# Precise High Energy Gamma Ray Calibration in DEAP-3600

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**on behalf of**
**the DEAP-3600 collaboration**

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*Sudbury, ON*

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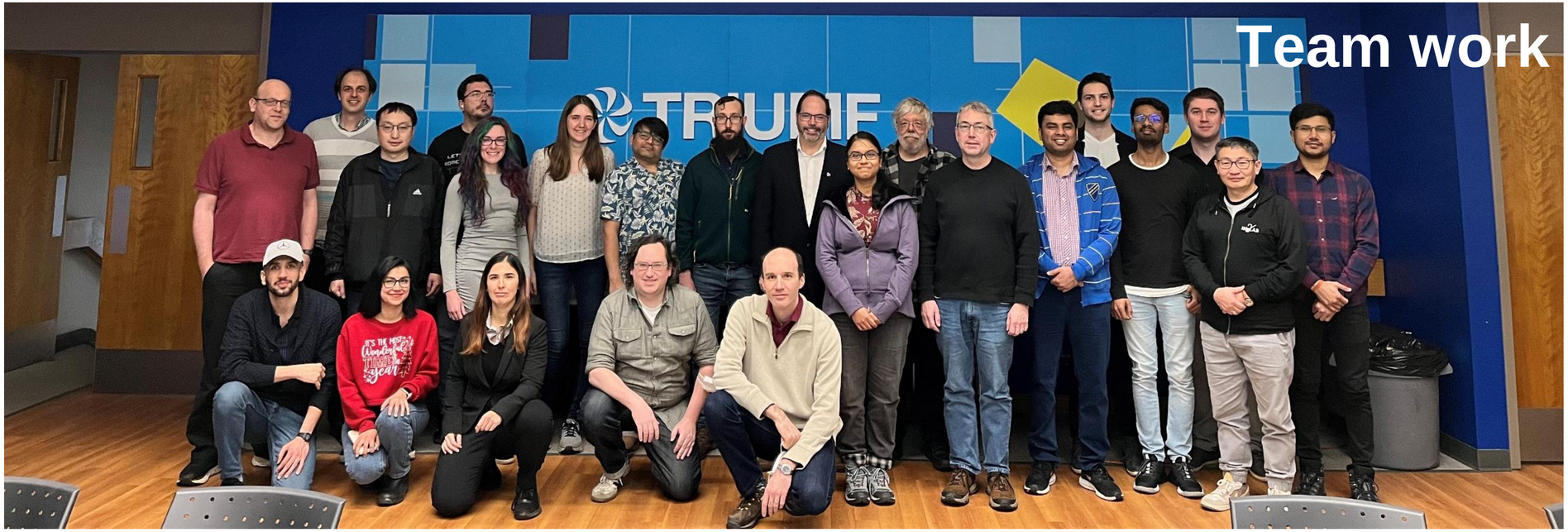
**2024 CAP Congress**
**Western University, London, ON**

# DEAP Collaboration

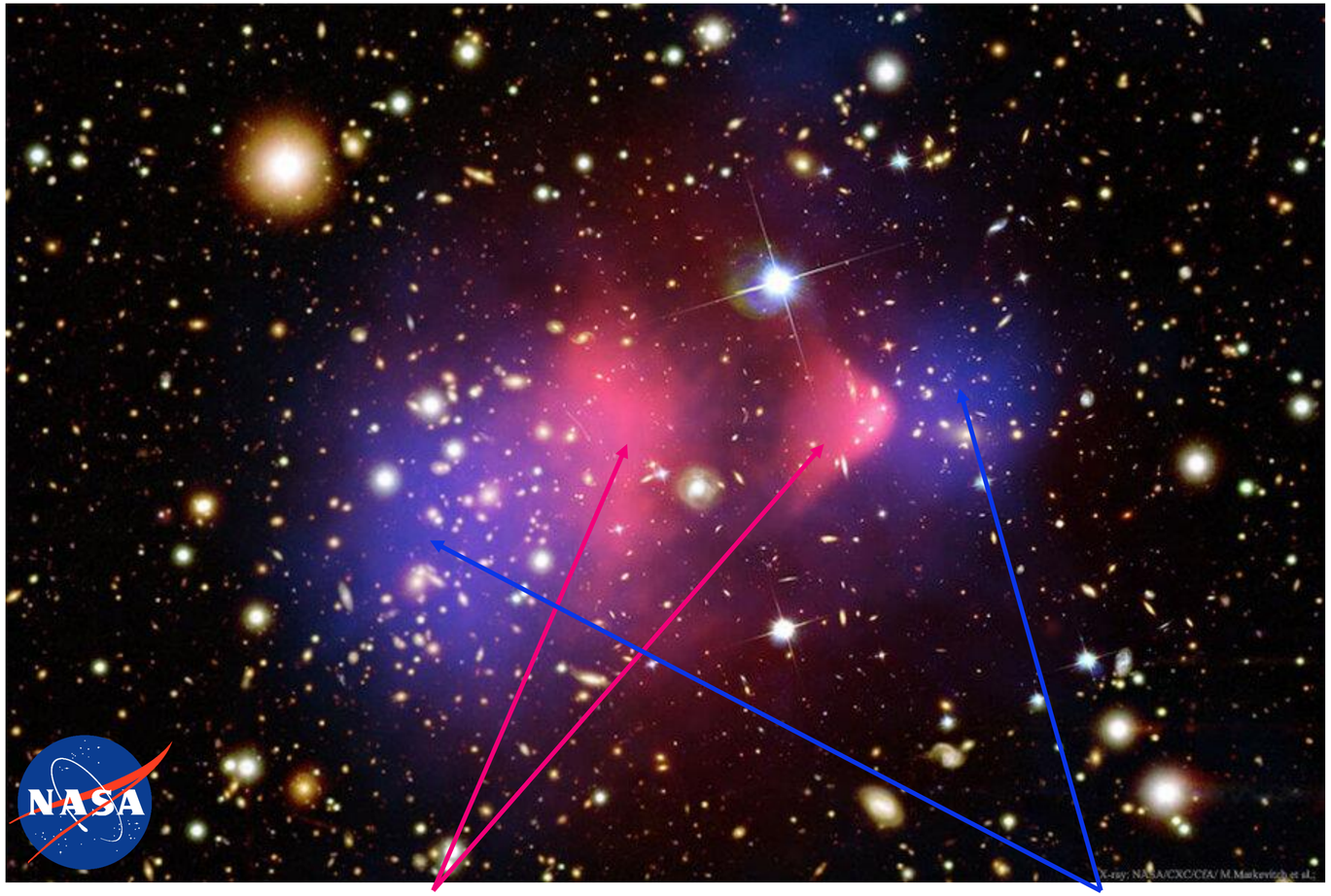



~ 100 researchers in Canada, Germany, Italy, Mexico, Poland, Russia, Spain, UK, USA

# Why do we search for DARK matter?

**One of the pieces of evidence for the existence of DARK matter:**

**A collision between galaxies: formed Bullet Cluster**




**Matter we know (hot gas) traced by X-ray detector**

**Matter we don't know observed by gravitational lensing**

**Most of the Bullet Cluster's total mass was in a different place than most of the 'normal' mass**

**Therefore, most of the total mass causing the gravitational lensing must be dark matter.**

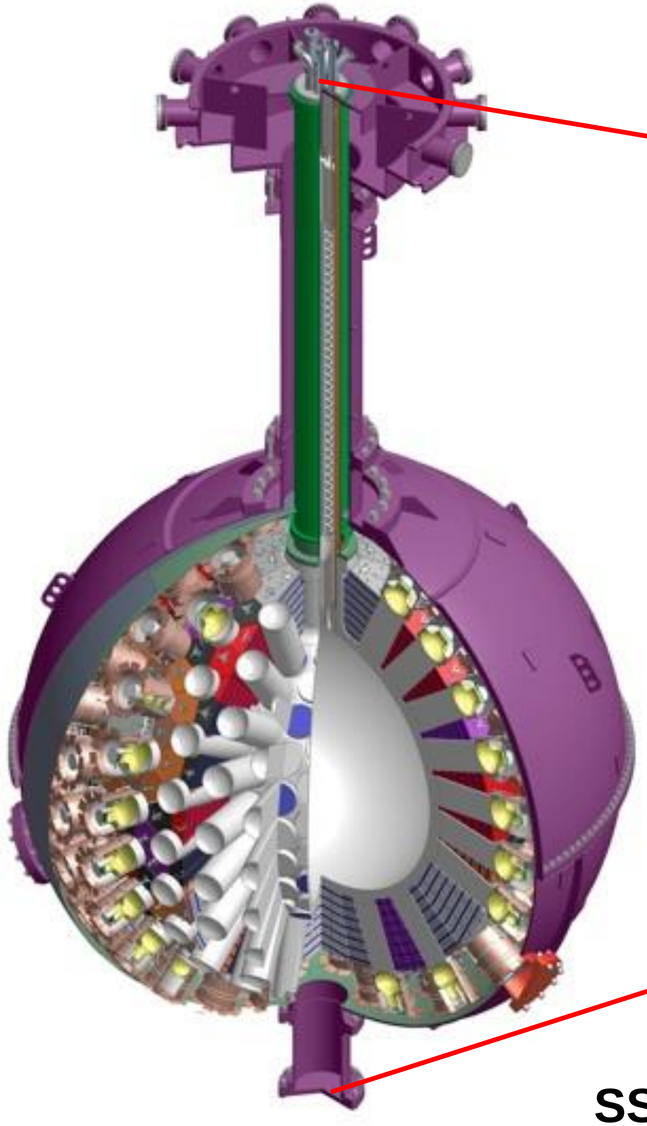
**Matter we know slowed down but matter we don't know did not slow down.**

**Therefore, unknown matter is neither collisional nor interactive with the ordinary matter.**

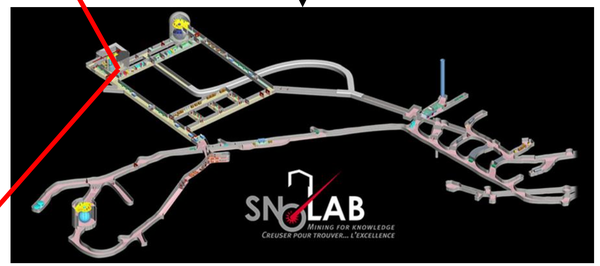
# DEAP-3600

≈ 14,000,000 muons/m$^2$ per day

**The Dark matter Experiment using Argon Pulse-shape discrimination 3600 – proposed mass of liquid argon in kg.**




2 km rock | ≈ 6 km water



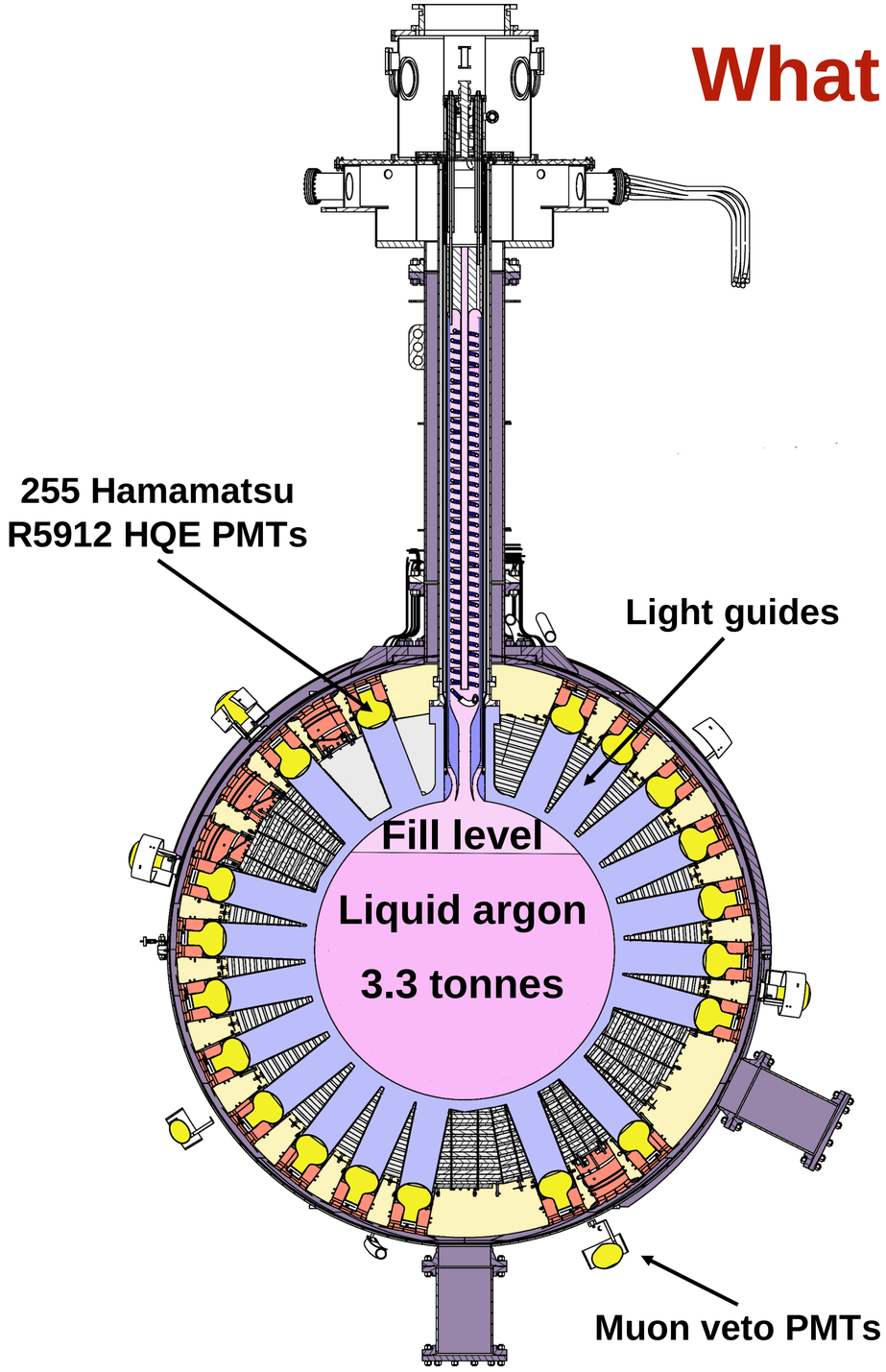

Underground lab

≈ 0.27 muons/m$^2$ per day

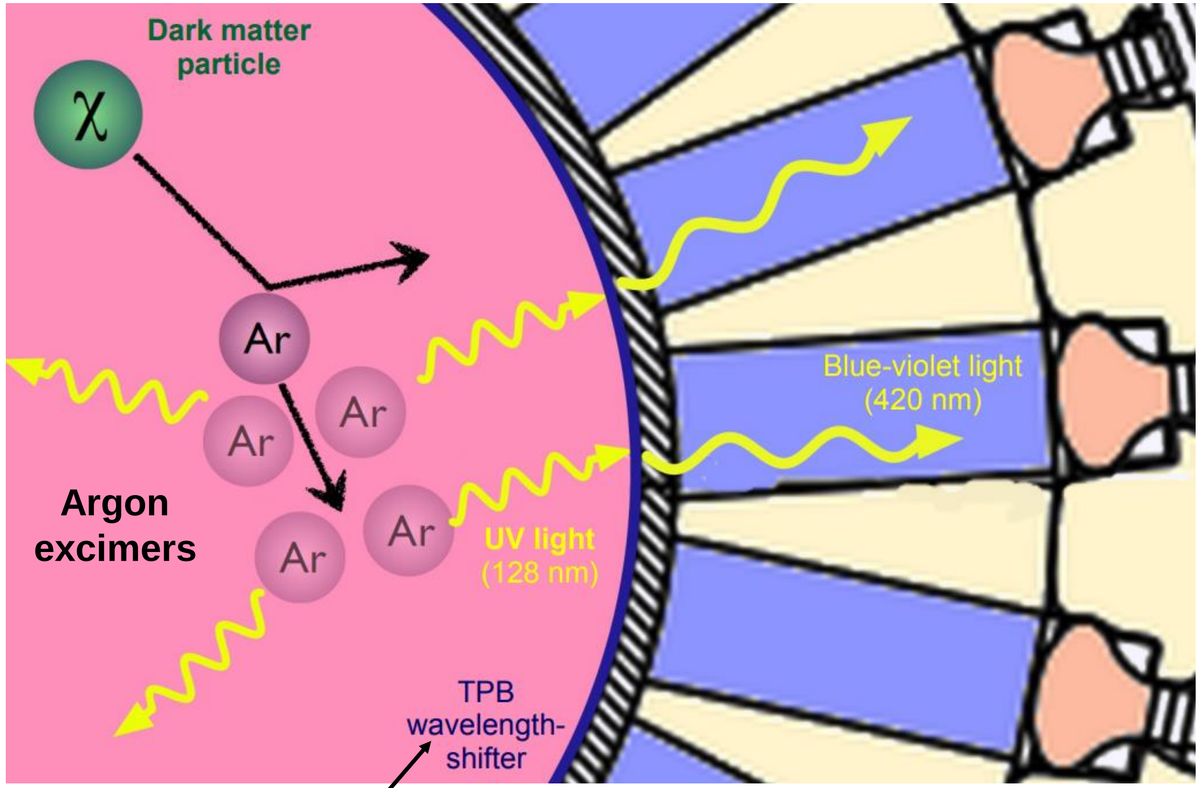
Worth hiding underground!!!

SSS submerged into 300 tonnes ultra-pure water

# What do we expect in the DEAP-3600 detector




**Target: Single phase liquid argon.**




**128 nm → 420 nm (3μm thick)**

**PMT Quantum efficiency 32%**

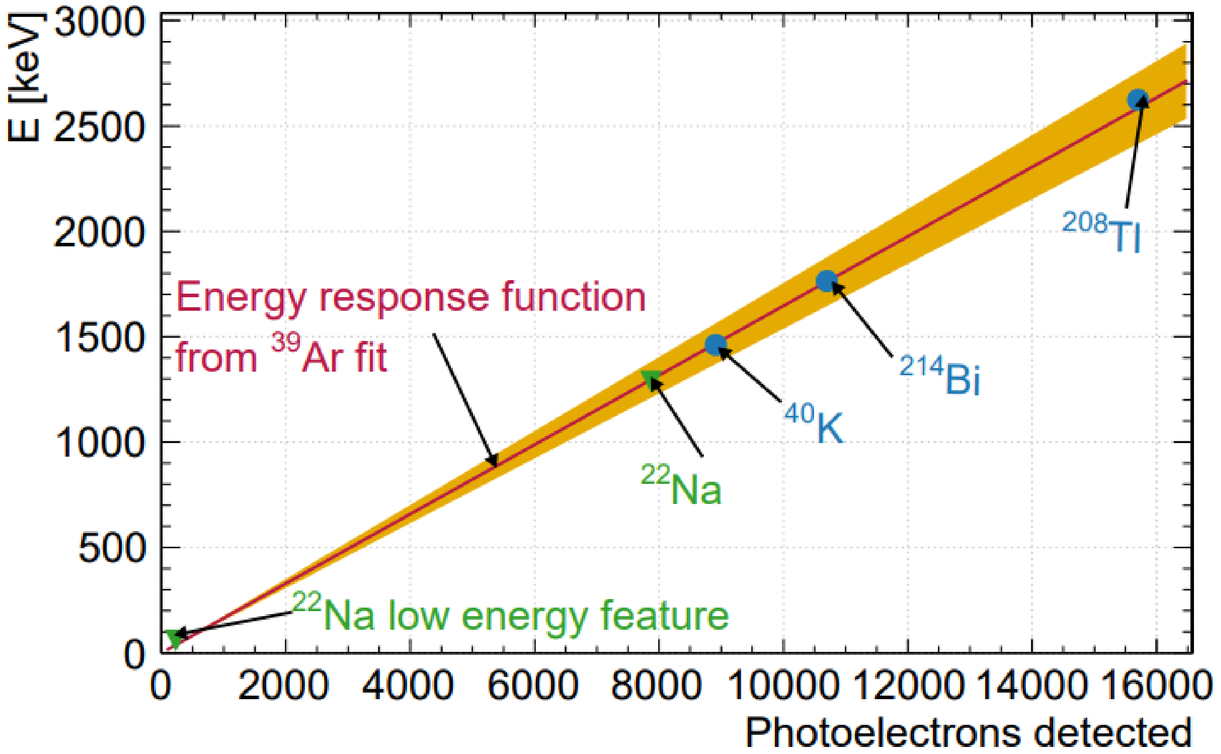
**Detector geometrical efficiency 75%**

[Astropart. Phys. 108 (2019) 1-23]

The Search for Dark Matter with Liquid Argon
Chris Jilling:
May 29, 2024, 11:00 AM
PAB Rm 148

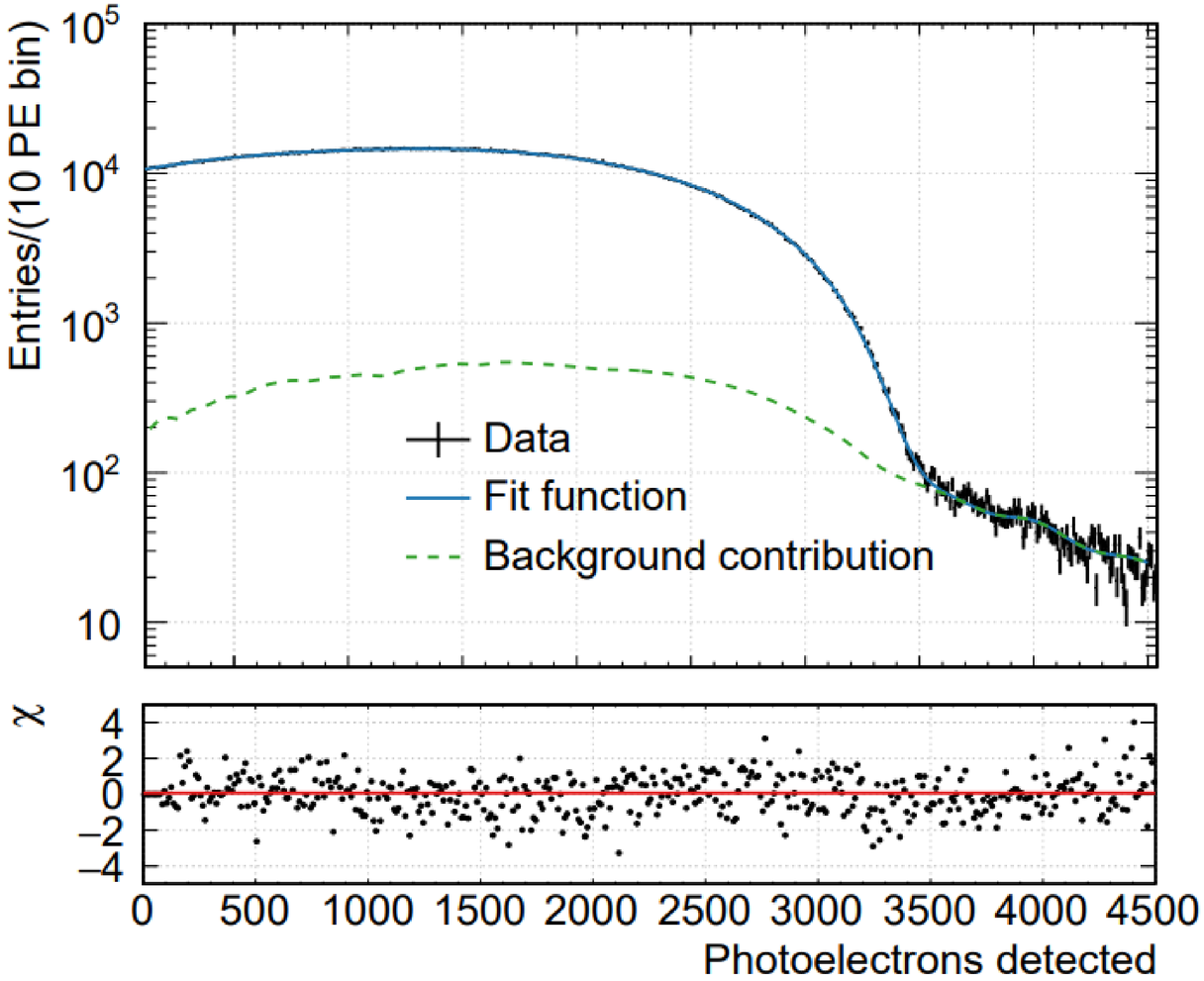
# Energy response function

Phys. Rev. D, 100, 022004 (2019)



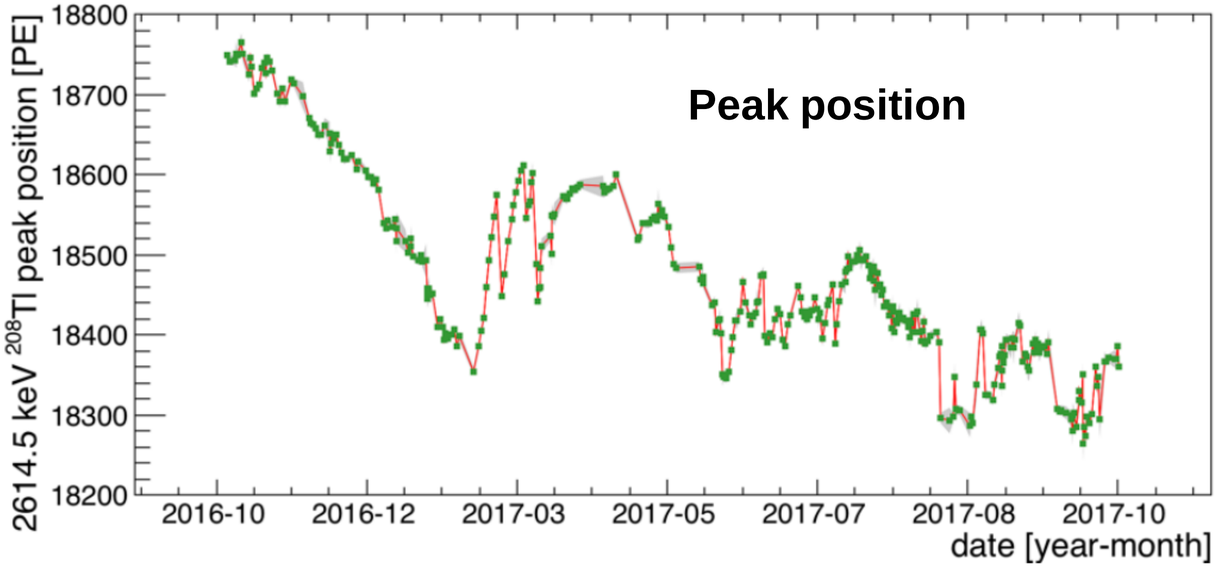

Na-22 source used to test the response function. The response function agrees with the number of PE detected from known mono-energetic sources of γ-rays from the detector materials.

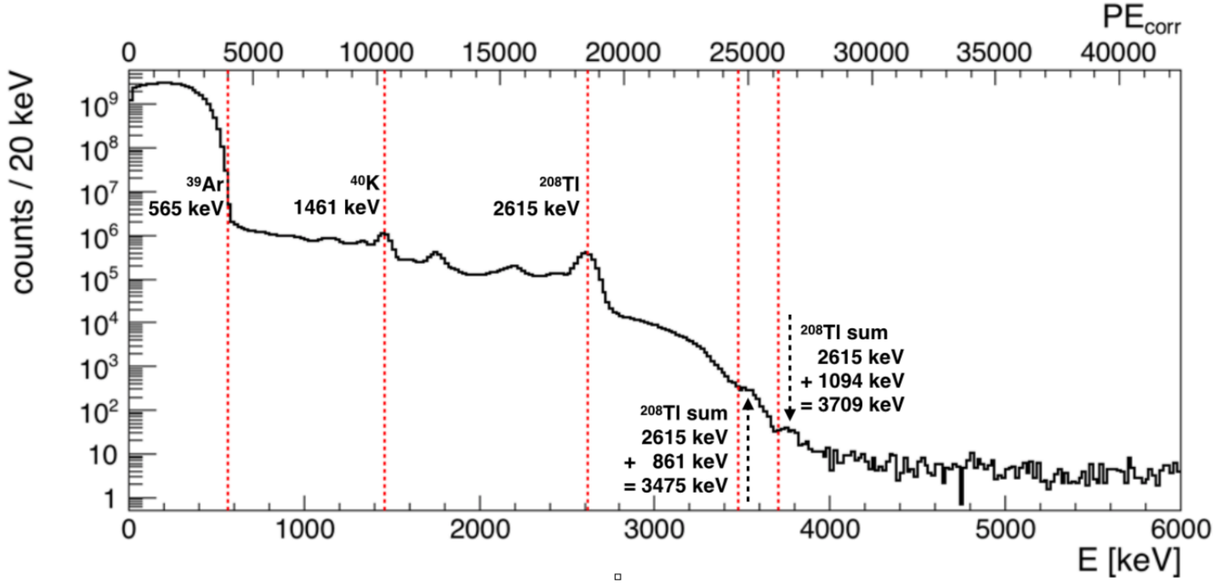
**The energy response function remains linear over a wide range of energies, with non-linearity starting to arise above 1.46 MeV.**




Ar-39 model (blue line) fit to data (black). Background contribution from γ-rays and Ar-39 pile-up events (green).

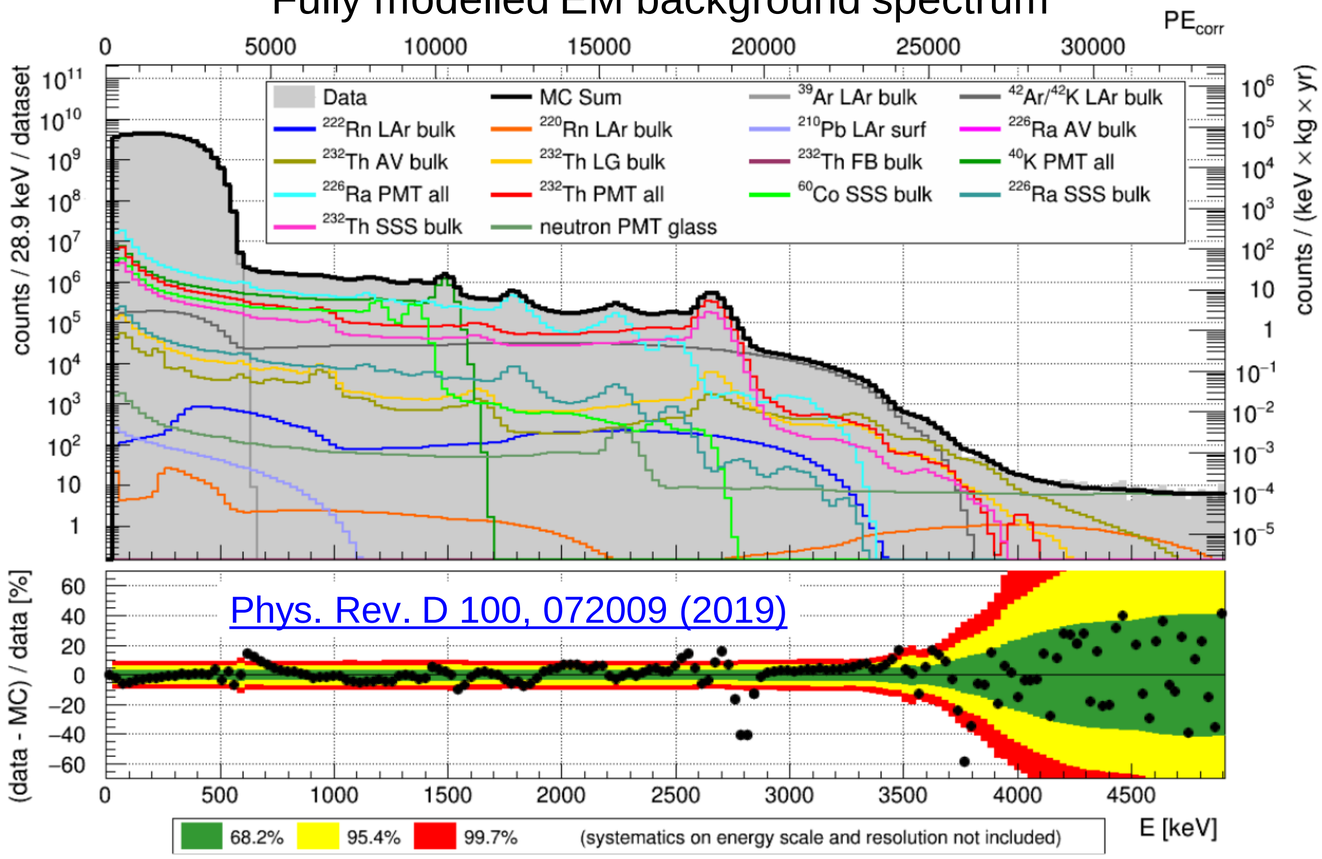
# Calibration for EM background spectrum




**Calibrated spectrum**

Fully modelled EM background spectrum




Energy spectrum is plotted with the fit result.

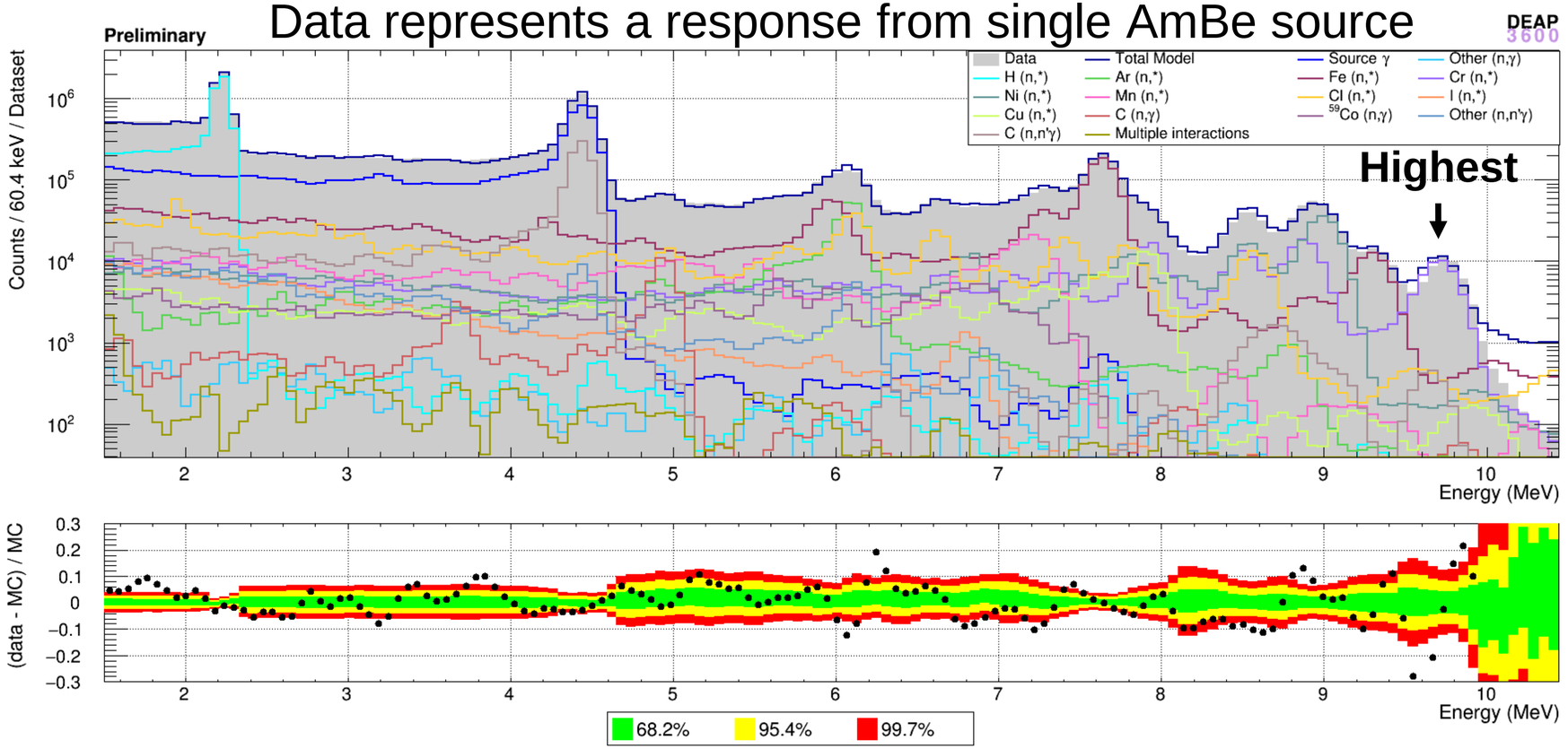
MC simulations are used to determine the energy depositions in the LAr for each background component in the model.

# Energy calibration for 5.5 MeV solar axion and neutrino searches.

- Expanded the energy response function to the high-energy region.
- The model utilizes MC simulations to generate datasets for calibration data.
- We then fit the MC calibration model to the AmBe calibration dataset to extract parameters for the following detector energy response function:

$$PE_{mean} = A \times E^2 + B \times E + C$$

Data represents a response from single AmBe source



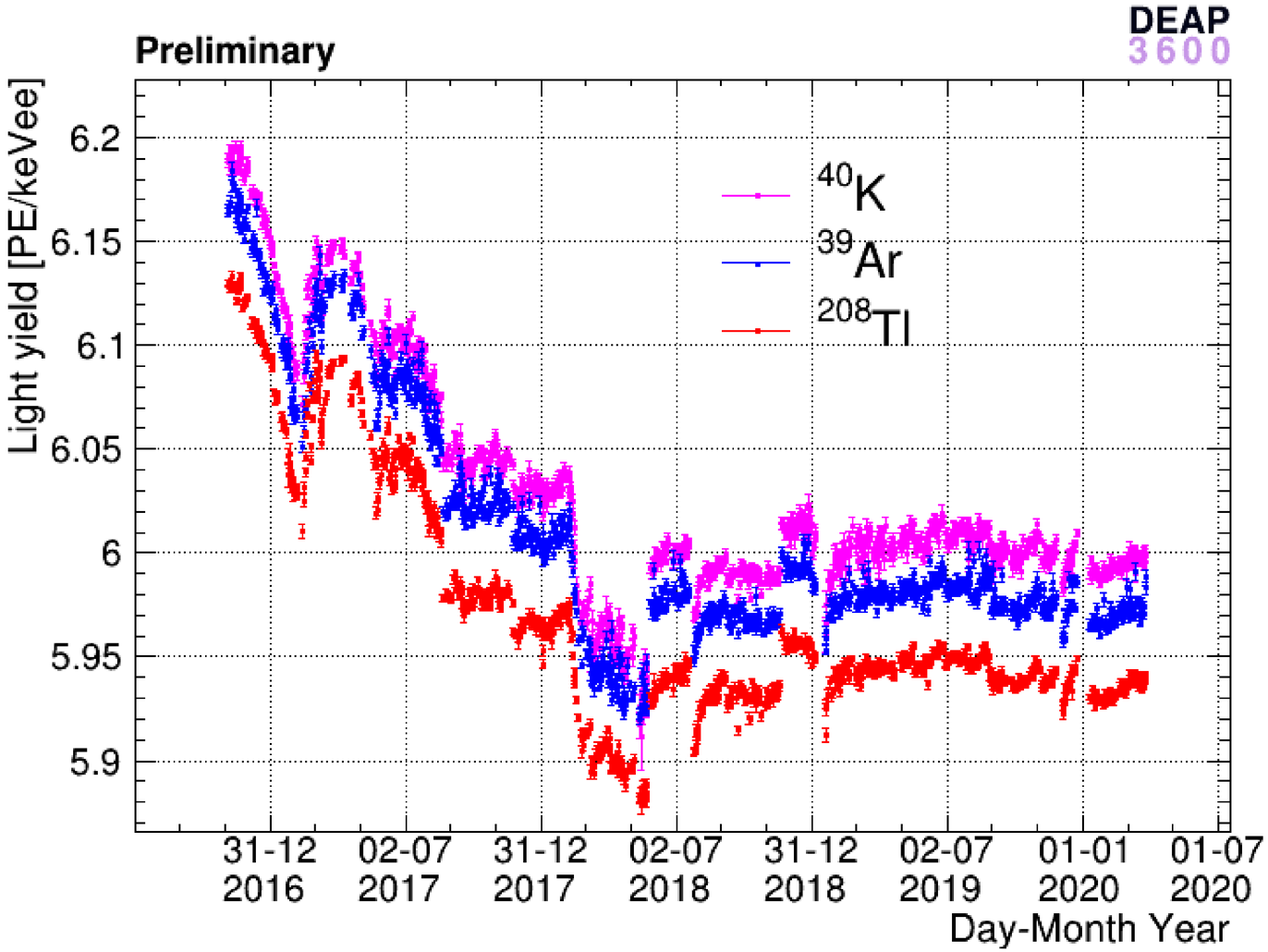

MC driven model fit to AmBe data for energy calibration

For neutrino searches, Emma Ellingwood talked about it on Monday, May 27, 2024, 11:45 AM

**What would be LY in high energy region?**

# Light Yield Variation

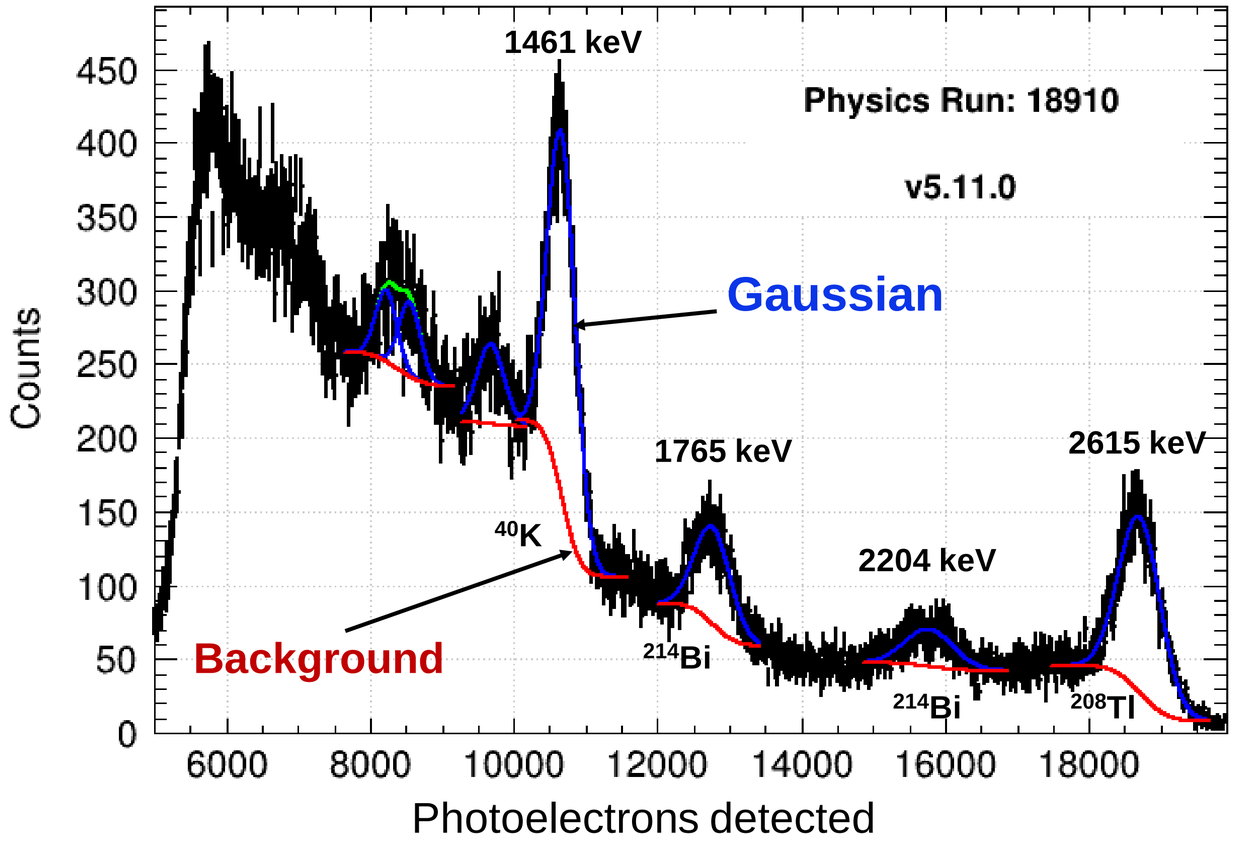
- The plot shows the variation in light yield (LY) over four years of collected data.
- We correct our photon counting to account for these variations.
- The energy response function is applied on a run-by-run basis to correct the LY and will also address LY non-linearity.



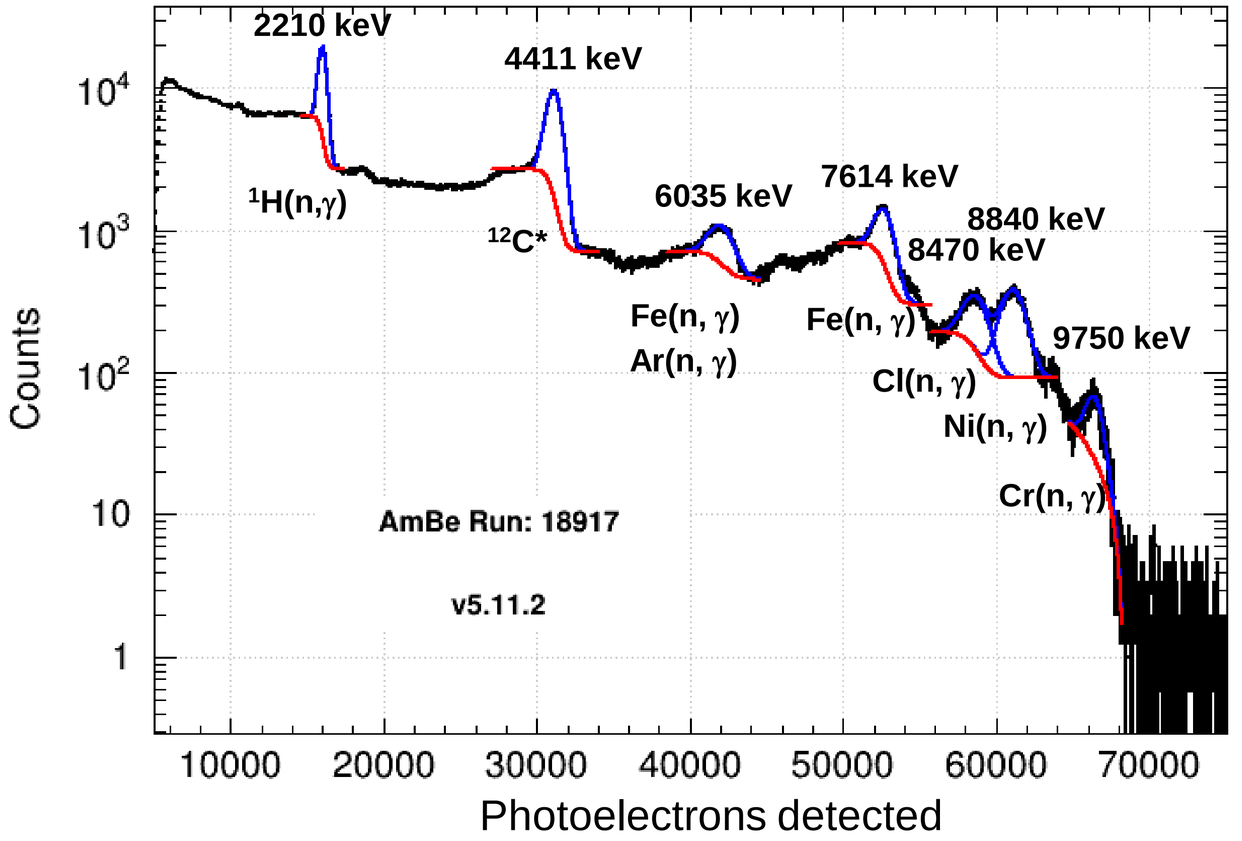

**The implementation of global non-linearity correction is currently underway.**

# Precise High Energy Gamma Ray Calibration

This method combines AmBe and physics runs.
It allows calibration over a wide energy range from 1461 keV to 9700 keV.
We choose runs close in time to perform the full calibration.
Individual peaks are fitted with Gaussians functions.




Physics background spectrum




AmBe calibration spectrum

**We repeated this analysis 15 times depending on how many close-in-time runs we can find.**

# LY non-linearity extracted from combined runs

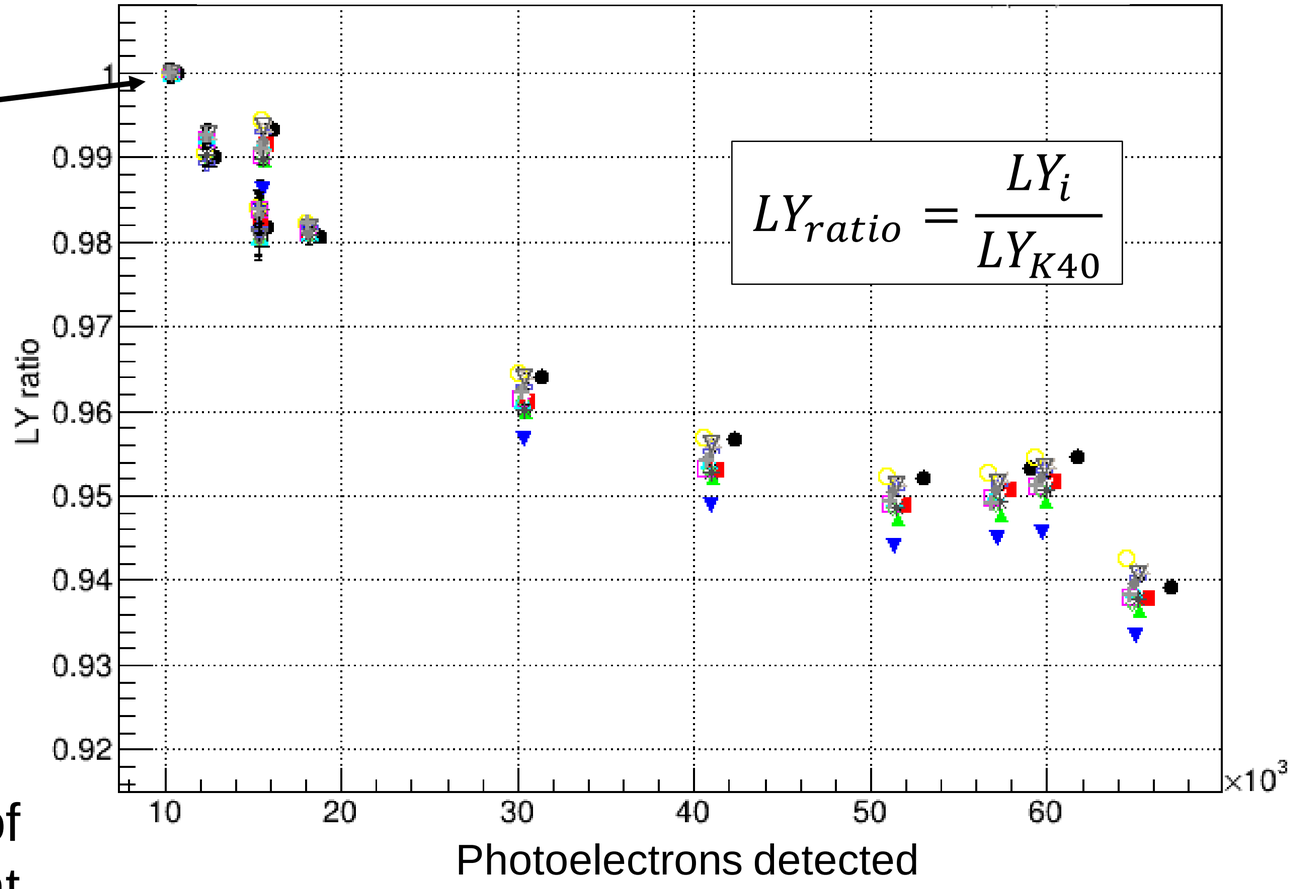
Energy response is linear at 1461 keV K-40 peak. All the light yields (LY) from the runs were compared to the LY of the K-40 peak.
The plot shows approximately 6% non-linearity over the energy range from 1.4 MeV to 9.7 MeV.

We count the LY non-linearity as following:

$$E = \frac{PE}{LY_{K40} * LY_{ratio}} \qquad LY_{ratio} = f(PE)$$

We will be using a simple and stable parameterization of the non-linearity to have a smooth function of energy.

We also observe that, within a 1σ uncertainty of 0.4%, the non-linearity remains constant throughout the runs.




LY ratio distributions for all 15 analyses.

**Even though the LY varies, the non-linearity does not.**

# First Test

- The first self-consistency test has passed for the physics data
- Peaks were well aligned.
- It showed that our calibration approach worked well.
- It looked promising for further improvements and analysis.

| Sampled Run number | Run start date |
|---|---|
| 18831 | Nov 18, 2016 |
| 21399 | Jan 2, 2018 |
| 24840 | Apr 3, 2019 |
| 27111 | Jan, 2020 |

**Further tests on the AmBe calibration runs are pending.**

# Summary

- **DEAP-3600 is a single-phase dark matter detector distinguished by its use of the largest volume of liquid argon medium in the field.**
- **Well tuned energy calibration is crucial not only for dark matter searches but also for other rare event searches like solar axions and solar neutrinos.**
- **To achieve this, we've integrated the most effective aspects of energy calibration methods into a unified gamma-ray energy calibration model.**
- **Precise energy calibration is specifically designed for the 1 MeV to 10 MeV energy range.**

# Next

- **The model will be improved by increasing the number of combined runs from AmBe and physics runs.**

# Thanks for your attention!