Supporting Measurements for Current and Future Argon Dark Matter Detectors with Argon-1

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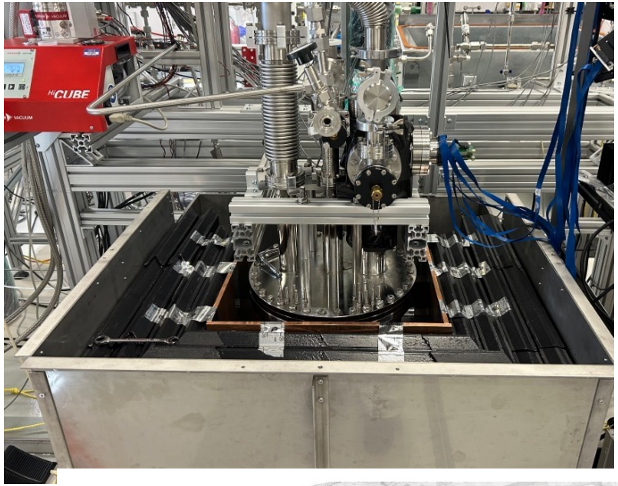
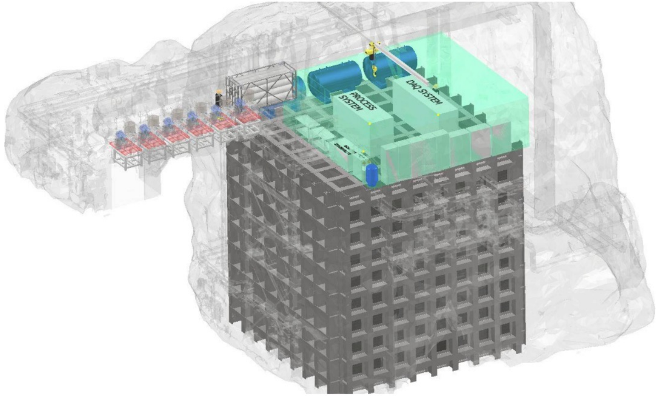
Outline

- Argon-1 at Carleton
    - Detector overview
- Measurements with Argon-1
    - Scintillation quenching, crosstalk, hit pattern identification
- ARGO and ARGOlite
    - The future of argon dark matter detectors





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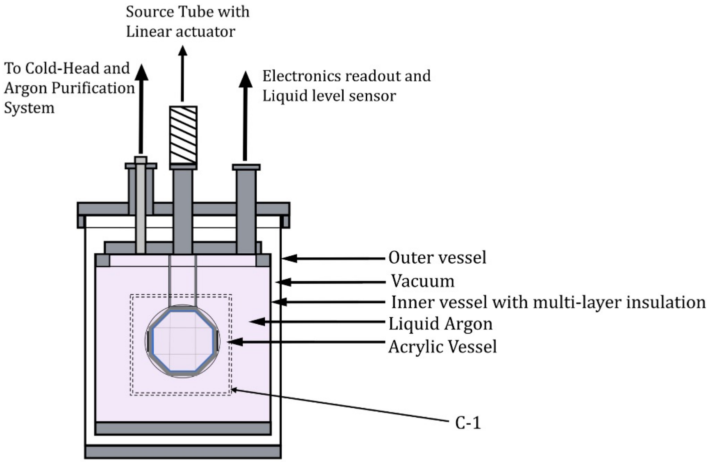
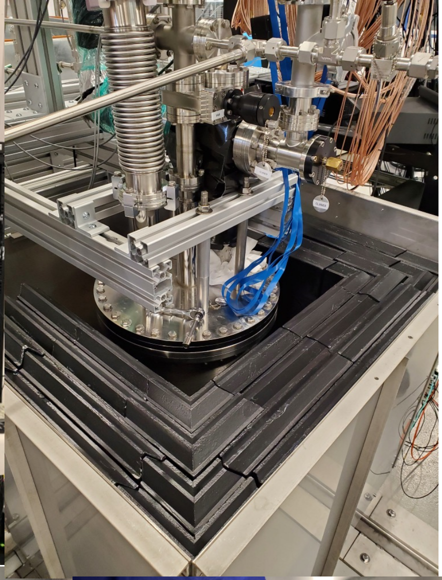
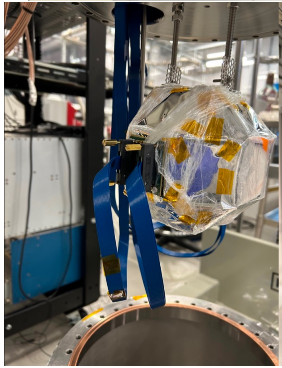
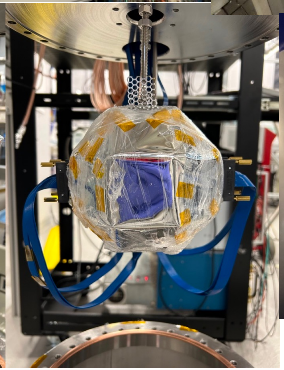
Argon-1 at Carleton

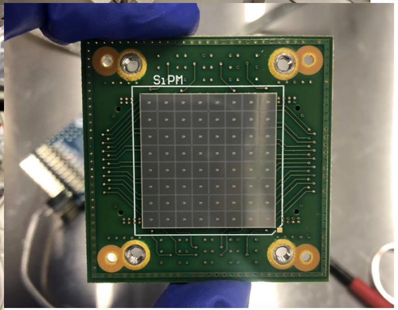
- Modular liquid argon detector in the COLD Lab at Carleton University Liquid argon cryostat containing ~35kg LAr (~10% within AV)
- Signal detection facilitated by Hamamatsu MPPC (SiPMs) 4x64 (256) individual channels readout – **Unique granularity of 3mm^2 channel area**
- Full data acquisition and purification system











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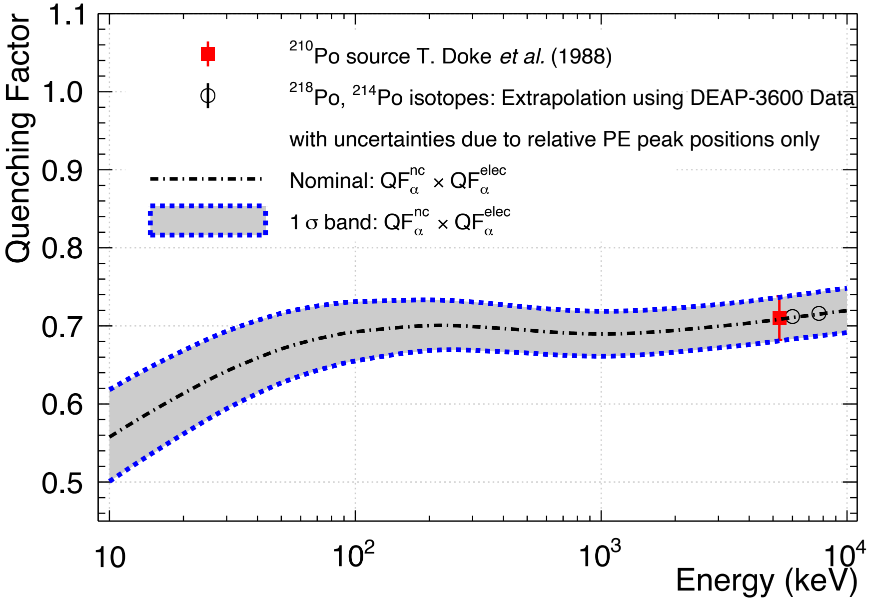
Alpha Scintillation Quenching

Measuring alpha scintillation quenching directly

- DEAP-3600 published model for alpha scintillation quenching factor as a function of energy Summer 2024
- Data point from T. Doke *et al.* (1988) , and DEAP data are all > 5 MeV
- **Model must extrapolate to low E**

$$\text{ERs : E [keVee]} = \frac{\text{\#PE [PE]}}{\text{Y [PE /keVee]}}$$

$$\alpha\text{s (+ other NRs): E [keVee]} = \frac{\text{\#PE [PE]}}{\text{Y} \times \boxed{\text{QF(E)}}} \text{!}$$



Alpha quenching factor as a function of alpha particle energy in liquid argon, from arXiv:2406.18597, accepted at Eur. Phys. J. C

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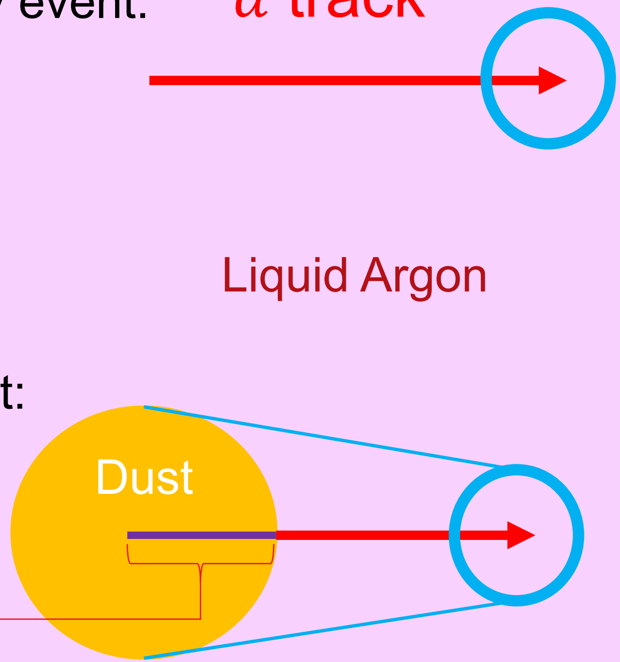
Why do we need to know quenching factors?

Full energy event: α track



Scintillation in 4π will be fully reconstructed

Identification of parent isotope straightforward

Liquid Argon

Dust event:

Energy is lost to dust particulate

Scintillation light also shadowed by presence of dust

Identification of parent isotope difficult

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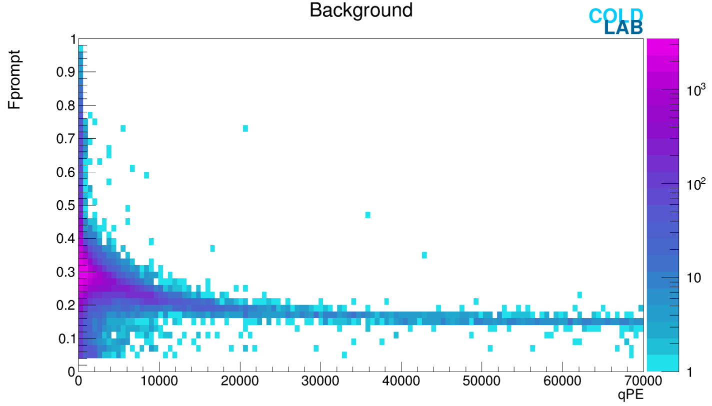
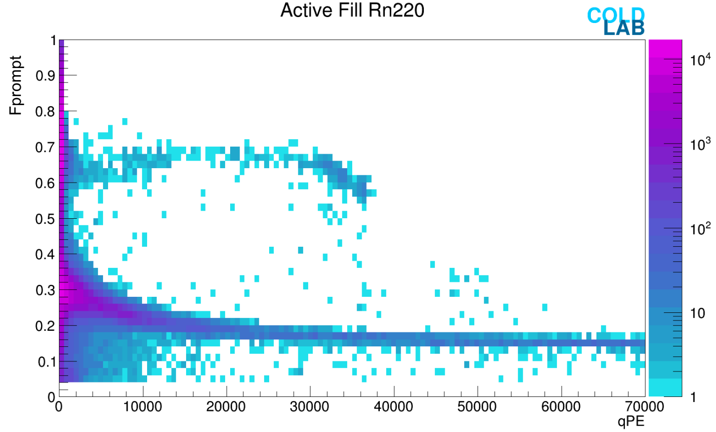
^{220}Rn direct deployment for high energy points





Argon gas is flowed through ^{220}Rn source, purified and sent into Argon-1 to mix with liquid volume

- Deployment of ^{220}Rn mixed uniformly in detector volume allows for direct re-measurement of high E points, benchmark for lower E measurements

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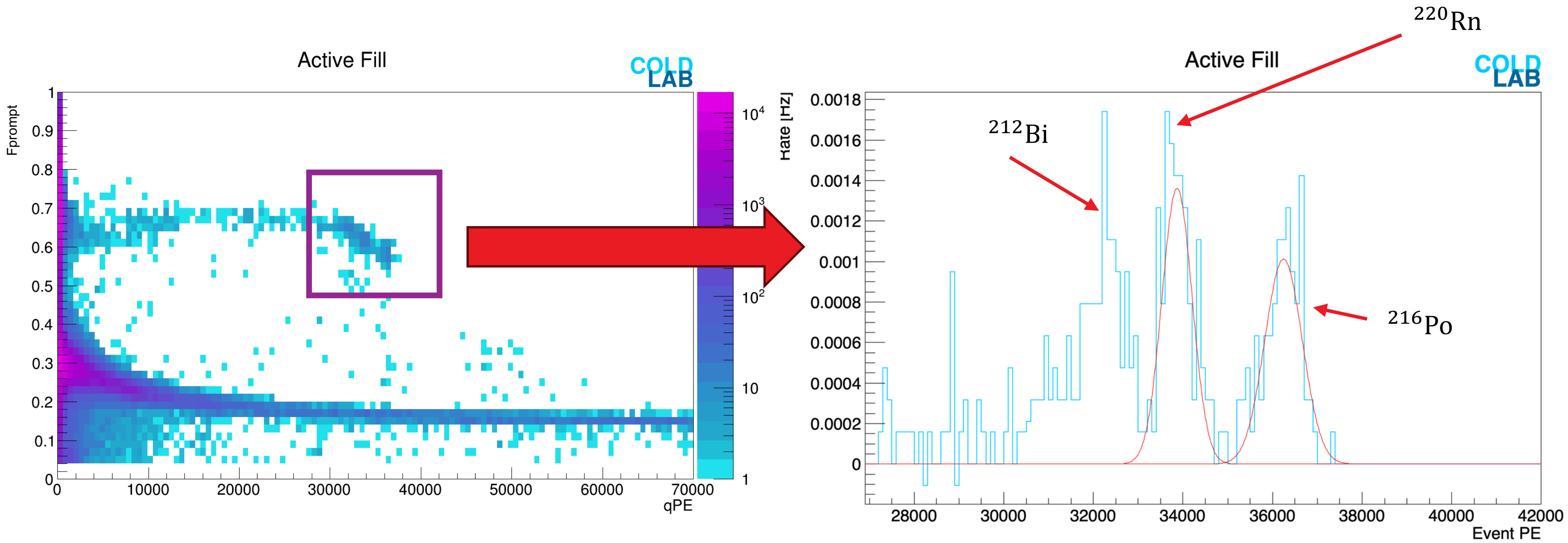
Peaks are well resolved in PE space



$$\mathrm{QF} = \frac{\mu_{PE} - (T_d \times QF_d \times Y)}{Y \times (Q_\alpha - T_d)} \tag{5.3}$$

where μ_{PE} is the mean of the fit to the PE spectrum, T_d is the kinetic energy of the daughter nucleus, QF_d is the recoil heavy nucleus quenching factor, and Y is the light yield of Argon-1.

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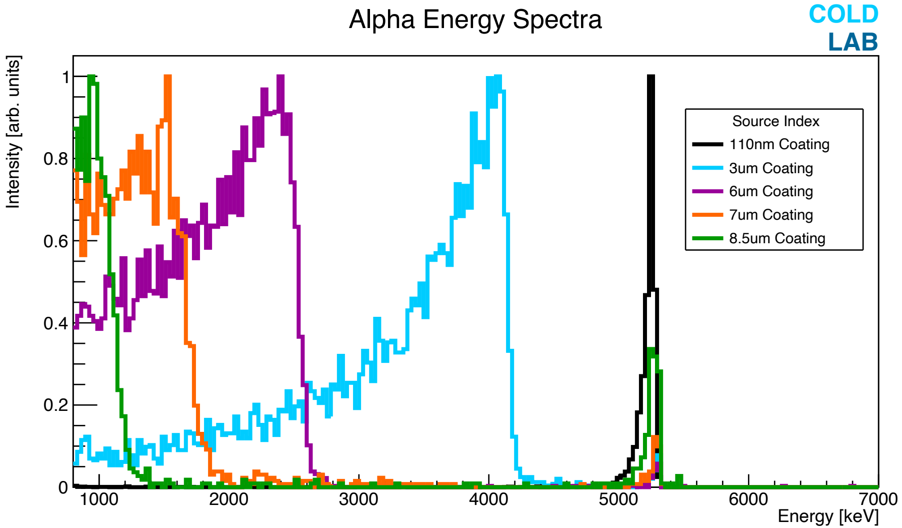
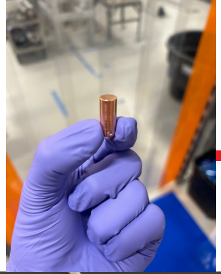
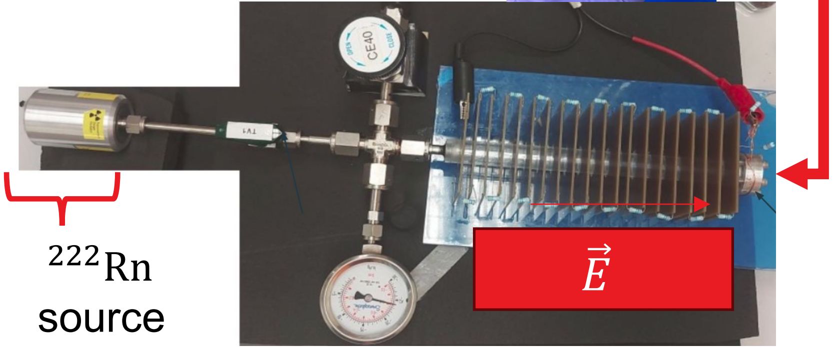
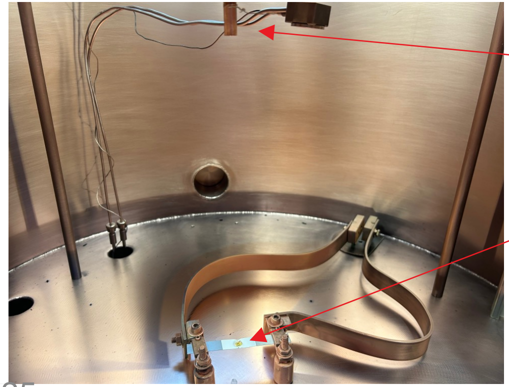
Probing Lower E - α Sources Made at Carleton

- Copper substrate bathed in focused ^{222}Rn gas source 3 weeks
- A stable ^{210}Po (5.3 MeV, ~1 Bq) source remains
- **Evaporative coating applied to source to degrade spectrum**
- **Technical paper on source production in progress**









Inside the thin film deposition chamber

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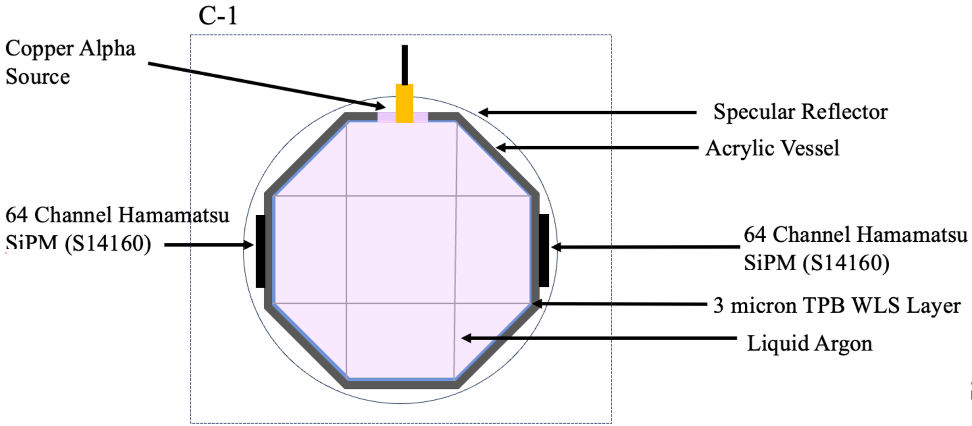
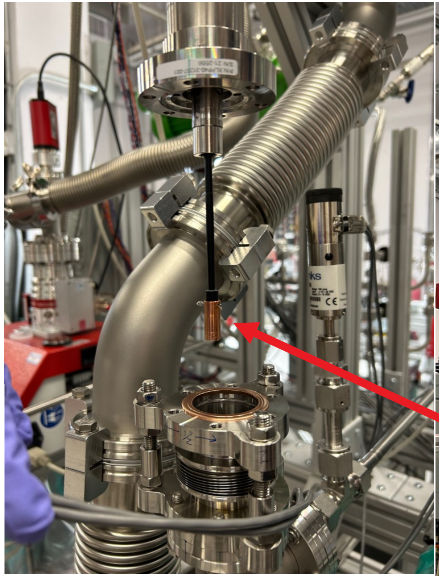
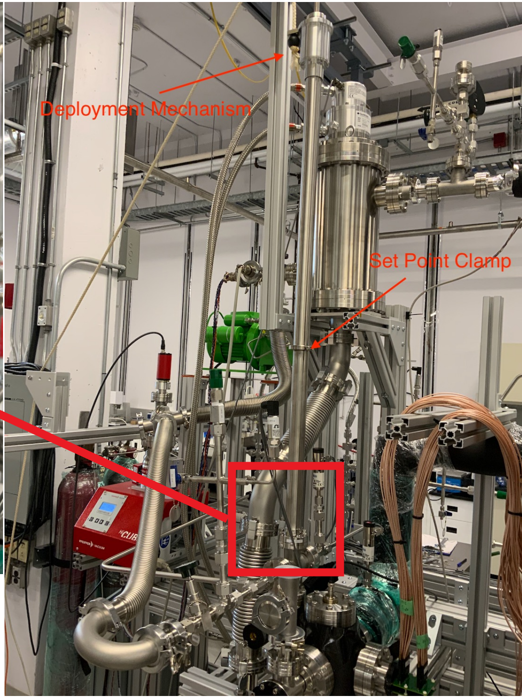
Cold Source Deployment

- Sources are inserted directly into Argon-1 AV to measure alpha spectrum







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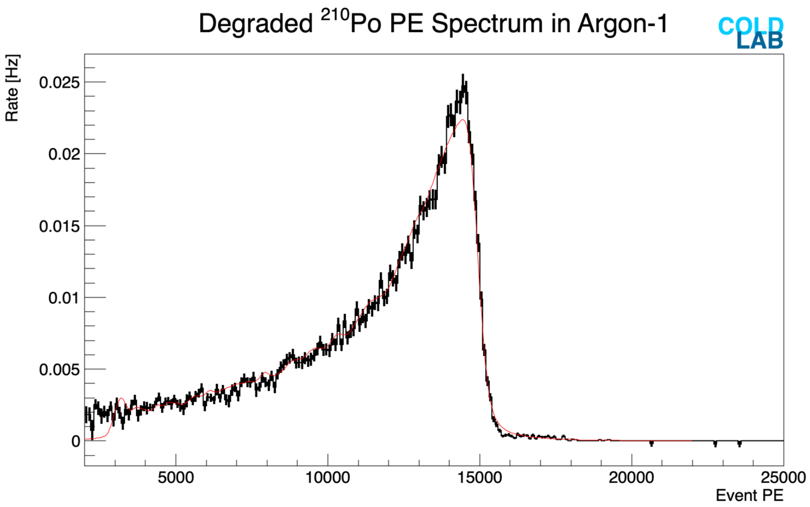
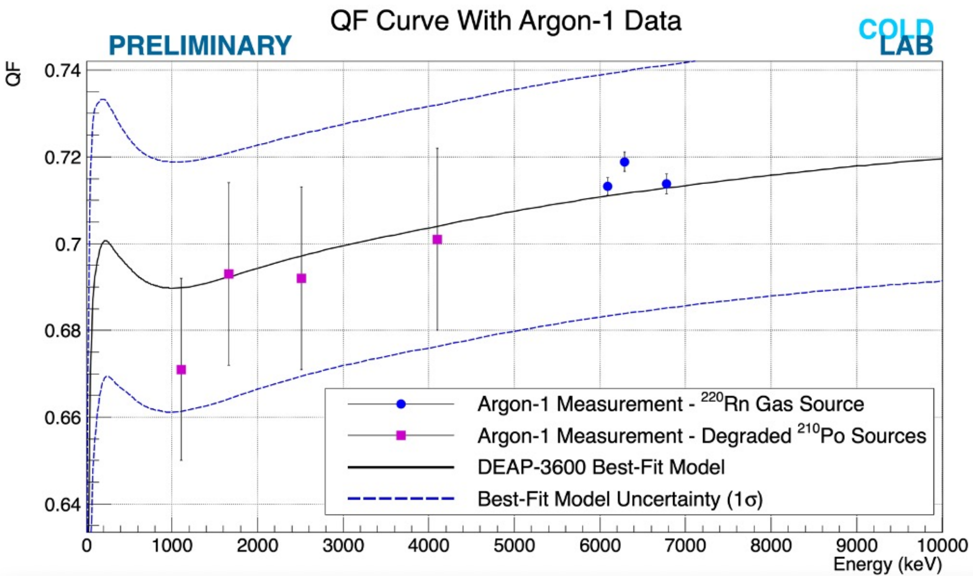
Preliminary results for alpha quenching in Argon-1



Model generated from input E spectrum fit to Argon-1 data



Preliminary measurements of QF vs E

- Future work aims to lower thresholds to probe sub 1 MeV quenching factors

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Other Measurements and Ongoing Studies

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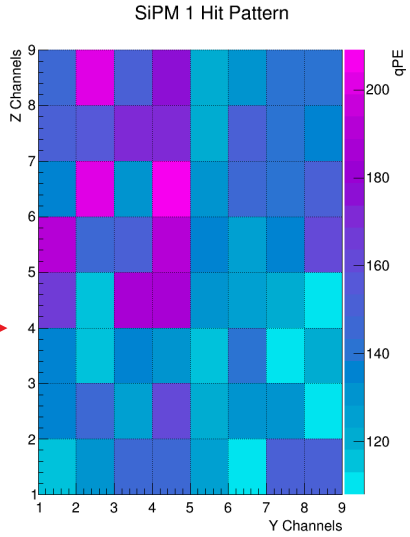
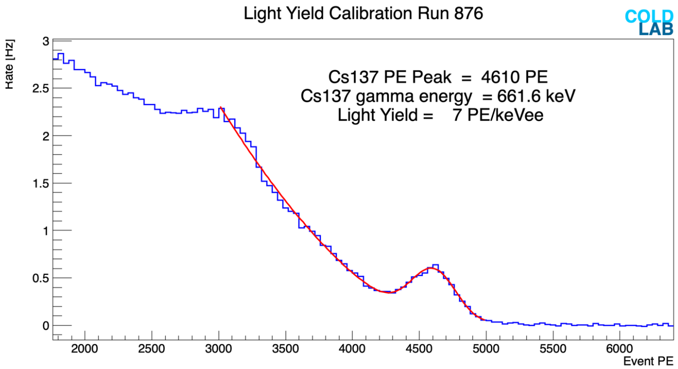
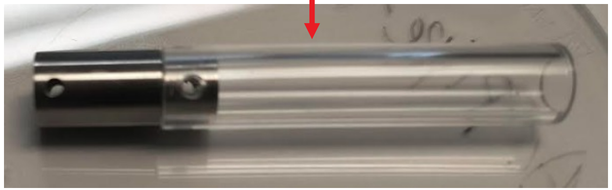
Ongoing/planned measurements

- Dedicated studies of internal and external SiPM cross talk using Kr^{83m} and Cs^{137} gamma source data and varying overvoltage applied to SiPMs – **Benchmark ARGO SiPM Simulations**
- Surface alpha rejection studies using hit patterns on high granularity SiPMs with radon doped acrylic panel
- Deployment of Pyrene coated, radon doped acrylic tube via alpha source deployment tube to assist DEAP analysis







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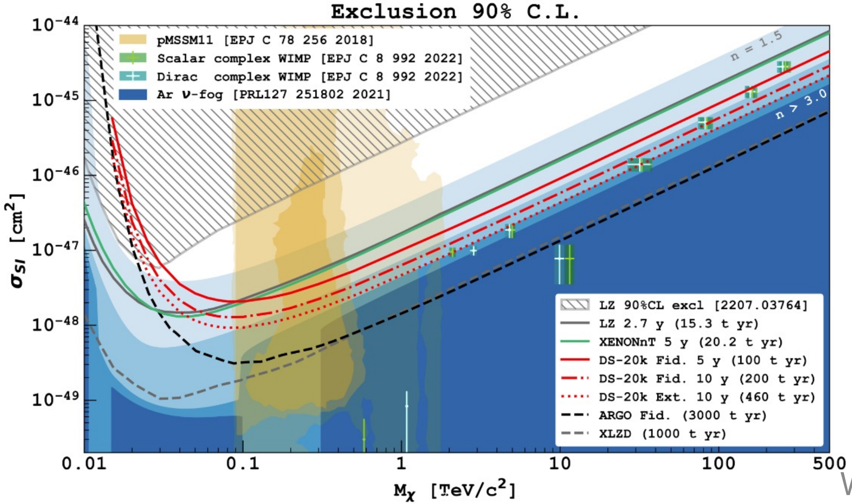
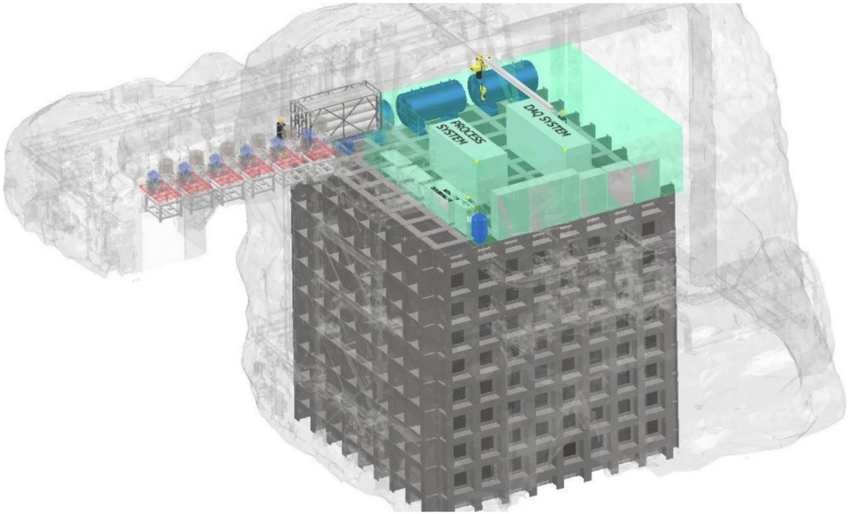
ARGO & ARGOlite

ARGO – The next (next) generation argon DM detector

- Future detector planned to be located at SNOLAB Cube Hall (2030s)
- 400 tonnes of low-radioactivity (low $^{39}\mathrm{Ar}$) underground argon
- Goal of 3000 tonne year exposure, will probe well into argon neutrino fog





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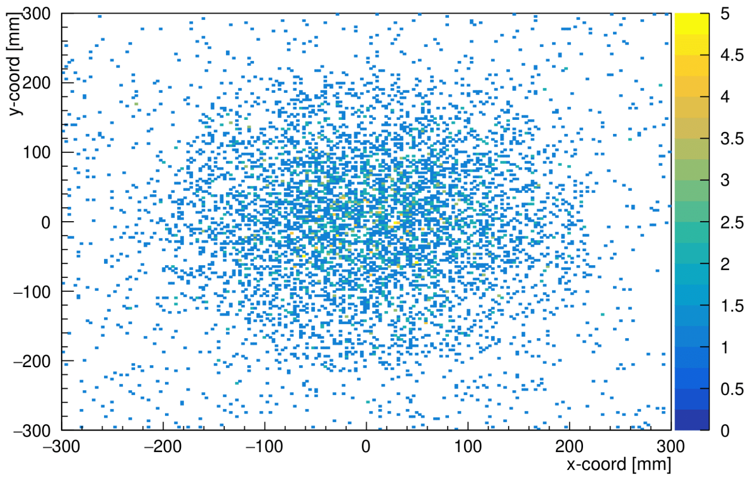
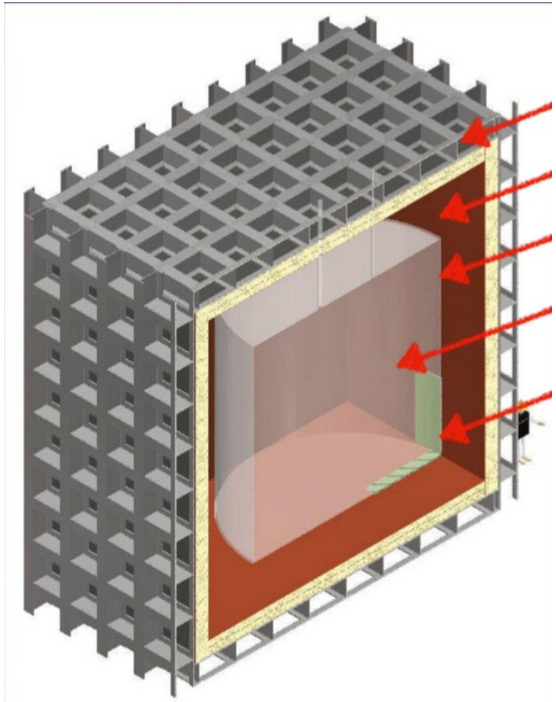
Effort towards ARGO is ramping up

- Detailed simulations on-going for ARGO (SiPM physics, position reconstruction, background estimates)



Hit pattern from ARGO simulation for an event close to the surface of the detector (Asish Moharana)



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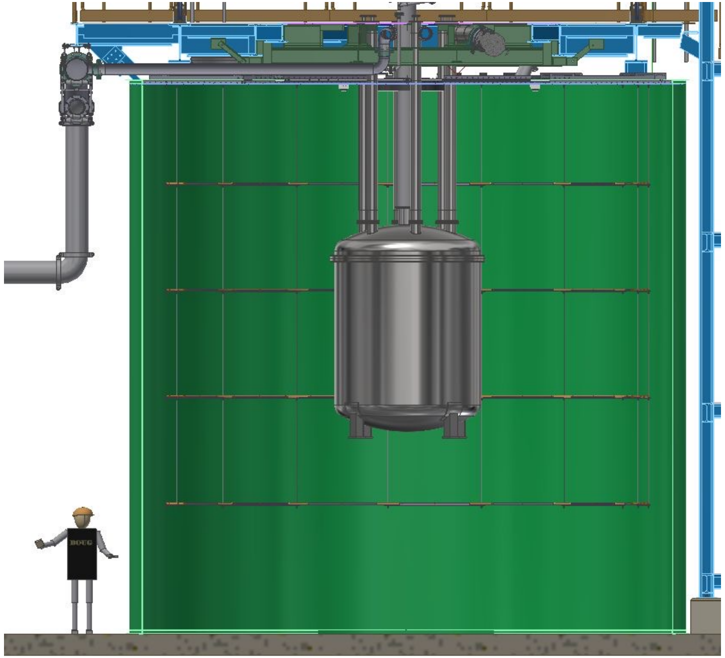
Effort towards ARGO is ramping up - ARGOlite

- A prototype for ARGO coming online in 2028
- Located at SNOLAB, will use DEAP-3600 water shield tank and process systems

- $2m^2$ pixelated photodetector coverage (using Sherbrooke dSiPMs)
- Will run for 3 years to finalize ARGO design by 2031



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Conclusion & Outlook

- Argon-1 is actively studying physics useful to current and future liquid argon dark matter detectors
- Quenching factors, crosstalk and hit pattern studies are all useful for energy reconstruction and background negation
- ARGO is the future of liquid argon DM searches, with the ARGOlite prototype planned to operate in former DEAP-3600 tank

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Thanks! Questions?

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Backup

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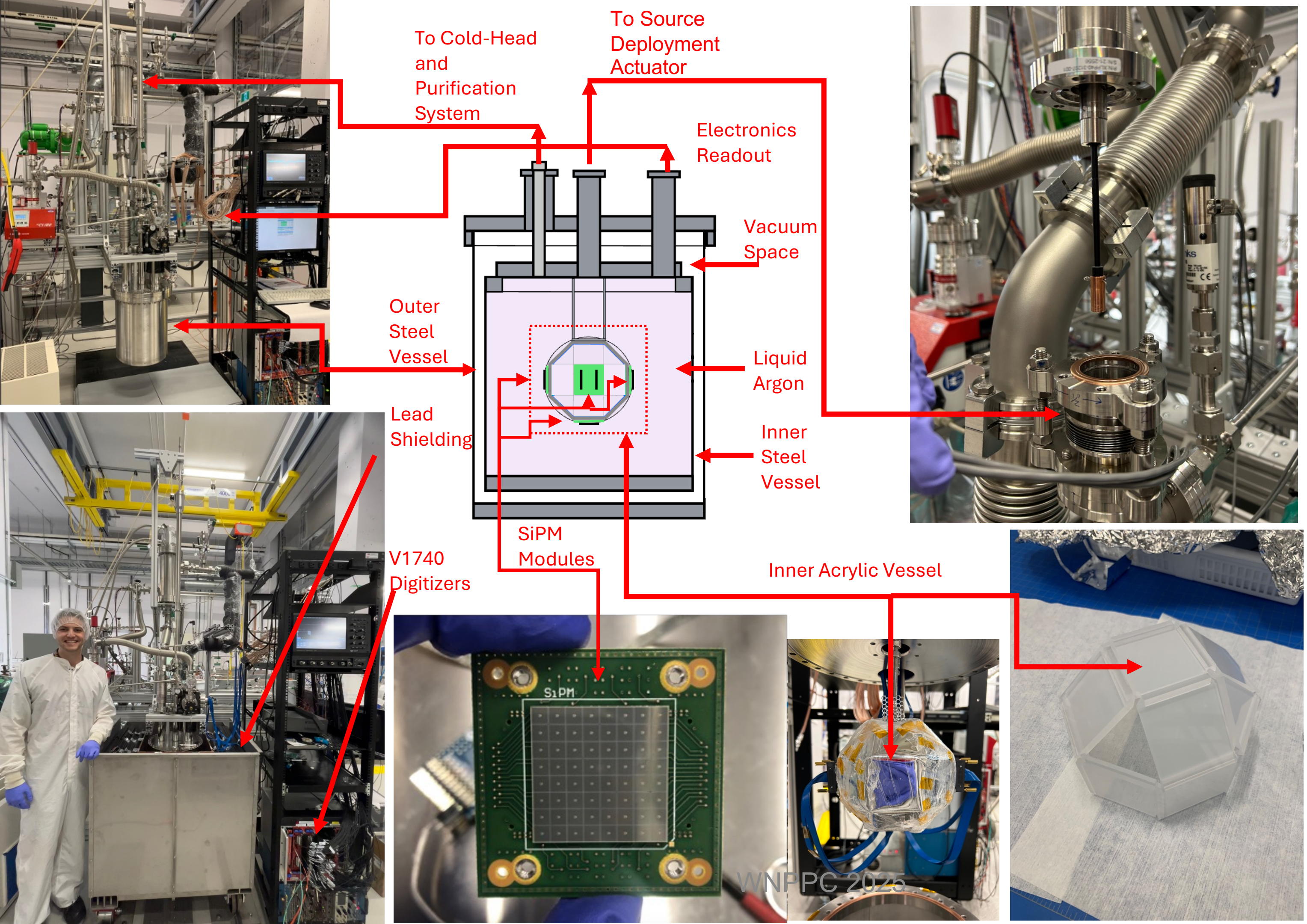

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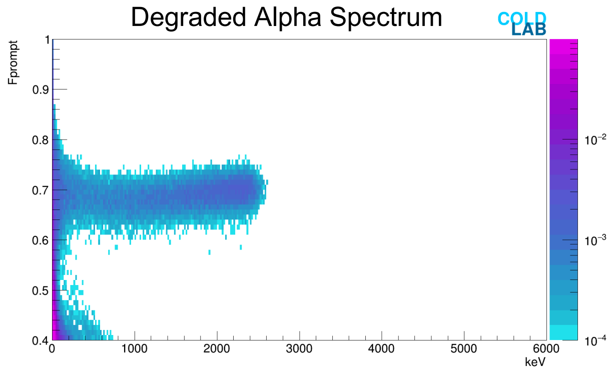
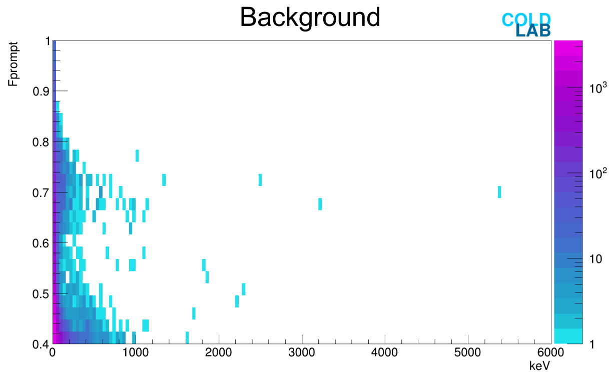
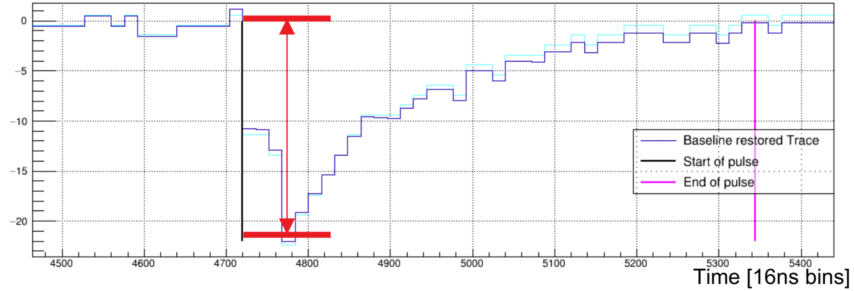
Argon-1 demonstrates pulseshape discrimination (PSD) with SiPMs

- SiPMs have a slower reset time than PMTs, making charge-based PSD difficult
- Using peak height information for SiPMs works quite well given uniform response, varying prompt window







$$\text{Fprompt} = \frac{\text{Prompt Light (0 − 250ns from trigger)}}{\text{Total Light (12000 ns)}}$$

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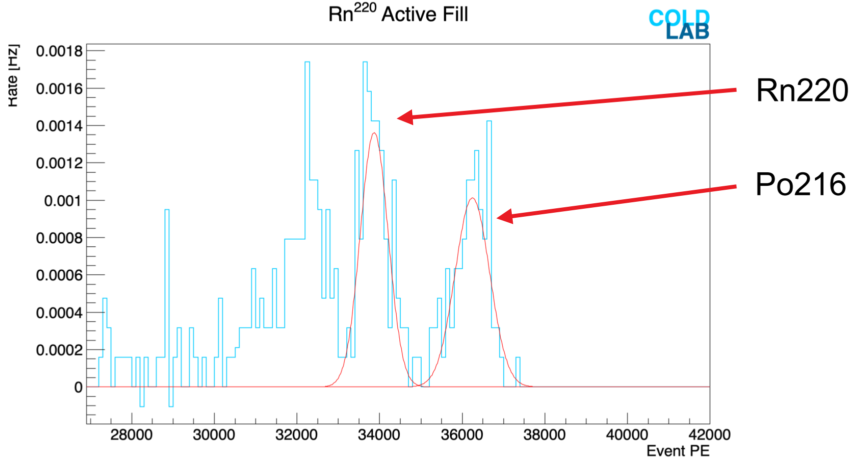
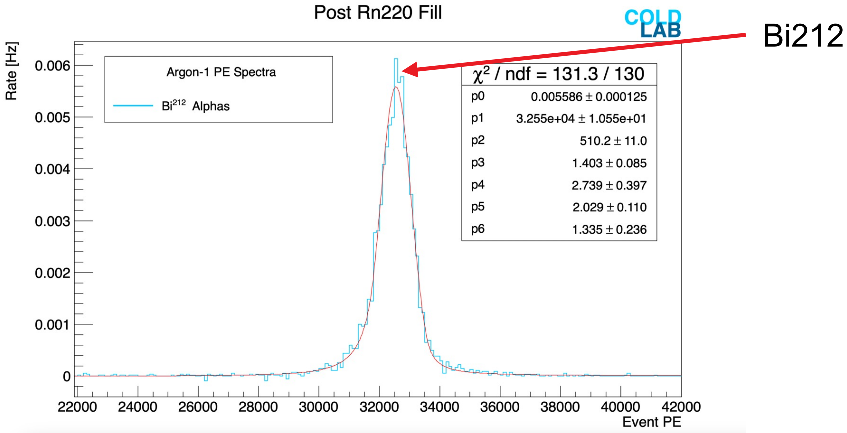
Extracting Quenching Factors





$$QF = \frac{\mu_{PE} - (T_d \times QF_d \times Y)}{Y \times (Q_\alpha - T_d)} \quad (5.3)$$

where μ_{PE} is the mean of the fit to the PE spectrum, T_d is the kinetic energy of the daughter nucleus, QF_d is the recoil heavy nucleus quenching factor, and Y is the light yield of Argon-1.

- Peaks fit; quenching calculation corrected for scintillation produced by daughter nucleus (data from https://www.nndc.bnl.gov/nudat3/)

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