Gamma-ray Detection using an Opaque Water-based Liquid Scintillator

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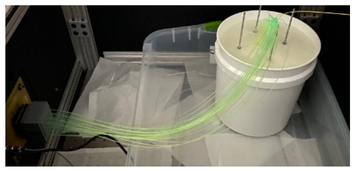
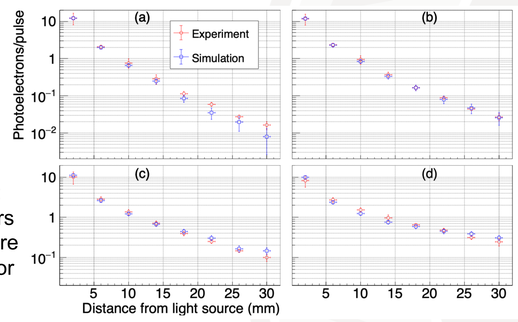
Introduction and Motivation

- Opaque scintillators achieve virtual voxelization by way of stochastic light confinement. The scintillation light must be extracted from the detector volume using wavelength-shifting fibers.
  A. Cabrera (LiquidO Consortium), Commun. Phys. 4, 273 (2021)
- The use of opaque scintillators for gamma-ray spectroscopy and event topological reconstruction has not yet been demonstrated. We present simulation studies as well as a plan to experimentally validate them.

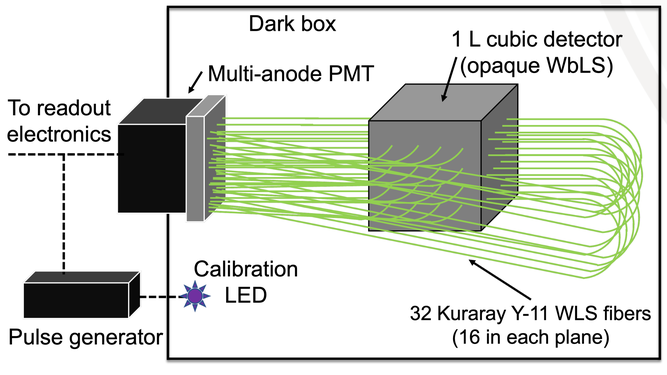
Technical Approach



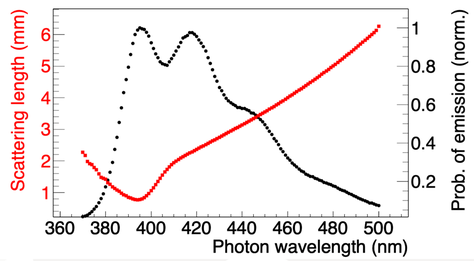
Prior work: A measurement of the light collection into wavelength-shifting fibers from an opaque liquid. The results were used to validate a Geant4 simulation for five different dilutions of cow milk.



Wilhelm et al., "Evaluation of light collection from highly scattering media using wavelength-shifting fibers" Nucl. Instr. Meths. A 1049, 168085 (2023).



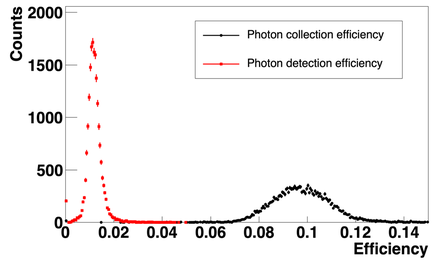
Results

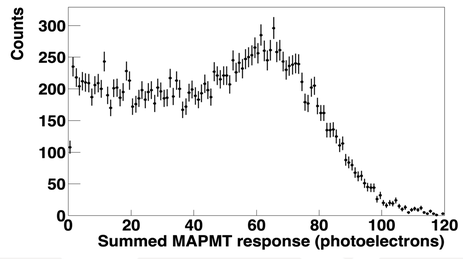


Emission spectrum and scattering length as a function of wavelength of an opaque formulation of water-based liquid scintillator (WbLS). The absorption length is estimated to be 2 m, and the light yield approximately 12,000 photons/MeV,.

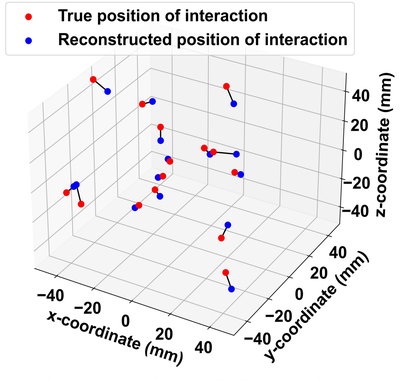
M. Yeh et al., Nucl. Instr. Meth. A 660, 51–56, (2011)

Collection efficiency vs. detection efficiency (including the losses due to the quantum efficiency of the MAPMT)

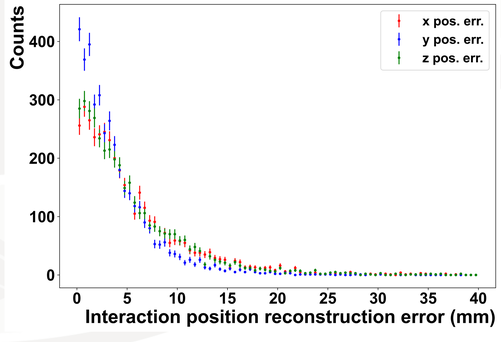




Simulated integrated response of the detector to 662-keV gamma rays. The Compton continuum and edge are clearly visible. The simulation accounts for all sources of signal degradation.



Reconstructed positions of 15 simulated single-scatter interactions from 662 keV gamma-rays. The median reconstruction error is 8.9 mm.



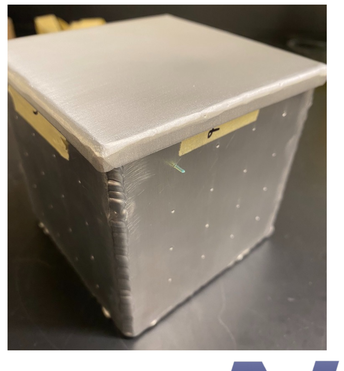
The distribution of reconstruction errors for interaction position by a neural network. The y-direction is the vertical with respect to detector orientation.

Relevance and Impact

- May enable shallow or aboveground deployment of large antineutrino detectors
- Potentially applicable to many nuclear security problems currently addressed by segmented detectors
- Partnerships:
  - WATCHMAN collaboration (Penn State, U. of Glasgow)
  - LiquidO Consortium (EU, UK, USA)
  - National laboratories (BNL, ORNL, LLNL)
  - DTRA NSERC and West Point Physics and Nuclear Engineering

Conclusion and Future Work

- Simulations indicate that accurate reconstruction of single-scatter events is possible
- Future work will seek to experimentally validate the simulation results and examine the possibility of double-scatter reconstruction



The prototype detector body is made of welded aluminum. Each plane of the detector will have 16 fibers in a 4x4 grid.

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