

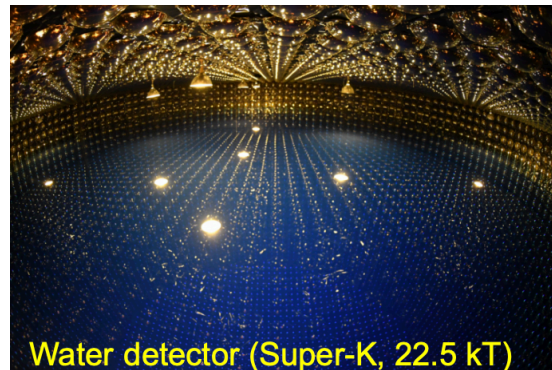
Water-based Liquid Scintillator R&D effort at Brookhaven National Laboratory

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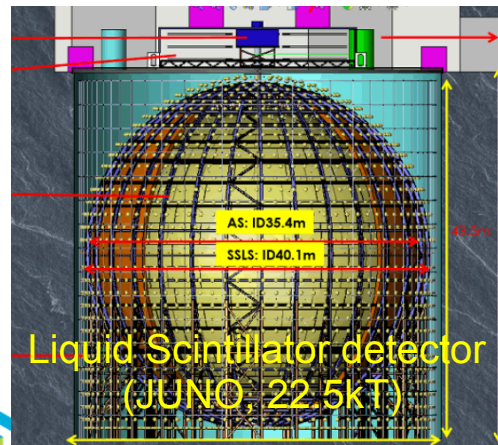
Oct. 27 2025

WbLS (Water-based Liquid Scintillator)

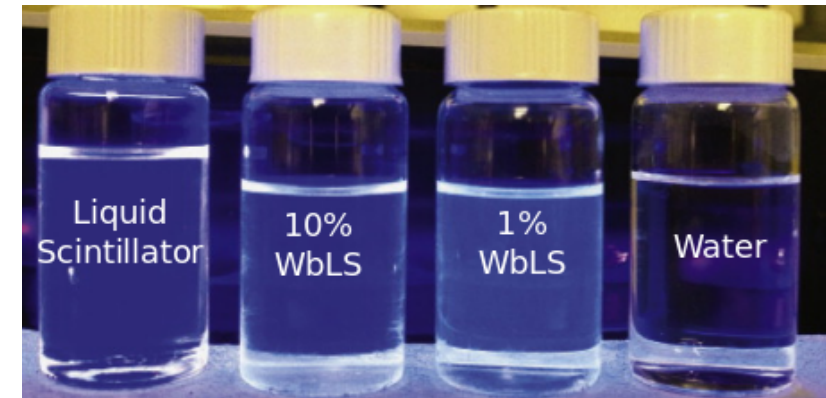
WbLS is a hybrid detection material that combines Cherenkov light and scintillation light.



Water:
Excellent transparency
Directionality
Particle ID
Cheap



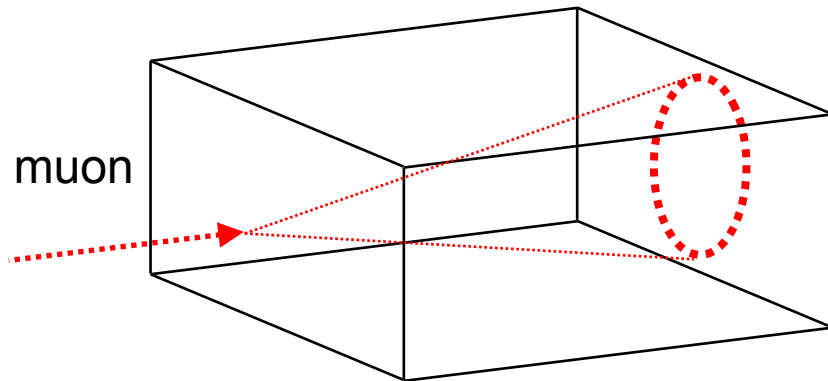
Liquid Scintillator:
High light yield
Low energy threshold
Good energy resolution



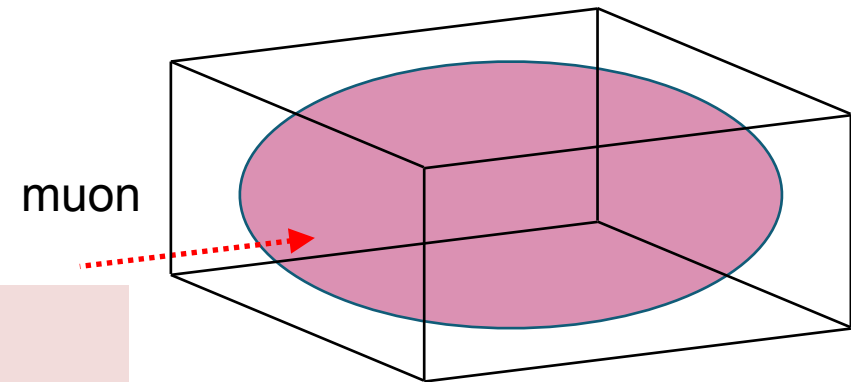
WbLS

WbLS Basic Performance

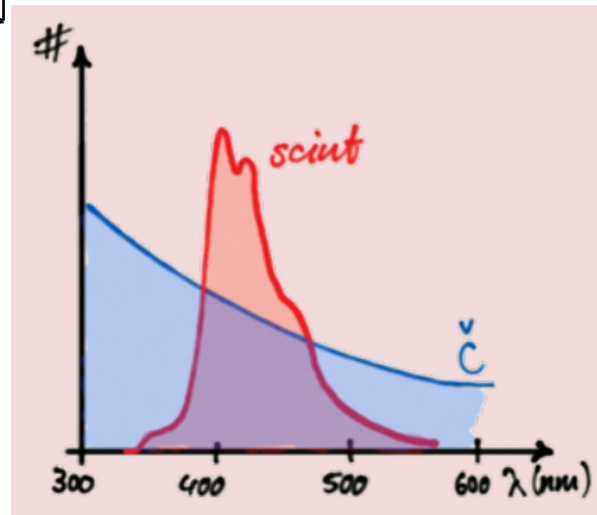
Separating Cherenkov and scintillation:
shape, time, wavelength



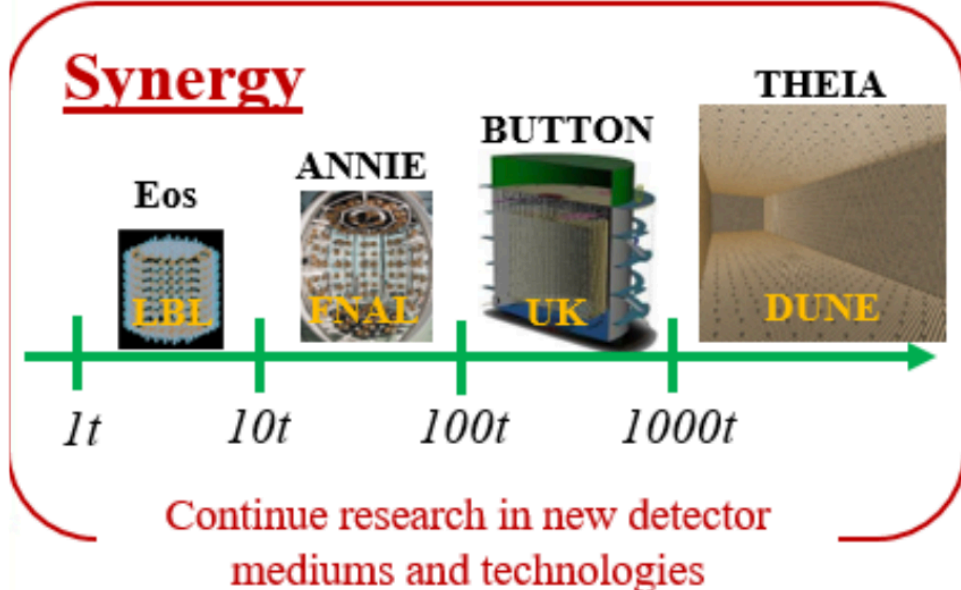
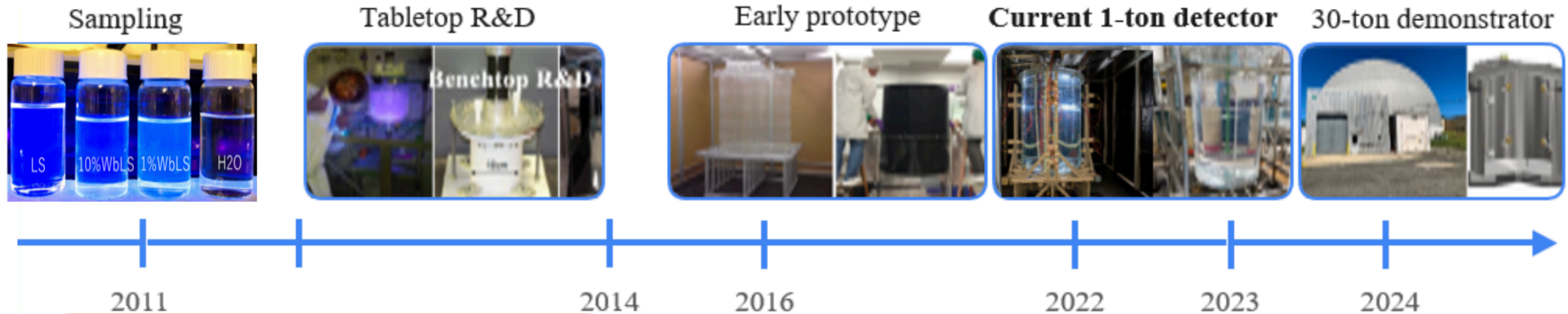
Cherenkov
unique shape
early



Scintillation
isotropic
late



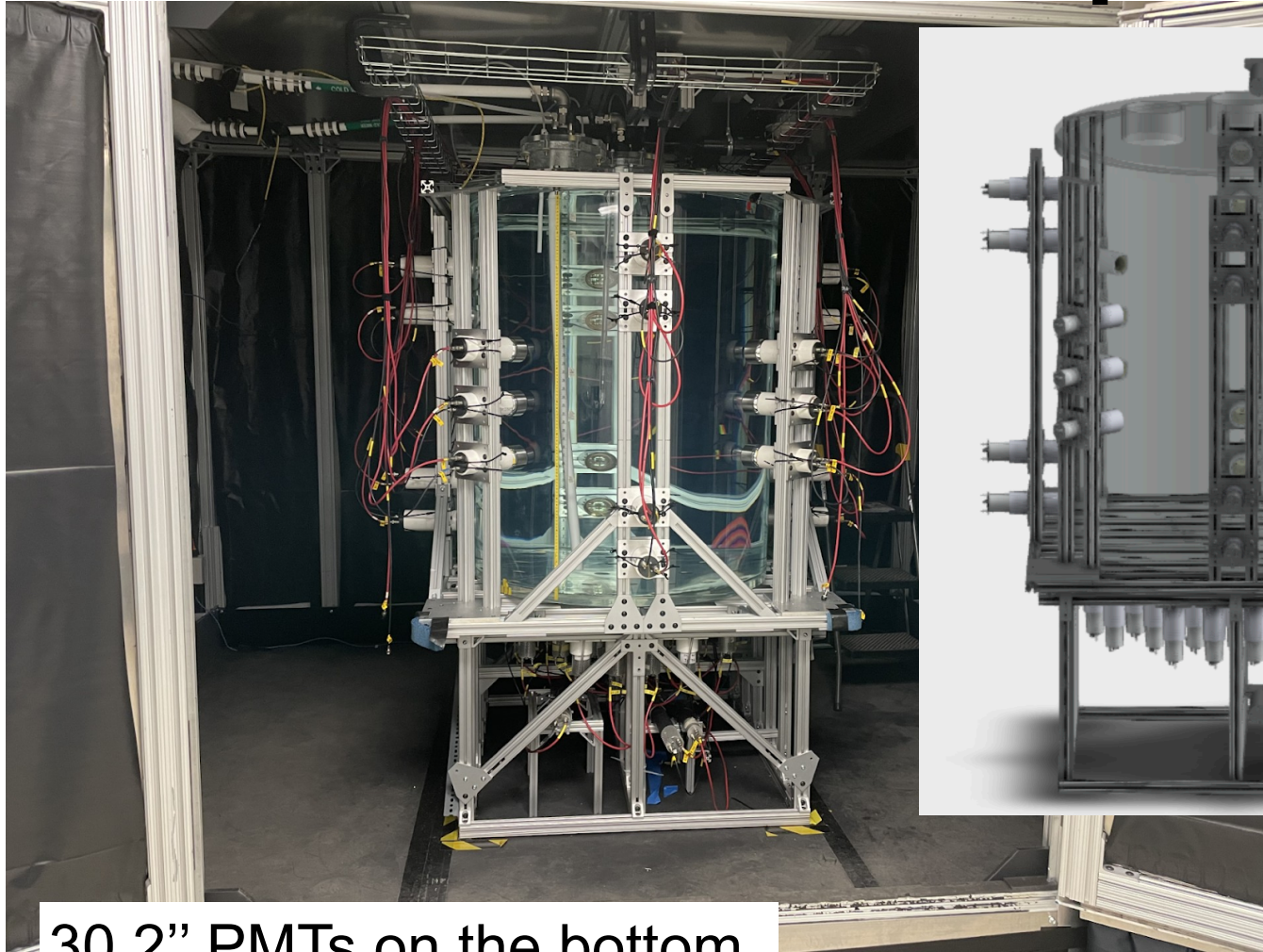
WbLS R&D efforts at BNL



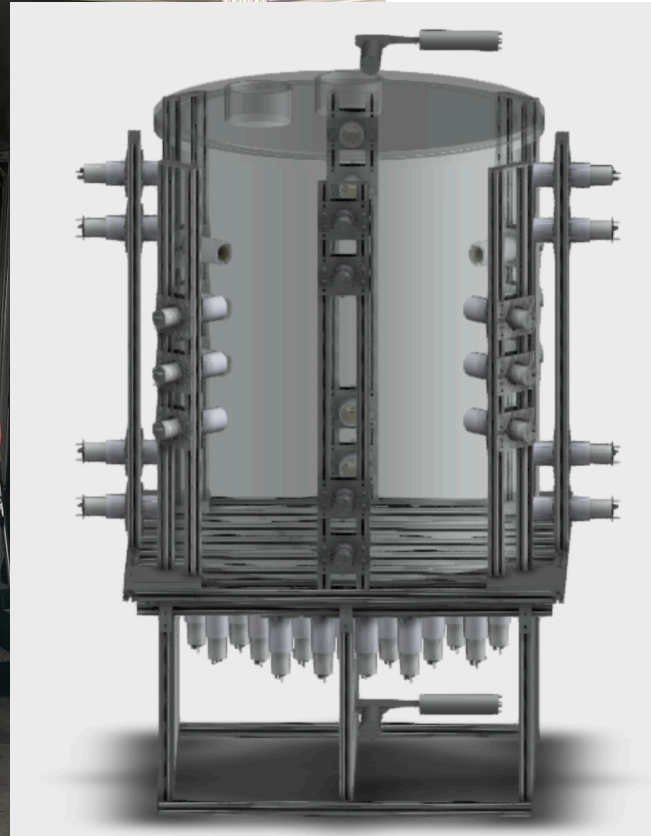
We are actively demonstrating and deploying WbLS for multi-ton scale neutrino detectors at BNL.

BNL WbLS is being sent to other experiments such as Eos, ANNIE, etc.

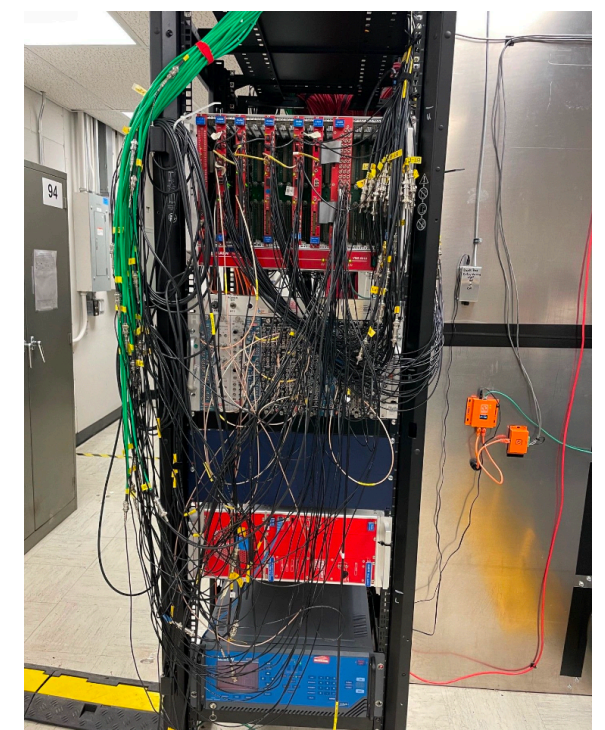
1 Ton Detector Setup



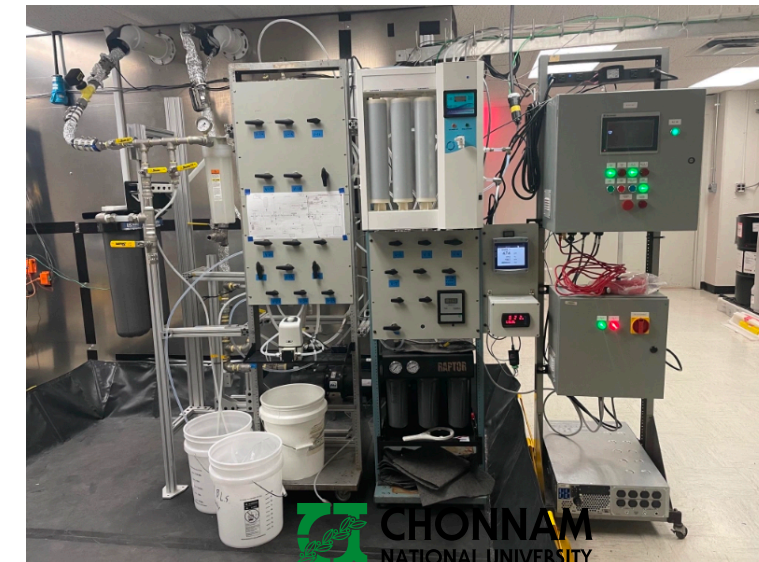
30 2" PMTs on the bottom
28 3" PMTs on the side



circulation and
filtration system



daq system



1 Ton Detector Analysis

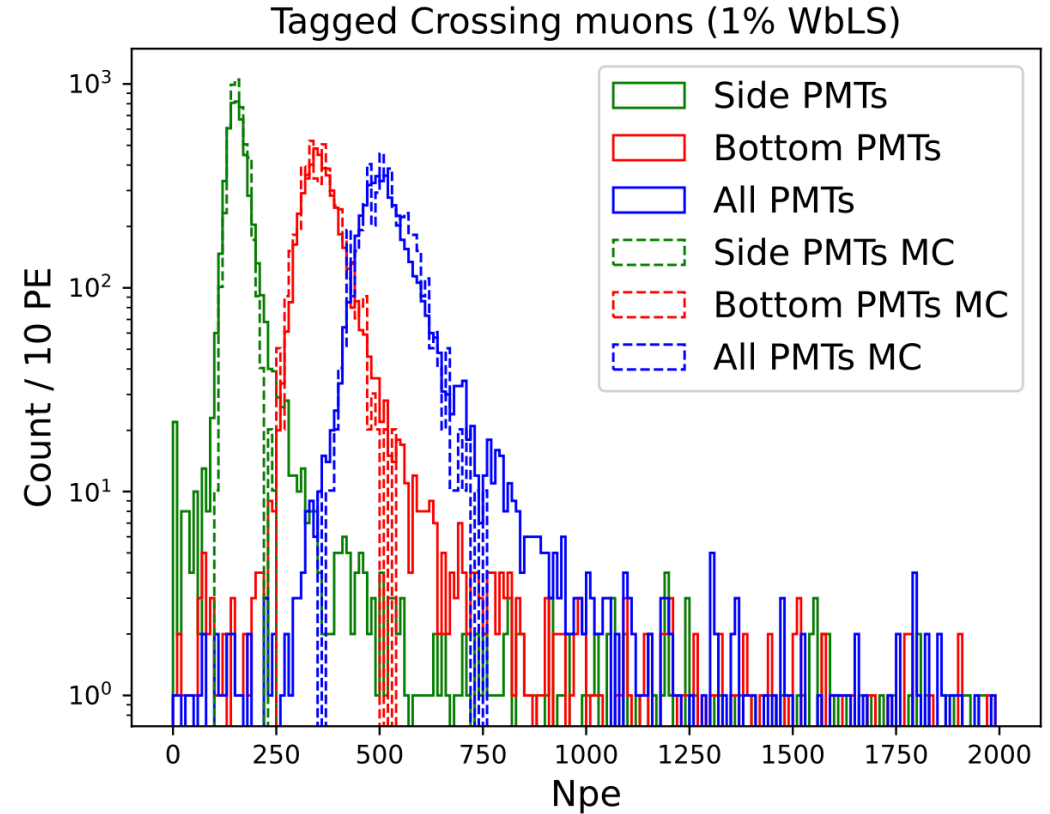
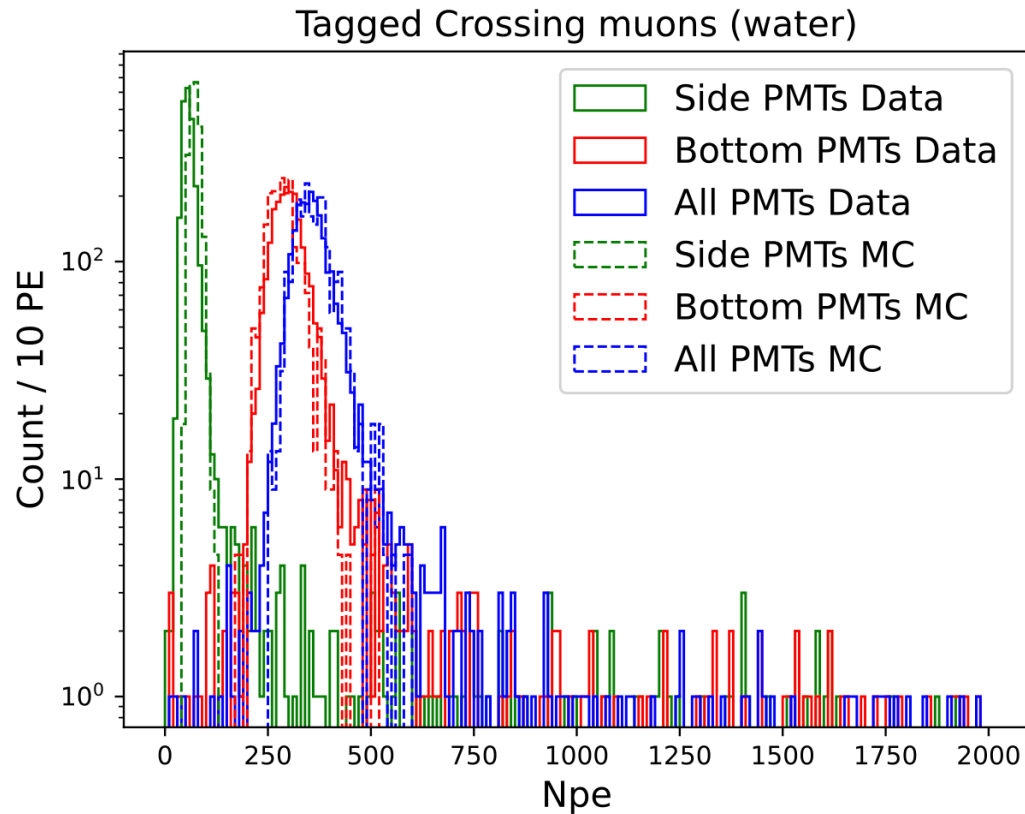
Crossing muon analysis:

- Selecting vertically through going muon **minimize angular variation and ensure consistent energy deposition.**

Injection analysis:

- WbLS is injected gradually, starting from pure water, **increasing concentrations in small steps** (0.3%, 0.4%, up to 1%).
- Assess how WbLS concentration impacts light yield.

2022 Result



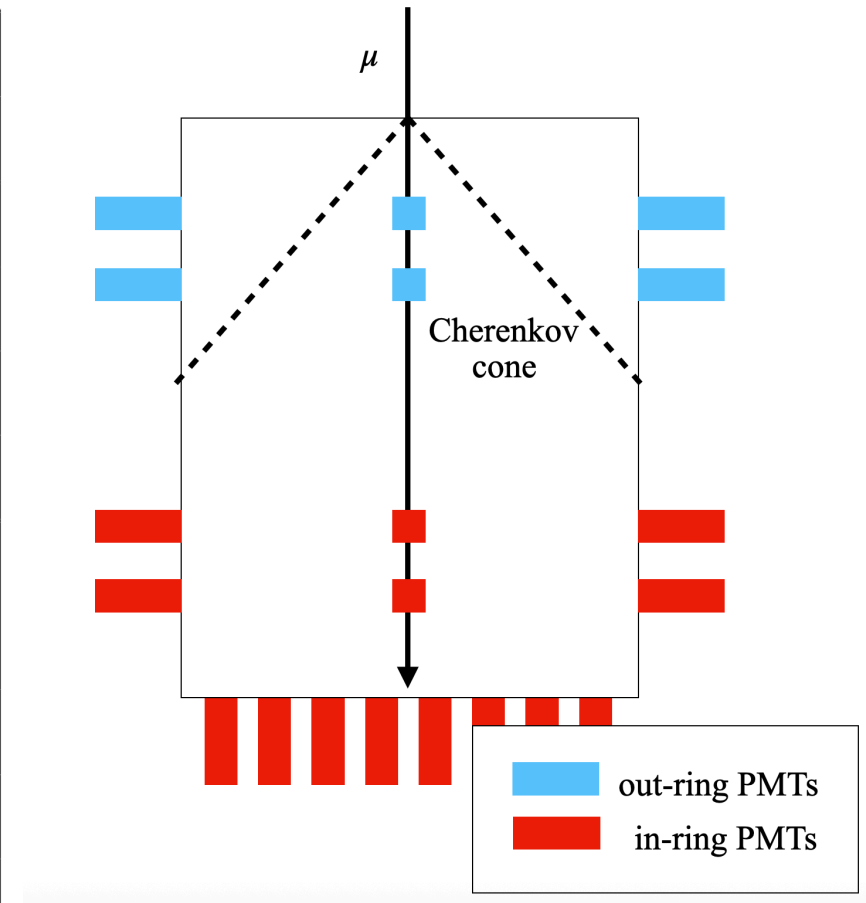
[X. Xiang et al 2024 JINST 19 P06033](#)

Cherenkov light (pure water): 297 ± 37 PE (bottom) and 56 ± 13 PE (side).

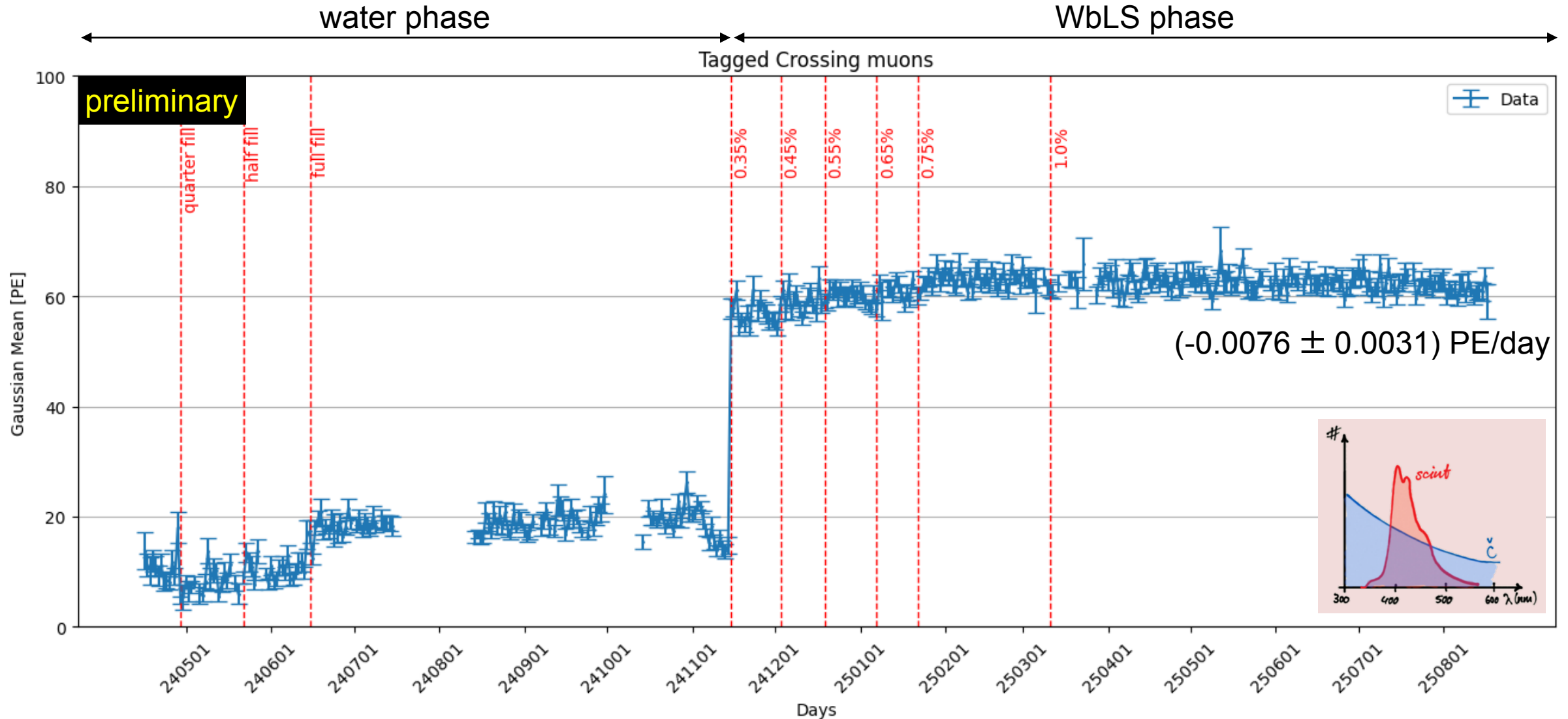
Total light yield (1% WbLS): 350 ± 37 PE (bottom) and 154 ± 22 PE (side)

2024 Run

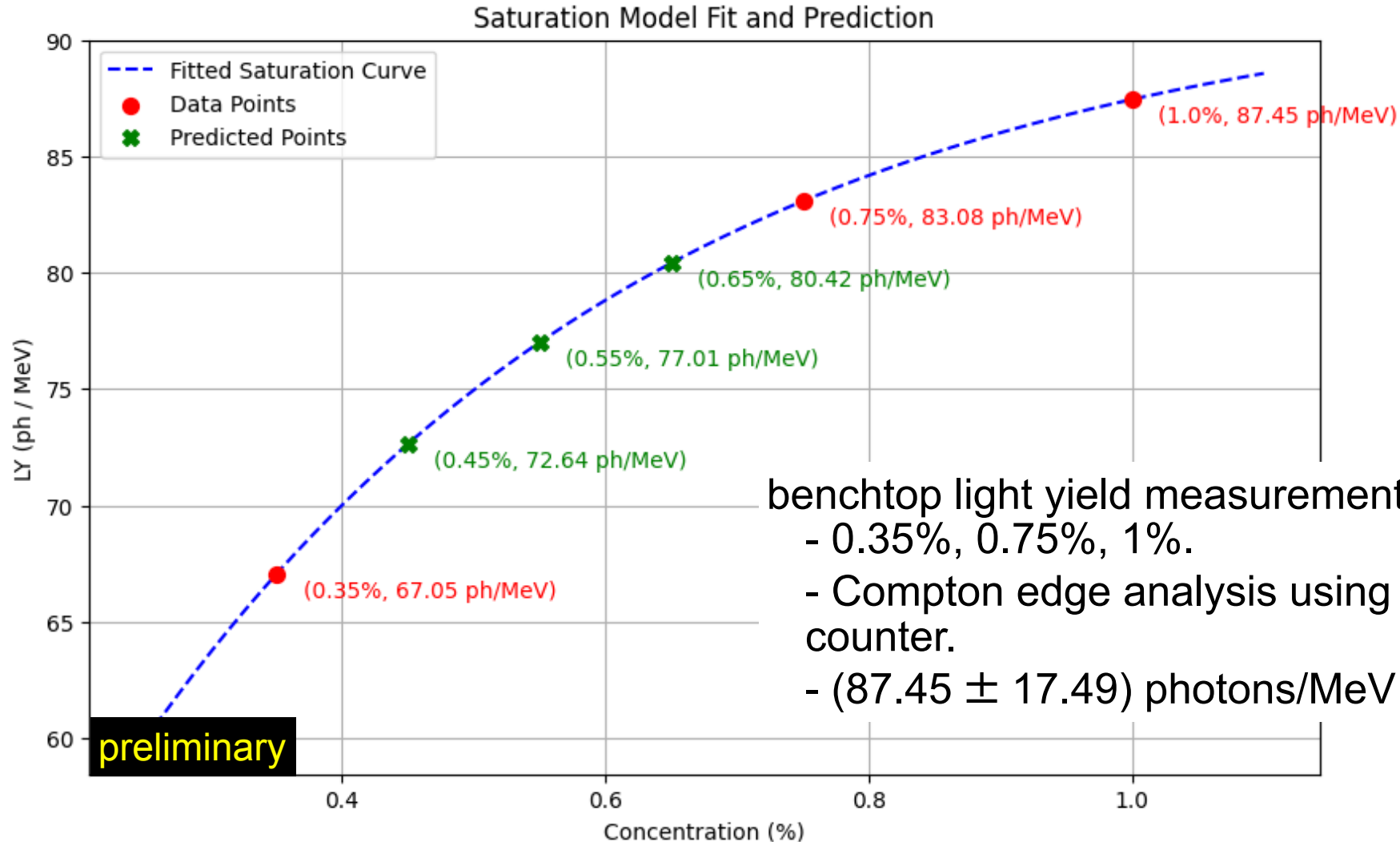
Liquid Configuration		Run Start
Type	Concentration/Fill Level	
Water	empty	250416
	quarter fill	240429
	half fill	240522
	full fill	240615
WbLS	0.35%	241115
	0.45%	241203
	0.55%	241219
	0.65%	250107
	0.75%	250122
	1.0%	250311



Daily detected PE in 1ton detector



Absolute LY



benchtop light yield measurement with small sample:

- 0.35%, 0.75%, 1%.
- Compton edge analysis using ^{137}Cs source and LS counter.
- (87.45 ± 17.49) photons/MeV with 1% WbLS

Why a 30-Ton Detector is Needed

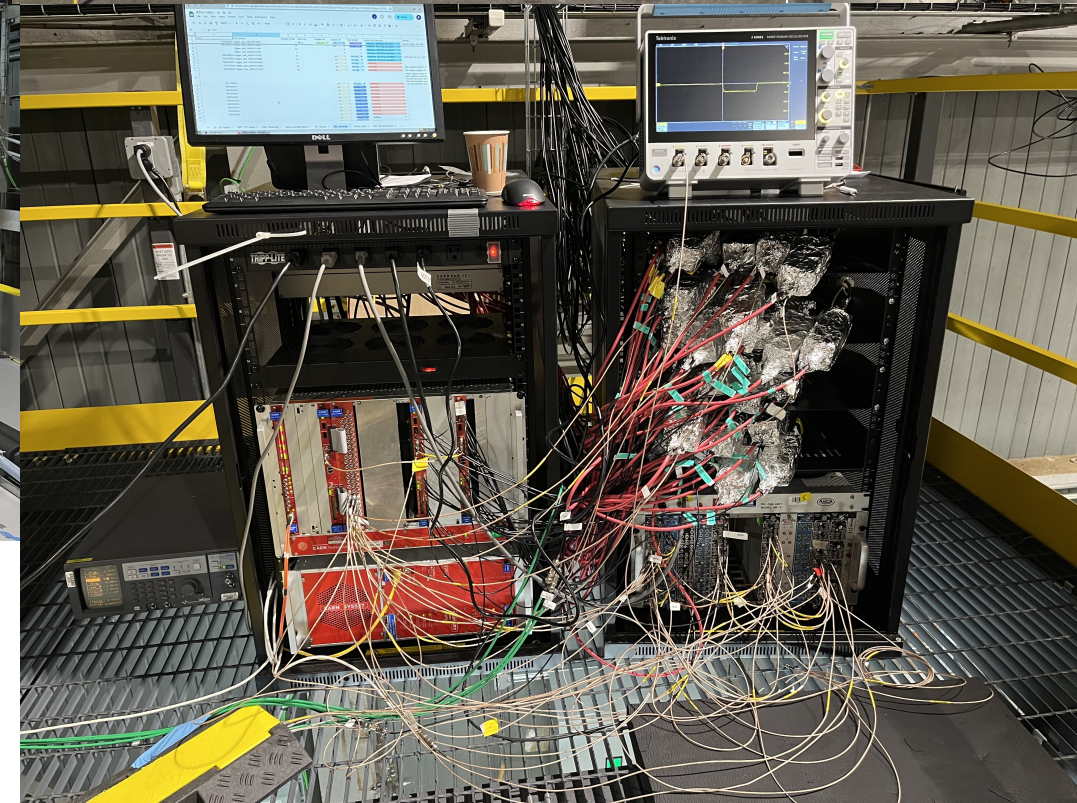
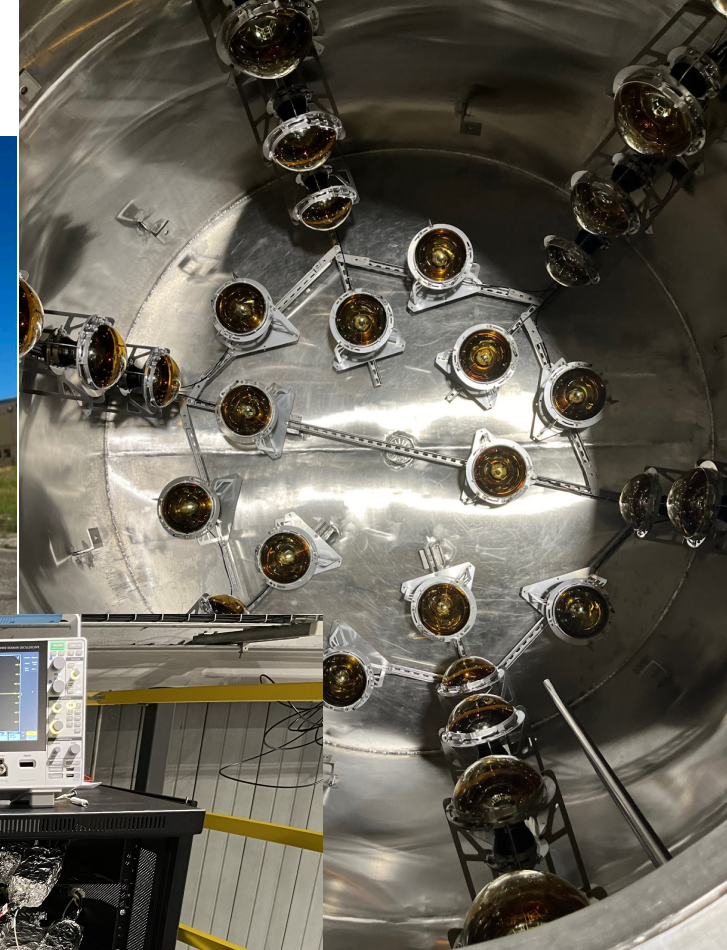
Technology Development for Detector Scaling:

- **The 30-ton detector** provides a step in scaling up from the 1-ton prototype, enabling us **to test and refine systems**.
- **Develop infrastructure** efficient filtration, purification, circulation, and DAQ systems is required to ensure the homogeneity of the WbLS mixture, maintain long-term chemical and optical stability.

Future-Ready for Kiloton-Scale Detectors:

- The 30-ton detector serves as a **benchmark to test the feasibility** of scaling up to even larger detectors.

30 Ton Detector



Summary

WbLS enables **hybrid detection of Cherenkov and scintillation light**, improving sensitivity, directional reconstruction, and energy resolution for next-generation neutrino experiments.

For 1.0% WbLS, the scintillation light yield is measured as (87.45 ± 17.49) photons/MeV.

The 30-ton detector serves as a **benchmark to test the feasibility** of scaling up to even larger detectors.

Measurement of Light Yield Response of Water-based Liquid Scintillator (WbLS) with Increasing Concentration from Pure Water to 1%

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(Dated: October 24, 2025)

Unlike conventional neutrino detectors limited to a single detection channel, Water-based liquid scintillators (WbLS) provides a hybrid detection medium that combines Cherenkov radiation and scintillation. We measured light yield of WbLS varying concentrations from 0.35% to 1% by mass, using cosmic-ray muons in a 1-ton scale detector at BNL. The light yield is measured as 67.0 ± 6.7 ph / MeV at 0.35% concentration, which increased to 87.4 ± 8.7 ph / MeV at 1%. These results establish a quantitative basis for optimizing future WbLS-based detectors in neutrino physics.

Back up

WbLS R&D efforts at BNL

Chemical stability:

- Ensure **long-term optical clarity and uniformity** of WbLS mixtures across diverse environmental conditions.
- Validate **scalability** from a 1-ton detector to large-scale systems without compromising performance.

Electronic system:

- Development of **DAQ systems** for large-scale detectors.

Benchmarking for **Future Experiments such as DUNE** phase2 FD4:

- Benchmark light yield, particle identification capabilities, and stability

Applications in **Nonproliferation**:

- Utilize WbLS for remote monitoring

Trigger Systems for the 1-Ton Detector

Scintillator top paddles:

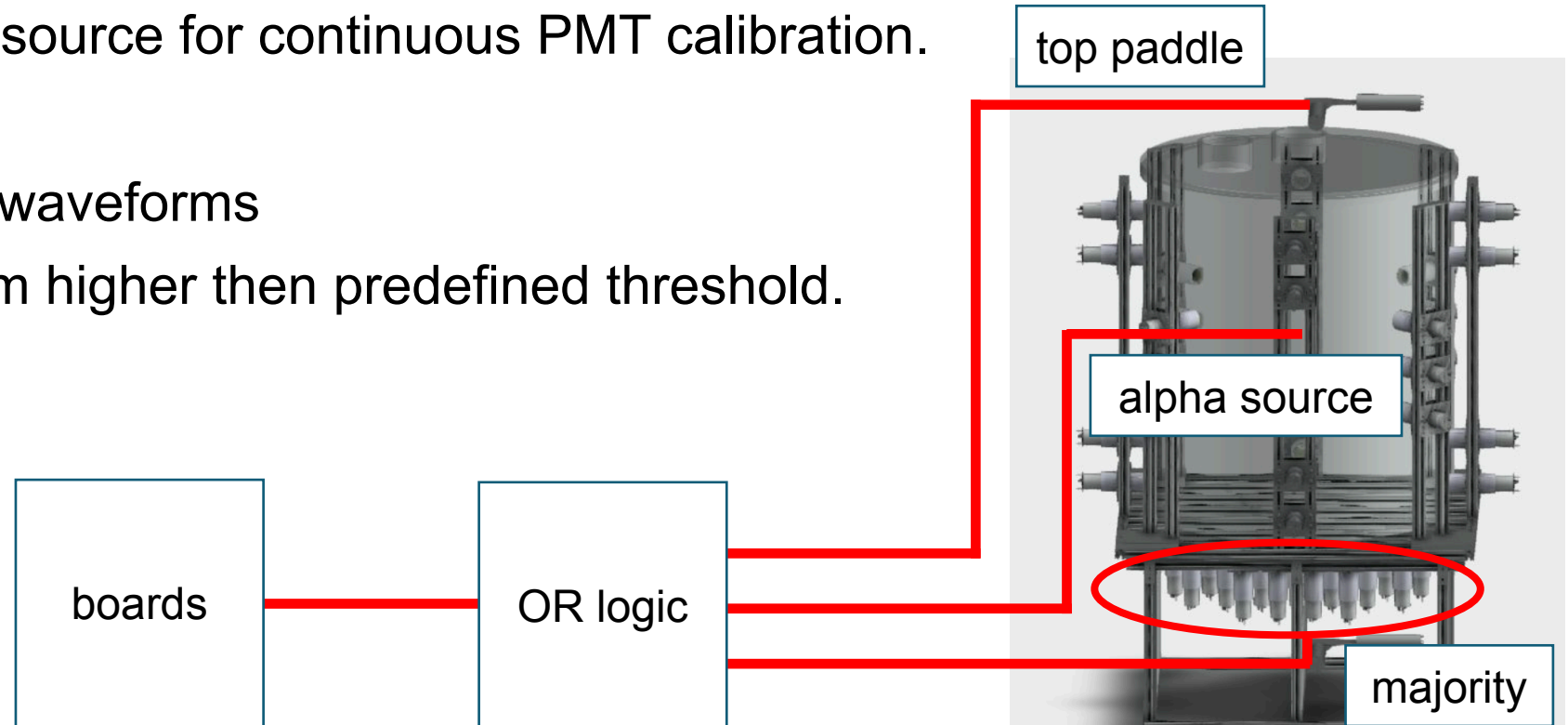
- Two rectangular paddles (10 cm × 12 cm) placed above the tank.

Alpha source trigger:

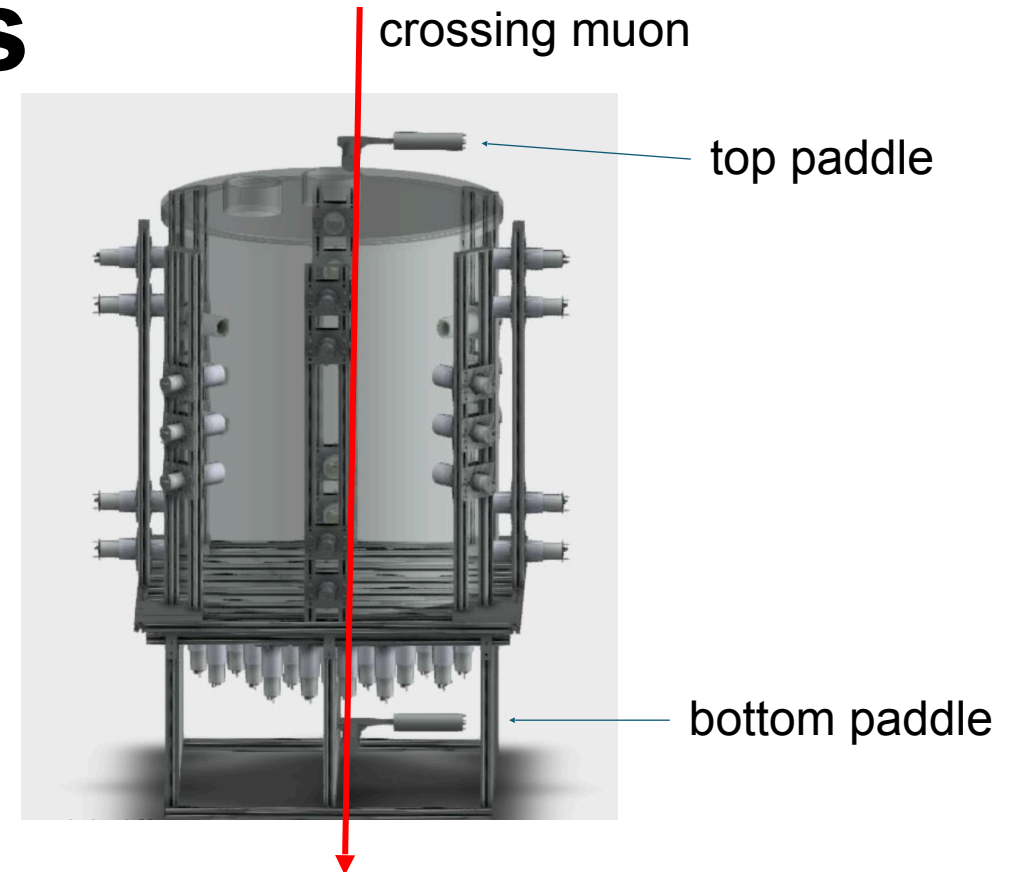
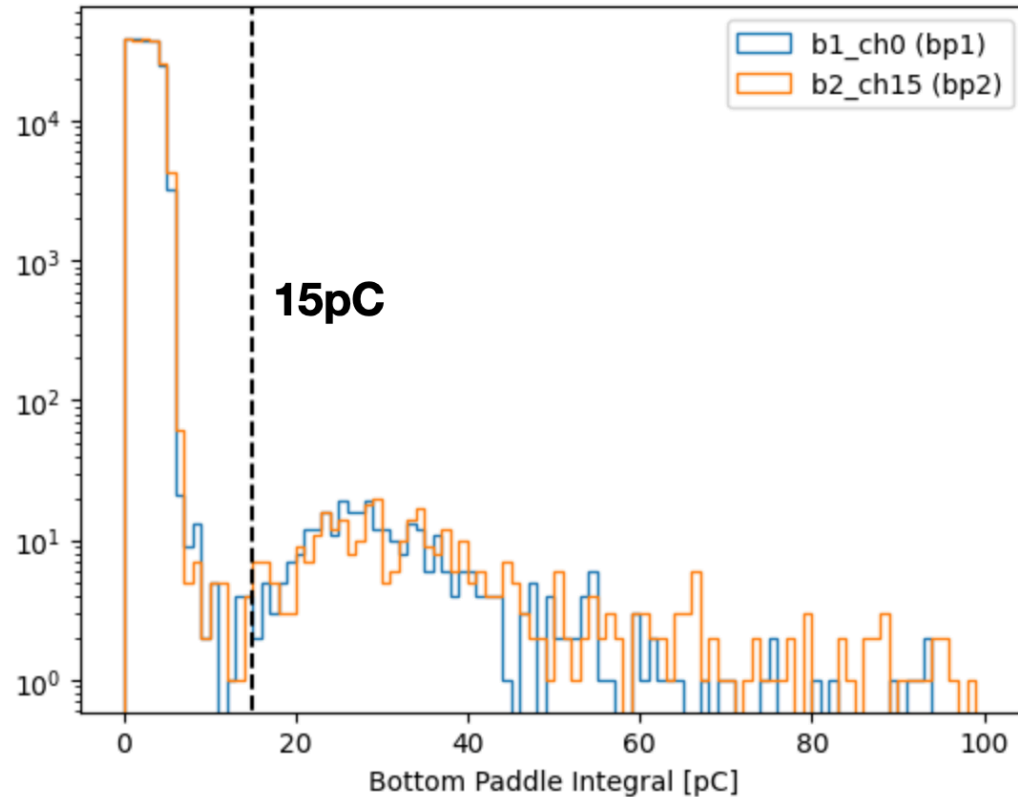
- Utilize the ^{210}Pb alpha source for continuous PMT calibration.

Majority trigger:

- Sum the bottom PMTs waveforms
- Triggered when the sum higher than predefined threshold.

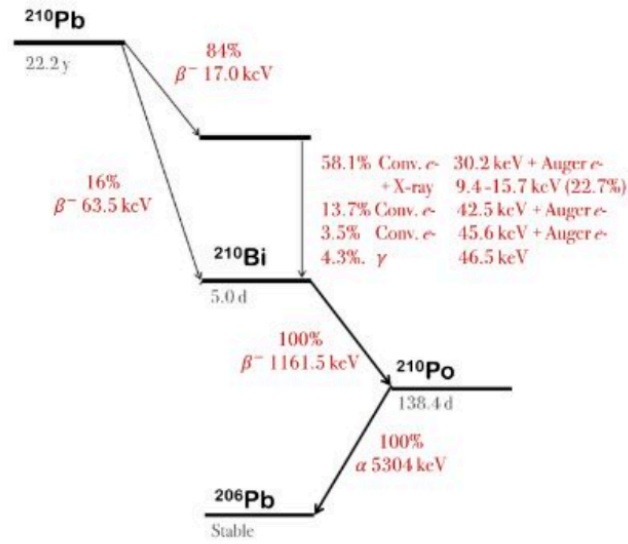
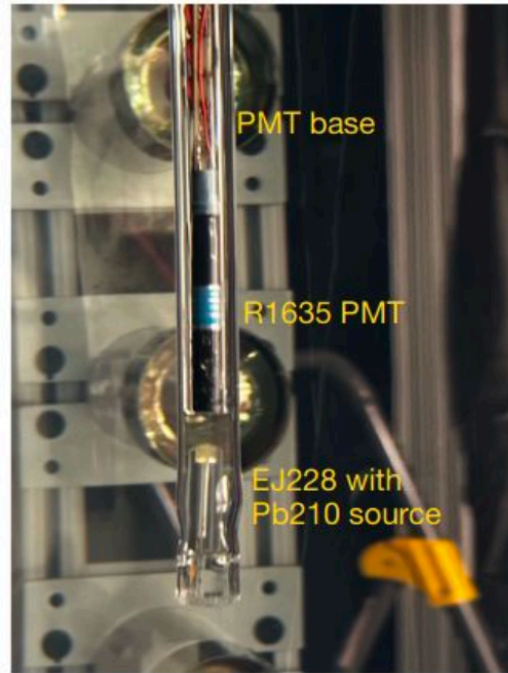


Crossing muon events

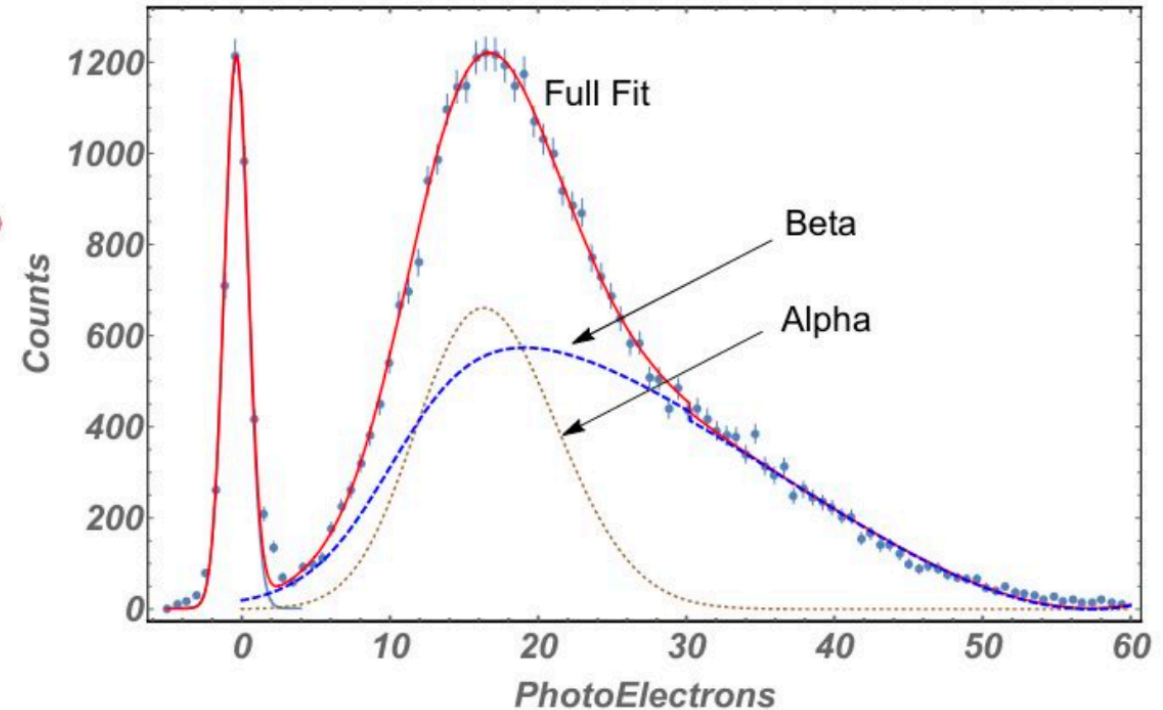


The crossing muon events are tagged by top and bottom scintillator paddles.
Restricts trajectories to vertical paths with minimal angular variation ($< 8^\circ$)

1 Ton Detector Calibration



Points are data



^{210}Pb -based source embedded in a plastic scintillator, at the center of the detector.
The source provides continuous light for PMT gain verification.

Stepwise Injection of WbLS at 1 Ton

After the initial pure water phase, we began the injection of WbLS in **small, incremental steps**

The injection steps were as follows:

0% (Pure Water) → 0.3% → 0.4% → 0.5% → 0.6% (current phase) → 0.7% (next week) → 1% WbLS concentration.

The increase in **light yield is continuously monitored** during each injection step.

WbLS Motivation

Advancements in Neutrino Physics:

- Enables simultaneous detection of Cherenkov and scintillation signals.
- Improves directional reconstruction, energy resolution, and sensitivity to low-energy neutrinos.

Feasibility for Large-Scale Detectors:

- Cost-effective and environmentally friendly alternative for kiloton-scale hybrid detectors.

Capability for Metal Loading:

- Supports Gd doping for neutron capture and broader scientific applications.

WbLS Advantages

Signal Quality and Flexibility:

- Tunable scintillation light yield and time profile for specific applications.
- Maintains long-term optical stability for large-scale experiments.

Enhanced Particle Identification:

- Cherenkov/scintillation separation improves background rejection and particle ID.

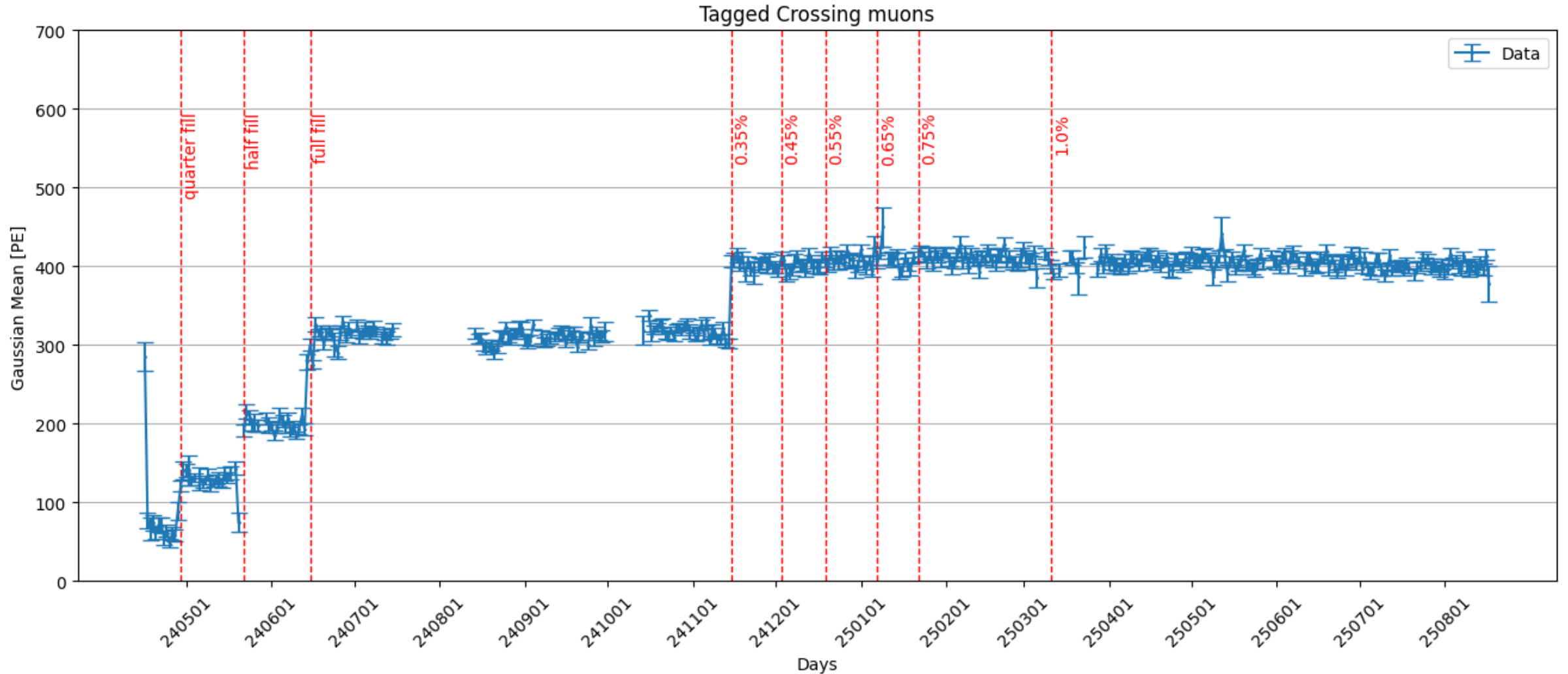
Economic Efficiency:

- Water-based composition reduces cost and simplifies production processes.

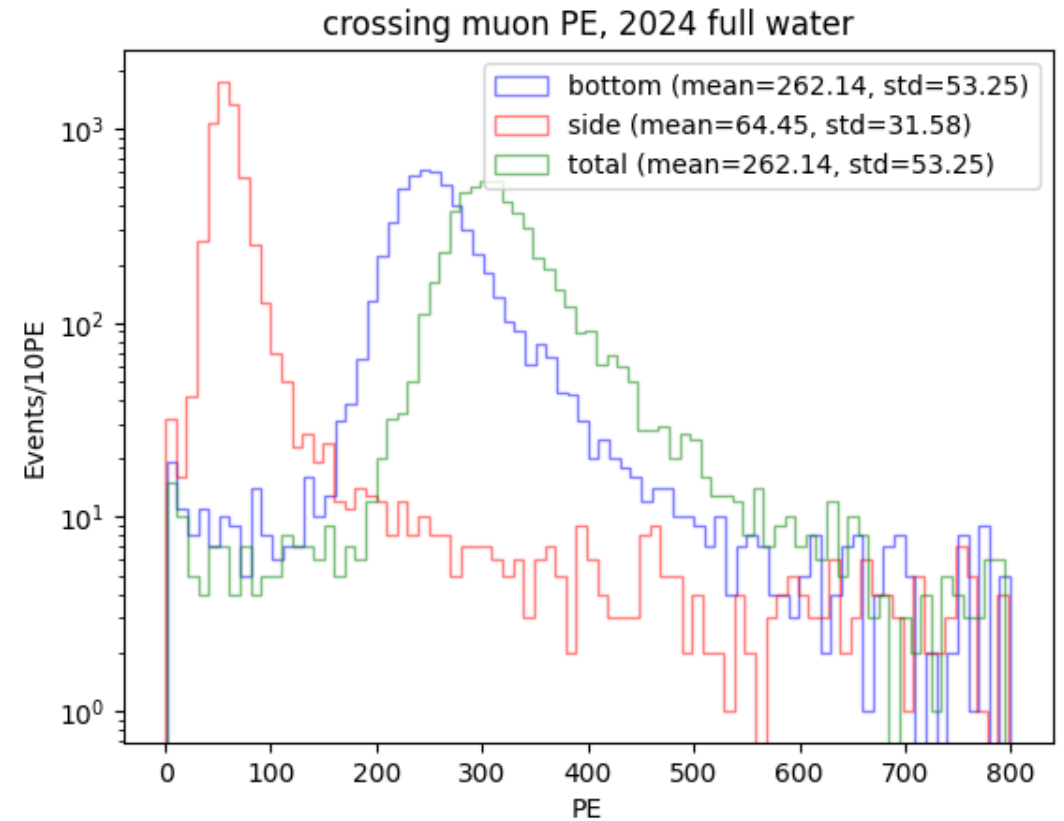
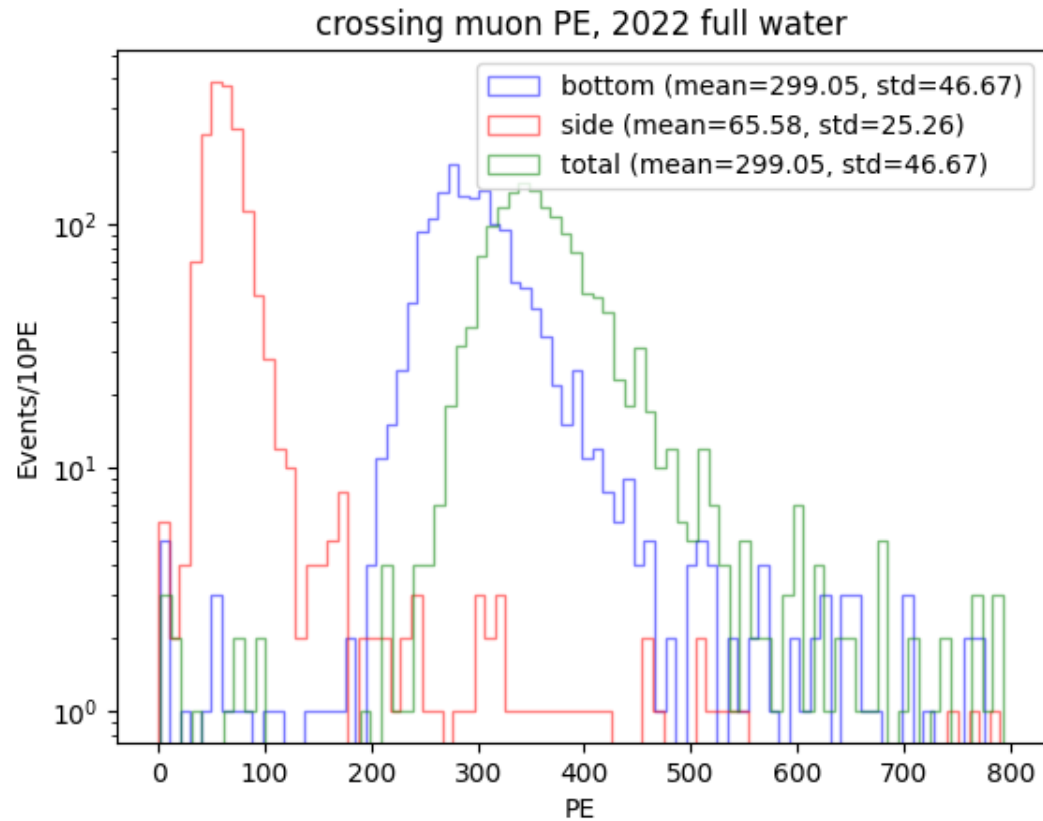
Optical Transparency and Durability:

- Stable across various temperatures and pH levels, ensuring longevity and reliability.

LY Curve - inring



Water phase



Simulation setup

RATPAC is used to simulate crossing muon

RATPAC is a simulation package built with GEANT4, ROOT

- physics processes of muon energy deposition
- physics model for Cherenkov light in pure water and acrylic
- optical model for light generation, propagation and light detection

1T detector geometry contains

- acrylic tank
- realistic PMTs