KDK+ Systematics and Calibration

KDK+

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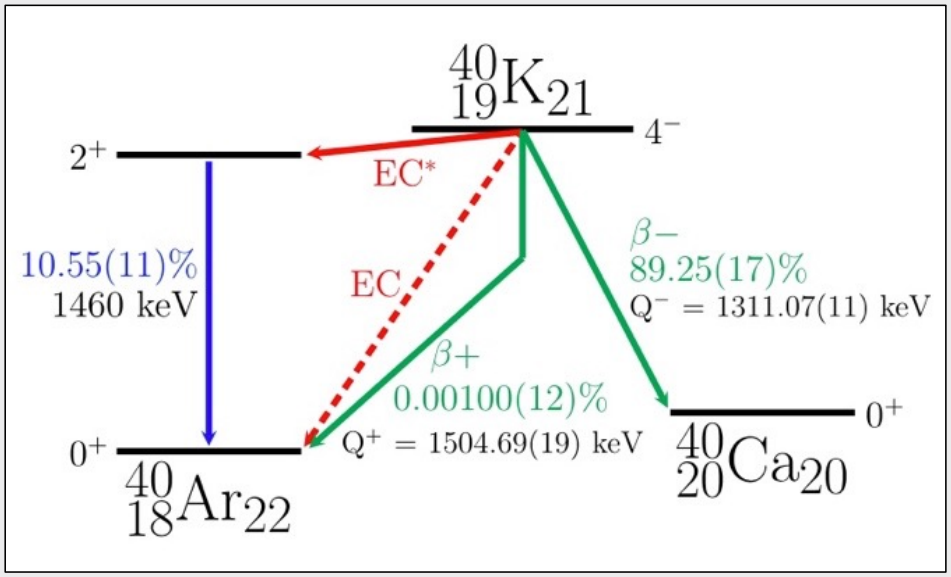
Potassium-40 Decay



Decay scheme for potassium-40 (^{40}K)

- Potassium-40 (^{40}K) can decay through either beta decays or electron captures
- The most common decay mode is the β- decay to calcium-40
- There are also three decay modes to argon-40, including two extremely rare modes directly to the ground state (electron capture and β+).

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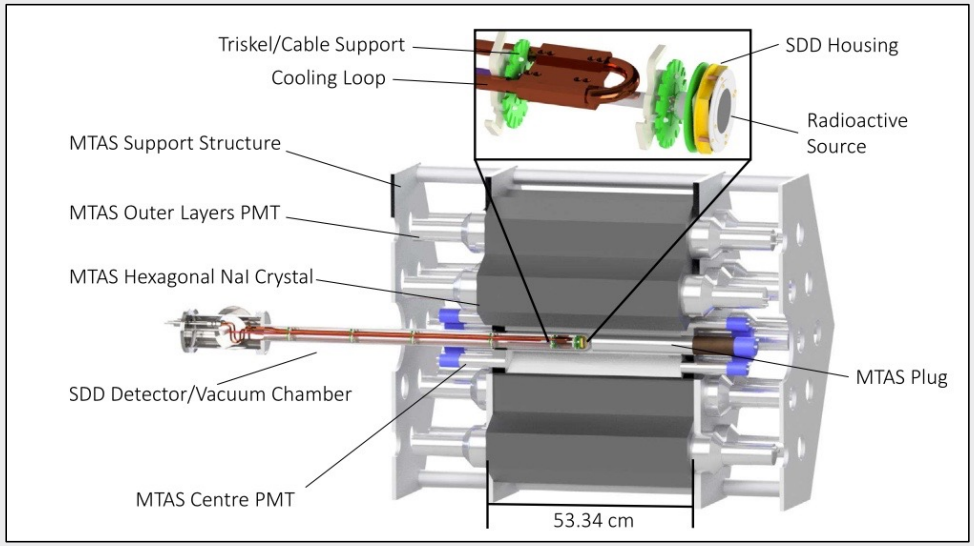
Ref. M. Stukel, et al., Phys. Rev. Lett. 131, 052503 (2023).

The KDK Experiment

- KDK collaboration: first measurement of the ^{40}K electron capture decay to the ground state of ^{40}Ar (PRL 131, 052503).
- KCl Source + SDD x-ray detector + large NaI gamma tagger (MTAS)
- Measured branching ratio of $0.098 \pm_{stat} 0.023 \pm_{sys} 0.010$



The Modular Total Absorption Spectrometer (MTAS) at ORNL used by the KDK collaboration

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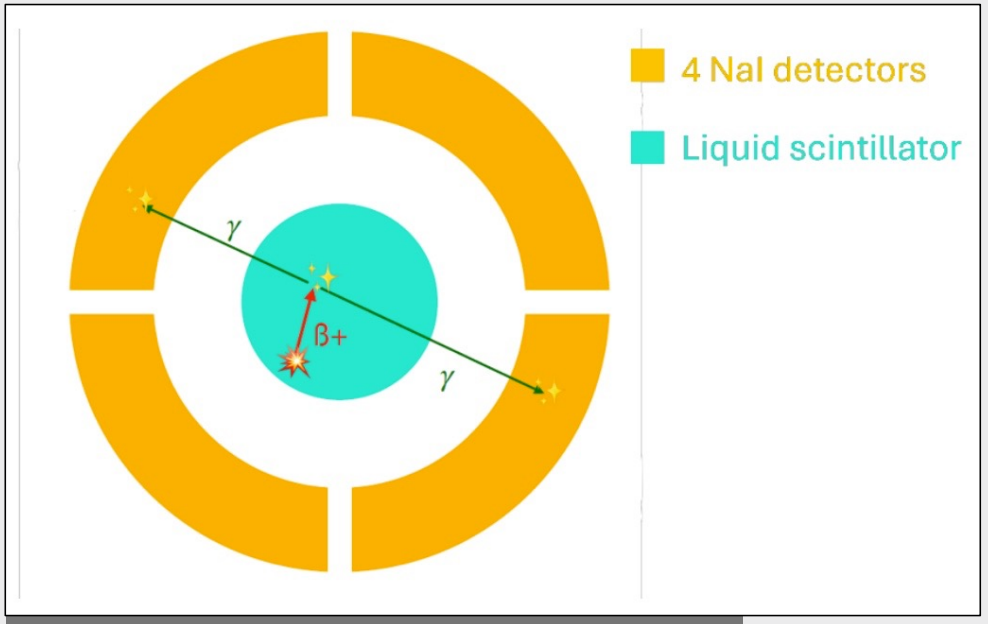
Ref. M. Stukel, et al., Phys. Rev. Lett. 131, 052503 (2023).

KDK+

- KDK+: will measure the β+ decay to the ground state of ^{40}Ar
- This decay was last measured in the early 1960s
- Will use a potassium loaded liquid scintillator surrounded by sodium iodide (NaI) crystals
- Liquid scintillator will detect positron emission; NaI will detect γs
- Aiming to detect 1000 positron emissions in preliminary test



KDK+ experiment concept

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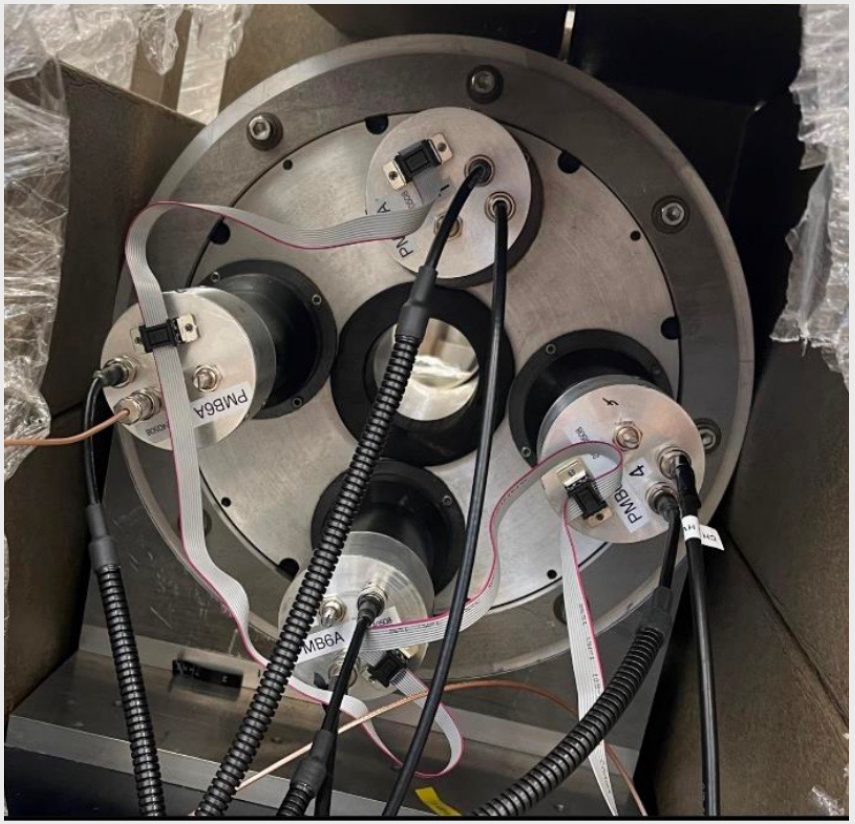
Ref. D. W. Engelkemeir, K. F. Flynn, L. E. Glendenin, Phys. Rev. 126 (5): 1818 (1962).

KDK+ Gamma Tagger

- The preliminary phase of the experiment will be conducted using an annulus containing four NaI crystals
- Tagging efficiency will be tested using sodium-22 loaded liquid scintillator



The annulus with four NaI crystals connected to PMTs

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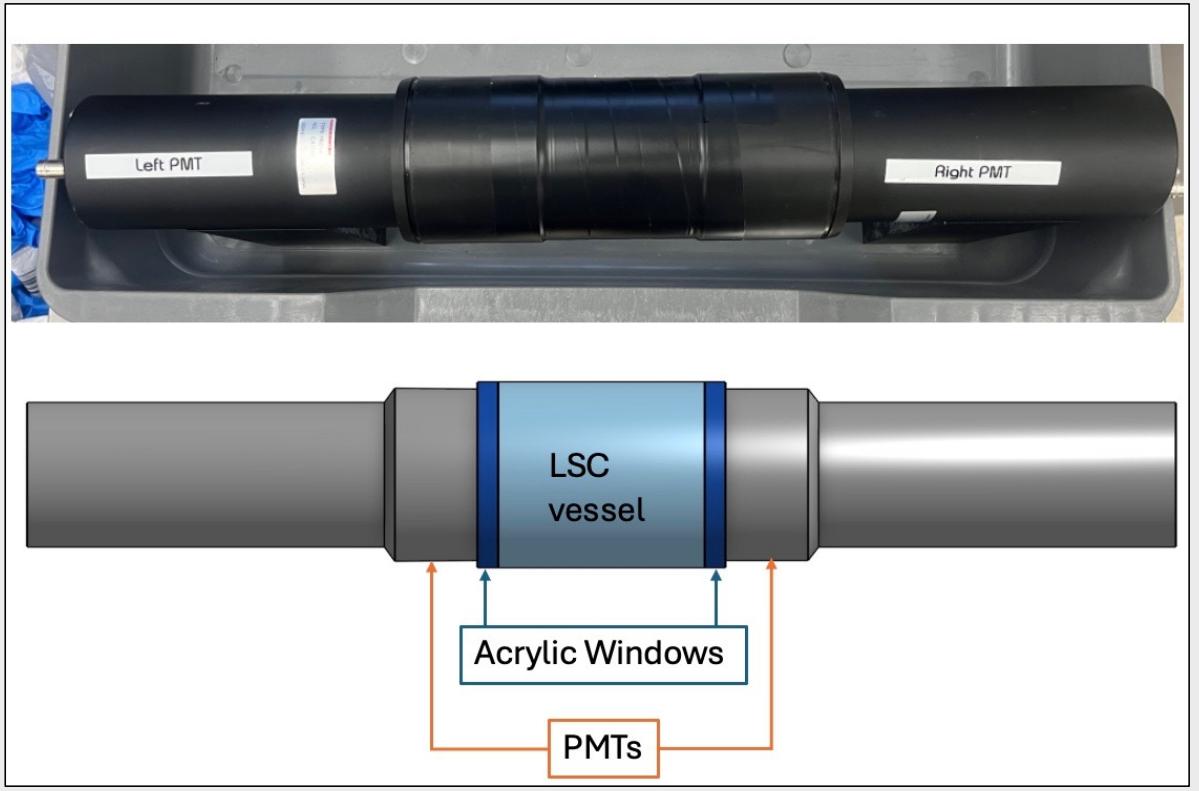
Liquid Scintillator Vessel

- A liquid scintillator vessel has been designed to fit in the center bore of the annulus with photomultiplier tubes (PMTs).
- Has a 300 mL active volume of liquid scintillator



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Liquid Scintillator Cocktail Mixing

- There are three considerations that were taken into account when designing a liquid scintillator cocktail (LSC) for use in this experiment:

01

Potassium mass fraction

02

Light yield

03

Long-term stability

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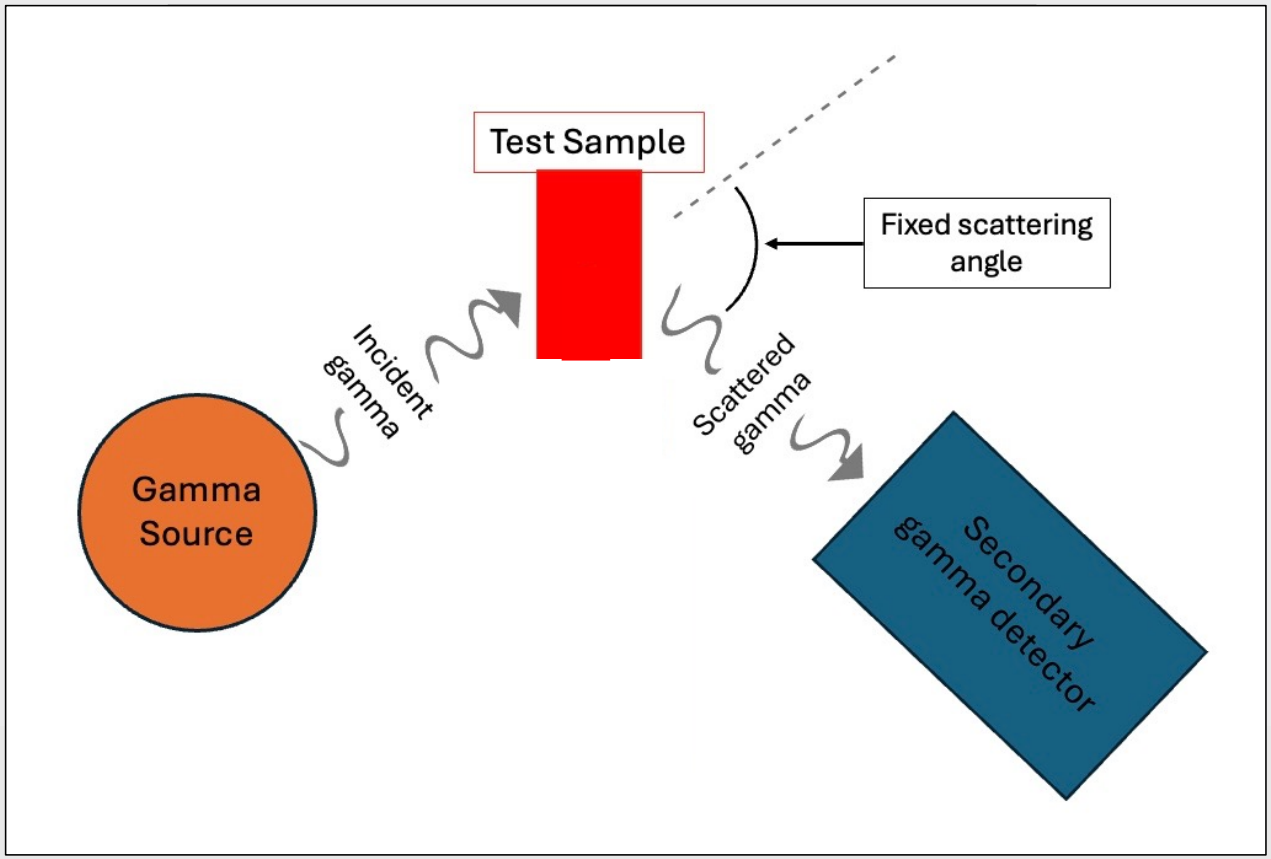
Liquid Scintillator Cocktail Testing



- To test the overall light yield as well as the stability, a series of Compton scattering experiments can be performed.

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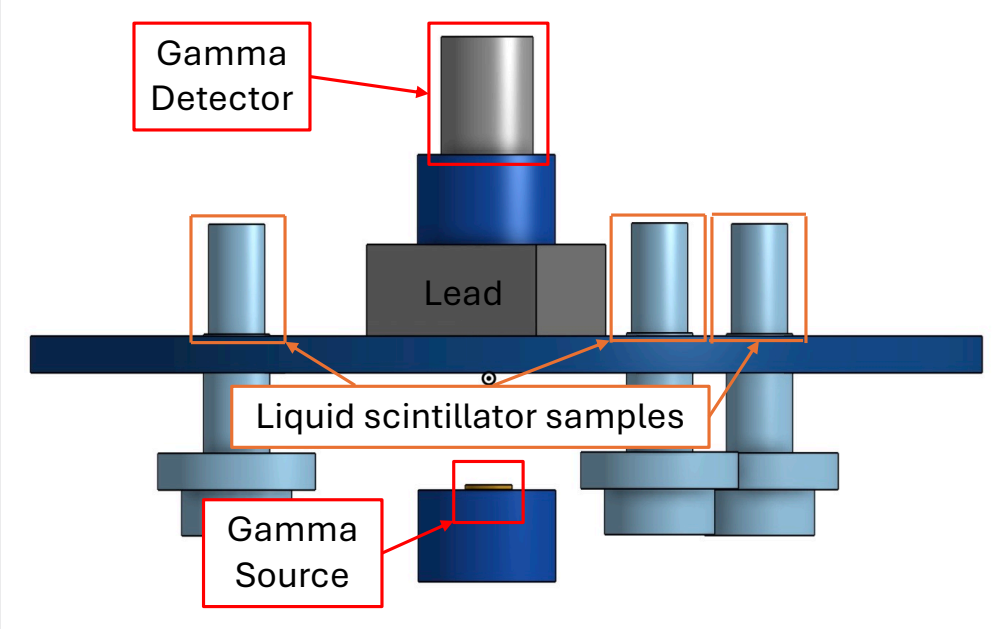
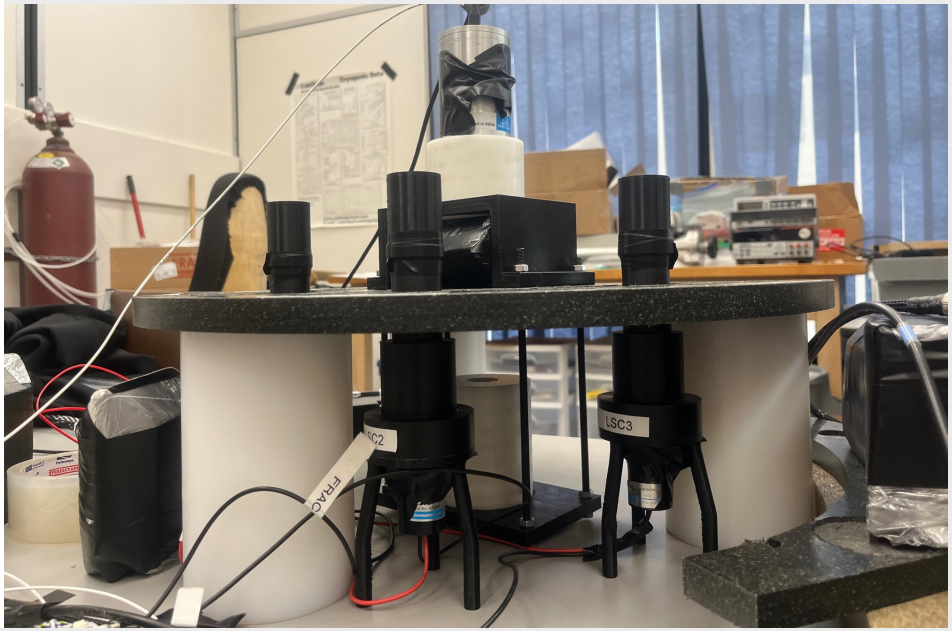
Liquid Scintillator Cocktail: Light Yield





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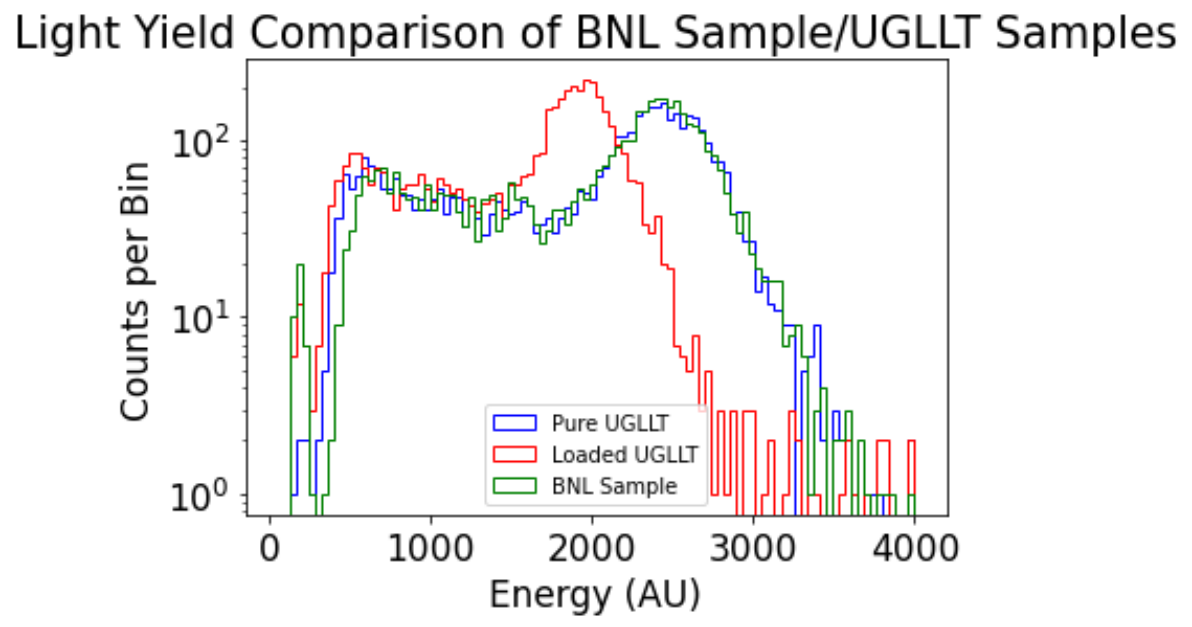
Liquid Scintillator Cocktail: Light Yield

- A variety of loaded liquid scintillators were tested for light yield
- One of the most promising mixtures we tested was Ultima Gold LLT loaded with KCl at 6 g/L
- The most successful loaded sample was provided by Brookhaven National Lab (BNL)



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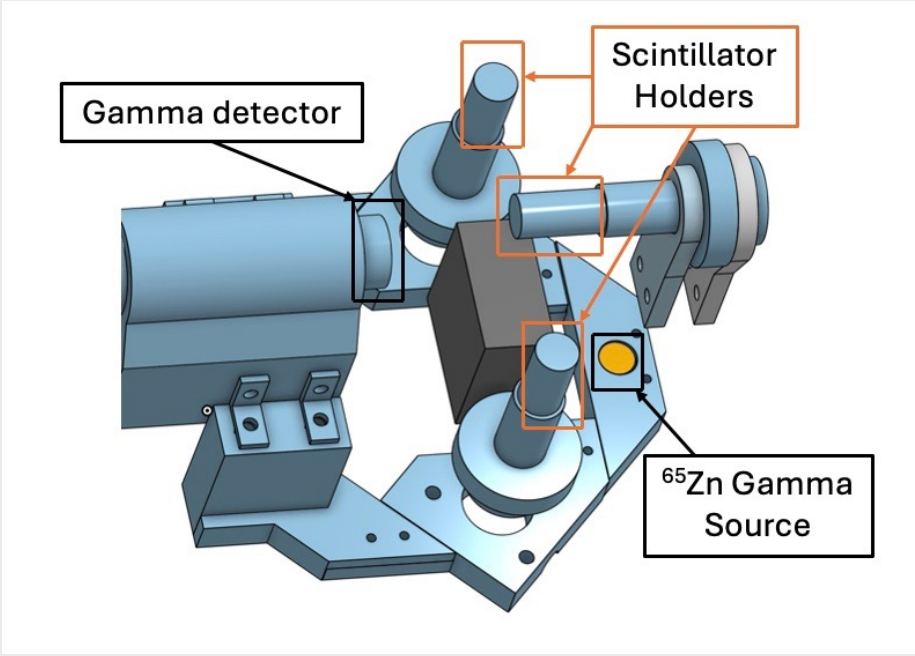

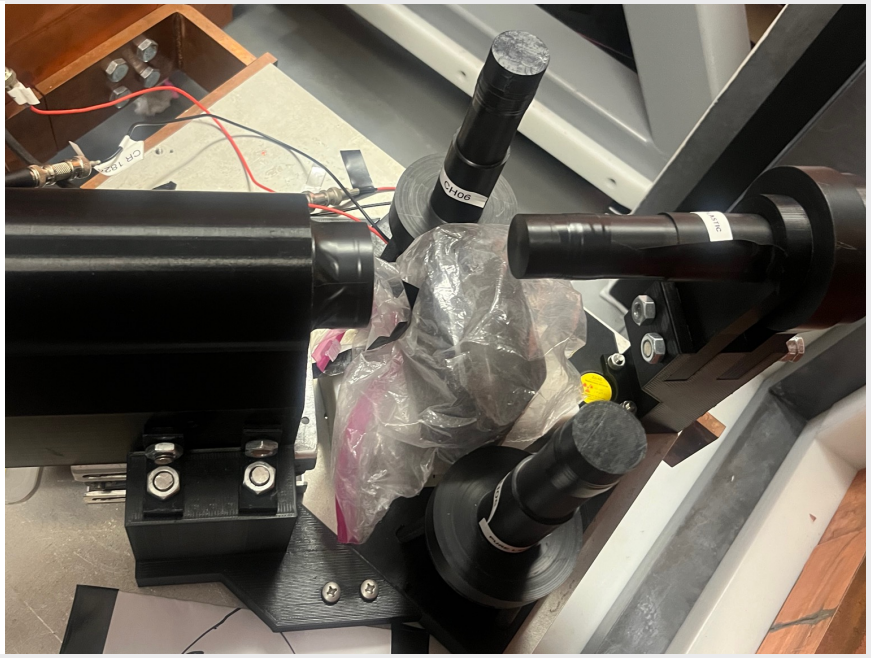

Liquid Scintillators: Stability

- A second Compton scattering experiment was designed to keep samples fixed in place over a long-term test
- This setup allows testing of two liquid samples simultaneously, as well as a plastic scintillator as a stable reference

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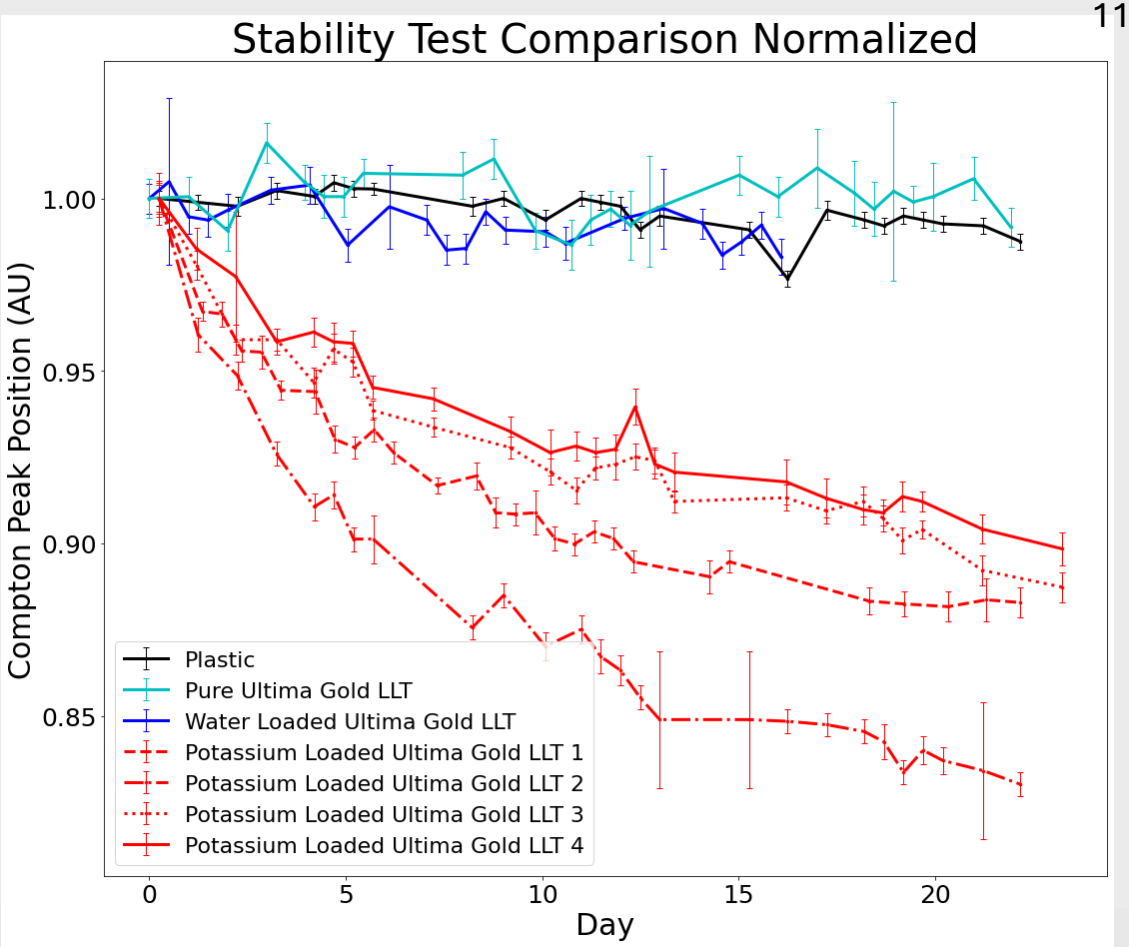
Liquid Scintillator: Stability

- Using this setup we tested several variations of Potassium loaded LSCs.
- Tests included:

  -Pure commercial scintillator

  -Water-loaded scintillator

  -Variety of Potassium loaded scintillators



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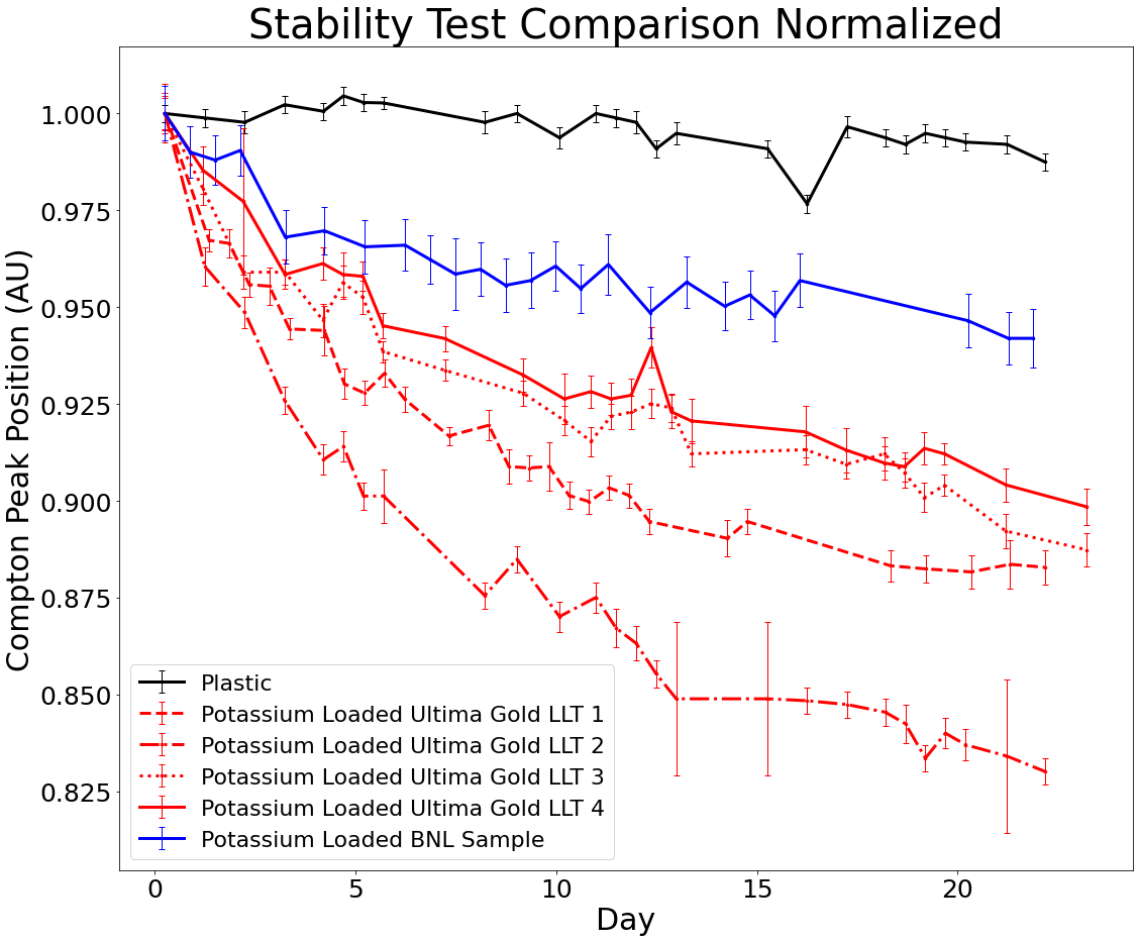
Liquid Scintillator: Stability

- The most stable potassium loaded scintillator that was tested was the mixture created by BNL.
- This mixture performed better than all tested commercial scintillator mixes.



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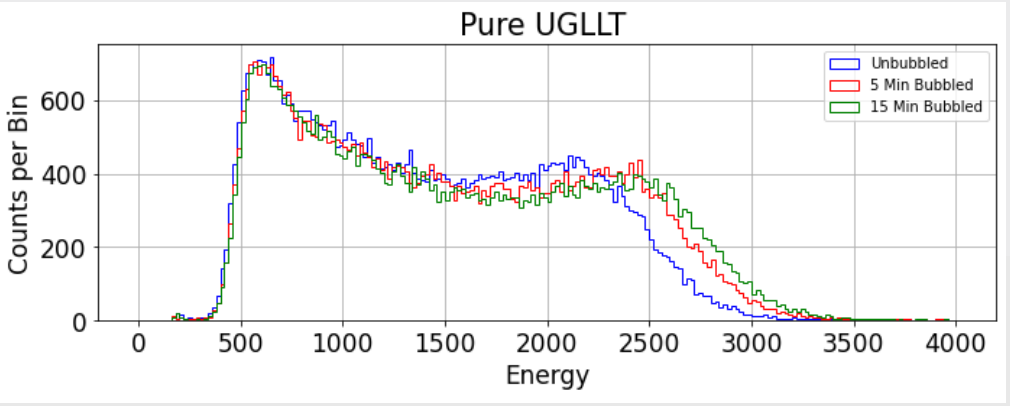
Liquid Scintillator Nitrogen Bubbling

- Several nitrogen bubbling tests were also carried out.
- A glovebox was pumped with nitrogen until oxygen levels reached ~2% and nitrogen was pumped into each sample.
- This showed some improvement in the overall light yield.



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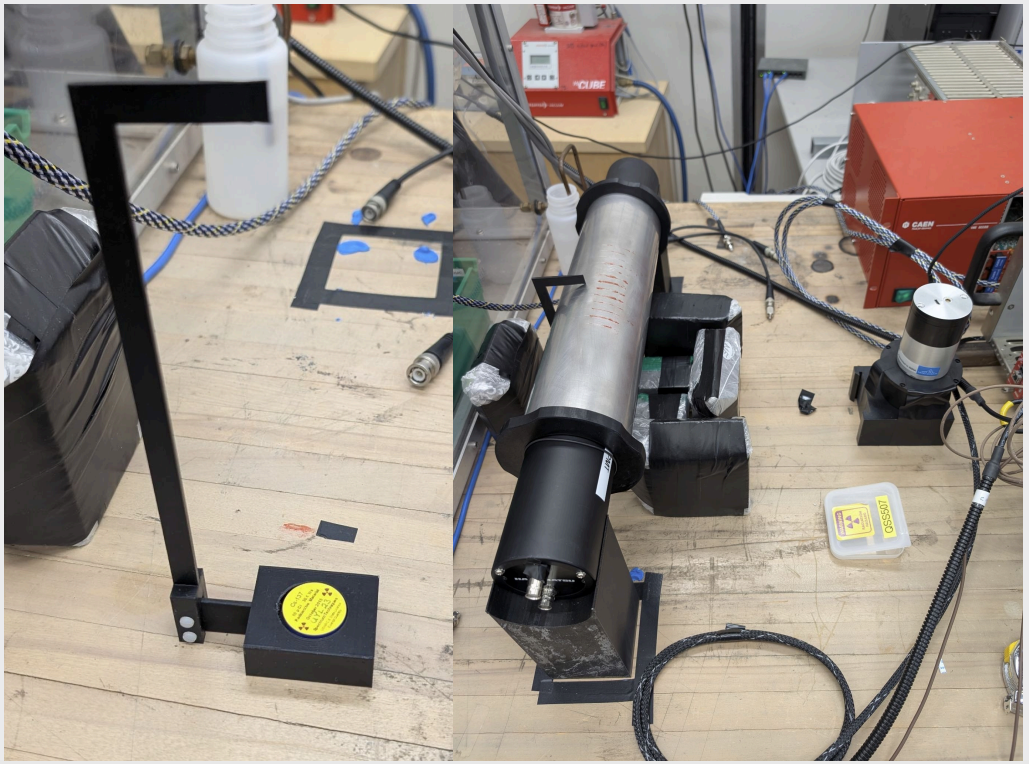
Liquid Scintillator Vessel Calibration

- The liquid scintillator vessel also needs to be calibrated.
- This can be done using another Compton scattering experiment.
- Need to calibrate at different positions along the length of the vessel.



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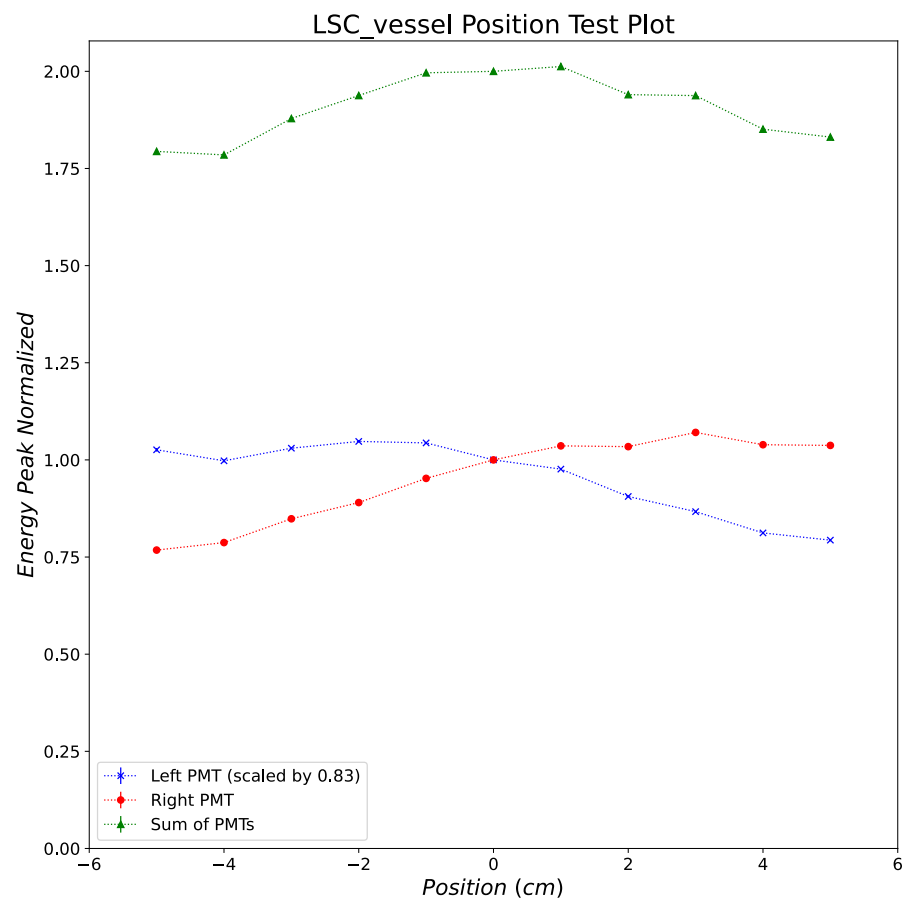
Liquid Scintillator Vessel Response

- The liquid scintillator vessel calibration again used Compton peak fits from each PMT which can be plotted against the position
- The sum of the means can also be plotted where we should expect to see a relatively flat response



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Daily Annulus Energy Calibration

- Instability in the liquid scintillator means daily energy calibrations may be necessary.
- Will use a collimated gamma source.

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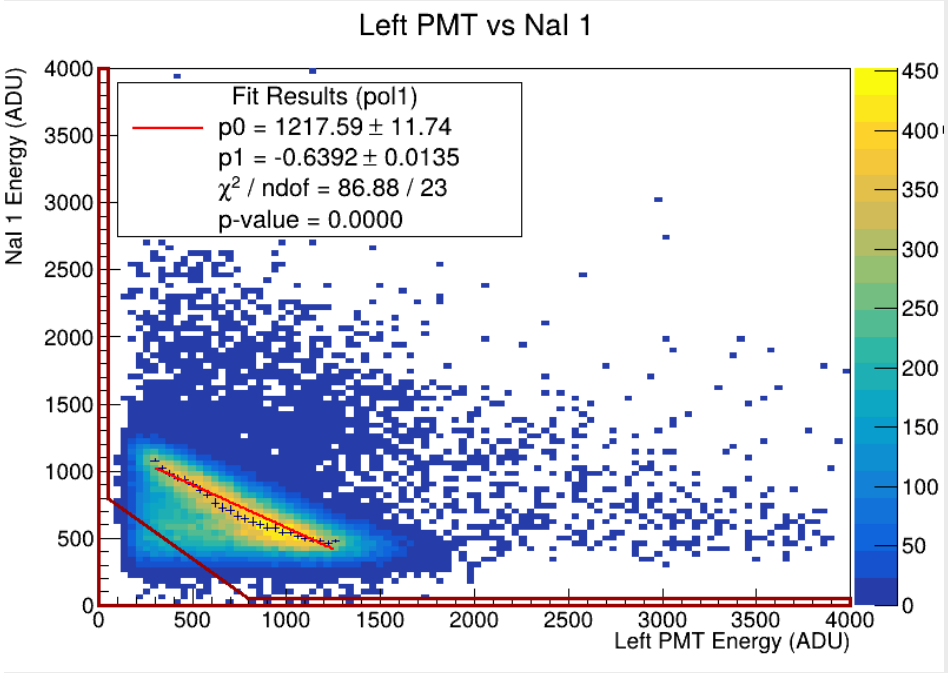

Daily Annulus Energy Calibration

- We can get a Compton scattering spectrum using a cesium-137 source.
- This is indicated by the downward sloping line.
- By fitting a line to the maximum value of each bin along the line we can obtain a light yield value in ADC per keV.

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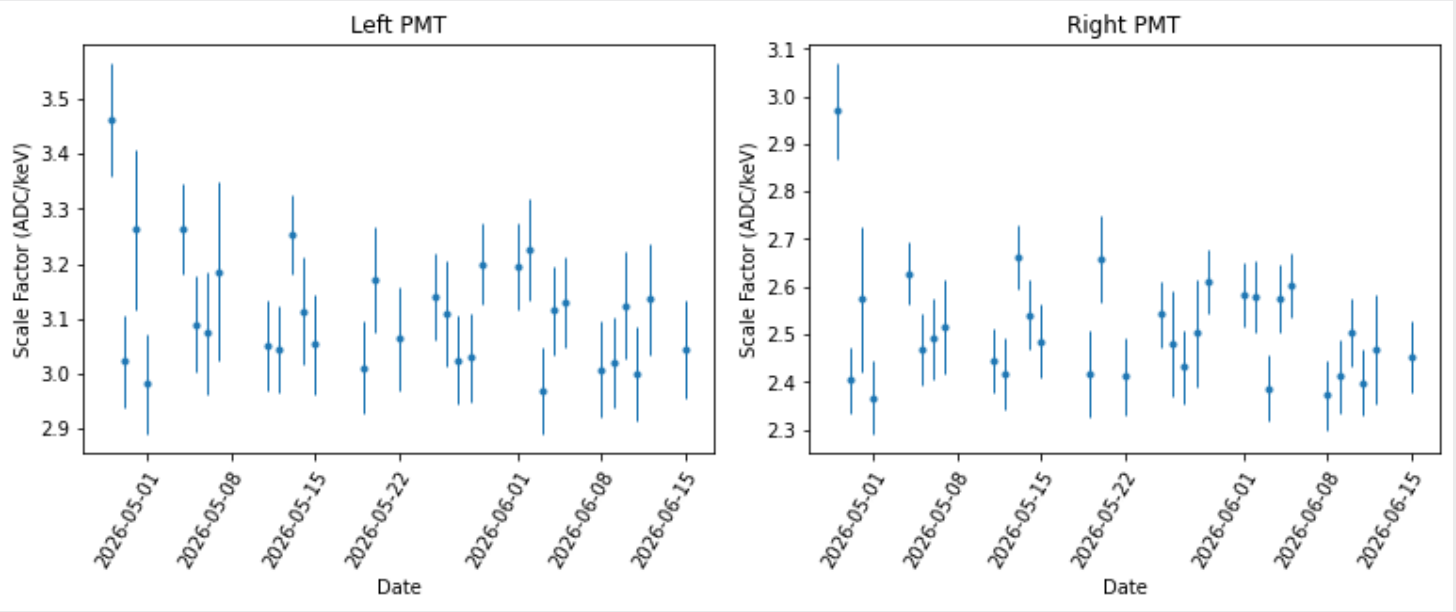
Daily Annulus Energy Calibration



- From these daily fits we can track the decay in the light yield.
- Current tests are showing a decay similar to what we have seen in stability tests.

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Current and Future Work

- An updated liquid scintillator stability experiment is currently underway.
- A calibration test with a K-loaded scintillator in the annulus is currently underway.
- The first data collection using a K-loaded liquid scintillator to look for positrons will occur over the next couple of months.

Thank You

OAK RIDGE National Laboratory

SNOLAB

Canadian Nuclear Laboratories | Laboratoires Nucléaires Canadiens

Brookhaven National Laboratory

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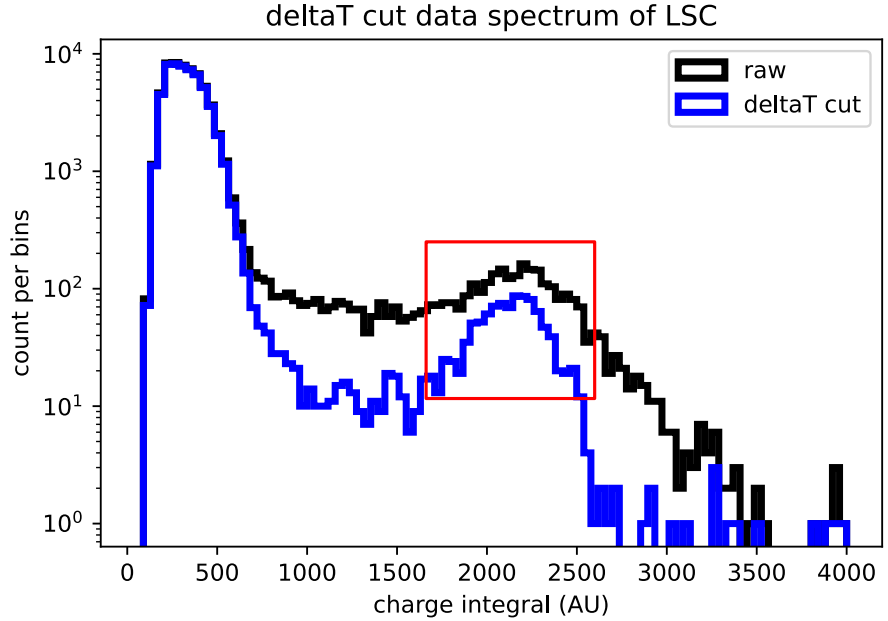
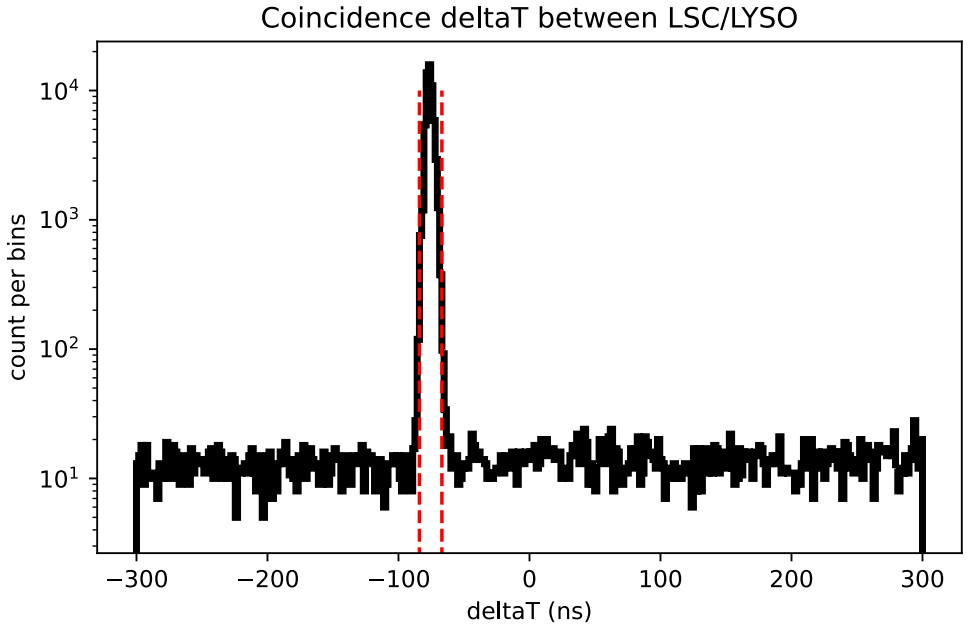
Liquid Scintillator Testing





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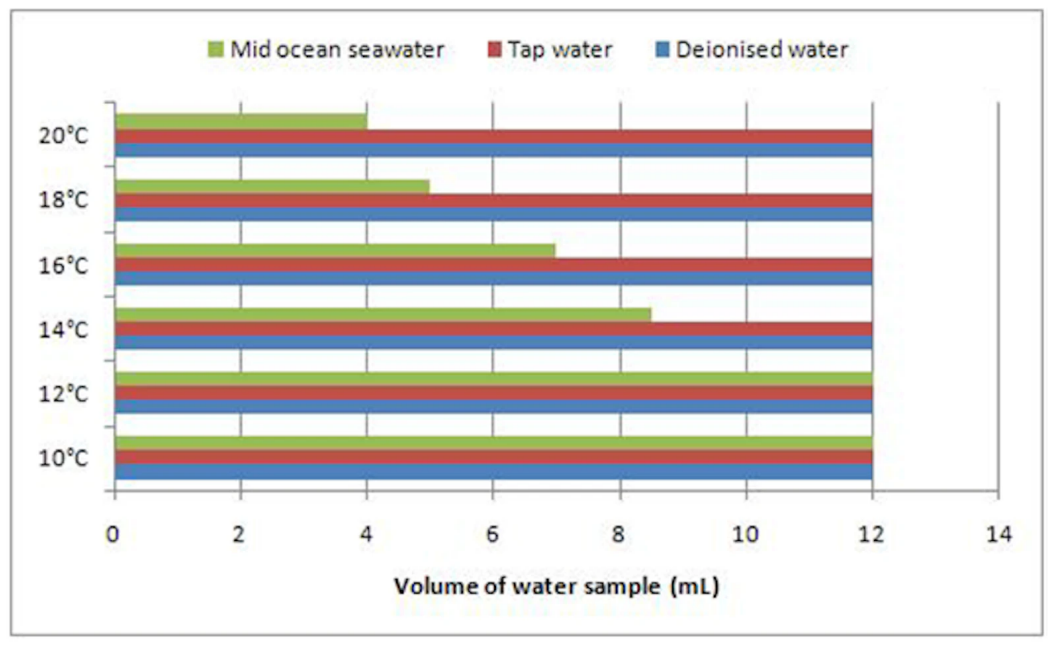
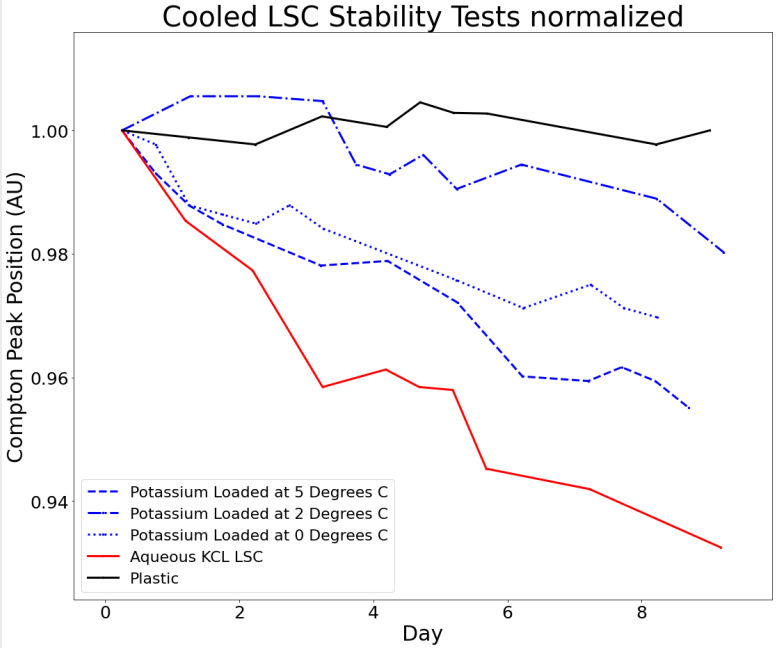
LSC Cooling Tests





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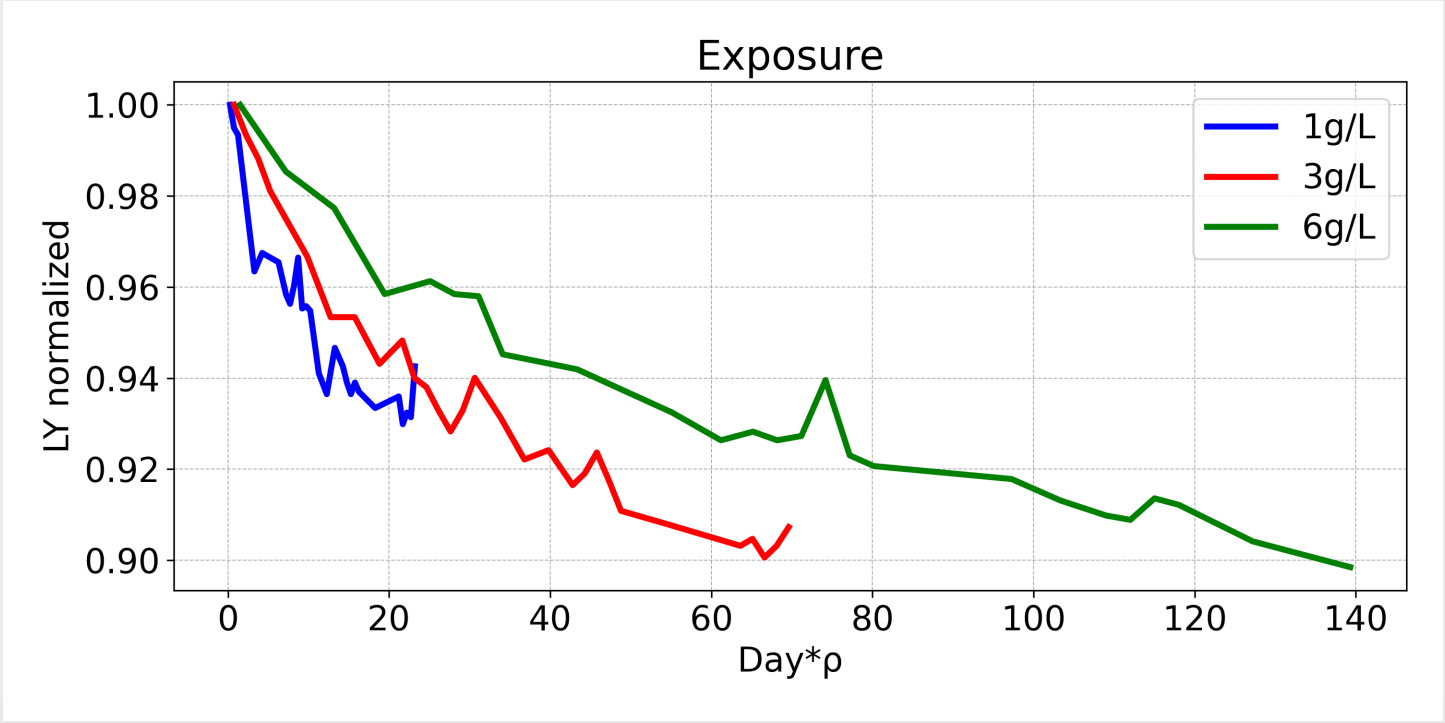
Ref. https://www.hidex.com/hidex-methods

Loading Level Tests



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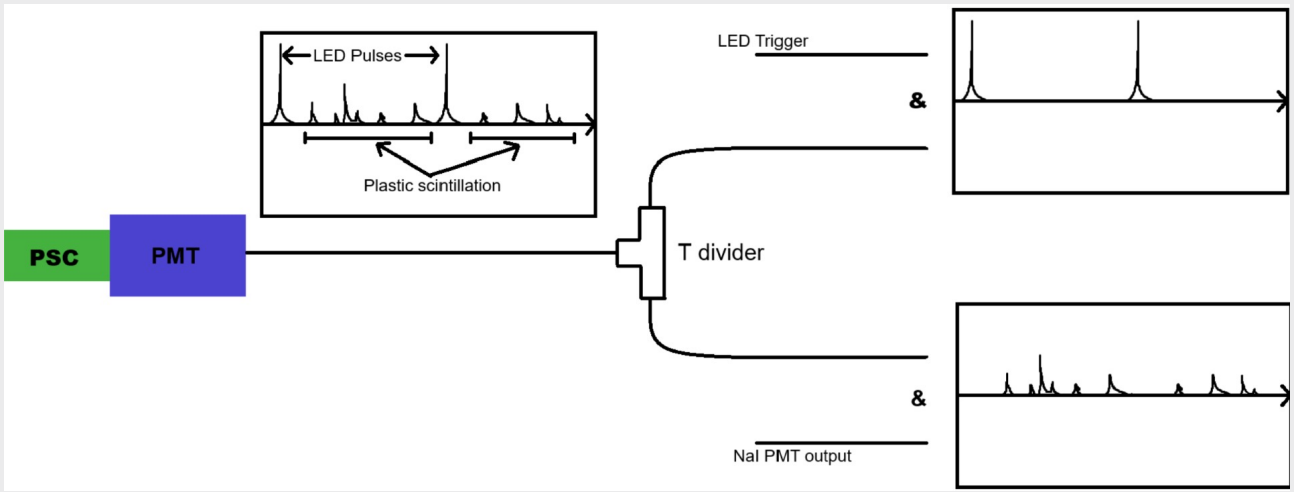
LED Pulses
Plastic scintillation
LED Trigger
&
PSC
PMT
T divider
&
NaI PMT output