Developing the Optical Model for WbLS Using the Eos Detector

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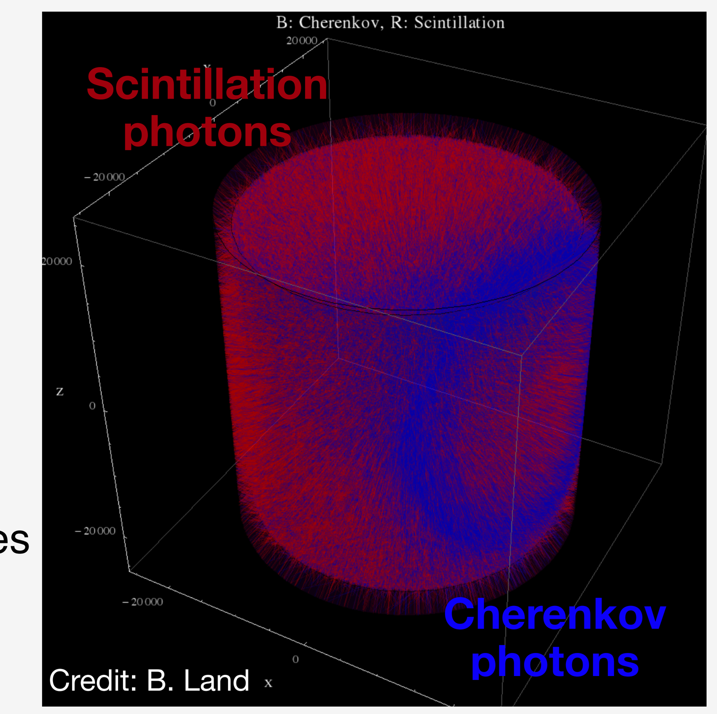
Motivation

Hybrid optical detectors are an emerging next-generation technology that separates Cherenkov and scintillation light, leveraging the strengths of both:

High light yield	Event-by-event directionality
Low energy threshold	Massive scalability
Pulse-shape PID	Topological PID



Physics opportunities [1]:

- Precision long-baseline oscillation measurements
- Low-energy solar neutrinos
- Supernova neutrinos
- Neutrinoless double-beta decay and other BSM searches

Applications [2]:

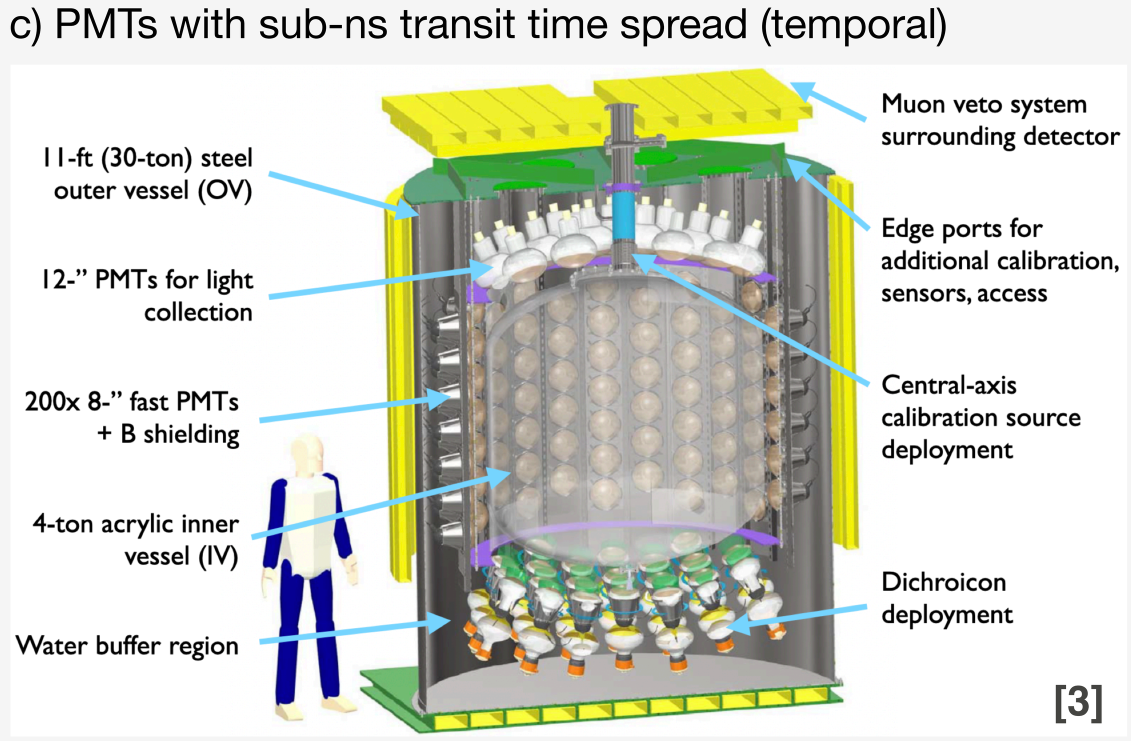
- Remote monitoring (such as test site transparency, maritime sensing)

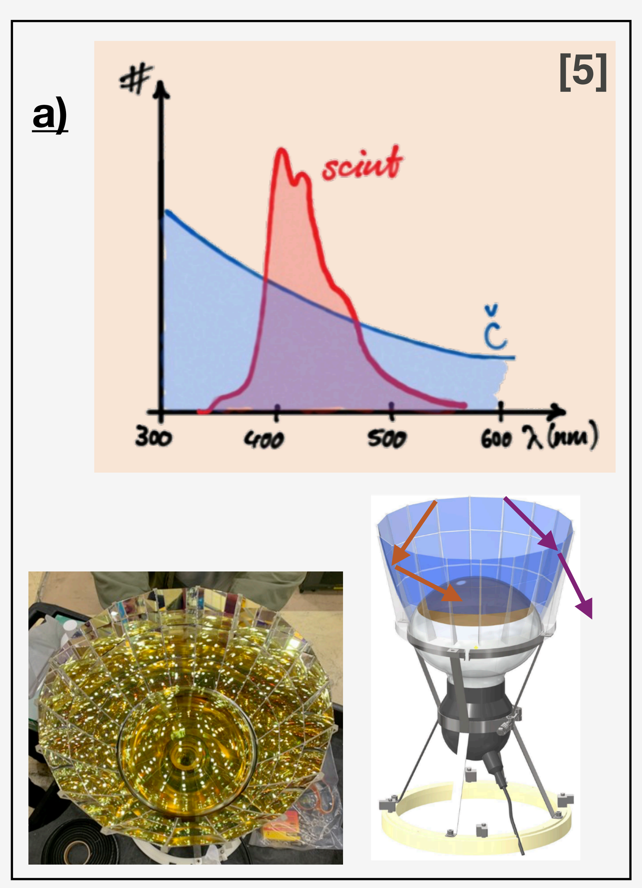
The Eos Detector

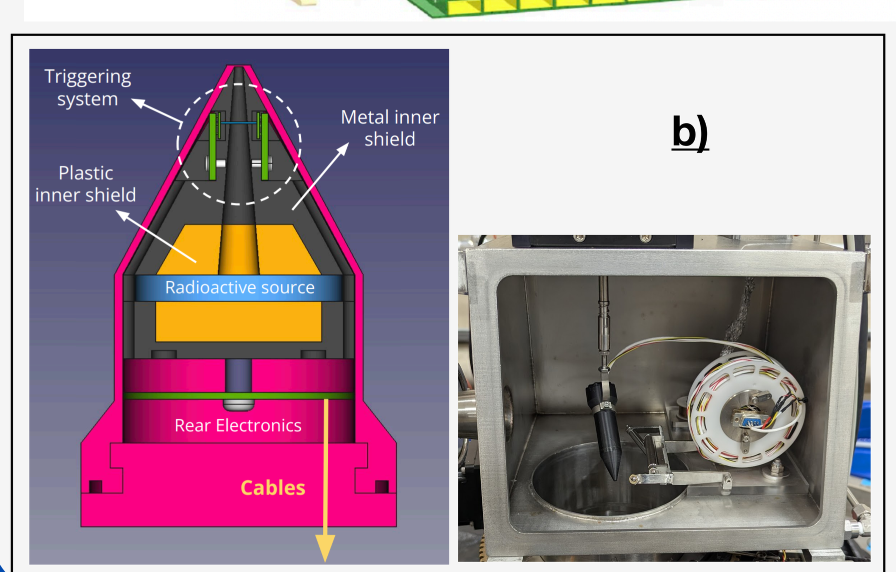
Located at UC Berkeley, Eos [3] is a 4-tonne fiducial-mass testbed for hybrid detector technologies. Eos will be used to explore the full phase space of performance, from low-% water-based liquid scintillators (WbLS) to pure liquid scintillators, including both slow and ultra-fast options, as part of its data-taking program.

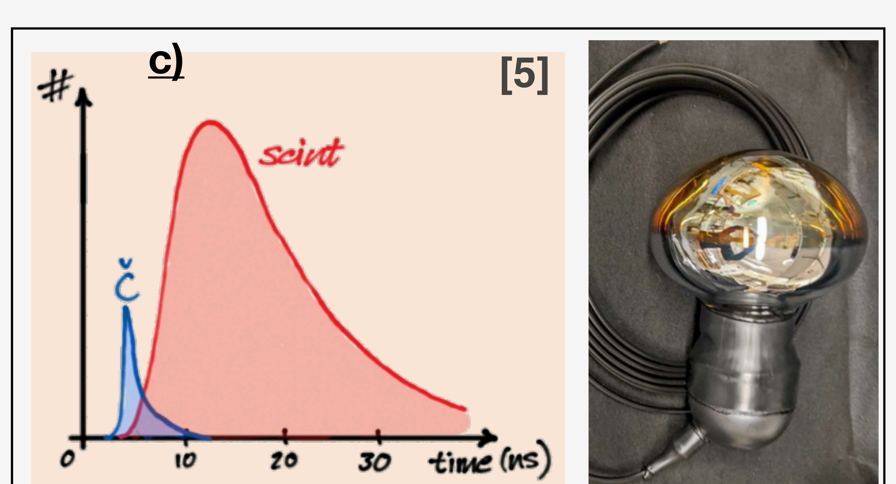
Cherenkov and scintillation light separation is achieved via novel capabilities:

a) Dichroicons [4] (spectral)
b) Directional sources (angular)
c) PMTs with sub-ns transit time spread (temporal)









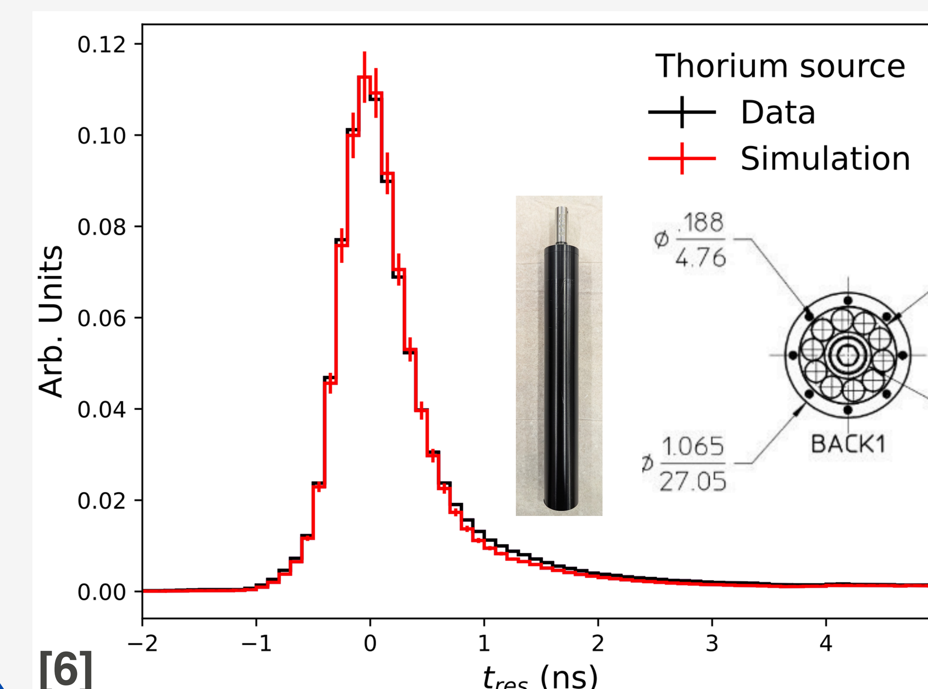
Acknowledgements

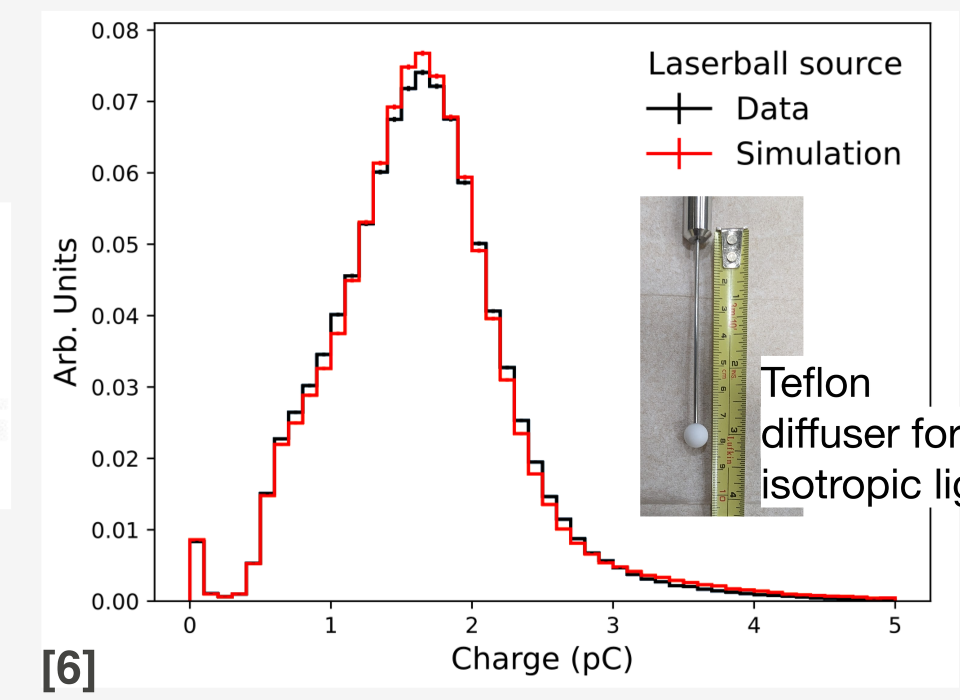
Supported by the U.S. Department of Energy under Contract DE-AC02-05CH11231. Funded by the National Nuclear Security Administration, Office of Defense Nuclear Nonproliferation Research and Development (DNN R&D).

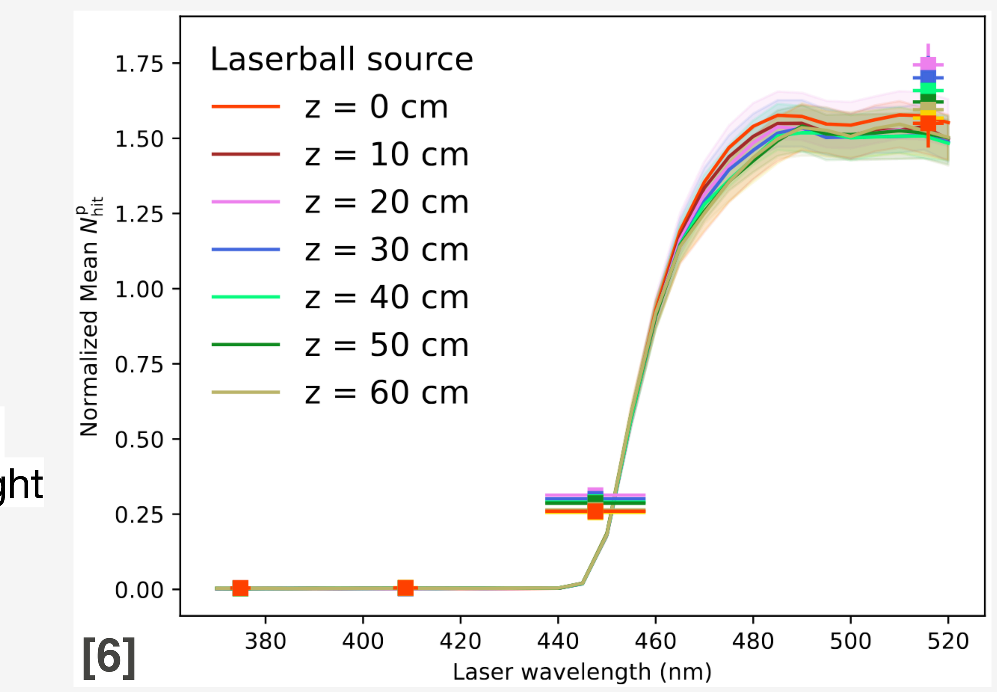
Water-Phase Calibration & Reconstruction

The water phase [6] served as a baseline characterization of Eos using a well-understood optical medium. Data were collected using radioactive and optical sources. Key outcomes:

- Utilizing laserball data, measurement of PMT response (timing delays from per-PMT time-residual fits, charge from bench-top measurements rescaled to data, pulse shape from per-pulse Gaussian fits) and trigger efficiency (fraction of events with global trigger-sum peak above 100 mV, evaluated as a function of Nhit)
- Tuning of dichroicon optical model with laserball data, scanning wavelength across deployment heights
- Development of position and direction reconstruction algorithms (two likelihood fitters, one ML), tuned and validated using thorium (vertex) and directional (angle) source data







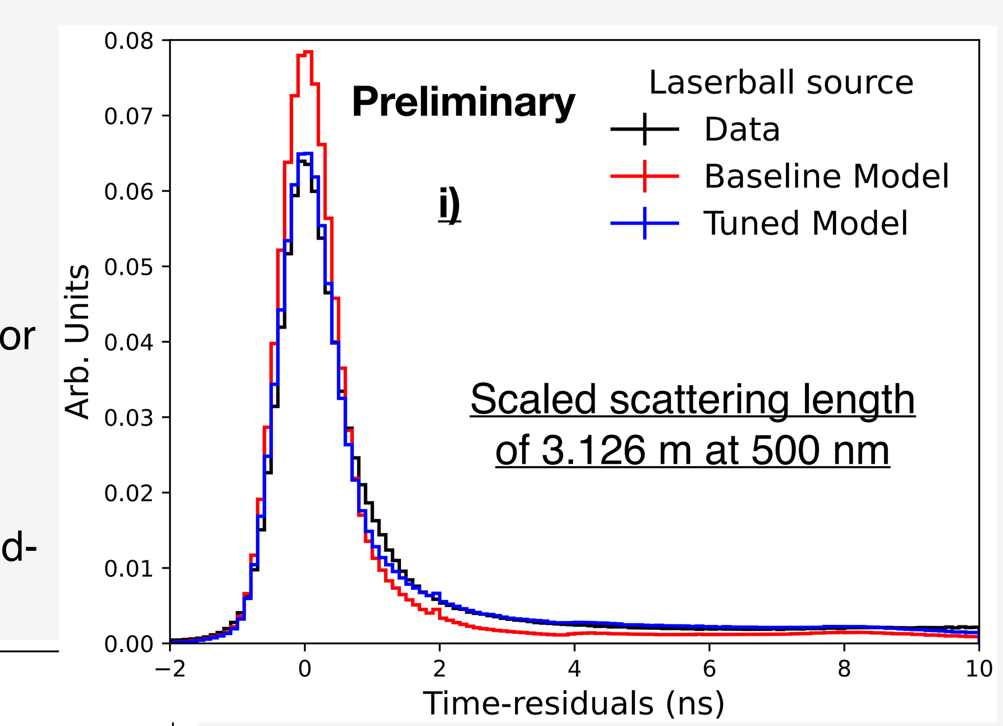
First Results from the WbLS Phase

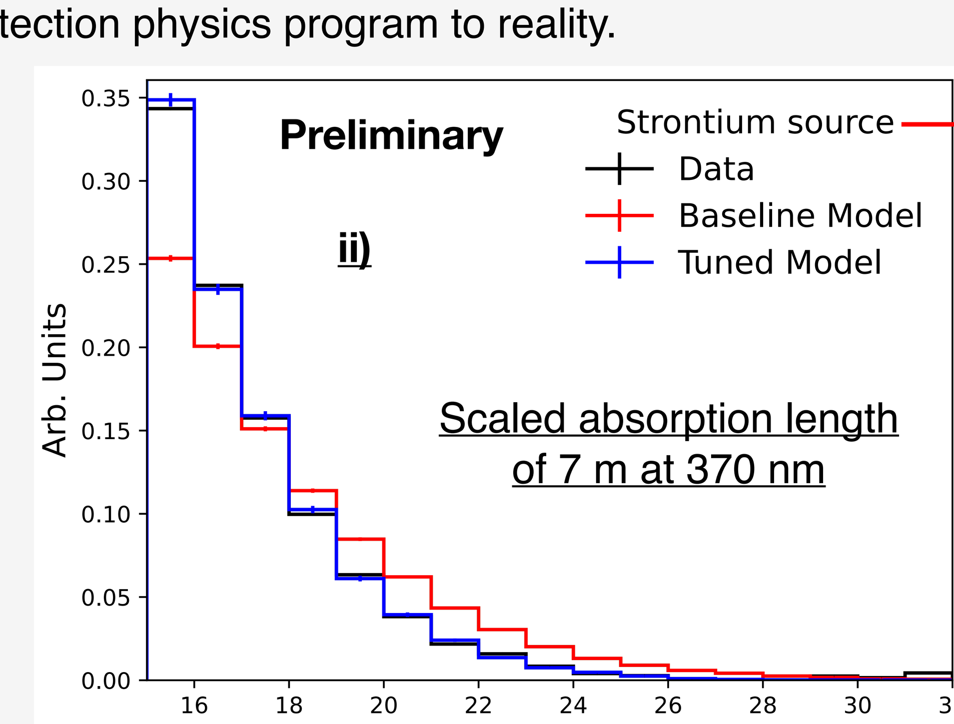
Folding in the detector response, we extract the WbLS optical parameters in the following sequence:

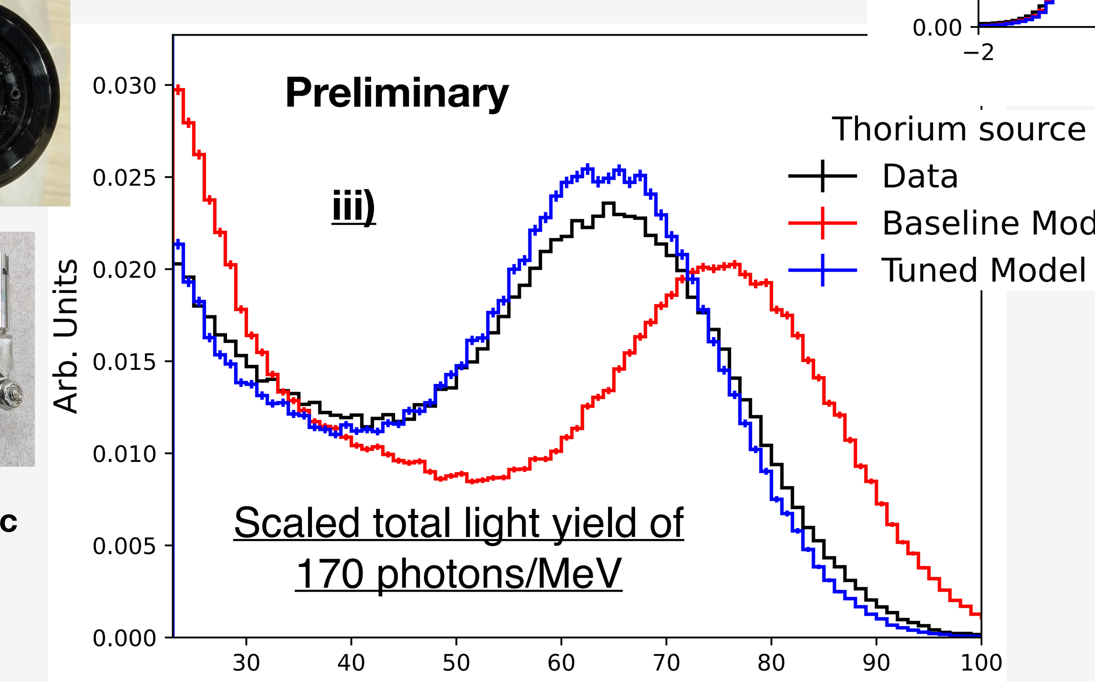
i) Scattering length — picosecond laser-driven laserball with 515 nm light. Detected time profile sensitive primarily to WbLS scattering length.
ii) Absorption length — "Cherenkov source": ^{90}Sr in UV-transparent acrylic, known emission spectrum. With scattering fixed, remaining attenuation is attributed to absorption.
iii) Total light yield — thorium source (primarily 2.6 MeV γ from ^{208}Tl). Detected photons per MeV, corrected for measured scattering and absorption.

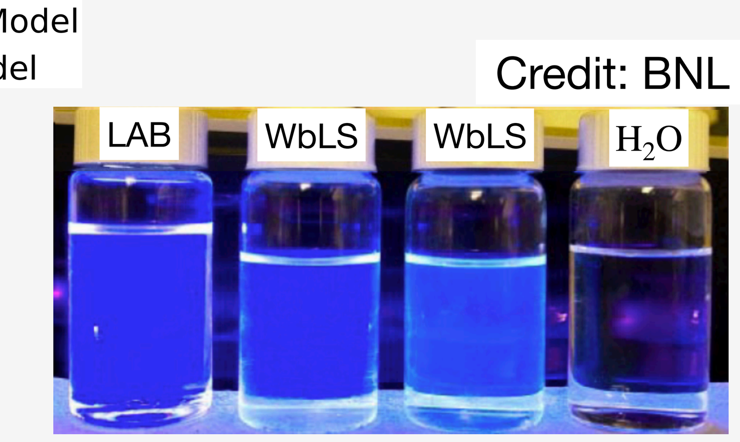
A benchtop-based model [7] serves as the baseline, tuned in situ to match the data.

This work lays the foundation for next-generation hybrid LS detectors such as Theia [1], bringing the full hybrid-detection physics program to reality.









References

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