



UNIVERSITY OF
BIRMINGHAM



Gas Property Studies for DarkSPHERE at Boulby Underground Laboratory

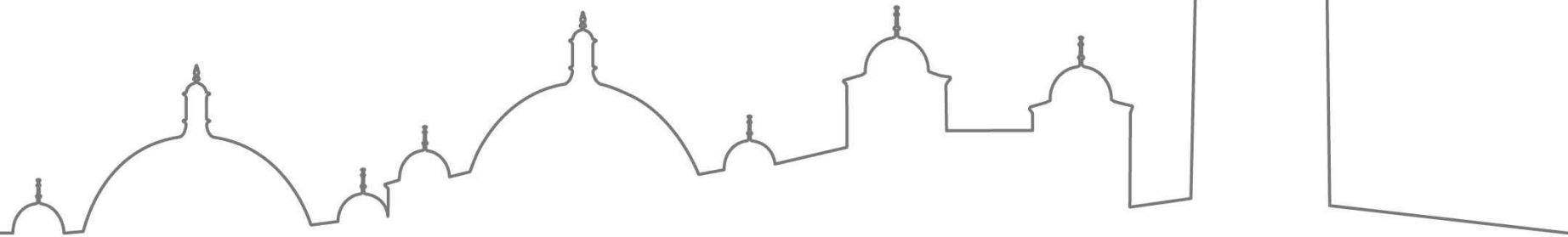
P. Knights, I. Manthos, L. Milligan, L. Millins, K. Nikolopoulos, G. Rogers, P. Walters

09/04/2026

IOP HEPP/APP Conference

John McIntyre Conference Centre, Edinburgh

pxw472@bham.ac.uk



Background

- DM constitutes $\sim 85\%$ of universe's matter [1]
- **Direct DM detection efforts** exploring **theoretically motivated** regions of parameter space [2,3]
- Fewer direct detection efforts for **sub-GeV** candidates
- **DarkSPHERE** aims to detect **sub-GeV DM** using **spherical proportional counters** (SPCs) [4]

See talks by Giovanni Rogers,
Lachlan Milligan

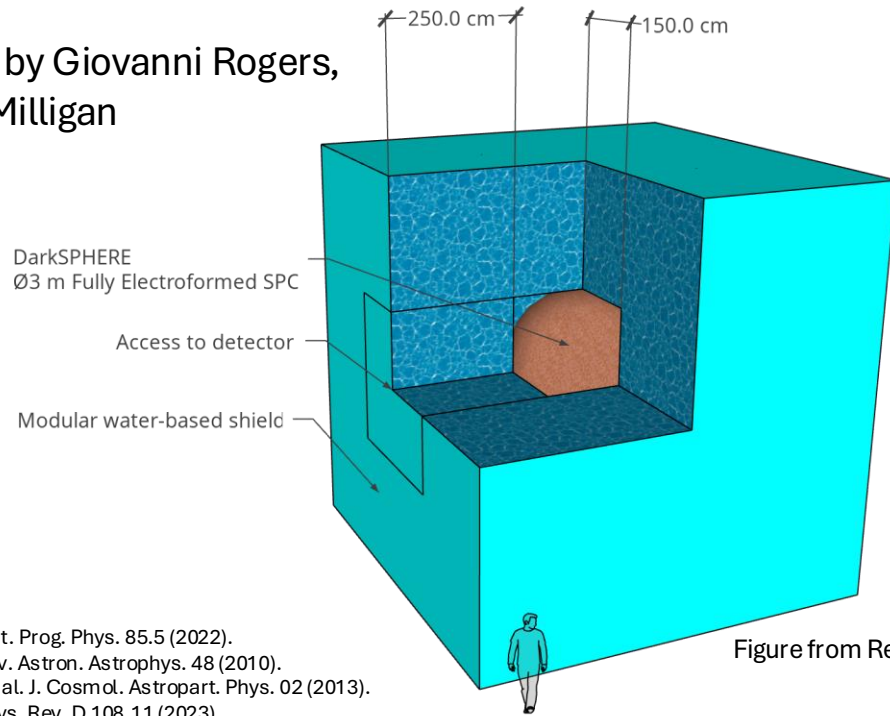
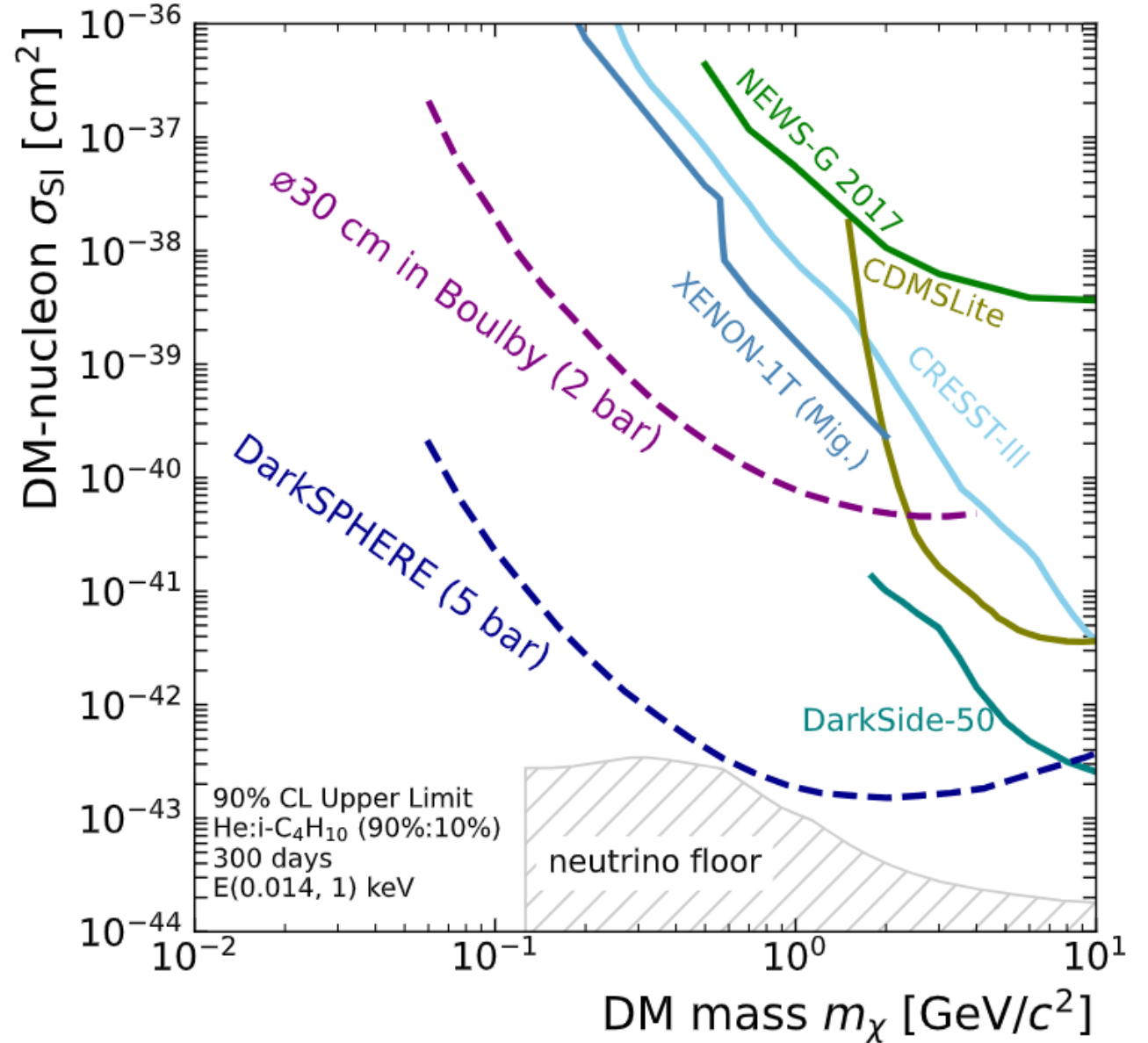


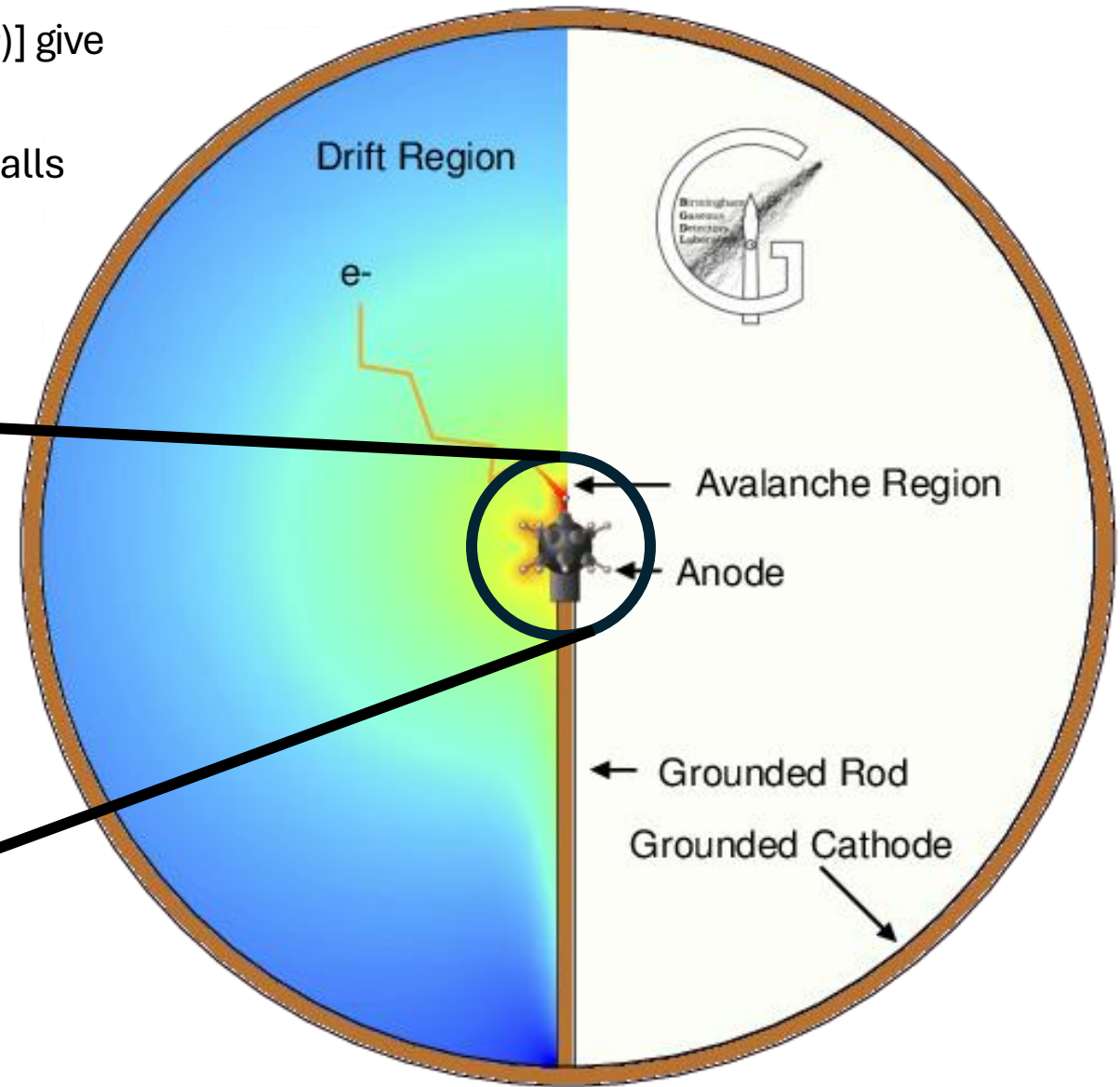
Figure from Ref. [4]



[1] J. Billard et al. Rept. Prog. Phys. 85.5 (2022).
 [2] J. L. Feng. Ann. Rev. Astron. Astrophys. 48 (2010).
 [3] A. L. Fitzpatrick et al. J. Cosmol. Astropart. Phys. 02 (2013).
 [4] L. Balogh et al. Phys. Rev. D 108.11 (2023).

Spherical Proportional Counter

- Energy Threshold: Low capacitance and high gas gain [$O(10^4)$] give sensitivity to **single electron ionisation events**.
- Low surface area to volume ratio: **lower background** from walls
- **ACHINOS** [5] readout sensor: **High field** at large radii
- **Position resolution**, used for **background rejection**
- **Flexible gases**: change target to **optimise search**



[5] I. Giomataris et al. J. Instrum. 15.11 (2020).

Gases

- Ne, He, Ar, and CH₄ gas mixtures used previously [6]
- **Different gases**, sensitivity to **different couplings and masses** of DM
- **Low mass nuclei** give **kinematic matching** to low-mass particle DM
- **Spin-dependent** interactions: ³He or ¹³C doped hydrocarbons
- **DM-electron interactions** can be constrained using Ne and i-C₄H₁₀ [7]
- DarkSPHERE gas must be characterised, **monitor gas quality**

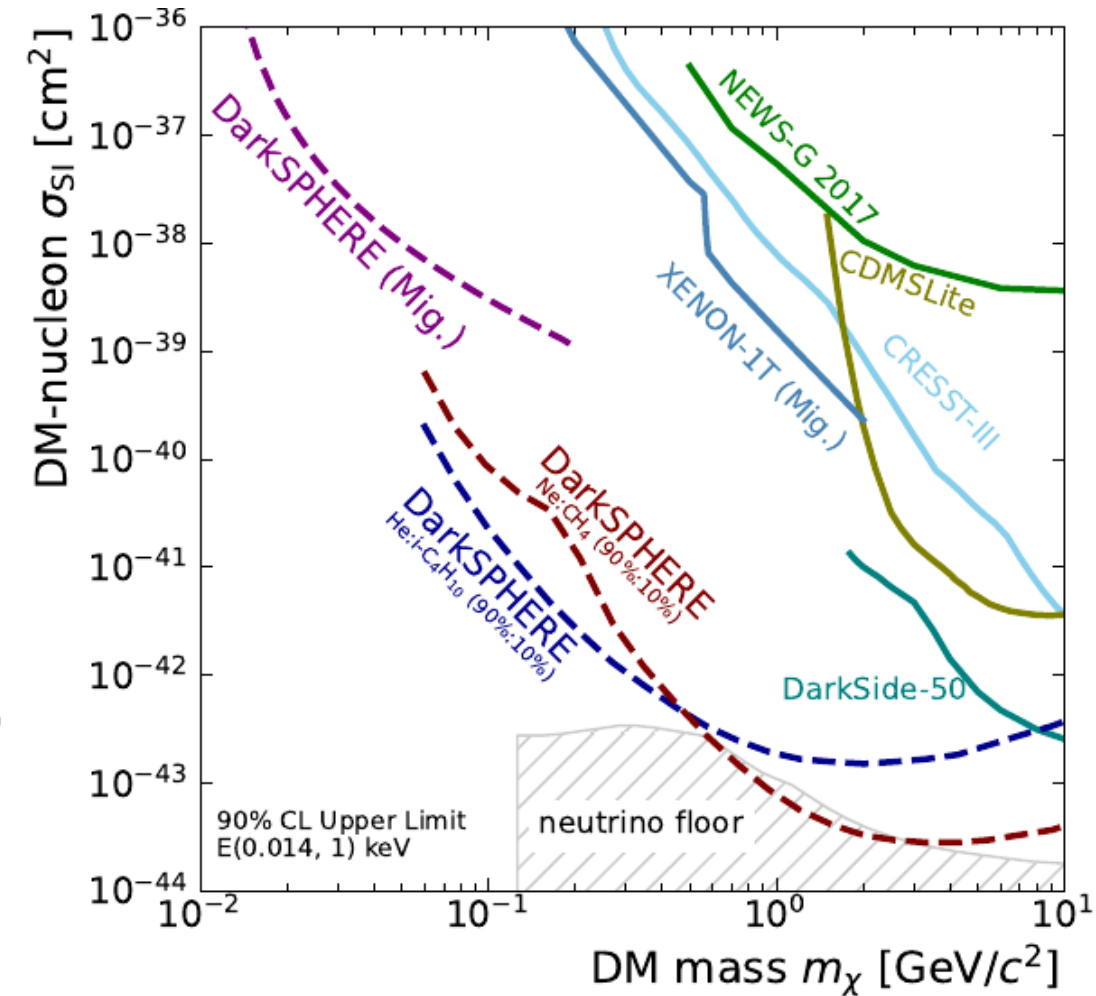
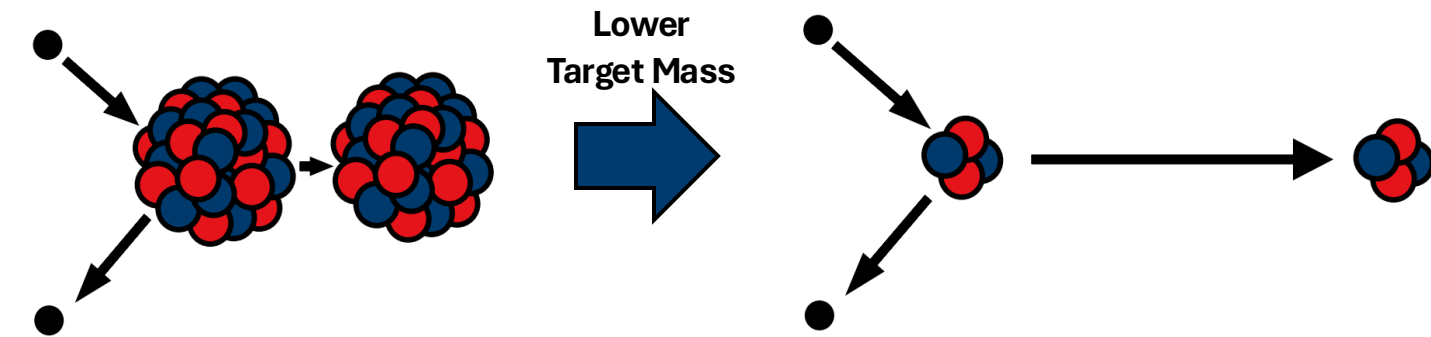


Figure from Ref. [8]

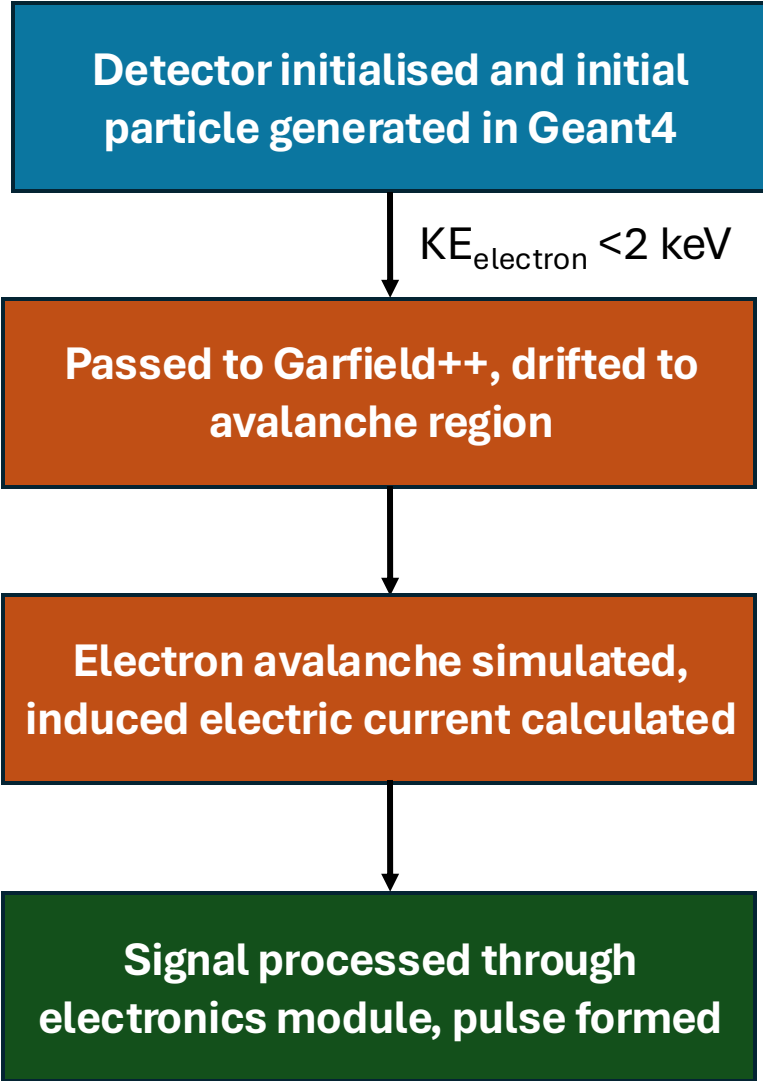
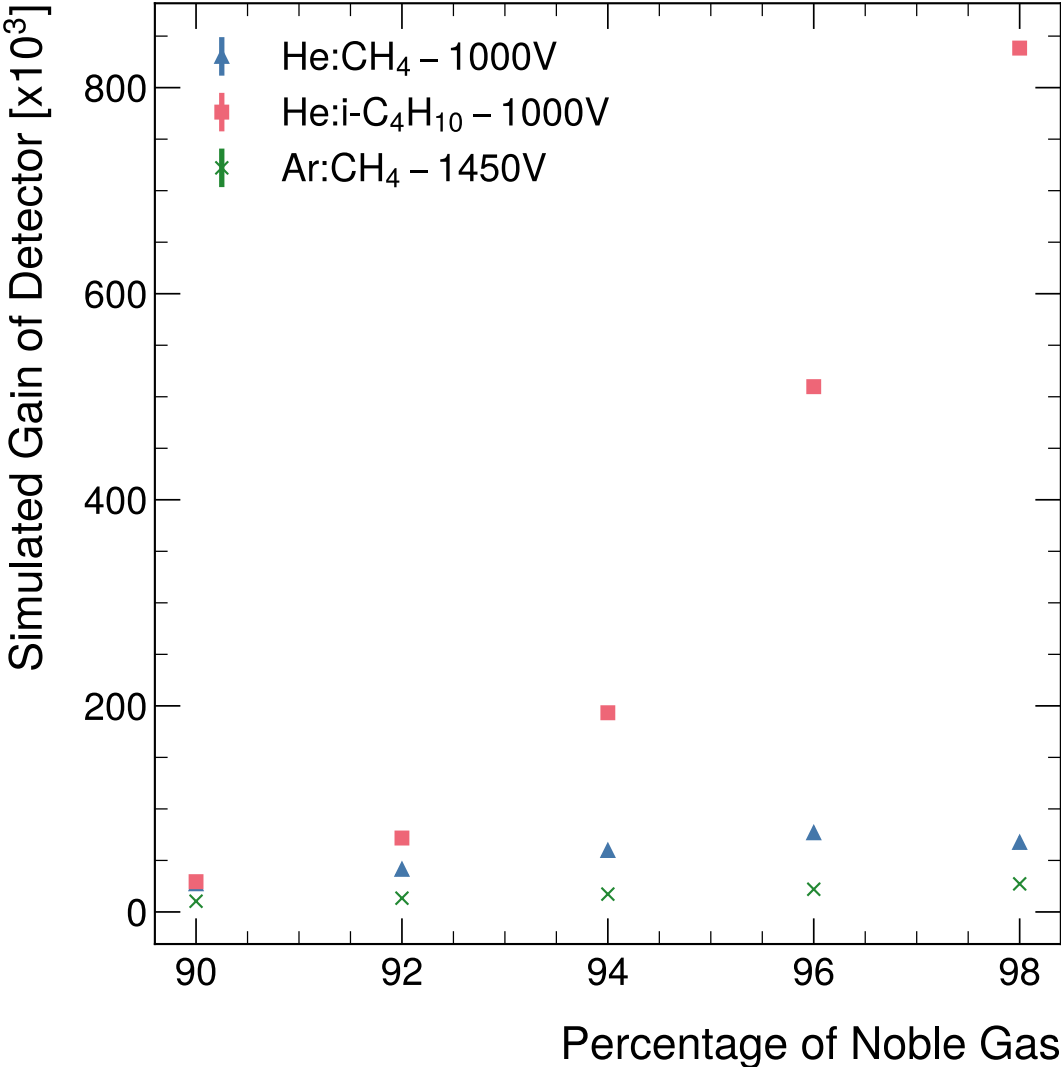
[6] M. M. Arora et al. Phys. Rev. Lett. 134.14 (2025).

[7] L. Hamaide and C. McCabe. Phys Rev D 107.6. (2023)

[8] D. Spathara et al. Commun. Phys. 8.1 (2025)

Simulation

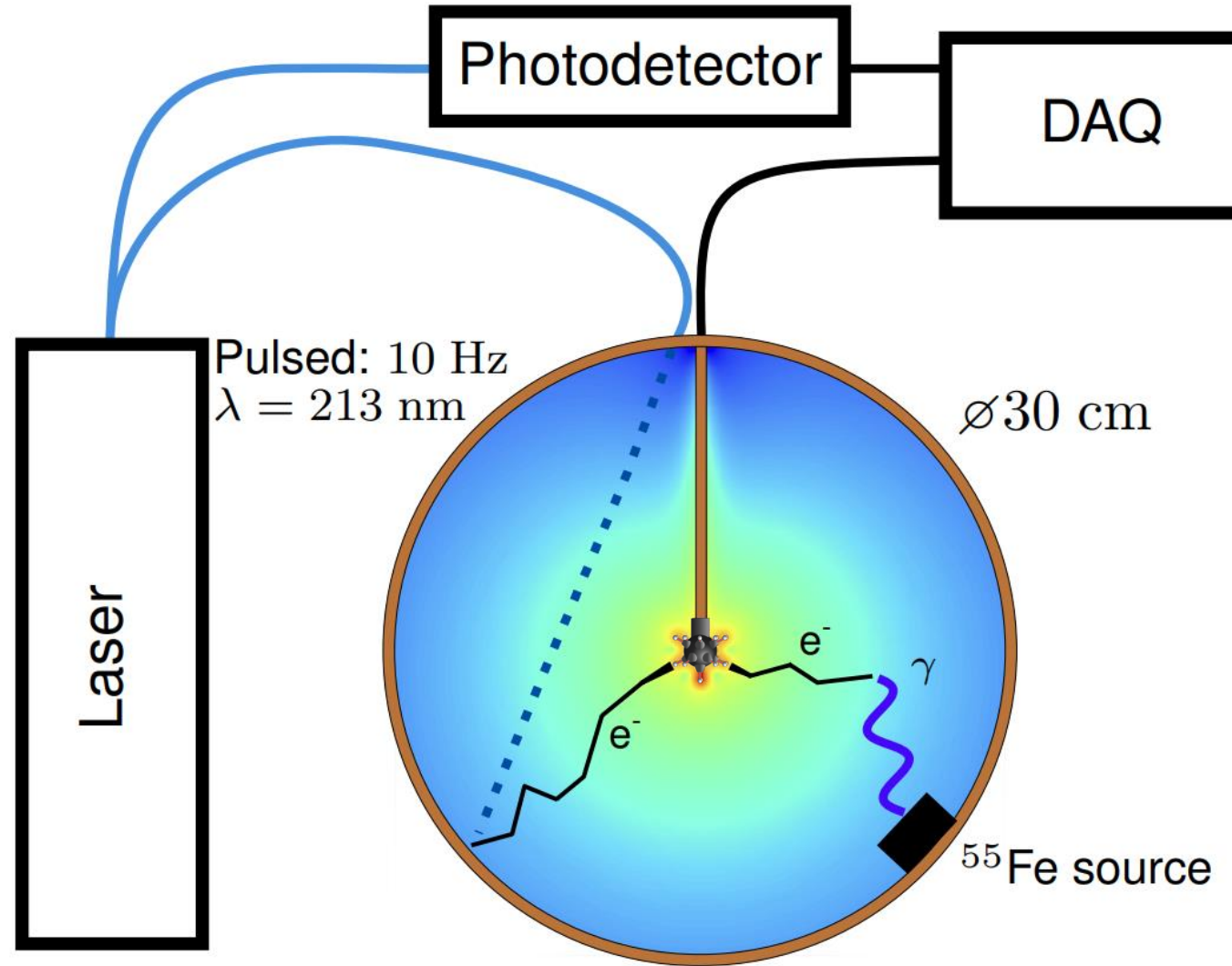
- Simulation [9] combining **GEANT4**, **Garfield++** field from **Elmer** and gas properties from **MAGBOLTZ**



[9] I. Katsioulas et al. J. Instrum. 15.06 (2020).

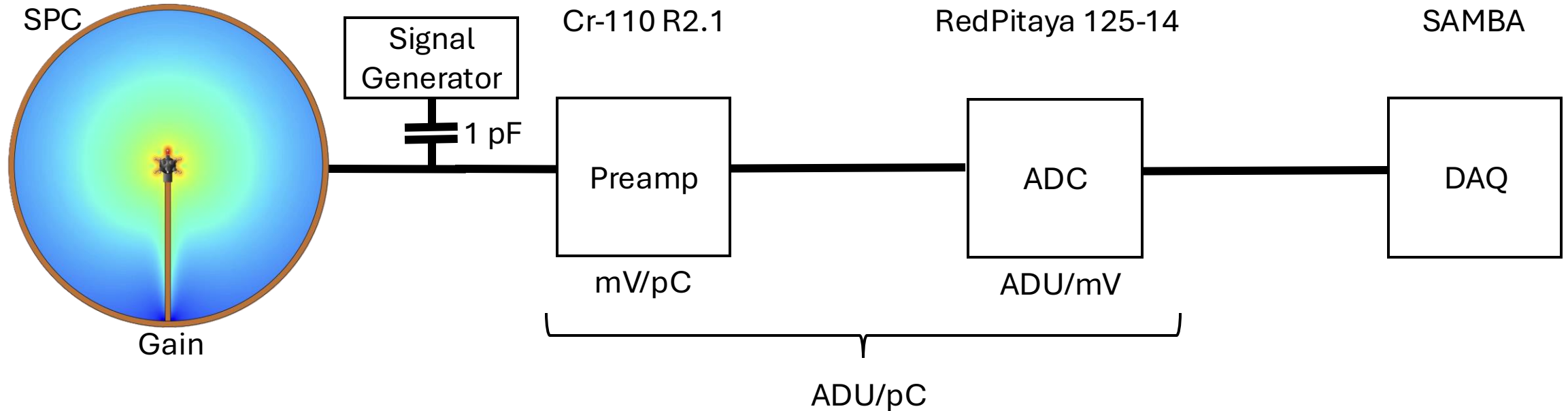
Experimental Method

- Gas properties can be measured from signal analysis
- **Drift time** measured using **UV Laser setup**
- **Gain** measured using **radioactive source**
- Laser tuned to give **single-electron ionisation events**
- Use for **in-situ monitoring** of detector

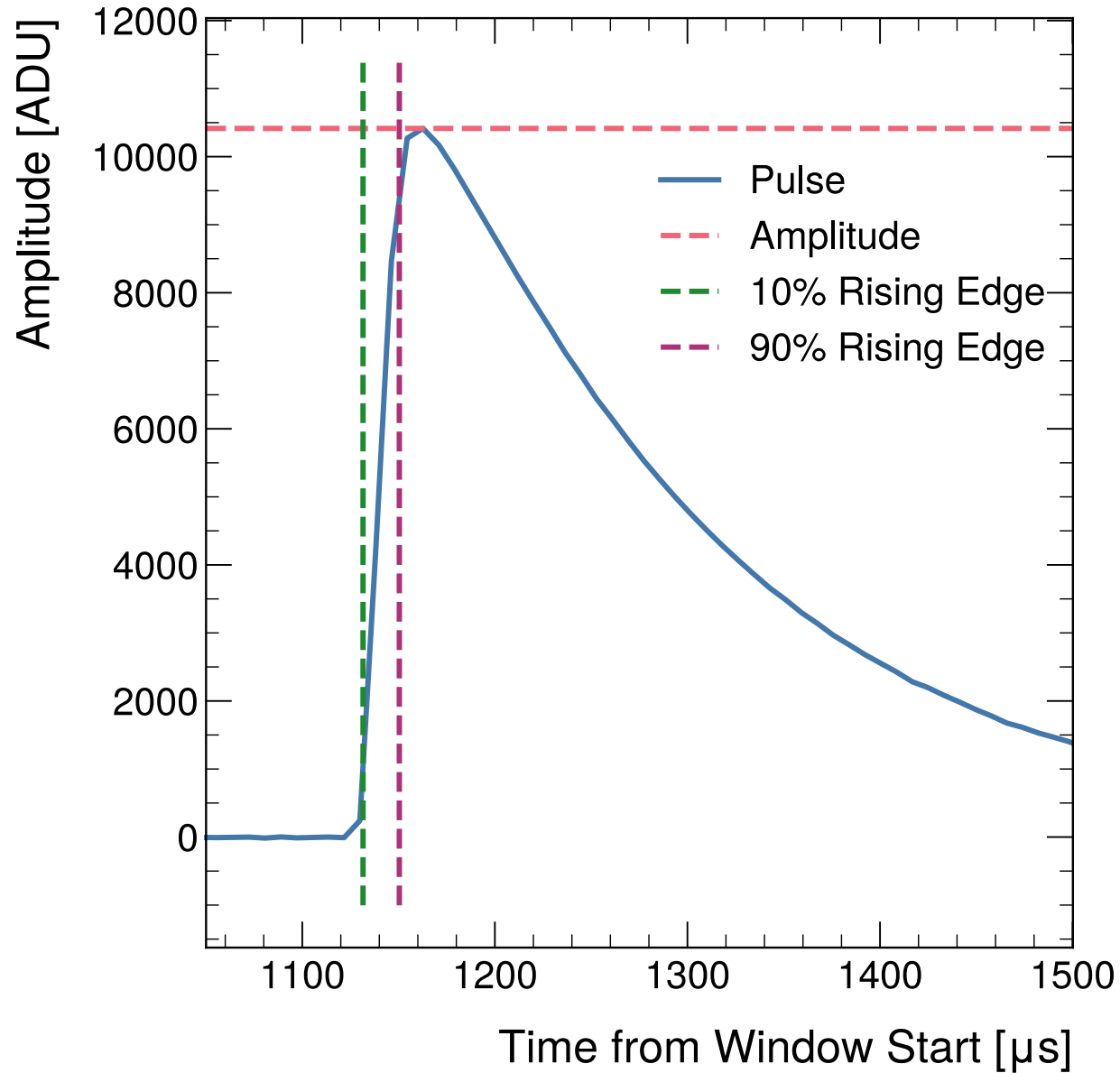


Experimental Method

- To characterise **gain**, each step of **signal generation must be fully understood**
- Current induced on anode passed through **charge-sensitive preamplifier board**
- Voltage signal passed into **digitiser**
- Output passed into **DAQ**
- **Electronics chain calibrated** by passing **known pulse** from signal generator across **1 pF capacitor** to preamplifier board



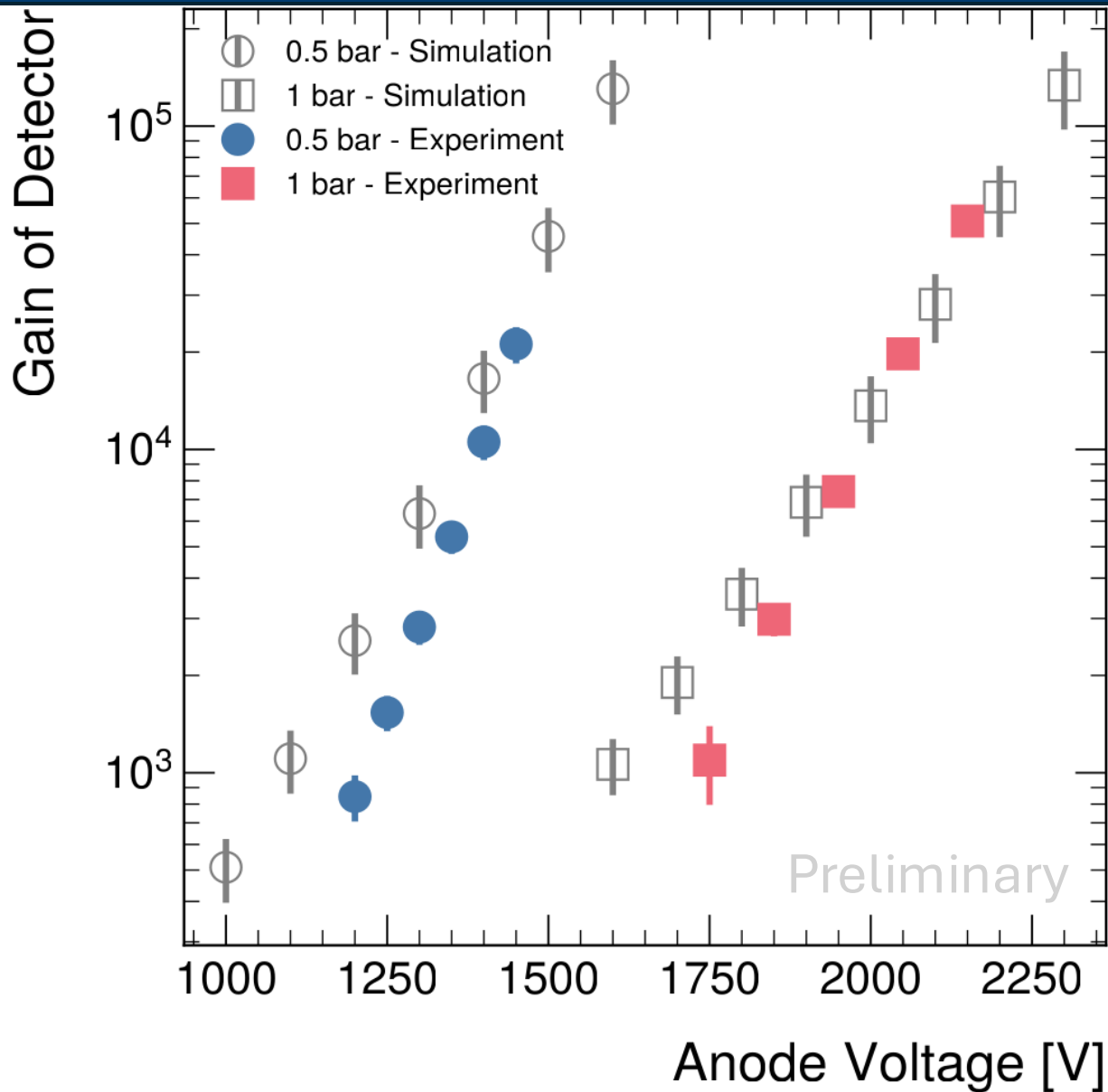
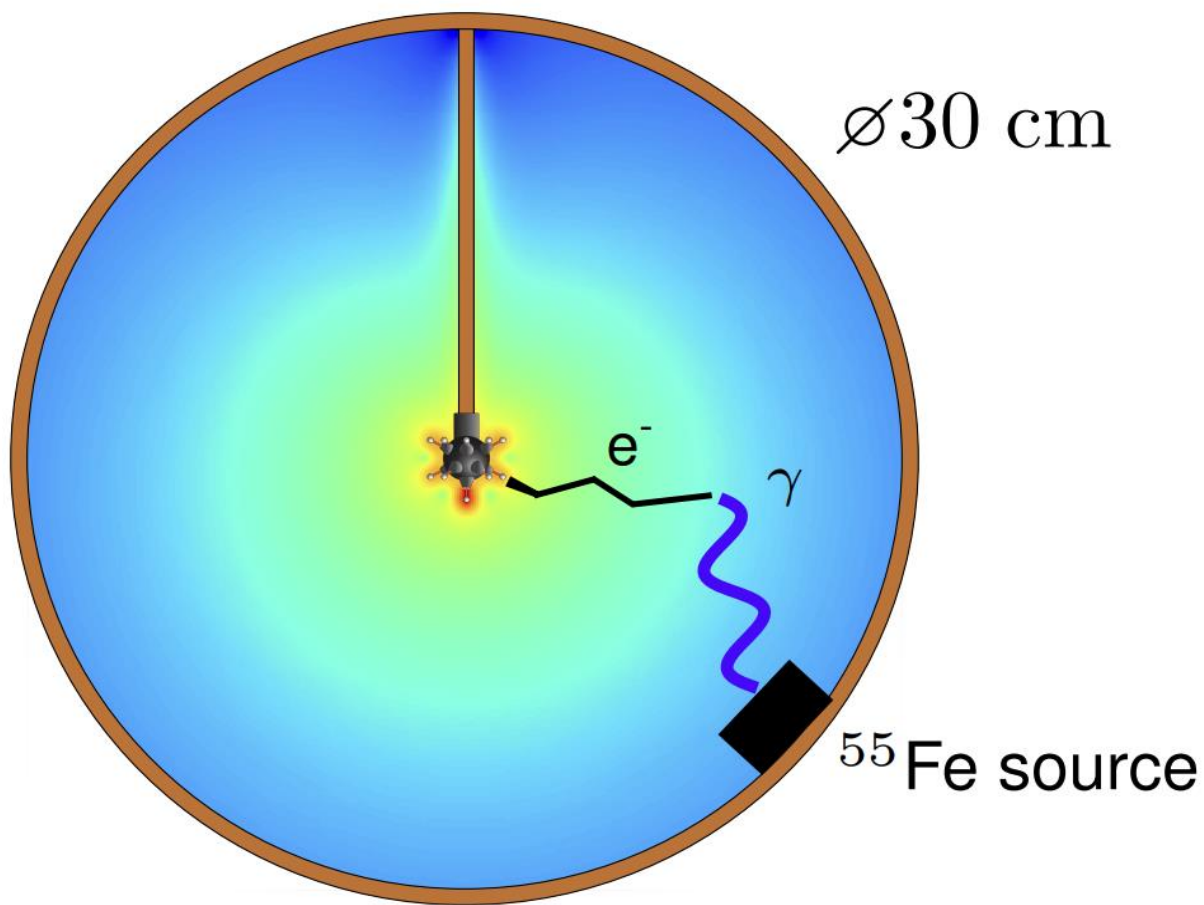
Pulse Analysis



- Example pulse from DAQ
- **Baseline subtracted** and **Amplitude** calculated
- **Rising edge** defined as time pulse surpasses **10% of amplitude** (**interpolated** between samples)

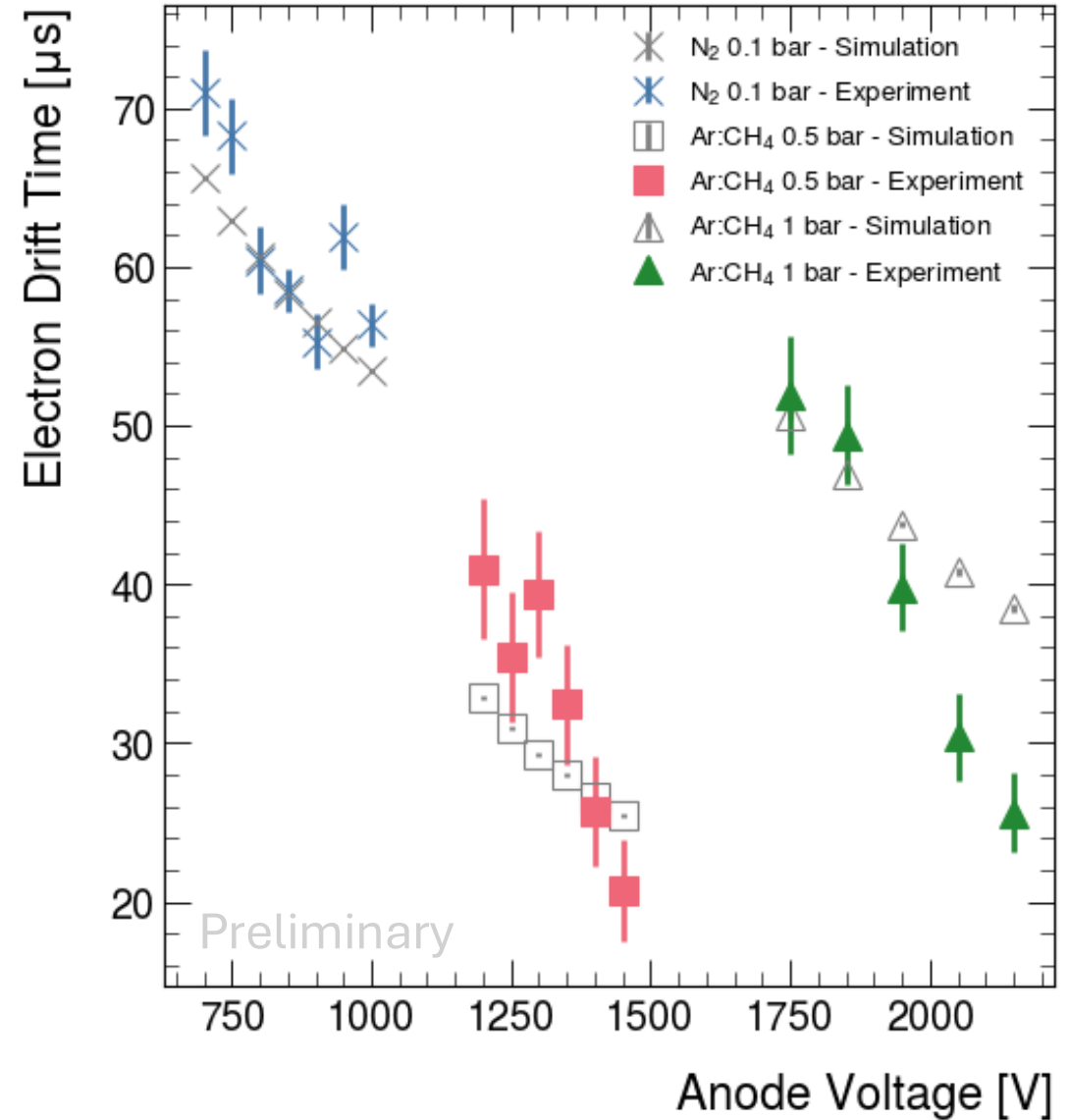
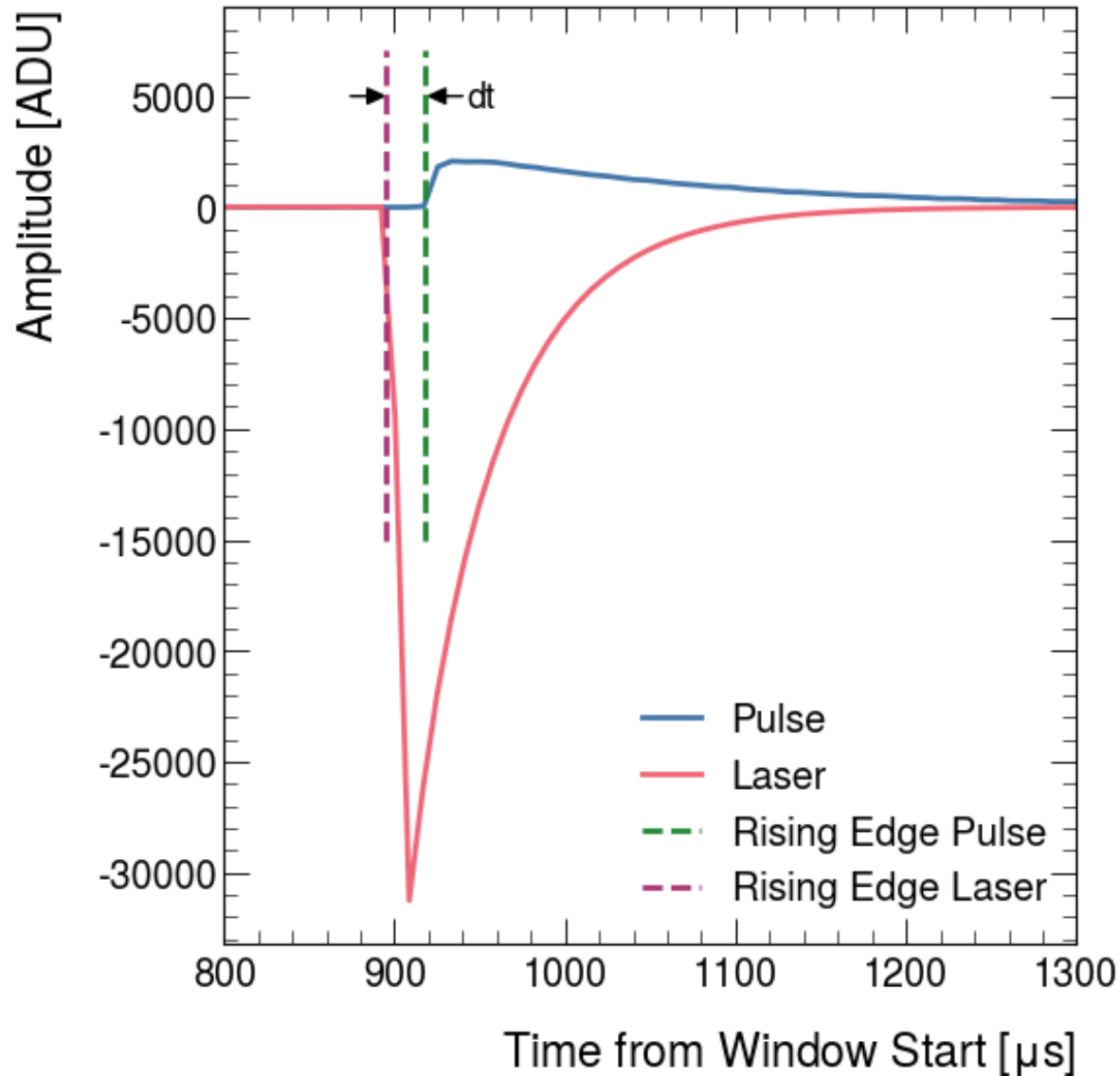
Results - Gain

- Measured in Ar:CH₄ (98%:2%) at 500 mbar and 1 bar as a function of anode voltage

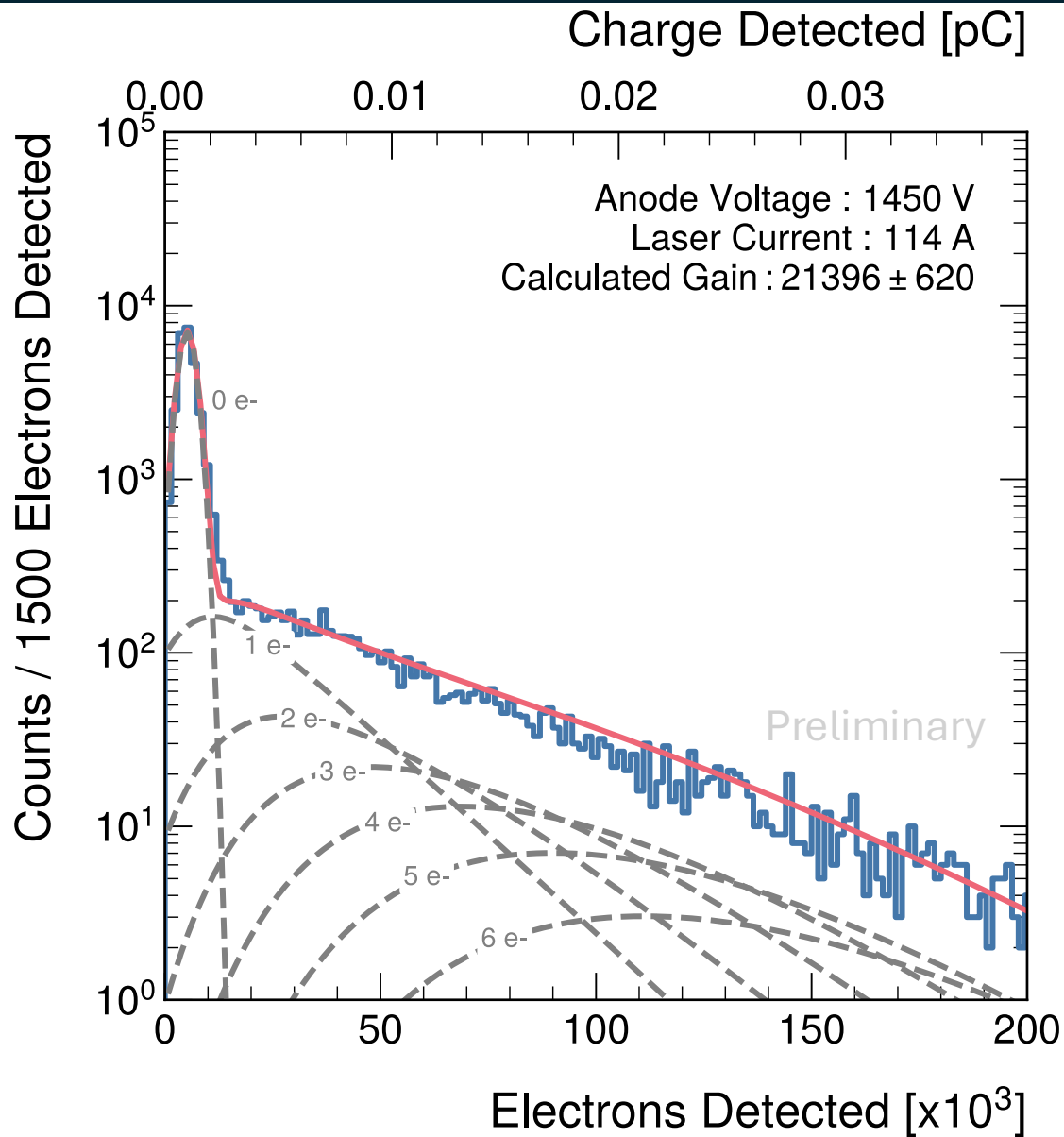


Results - Drift Time

- Electron drift time measured as a function of anode voltage

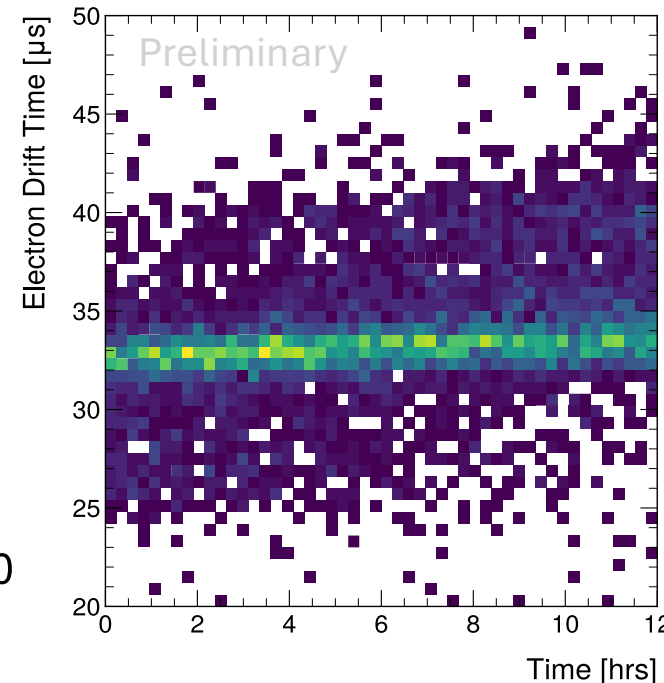


Results - Single Electron Monitoring



- Laser power tuned to **reduce occupancy** of pulse
- **Fewer photoionisation events**
- **Statistical fluctuation** cause different number of photoelectrons – **Polya Distribution, Poisson Statistics**
- Fit with a **convolution of Polya distributions** to show **single electron readout capability**

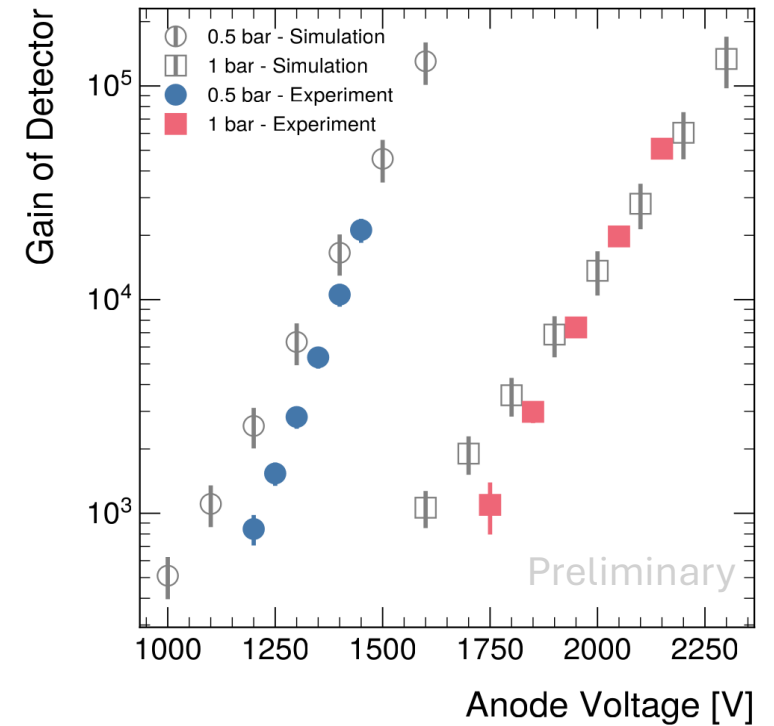
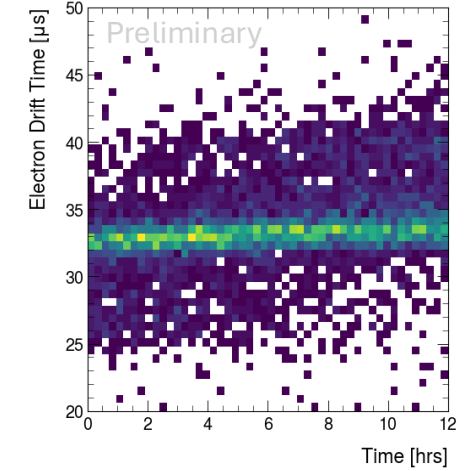
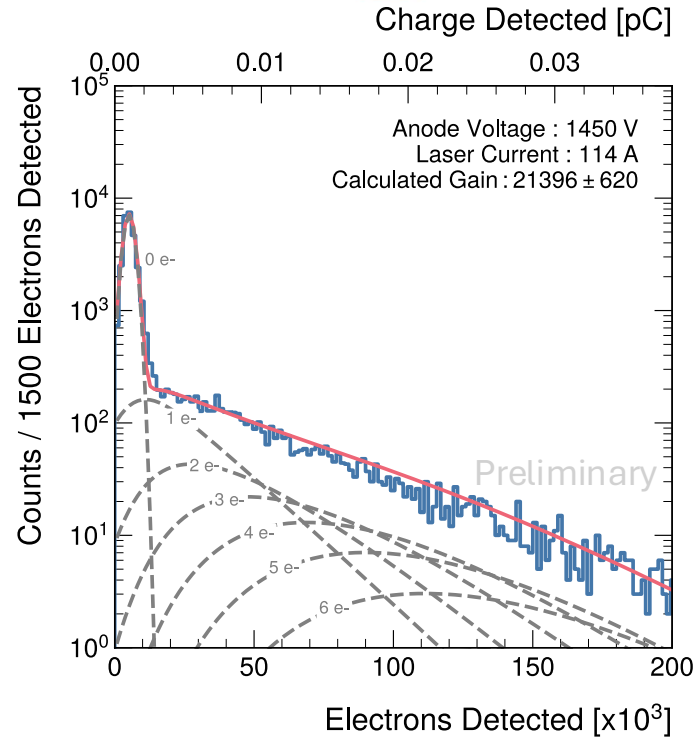
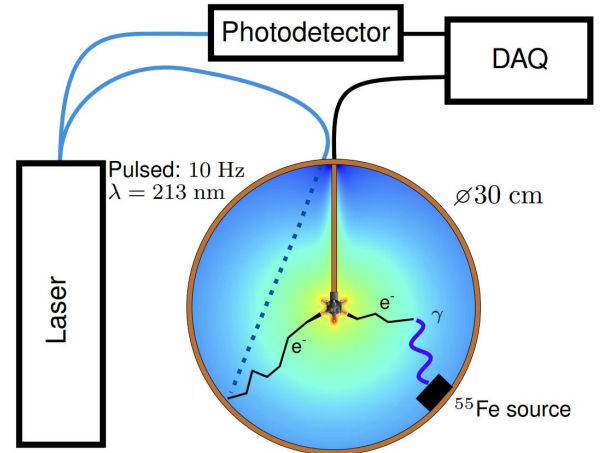
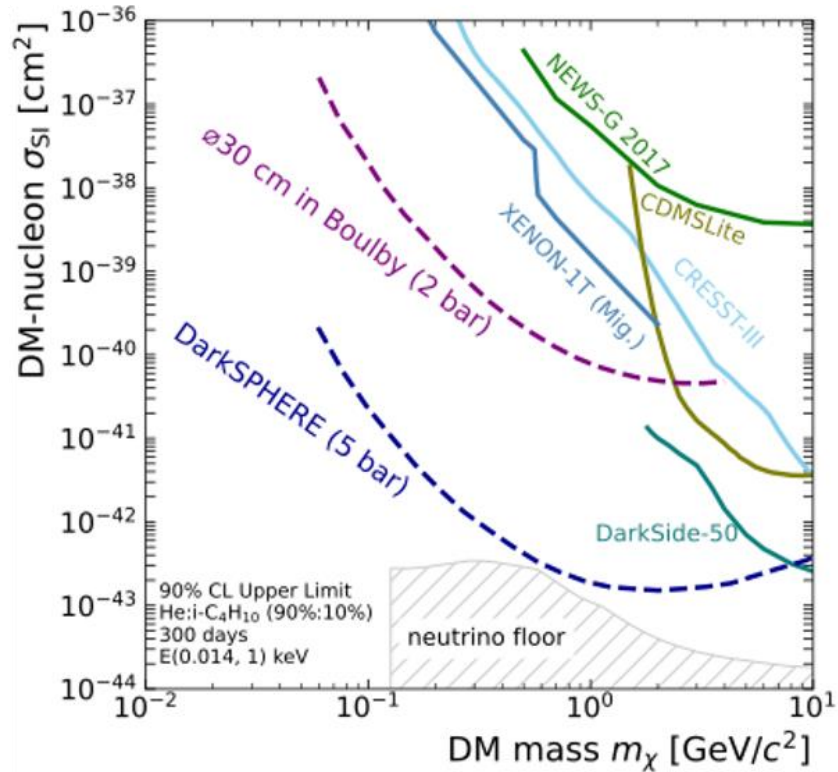
$$P(N) = A_{Gauss} \times P_{Gauss} + A_{Polya} \left(\sum_{n=1}^6 (P_{Polya} \otimes P_{Gauss}) \times P_{Poisson} \right)$$



- Electron **drift time monitored** continuously over **12 hours**

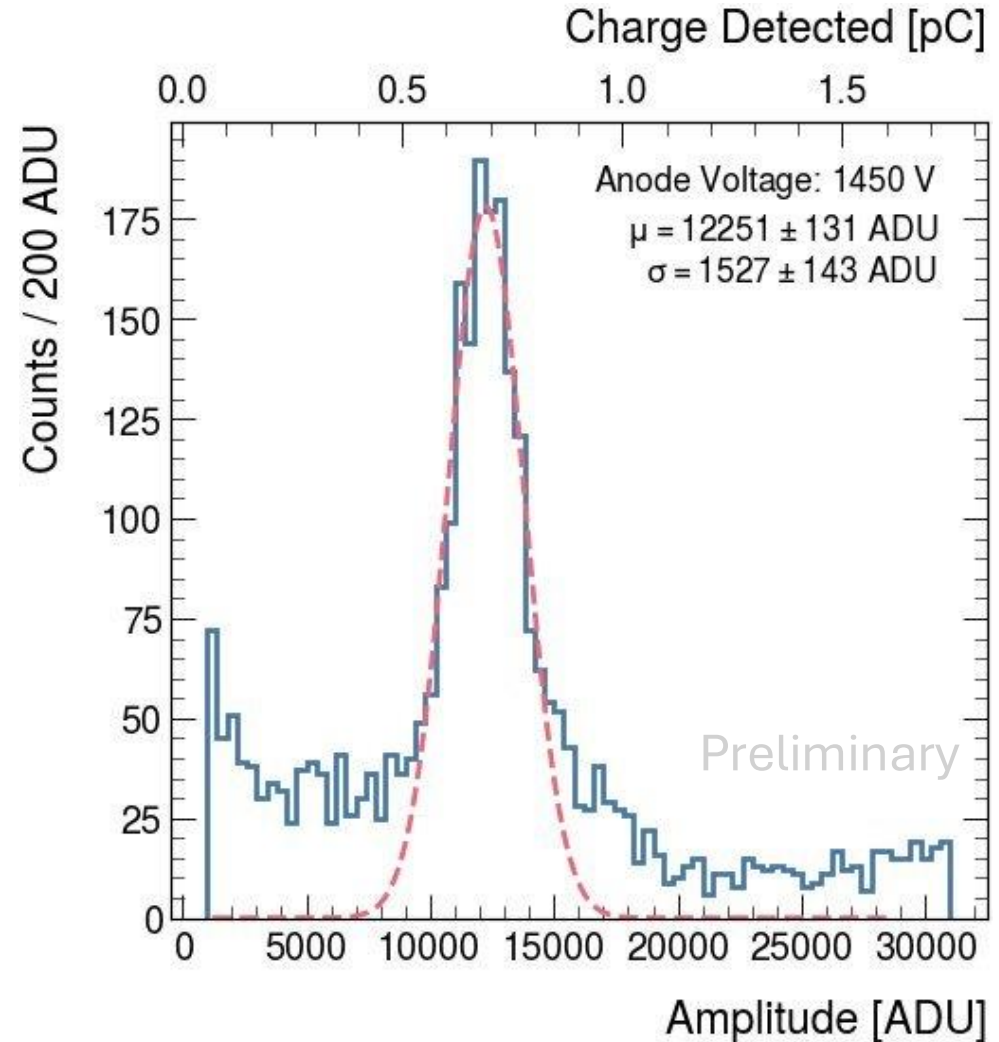
Conclusion

- **Gas properties** of interest to **DarkSPHERE**
- Studied using **SPC with UV laser setup**
- **In-situ measurements of gas purity**
- Verified **single electron readout ability**
- Next steps to test using **other gas mixtures**



Fe55 Amplitude Distribution

- Fit with a Gaussian
- Events selected with positive signal in only chosen anode, preventing events where charge distributed



Fitting Function

$$P(n) = \underbrace{A_G \times P_G(\mu_G, \sigma_G)}_1 + \overbrace{A_P}^6 \left(\underbrace{\sum}_{5} \left(\underbrace{P_{Polya}(n, M, \theta|N)}_2 \right) \underbrace{\otimes P_G(\mu_G, \sigma_G)}_3 \right) \times \underbrace{P_{Poisson}(N|\mu_P)}_4$$

1. Gaussian corresponding to events with 0 electrons emitted (noise)
2. Polya distribution of electrons detected given N electrons deposited in gas
3. Convolution with a gaussian to implement noise
4. Poisson distribution used to scale relative probabilities of seeing N electrons when μ_p expected (free parameter)
5. Sum from 1 to 6 initial electrons
6. Scaling factor for relative height of Polya distributions to Gaussian

Laser

- Model: Q1-B10-1064, H1-FiH-AT5-FC5-APU2
- Tunable parameters:
- Harmonic Temperatures (Second, Fourth, Fifth)
- Attenuator positions
- Transmission (0.5%-100%)
- Current (80 A-160 A)
- Pulse repetition rate (-10Hz)

