Light Yield Response of Gd-compatible WbLS with the Brookhaven 1-ton Testbed

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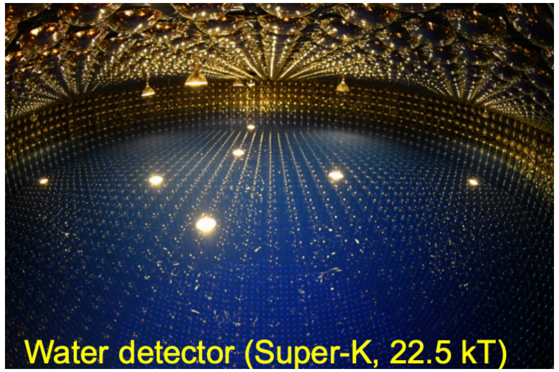
CPNR-OMEG Joint Workshop
May. 22 2026

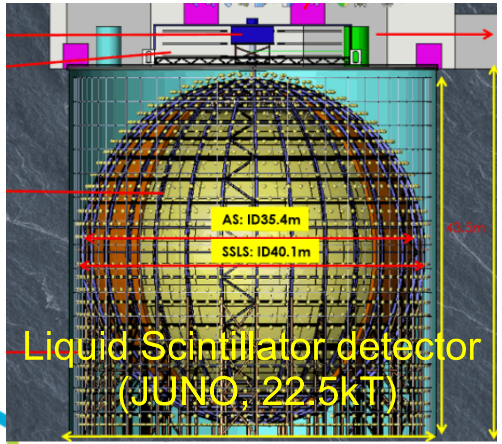
WbLS (Water-based Liquid Scintillator)

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



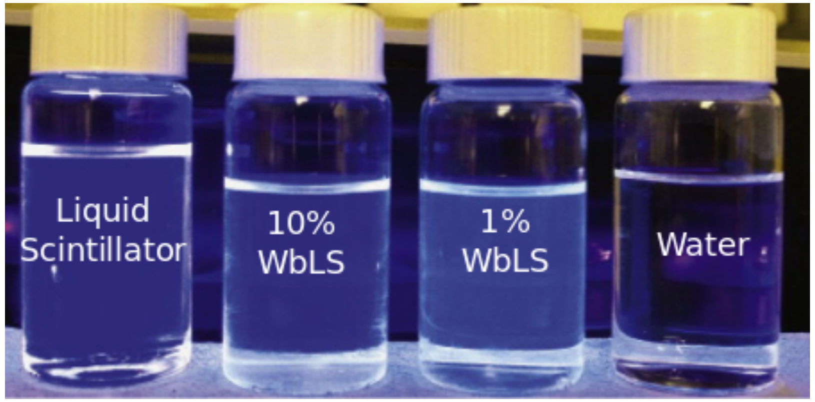
Water detector (Super-K, 22.5 kT)

Water:
Excellent transparency
Directionality
Particle ID
Cheap



Liquid Scintillator detector (JUNO, 22.5kT)

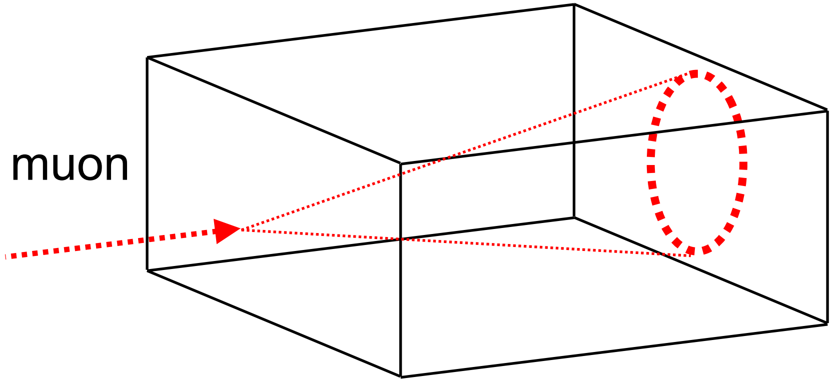
Liquid Scintillator:
High light yield
Low energy threshold
Good energy resolution



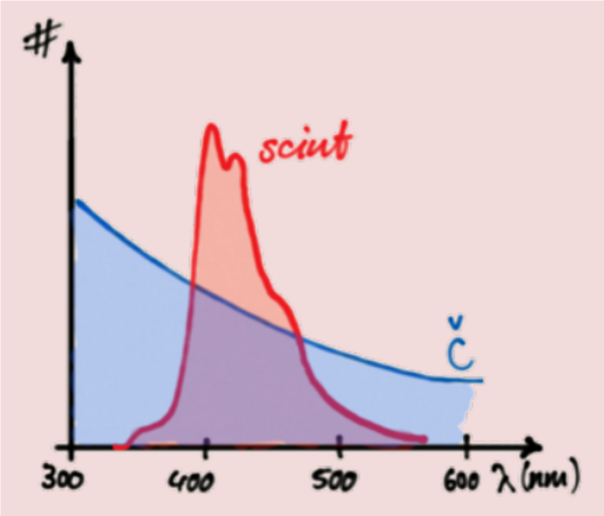
WbLS

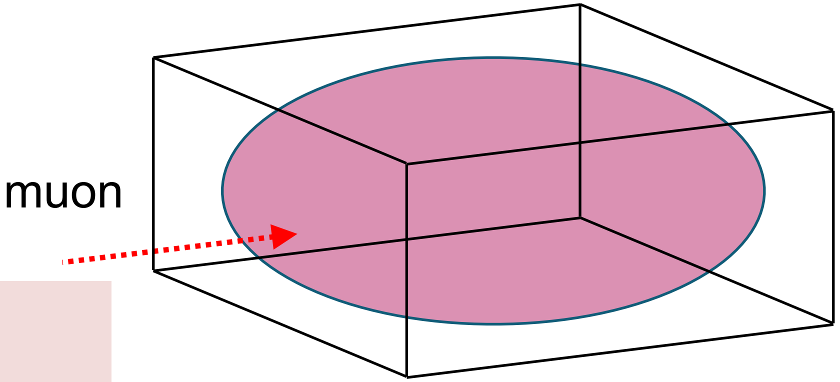
WbLS Basic Performance

Separating Cherenkov and scintillation:
shape, time, wavelength



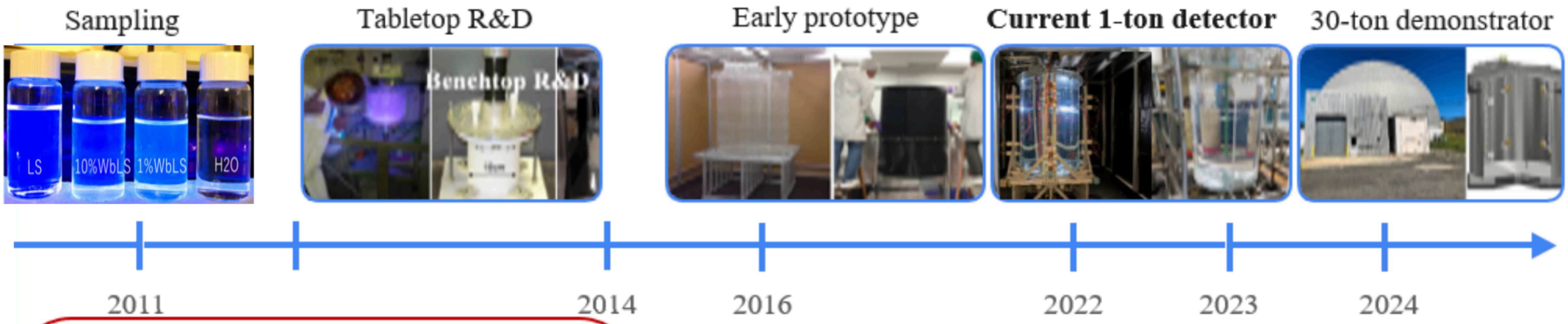
Cherenkov
unique shape
early

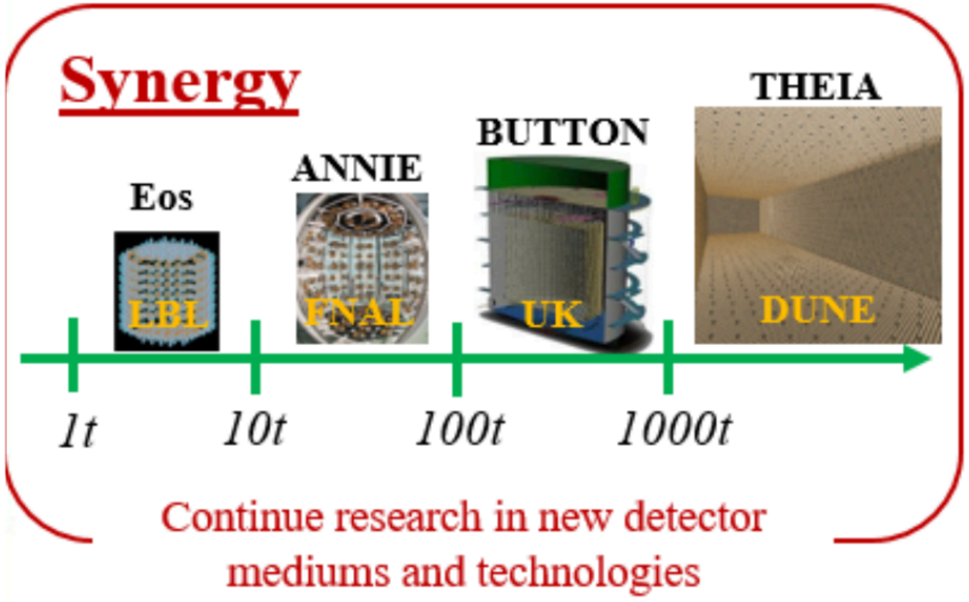




Scintillation
isotropic
late

WbLS R&D efforts at BNL

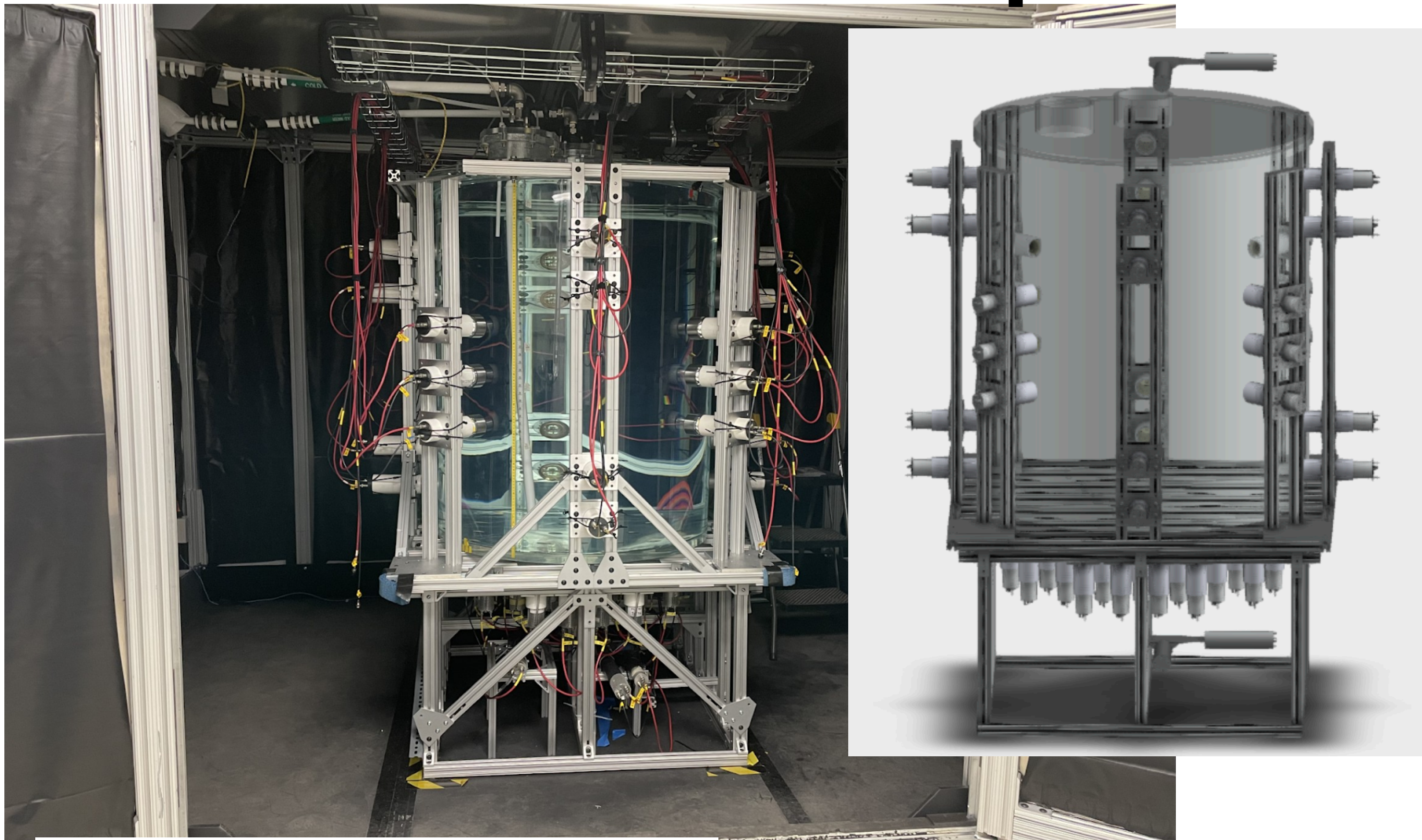




We are actively demonstrating and deploying WbLS for multi-ton scale neutrino detectors at BNL.

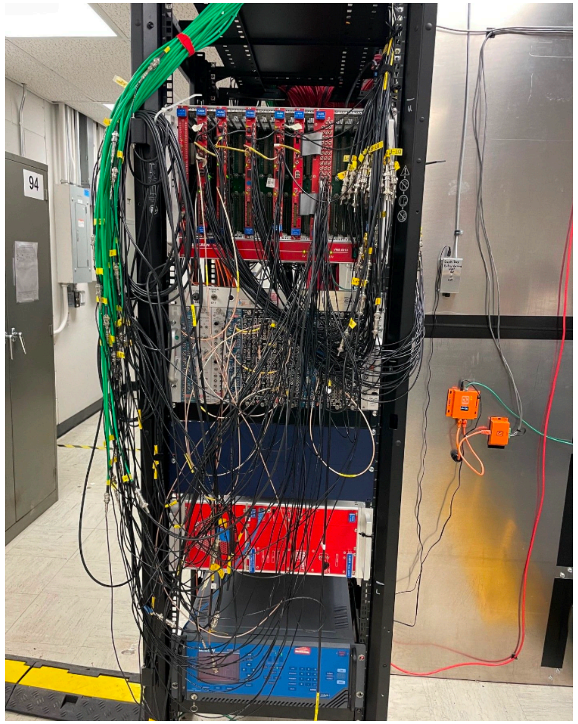
BNL WbLS is being sent to other experiments such as Eos, ANNIE, etc.

1 Ton Detector Setup



30 2” PMTs on the bottom

28 3” PMTs on the side



daq system

circulation and
filteration system

1 Ton Detector Analysis

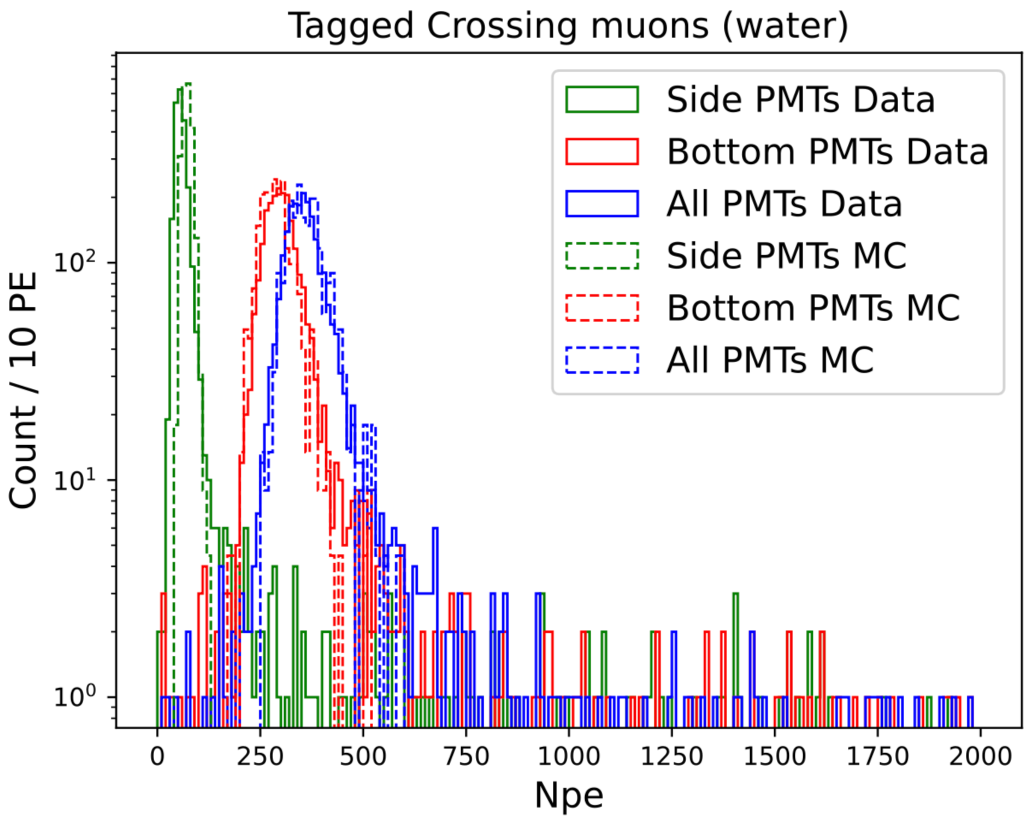
Crossing muon analysis:

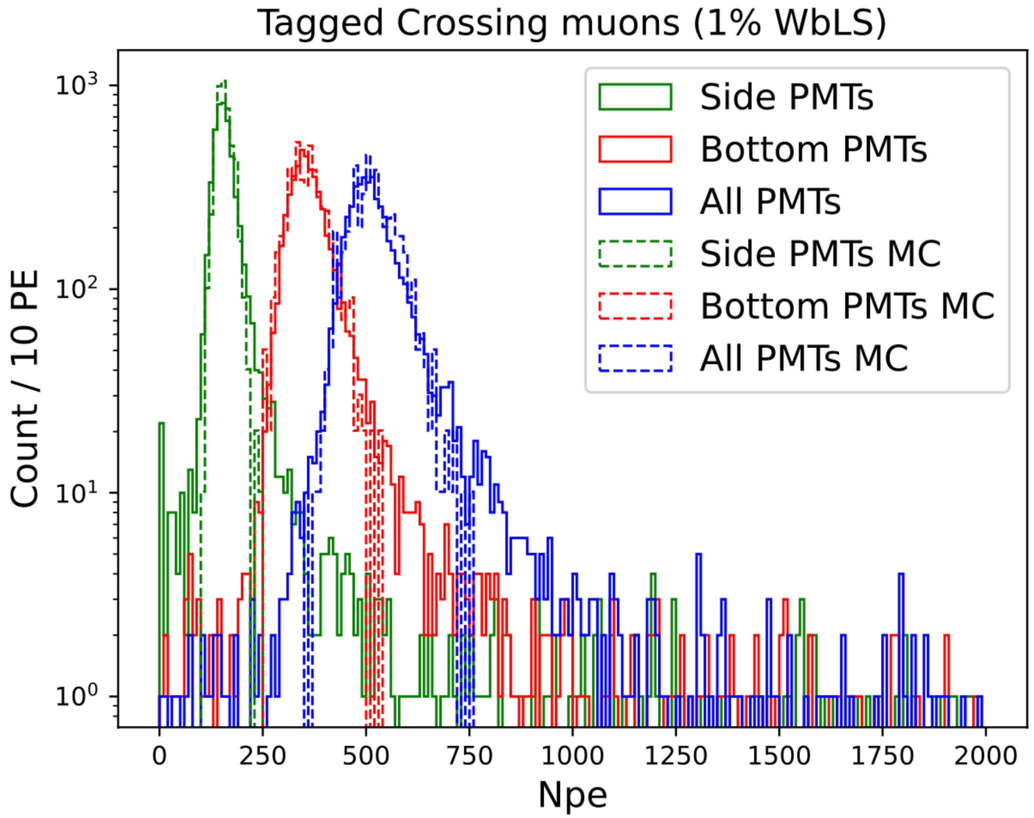
- Selecting vertically through going muon **minimize angular variation and ensure consistent energy deposition**.

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).

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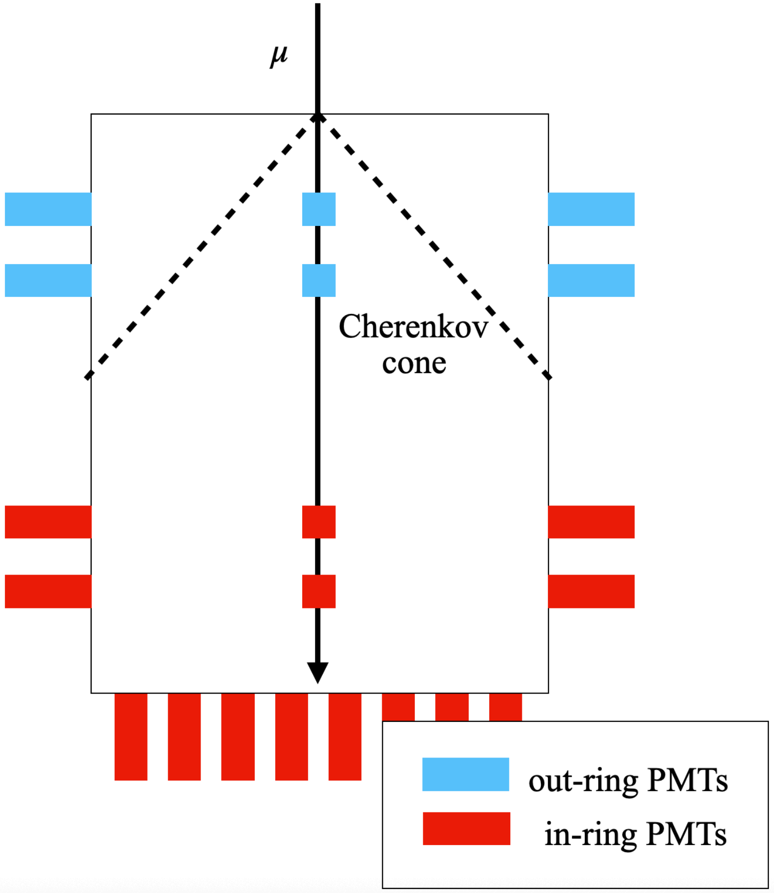
Injection campaign: water to 1.0% WbLS

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



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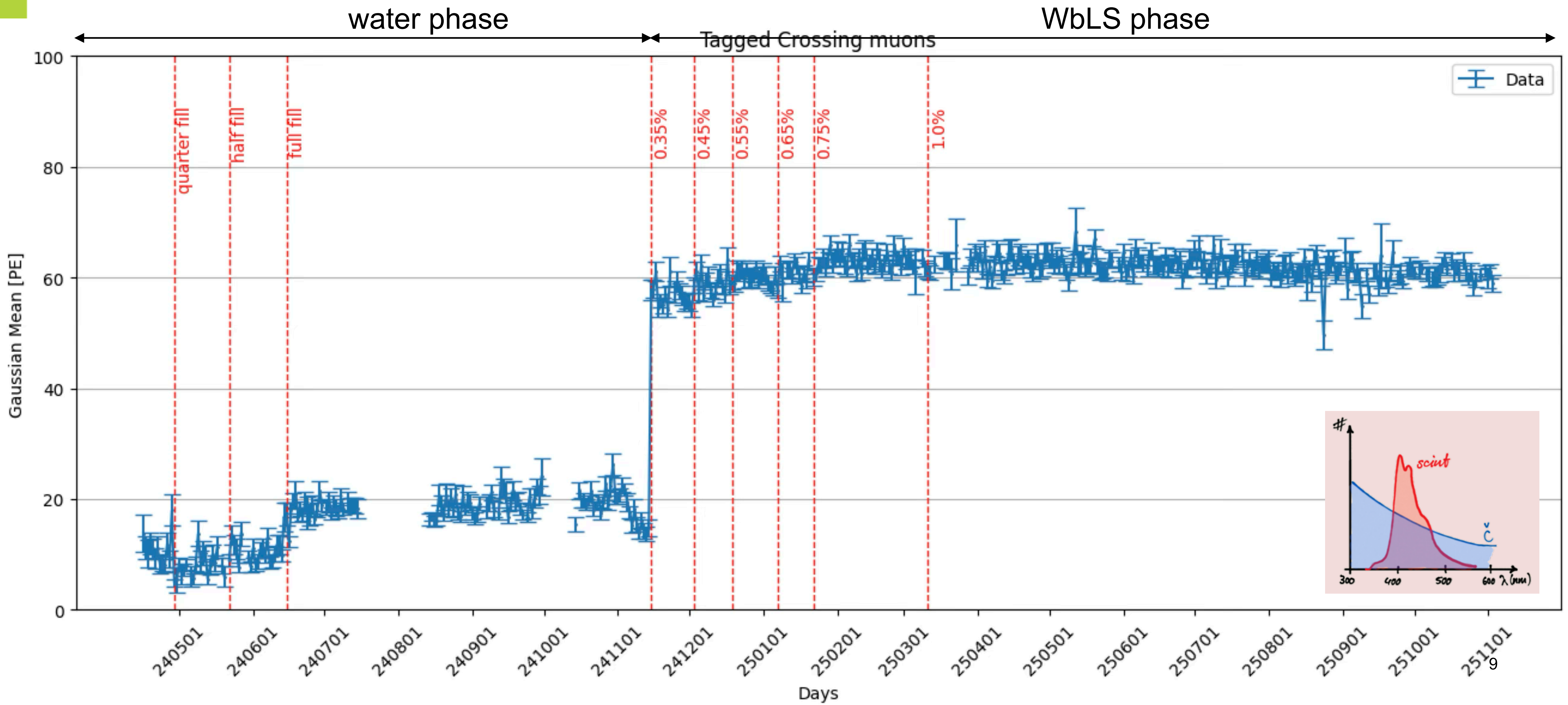
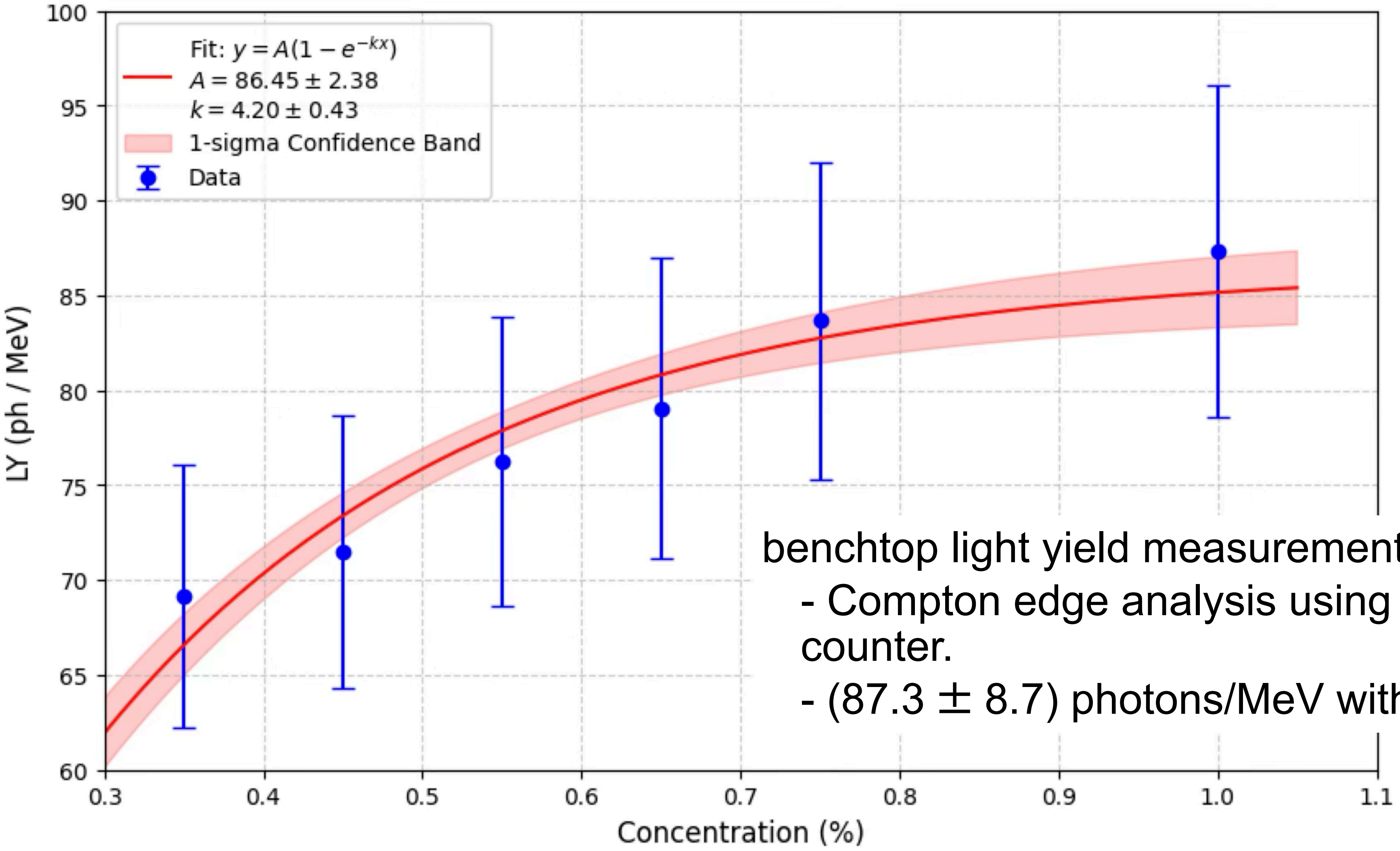
Daily detected PE in 1ton detector



Absolute light yield of WbLS



benchtop light yield measurement with small sample:

- Compton edge analysis using ^{137}Cs source and LS counter.
- (87.3 ± 8.7) photons/MeV with 1% WbLS

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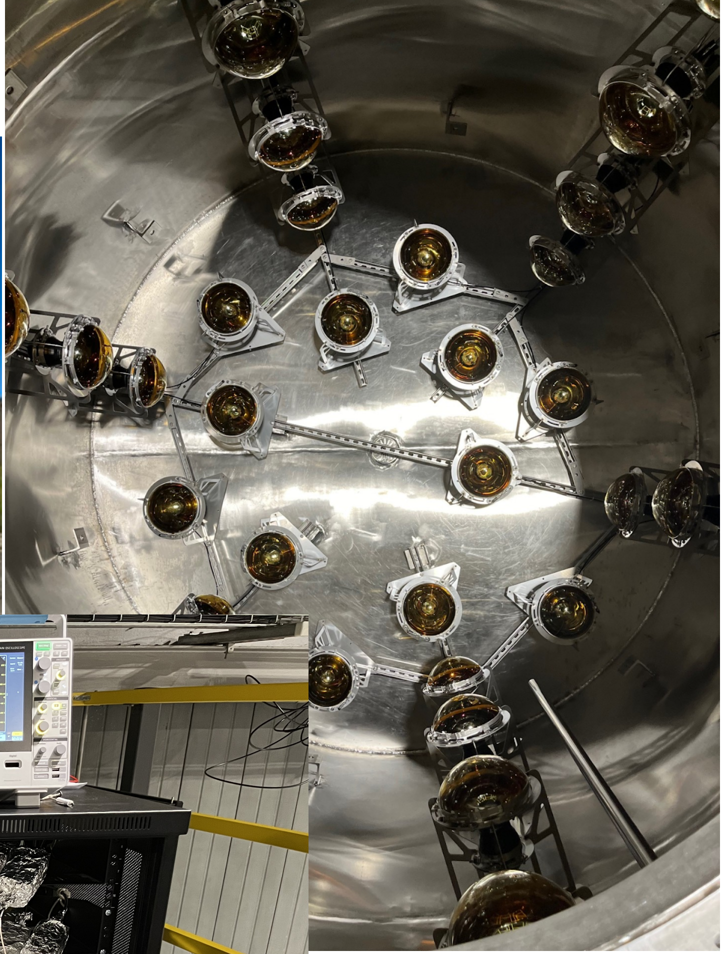
Why scale from 1 ton to 30 tons?

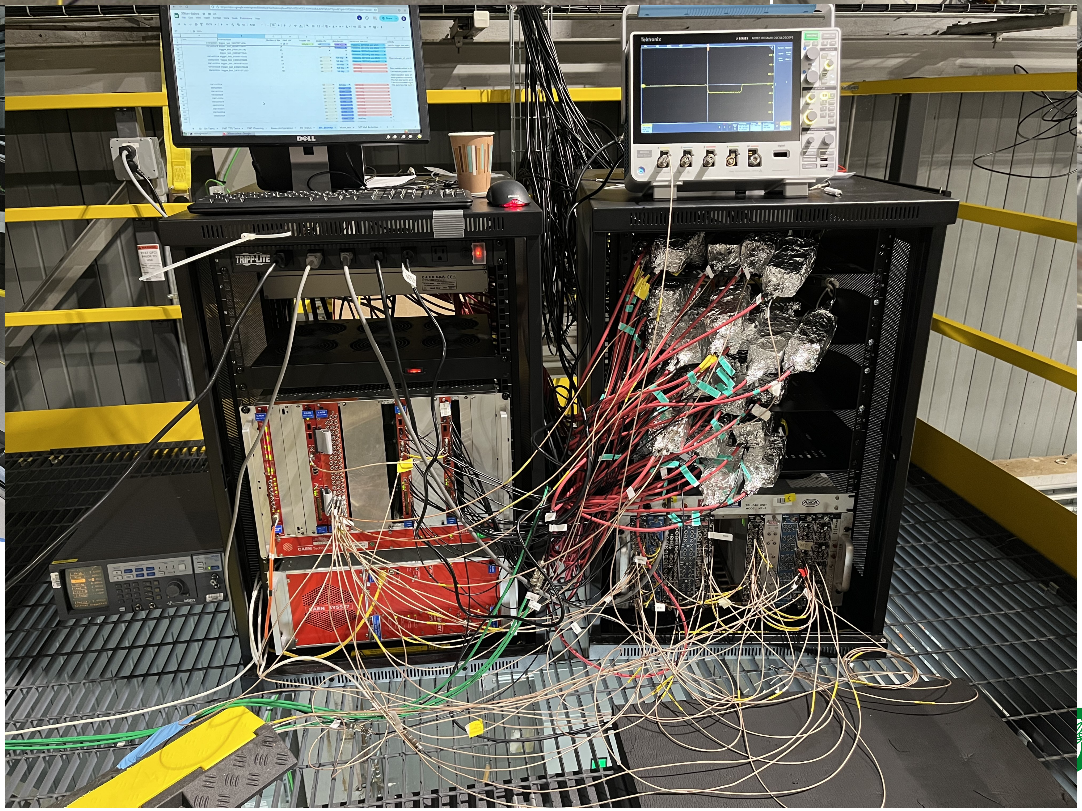
1-ton PRD result: concentration-dependent light-yield response established

Remaining scaling questions:
- optical homogeneity
- circulation and filtration at larger volume
- detector response uniformity
- DAQ scalability

30-ton detector: engineering and detector-response benchmark before kiloton scale

30 Ton Detector





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Summary

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

Gd-compatible WbLS was deployed in the Brookhaven 1-ton testbed and studied from 0.35% to 1.0% concentration by mass.

For 1.0% WbLS, the scintillation light yield is measured as (87.3 ± 8.7) photons/MeV.

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

ACCEPTED PAPER

Measurement of the light yield response of the Gd-compatible water-based liquid scintillator with the Brookhaven one-ton testbed

S. Gwon and M. Askins and D. M. Asner and A. Baldoni and D. F. Cowen and R. Diaz Prerez and M. V. Diwan and S. Gokhale and S. Hans and P. Kumar and G. Lawley and S. Linden and G. D. Orebi Gann and J. Park and C. Reyes and R. Rosero and K. Siyeon and M. Smiley and J. J. Wang and M. Wilking and G. Yang and M. Yeh

Phys. Rev. D - **Accepted** 6 May, 2026

DOI: https://doi.org/10.1103/m1qd-yg4r

Export Citation

Abstract

The Water-based Liquid Scintillator (WbLS) enables hybrid detection by combining scintillation and Cherenkov signals, providing superior event reconstruction capabilities compared to conventional neutrino detectors. We measured the light yield of Gd-compatible WbLS at 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 (69.2 ± 6.9) ph / MeV at 0.35% concentration, which increased to (87.3 ± 8.7) ph / MeV at 1%. These results establish a quantitative basis for optimizing future WbLS-based detectors in neutrino physics.

DOI: 10.1103/m1qd-yg4r

The measured response provides a quantitative basis for selecting WbLS concentration in future detector designs.

Back up

Trigger Systems for the 1-Ton Detector

Scintillator top paddles:

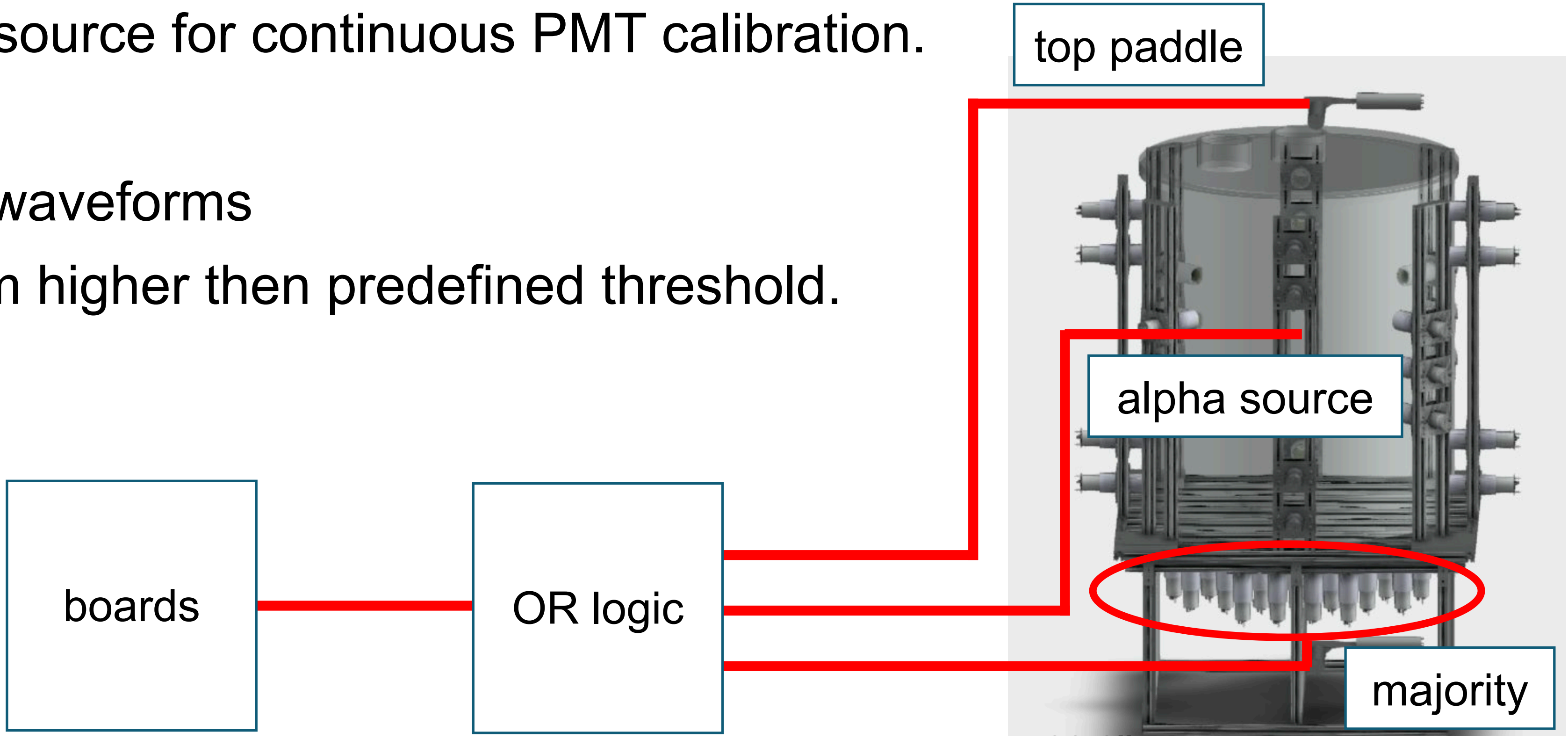
- Two rectangular paddles (10 cm × 12 cm) placed above the tank.

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 then predefined threshold.



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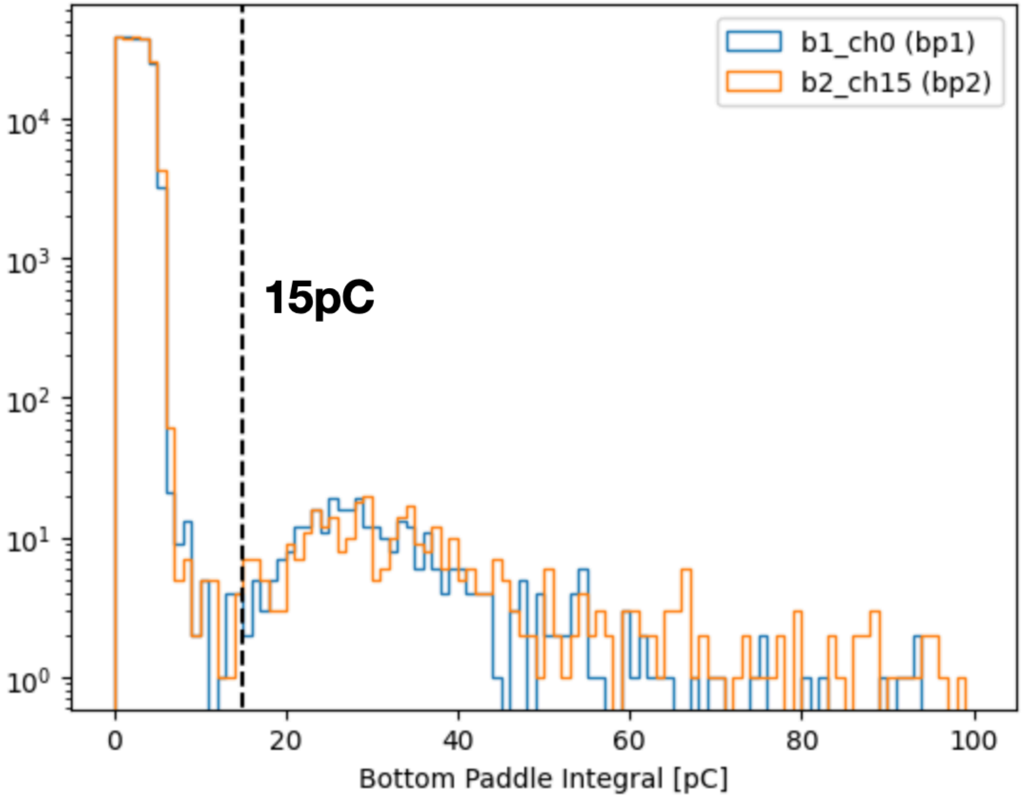
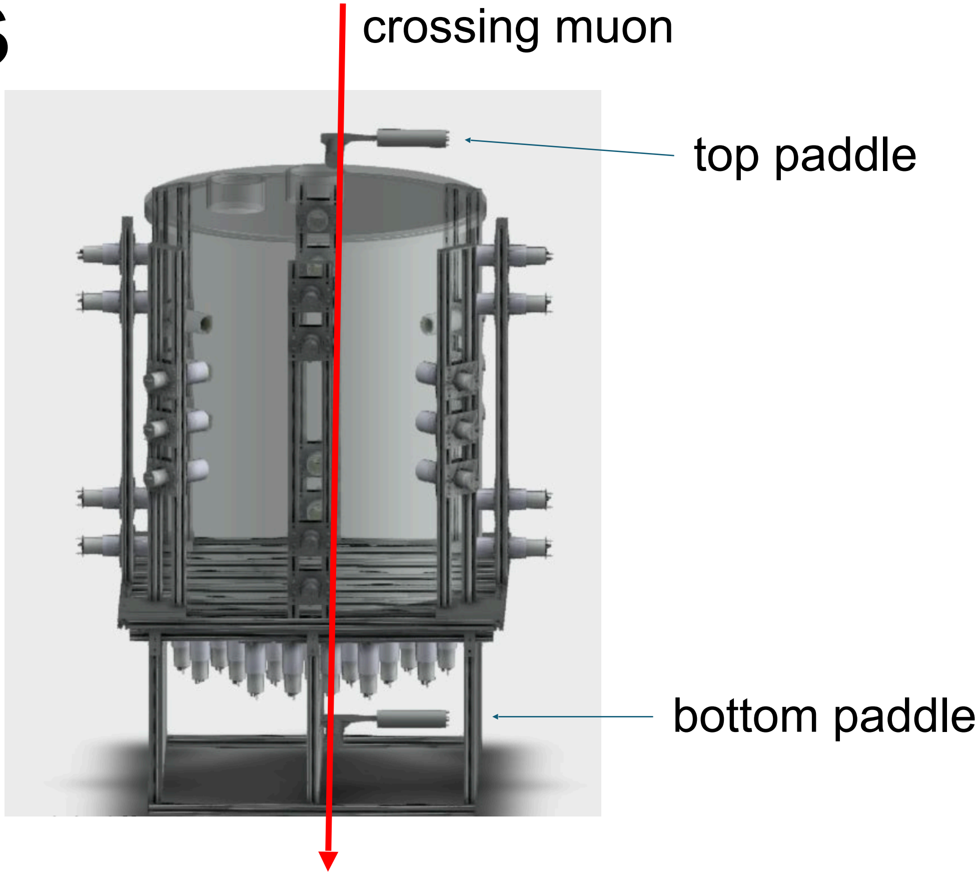
Crossing muon events

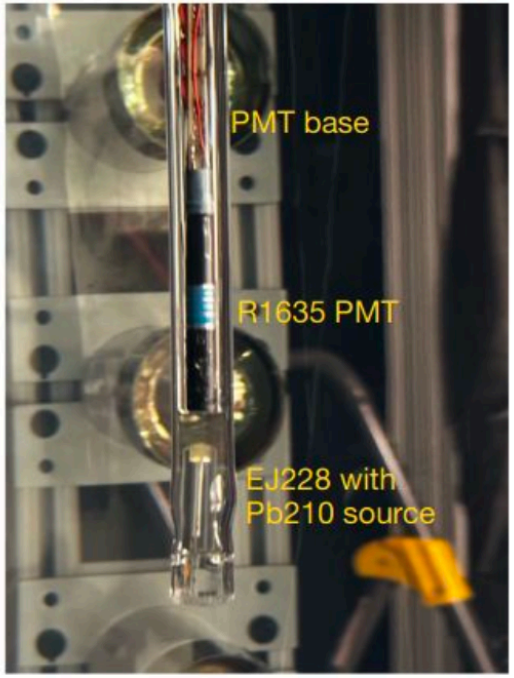


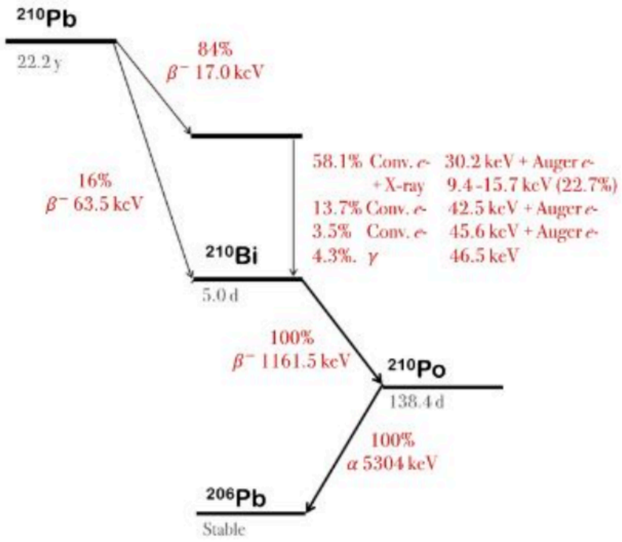


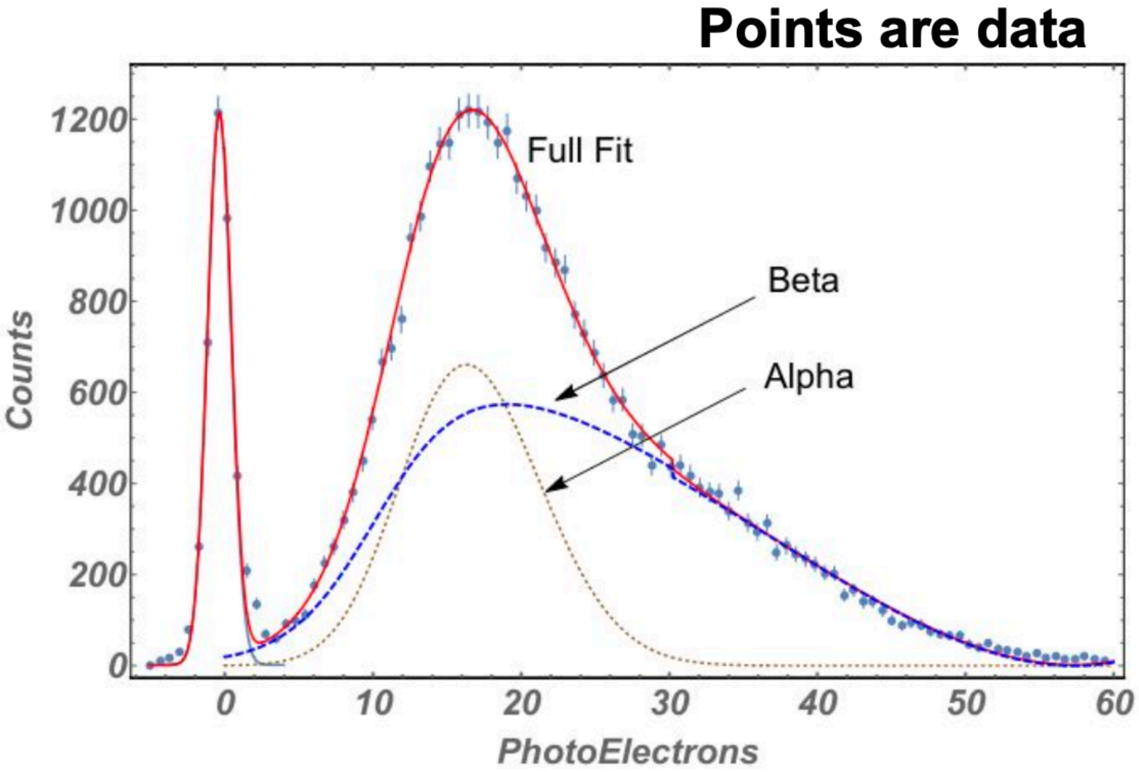
The crossing muon events are tagged by top and bottom scintillator paddles.

Restricts trajectories to vertical paths with minimal angular variation (< 8)

1 Ton Detector Calibration







^{210}Pb-based source embedded in a plastic scintillator, at the center of the detector.

The source provides continuous light for PMT gain verification.

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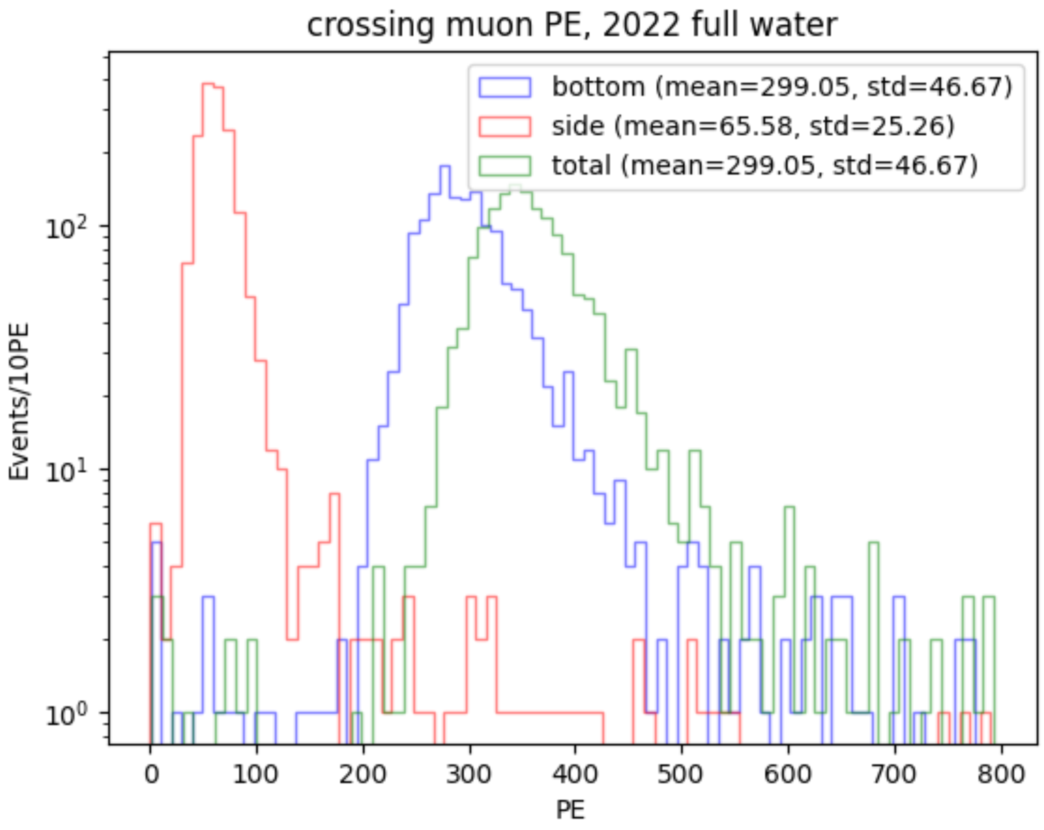
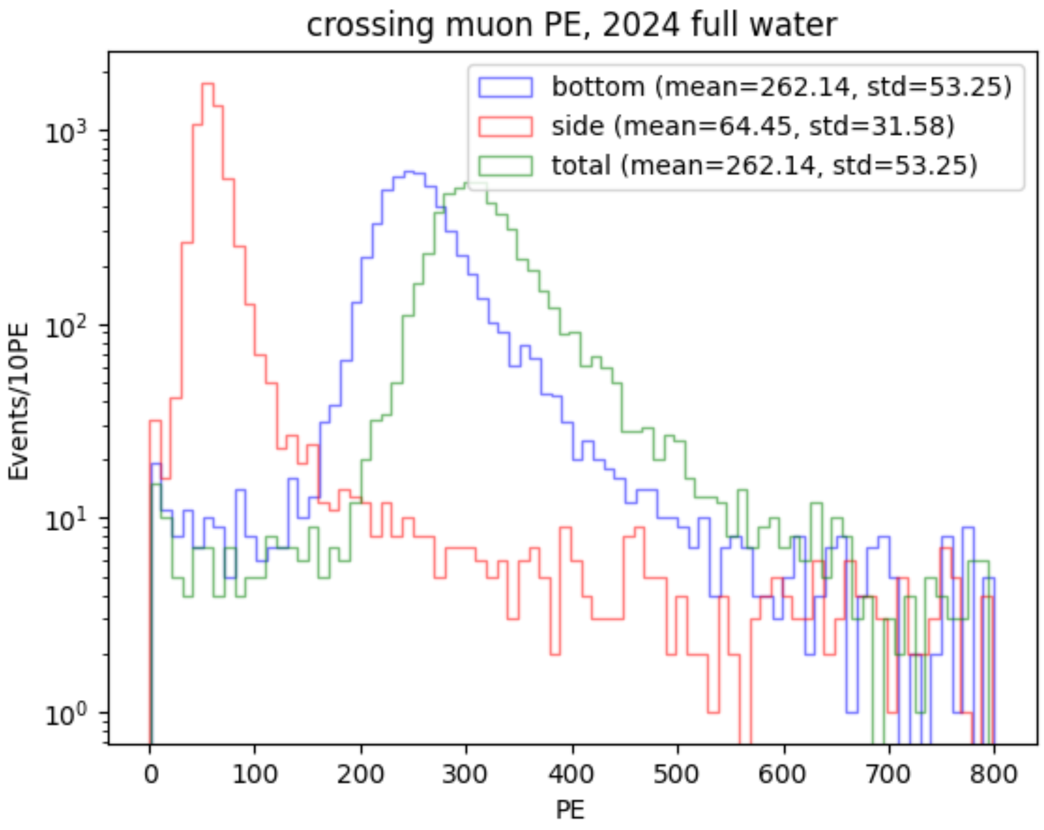
Water phase





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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