Development of a pilot Opaque Liquid Scintillator 3D-Projection Calorimeter for Future Neutrino Experiments

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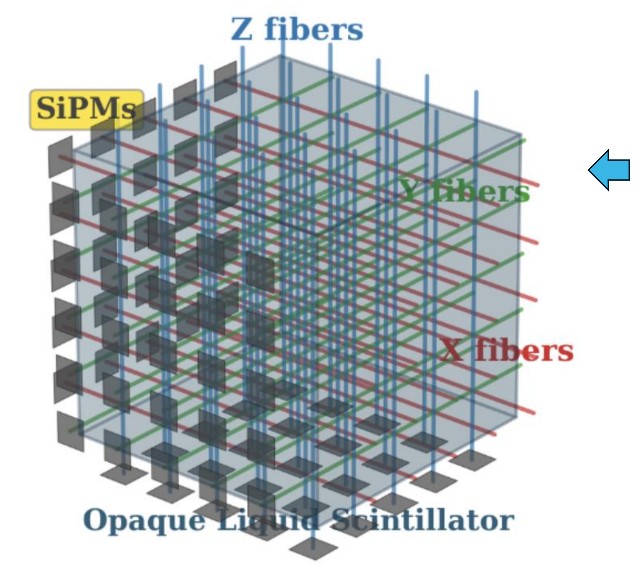
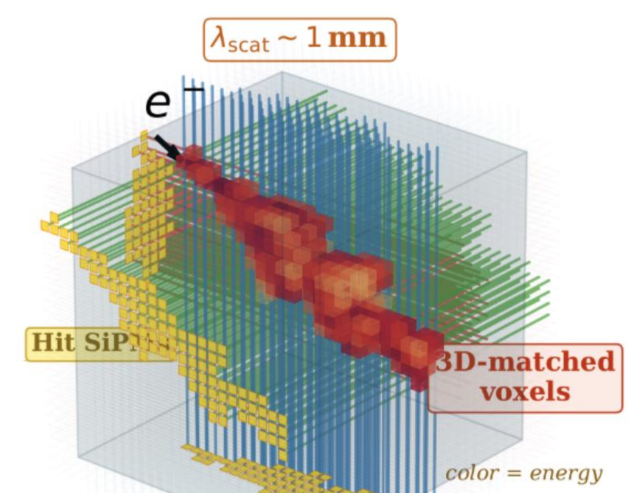
Abstract

To build on T2K SFGD[1], Brookhaven National Laboratory (BNL) is developing a liquid implementation that removes physical voxel boundaries while preserving fine-grained three-dimensional reconstruction.



A simple schematic of an opaque liquid scintillator 3D detector.

An example event in the detector with projections on each of the faces.



We employ an opaque water-based-liquid scintillator (oWBLS) with a controlled, short scattering length[2], enabling high-resolution imaging with submerged orthogonal wavelength-shifting fiber readout and reduced mechanical complexity. This design offers additional advantages including radiation length modulation via heavy metal loading, easy maintenance, and superb scalability.

Detector Overview

Detector system

- 8 × 8 × 16 cm^3 active volume
- oWBLS with di-isopropylnaphthalene, 2,5-diphenyloxazole, bis-MSB, and opaqueness modulating surfactances

Why 3D?

While 3D reconstruction can be done with just 2D readout, the additional view from a 3D readout detector would greatly suppress "ghost hits" during reconstruction by up to 20-fold! Check out: **arXiv:2601.07633**

- 320 Kuraray Y11 wavelength-shifting fibers
- 5 Hamamatsu SiPM sensor boards --- 64 channels each, 320 channels in total
- 3 Baby MIND based front-end boards[3]

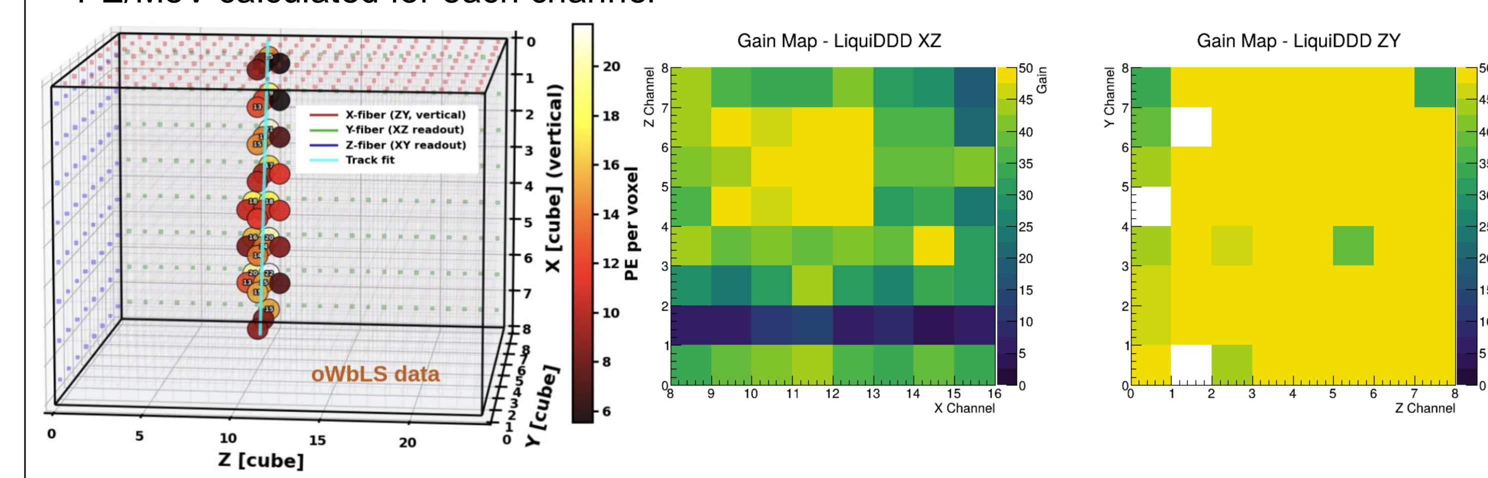
Event Processing & Calibration

Data Analysis

Unpack: raw binary data converted into ROOT tree structures → **ADC→PE**: ADC counts converted to PE via LED calibration info → **Event Structuring**: Hits grouped into events by amplitude and time → **3D Voxel Reconstruction**: Hits from three views are matched to form voxels with minimal "ghost hit" probability[4]; True energy assigned with muon calibrated light yield

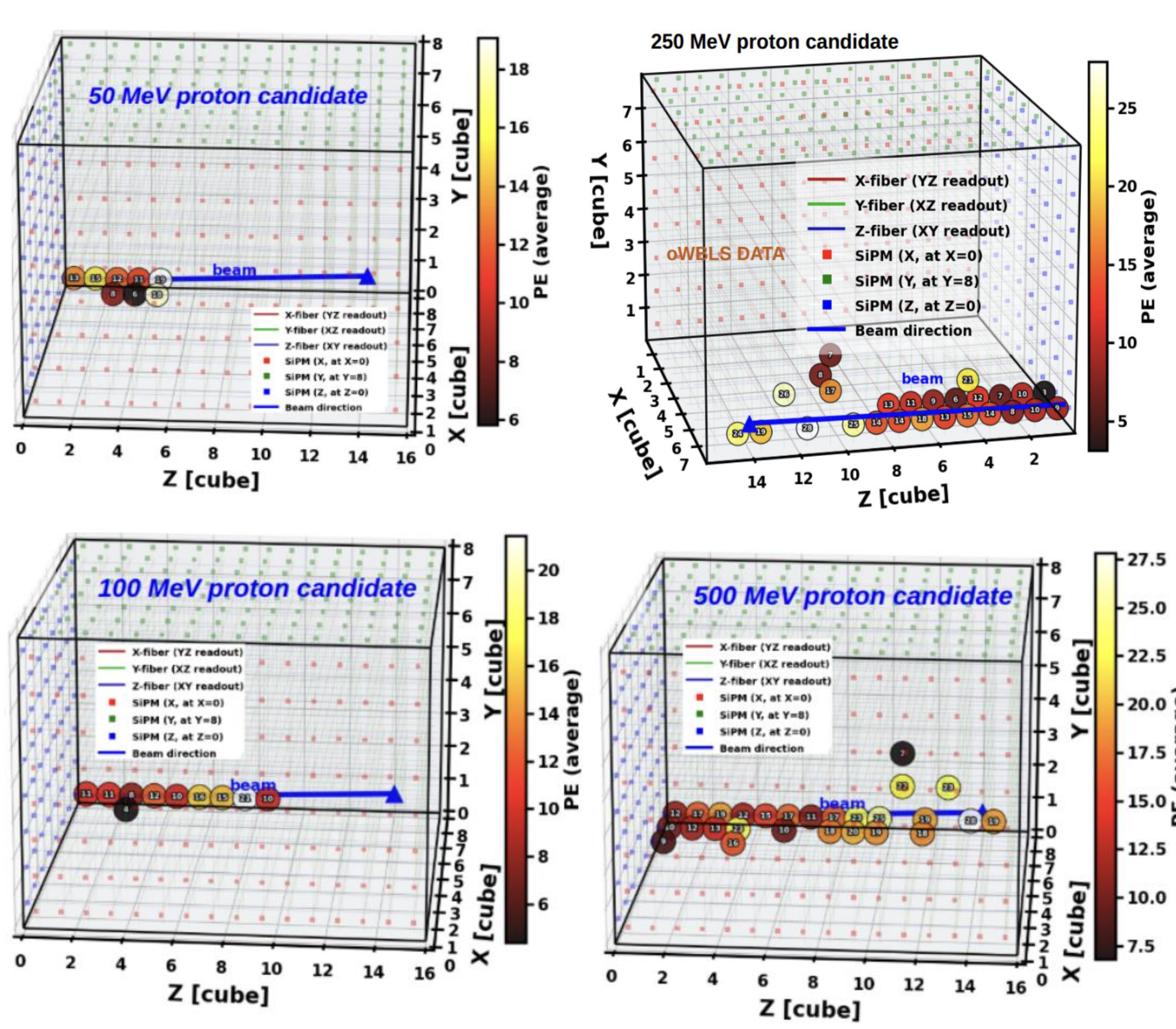
Light Yield Calibration

- Cosmic muons selected by topology
- Track length calculated for each fiber absorption region
- Deposition energy mapped from track length
- PE/MeV calculated for each channel

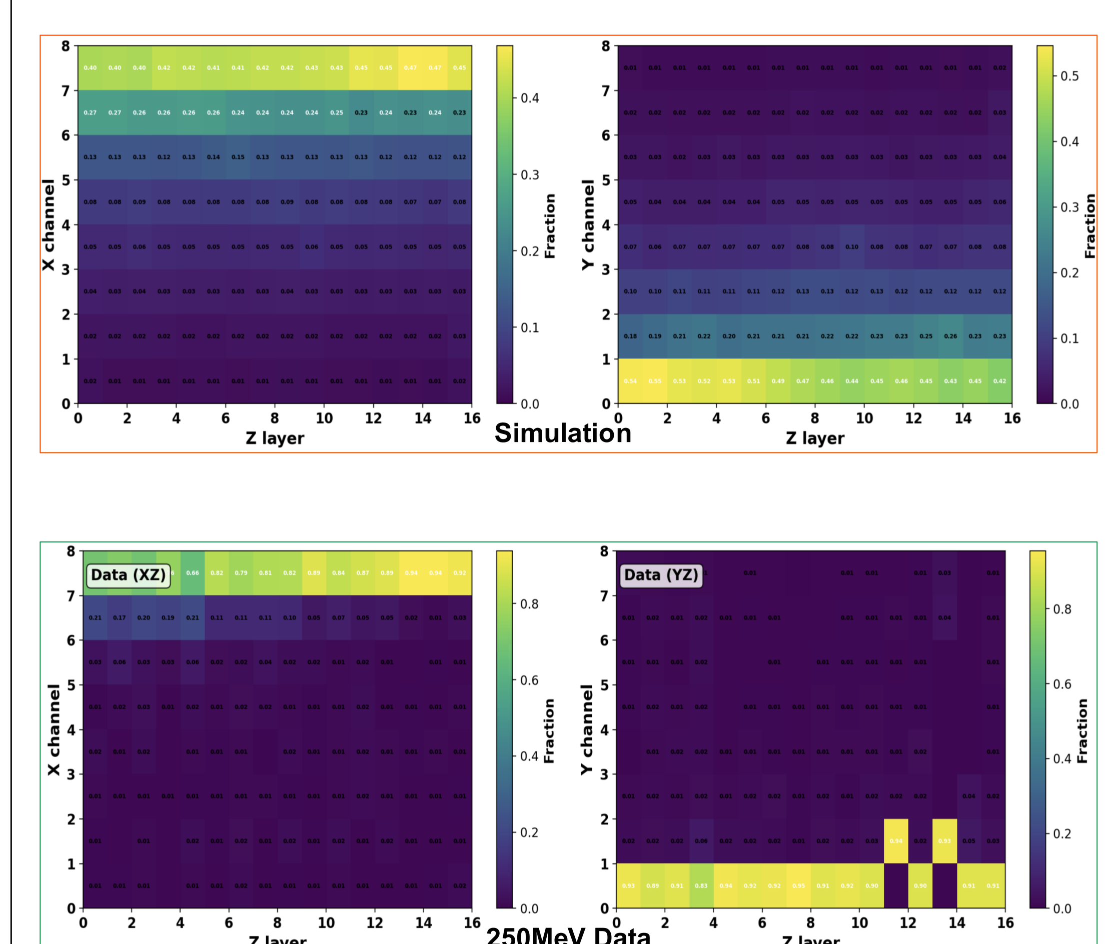


NSRL Beam Test

Energy Profile: Protons with 50, 100, 250, and 500 MeV were used in the beam test.



Transverse Light Spread: Thanks to the 3D and fine-grained nature of the detector, light spread from the beam can be measured. A smaller light spread would indicate a shorter scattering length and an opaquer scintillating medium.

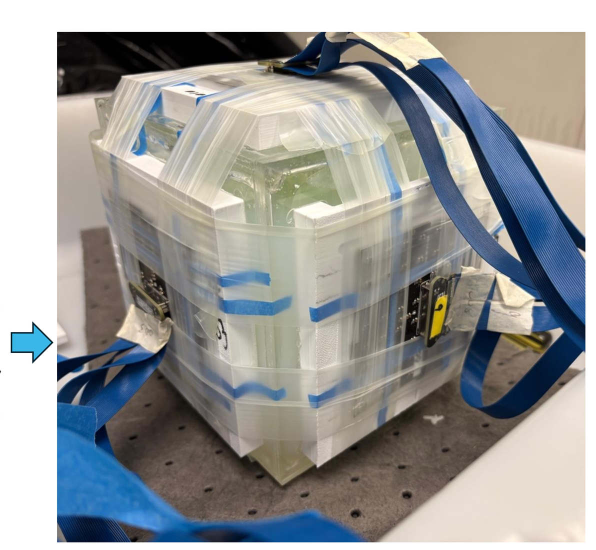


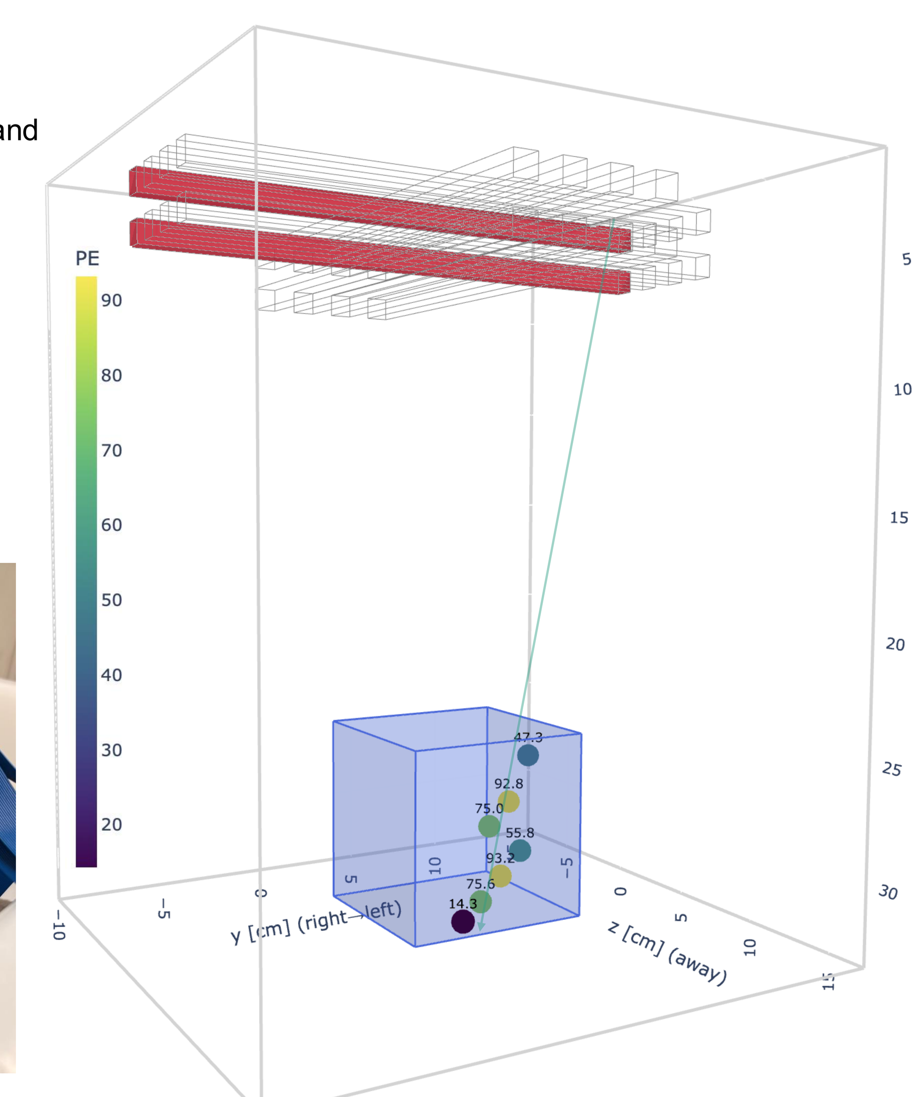
Liqui3D

Overview: Second iteration of the opaque liquid scintillator 3D detector design with 8 x 8 x 8 cm^3 active volume. The design is improved for better structural robustness, fiber installation, and sensor coupling.

Liqui3D before oWBLS filling and sensor+DAQ installation

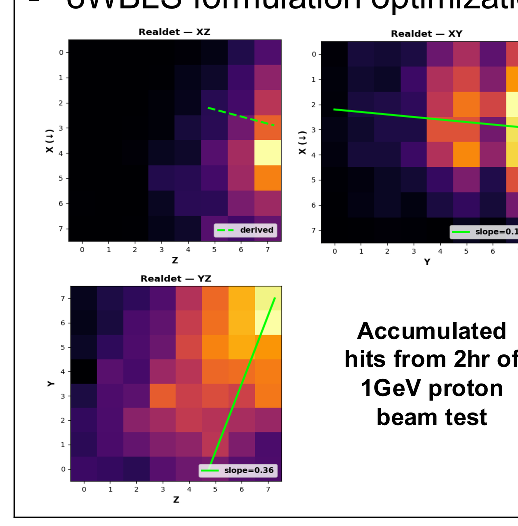
Liqui3D filled with oWBLS and connected to the sensor +DAQ system





Future

- Liqui3D beam tests
- Heavy metal loading
- oWBLS formulation optimization



Accumulated hits from 2hr of 1GeV proton beam test

More?

Check out our full-length report paper on the pilot detector[5] at **arXiv:2605.10683v1**

More is to come! Look out for Liqui3D…

References

[1] S. Abe *et al.*, 2026. arXiv:2603.14921
[2] J. Apilluelo *et al.*, 2025. *Nucl. Instrum. Meth. A* **1071** 170075
[3] M. Antonova *et al.*, 2017. *JINST* **12** C07028
[4] H. Che and G. Yang, 2026 *JINST* **21** P06010
[5] H. Che *et al.*, 2026. arXiv:2605.10683v1

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