Argon-1 @ Carleton

An R&D detector for next generation liquid argon experiments

CAP Congress – June 9th 2021

Speaker: David Gallacher (MSc. Student)

+ Mark Boulay, Michael Perry, Ryan Crampton, Jeff Mason, Vance Strickland, Jason Antsey

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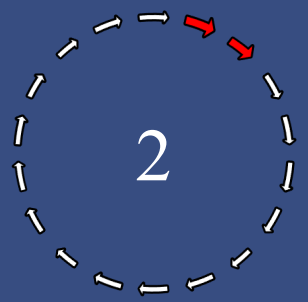
Talk Trajectory



- Introduction and Motivation
- Argon-1 Detector and Physics Goals
- Preliminary Detector Data

Introduction

And The Future of Single-Phase LAr DM Detectors

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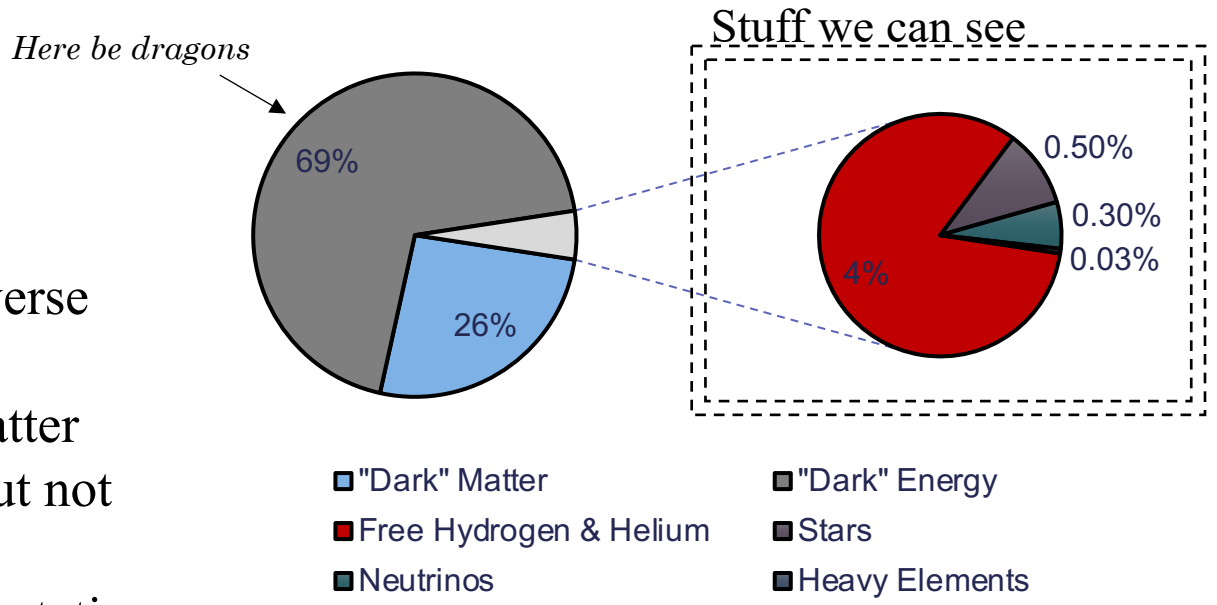
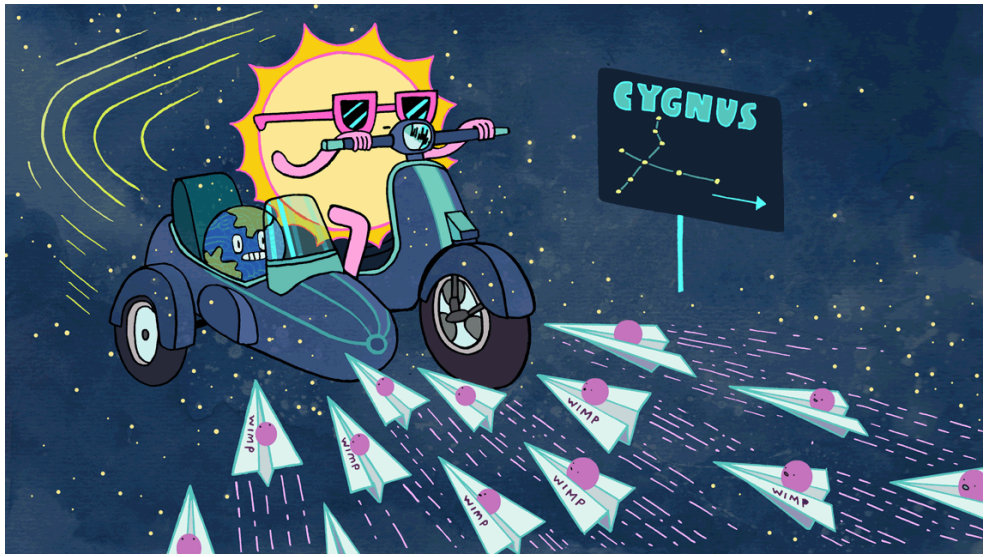
Introduction

What's the matter?

- Only ~5% of energy in the universe makes up "Normal Matter"
- ~26% in "Dark" or invisible matter
  - Interacts through gravity but not with light
  - Well known from galactic rotation curves and CMBR data (Gravitational signatures)
- Question:
  - What makes up this missing matter?
- Possible candidates:
  - Cold dark baryonic matter?
  - Rogue black holes?
  - New particle(s)?





WIMPs: Weaky Interacting Massive Particles.
A highly motivated candidate for particle DM

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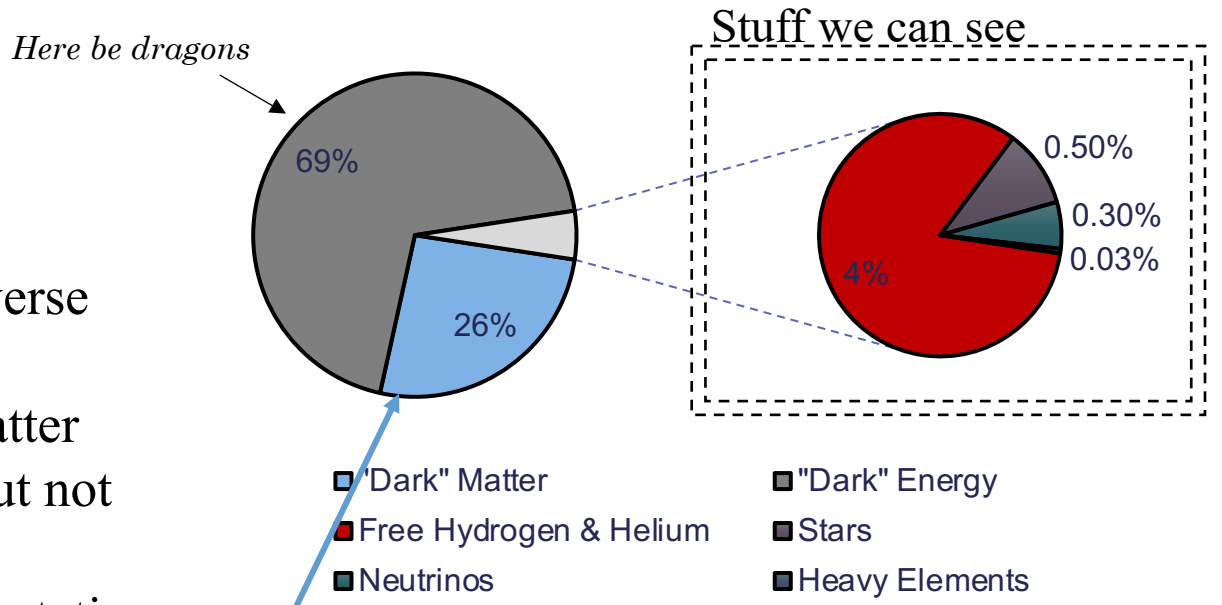
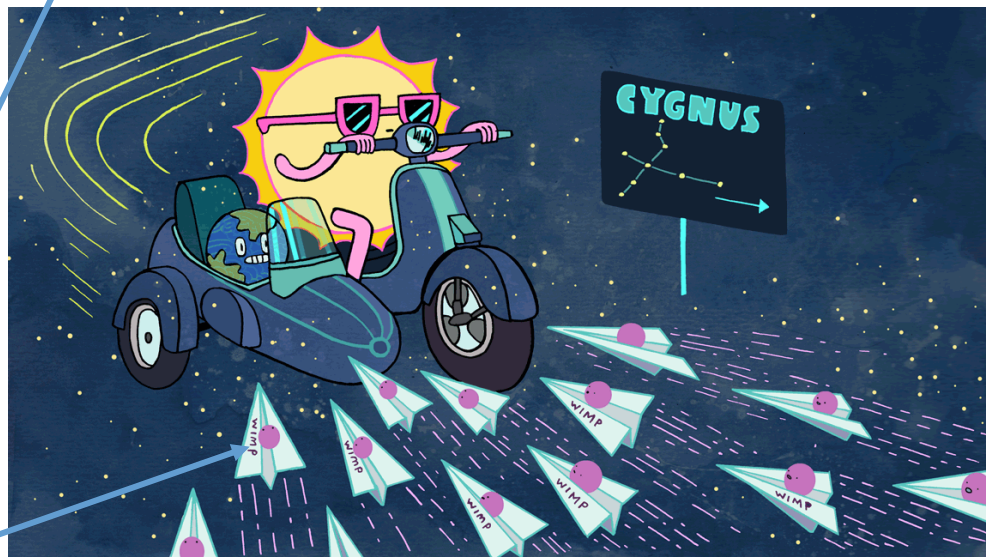
  - New particle(s)?
    - **This is where we search!**





WIMPs: Weaky Interacting Massive Particles.
A highly motivated candidate for particle DM

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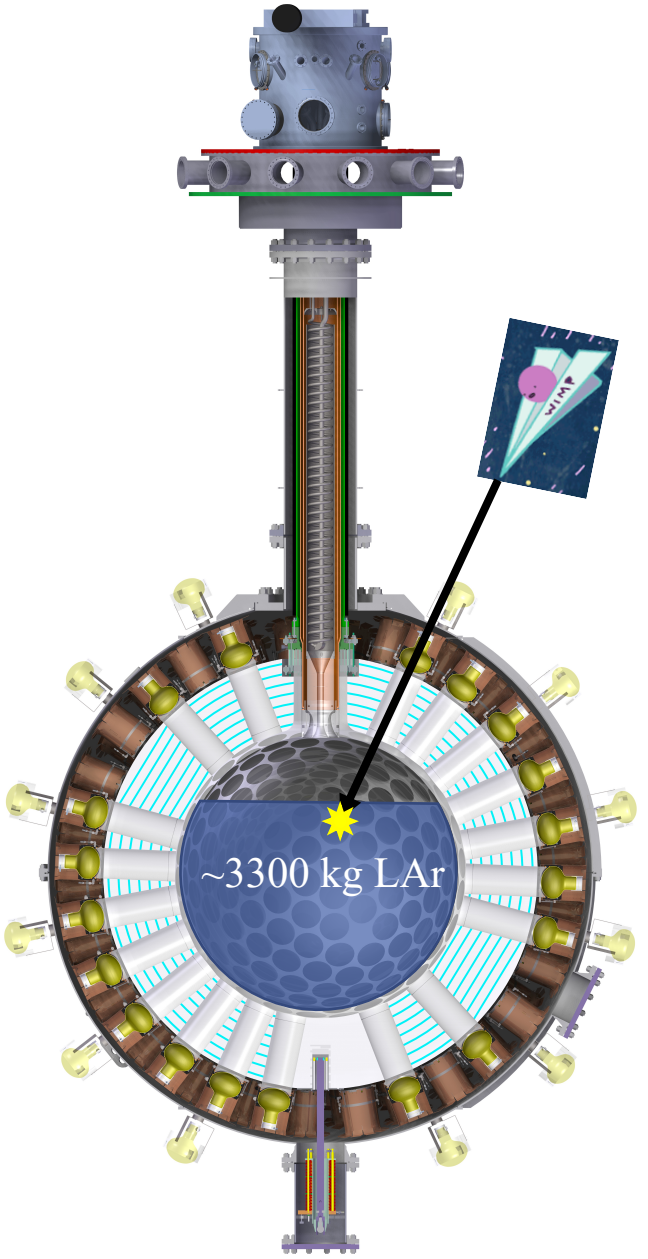
Introduction

DEAP-3600

- DEAP-3600 is a direct dark matter search experiment collecting data at SNOLAB since 2016
- Single Phase liquid argon (LAr) detector:
  - WIMPs interact with Ar nuclei, which creates scintillation light
  - Photons from LAr (128 nm) scintillation are shifted to visible (~ 420 nm) by TPB coating on vessel
- Uses pulse-shape discrimination (PSD) to separate signal-like (WIMP DM) and background-like events (Predominantly Ar39 decays)
  - Singlet decay time τ_s ~ 6 ns
  - Triplet decay time τ_t ~ 1400 ns



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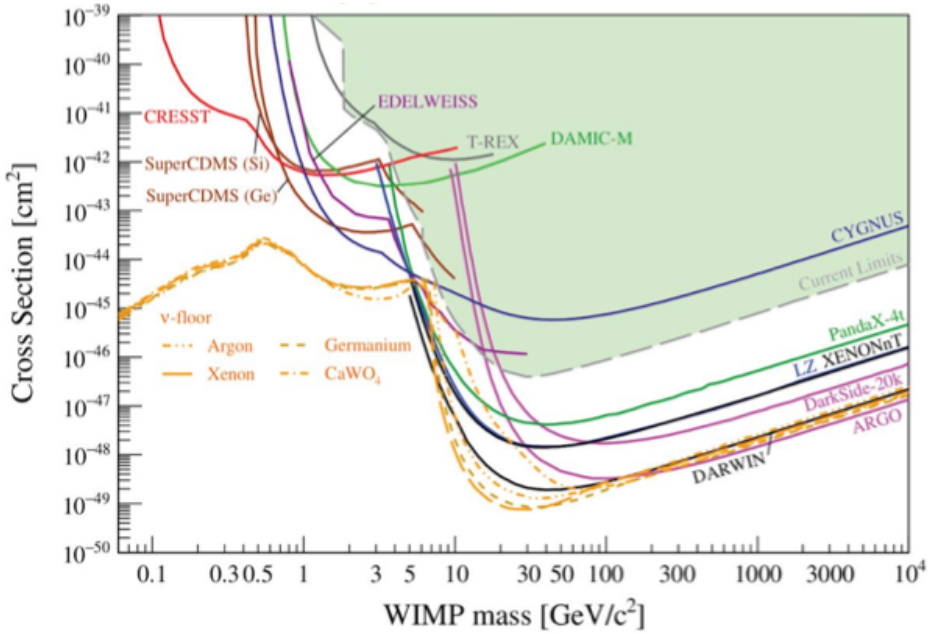
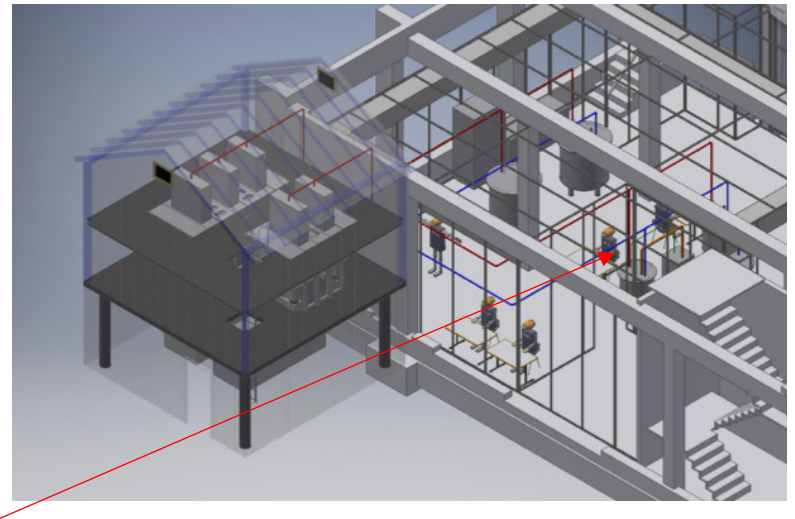
Introduction

Beyond DEAP

- Researchers from DEAP, Darkside, MiniCLEAN, and ArDM + more, have come together to form the Global Argon Dark Matter Collaboration
- Research and development efforts are directed towards a next generation O(100t) LAr detector
- Proposed experiment ‘ARGO’ will have sensitivity to the argon neutrino floor
- COLD Lab at Carleton will play a major role in this R&D





Carleton Noble Liquid Detector Lab

Argon-1

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Introduction

Beyond DEAP

See Mark Boulay's talk (Development of the ARGO dark matter experiment) [Thursday @ 2:30 R-PPD] for more details!

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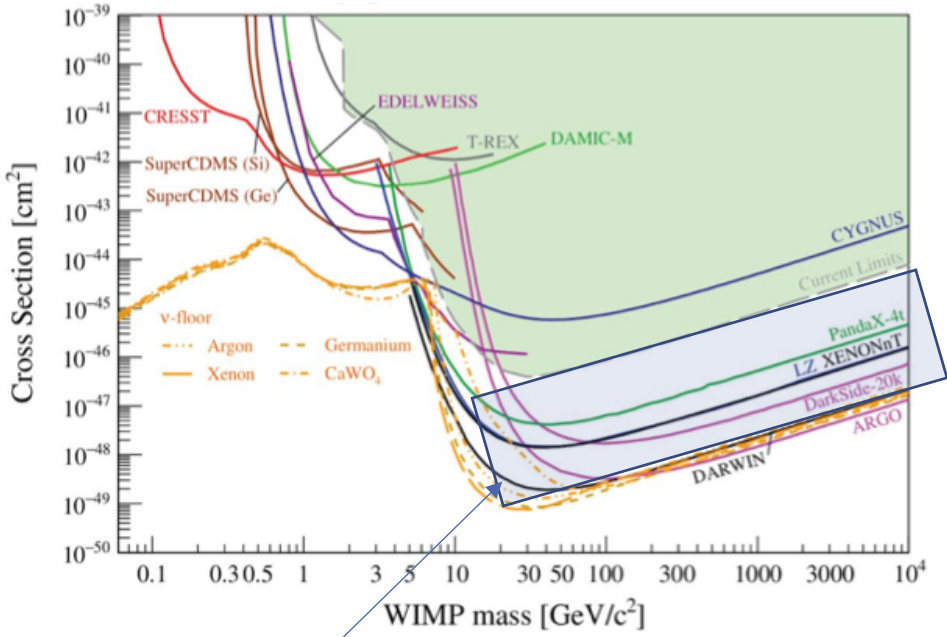

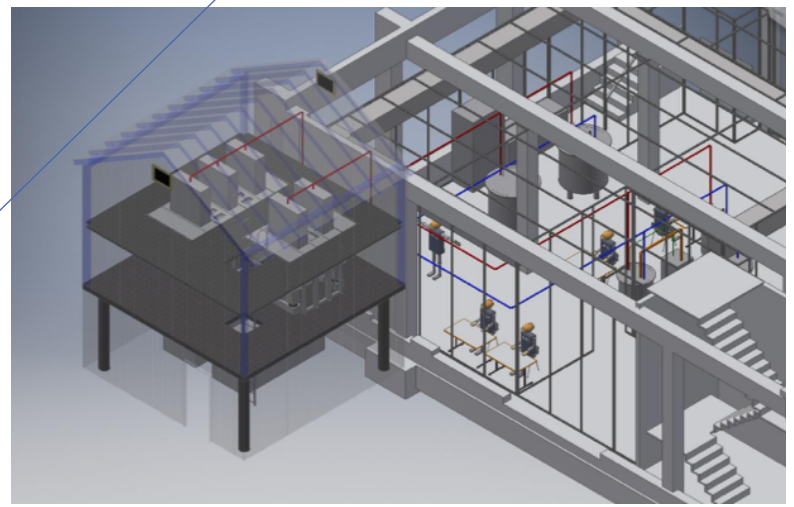

Carleton Noble Liquid Detector Lab

Lots of parameter space left to explore

Argon-1

The Detector and Physics Goals

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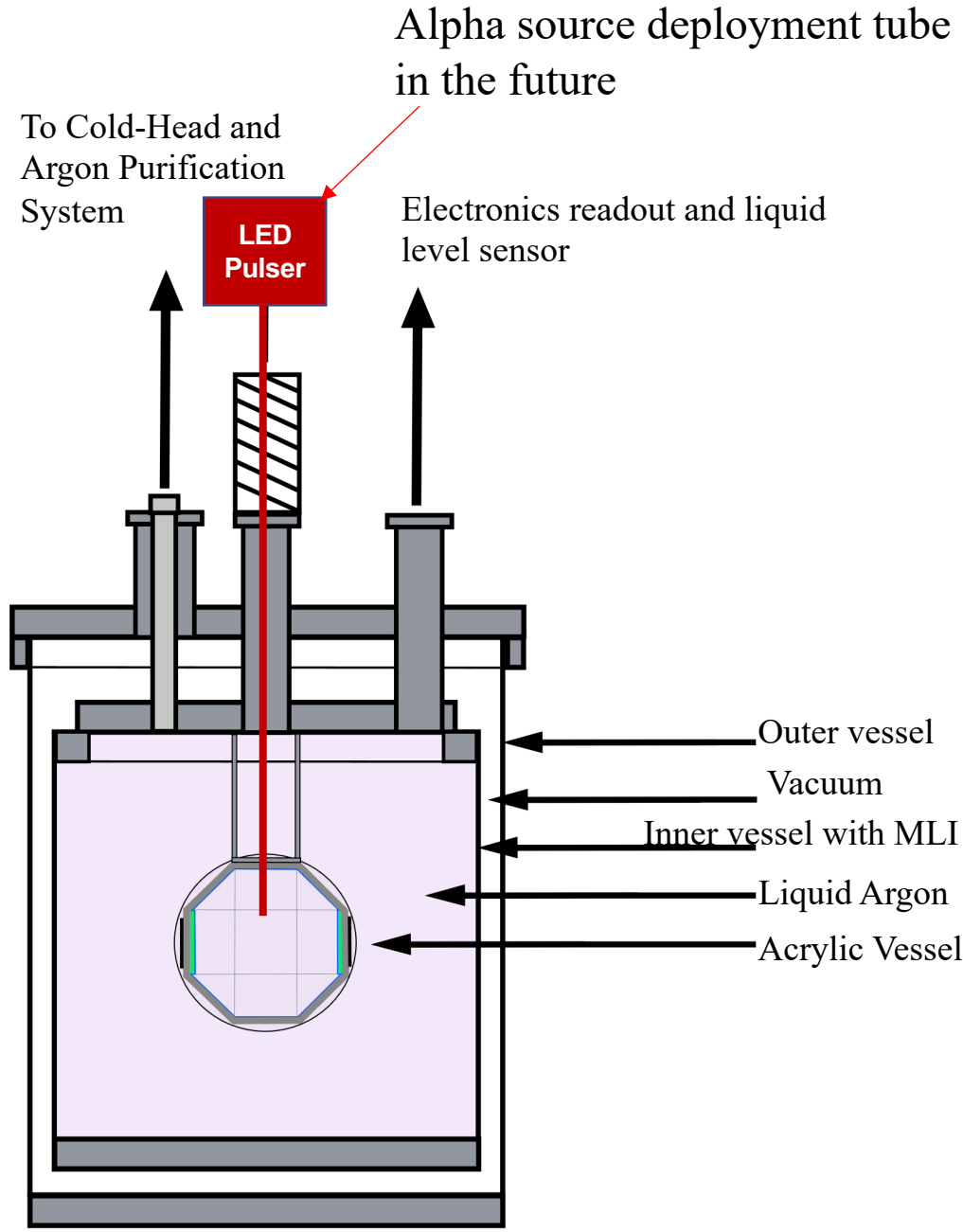
The Detector

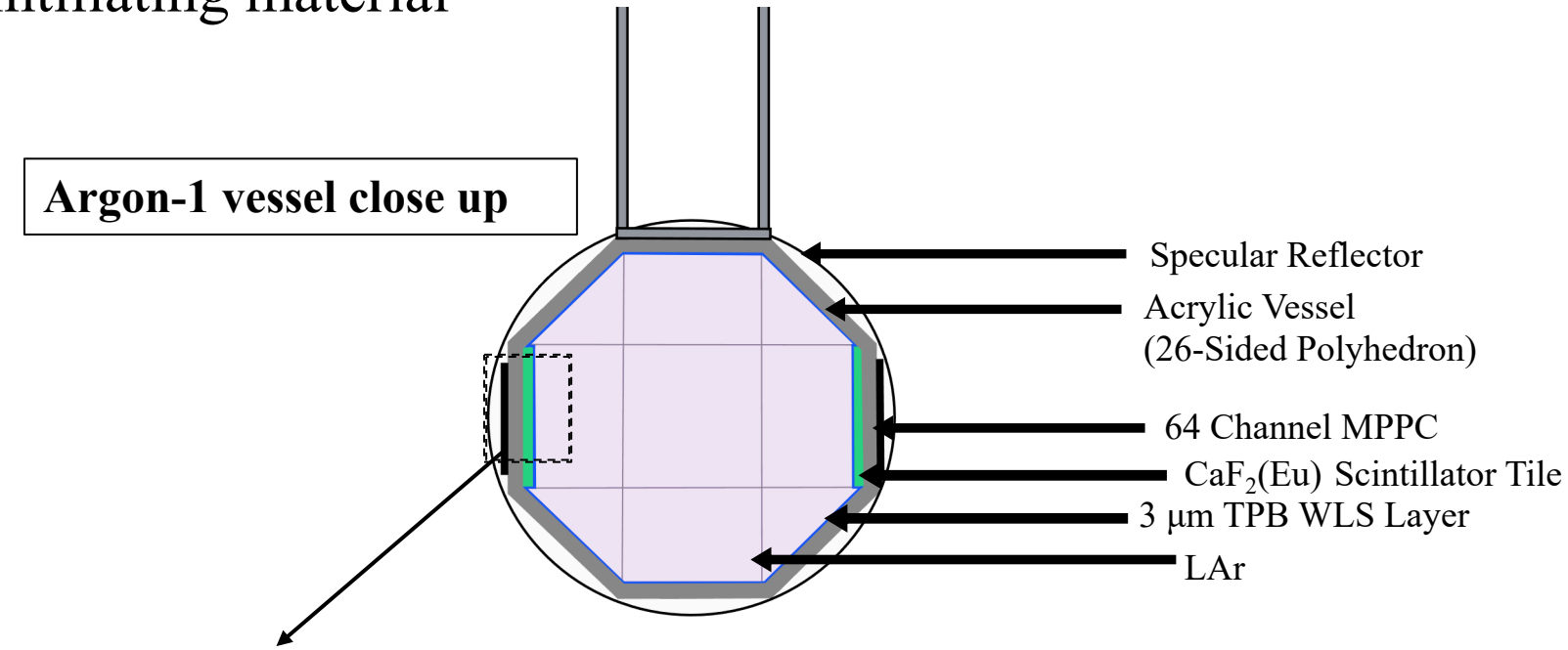
Argon-1

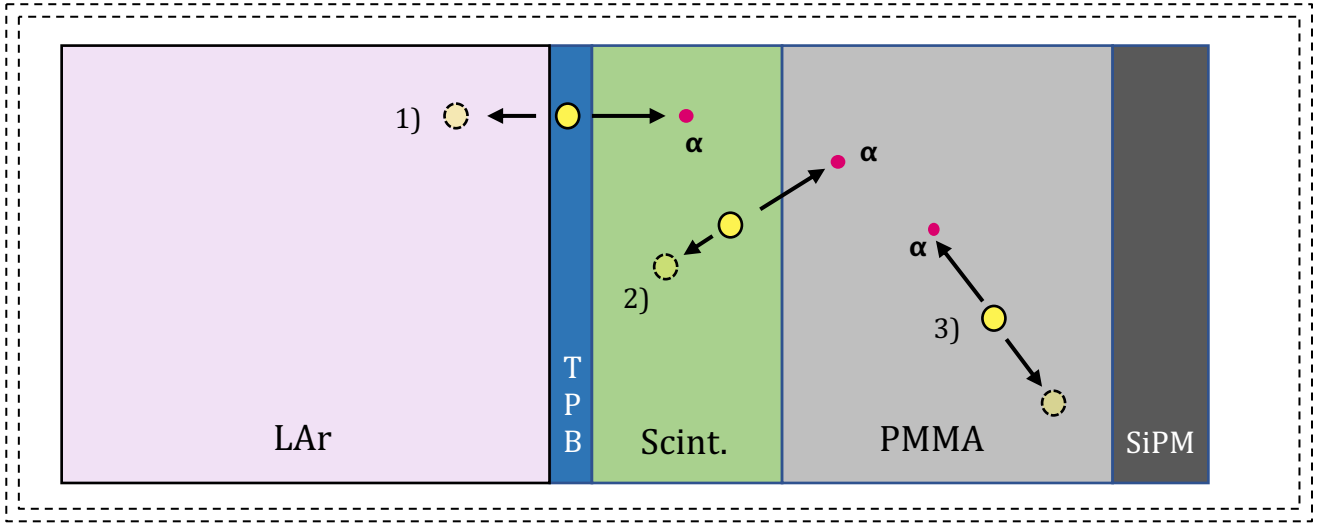
- Argon-1 is a single-phase LAr detector inside of a ~30kg cryostat, LAr scintillation light is shifted to visible by a TPB coating
- The blue TPB light is detected by SiPMs mounted inside the LAr on the sides of the vessel
- Plan to have 17 SiPM arrays surrounding detector for a total of 80 channels
  - Currently operating with 2 SiPMs with 65 channels



Physics Goals – Surface Background Rejection Technique

- Current primary objective:
  - Surface Background rejection technique using a thin layered scintillating material





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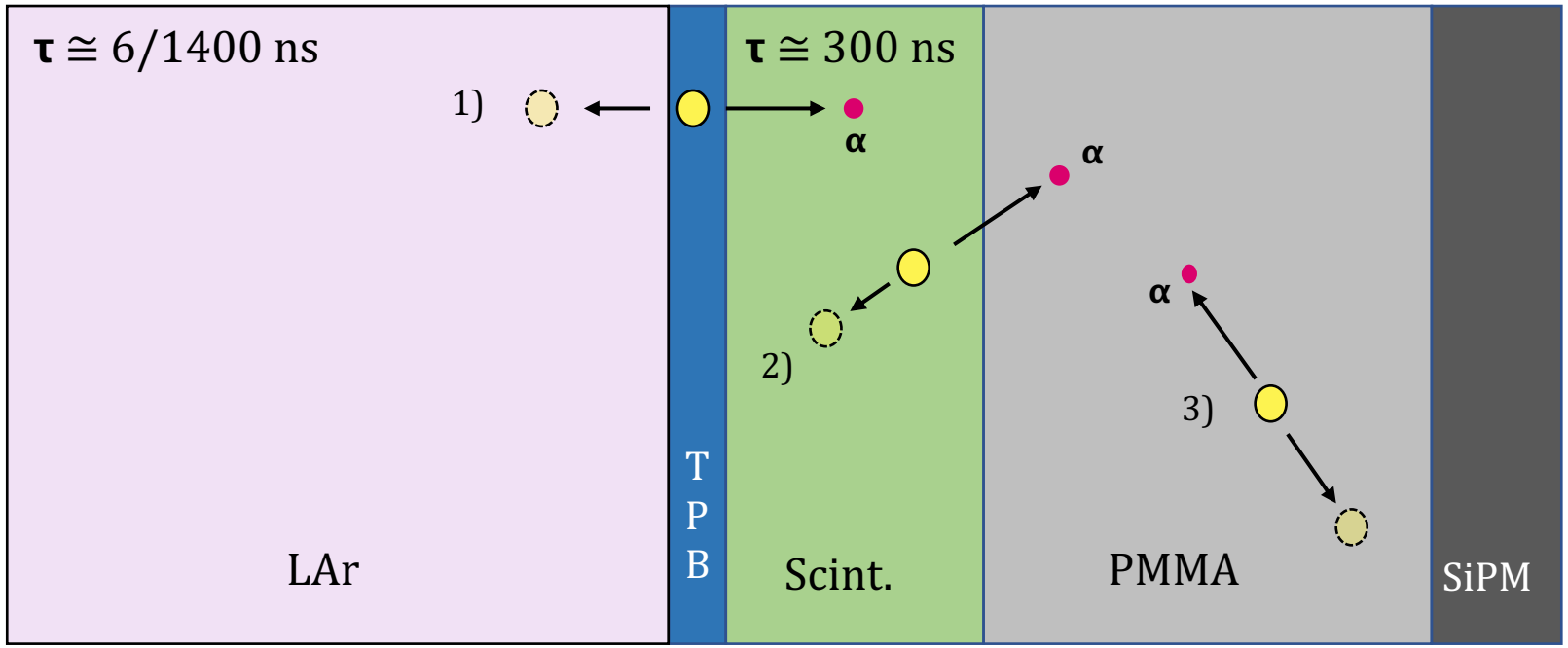
The Detector

Physics Goals – Surface Background Rejection Technique

12

See Hicham's Talk at 3:55 PM (R3-6)
Characterization of wavelength shifters for background rejection in liquid argon dark matter experiments

- Current primary objective:
  - Surface Background rejection technique using a thin layered scintillating material



Using a long-time constant scintillator layer we can use pulse-shape discrimination to reject surface events by shifting them away from our region of interest

- Case 1) Po-210 decay in TPB layer (active)
- Case 2) Po-210 decay in long decay time constant scintillator layer (active)
- Case 3) Po-210 decay in PMMA (non-active)

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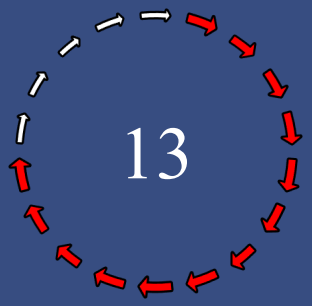
Monte-Carlo

RAT: Argon-1



- Built a Monte-Carlo simulation using a GEANT4 based software called RAT (Used by DEAP-3600, SNO+ & more)
- MC shows promise for an independent check of surface alpha tagging using light pattern on high channel density SiPM

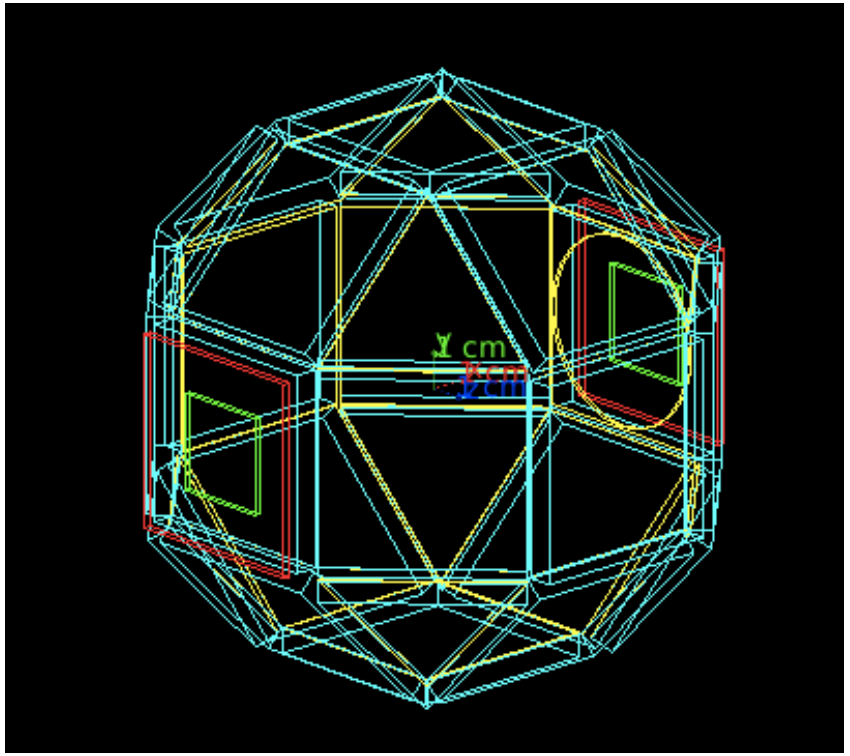
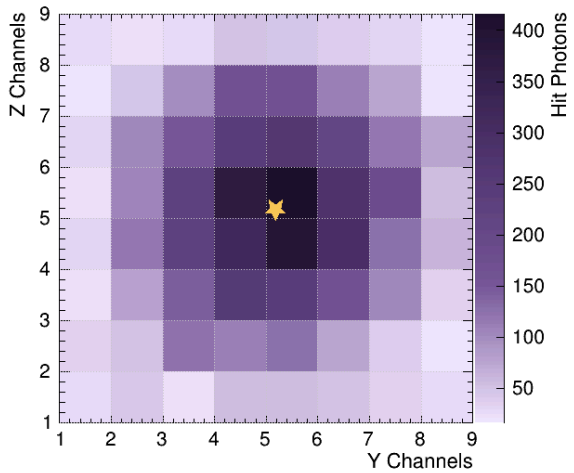
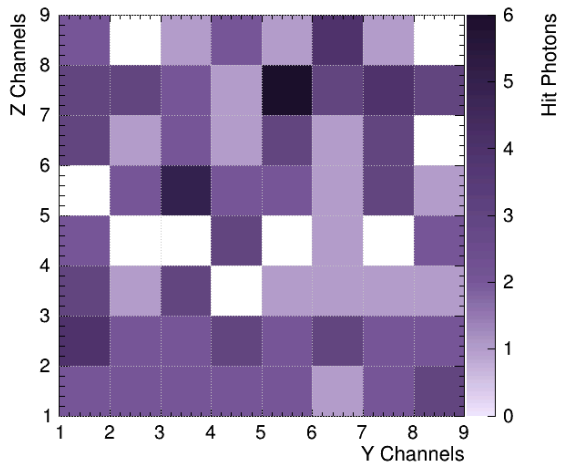


Figure: Simulated Argon-1, Acrylic vessel(Cyan), TPB(Yellow) and SiPMs(Green)

Surface Event



LAr Event (Ar40 NR)



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Monte-Carlo

Detector Response

- Will use MC to help understand detector response for surface-alpha measurement
- First Step: Determine MC detector light yield and calibrate to data

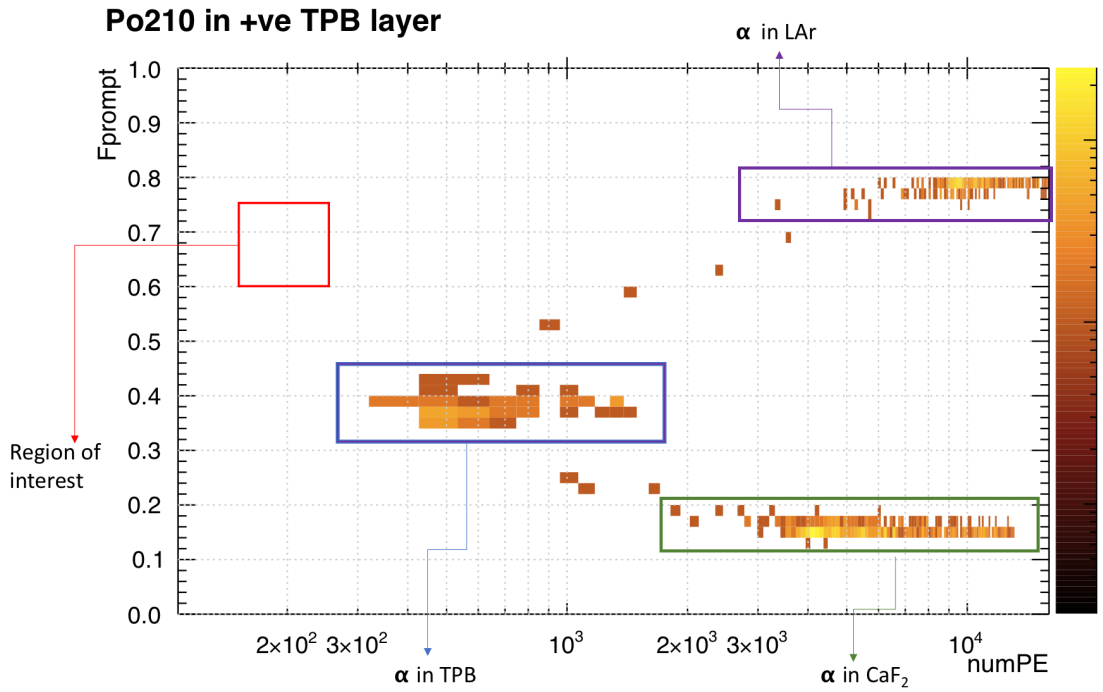
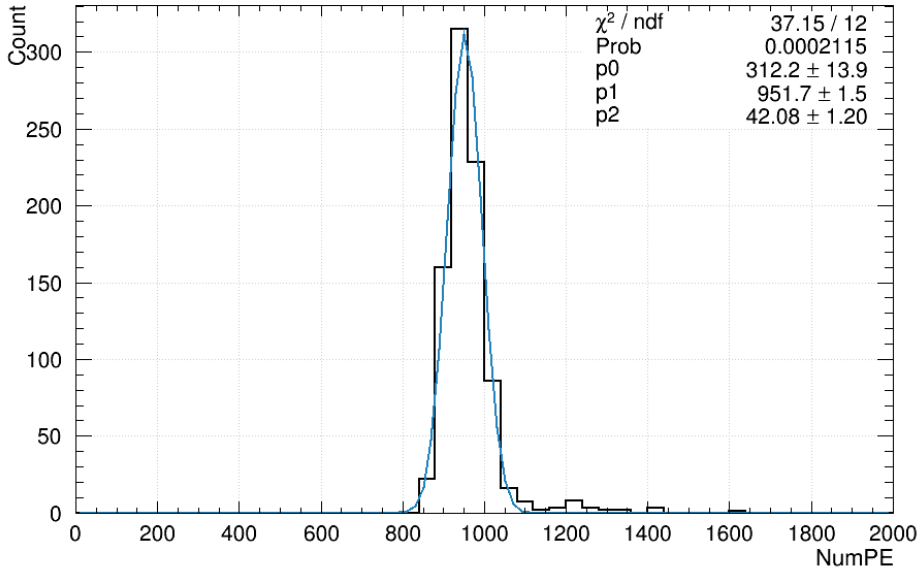


Figure: Example of A1 MC with 2 SiPM arrays and different event topologies, reference of approximate DM ROI included for comparison

Right: Simulated monoenergetic β's with 200 keV across the inner vessel

$$Light\ yield\ = \frac{Mean\ of\ detected\ PE}{Energy\ Deposited\ (keV)}$$

Using Gaussian fit: MC LY = **4.7586 PE/keV**
Resolution = 20.82 keV **(10.4%) at 200 keV**



Preliminary Data

Fresh off the DAQ

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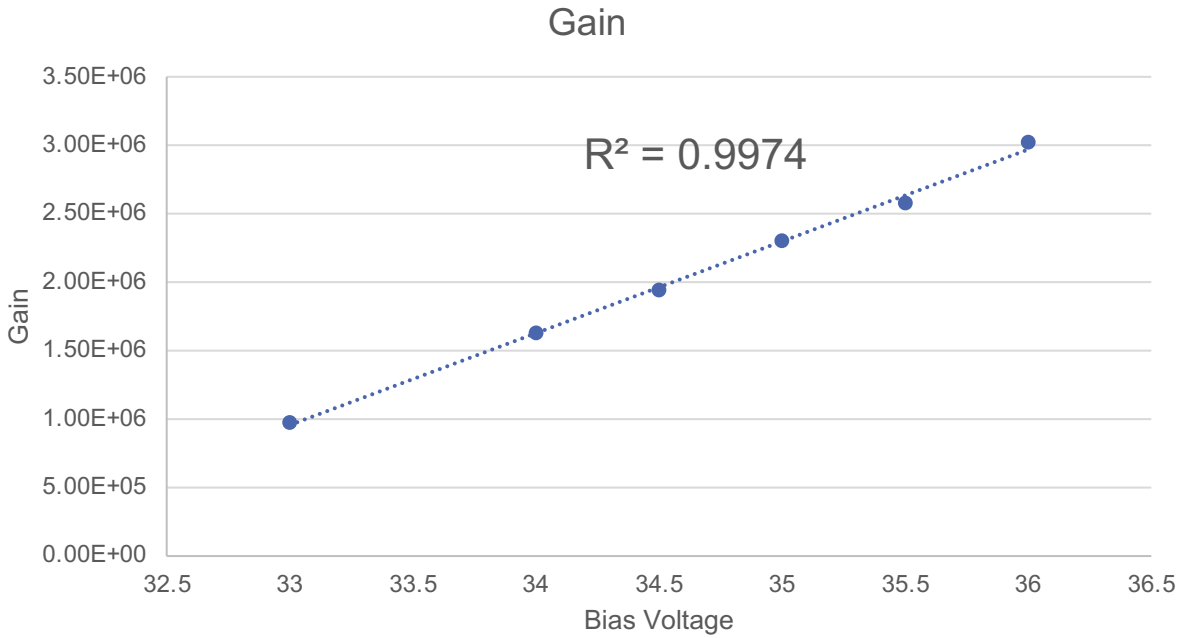
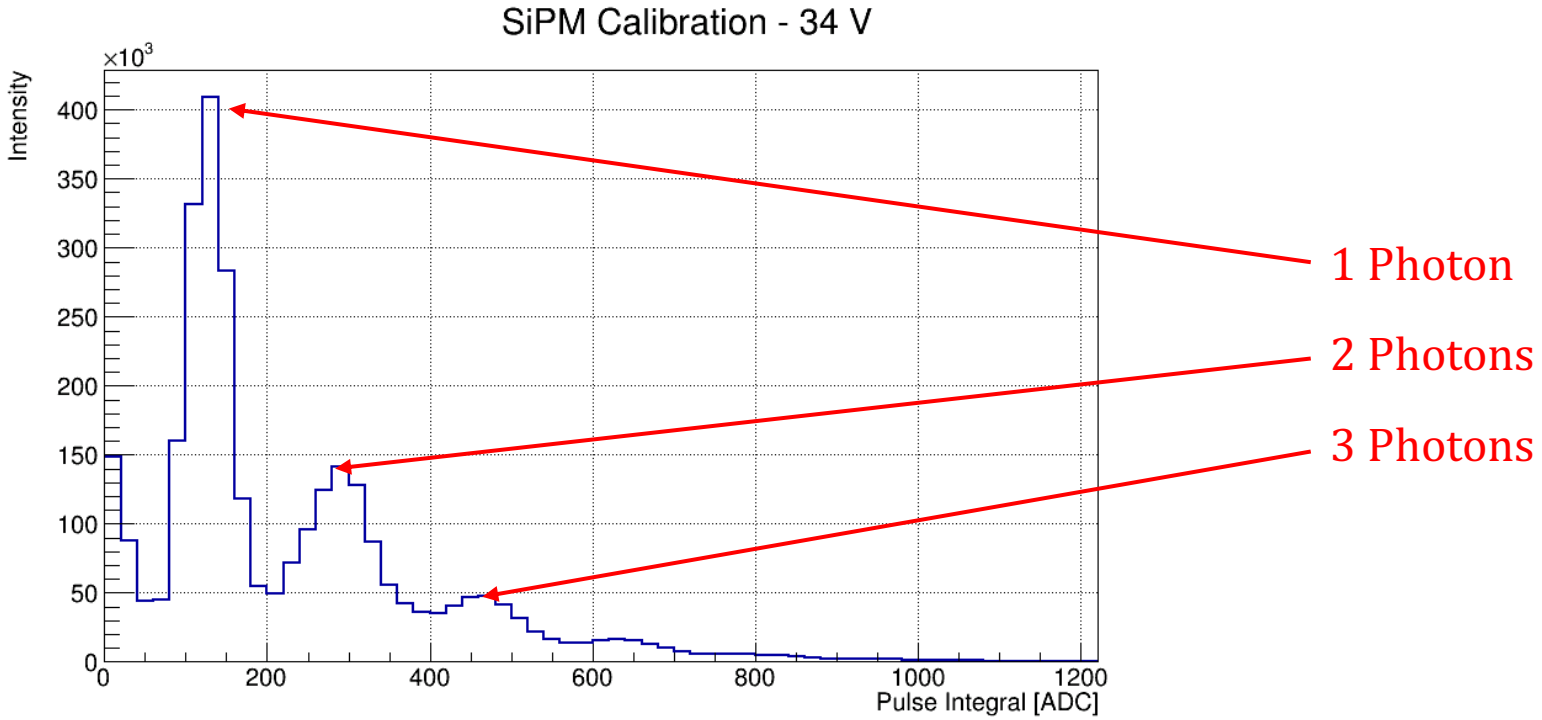
Preliminary Data

SiPM Calibration

Using a pulsed LED light source, we can calibrate the SiPMs





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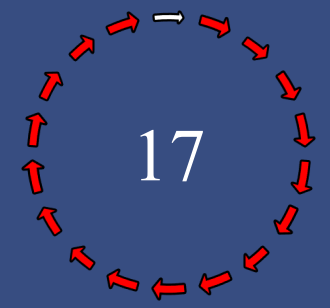
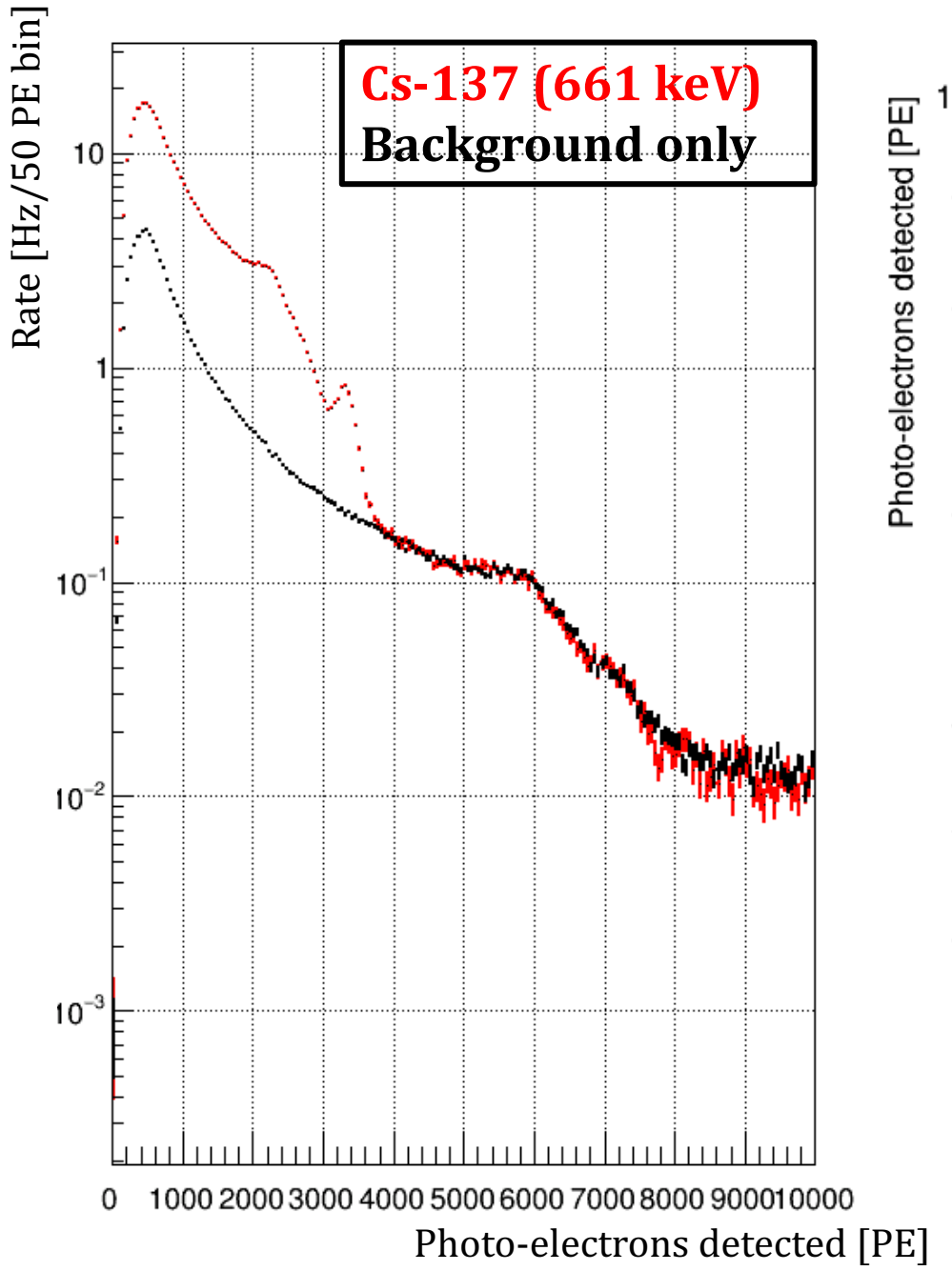
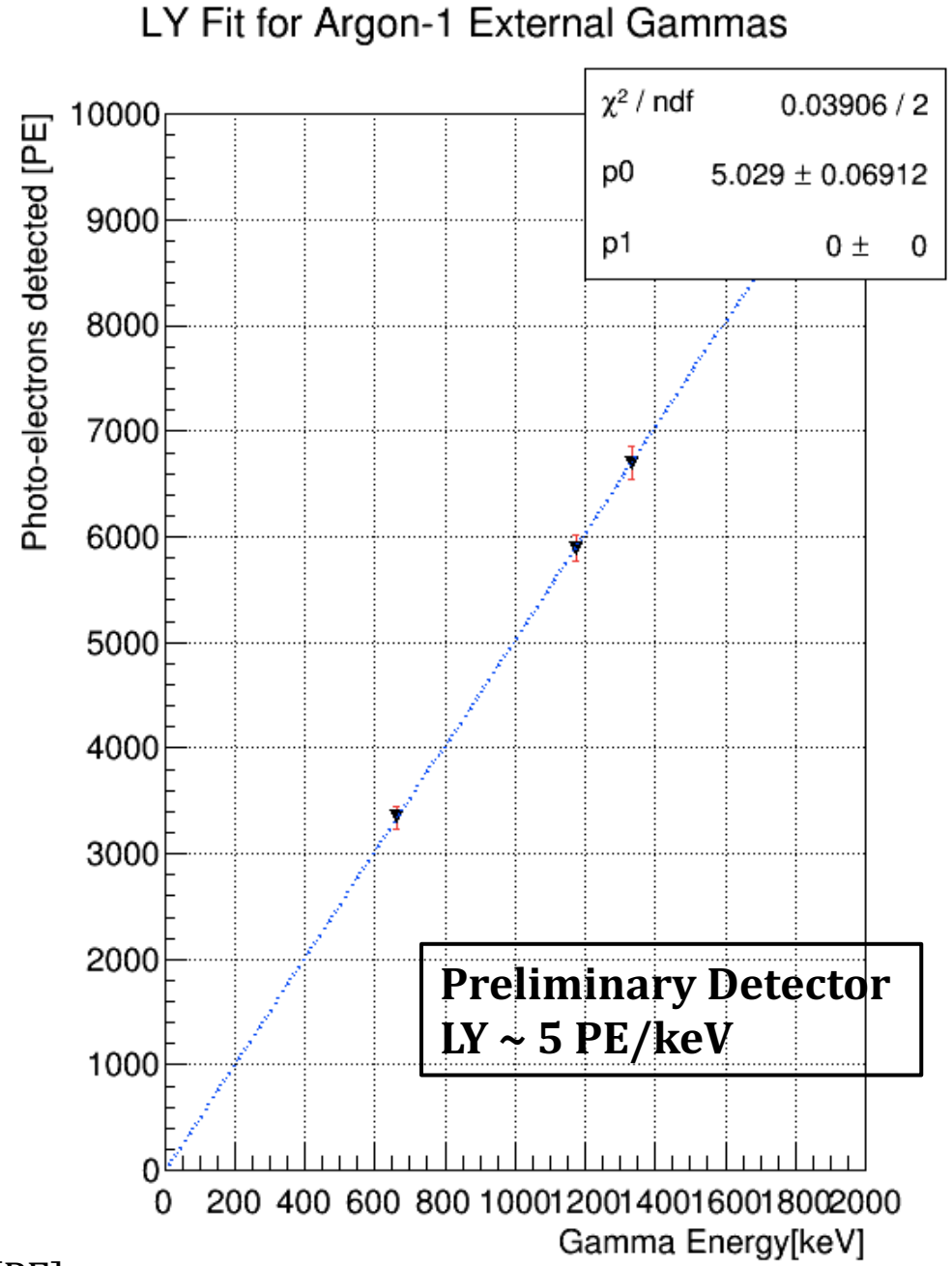
Preliminary Data

External gammas for detector calibration







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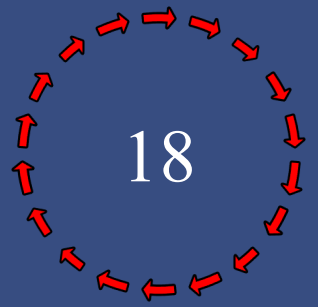
Conclusion

What's next?



What we've accomplished so far:

- Argon-1 R&D detector successfully commissioned
- DAQ Running with 65 SiPM channels with full waveform readout, and capacity to expand to 130+ in the future
- Monte-Carlo Simulations shows excellent promise for novel background rejection using a layered active surface

The Next Steps:

- Continue detector calibration using external gammas (Tl-208, Cs-137 and Na-22 sources) and with internal gammas using Kr-83m
- Ongoing study of SiPM Characterization in LAr conditions
- Reconfigure the detector to perform surface-background discrimination measurement
- Deploy proto-type PDCs from USherbrooke being developed for ARGO, inside Argon-1for in-situ comparison to analogue SiPMs

Thanks for your attention!

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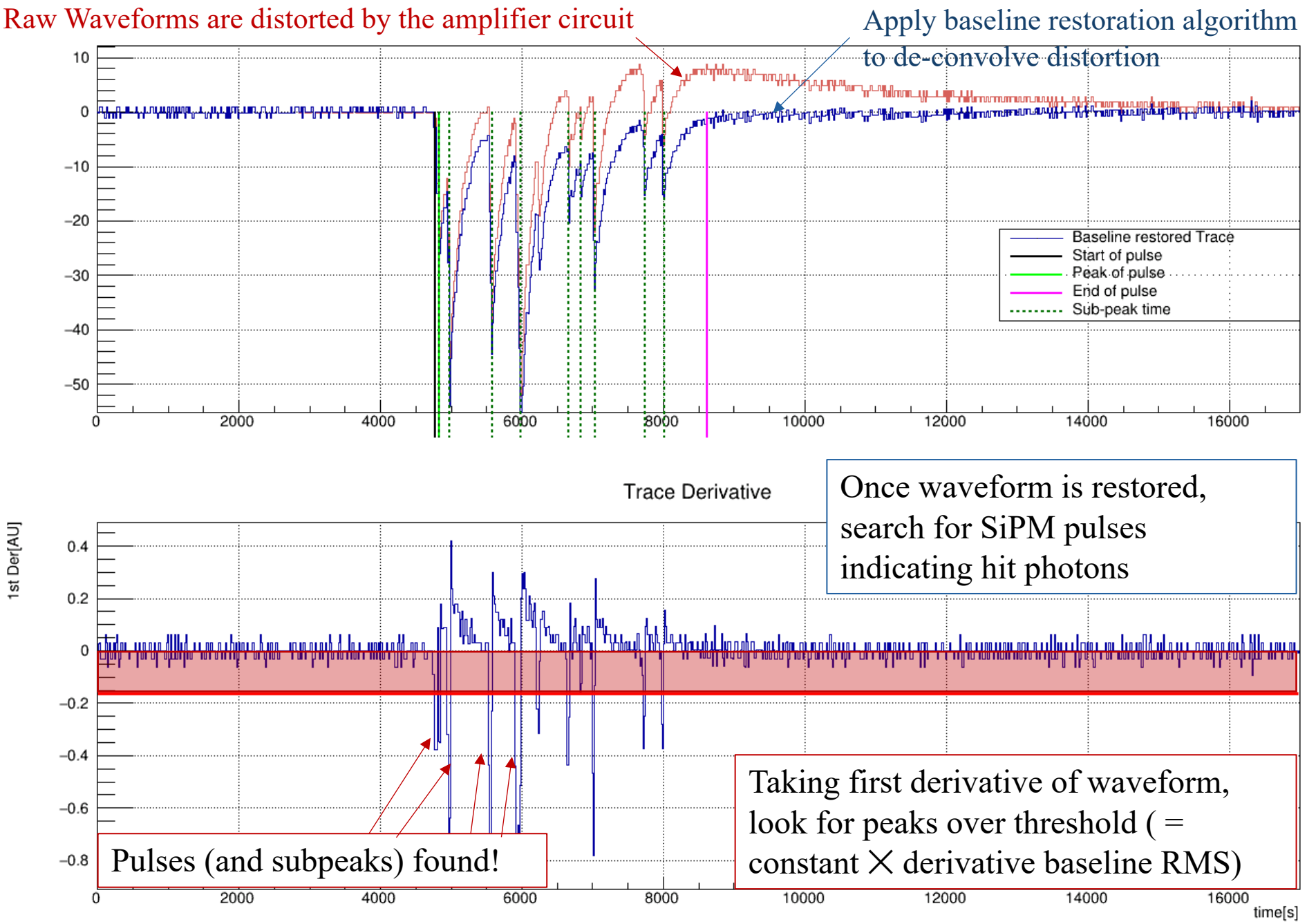
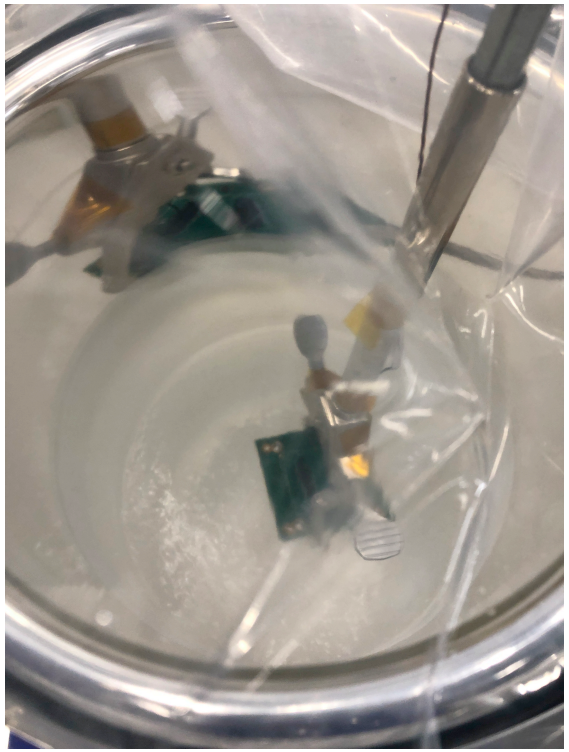
Backup

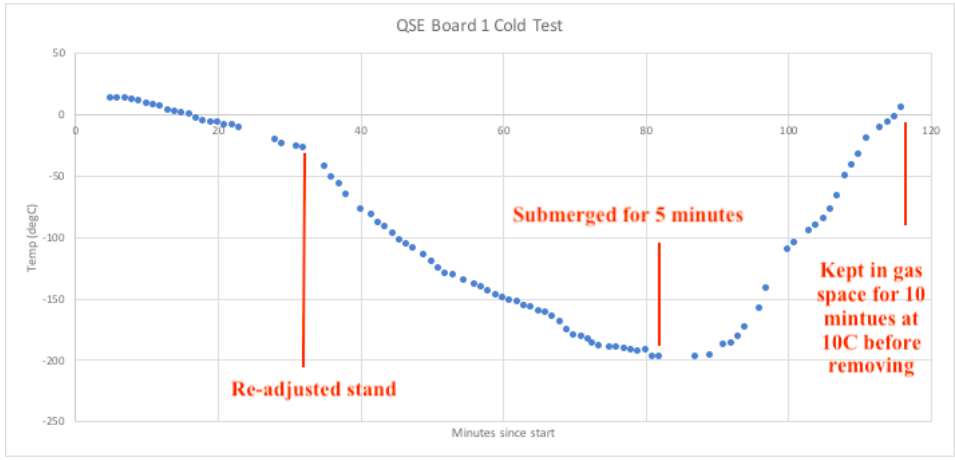
SiPM Pulse-Finding

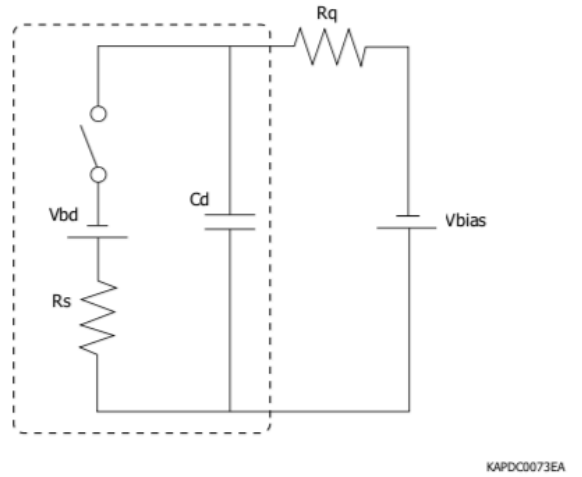


Backup

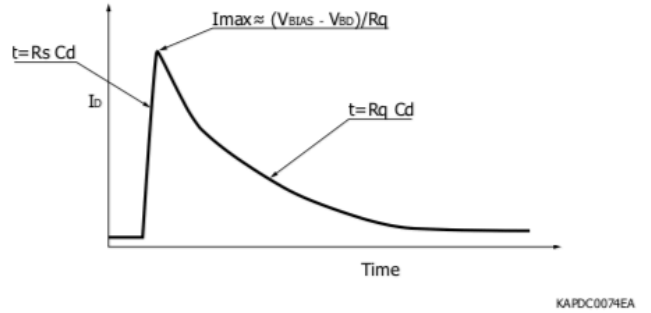
- Ran cryogenic cycle of “QSE” board with adapter attached (To mimic SiPM Soldered)
- No cracking or issues, X-rayed before and after with no noticeable issues
- Continuity good for all channels before and after cooling cycle







[Figure 1-13] Conceptual output pulse of the equivalent circuit



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Backup

MIDAS DAQ

- Front-end software controls V1740 boards for data readout
- FE also controls SiPM Pre-amplifiers and HV supply
- Triggered events are saved to a custom ROOT DS for analysis
- Write out full waveforms first then apply pulse-finding and high-level analysis

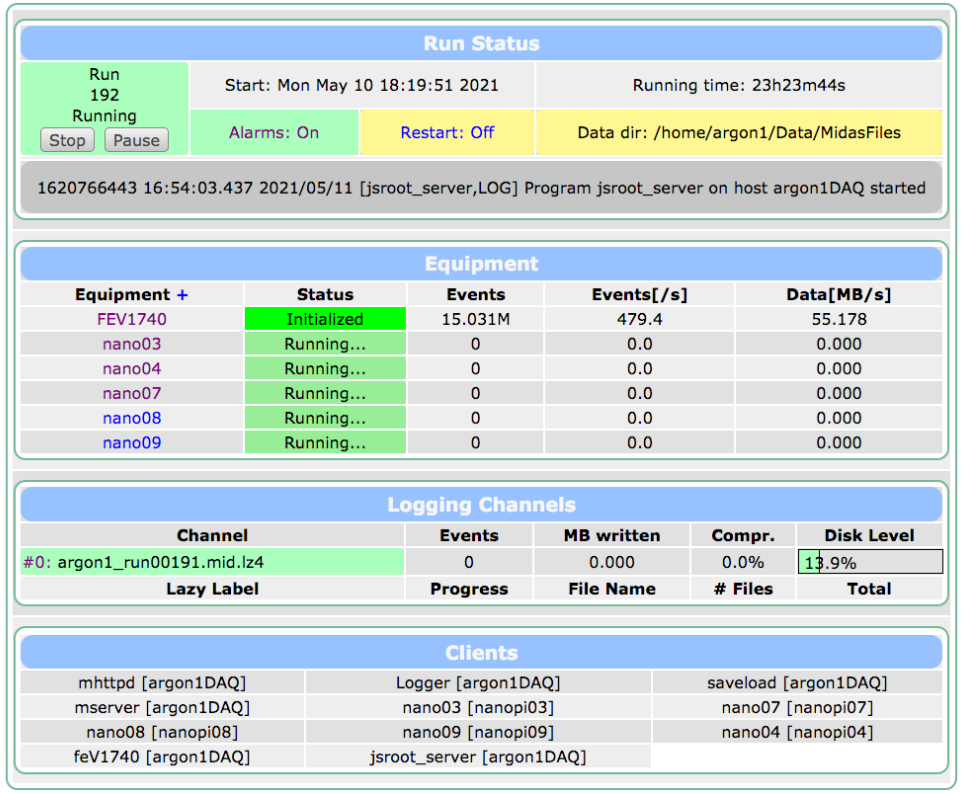
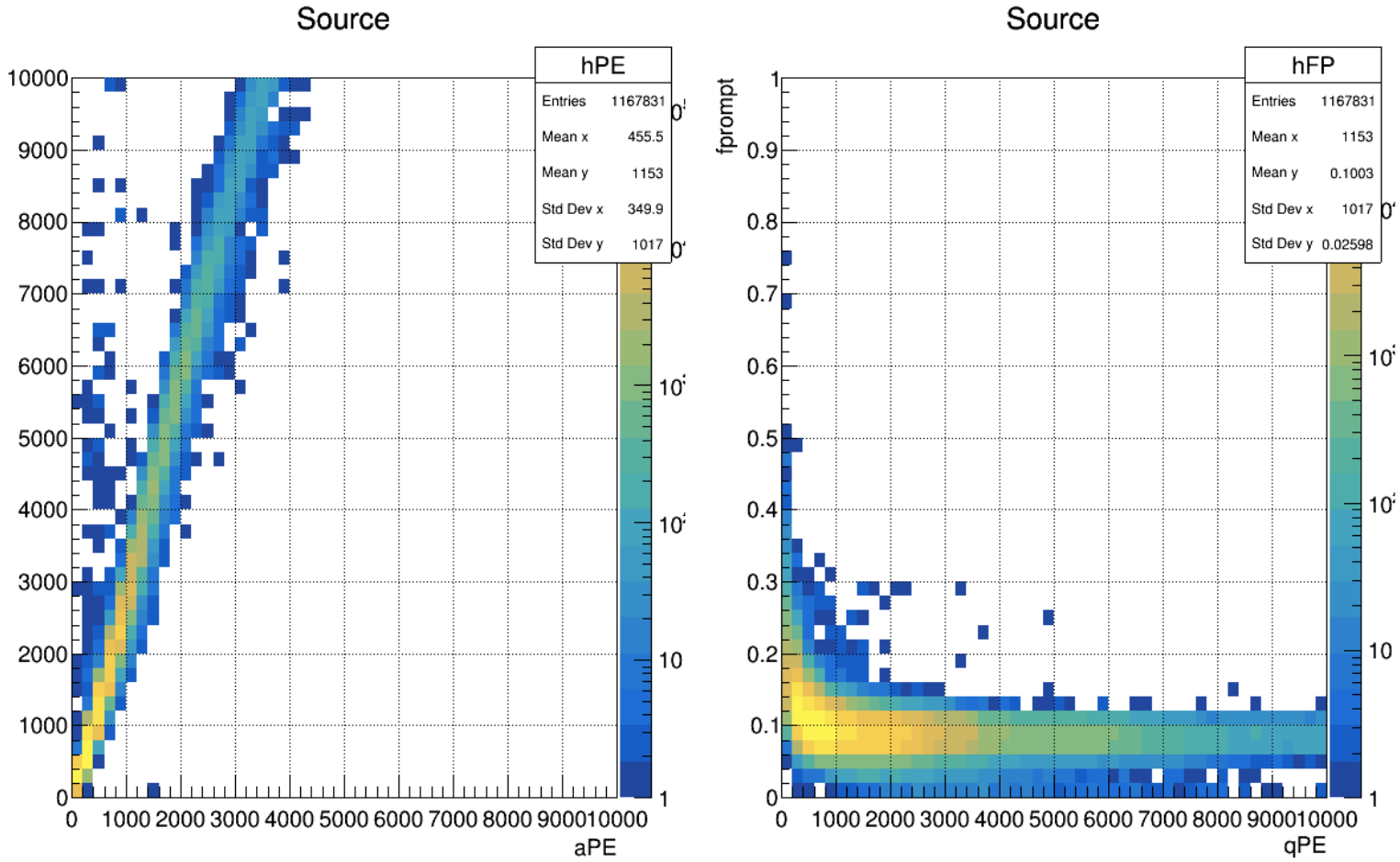


Figure: Argon-1 DAQ MIDAS FE Interactive webpage

Fprompt vs PE



aPE = Sum of all subpeak amplitudes, Divided by SPE amplitude

qPE = Integral under baseline for each pulse, divided by SPE charge

Fprompt = integral of waveform in “prompt” window [-50ns,250ns] about trigger time

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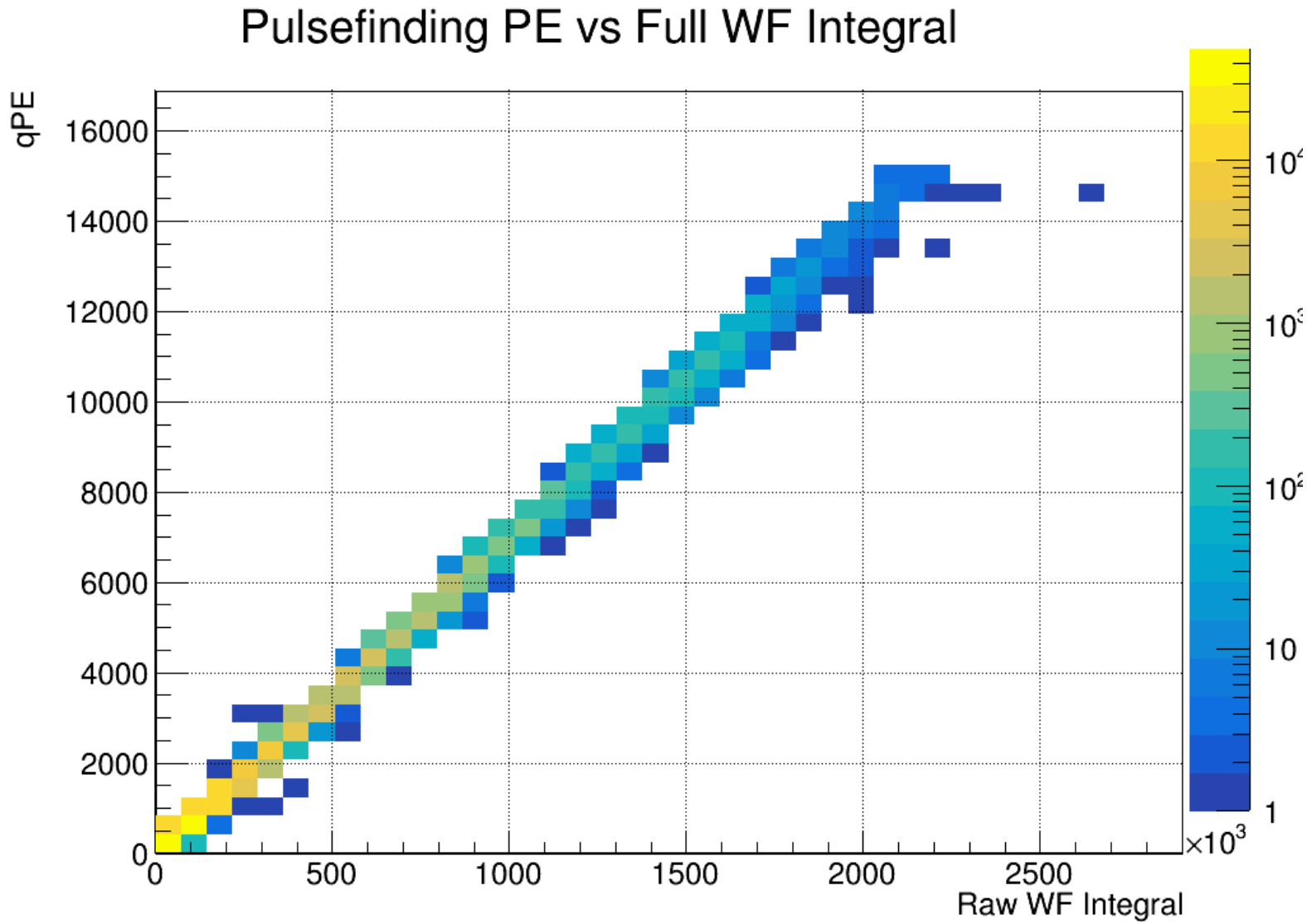
Backup

Charge Linearity

- We scale the integrated charge by SPE constants for each channel for each pulse found, but we can look at how linear the charge is to compare



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Backup

Co60

- Co60 spectrum is not so clean because of the 2 gammas and Compton edge of 1337 kev gamma combining with peak of 1173 kev gamma