

Dual-Phase Argon Detector Development at LLNL

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 **Lawrence Livermore
National Laboratory**

Workshop on
Low Threshold Detectors
for Detection of Coherent
Neutrino Scattering

Oct 15, 2012

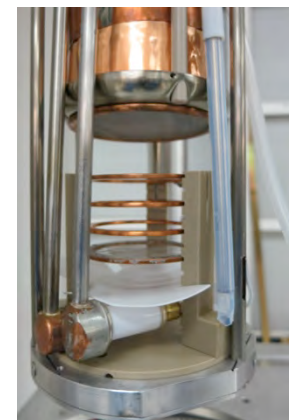
LLNL-PRES-XXXXXX

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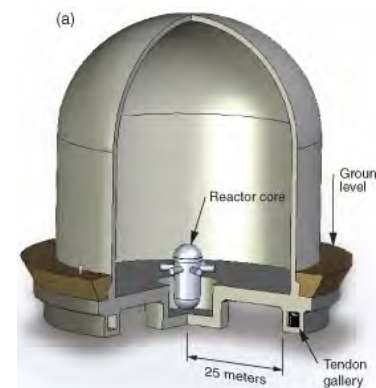


Overview of LLNL experimental program on LAr

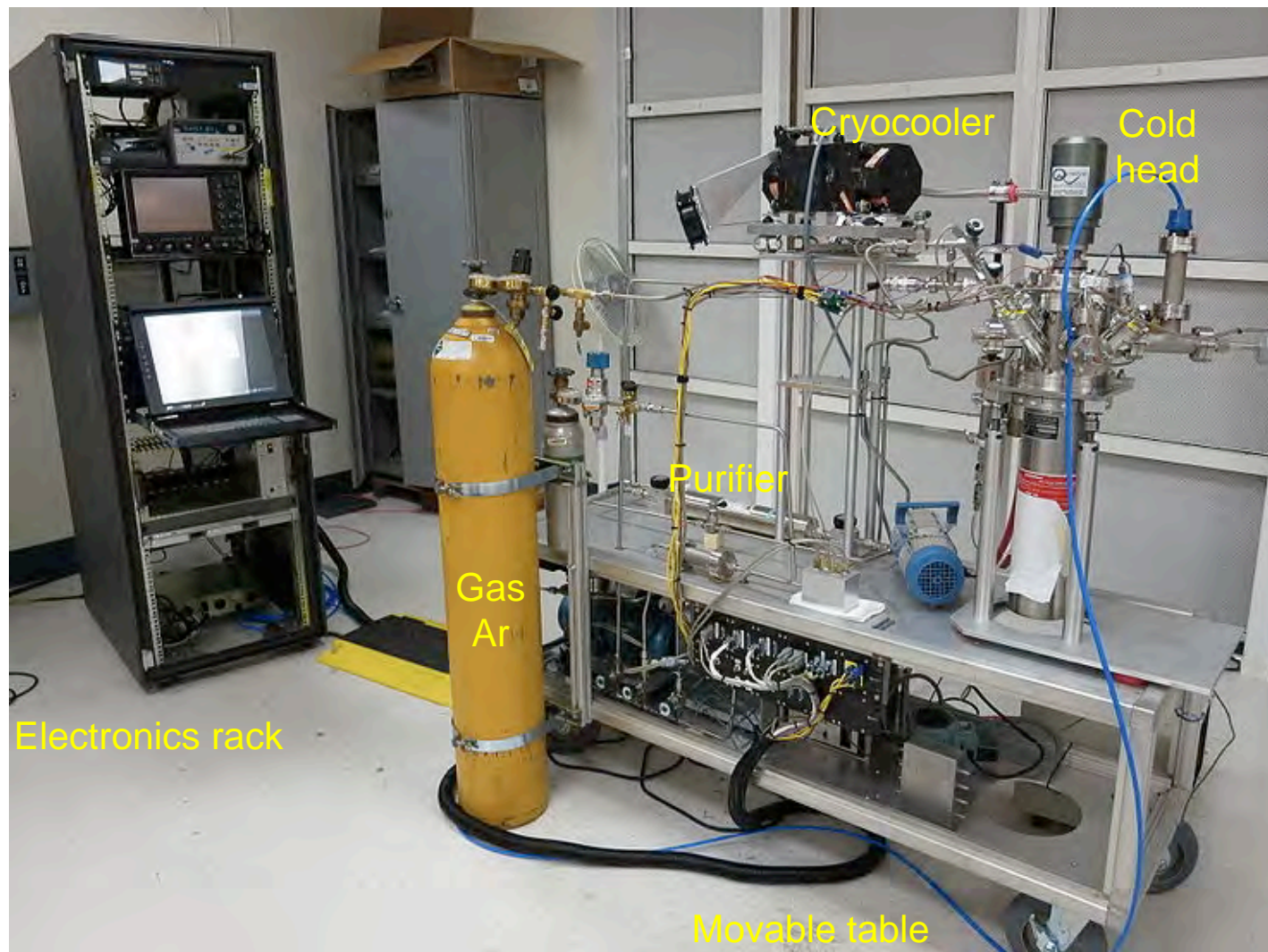
- **Single-phase detector [2007 – 2010]**
 - Understand the gaseous region of the proposed dual-phase detectors
 - Pulse Shape Modeling
- **Small (~100 g) dual-phase detector [since 2010]**
 - Develop an understanding of dual-phase detector design and operation
 - Study the ionization yield of nuclear recoils in liquid argon
- **Large (10 kg) dual-phase detector**
 - Study and suppress backgrounds
 - Deployment at a reactor. Look for variation of CNS signal due to outages
 - Detection of CNS!



More details in
M.Foxe and
T.Joshi talks

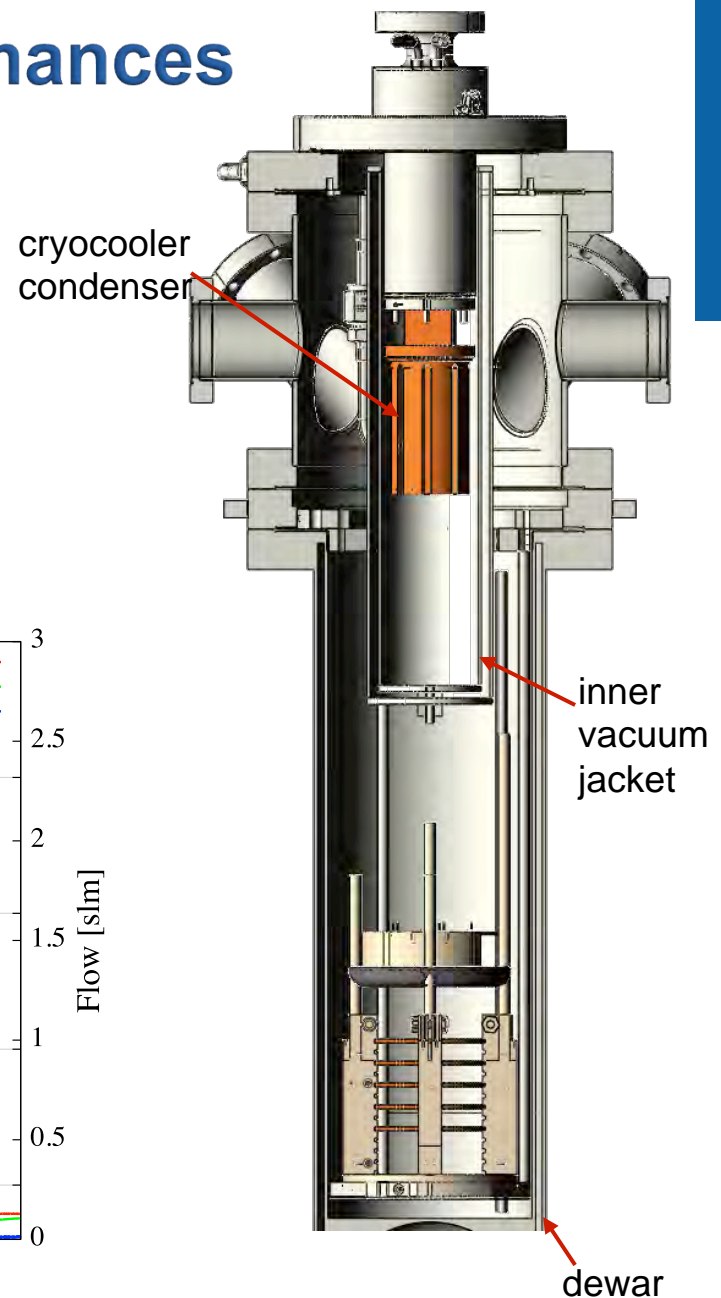
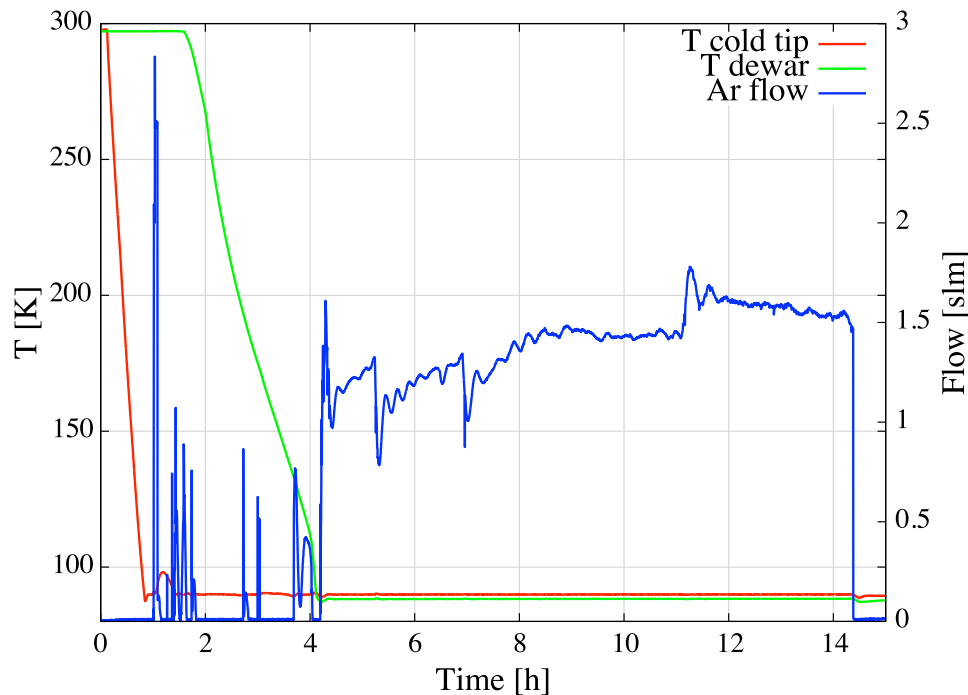


The Dual-Phase LAr Setup



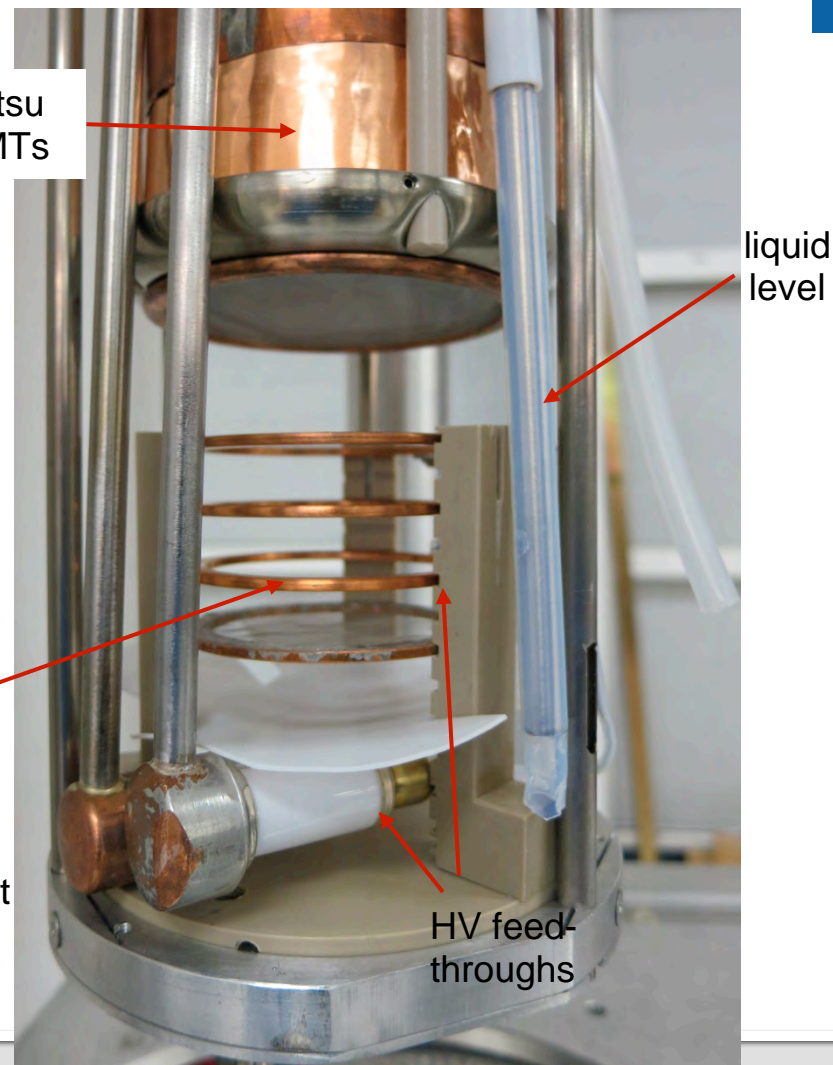
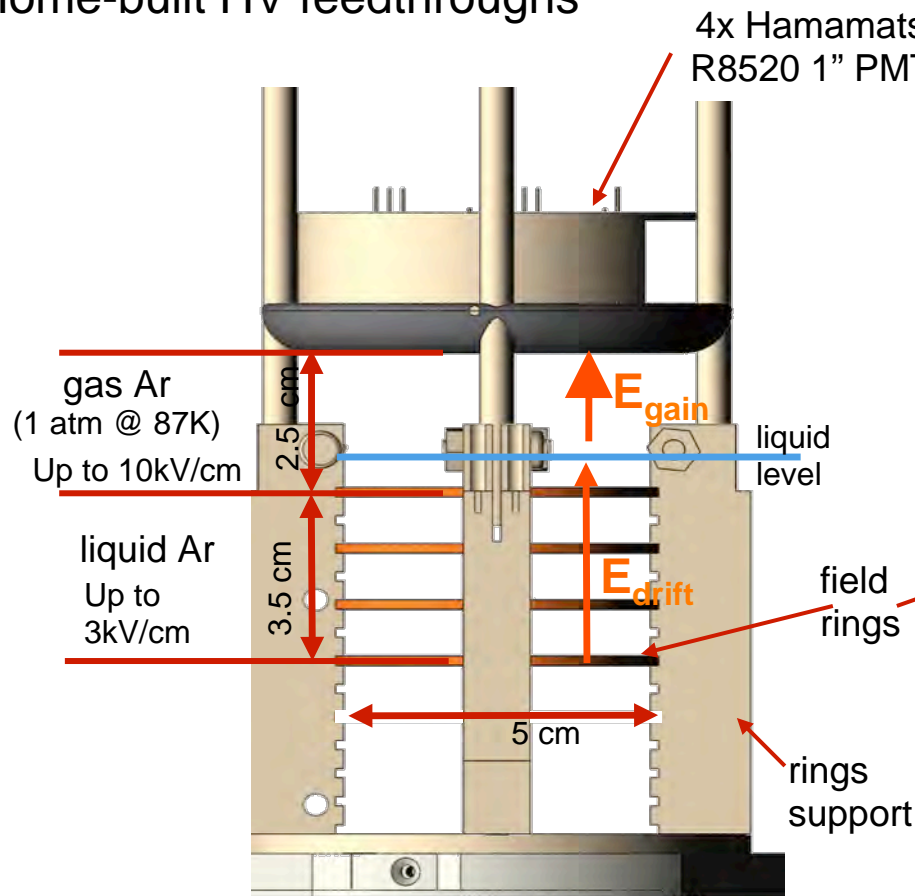
Cryogenic Operation & Performances

- In-situ production of LAr w/ cryocooler
- Automated cooldown and liquefaction in ~14h
- Temperature stability ± 0.05 K
- Total ~1 liter of Argon can be circulated 3-4 times per day



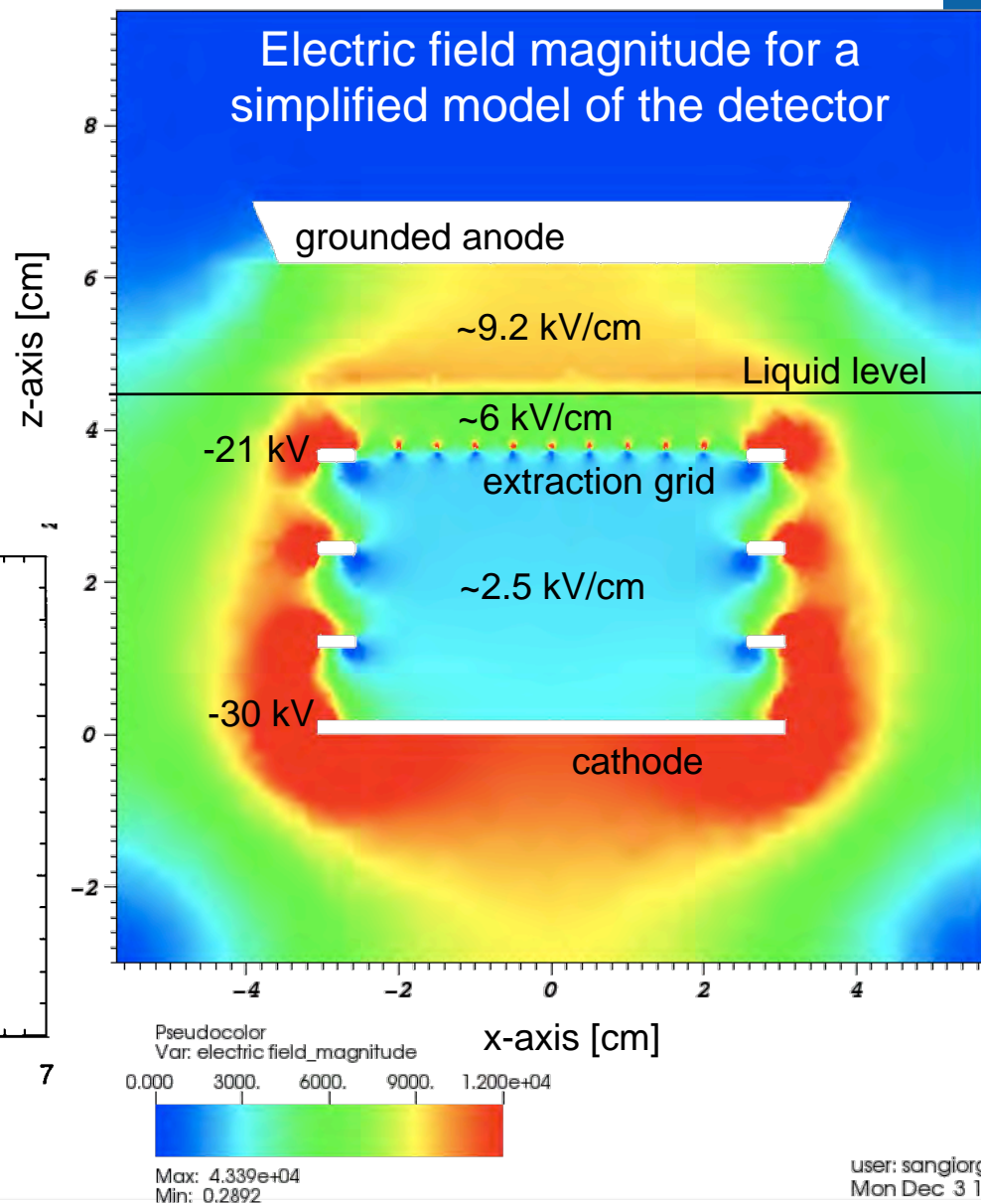
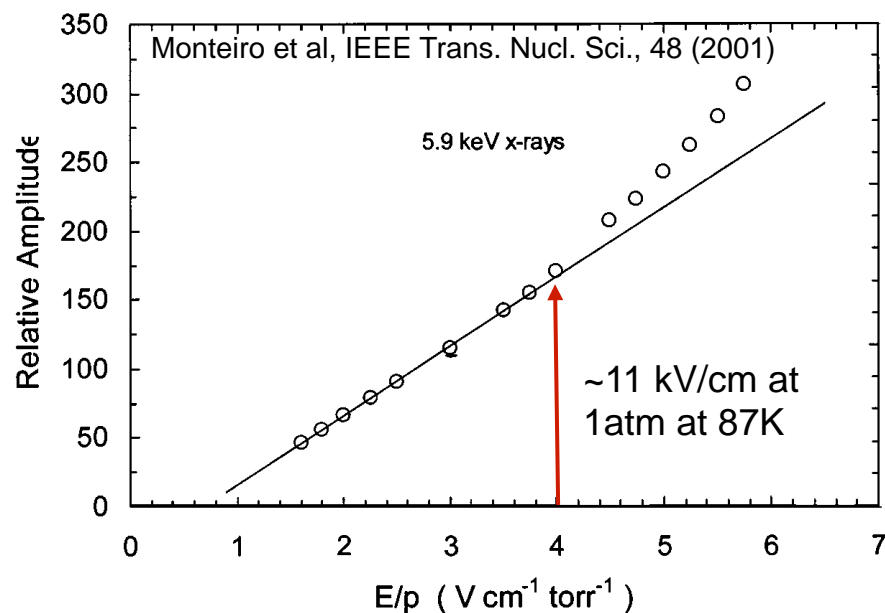
LLNL Dual-phase Ar Prototype Detector

- Active volume: ~ 100 g LAr
- Materials selected for low outgassing
- TPB as wavelength shifter
- Home-built HV feedthroughs



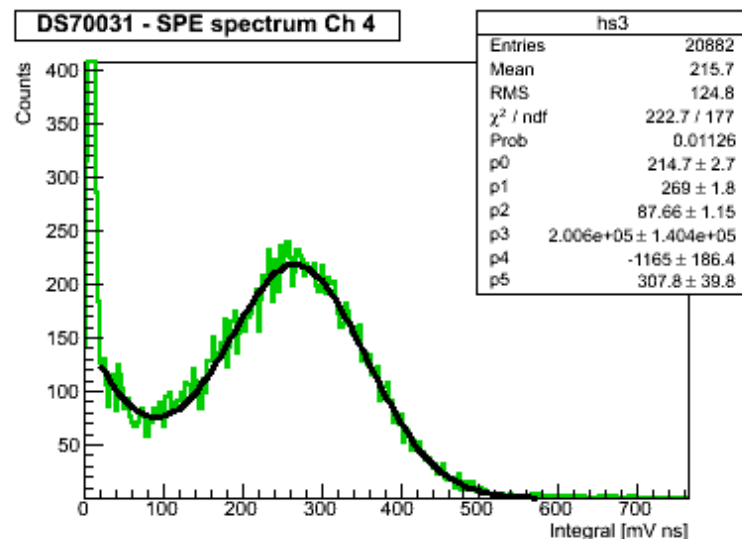
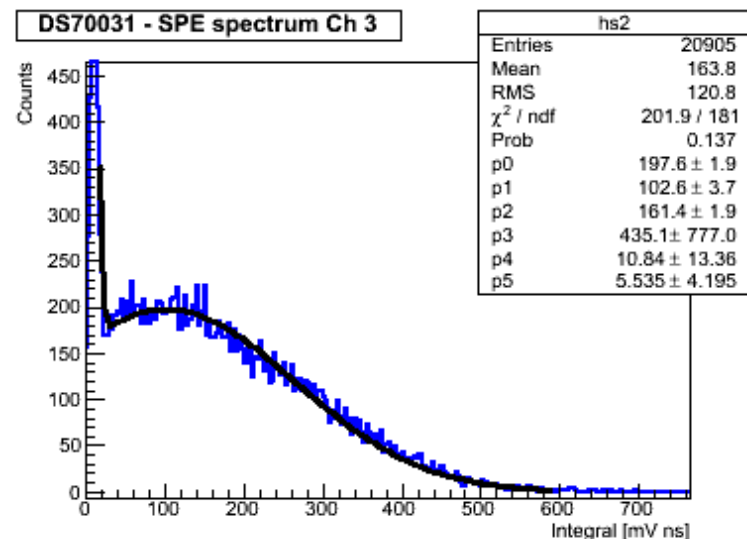
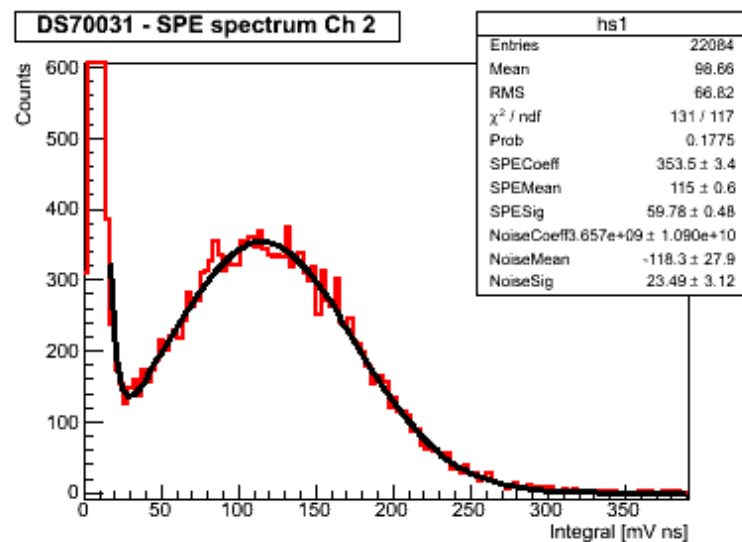
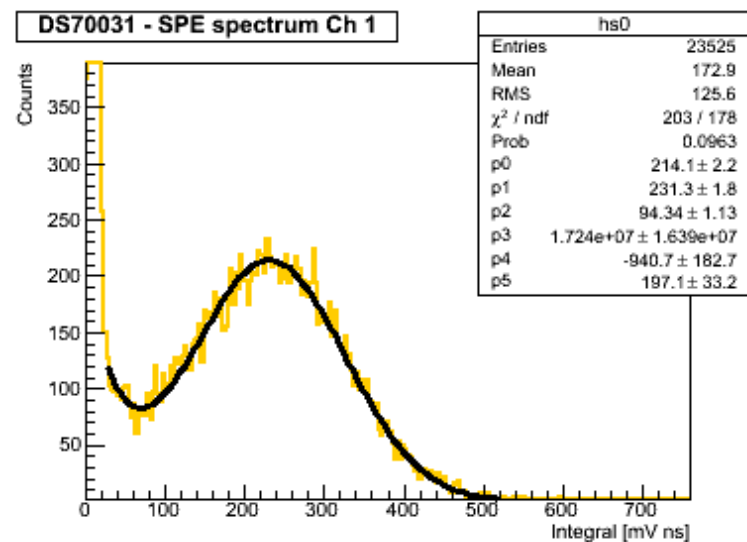
High Gain Detection of Ionization Signal

- Emphasis on detection of ionization by means of S2 only
- Operate close to electron multiplication in gas



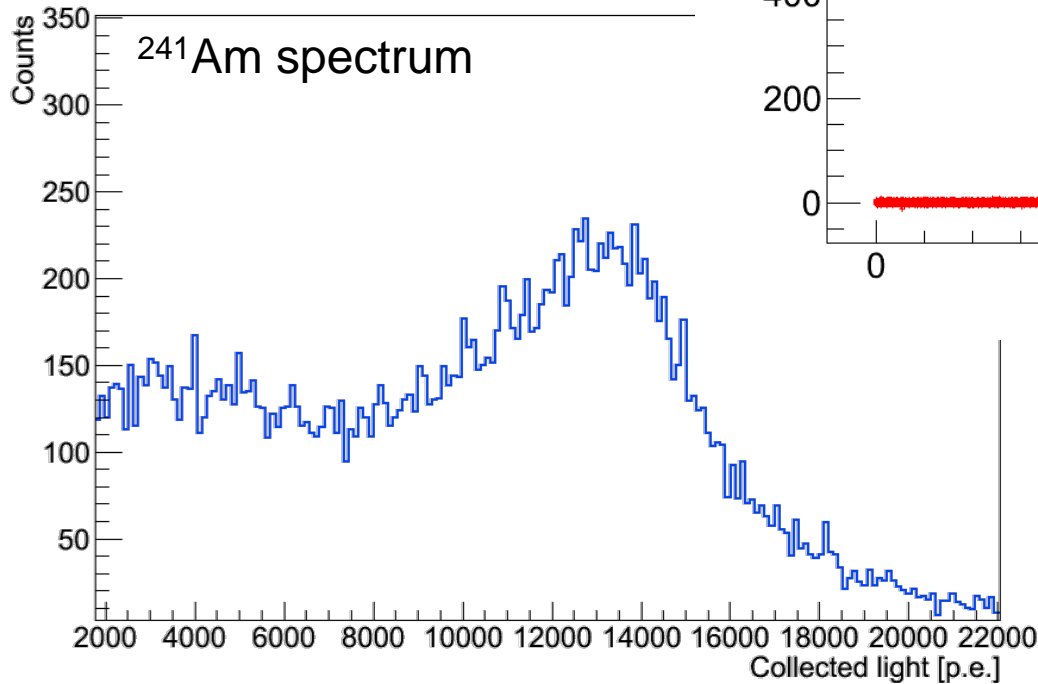
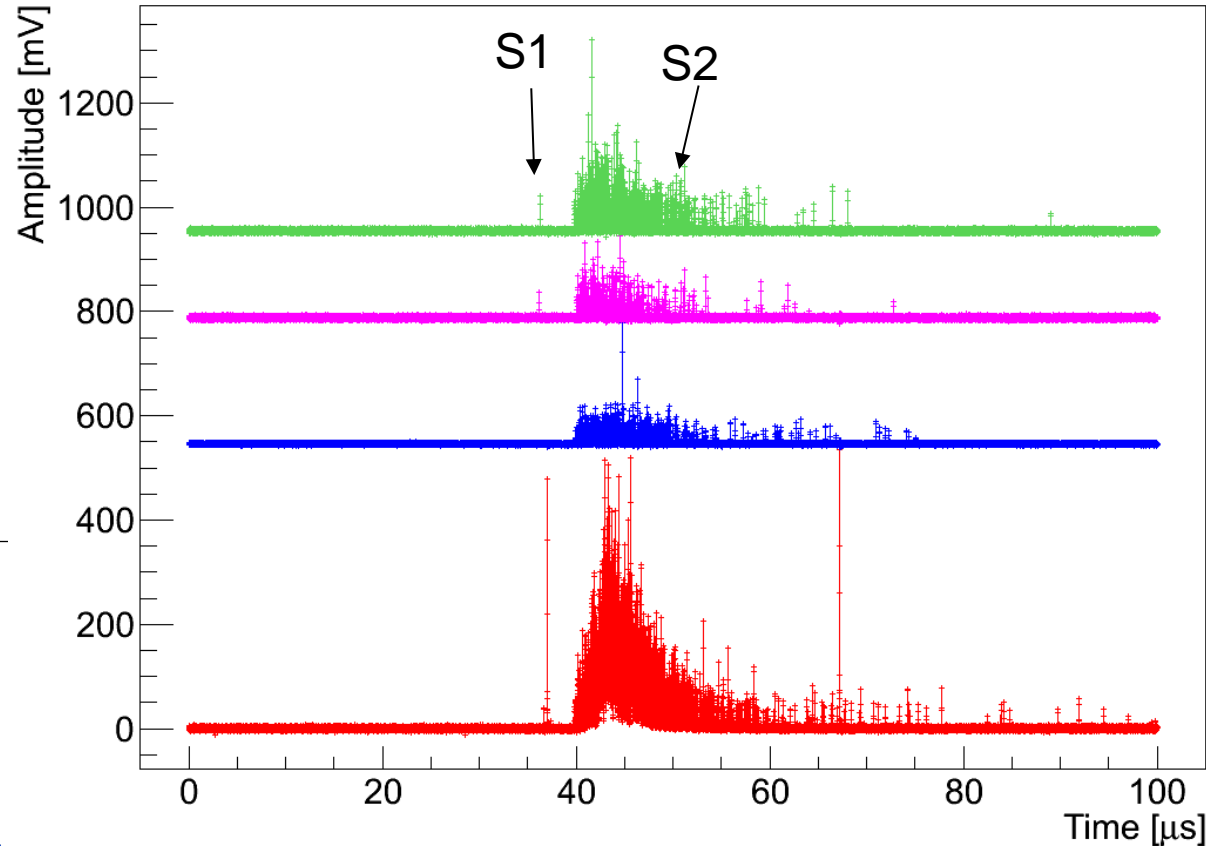
PMTs S.P.E. Response

Hamamatsu R8520 1" PMTs for cryogenic operation

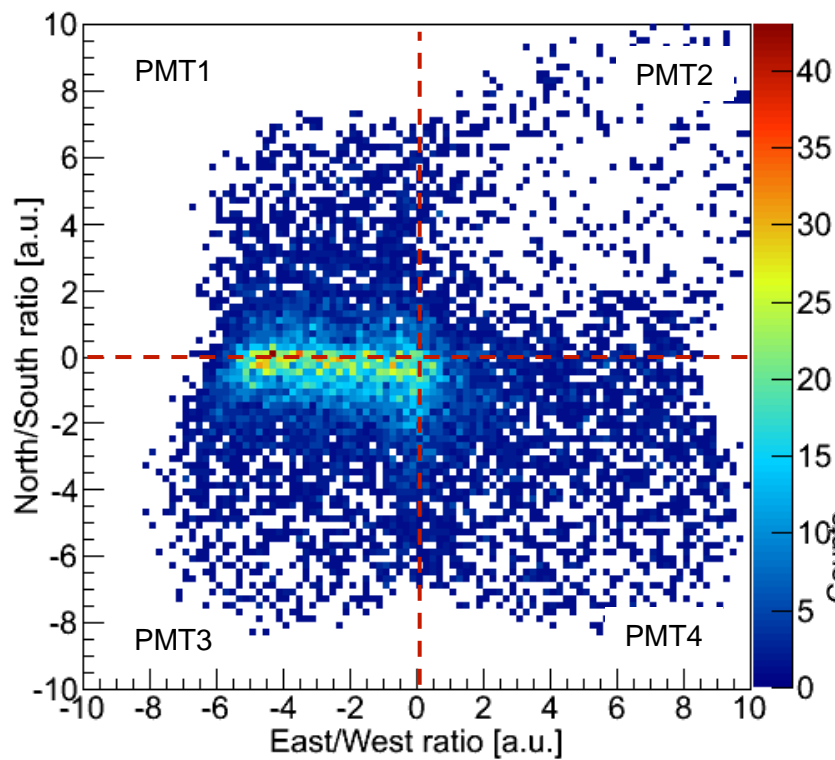


Detector Response

Sample event from a 60 keV photoelectric interaction in the detector as seen by the 4-PMT array



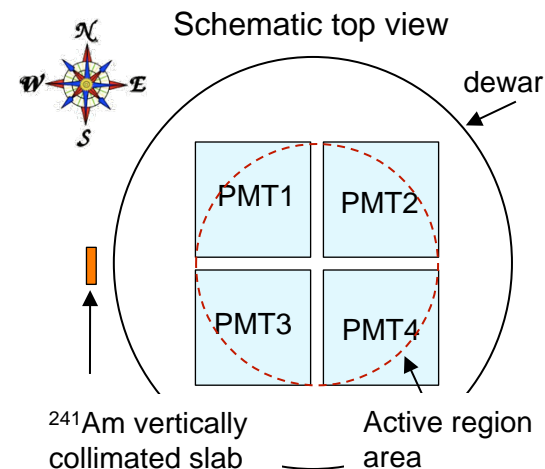
Event Localization



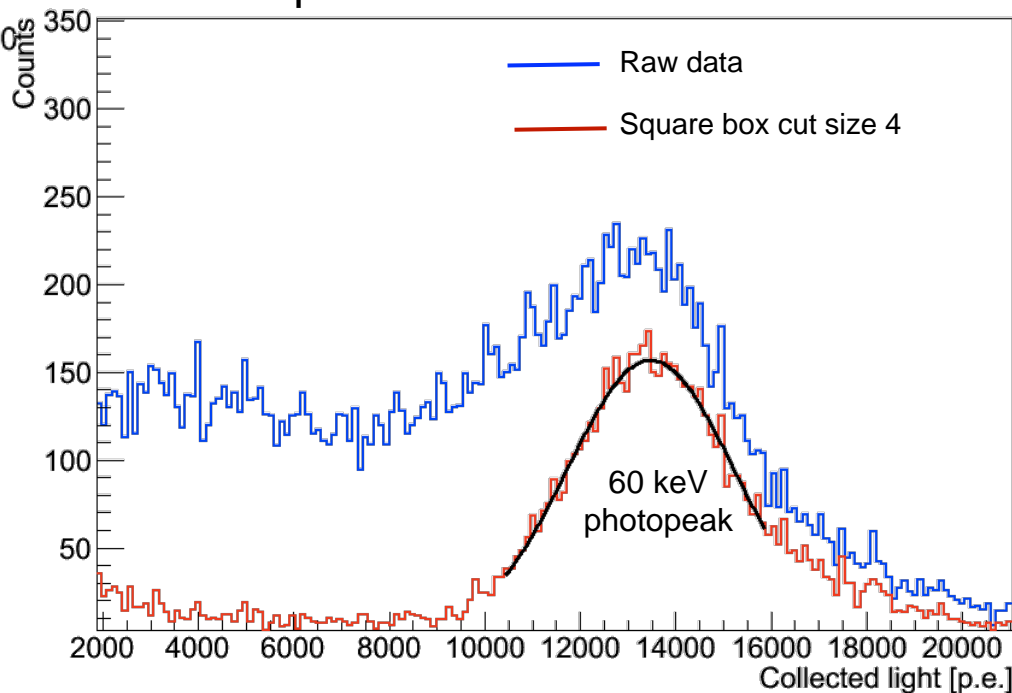
^{241}Am spectrum fiducial plot

$$\frac{\text{PMT1} + \text{PMT2}}{\text{PMT3} + \text{PMT4}}$$

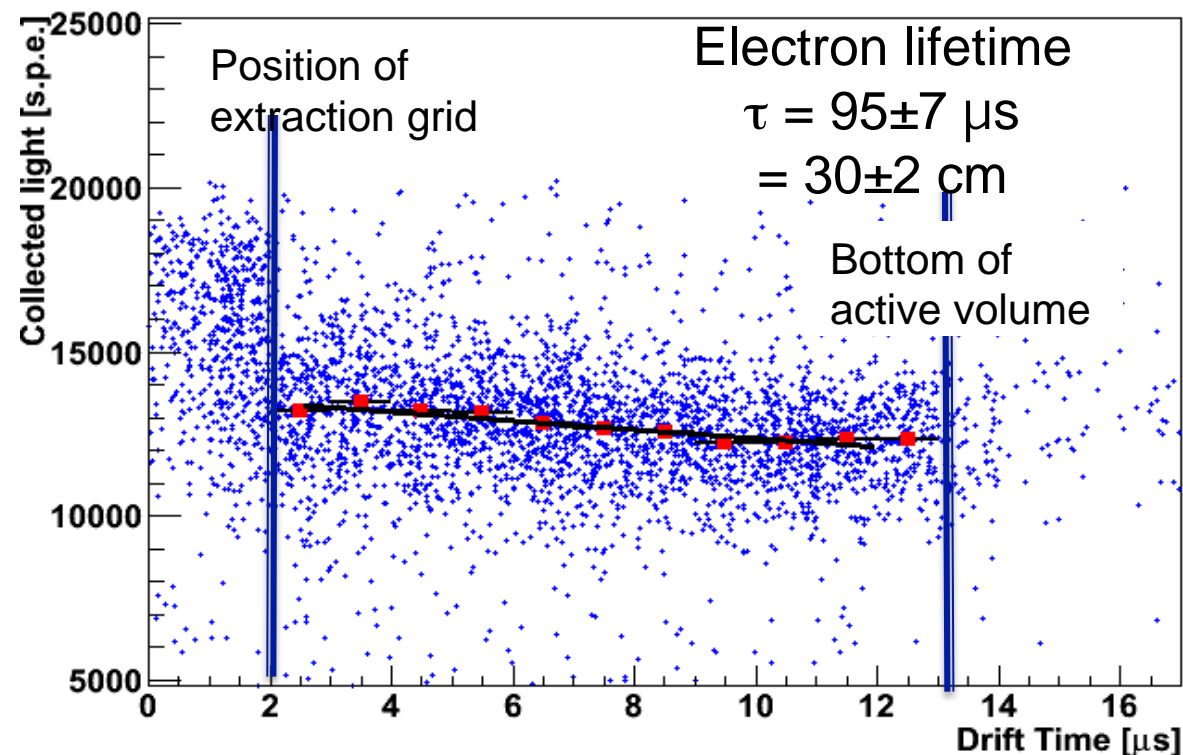
$$\frac{\text{PMT1} + \text{PMT3}}{\text{PMT2} + \text{PMT4}}$$



^{241}Am spectrum with fiducialization

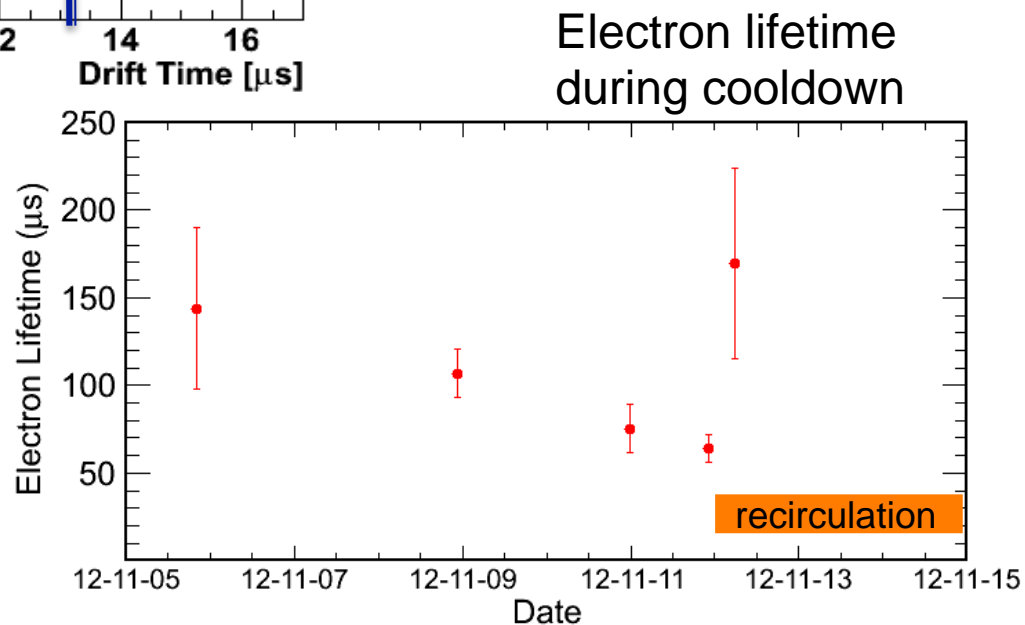


Long-lasting Argon Purity



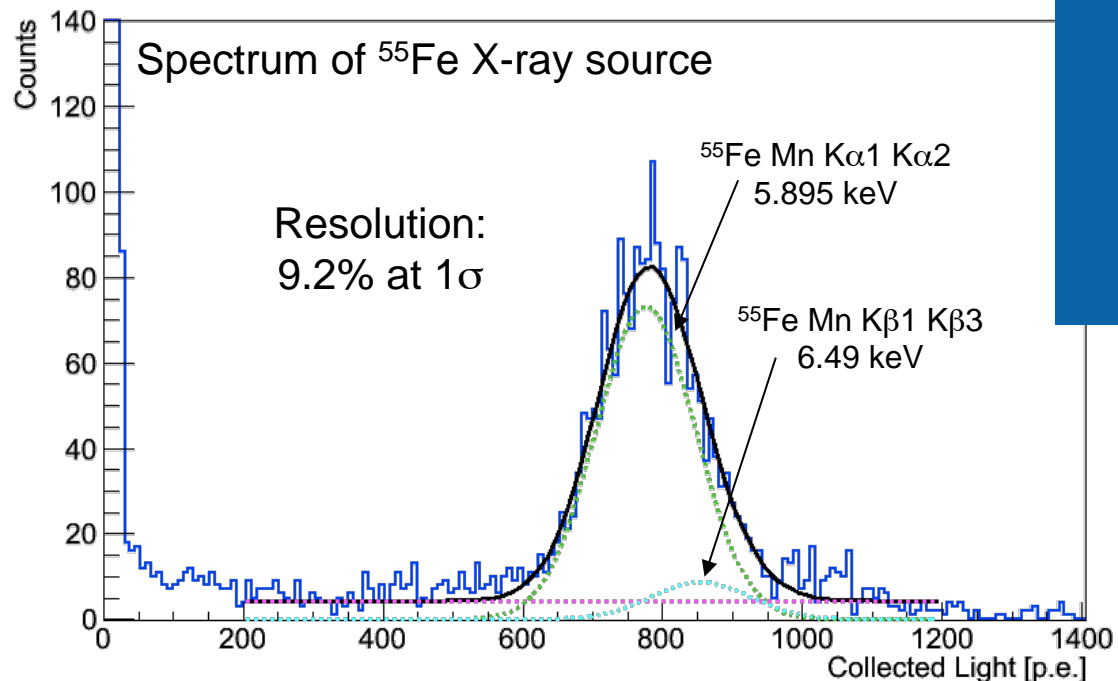
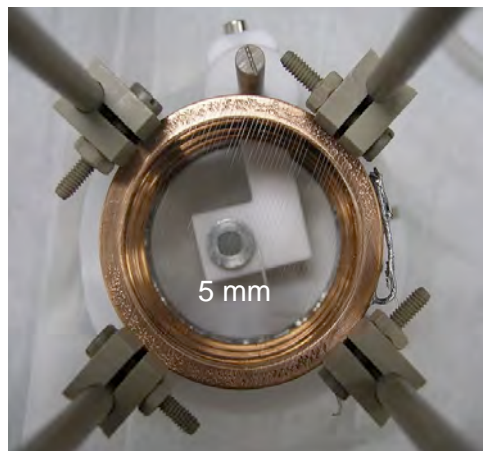
Plot of S2 amplitude in ^{241}Am photopeak as a function of depth extracted from S1-S2 time

Recirculation needed only after ~6.5 days



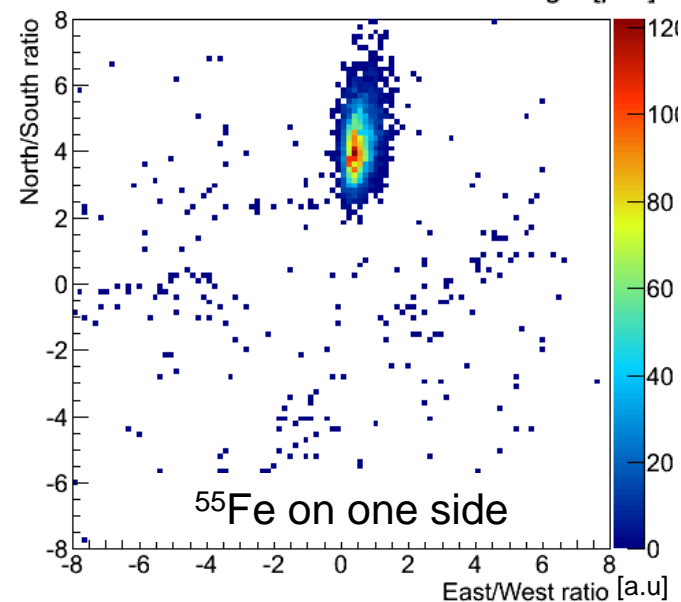
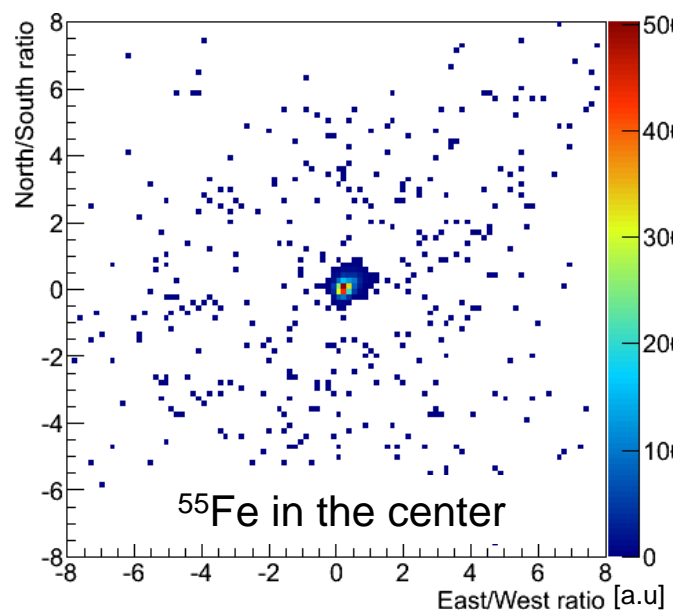
^{55}Fe Calibration

Electroplated $\sim 100\text{Bq}$
 ^{55}Fe on a movable arm



Under study:

- Mapping of fiducialization parameter space
- Position systematics



Novel Approach for Calibration: ^{37}Ar

Provides low-energy uniform calibration throughout the whole detector volume

Isotope production

Produced by neutron irradiation of $^{\text{nat}}\text{Ar}$ at a nuclear reactor

Decay scheme

100% electron capture

$t_{1/2} = 35.04 \text{ d}$

$Q(\text{gs}) = 813.5 \text{ keV}$

Decay radiation

K- capture **2.82 keV** (90.2%)

L- capture 0.27 keV (8.9%)

M- capture 0.02 keV (0.9%)

$^{\text{nat}}\text{Ar}$ isotopes

Mass number	Natural Abundance
40	99.6%
36	0.34%
38	0.06%

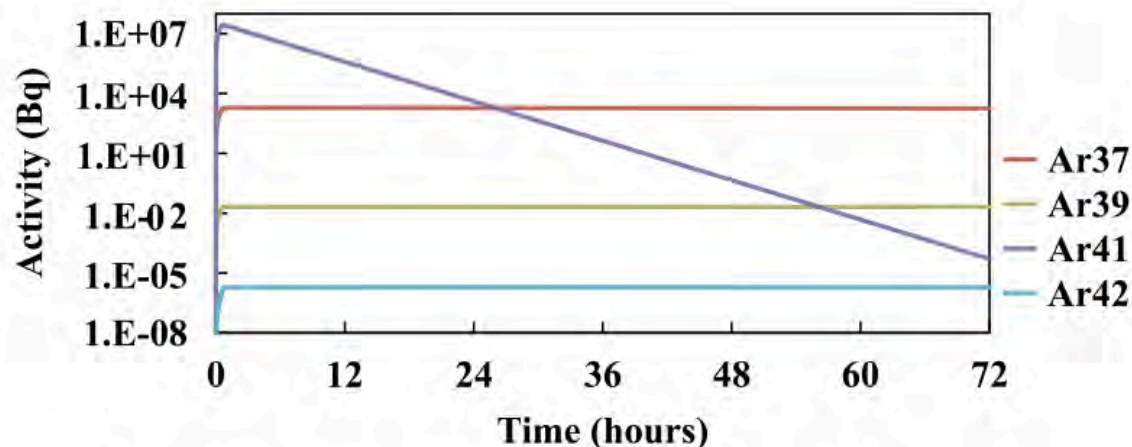


Fig. 1. Calculated activity of radioargon isotopes from 1 h, in-core neutron irradiation of 1 cm^3 of natural argon gas.

Barsanov, V. I. *et al. Phys. Atomic Nucl* **70** (2007).

Aalseth, C. E. *et al. NIM A* **652**, 58–61 (2011).

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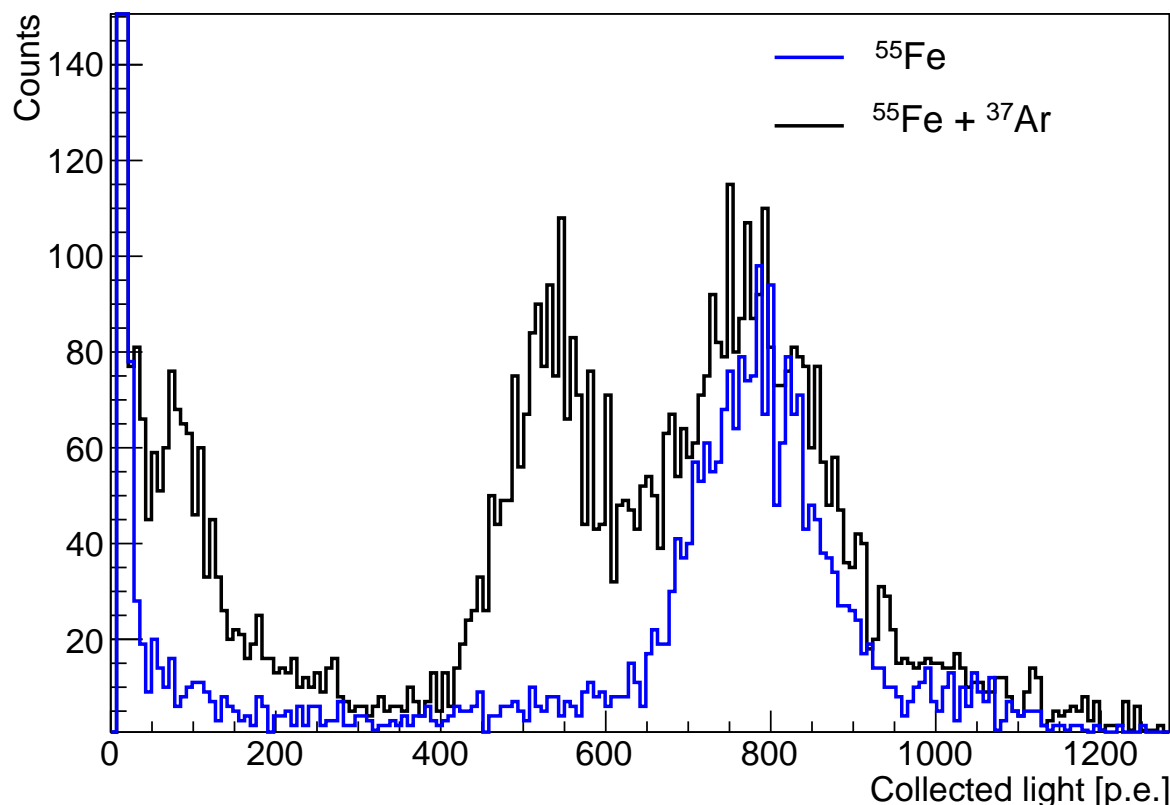
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Decay radiation

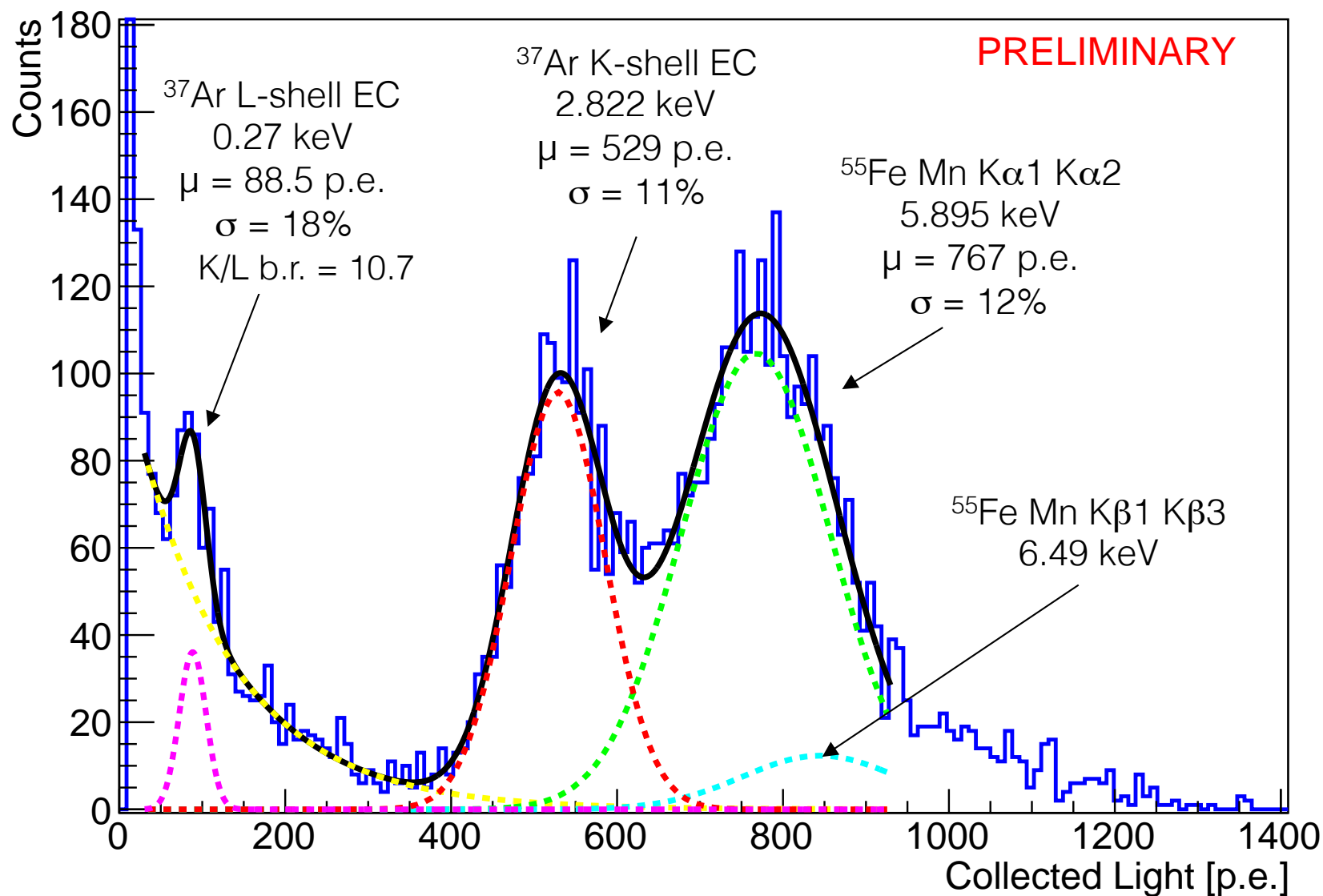
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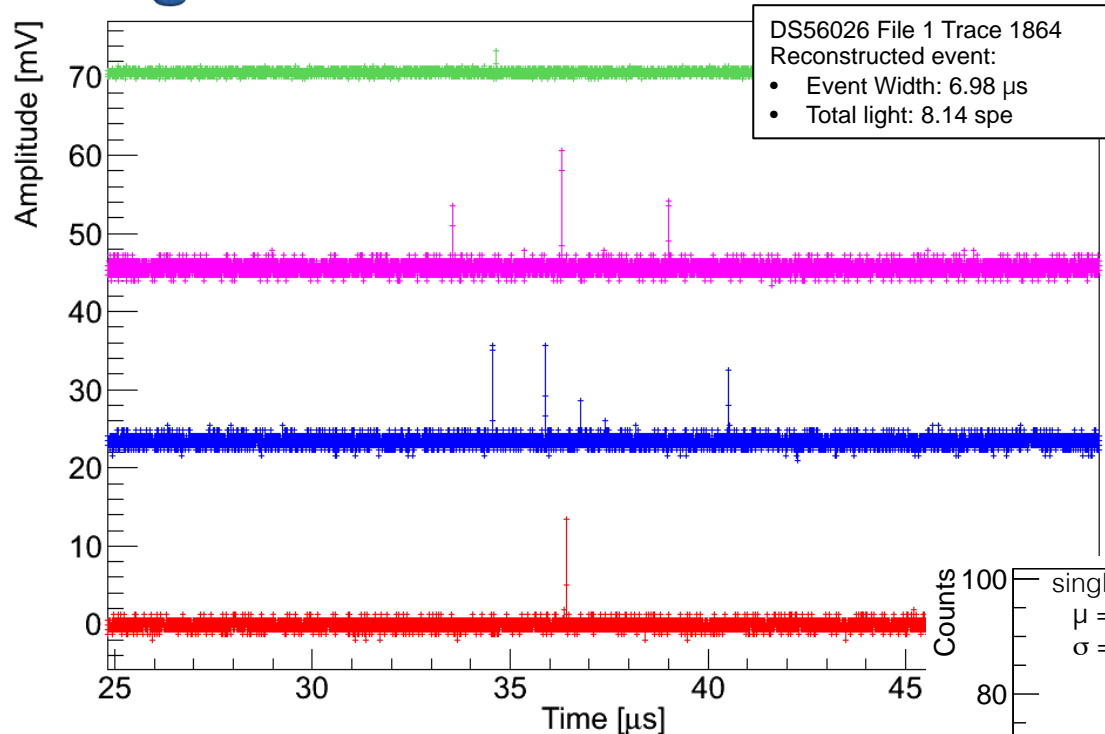
M- capture 0.02 keV (0.9%)



Sub-keV Sensitivity for Electron Recoils



Single Ionization Electrons

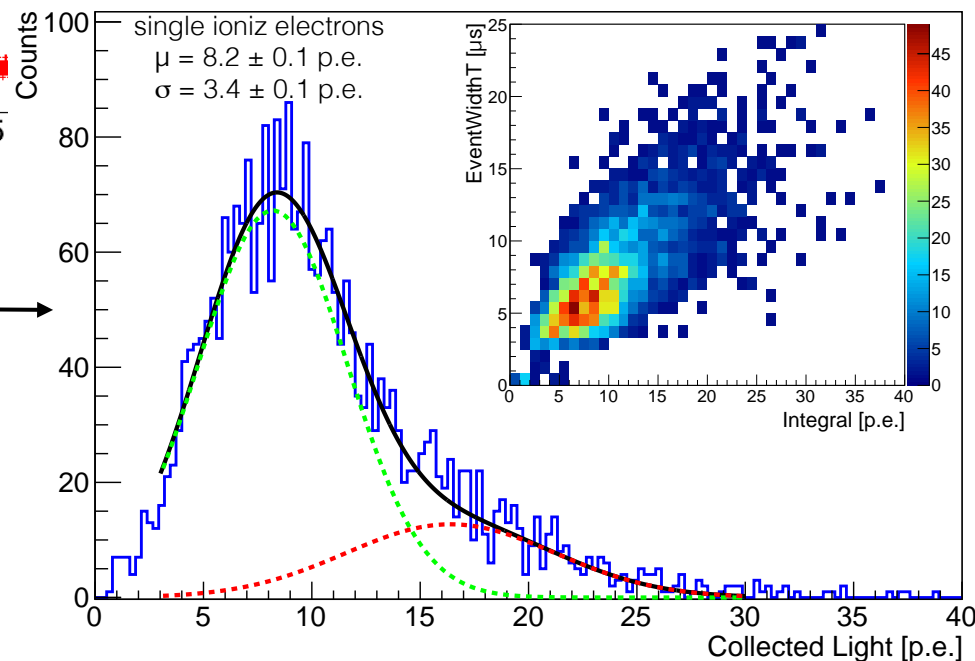


- Typical S.E. event as seen on the scope
- Full trace is 100μs long and has no s.p.e. other than those shown



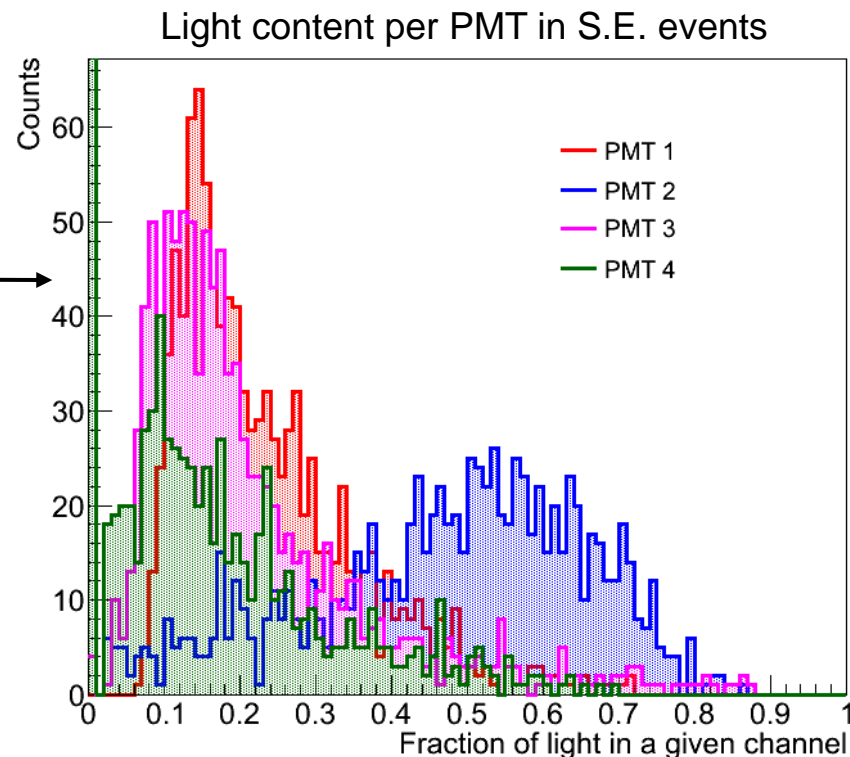
PRELIMINARY

- Experimental spectrum of single and double ionization electrons
- Not compatible with primary scintillation signal (S1) because:
 - Event width of 5-8 μs is too long
 - Light distribution not compatible with LAr S1 characteristics
 - Dependence on gain field



Single Electron Investigation in Progress

- S.E.s appearance has been seen in the aftermath of electrical discharges from the HV system, with rate decreasing with time
- S.E.s correlate with the presence of PTFE in the active region.
- Indications of S.E. production from a specific point in the detector from the light content per PMT
→
- Single Electrons:
 - Absolute detector calibration
 - Background for CNNs
 - Need to understand sources
 - Controlled production



Model of Ionization in Liquid Argon

Initial ionization from energy partitioning between ionization and excitation:

$$N_i = \frac{E_{er}}{w_q} \frac{1}{(1 + N_{ex}/N_i)}$$

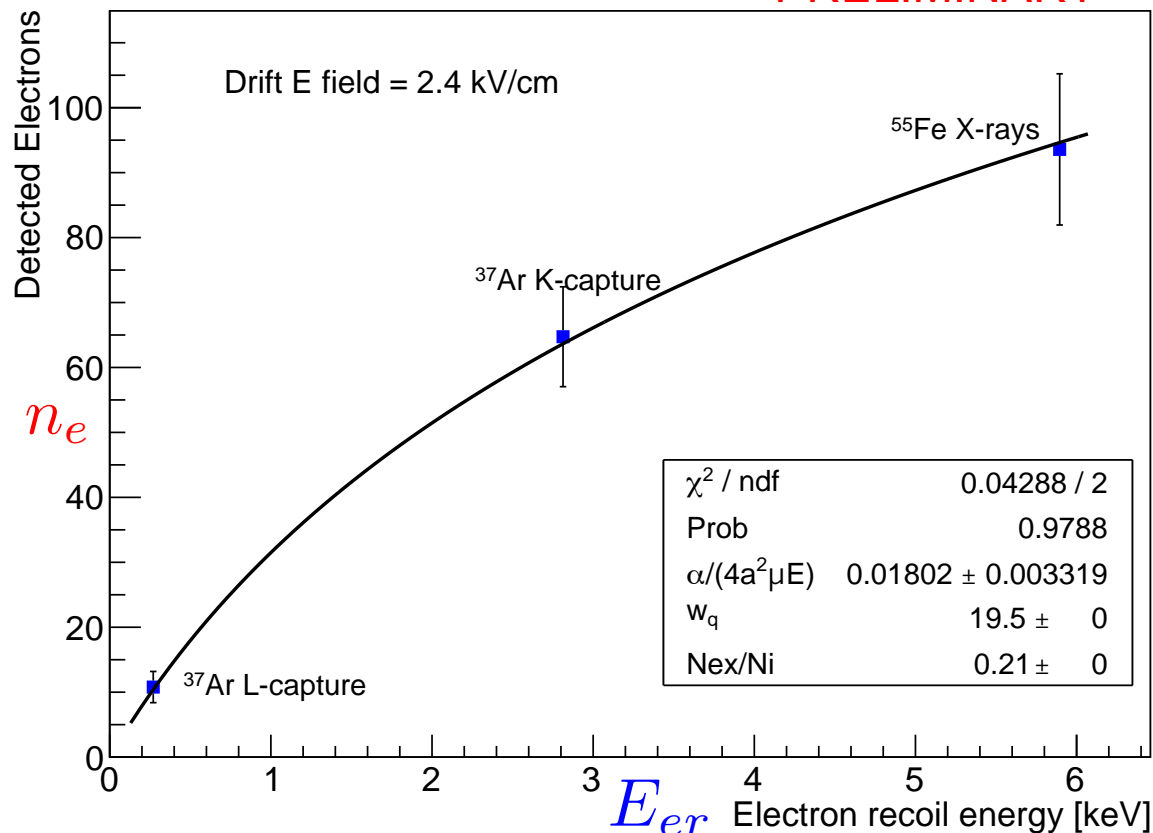
Assume Thomas-Imel box model of recombination:

$$\frac{n_e}{N_i} = \frac{1}{\xi} \ln(1 + \xi)$$

$$\xi = \frac{N_i \alpha}{4a^2 u E}$$

constant single
fit parameter

PRELIMINARY



Cfr. Sorensen, P. and Dahl, C. E., *Phys. Rev. D.* **83** (2011)

Further discussions in M.Foxe and P. Sorensen talks

Future detector development

- Detector has capabilities to observe nuclear recoils $> 2\text{keVr}$ for reasonable quenching values (> 0.1).
- Planned measurement at LLNL.
- Detector improvements are being considered to:
 - extend sensitivity to lower energies
 - reduce measurement uncertainties
- Understanding of few-electrons processes is critical for CNNS (and Dark Matter)
- Need better single electron resolution
 - by reducing known detector systematics
 - by increasing production and/or collection of secondary light

More details in
M.Foxe and
T.Joshi talks

Conclusions

- LLNL LAr detector:
 - Single electrons: achieved lowest detector sensitivity
 - Demonstrated sub-keV spectroscopy with LAr
- Ready to measure low energy nuclear recoils in LAr
 - determine ionization yield
 - key to assess CNNS feasibility
- Next:
 - Understanding and suppressing backgrounds in a large detector
 - CNNS detection!