# Status of the large prototype LXe calorimeter

Emma Klemets (she/her)

TRIUMF, UBC

June 20th, 2024

# Goals

**Using a high momentum resolution 20-100 MeV e+ beam (PIM1) at PSI:**

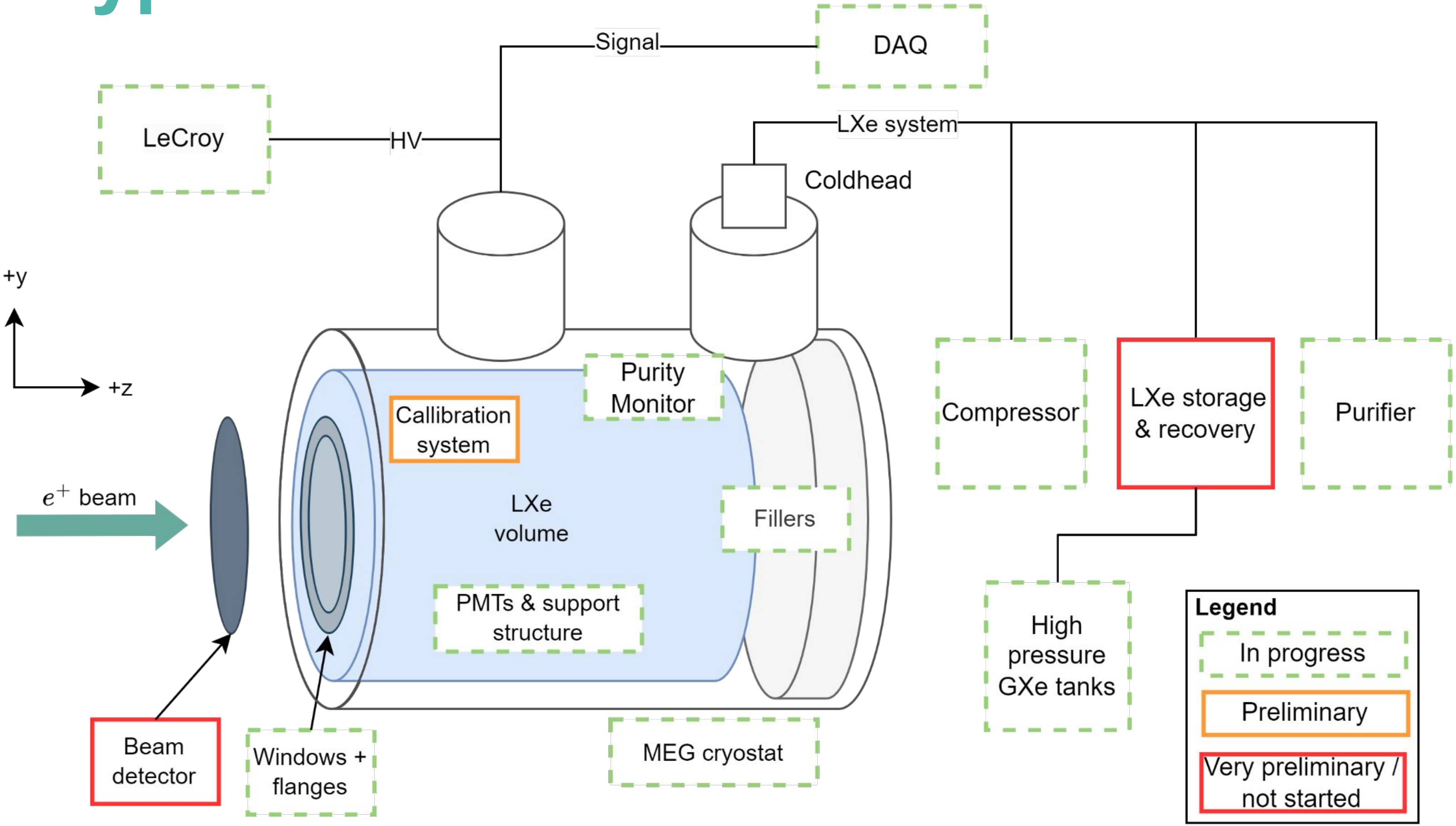
- Measure energy resolution at several energies and compare to MC simulations
- Measure detector lineshape including contribution of photonuclear reactions
- Study shower leakages (resolution versus angle)
- Measure albedo
- Monitor LXe purity during data taking - measure effect of purity on energy resolution
- Study pileup suppression: both temporally and spatially.

**Technical and R&D aspects**

**Physics**

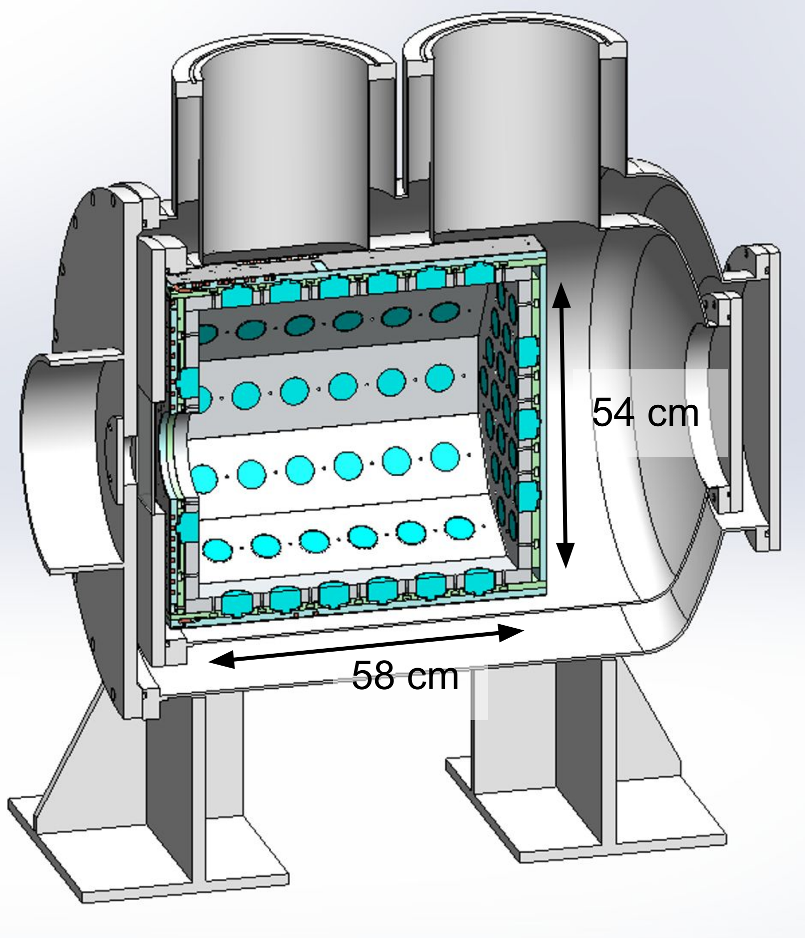
- **$\mu \rightarrow$ 5e measurement**

# Prototype overview



# Design

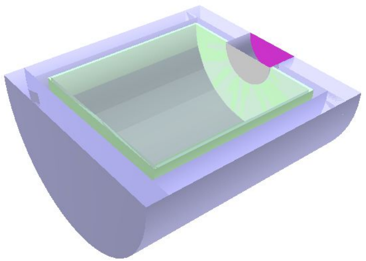
- The cryostat → from MEG large prototype
- Support structure → being designed by TRIUMF engineer
- Windows → being developed by Satoshi
- PMTs → from MEG large prototype
- LXe system
- 2 PMT calibration systems
- Purity monitor

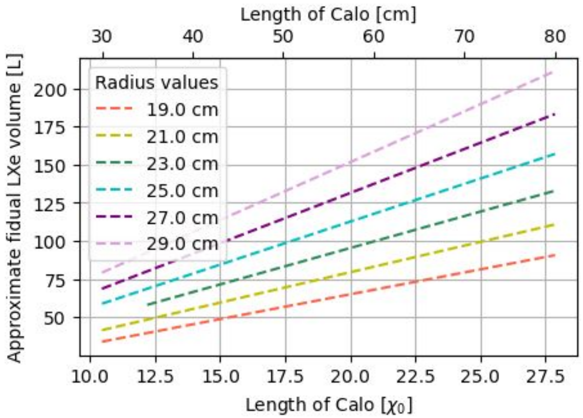


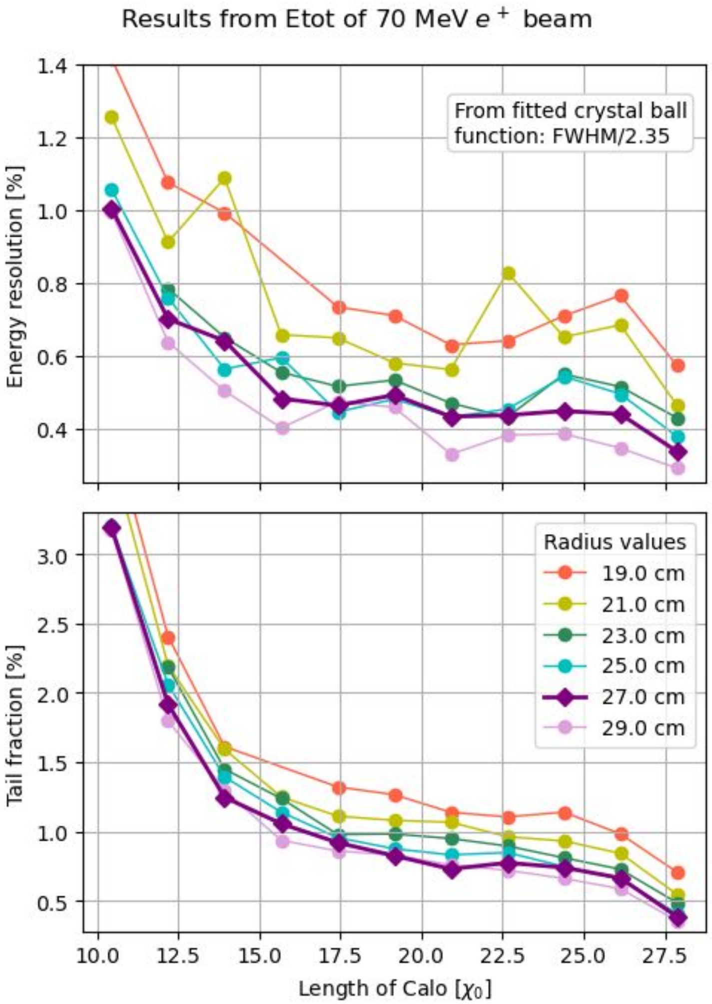

Current large prototype design with 140 PMTs; dimensions shown are for PMT face to face.

# Geometry choice

- Basic simulation of cryostat with no optics on
- Using total energy deposited truth values to see energy resolution and tail fraction as function of the LXe volume radius and length
- Maximum radius that fits in cryostat is 27 cm, at this radius not much LXe is saved for a reasonable energy resolution by using the conical frustum





# Optical simulations

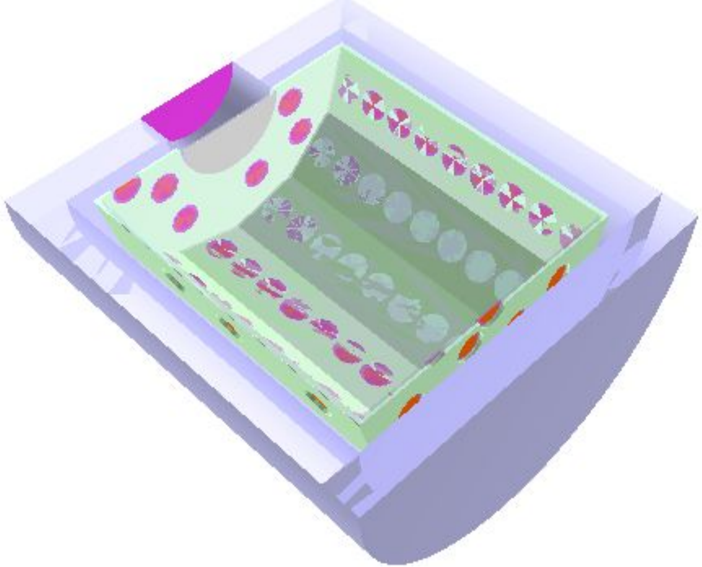
Currently for getting optimal placement of PMTs

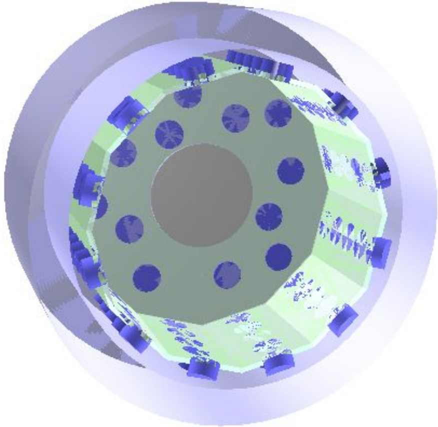
```
QGSP_BERT_EM4
rMaxCalo = 27.0 #cm
zCalo = 58.0 #cm
```

→ See backup slides for more properties used

- 100 % absorbing support structure walls
- Quartz windows on PMTs (not optical surfaces)
- LXe light yield of 45 000 optical photons/MeV
- Scintillation turned down to 10% → effective QE

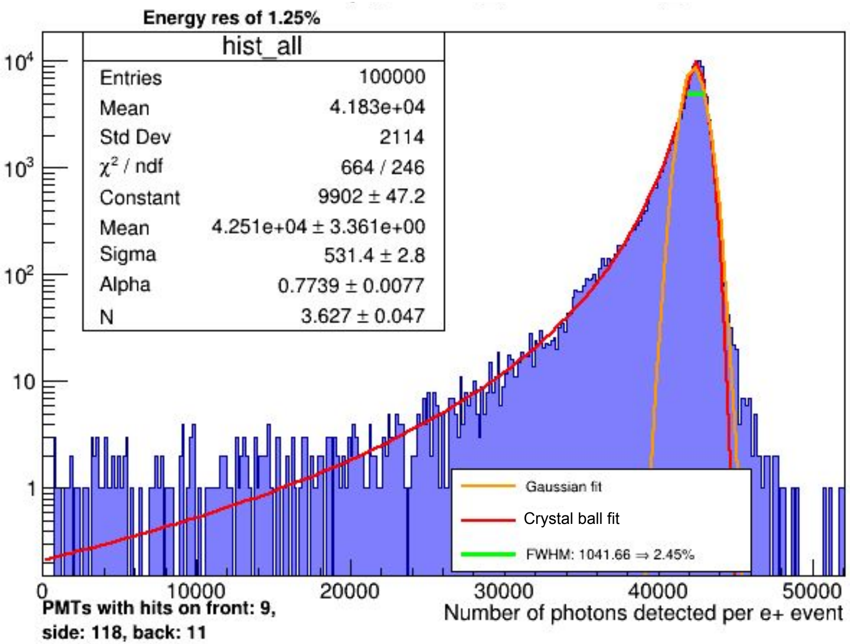
- We have about 140 PMTs from MEG → total photocathode coverage of the inside surface of 15%
- Currently unclear how feasible a reflective support structure surface would be



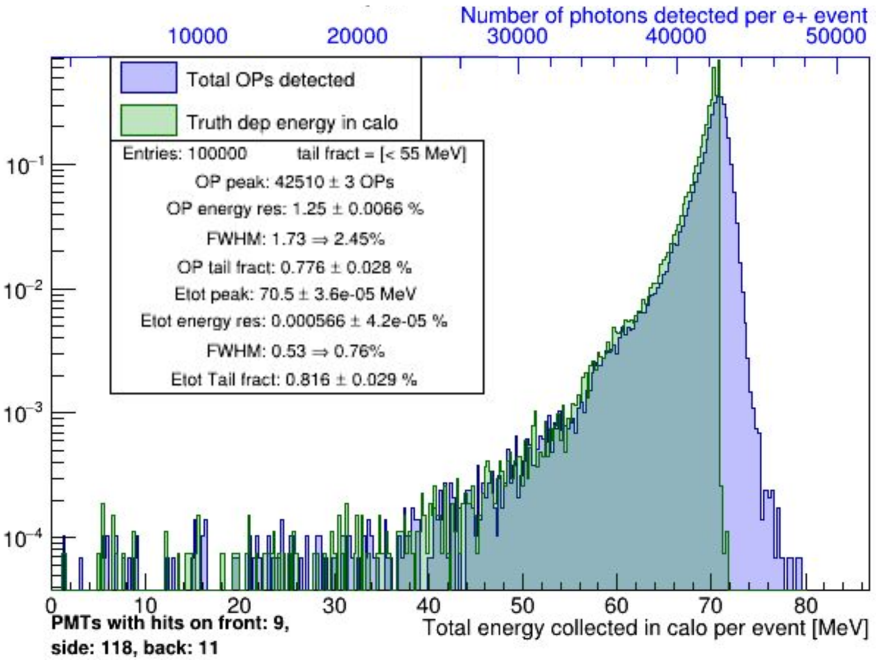


See full geometry set up in LargePrototypeCalo.py in geometry/tree/feature/ProtoCalo

*Work in progress*



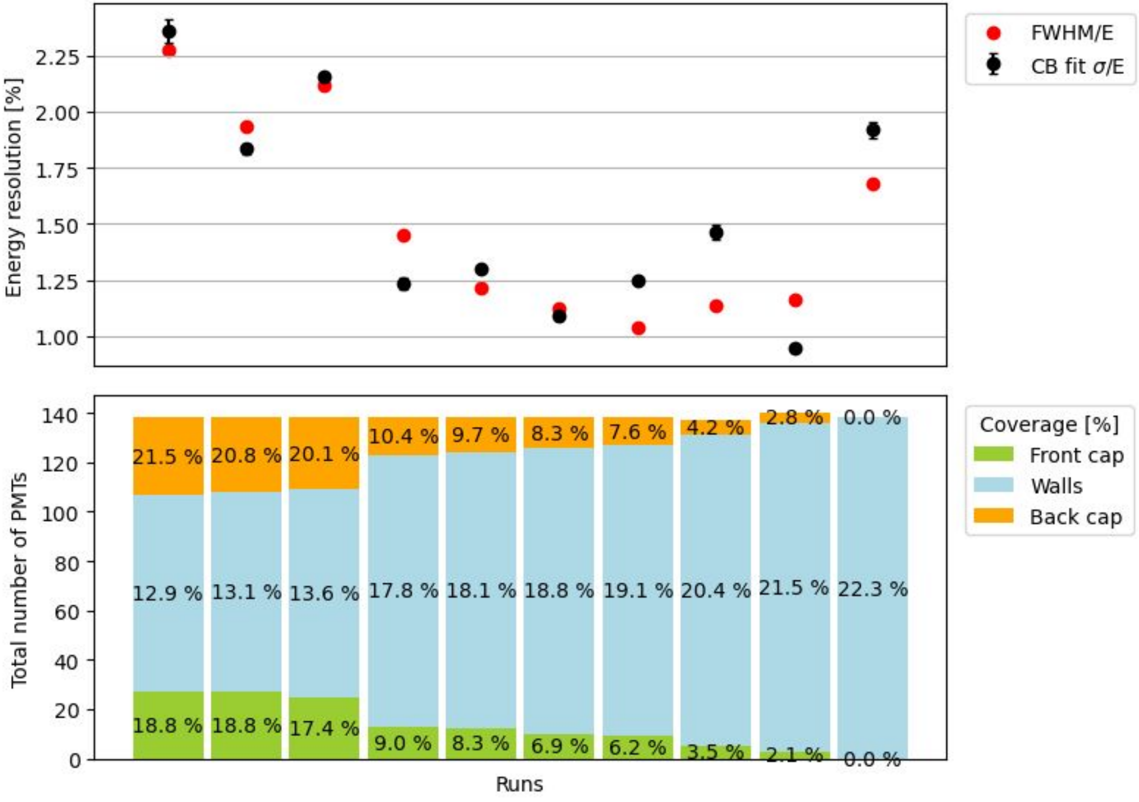

Example optical photon detection & truth energy (sum of Edep with time < 100 ns) distributions for PMT placement study




Moving from left to right plot: use peak position of Edep histogram to match up the peak of OP histogram and scale it to be a function of energy

*Work in progress*

E = 70 MeV, no reflections, 10% light yield (4.5 x $10^{-4}$ OP/MeV)




Getting best energy resolution with ~140 uniformly distributed PMTs at around:

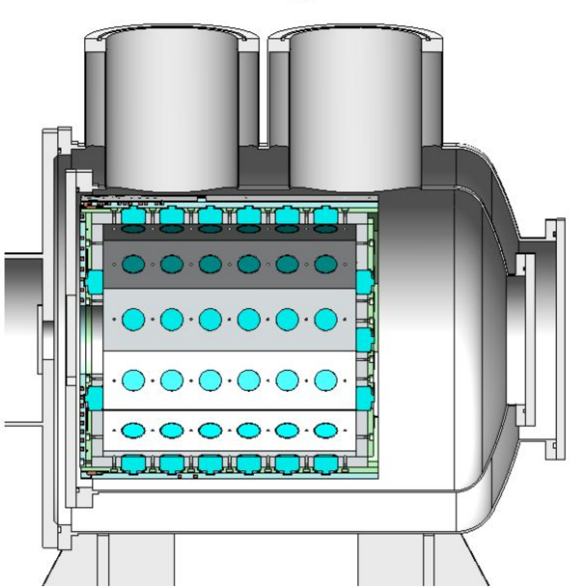
- 10 on front cap
- 116 on walls
- 12 on back cap

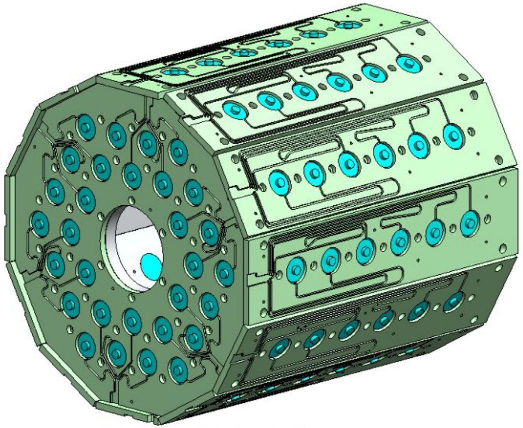
Corresponding to a coverage of about:
Front: 8%, wall: 19 %, back: 7 %

- Energy resolution does however change depend on how you calculate the distribution width
- Not enough statistics in these run to get meaningful tail fractions

# Hardware status

- Cryostat
  - Will need some new fillers to be designed along with the support structure
- Windows
  - Vacuum window: 500 um of Al, tolerable to 0.1 MPa
  - Xe window: 200 um of Ti-6Al-4V, 20 cm diameter, Tolerable up to 0.3 MPa
- PMT support structure
  - Mainly made of Aluminum, set on rails at base
  - Ongoing work on PMT holders to ensure thermal compression is not a problem
  - Wire routing through top-back chimmy, feedthroughs
- LXe system
  - Need to get a HP tank
  - Gaseous purification is slow (1 month) in the current setup → Satoshi is working on scaling up the system

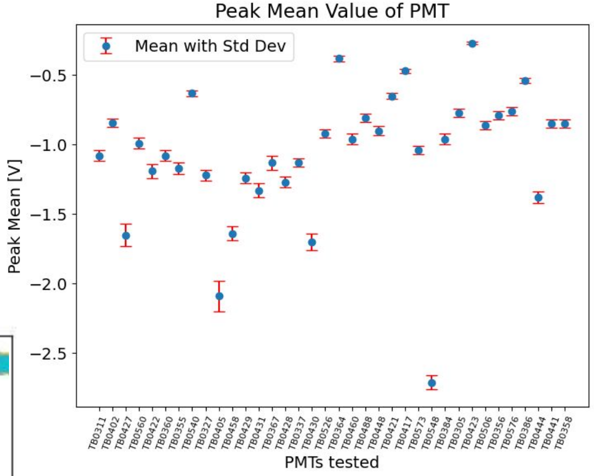


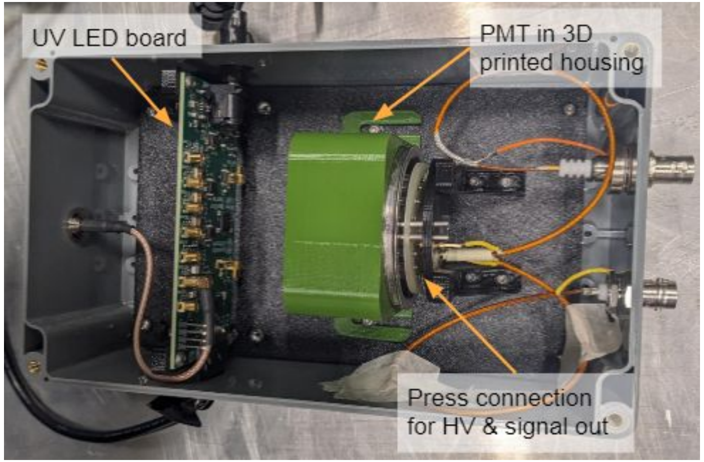


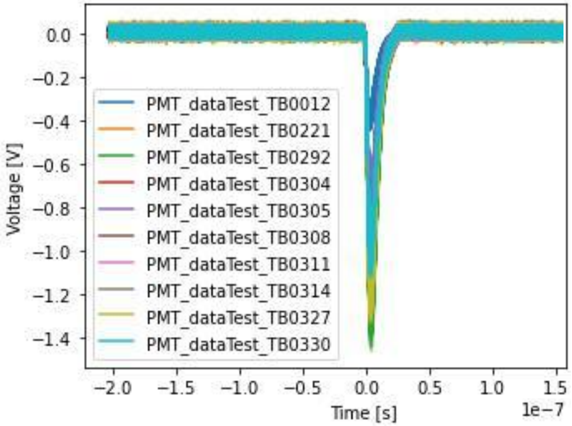
# **PMT testing** - co-op student William

| Generation | Model number | photocathode material | ~ QE | Number |
|---|---|---|---|---|
| 1st | R6041Q | RB-Cs-Sb | 6% at 165 K | 27 |
| 2nd | R9288 | K-Cs-Sb | 15% | 109 |
| 3rd | R9288-01MOD | K-Cs-Sb | 15% | 3 |

- All PMTs have been tested in simple test box, except 4 potted ones
- Most have signal, but seeing a higher than expected distribution of readout voltage peaks
  - LED being used was tested with a SIPM and looked fine
  - Setup is a little temperamental
- Next steps:
  - Linearity tests
  - Cold tests in cold box that will also be used for the purity monitor



**DAQ** - Previously used by Muon g-2, sent to TRIUMF by Lawrence @ Cornell, being set up by Ben & Bob

- Software installed on local Alma9 machine thanks to updates & help from Lawrence, Jack
- Network card and SFP+ modules tested and working (after some debugging…)
- Remaining hardware still to be installed, synced to software, tested
- Planned for use for future phases of PMT testing (Fall 2024), next pion lifetime prep measurement - surface muons (Early 2025? - endorsed @ TRIUMF, awaiting scheduling)
- DAQ will be fully operational before sending to PSI for future LXe prototype test

WFD5 crate @ TRIUMF. 10 modules x 5 channels = 50 channels. Will eventually need 1-2 more crates for all PMTs.

## PMT HV power supply

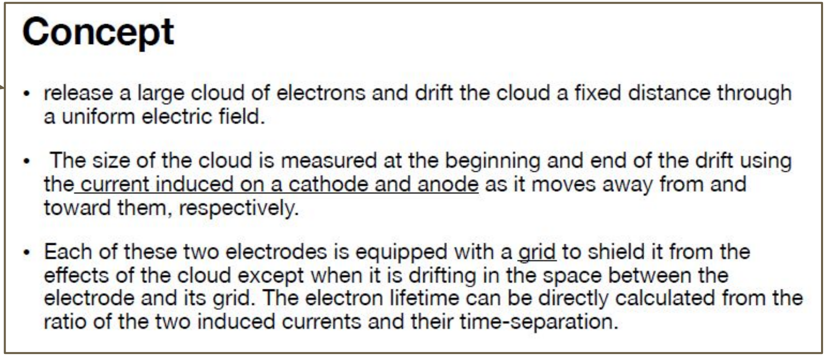
All channels (224) have been tested on a Lecroy 1440. Most channels are working, more than the number of PMTs we have.

- Some control issues remain, but almost ready

# **Purity monitor** - summer student Pierce

Will monitor for EM impurities in the LXe which decrease attenuation lengths. This is done by measuring the e- lifetime in a drift chamber.

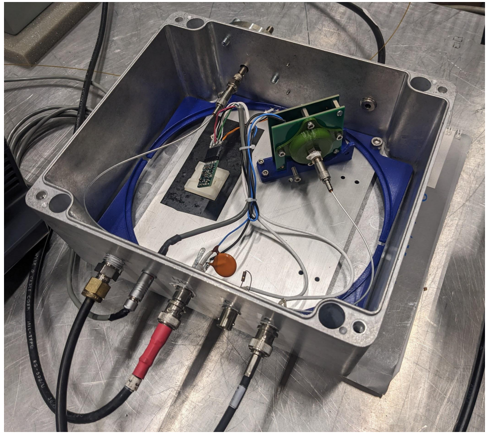
- Design has been finalized:
  - Resistor and electric field set (optimized in COMSOL by co-op student Claire)
  - Amplifier to be designed such that it can sit outside the LXe volume
- Currently the prototype is being tested at TRIUMF:
  - Different photocathodes from SFU
  - Next is testing in cold box

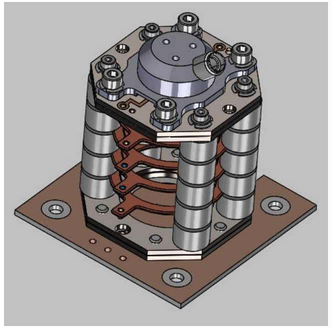


**Concept**

- release a large cloud of electrons and drift the cloud a fixed distance through a uniform electric field.
- The size of the cloud is measured at the beginning and end of the drift using the current induced on a cathode and anode as it moves away from and toward them, respectively.
- Each of these two electrodes is equipped with a grid to shield it from the effects of the cloud except when it is drifting in the space between the electrode and its grid. The electron lifetime can be directly calculated from the ratio of the two induced currents and their time-separation.

The prototype purity monitor will be tested in LoLX before being used in the large prototype.





Test setup for charge yield of photocathodes

# Calibration

Based on MEG large prototype. What they had was:

- 8 LEDs (2 on each lateral face)

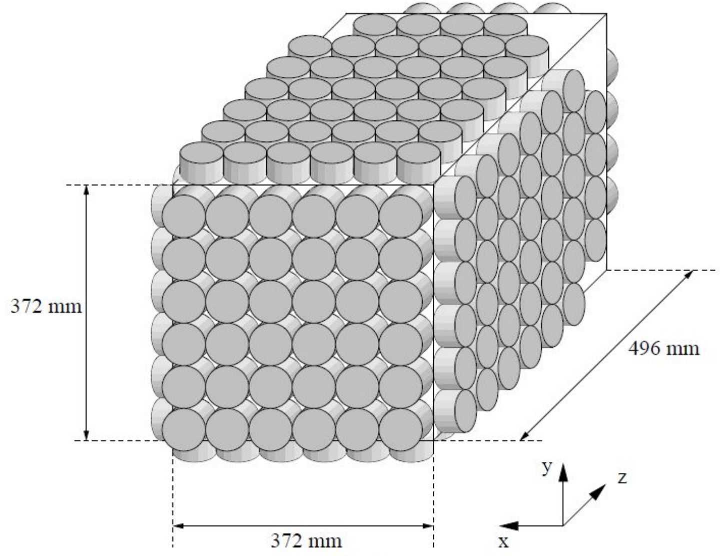
  → Set gain of each PMT

  - This is to convert ADC count to number of photoelectrons ($N_{pe}$)

- 4 241-Am alpha sources

  → Get QEs of each PMT

  - This is to convert from $N_{pe}$ to number of photons ($N_{ph}$) & position reconstruction

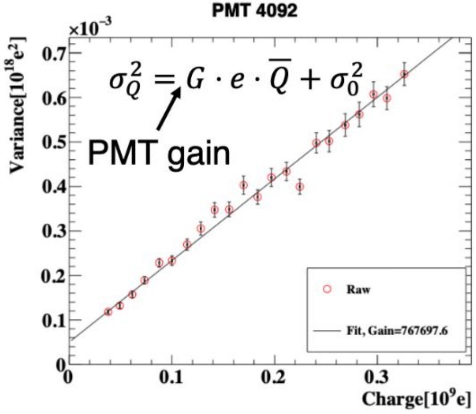



Schematic of the PMTs arranged in their prototype, with ~ 37% photocathode coverage (K. Ozone's PhD thesis', 2005, Fig 3.6 (a))

# Calibration

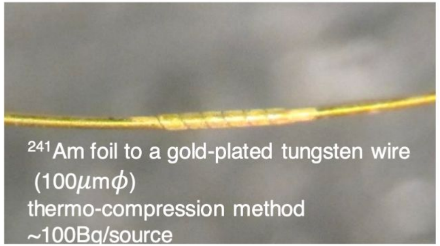
LEDs

- Need a couple blue LEDs
  - Must be stable → stability should be better than random noise amplitude
  - Multiple pairs of LEDs just to check calibration
- Get relation of variance vs charge mean with different LED intensities

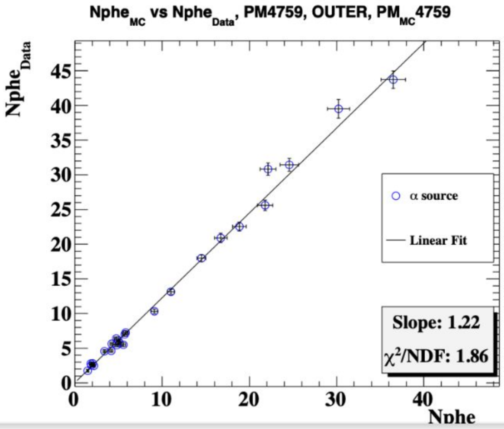




Alpha sources

- Can use the MEG prototype ones: 100 micron-meter tungsten wire with $^{241}$Am source wrapped around it
- Need to compare with MC results




Ratio of data/MC for a PMT



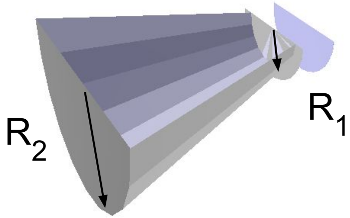

All images from Toshiyuki Iwamoto

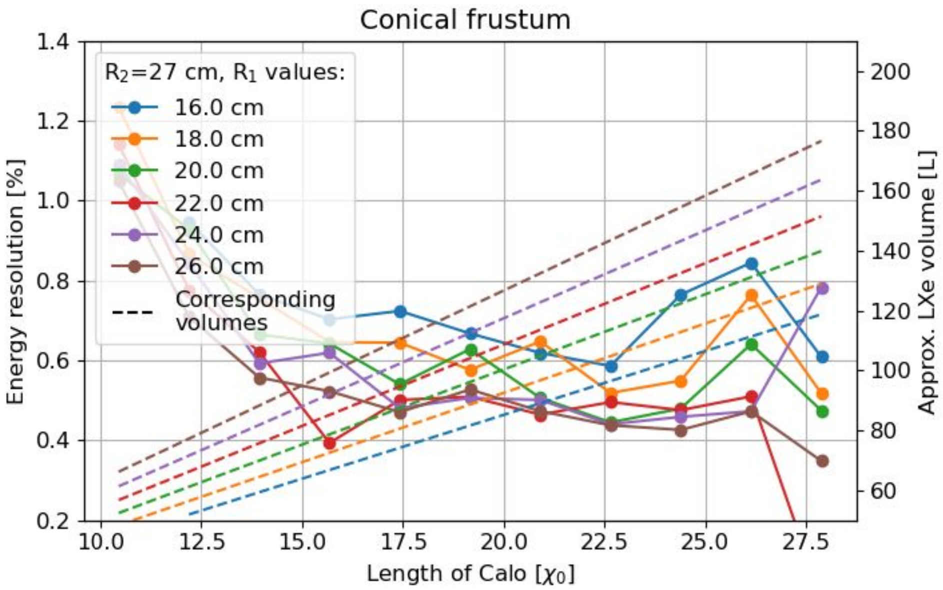
# Backup slides

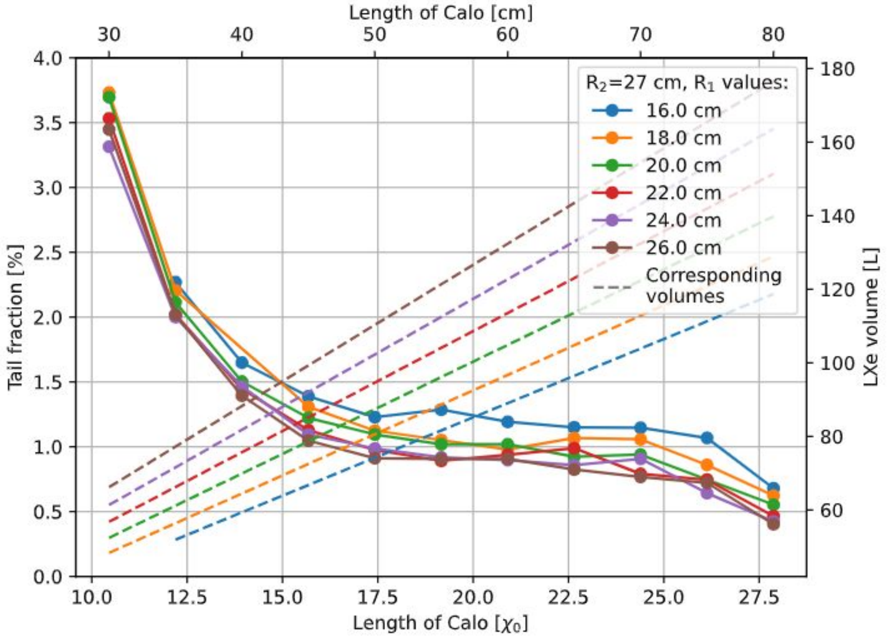
# Conical frustum geometry study results

Energy resolution is calculated as:

FWHM/2.35 / peak energy



# Simulation details

## LXe optical properties

```
"light_yield": 45000, #OP/MeV
"decay_constant": 45.0, #ns
"decay_constant_slow": 45.0, #ns
"Absorbtion_length": 150.0, #cm
"Yield_ratio": 1.0,
"Scattering_length": 45.0, #cm, recently added
"refractive_index":
```

A function of wavelength, ex: at `175.01 nm : 1.67710 mm`

## Quartz

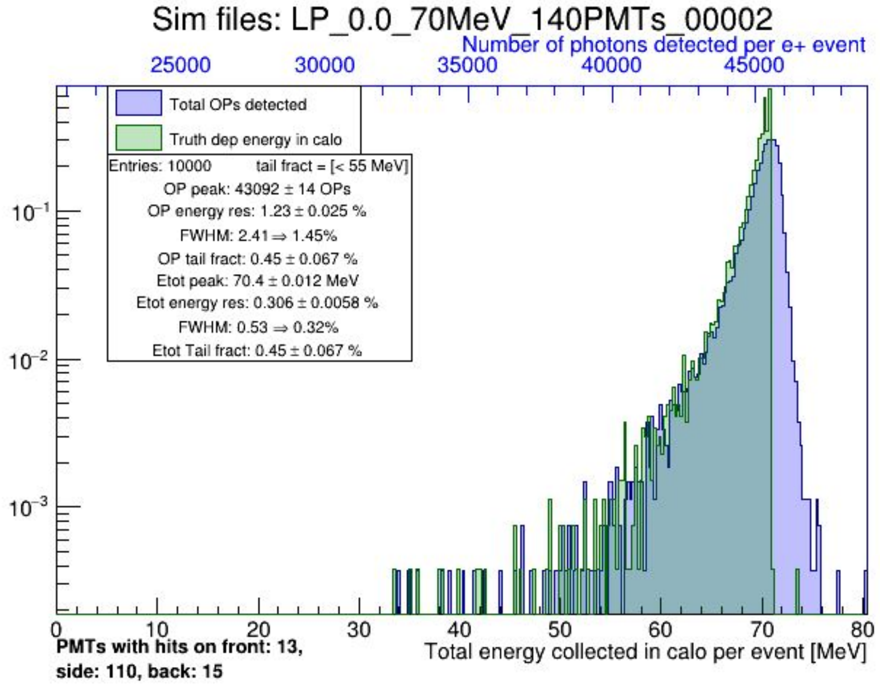
```
"Refractive_index":
```

A function of wavelength, ex: at `175.0 nm : 1.60690 mm`

# Quick reflectivity run

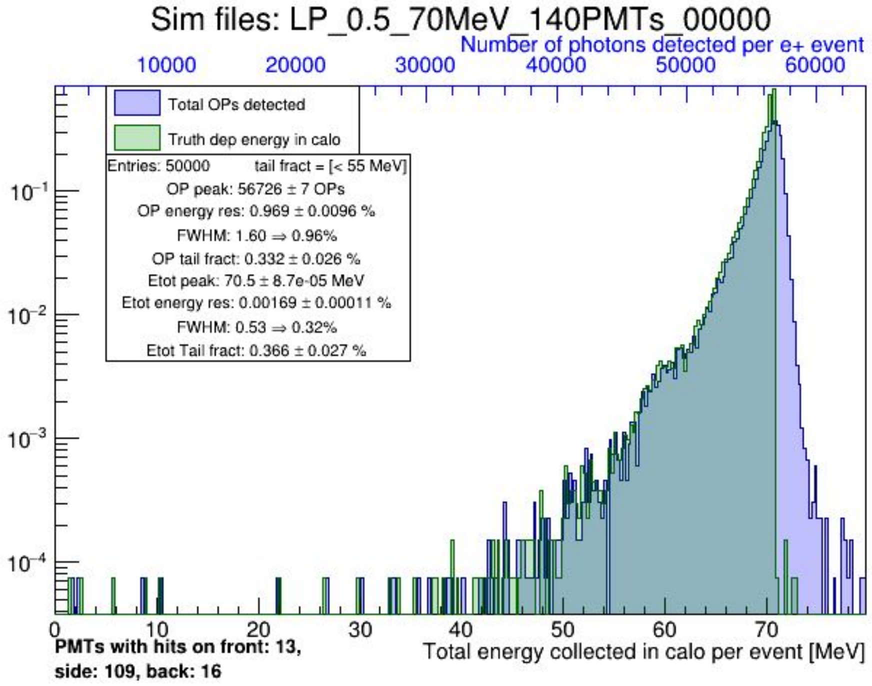
Run with 0% reflective support structure walls

OP energy resolution from CB fit: 1.23(2)%

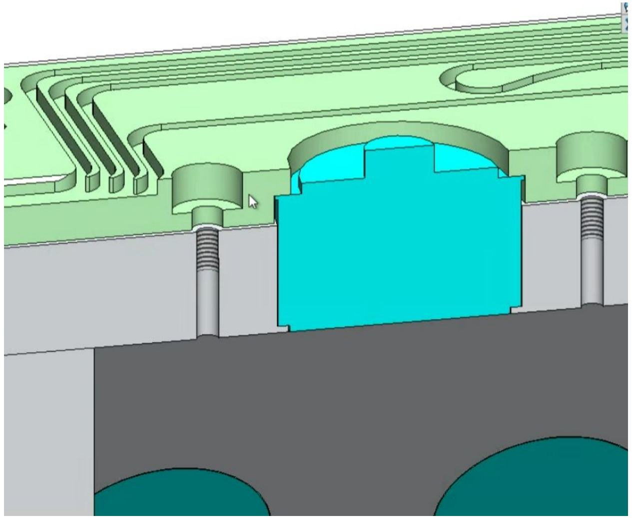



Very similar PMT configuration but with 50% reflective support structure walls.

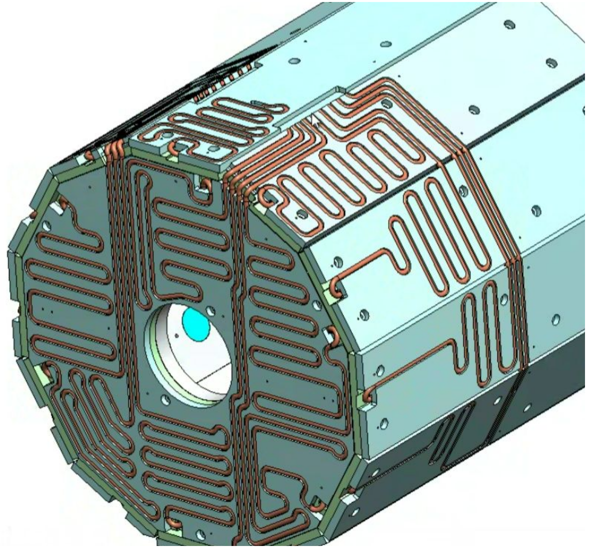
OP energy resolution from CB fit: 0.97(1)%



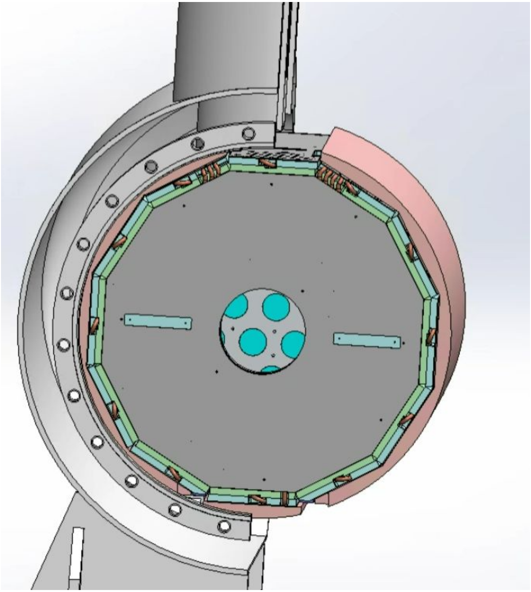
# More support structure design images



Clamp plate to hold PMTs in with conical washers. Individual wire routing on the top of these clamp plates.



Outer cable bundle routing.



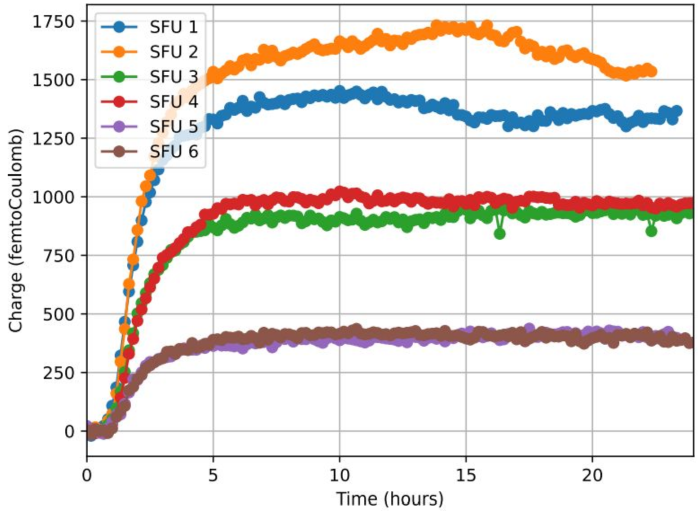
Example of filler (pink color) to be installed in pieces before the support structure is slid in. Also seen here is the attachment point for removable handles on the front.

This design is still a work in progress, but the general concepts are fairly adaptable.

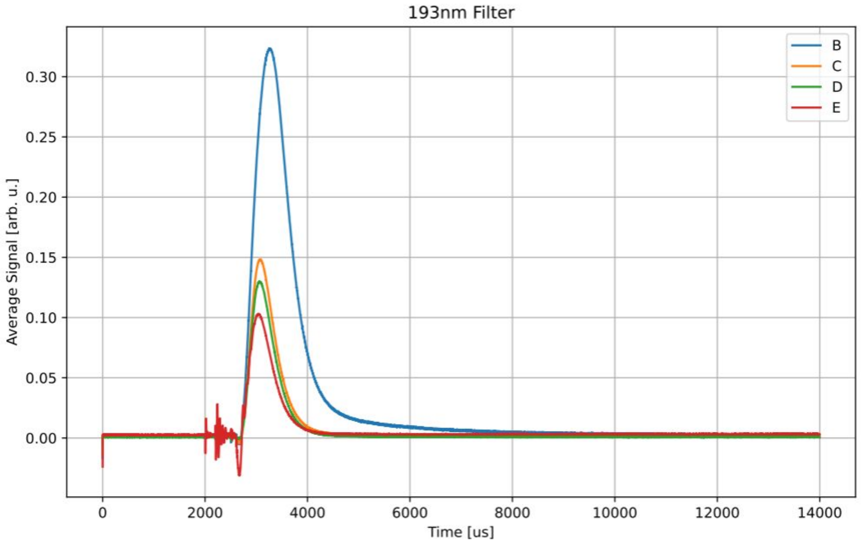
# Additional purity monitor information

Current prototype work by summer student Peirce

- Tested the charge yield of each of 6 photocathodes from SFU → results looking good, on the order of a few picocoulombs
- Setup is slightly subject to change since one of the optical fibers is wavelength-dependent, which was discovered when testing optical filters




Inconsistency between the two 10 nm photocathodes (red & green) is due to hard manufacturing limitation



# Physics with the prototype

$\mu \to 5e$

- Requires as uniform PMT coverage as possible
  - Current limit is $Br(\mu \to 5e) < 4 \times 10^{-6}$
- *Doug's estimate →*

Simulation work is needed to decide the feasibility of this study

Compared to the previous experiment: the PIONEER prototype can improve by $\sim O(10^4 - 10^6)x$ in a 10 day run

---

Energy resolution 2%: 5x

Scint. Decay time : 5x

Timing resolution 100 ps : (50 x)

Pile-up recognition: 10x

Beam rate 50 kHz : 30 x

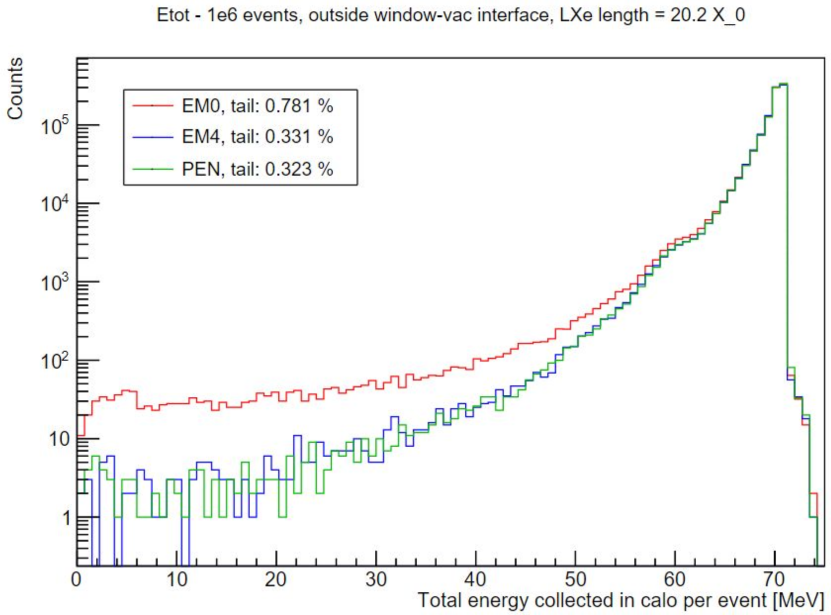
Run time 10 days: 10 x

Analysis improvement factor: 3 x

Efficiency factor: 2x

# Albedo

Similar quick study like Omar's work on the Albedo from different physics lists with the large prototype simulation, getting similar results




Also looking at where we are losing particles in the current simulation of the large prototype