Measuring Alpha Scintillation Quenching Factors in Argon Using the Argon-1 Detector

Michael Perry, PhD Candidate
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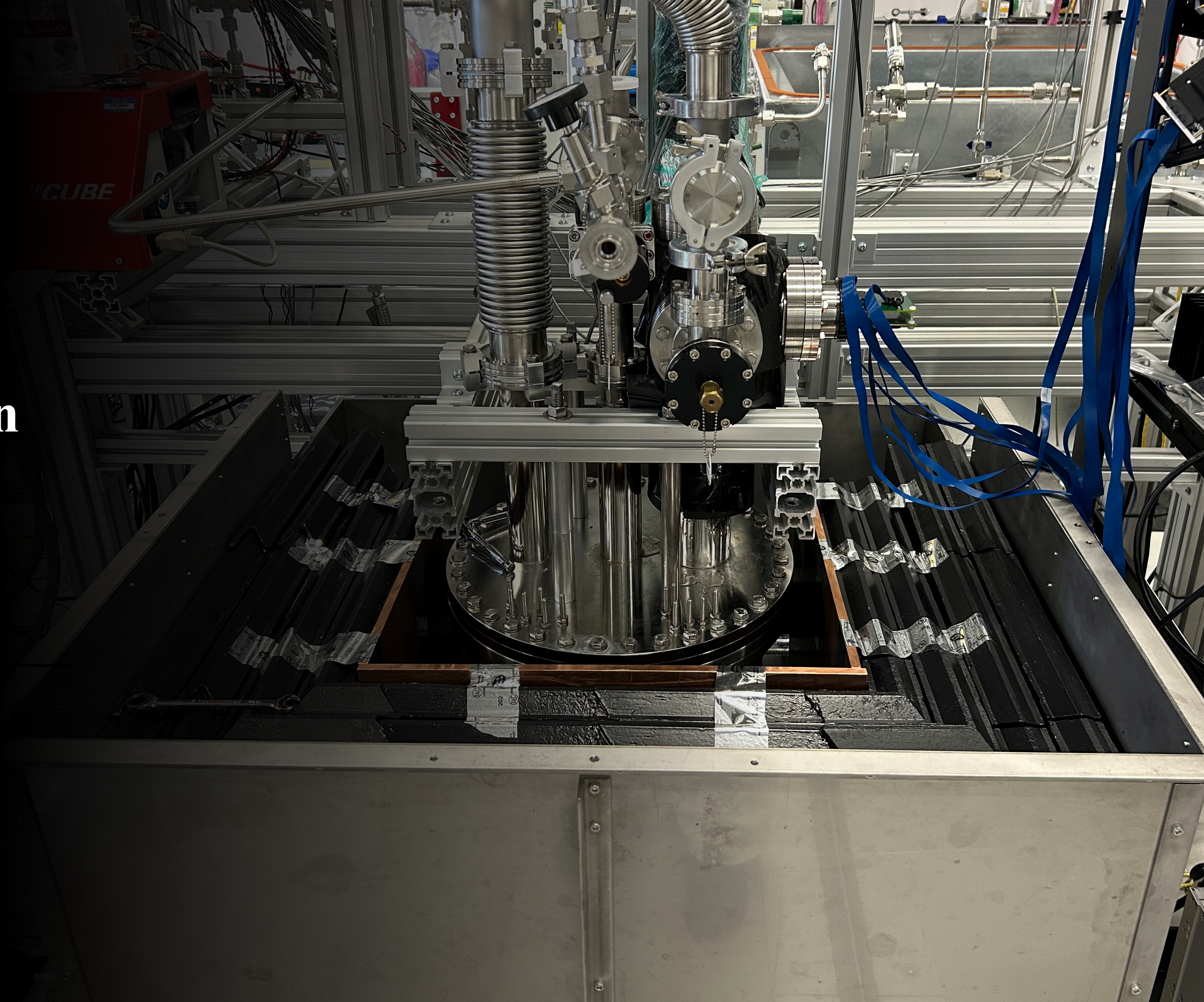
Carleton University
DEAP-3600 Collaboration
Supervisor: Mark Boulay

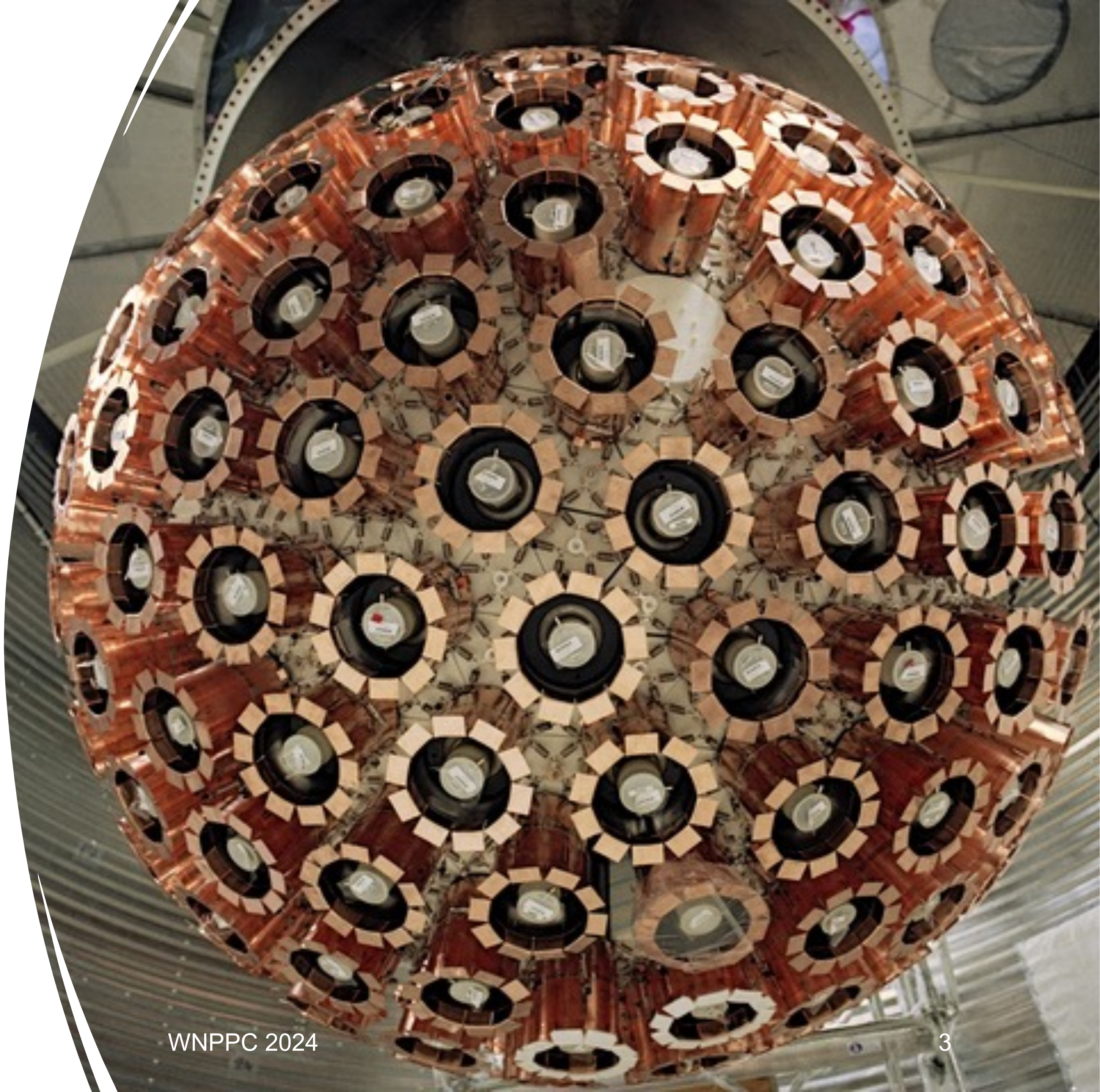


Overview

- Part I – Motivation
  - What is scintillation quenching and what are quenching factors?
  - DEAP-3600 & why we want to understand quenching
- Part II – The Measurement
  - Alpha Sources
  - Data Required
  - Analysis
  - Results
- Conclusions

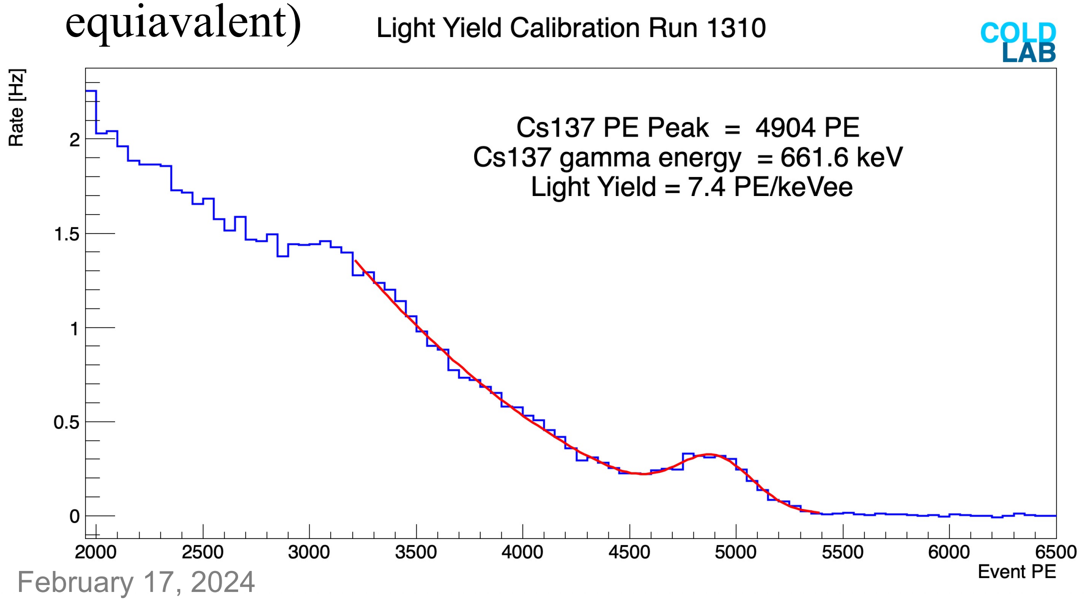
Part I

- What is scintillation quenching and what are quenching factors?
- DEAP-3600 & why we want to understand quenching



Scintillation quenching

- Scintillation counters estimate energy of physics events based on how much light (PE) is observed by photodetectors
- In liquid argon, beta and gamma radiation (**ER**s) produce a **linear energy response** quantified by the light yield (Y) of the detector, in units PE/keVee (keV electron equiavalent)



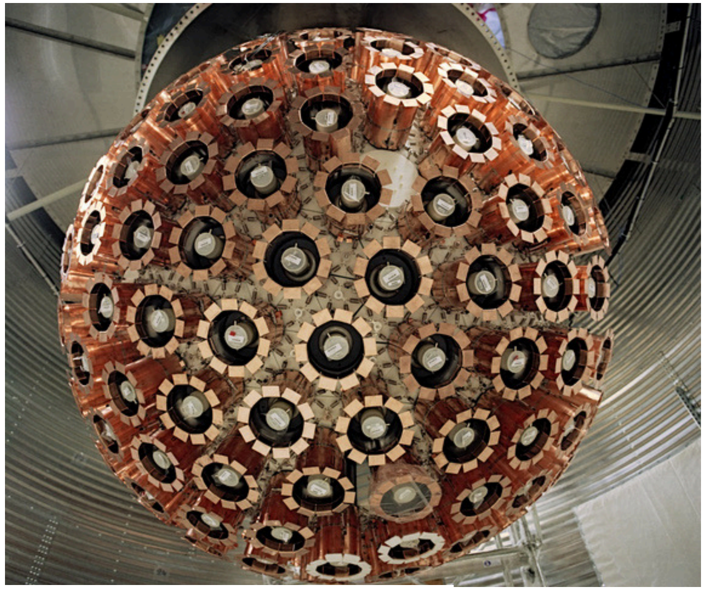
- For alpha and neutron radiation (**NR**s), the energy available for scintillation may be lost to other mechanisms – **scintillation quenching**
- E.g. a 1 MeV gamma event will **produce more light** than a 1 MeV alpha event
- **Quenching factors** quantify the amount of light lost to these mechanisms, and are in **general energy dependent**

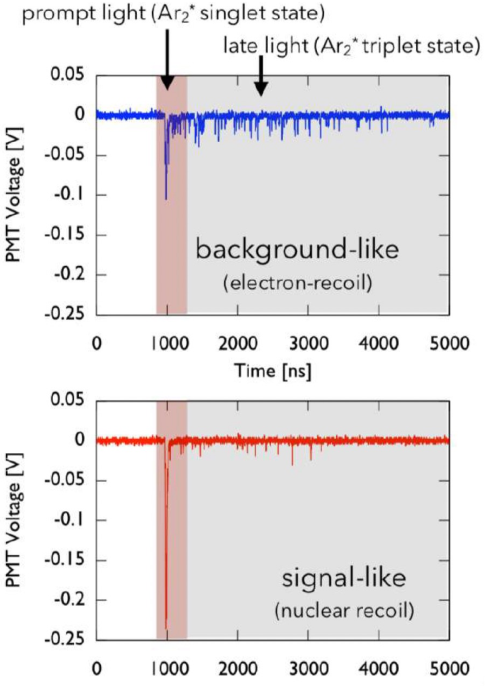
$$QF = \frac{E_{measured}}{E_{dep}}$$

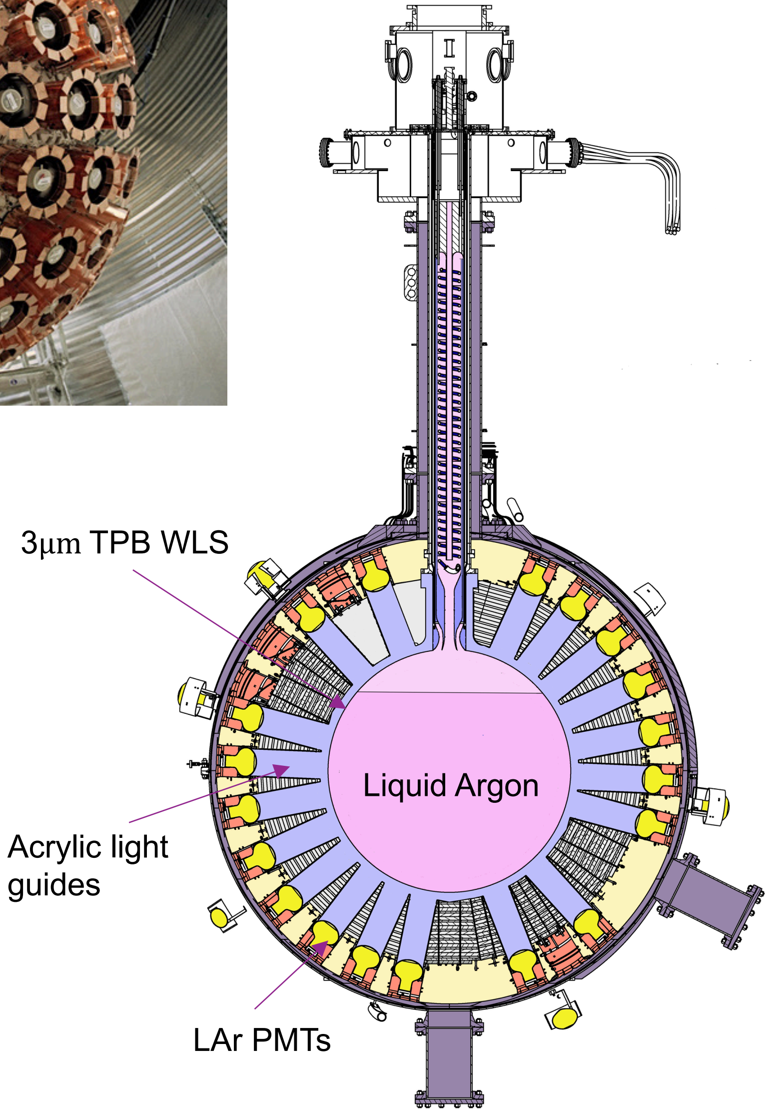
ERs: QF = 1

DEAP-3600

- **D**ark matter **E**xperiment using **A**rgon **P**ulseshape discrimination
- Direct detection experiment at SNOLAB looking primarily for WIMP dark matter (DM)
- Largest liquid argon (LAr) DM detector in the world [Phys. Rev. D 100, 022004](#)
- Excellent ER background rejection by employing pulseshape discrimination (PSD) [Eur. Phys. J. C (2021) 81:823](#)
- **Understanding backgrounds is critical in rare event searches**

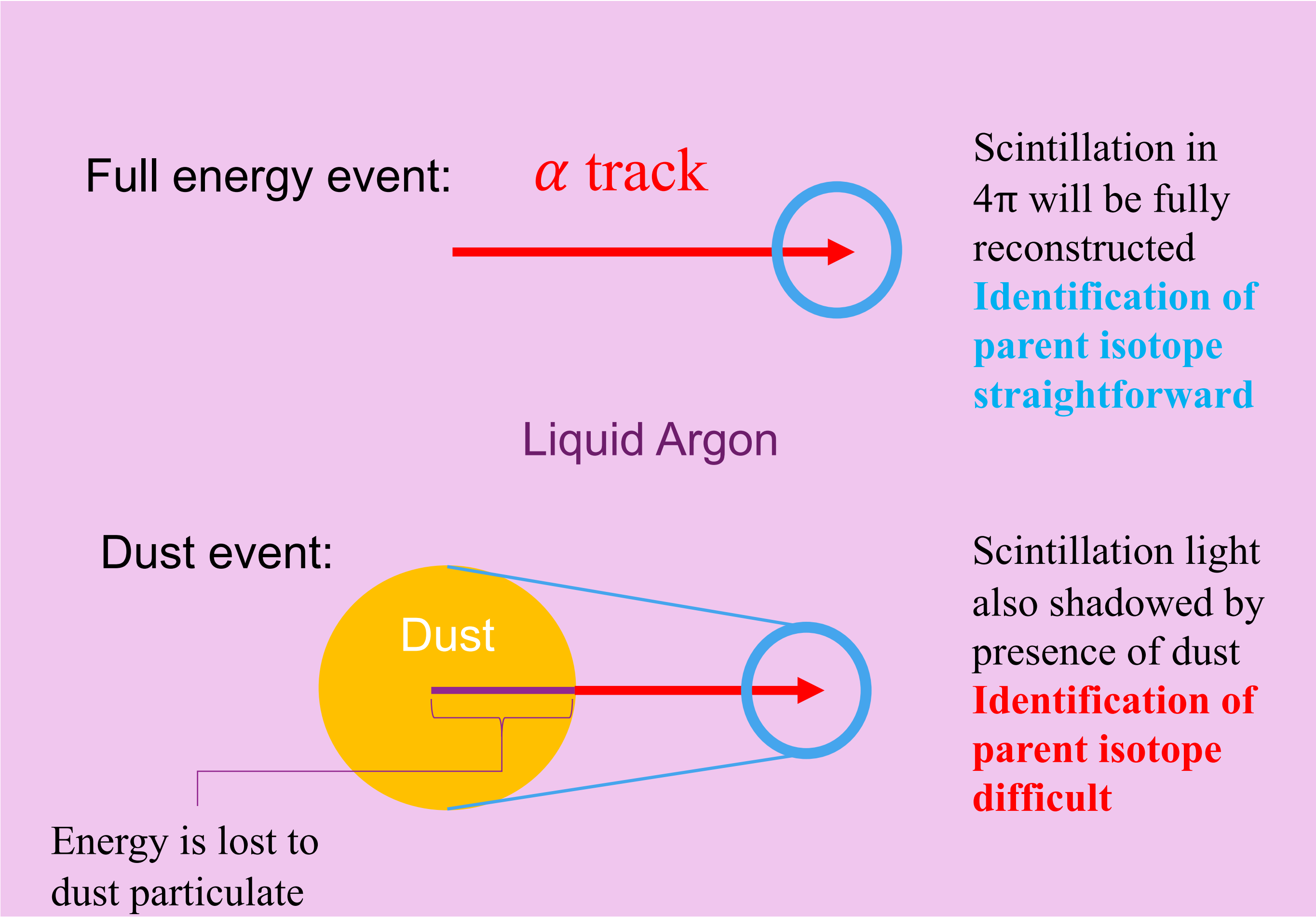


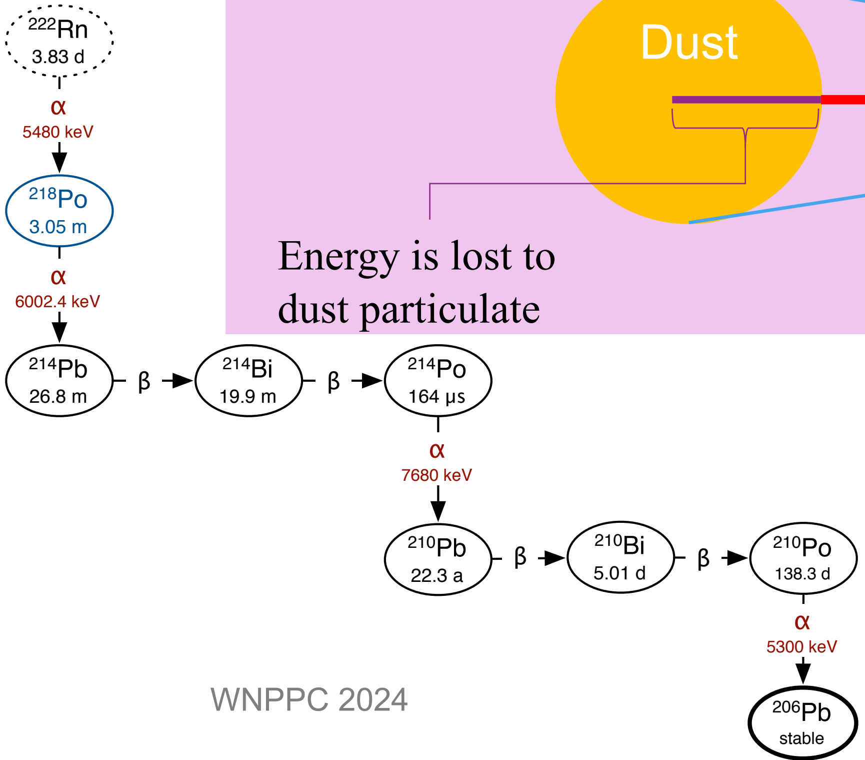




Dust Alphas

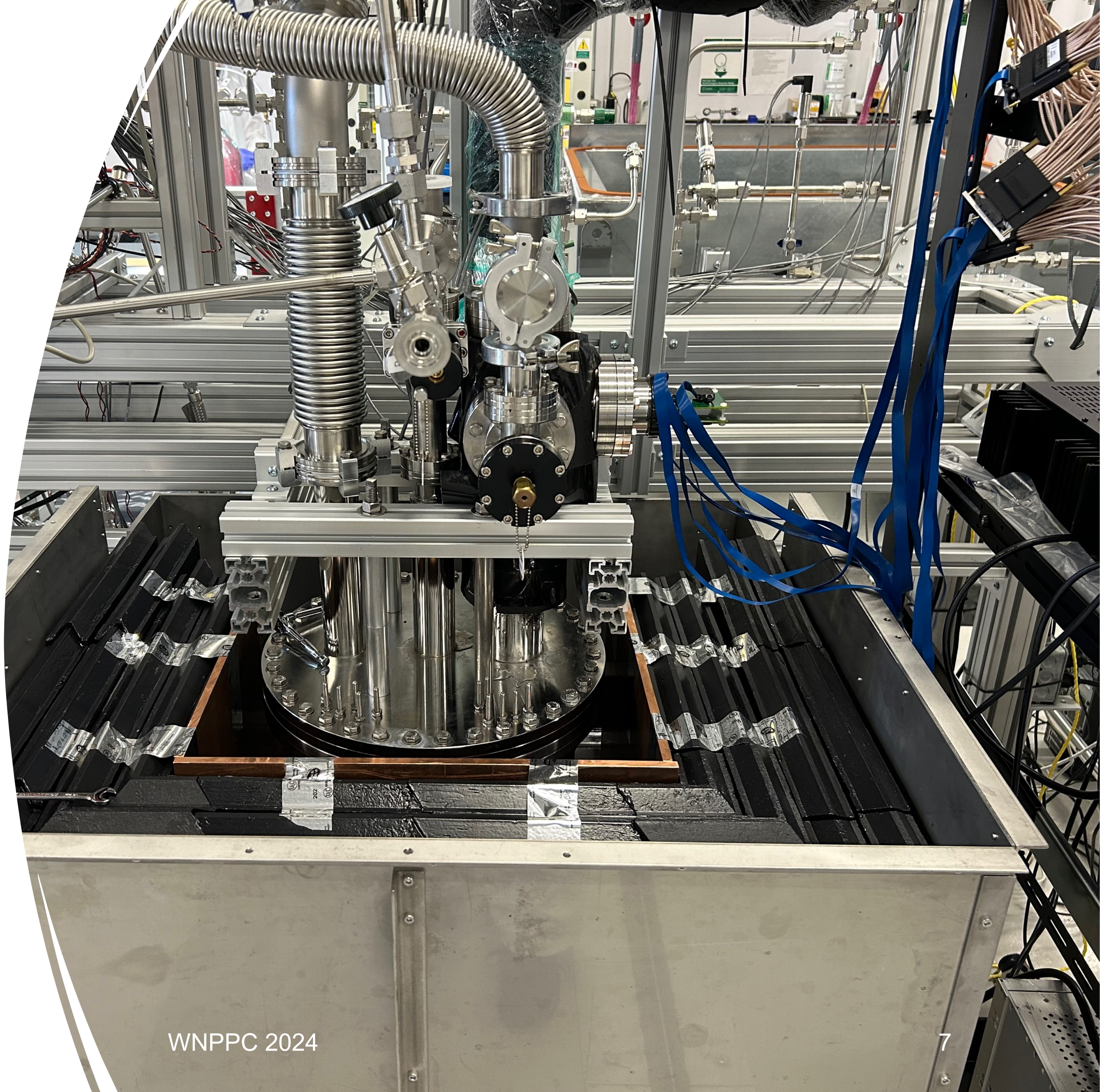
- WIMP-Argon interactions are **NRs**, as are alpha and neutron events (PSD not effective)
- Alphas originating in **dust particulates** within the detector lose energy before entering liquid argon – these **may mimic WIMP signals!**
- Presence of dust can be modelled, but a key parameter in this modelling are the **alpha scintillation quenching factors**
- Literature exists for a quenching factor at 5.3 MeV (Po^{210}, QF = 0.71 $\pm$ 0.028) [T. Doke et al. NIMA 269 (1988) 291](#) ... but **no LAr quenching factors measured down to low energies (10s keV – 5 MeV)**





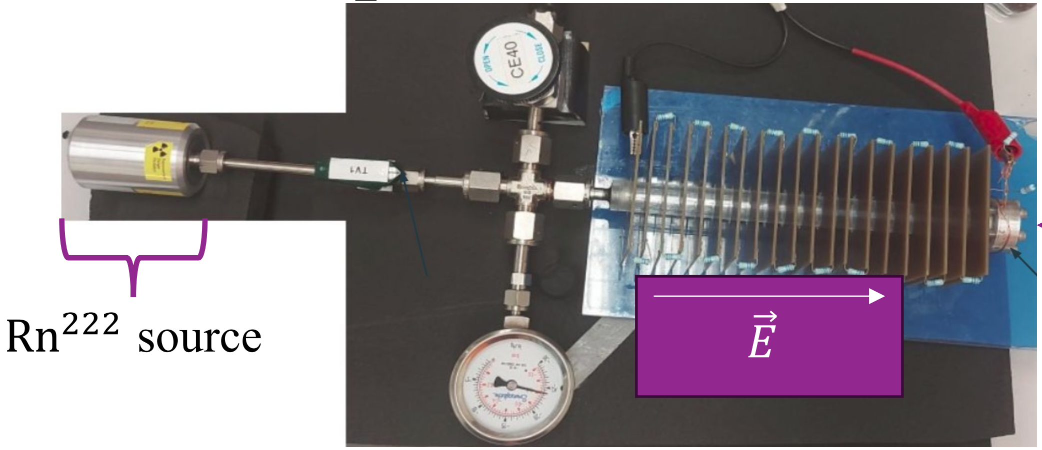
Part II

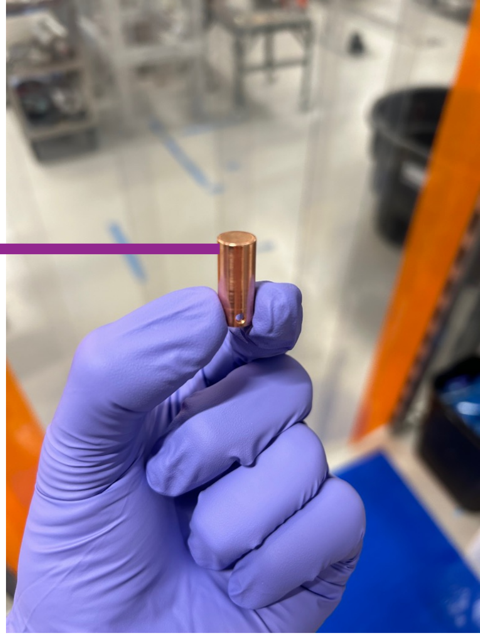
- Alpha Sources
- Argon-1
- Method
- Results so far



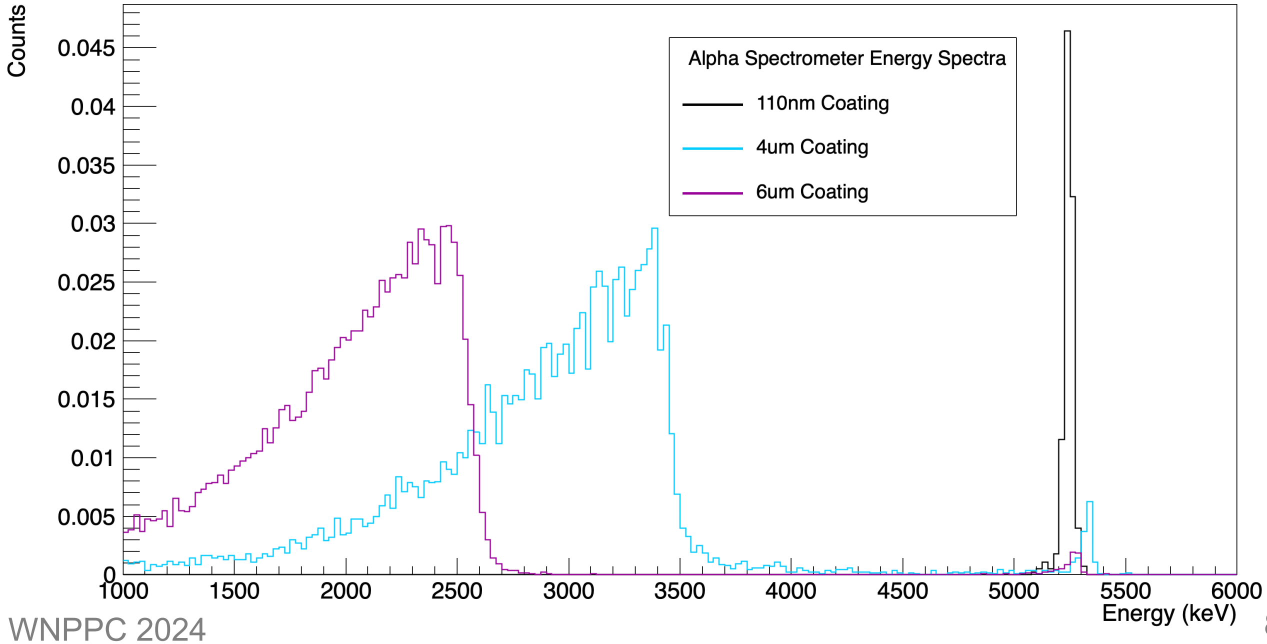
Measuring Quenching – Our Alpha Sources

- Copper substrate bathed in focused Rn^{222} gas source 3 weeks
- A stable Po^{210} (5.3 MeV, ~1 Bq) source remains
- **Evaporative coating applied to source to degrade spectrum**
- Currently 110nm*, 4µm, 6 µm coated sources
- Planned 8.5 µm source in process of coating





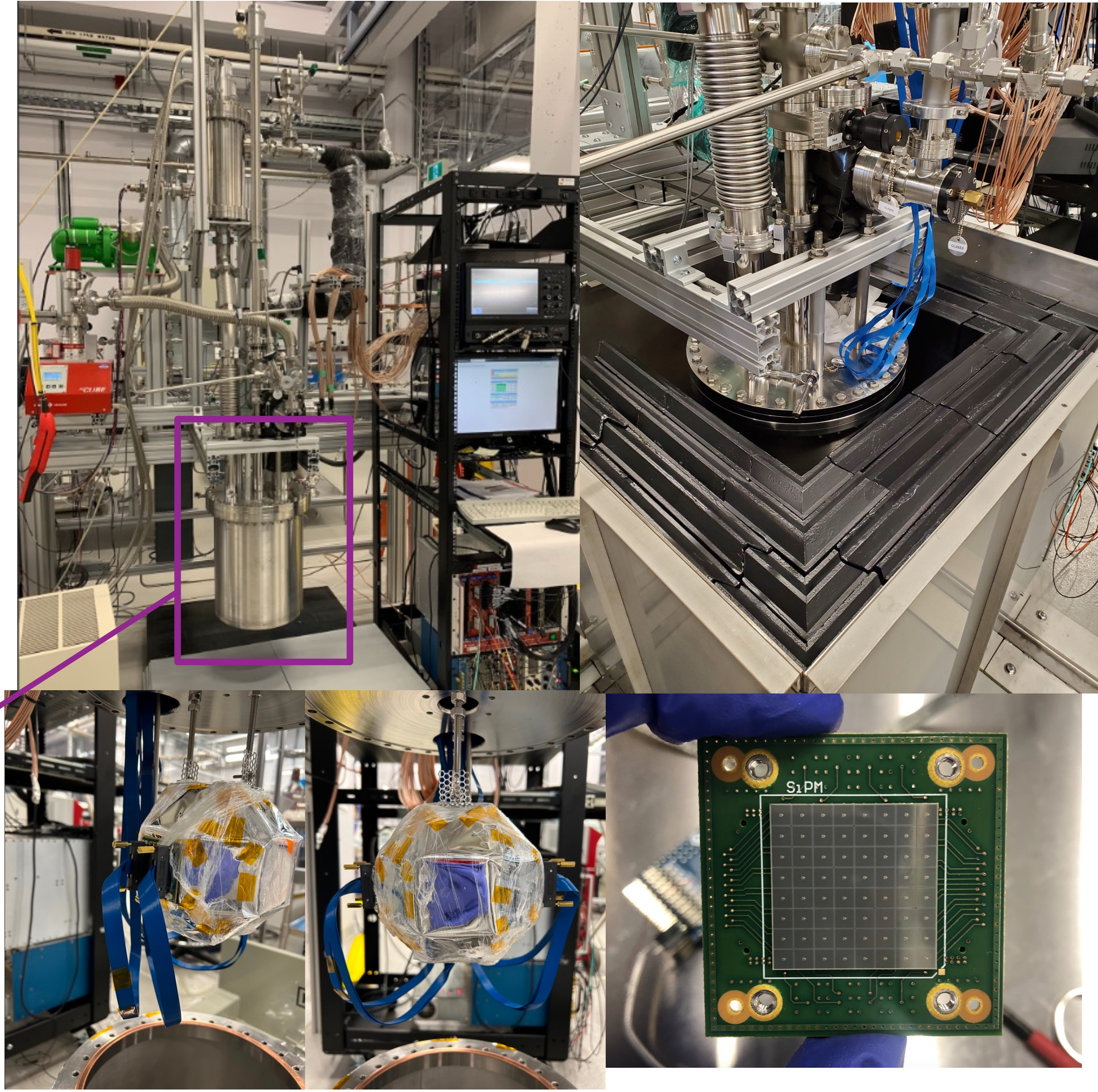
COLD
LAB

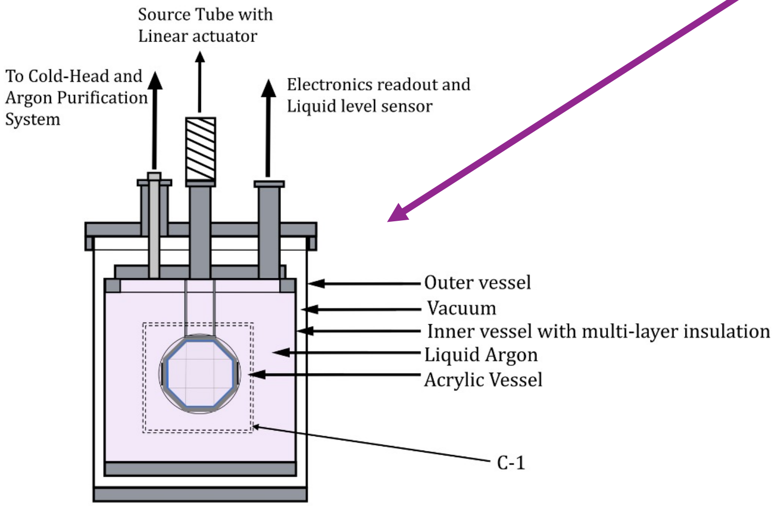


*110nm copper minimum amount of material required to “seal” the source

Argon-1

- Modular liquid argon detector in the COLD Lab at Carleton University for current and future DM detector supporting measurements
- Liquid argon cryostat containing ~35kg LAr (~10% within AV)
- Signal detection facilitated by Hamamatsu MPPC Silicon Photomultipliers (SiPMs) 2x64 individual channels readout
- Full DAQ and purification system

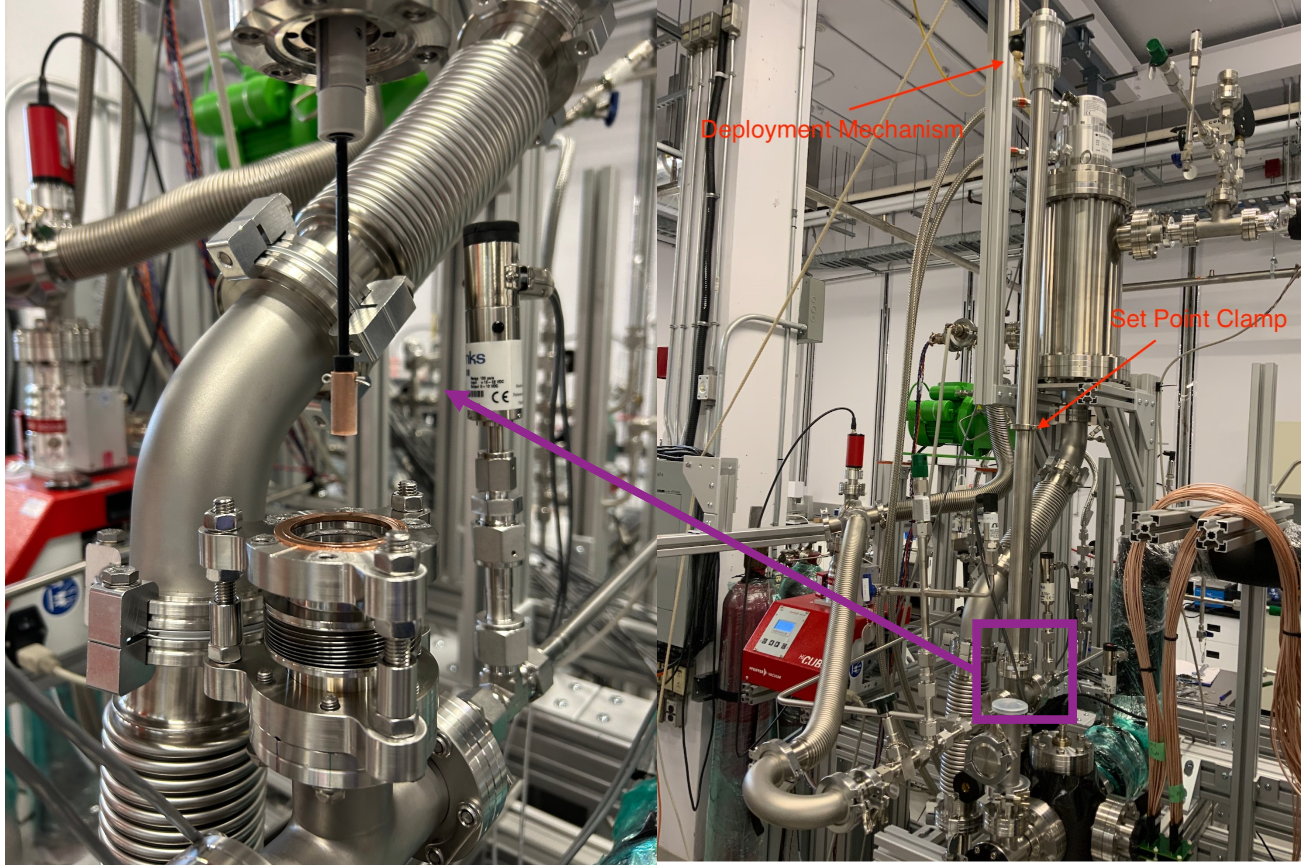


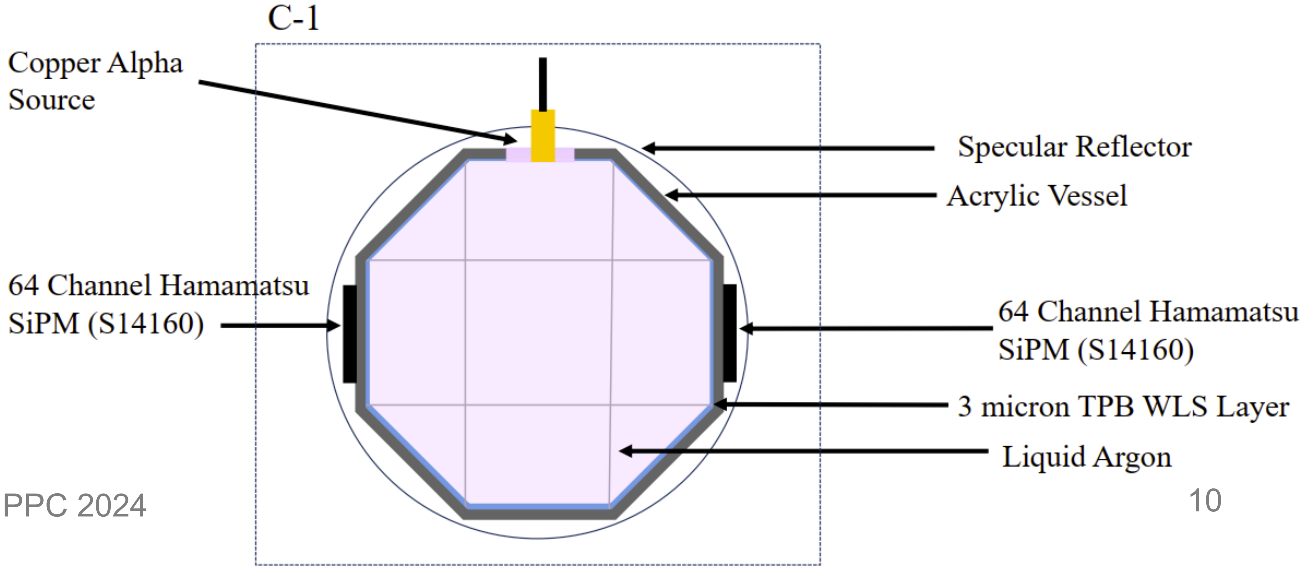


Cold Source Deployments

- Gate valve-linear actuator system allows for sources to be deployed **into the liquid argon without needing to warm the detector**

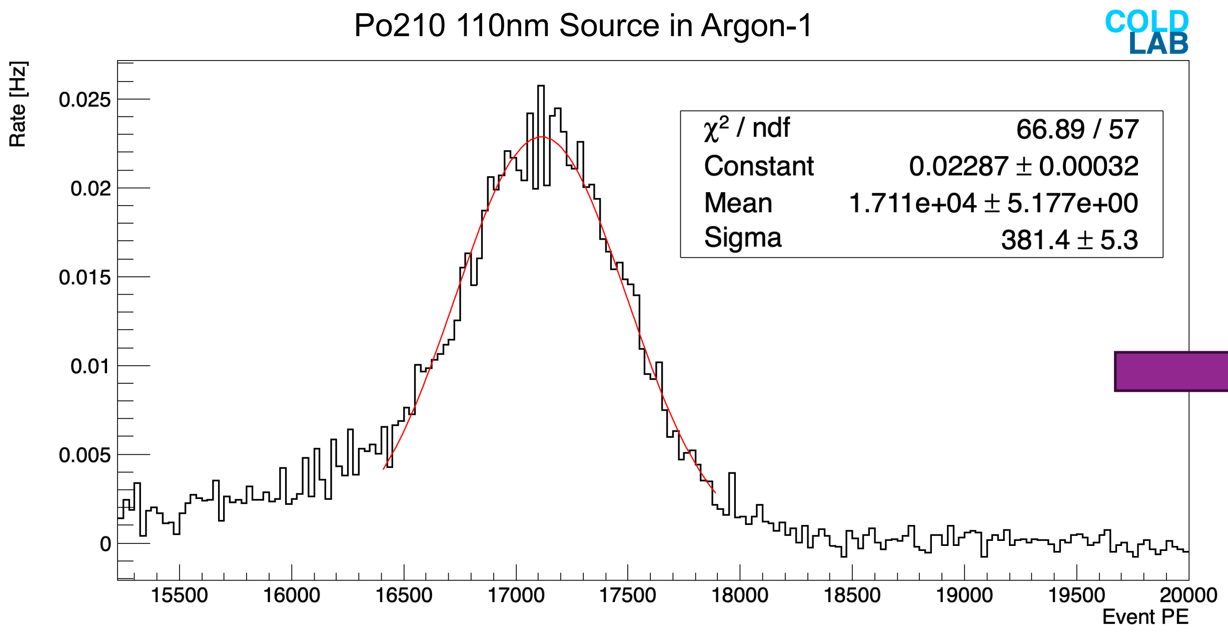
1. Remove actuator flange and install desired source
2. Torque flange with new copper gasket and leak check connection with He leak checker
3. Pump and purge line exposed to room with purified argon gas (< ppb contaminant level) scanned by RGA system
4. Trap clean argon in dedicated portion
5. Open gate valve to experiment volume
6. Lower source into detector





Initial Results & Analysis

- **Preliminary Approach**: Use the 110nm coated source to model detector response, quenching value for Po^{210} (slide 6) assumed. **Attempt to reconstruct true PE spectrum from spectrometer data trying different quenching factor curves**

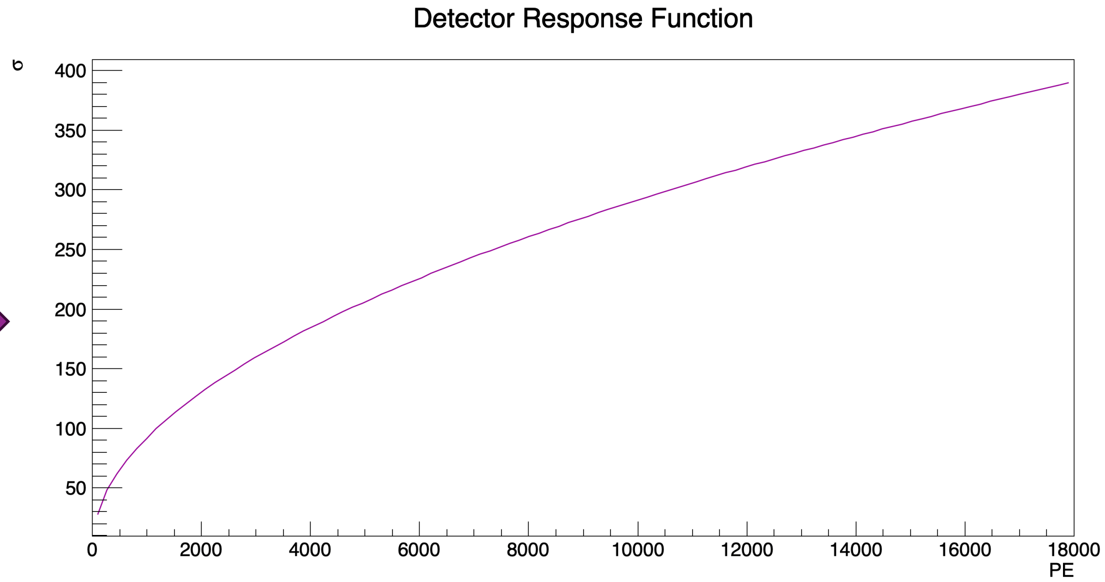


Assume a Gaussian detector response with

$$\mu = Y \times \epsilon^{*}_{shad} \times E_{quench} \text{ [PE]}$$
$$\sigma = \sqrt{\mu} \times 2.91^{**}$$ (**from fit to left spectrum)

ϵ^{*}_{shad} is a shadowing correction factor (0.62)

Output is a reconstructed PE spectrum



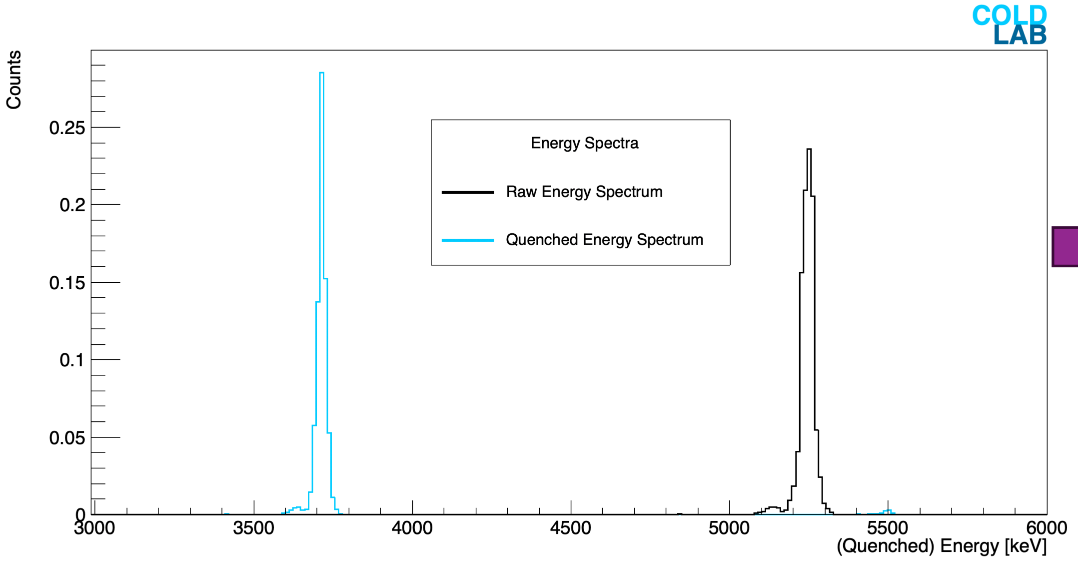
Initial Results & Analysis

- The alpha spectrometer spectrum has a quenching factor applied, and convolved with the detector response function to obtain a reconstructed PE spectrum
- **This is our calibration**
- **We apply the QF = 0.71 from literature across the whole spectrum, and receive good agreement between reconstruction and data**

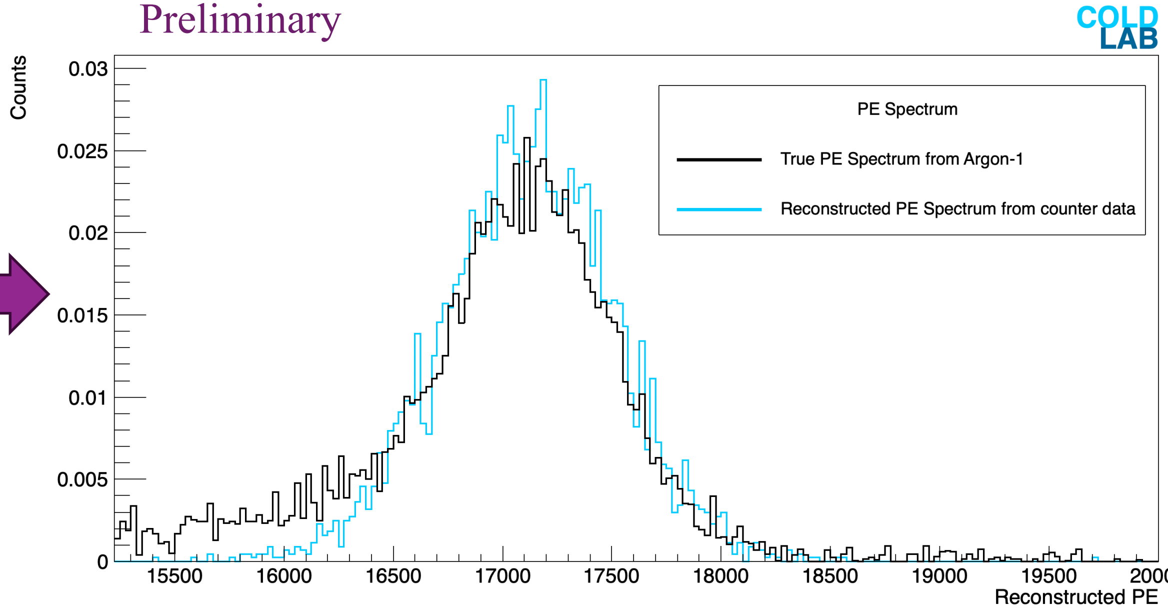
Assume a Gaussian detector response with

$$\mu = Y \times \epsilon_{shad} \times E_{quench} \text{ [PE]}$$

$$\sigma = \sqrt{PE} \times 2.91$$



Preliminary



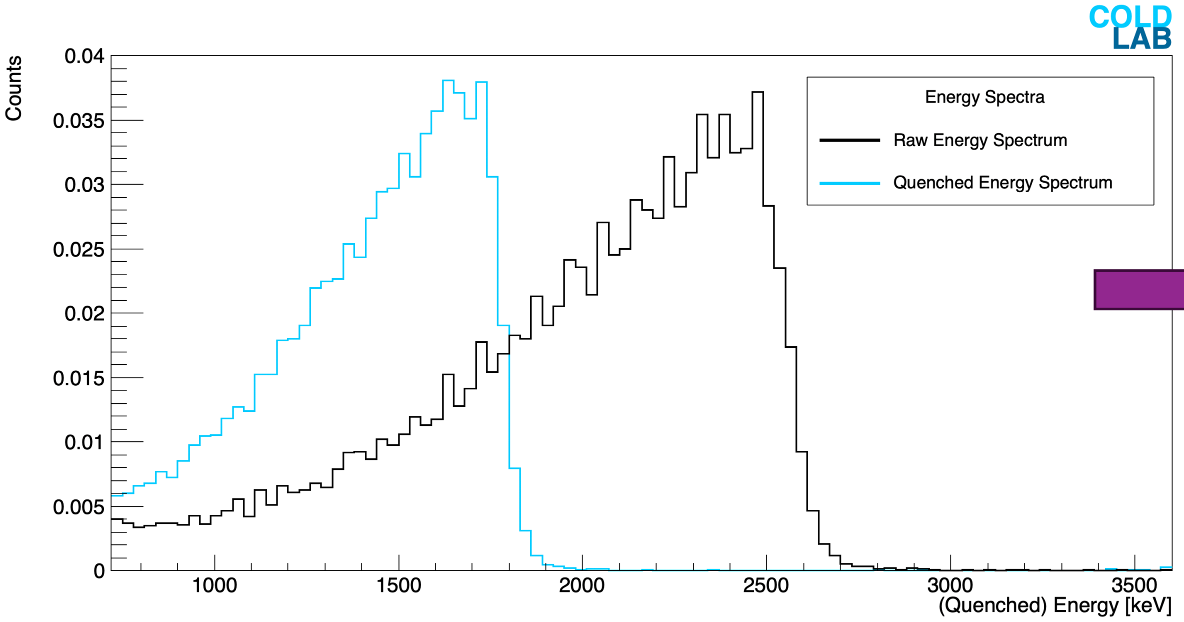
Initial Results & Analysis

- **The same logic is now applied to the other sources**
- **Use the same literature QF = 0.71**
- Currently 6um source data processed, 4um source data coming next week
- **Good agreement at high PE edge**
- **Variation at low PE under investigation (QF energy dependence?)**

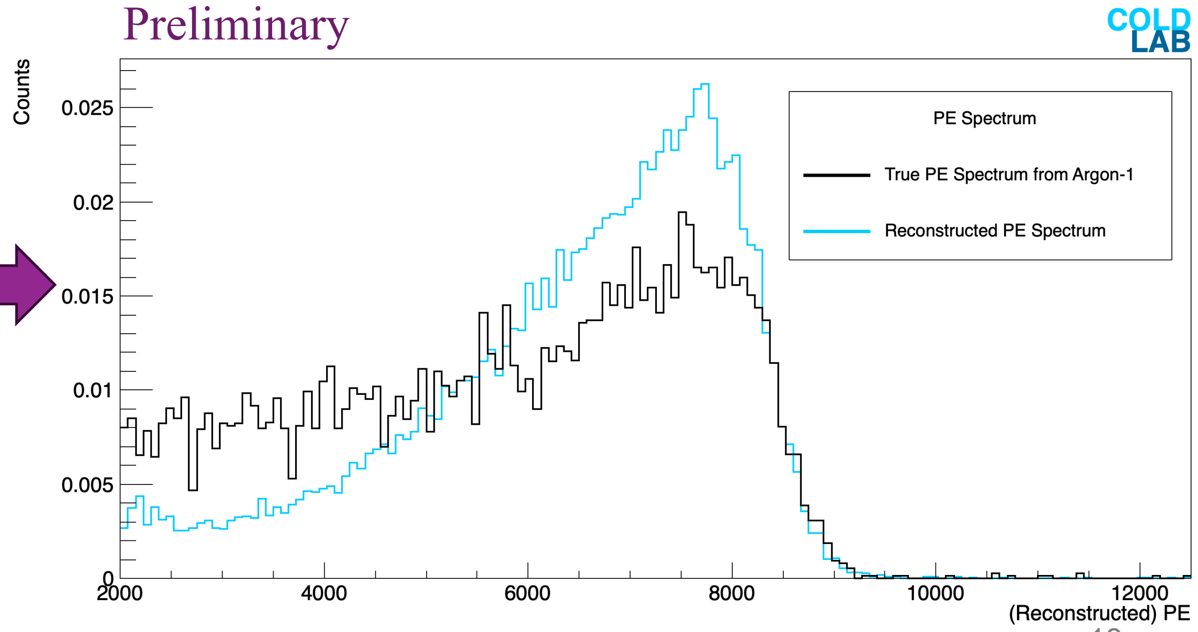
Assume a Gaussian detector response with

$$\mu = Y \times \epsilon_{shad} \times E_{quench} \text{ [PE]}$$

$$\sigma = \sqrt{PE} \times 2.91$$



Preliminary



Conclusions & Acknowledgements

- Understanding backgrounds in dark matter detectors is critical
- Understanding alpha scintillation quenching factors in liquid argon, particularly at low energies is a critical ingredient in a background model
- Argon-1 is well equipped to probe quenching factors across a wide energy range
- Further data taking and analysis are currently ongoing but show promising initial results

Thanks to …

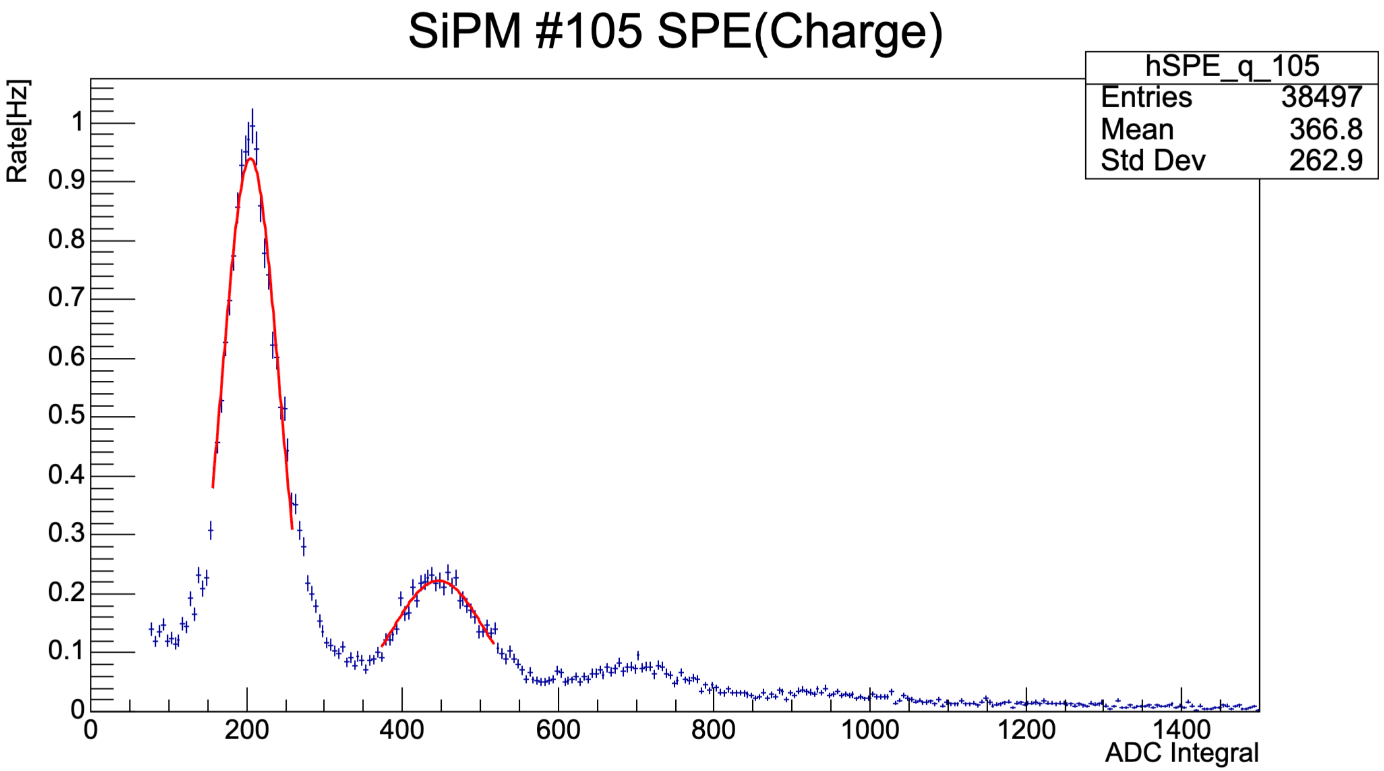
- My supervisor Mark Boulay
- NSERC and CFI funds
- DEAP-3600 Collaborataion
- David Gallacher (who is speaking after me!)

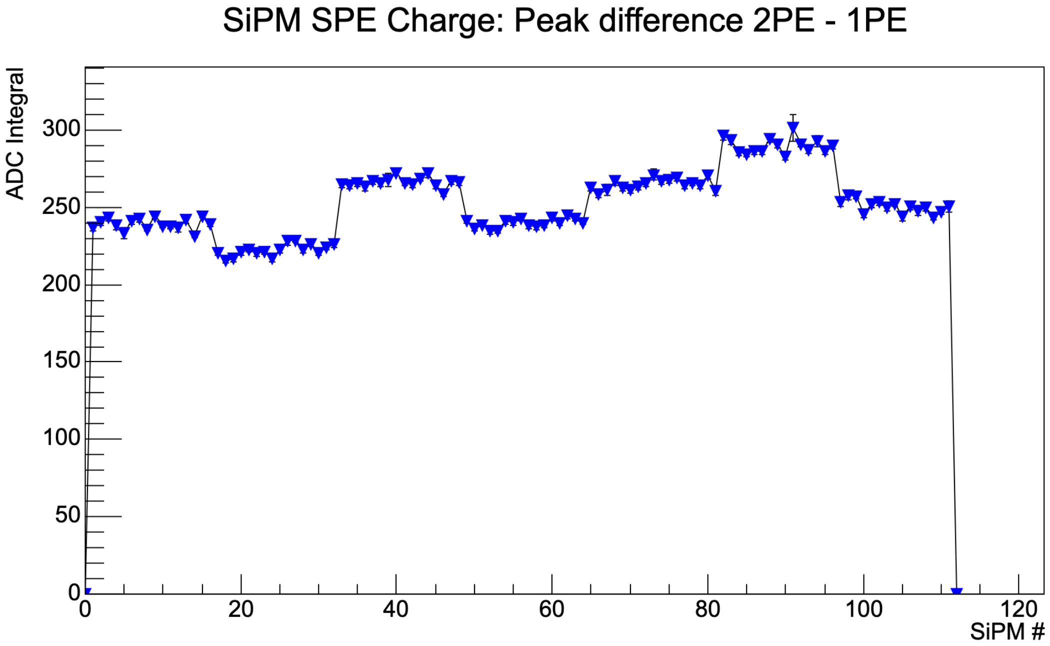
INNOVATION
Canada Foundation for Innovation
Fondation canadienne pour l'innovation

NSERC
CRSNG

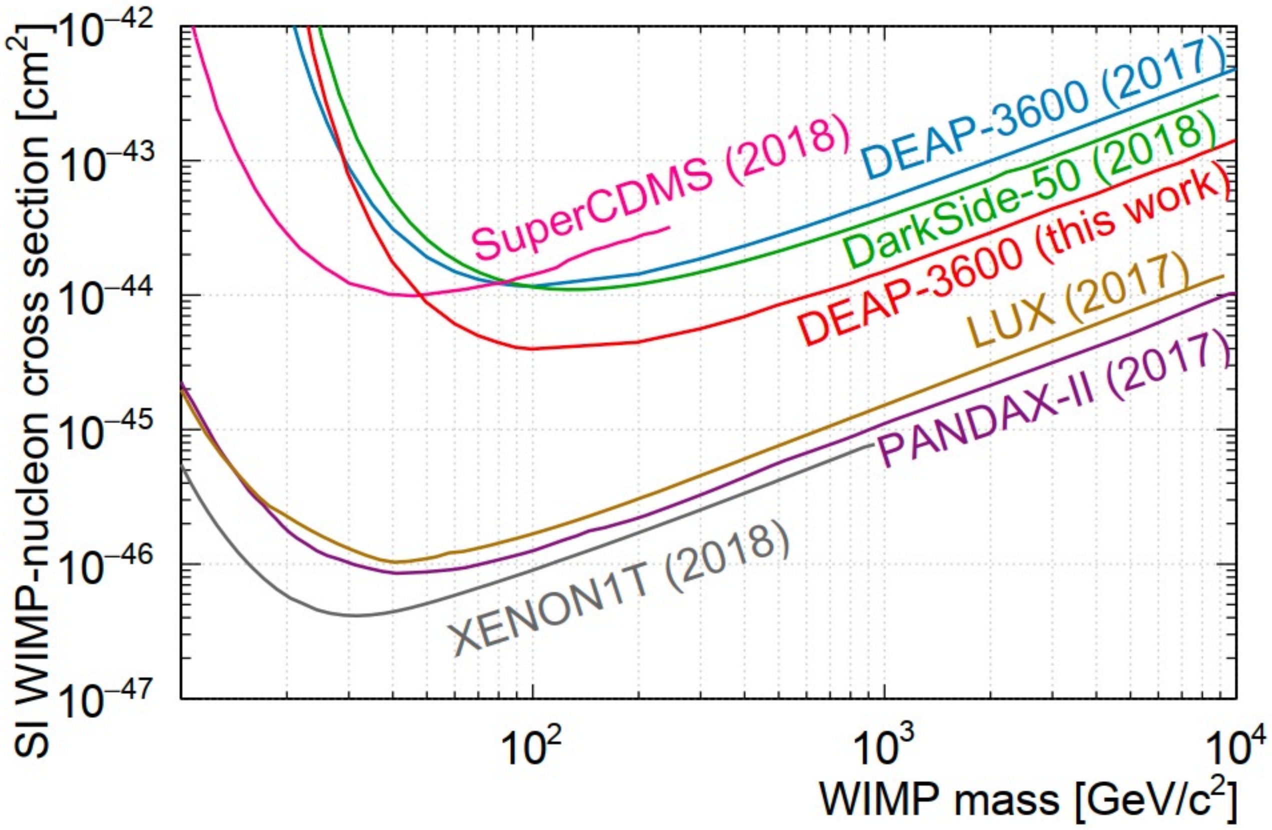
BACKUP

SPE Calibrations



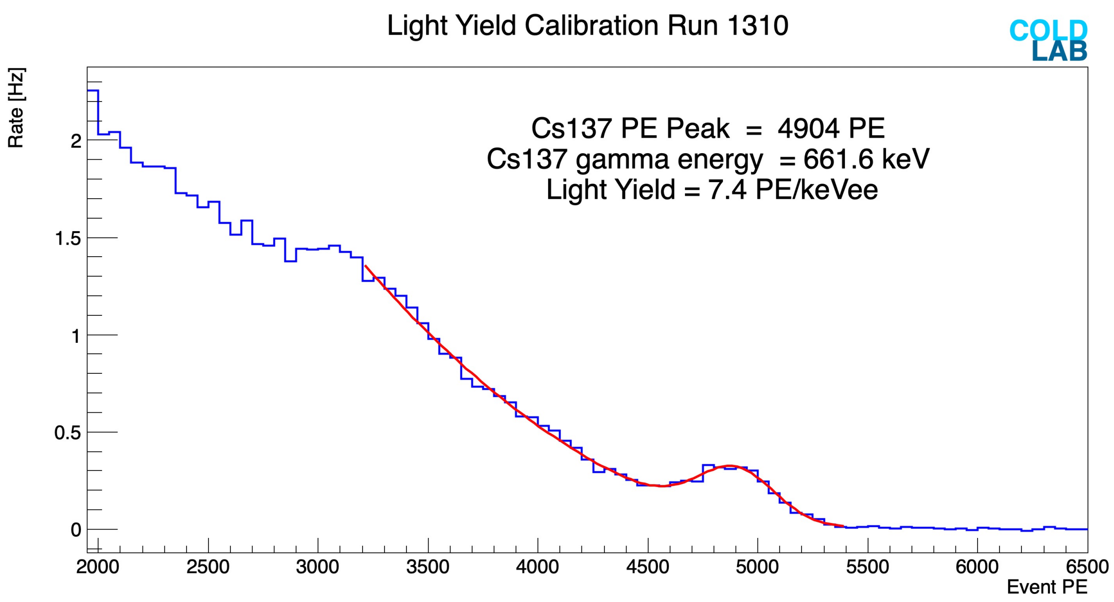


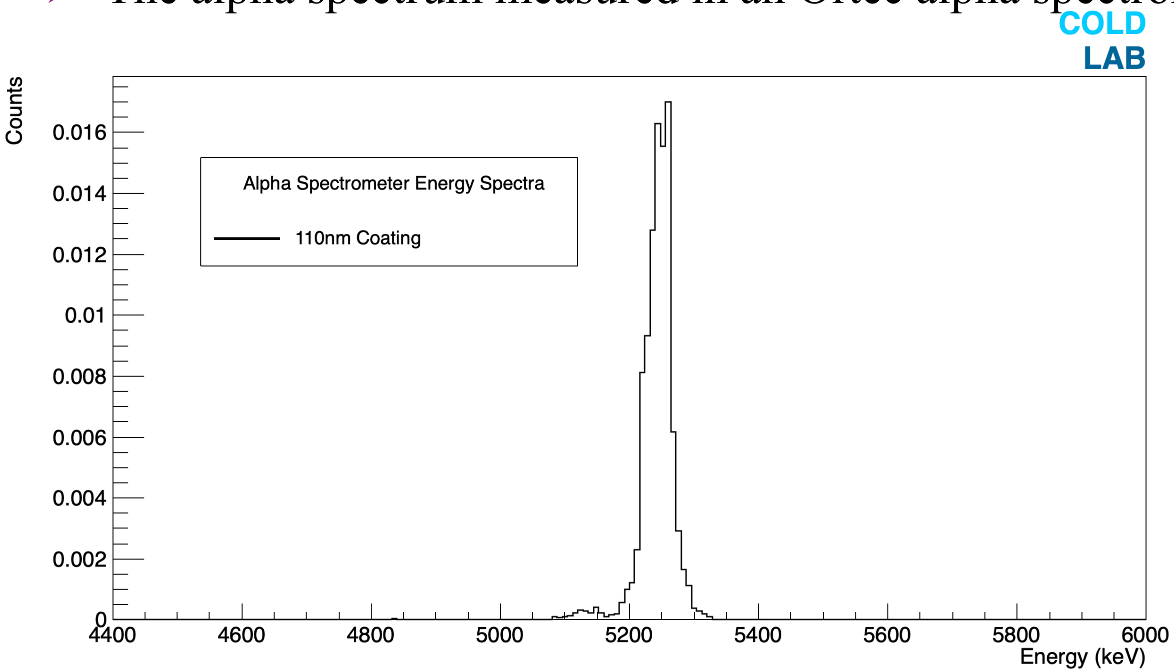
DEAP-3600 Exclusion Curve

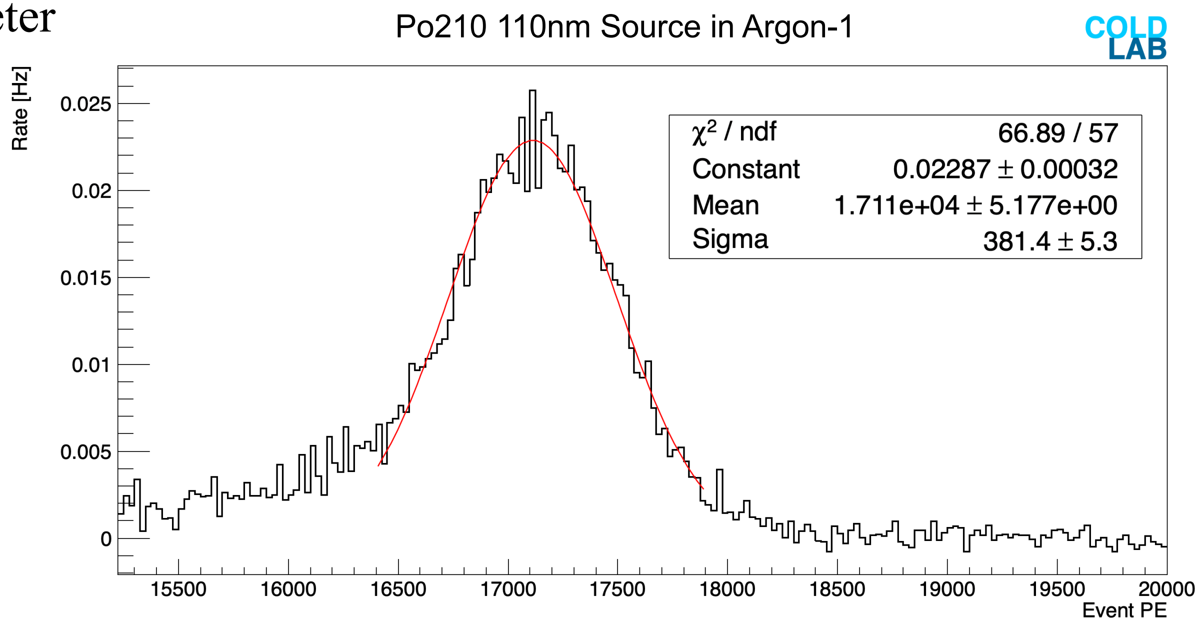


Data Taking

- **Four data runs are taken for each source deployment**
  - A background run in Argon-1 for subtraction of subsequent runs
  - A Cs^{137} gamma source run to calibrate the light yield, Y
  - The copper alpha source deployed directly in the detector
  - The alpha spectrum measured in an Ortec alpha spectrometer







Shadowing

- **Quenching quantifies fraction of energy not emitted as light i the detector ... or not seen by photodetectors**
- Shadowing of the alpha due to presence of source is in **direct competition** with quenching
- Idea: **Install Rn222 on Argon-1 Process System – Measure unshadowed peaks**