

Novel Opaque Liquid 3D-projection Detector (OL3D) Development at Brookhaven



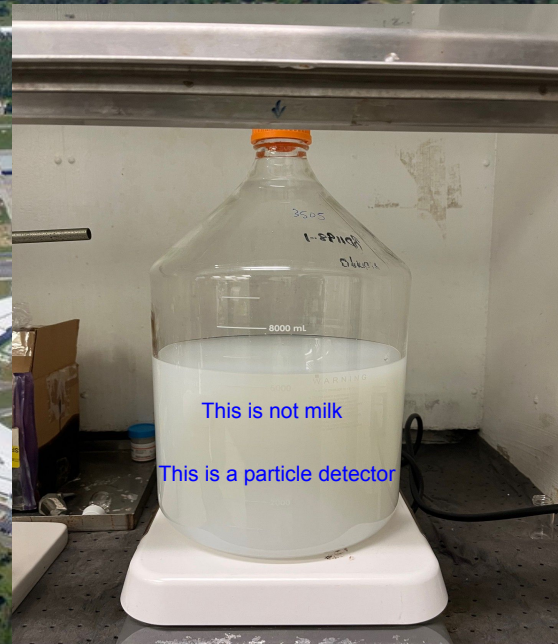
Brookhaven
National Laboratory



U.S. DEPARTMENT OF
ENERGY

*Guang Yang
Brookhaven National Lab
CPAD 2026 at Seattle*

Special thanks to Minfang Yeh, Milind Diwan and Gabriella Carini



Tokai-2-Kamioka (T2K)

$$\frac{dN_{\nu_e}^{far}}{dE_{rec}} = \frac{\int P_{\nu_\mu \rightarrow \nu_e}(E_\nu) * \phi_{\nu_\mu}^{near}(E_\nu) * F_{far/near}(E_\nu) * \sigma_{\nu_e}^{Ar}(E_\nu) * T_{\nu_e}^{far}(E_\nu, E_{rec}) dE_\nu}{\int \phi_{\nu_\mu}^{near}(E_\nu) * \sigma_{\nu_\mu}^{Ar}(E_\nu) * T_{\nu_\mu}^{near}(E_\nu, E_{rec}) dE_\nu}$$

All requires good near detector

T2K near detector can't cover the same phase space.

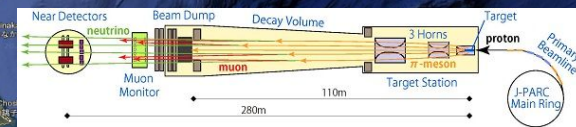
T2K near detector can't reconstruct final states with neutrons.

ND: Magnetized system



FD: Water Cherenkov detector

295 km baseline



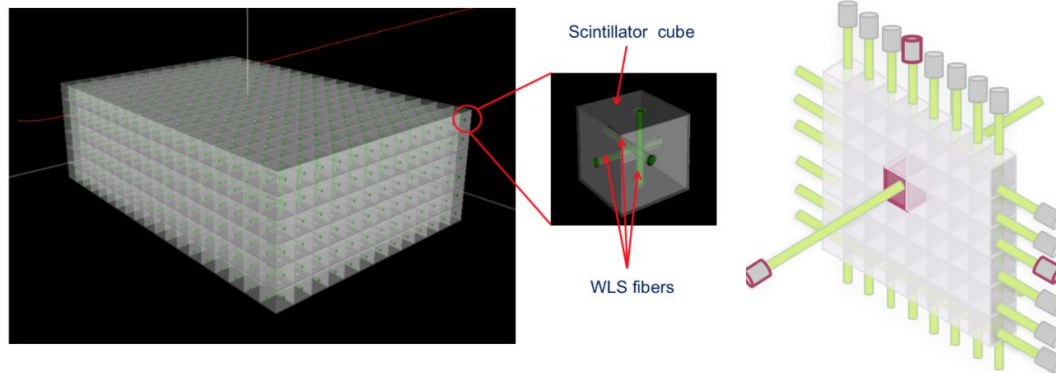
J-PARC beam

Plastic 3D-projection scintillator detector

3D array of optically isolated scintillator cubes

- Cube size and material can vary.

3D readout with 3 WLS fibers passing through each cube and connected to MPPCs (multi-pixel photon counters)



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Performance benchmarks for 2-View and 3-View
fiber-projection fine-grained particle detectors

Haohui Che^a and Guang Yang^{b,*}

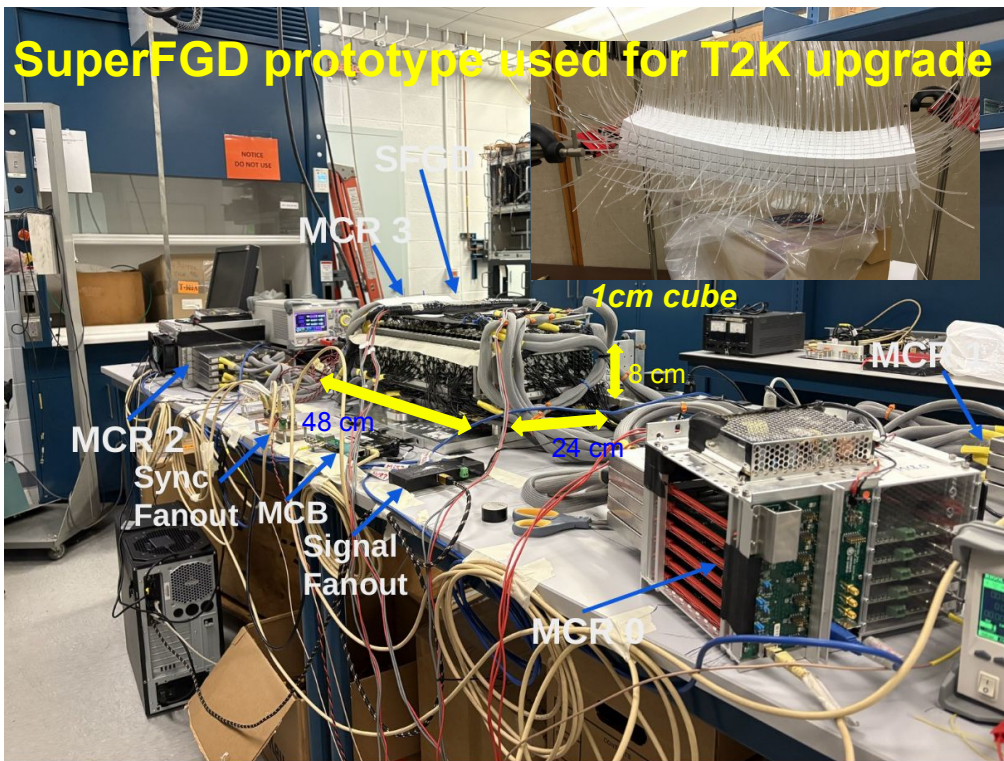
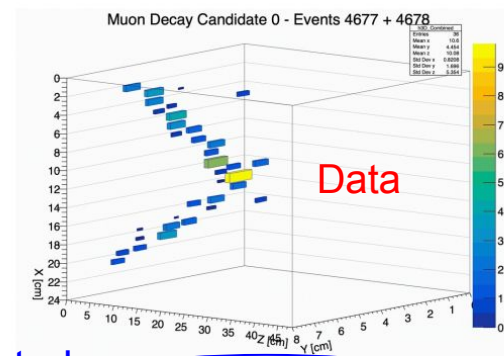
^aDepartment of Physics, Washington University in St. Louis,
1 Brookings Dr, St. Louis, MO 63130, U.S.A.

^bBrookhaven National Laboratory,
98 Rochester Road, Upton, NY 11973, U.S.A.

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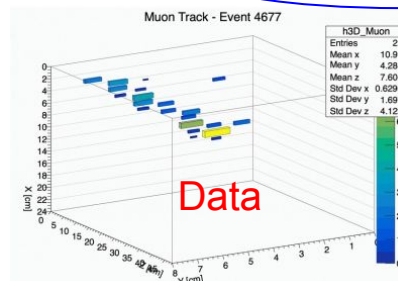
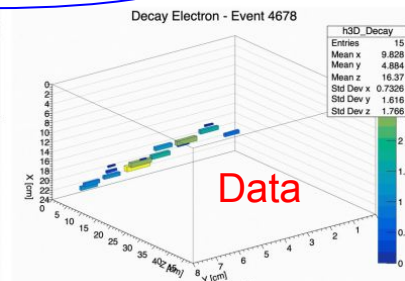
Fully active!
Single fiber 0.9 ns timing resolution: Fast timing!
1-cm-scale size:
Fine granularity!
>50 PE/MeV each
readout: High light yield!

Those plastic prototypes running at BNL

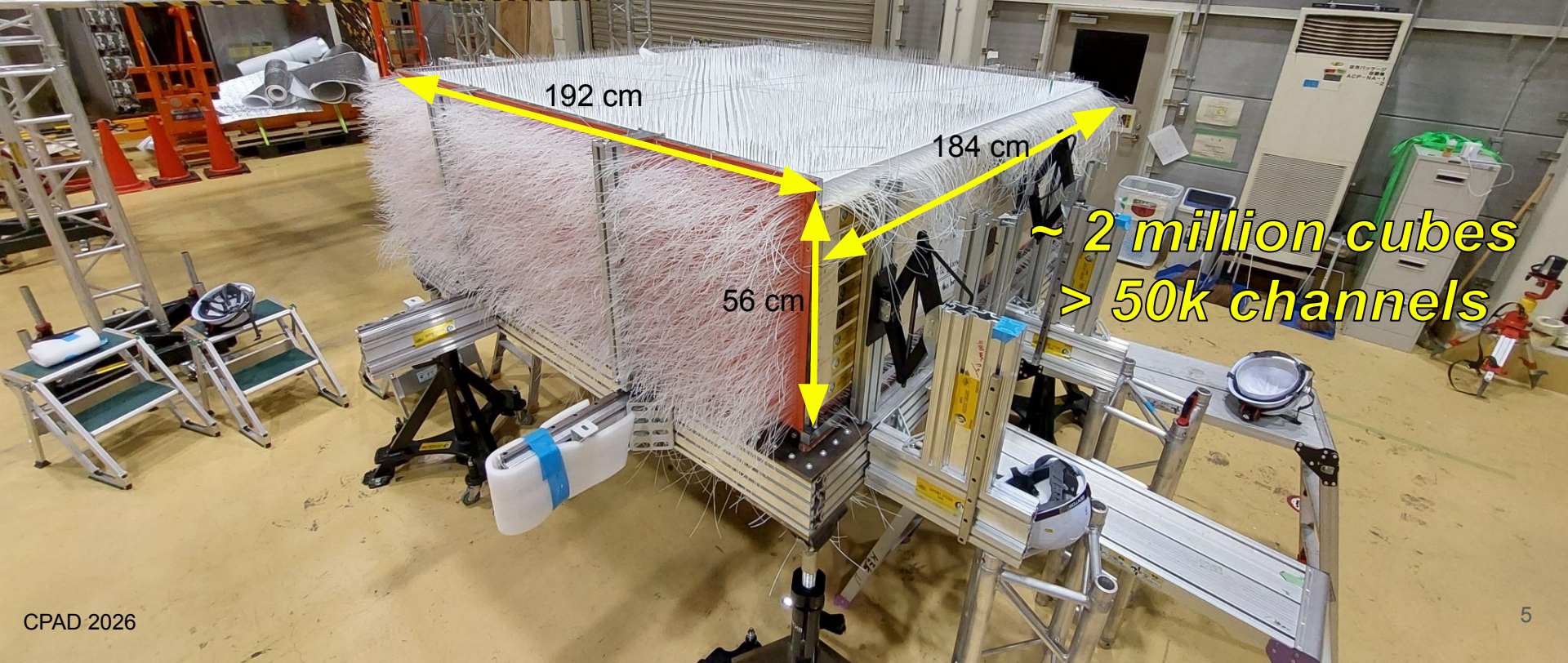


Fully
calibrated

Muon Decay; $\Delta T = 1.445 \mu s$



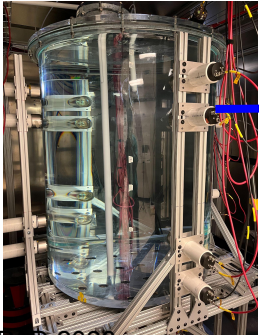
*People made it big at JPARC:
working great, but can't be tuned*



Scaling-up novel calorimeter

A Path Forward: The 3D-Projection "Tracking Calorimeter": A possible solution is a detector that is simultaneously a tracker and a calorimeter. This approach unifies these functions within a **scalable**, single, fully active, homogeneous volume.

1ton water-based
liquid scintillator



30ton water-based
liquid scintillator



Make it opaque liquid for large-scale tunable detector



Make it water-based for low-cost while preserving performance



Make it metal loaded to tune radiation length



Fiber 3D-projection readout

We put the pixels in the liquid: granularity from chemistry, not machining

Scattering length handling

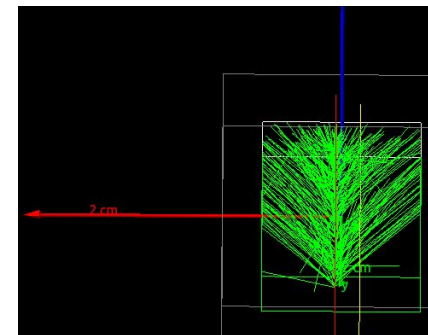
Short scattering length



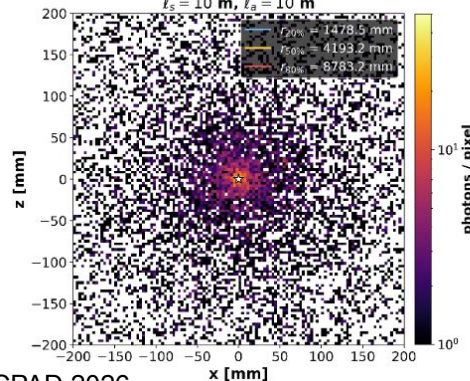
Short absorption length



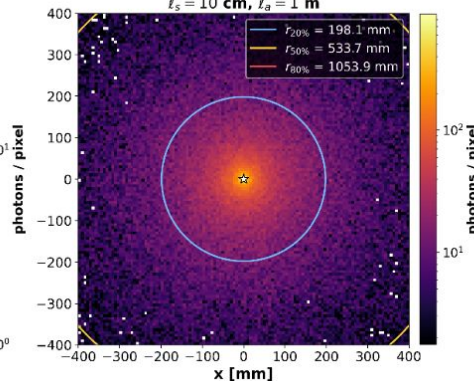
Long sct./abs. length



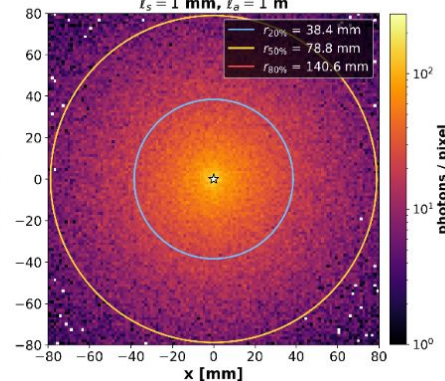
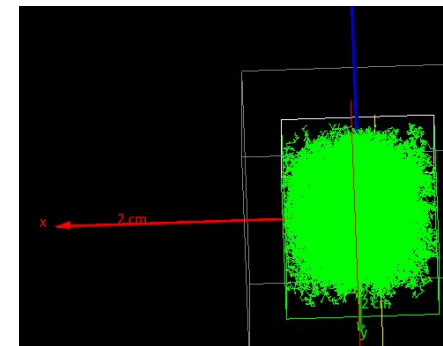
(a) clear LS
 $\ell_s = 10 \text{ m}, \ell_a = 10 \text{ m}$



(b) intermediate
 $\ell_s = 10 \text{ cm}, \ell_a = 1 \text{ m}$



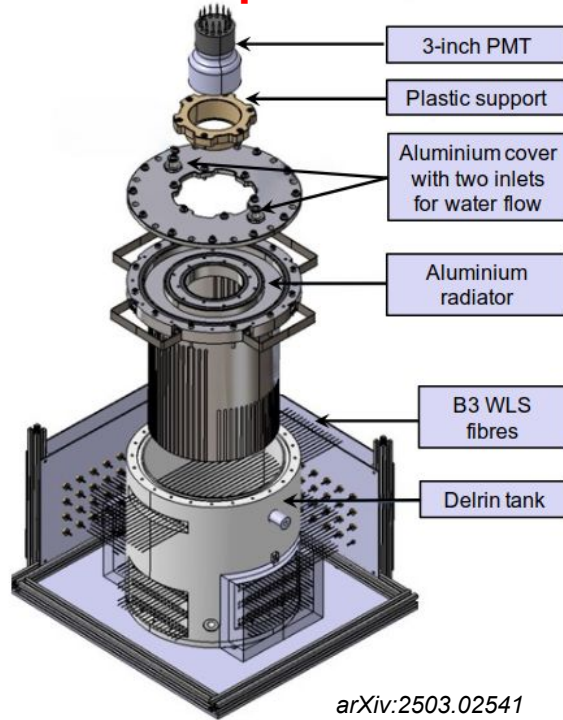
(c) opaque target
 $\ell_s = 1 \text{ mm}, \ell_a = 1 \text{ m}$





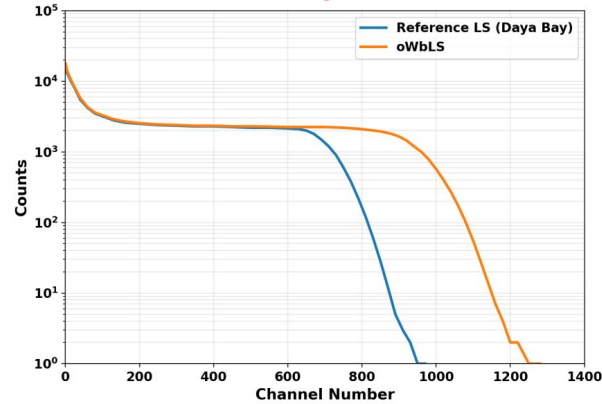
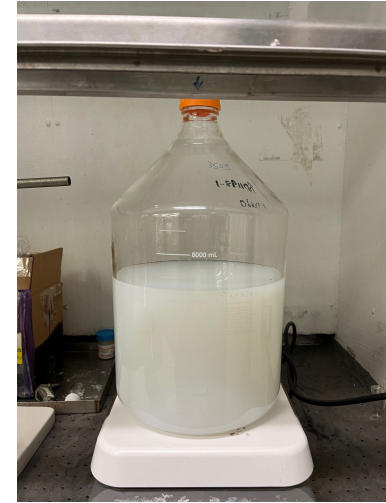
Opaque (Water-based) Liquid Scintillator at BNL

Used in LiquidO

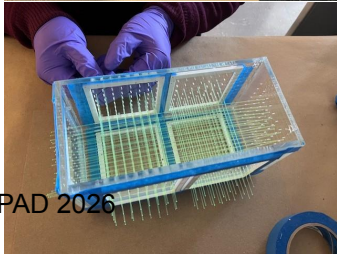


arXiv:2503.02541

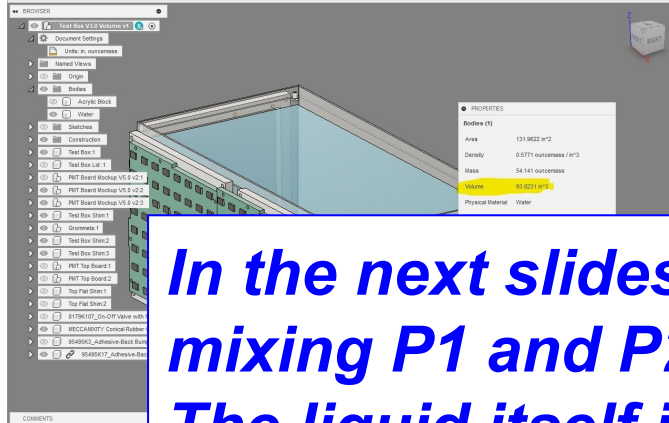
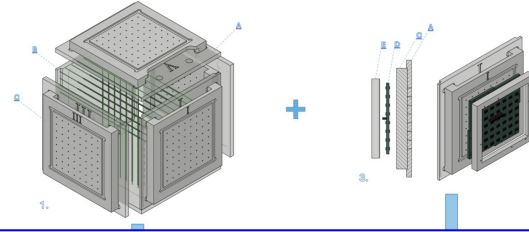
Made it 30% brighter than DYB



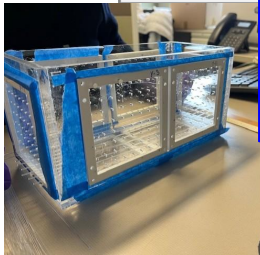
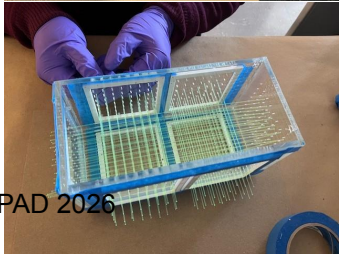
- Produced for LiquidO at BNL
- Rested for 1 year
- The optical response is stable.



Built twice - P1 taught us (no metal loading)

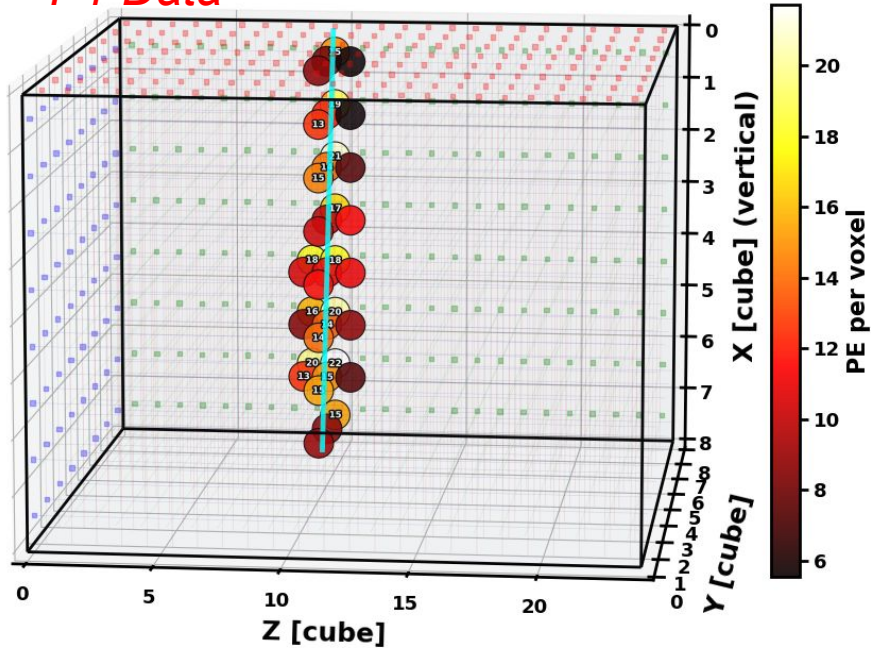


*In the next slides, I will show the results mixing P1 and P2.
The liquid itself is the same.
The optical coupling is different.*



The liquid tracks muons in 3D

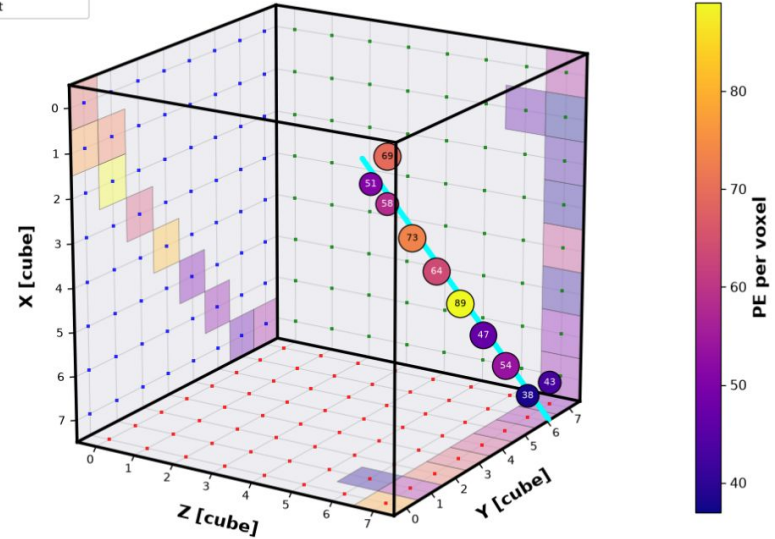
P1 Data



P2 Data



OL3D Data



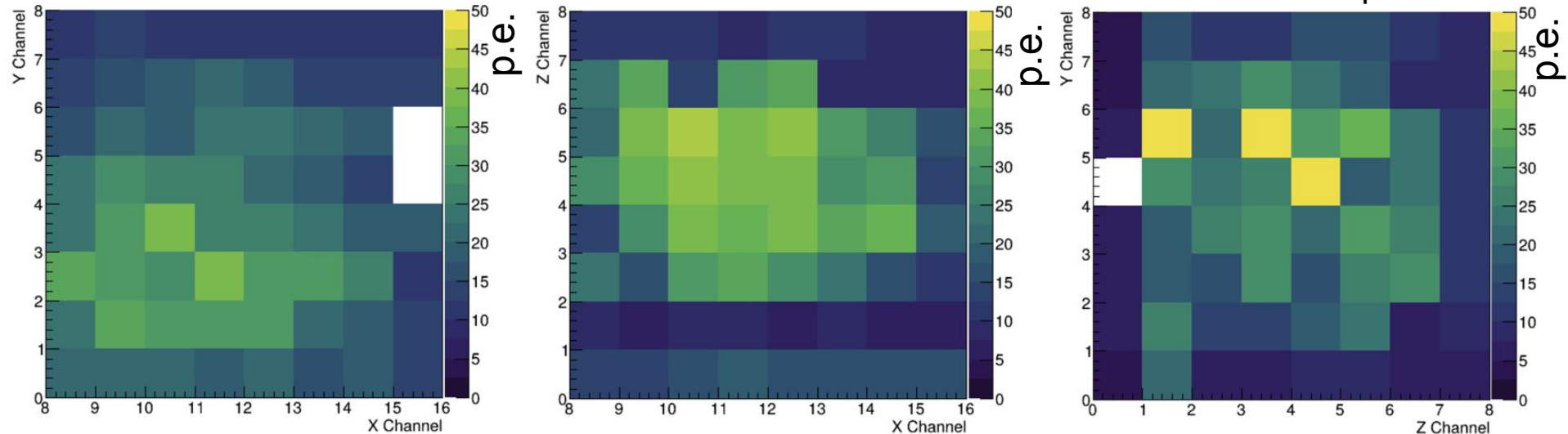
P2 collected significantly more light than P1.

Light yield measurement

- Not too far from plastic***

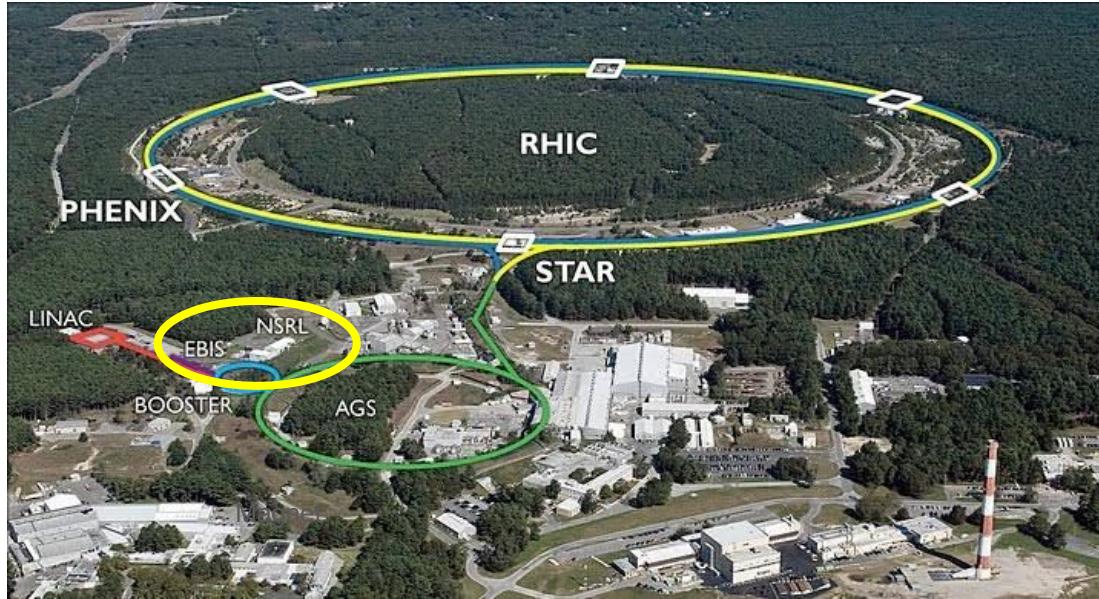
Accumulated a few days of cosmic muons

Track fit for muon length in each voxel volume



Top view

Beam test at NASA Space Radiation Lab (NSRL)



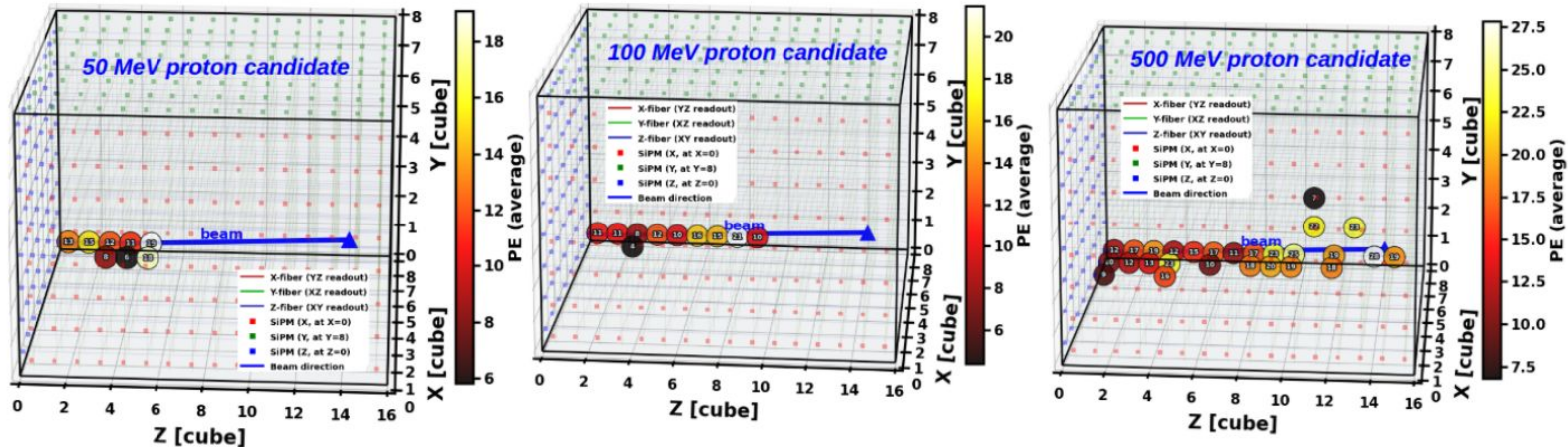
Magnet (0.5 T)

Target

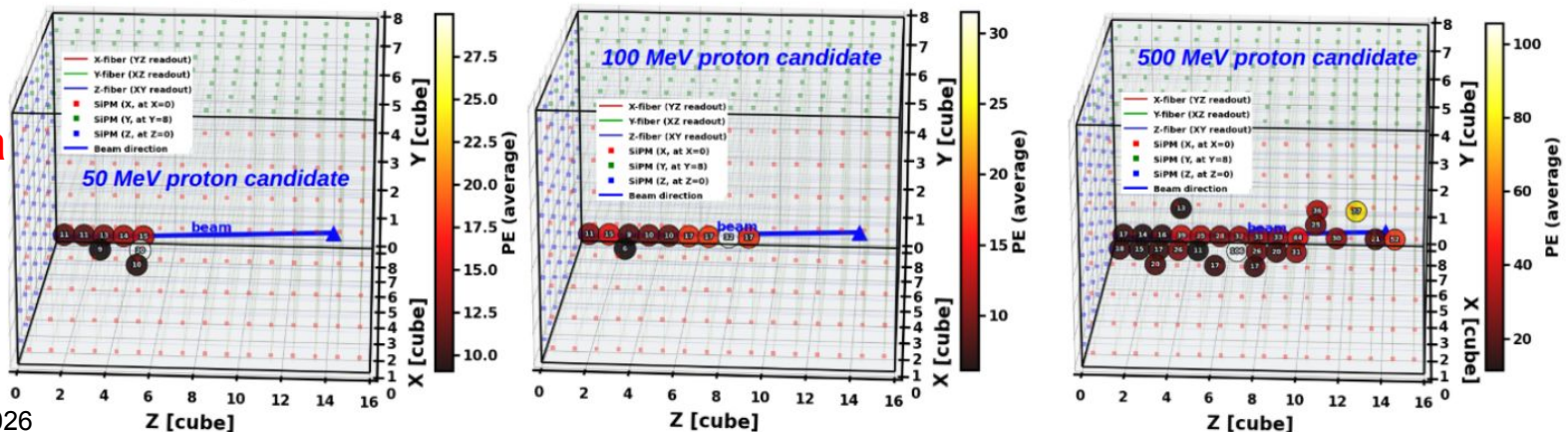


50-500 MeV protons imaged in 3D

P1
Data

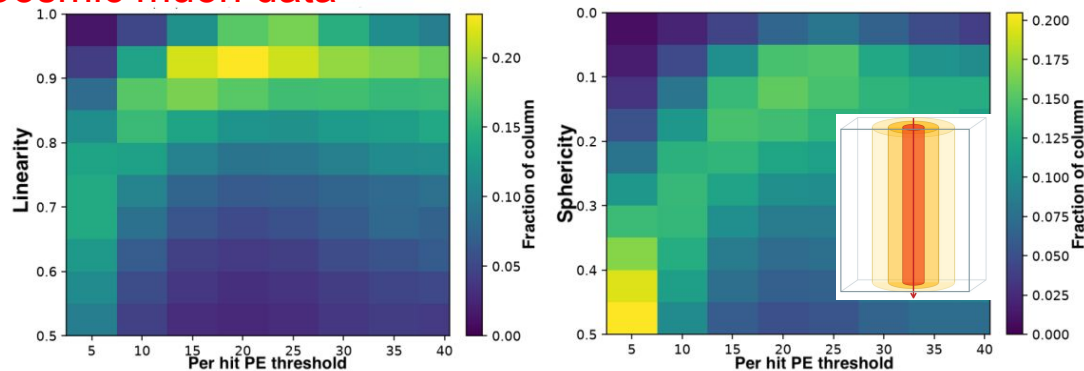


P1
Data

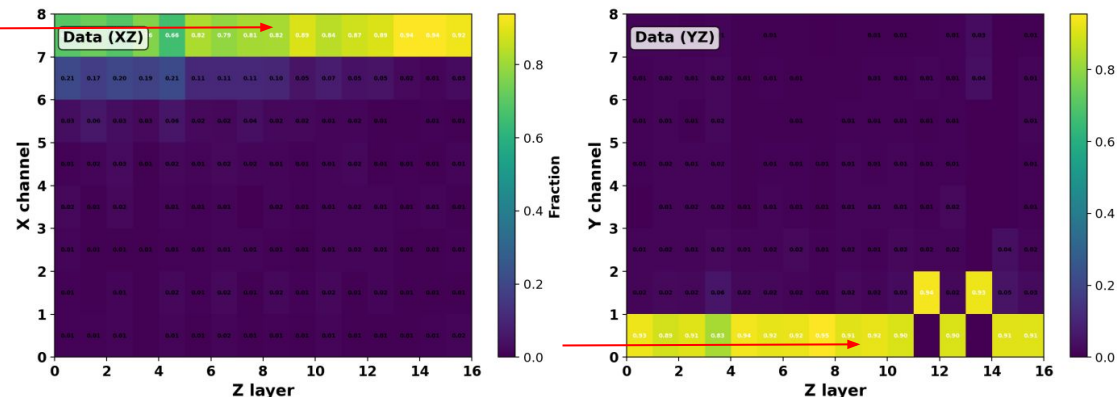


Light confinement > 90% in single voxel

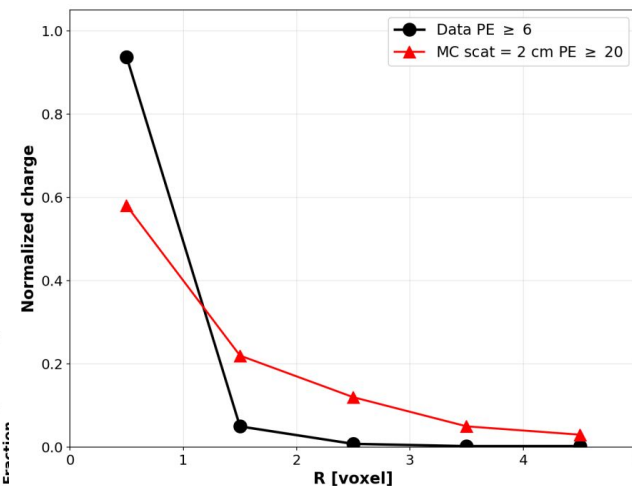
Cosmic muon data



Proton data

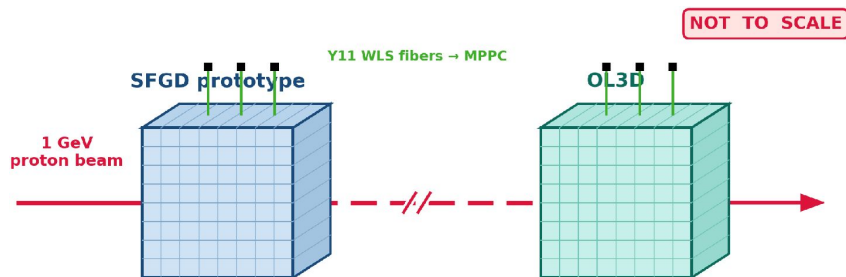
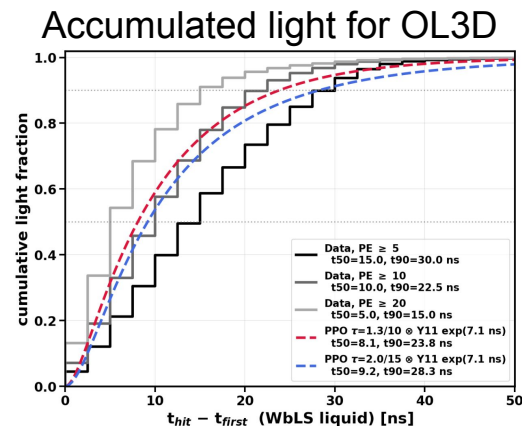


Proton data vs MC

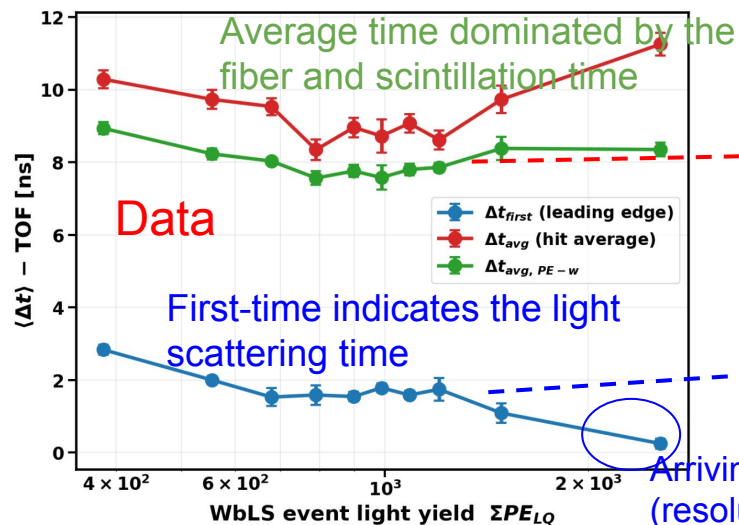
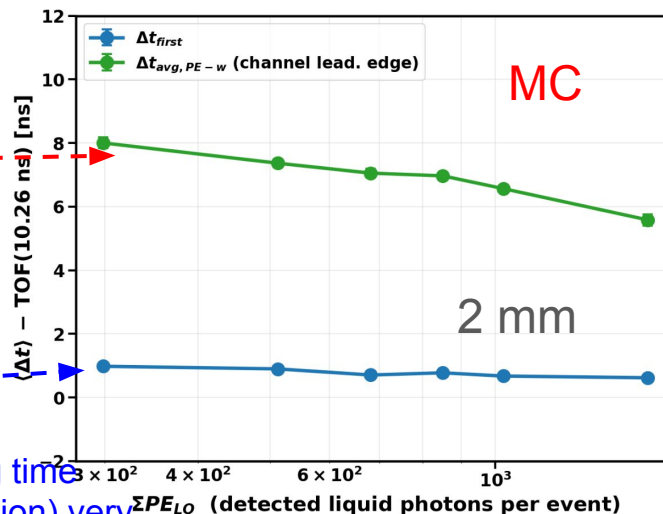
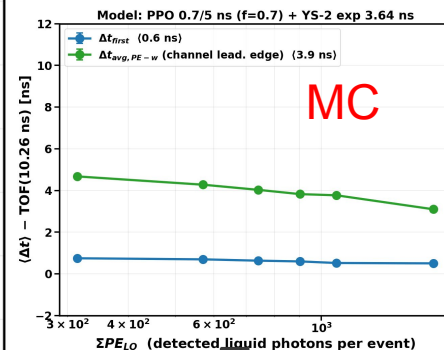


We engineered for mm, we measured mm.

Response time



**Faster fiber
and
scintillator
are available!**



Arriving time
(resolution) very
precise

Summary

We put the pixels in the liquid: granularity from chemistry, not machining

Demonstrated (2025-2026)

- OL3D chemistry at BNL; optically stable > 1 year
- 3D fiber readout works in liquid + 50-1000 MeV protons in 3D
- Light confined: < 2 cm;
> 90% within 1 cm
- Timing limited by fiber; can have faster scintillator and fiber
- > 20 wt% Pb loading synthesized
- 2 papers + JINST readout benchmarks

Next 12 months

- Jan 5 2027: NSRL multi-module beam run
- 2 liquid modules + CsI with 0.5 T
- ***First metal-loading module in beam***
- Aim for a good energy estimator
- Try for pion decay for absolute calibration

Longer term

- Meter-scale detector demonstration
- X0 tuning demonstration
- Pumpable liquid test
- Maintainable and refillable test
- Calorimetry for neutrino, Kaon and Pion experiments, Colliders and other areas

Some useful references

Neutron detection with 3D-projection

PHYSICAL REVIEW D **107**, 032012 (2023)

Neutron detection and application with a novel 3D-projection scintillator tracker in the future long-baseline neutrino oscillation experiments

S. Gwon,¹ P. Granger,² G. Yang^{3,4,*}, S. Bolognesi,² T. Cai,³ M. Danilov,⁶ A. Delbart,⁷ S. De Roeck,⁷ S. Dolan,⁷ G. Eurin,² R. F. Razakamiandra,⁸ S. Fedotov,⁹ G. Fiorentini Aguirre,¹⁰ R. Flight,¹¹ R. Gran,¹¹ C. Ha,¹ C. K. Jung,¹² K. Y. Jung,¹ S. Ketell,¹³ M. Khabibullin,² A. Khojantsev,² M. Kordosky,¹⁴ Y. Kudenko,^{9,15,16} T. Kutter,¹⁷ J. Maneira,¹⁸ S. Manly,⁵ D. A. Martinez Caicedo,¹⁰ C. Mauger,¹⁹ K. McFarland,² C. McGrew,¹² A. Mefodiev,⁹ O. Mineev,⁹ D. Naples,²⁰ A. Olivier,² V. Paolone,²⁰ S. Prasad,¹⁷ C. Riccio,¹² J. Rodriguez Rondon,¹⁰ D. Sgalaberna,²¹ A. Sitiraka,¹⁰ K. Siyeon,¹ N. Skrobova,⁶ H. Su,²⁰ S. Suvorov,² A. Teklu,¹² M. Tzanov,¹⁷ E. Valencia,¹⁴ K. Wood,¹² E. Worcester,¹³ and N. Yershov⁹

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Benefit of 3D-projection

Jinst

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Performance benchmarks for 2-View and 3-View fiber-projection fine-grained particle detectors

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^bBrookhaven National Laboratory,
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arXiv: 2607.14290

Comprehensive study of timing resolution in plastic scintillator detectors with wavelength-shifting fiber and silicon photomultiplier readout

H. Che^{a,1} and G. Yang^{b,2}

^aWashington University in St. Louis, St. Louis, MO 63130, USA

^bBrookhaven National Laboratory, Upton, NY 11973, USA

OL3D prototype performance

Light accumulation and particle identification of an opaque water-based liquid scintillator detector

To be published

H. Che^{a,b}, G. Roche^c, G. Yang^{a,*}, M.V. Diwan^a, S. Gokhale^a, P. Kumar^{a,d}, C. Reyes^a, R. Rosero^a, R. Shaikh^d, J.J. Wang^d, M. Yeh^a

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^cUniversity of Illinois at Urbana-Champaign, Champaign, IL 61820, USA

^dUniversity of Alabama, Tuscaloosa, AL 35487, USA

arXiv: 2605.10683

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Zoom-out the picture

Opaque
-> tracking calorimeter

Liquid scintillator

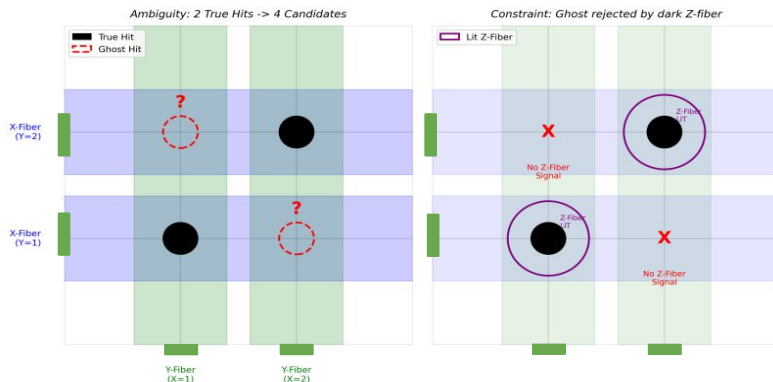
Transparent
-> Large-scale multi-purpose labs

Praveen Kumar Next!



Backups

3D-projection scintillator detector



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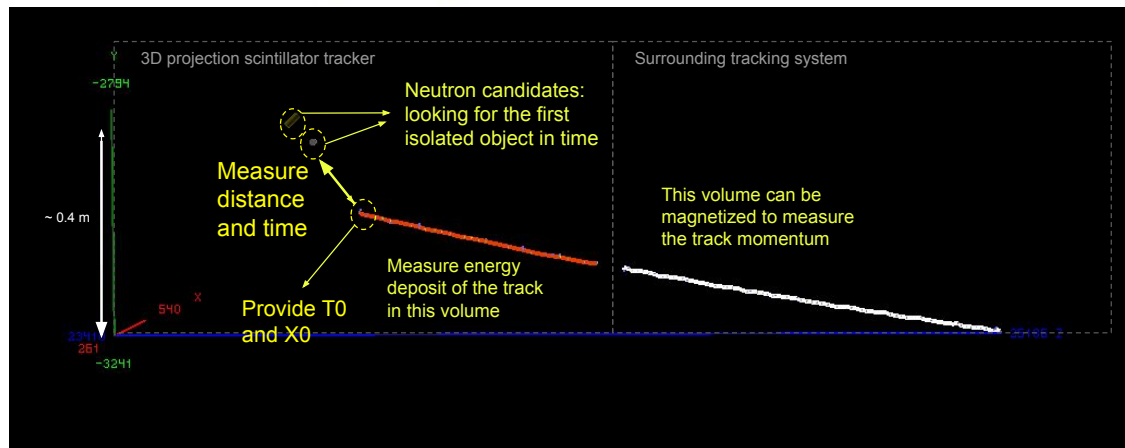
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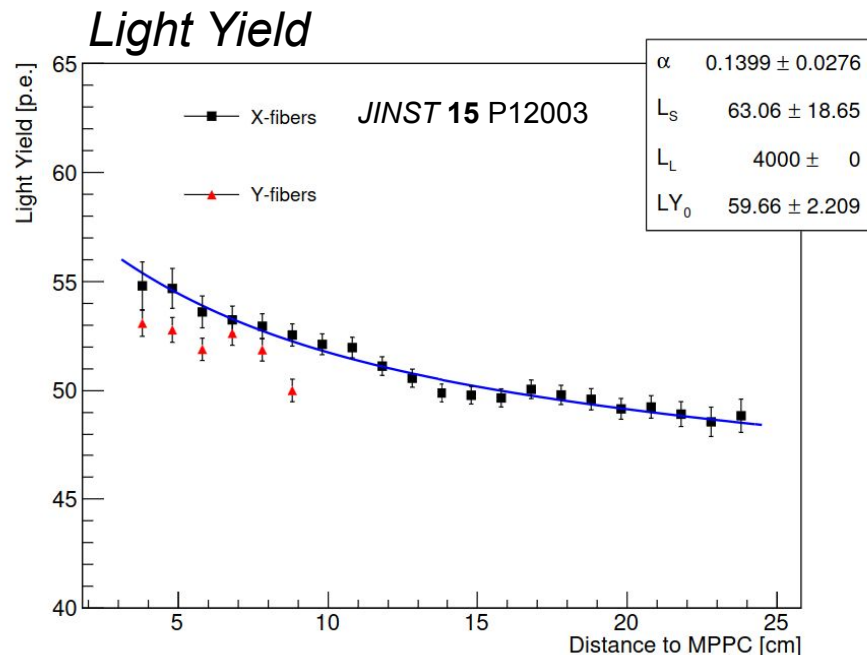
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Other results

To be published

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Construction, commissioning, and beam test of a pilot 3D-projection opaque water-based liquid scintillator detector

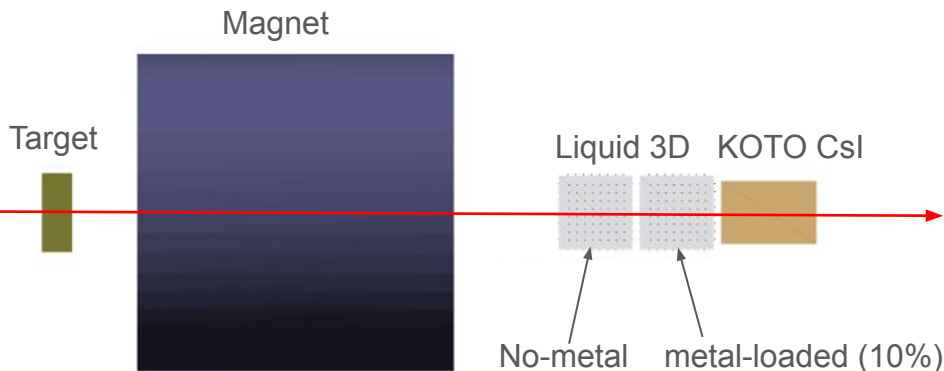
H. Che^{a,b}, M.V. Diwan^a, S. Gokhale^a, P. Kumar^{a,c}, C. Reyes^a, R. Rosero^a, J.J. Wang^c, G. Yang^{a,*}, M. Yeh^a

^aBrookhaven National Laboratory, Upton, NY 11973, USA

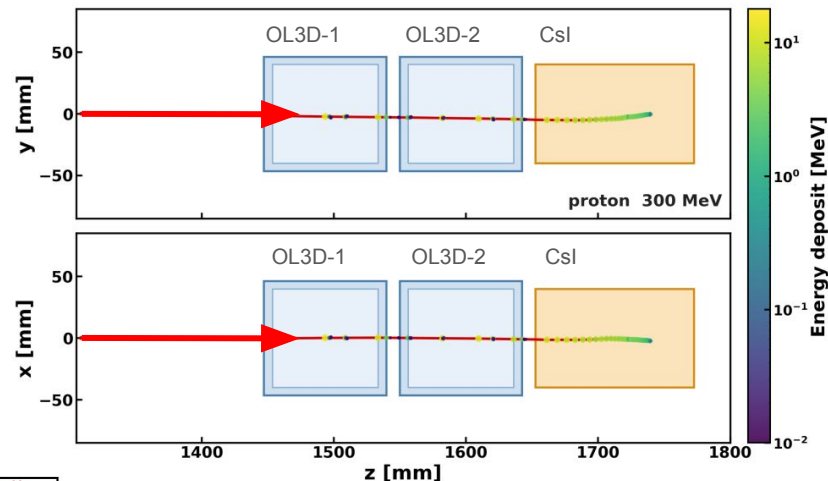
^bWashington University in St. Louis, St. Louis, MO 63130, USA

^cUniversity of Alabama, Tuscaloosa, AL 35487, USA

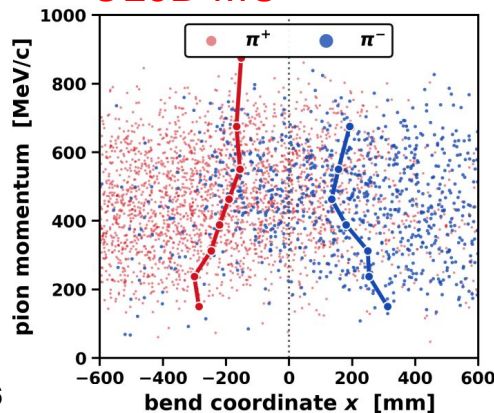
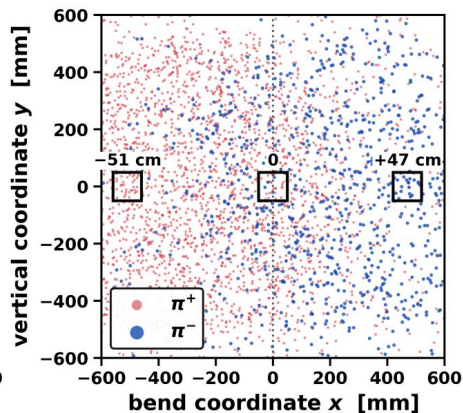
Next run in January 2027



OL3D MC



OL3D MC



Two clear goals

Measure the full proton energy for the first energy estimate

Try to capture some pion decays (absolute calibration)

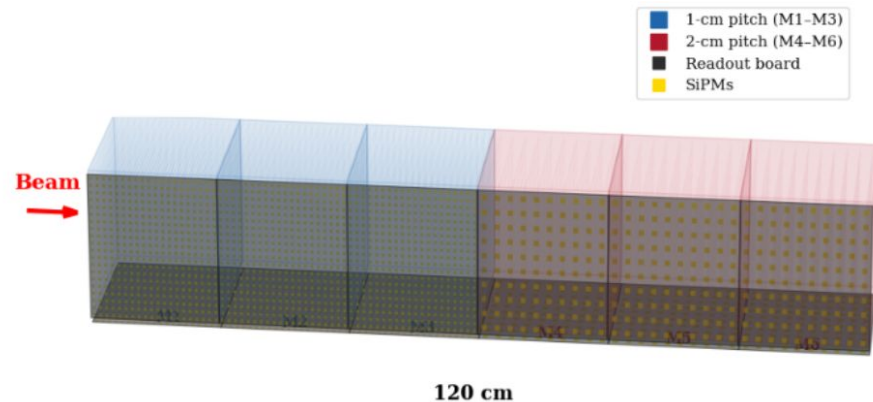
Longer-term plan

Resolved the mechanical design issues with small-scale prototype including leaking, optical coupling and liquid filling.

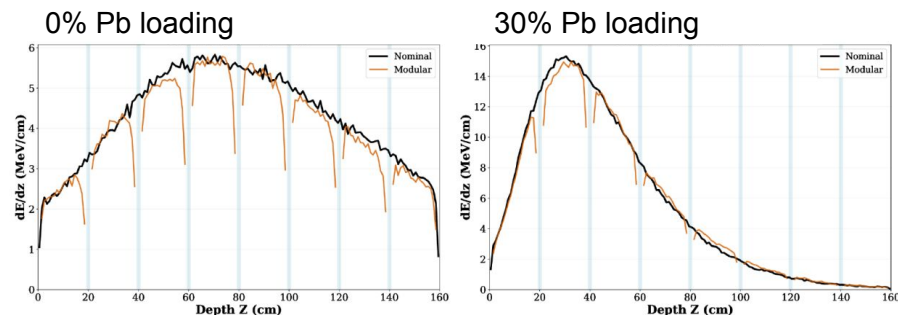
Now suffer from the small volume, particularly the fiducial.

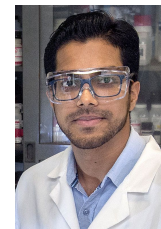
In order to measure more fundamental detector performance such as radiation length measurement, good PID, angular and energy resolution measurements etc., a significantly larger detector is needed.

For longer planning, we can do several moderate modules and combine them to perform more significant physics measurements.



OL3D MC 1 GeV electron





Heavy metal loading

Preliminary success in developing liquid scintillator synthesis techniques for loading high concentrations (>10 wt.%) of heavy metallic elements

- Organometallic complex synthesized by a ligand exchange process

Efforts are ongoing to characterize the material properties, scintillation response, chemical stability etc.

