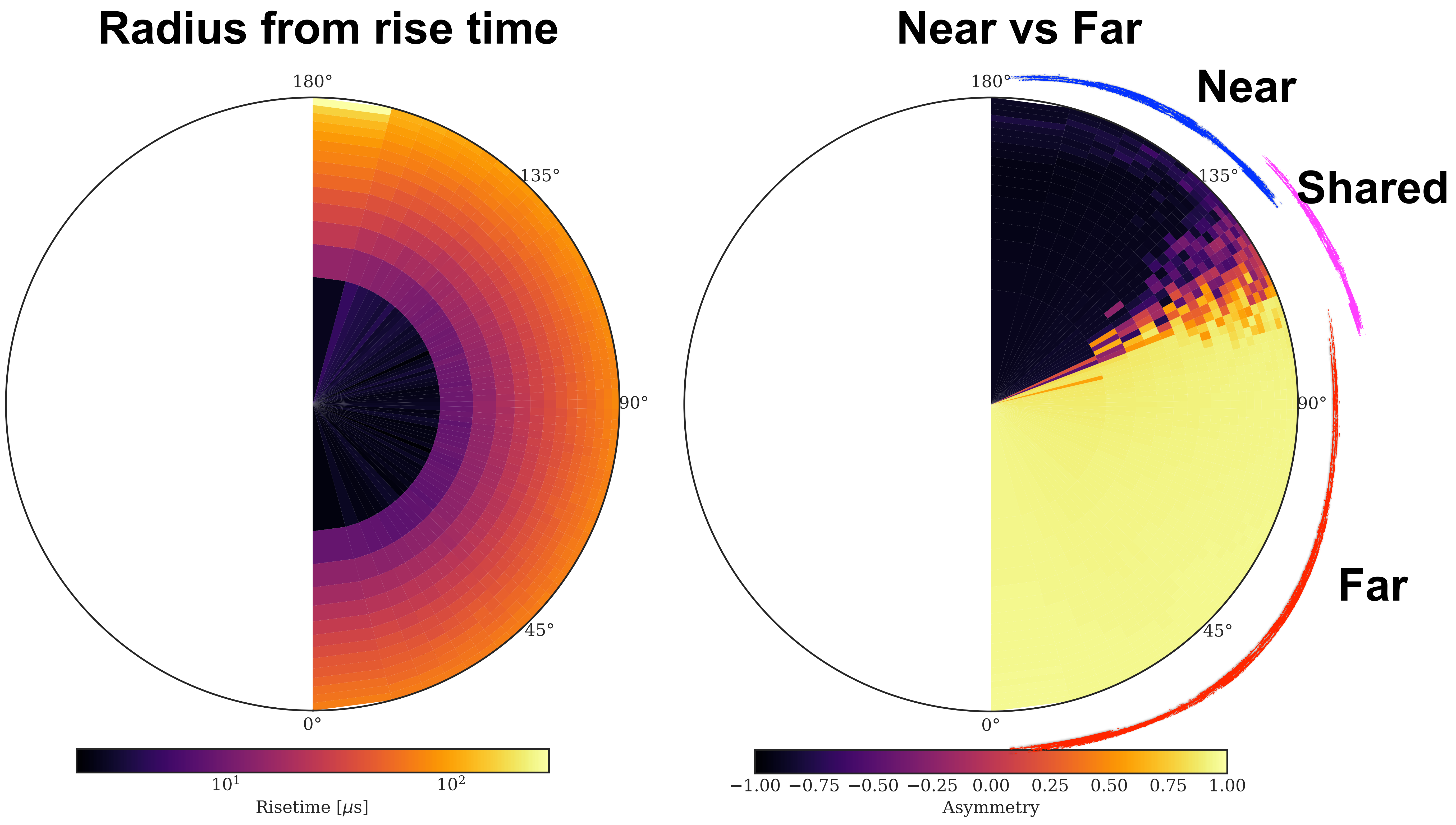


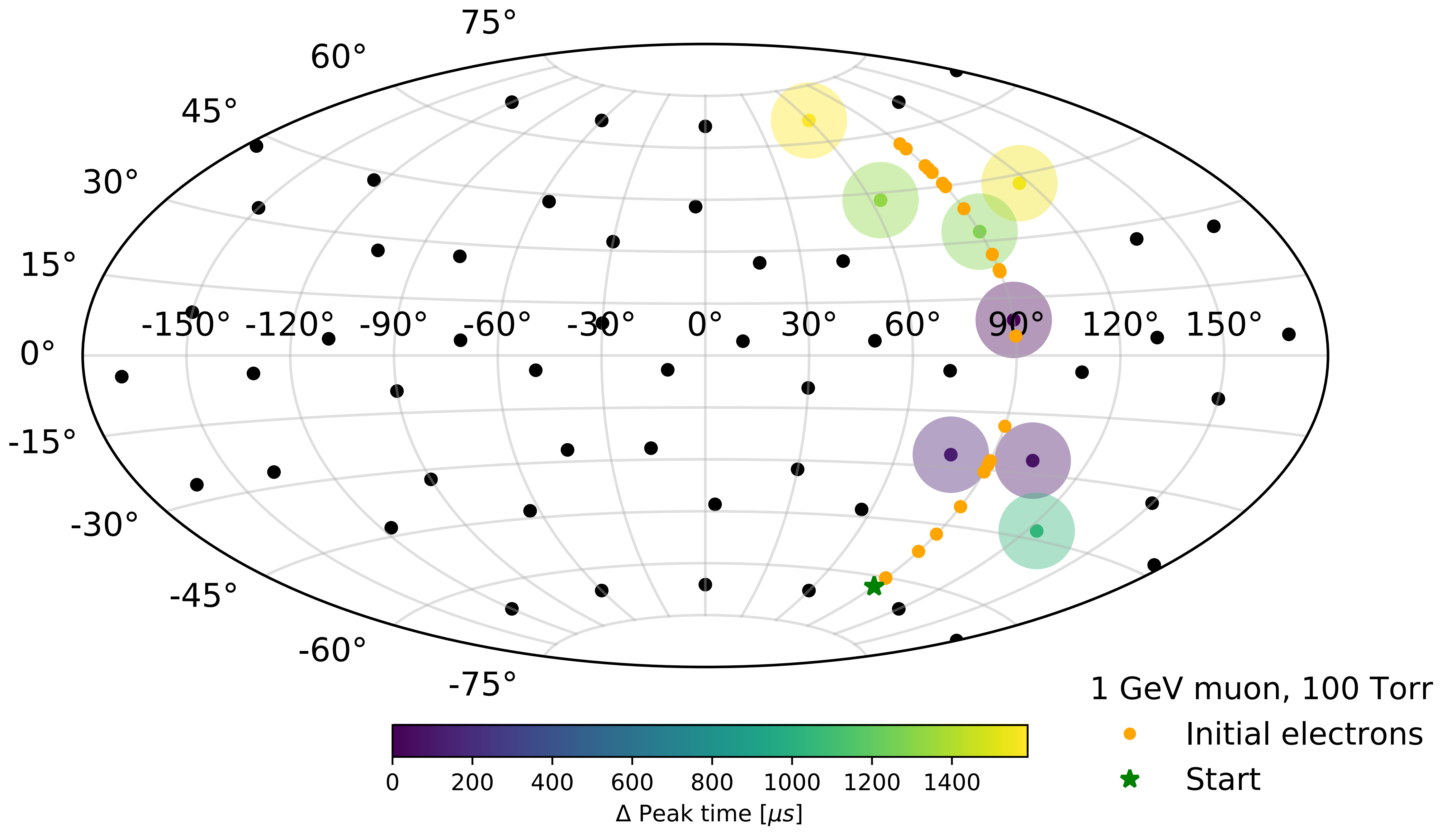
- Simulate experiment sending 5.9 keV photons from different positions
- Looking at signal generated on Near and Far anodes separately found higher amplitudes on Near
  - Electric field higher on Near side due to grounded rod
- Reducing voltage applied to Near anodes corrects for effect

Track Reconstruction

- Can infer interaction location from looking at Near/Far signal
- Higher number of anodes = improved spatial/timing resolution
  - Also, higher electric field magnitude
- 60-anode ACHINOS being designed
- Preliminary testing for track identification is ongoing







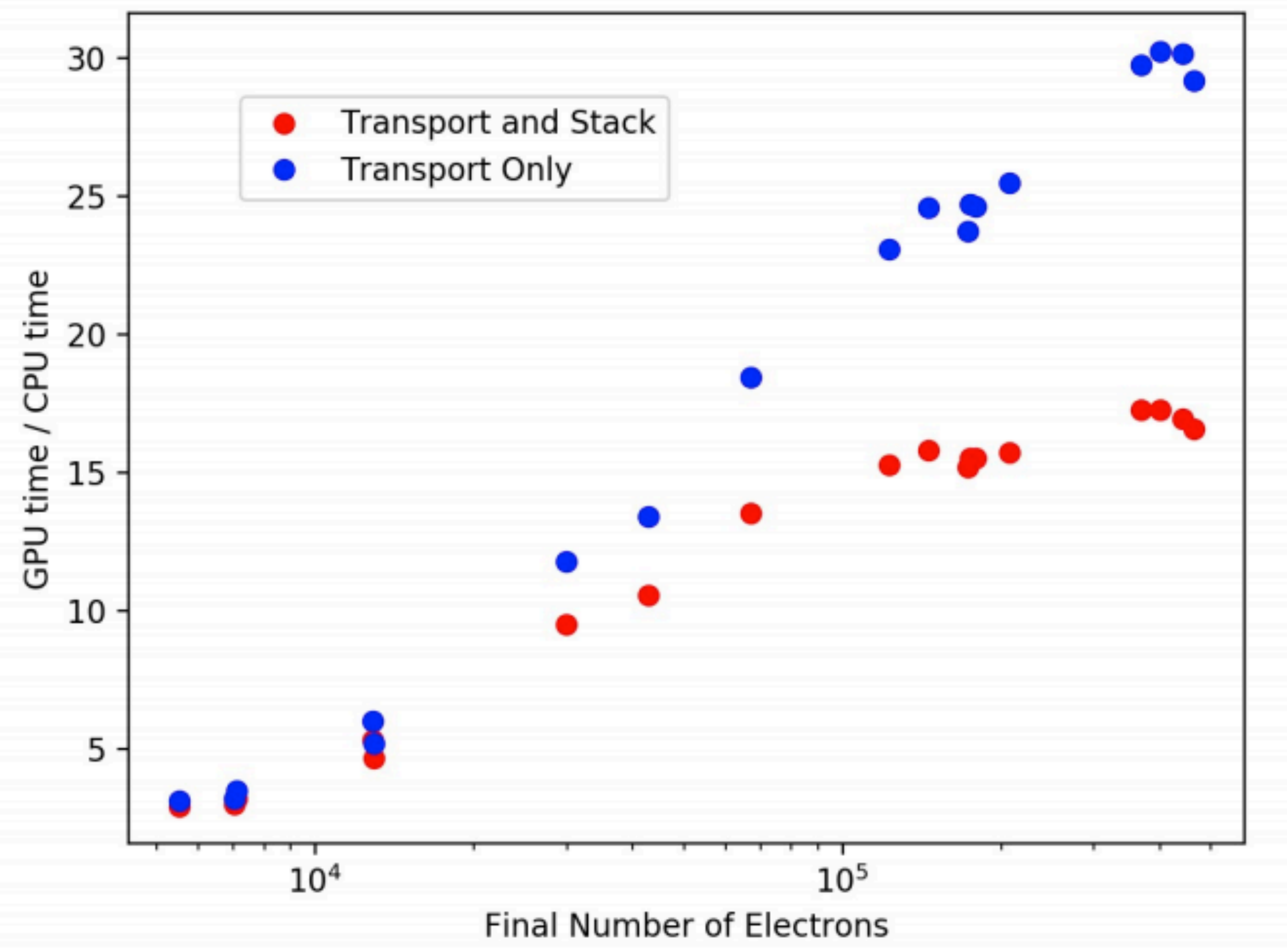
Performance

- Garfield++ has microscopic tracking for avalanche
  - Computationally expensive
- Parameterised avalanche process
- 1 ‘large’ ion after avalanche

- Example:
  - 5.3 MeV alpha particle in 1.1 bar $Ar:CH_4$

  → ~200k electrons → 20 minutes per α

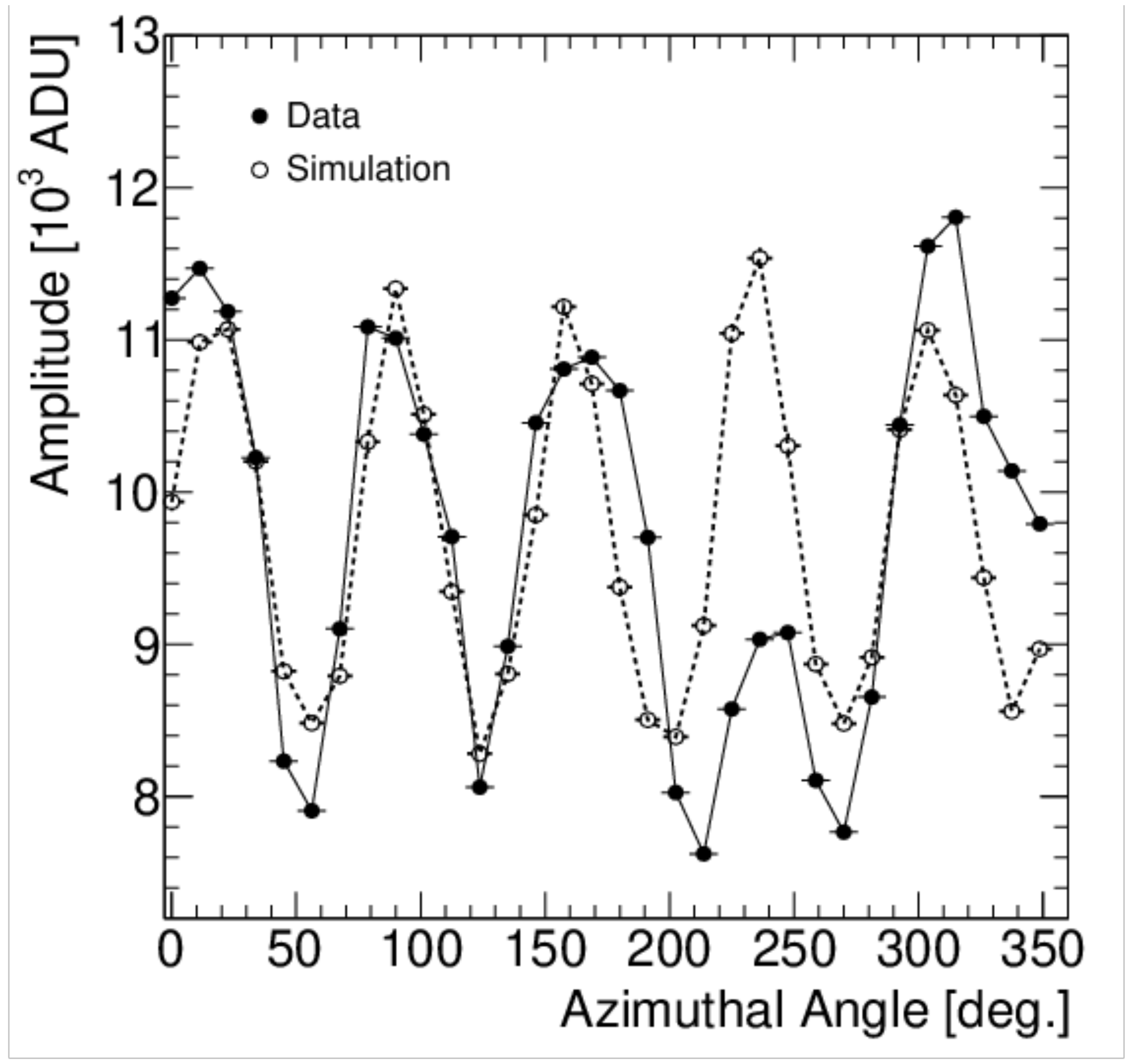
- Developed method to run electron transport/avalanche parts of Garfield++ on a GPU
  - Consistent physics results with standard CPU (up to compiler/architecture differences)
  - First result: ~20x average speed increase
  - Paves way for complete parallelisation of Garfield++



See RD51 Miniweek (18 Feb 2021) talk by M. Slater on this

Summary

- Spherical proportional counter has several physics application
  - See T. Neep's talk or I. Manthos' poster for examples
- A dedicated simulation framework developed, combining strengths of Geant4, Garfield++ and ANSYS
- Simulation from initial particle interactions in full detector to signal read-out
- Initial comparisons with data show good agreement
- Already used for detector R&D and understanding multiple experiments



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2020 JINST 15 C06013

A resistive ACHINOS multi-anode structure with DLC coating for spherical proportional counters

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Abstract: The spherical proportional counter is a gaseous detector used in a variety of applications, including direct dark matter and neutrino-less double beta decay searches. The ACHINOS multi-anode structure is a read-out technology that overcomes the limitations of single-anode read-out structures for large-size detectors and operation under high pressure. A resistive ACHINOS is presented, where the 3D printed central component is coated in a Diamond-Like Carbon (DLC) layer. The production and testing of the structure, in terms of stability and resolution, is described.

2020 JINST 15 P11023