Event Topological Reconstruction using an Opaque Water-based Liquid Scintillator

2024 MTV Workshop

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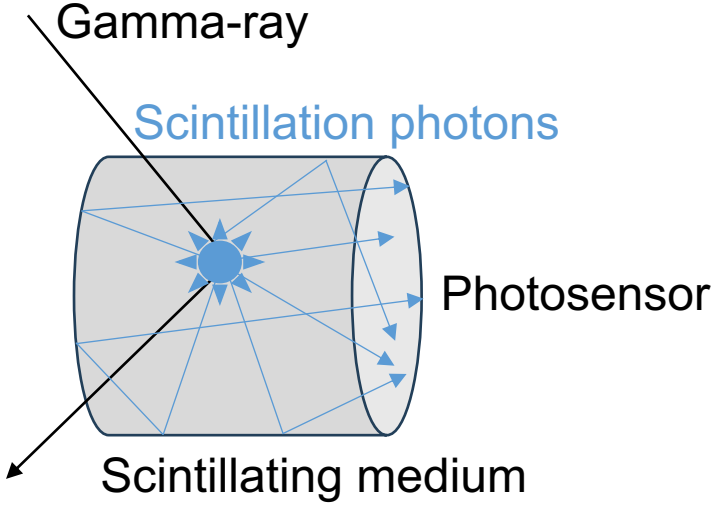
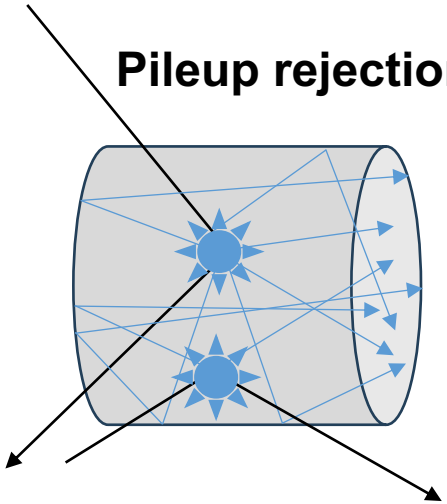
Andrew Wilhelm
PhD student, University of Michigan
Igor Jovanovic, University of Michigan

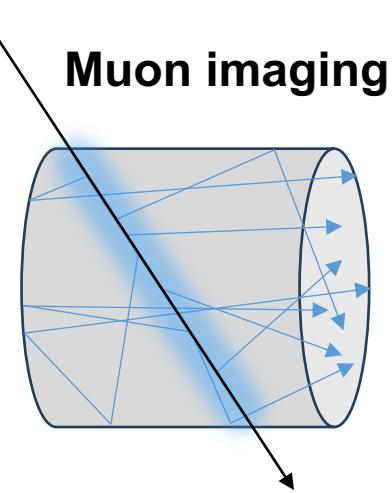
Reconstructing Event Topology in Scintillators



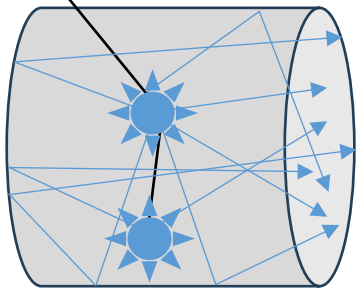
Pileup rejection



Muon imaging

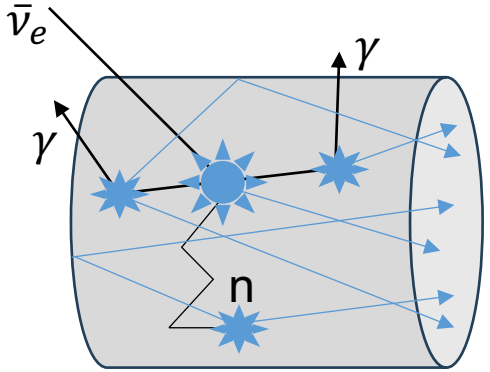


Gamma-ray imaging



Compton scatter +
photoelectric absorption

Particle-type identification

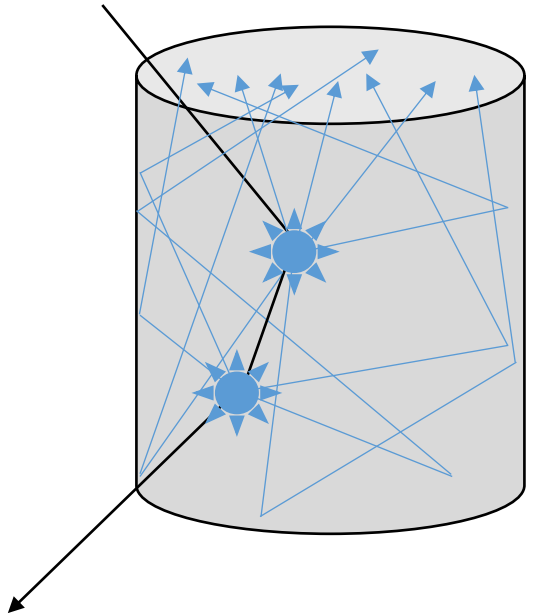


Antineutrino-induced
inverse beta decay

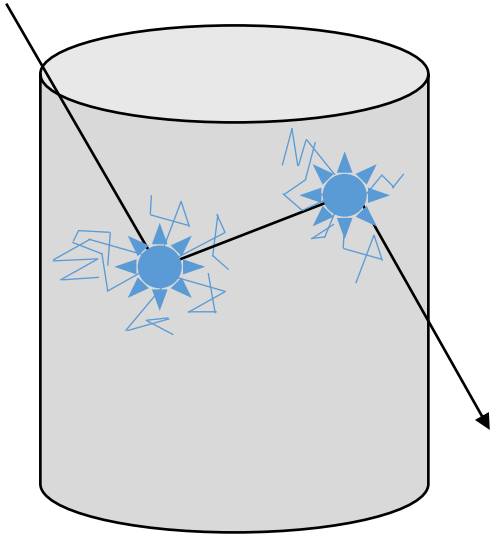
$\bar{\nu}_e + p \rightarrow e^+ + n$

Technical Approach

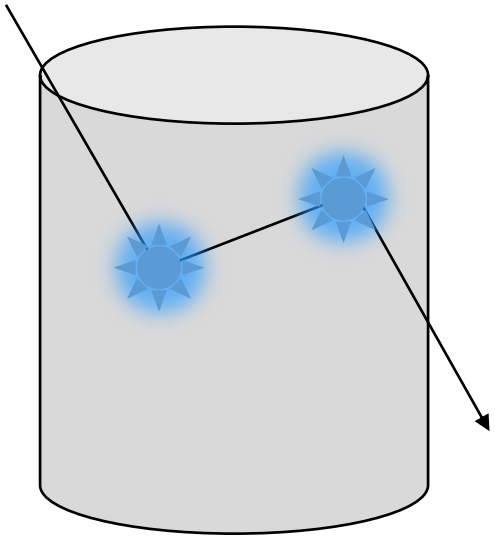
Transparent scintillator



Opaque scintillators

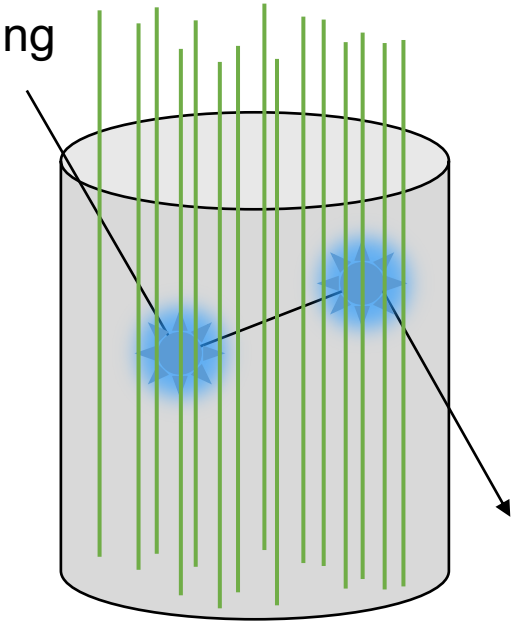


Highly scattering media

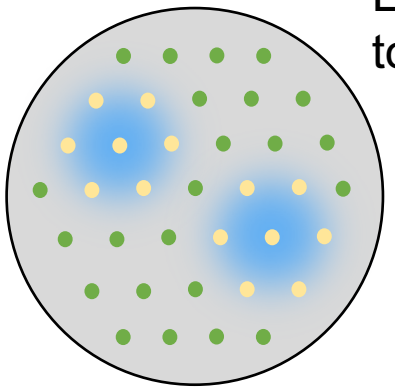


Virtual segmentation

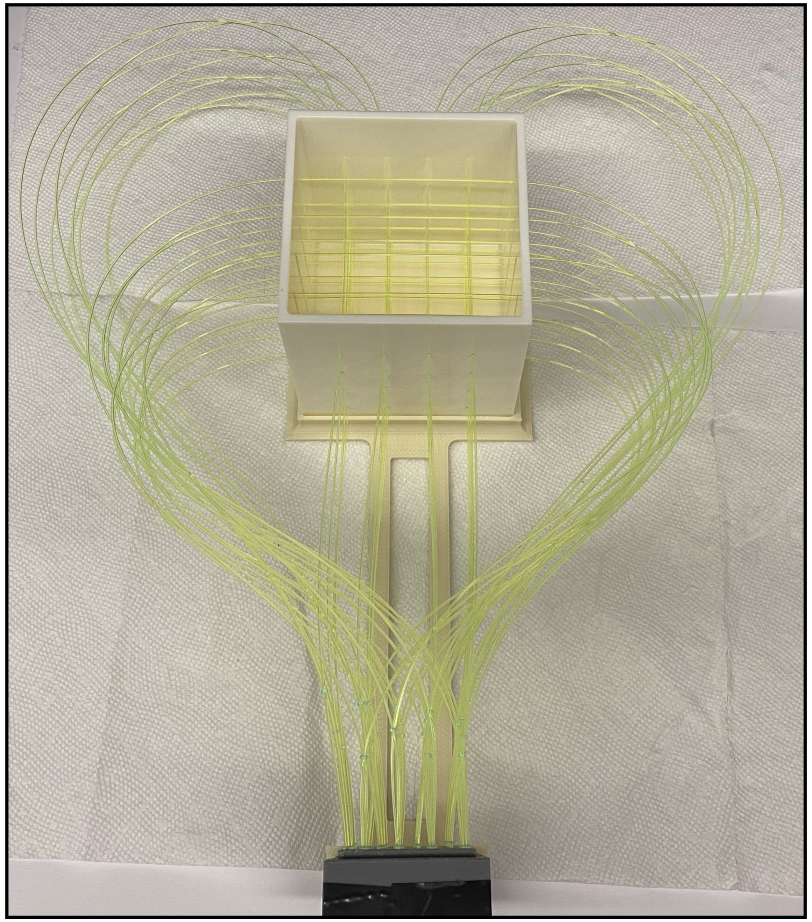
Wavelength-shifting fibers

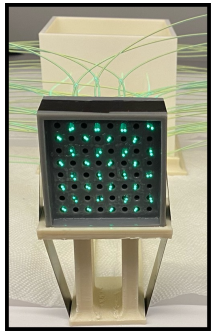


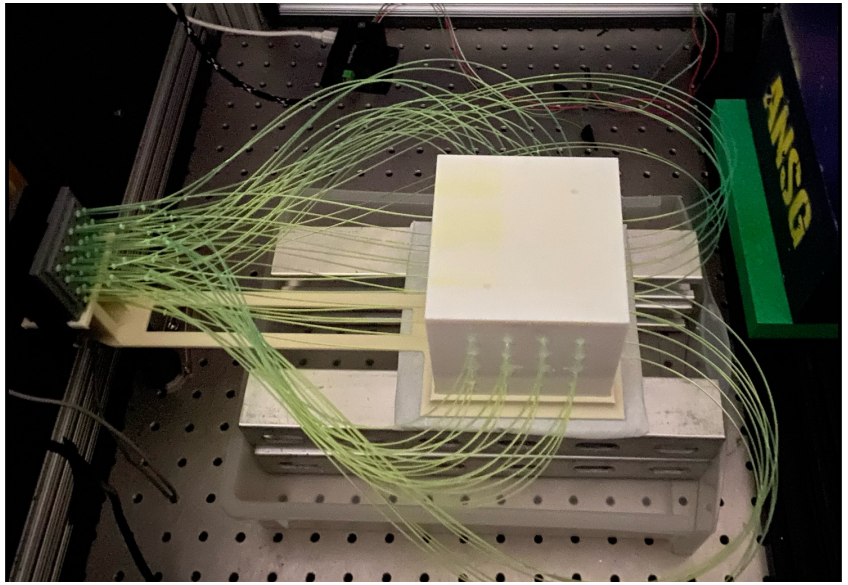
Event topology

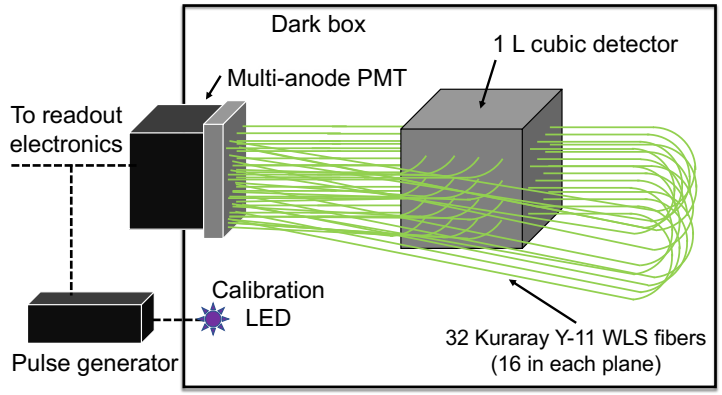


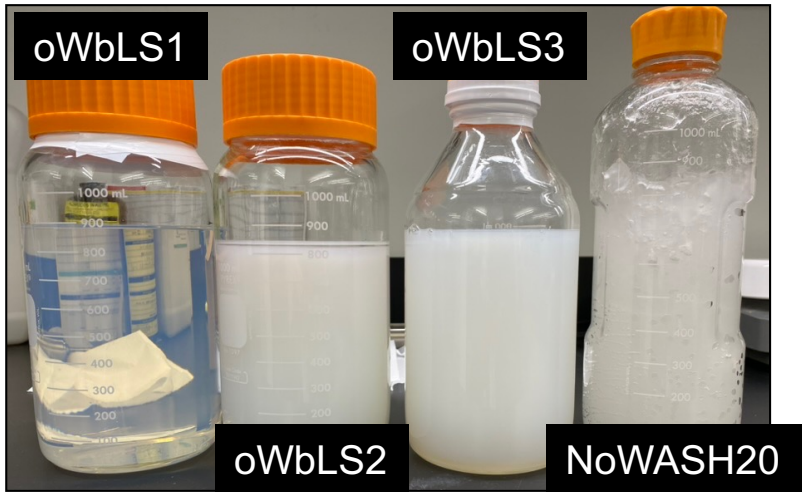
Apparatus











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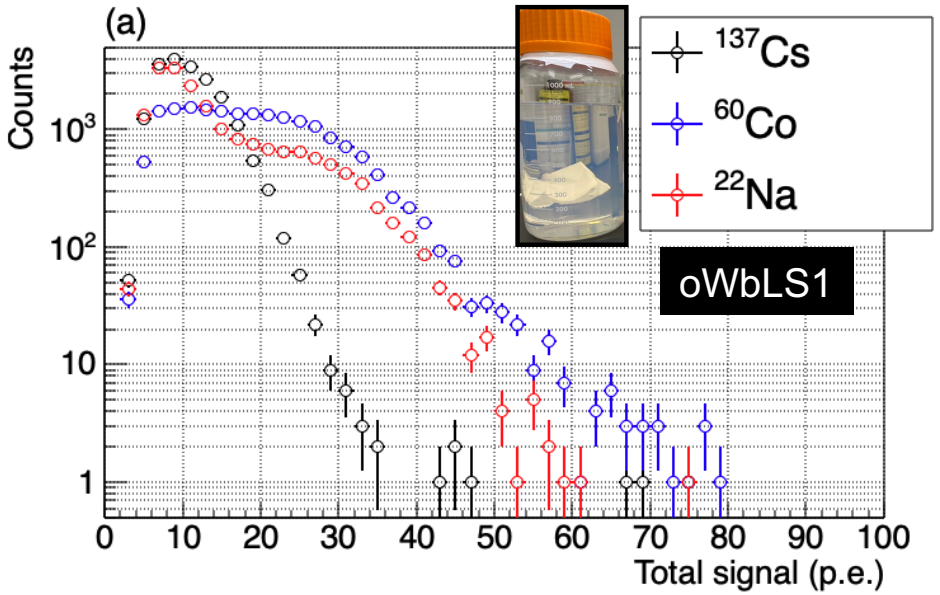
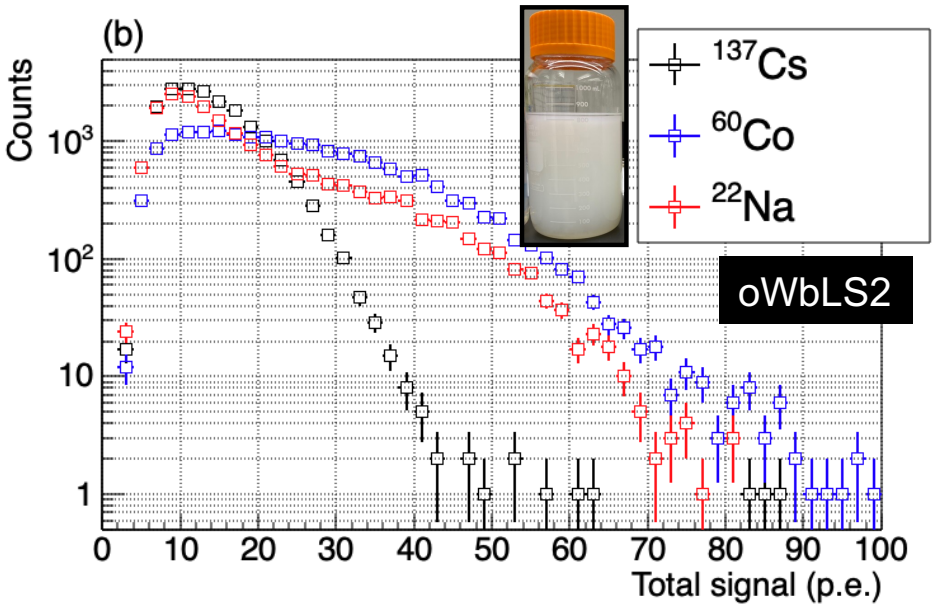
Results

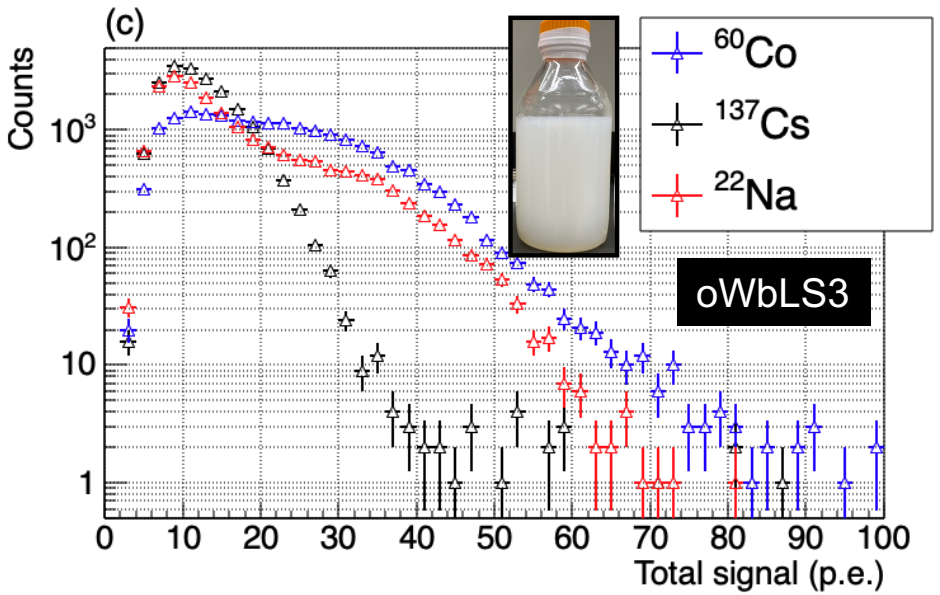
Response of scintillation liquids to gamma-rays from ^{137}Cs, ^{60}Co, and ^{22}Na

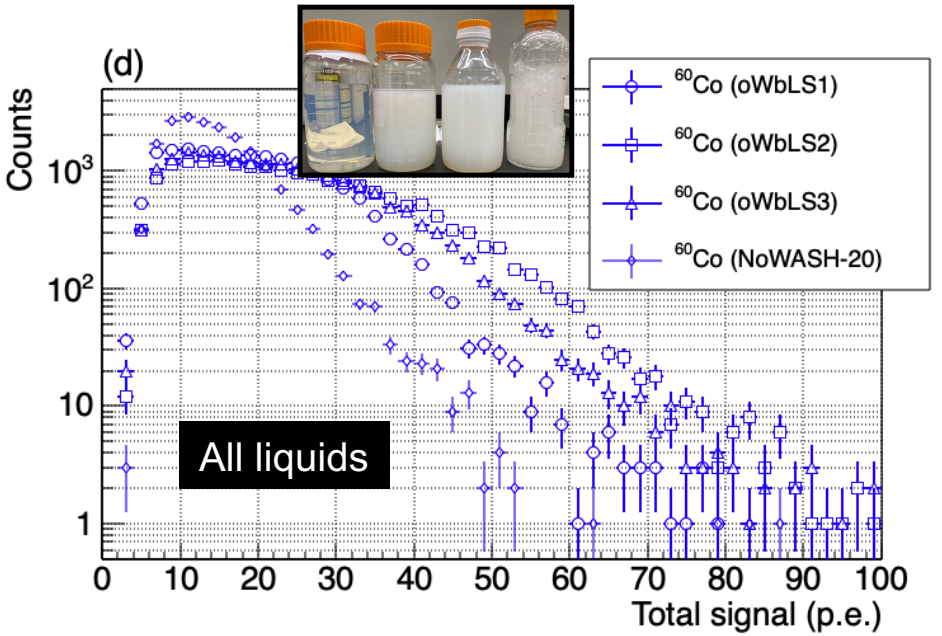
X-axis units are total photoelectrons across all channels

oWbLS2 produces the highest integrated signal





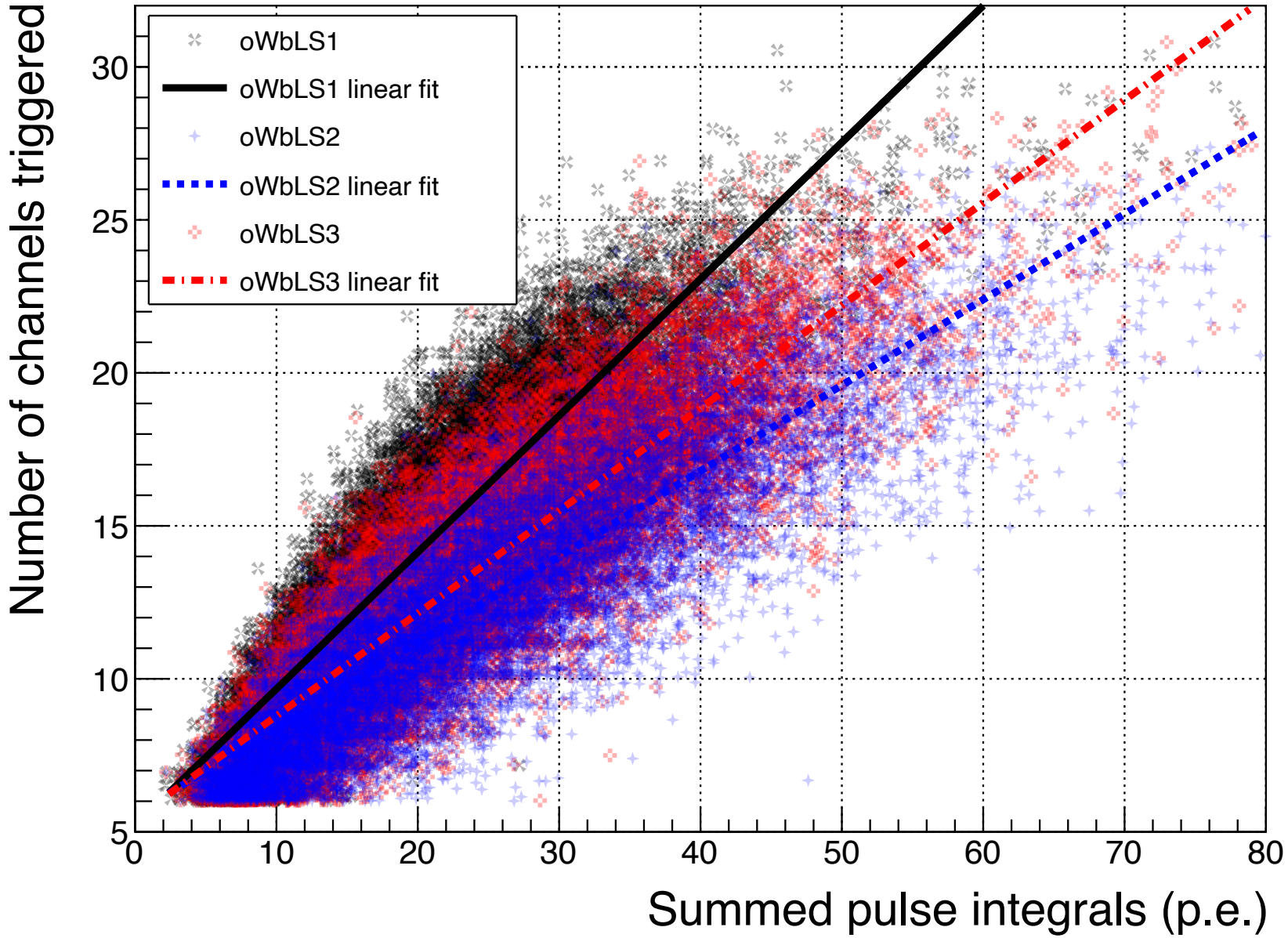




Results

Comparison of light-confinement by oWbLS1-3 for gamma-rays from ^{60}Co

oWbLS2 shows the most light-confinement

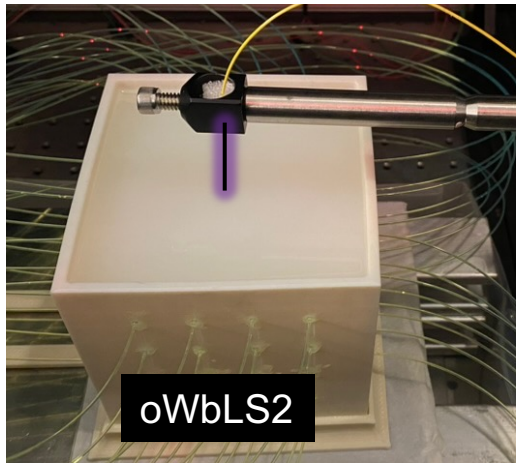


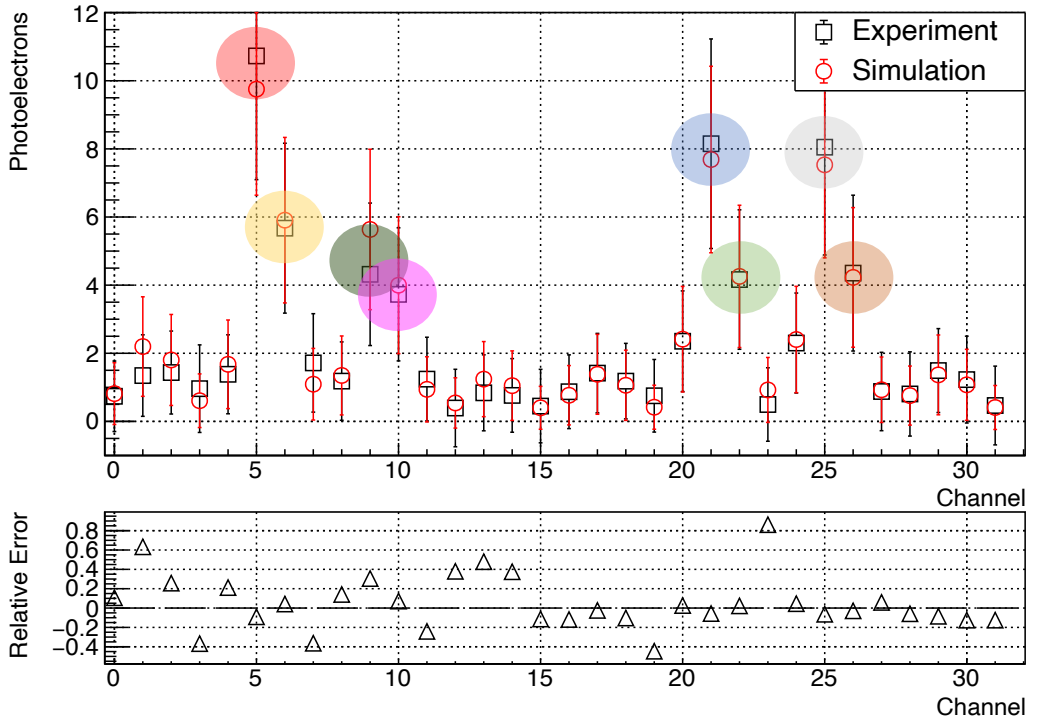
Results

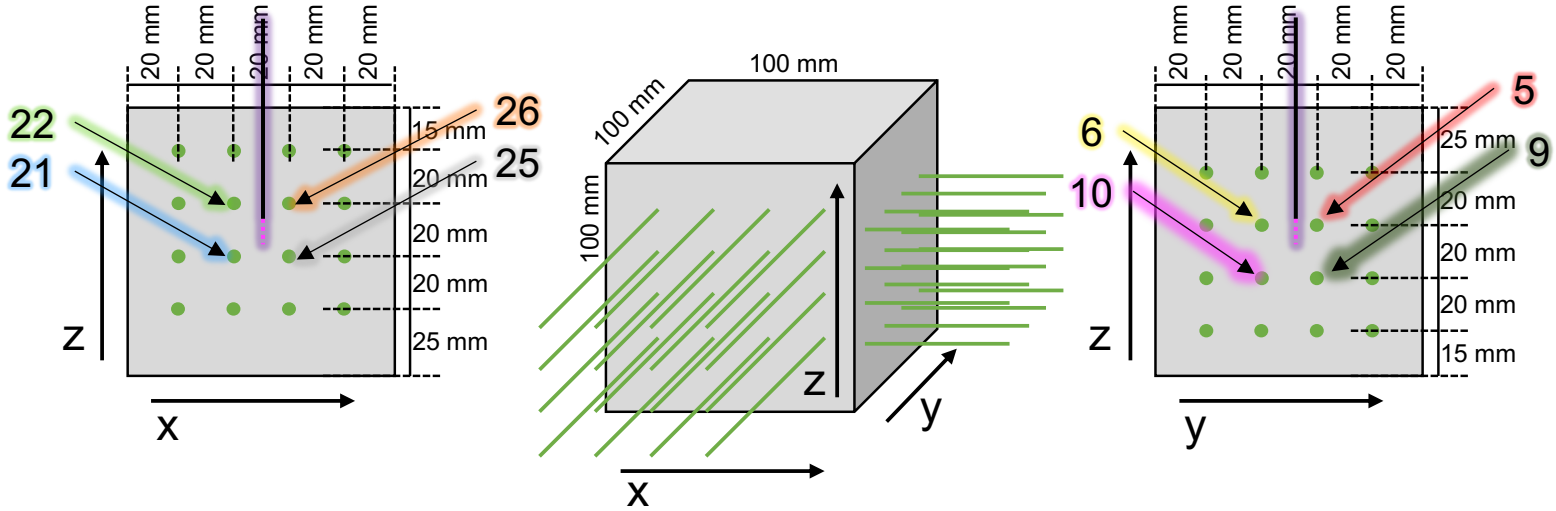
Fiber-coupled pulsed laser allows for injection of light at known location and intensity

Photoelectrons/pulse in each channel used to tune optical parameters of Geant4 simulation

- Reduced scattering length: 5.7 mm
- Absorption length: 169 mm
- X^2/NDF for all pulses: 0.6 ± 0.2





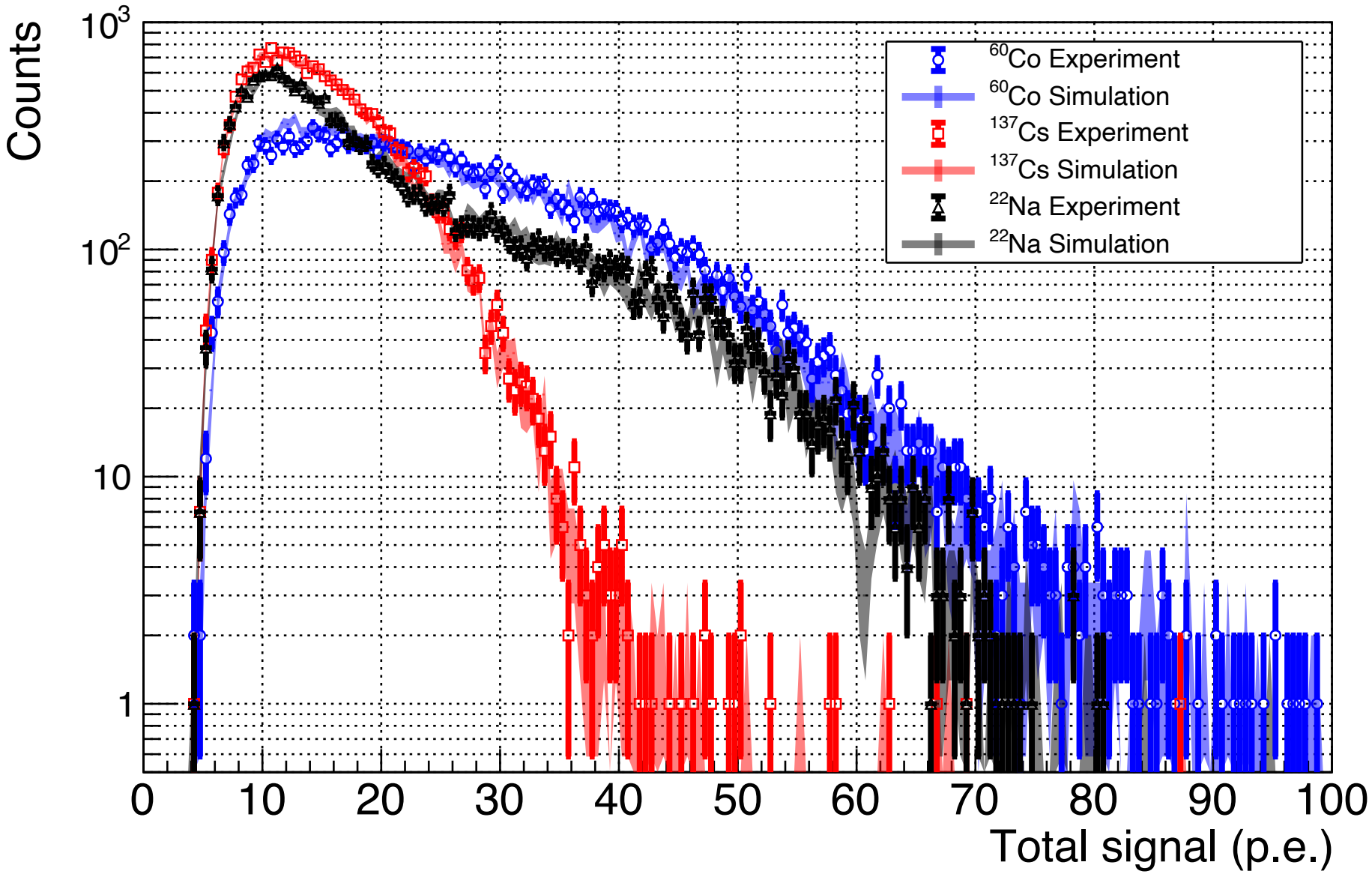


Results

Comparison of experimental and simulated oWbLS2 response to gamma-rays from ^{137}Cs, ^{60}Co, and ^{22}Na

X^2/NDF:

- ^{137}Cs: 1.45
- ^{60}Co: 1.13
- ^{22}Na: 1.23

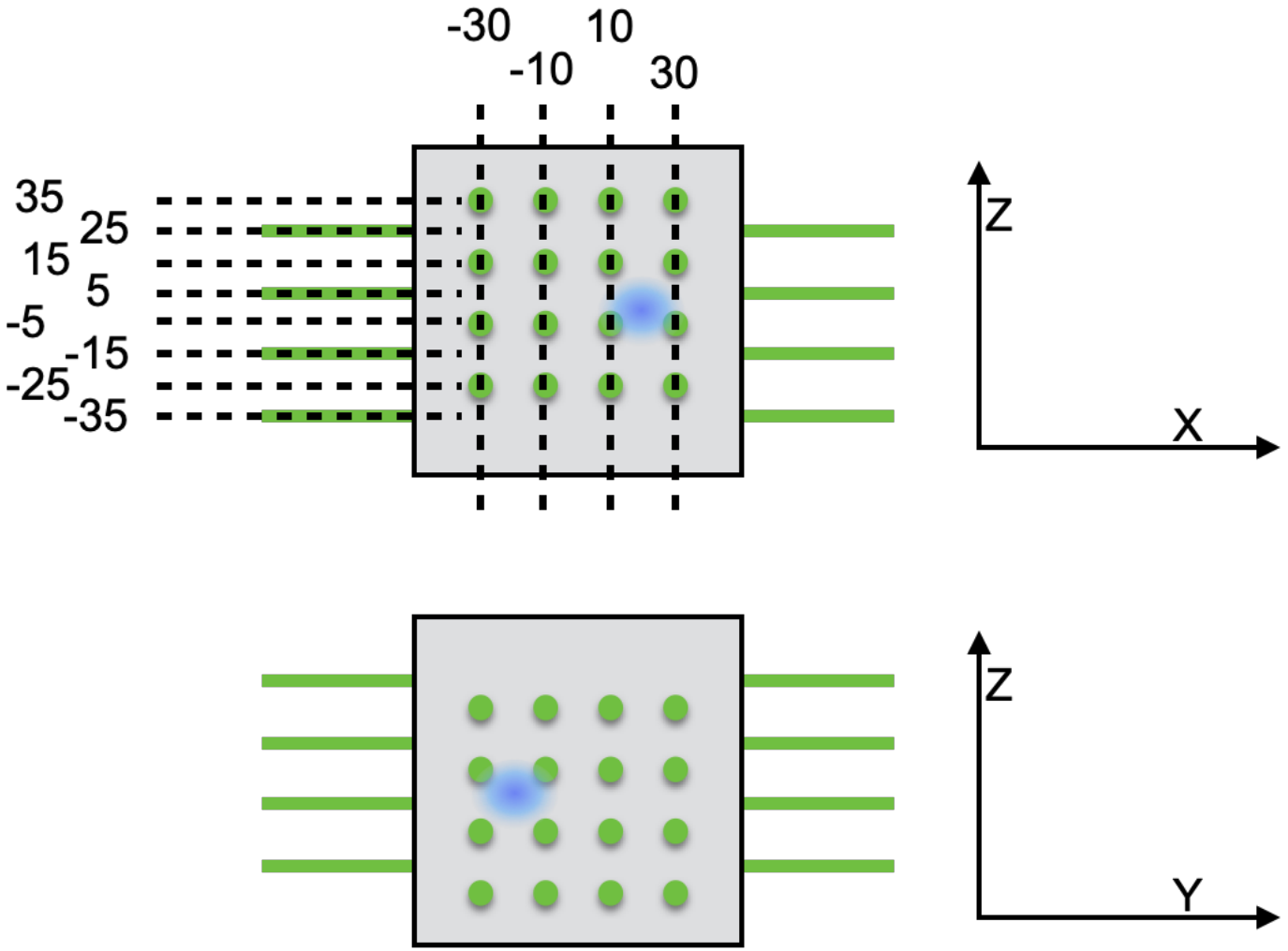


CoM Calculations

$$CoM_x = \frac{\sum_{i=0}^{16} s_i p_{i,x}}{\sum_{j=0}^{16} s_j}$$

$$CoM_y = \frac{\sum_{i=0}^{16} s_i p_{i,y}}{\sum_{j=0}^{16} s_j}$$

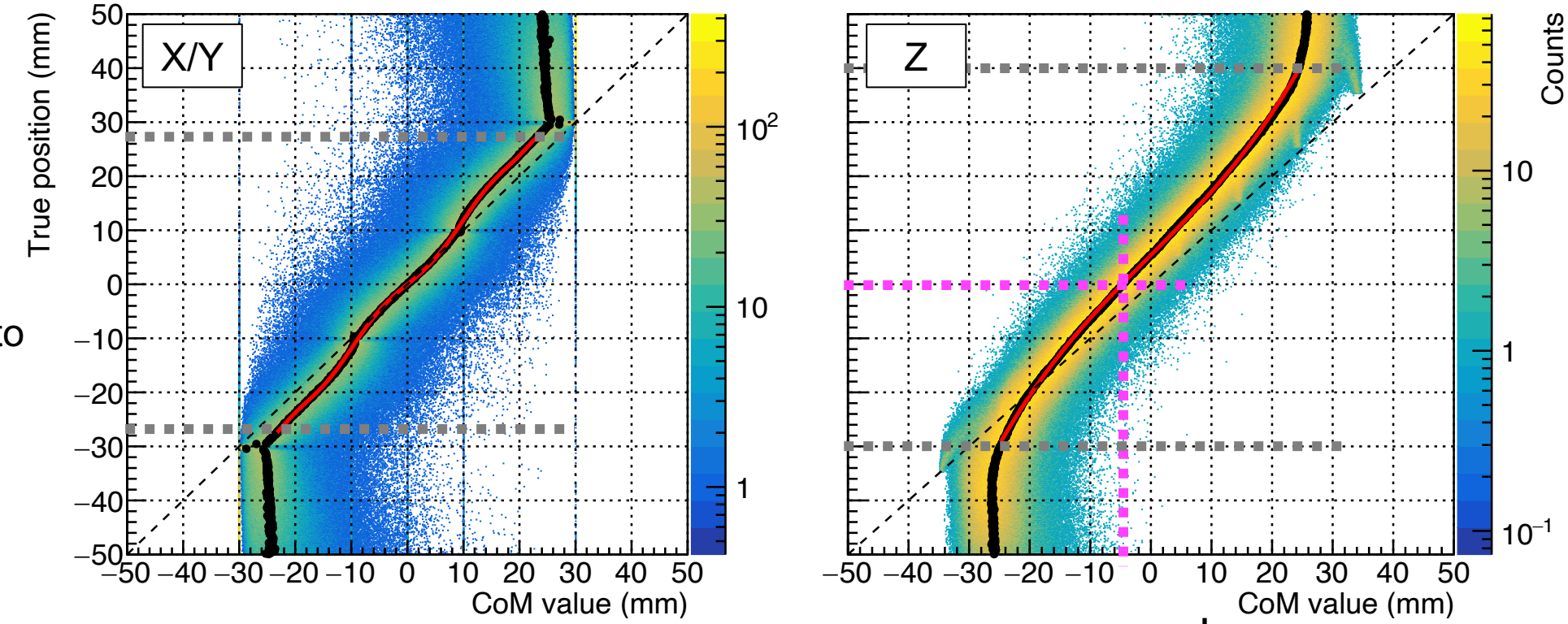
$$CoM_z = \frac{\sum_{i=0}^{32} s_i p_{i,z}}{\sum_{j=0}^{32} s_j}$$

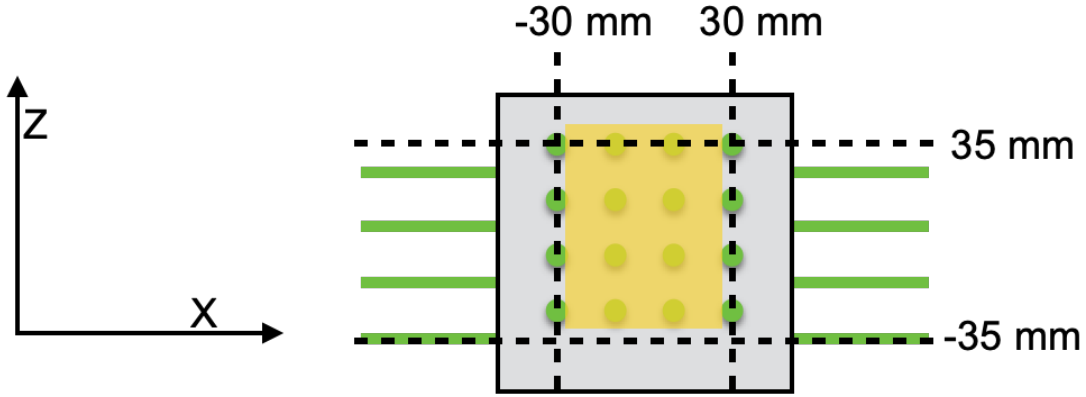


Results

Simulation used to determine correction for center-of-mass of event to true position

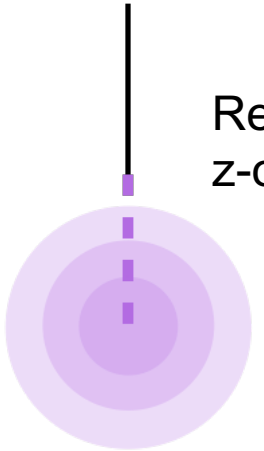
$$CCoM_z = f_z(CoM_z)$$





Fiducial region:
X: -27 to 27 mm
Y: -27 to 27 mm
Z: -30 to 40 mm

Reason for z-offset

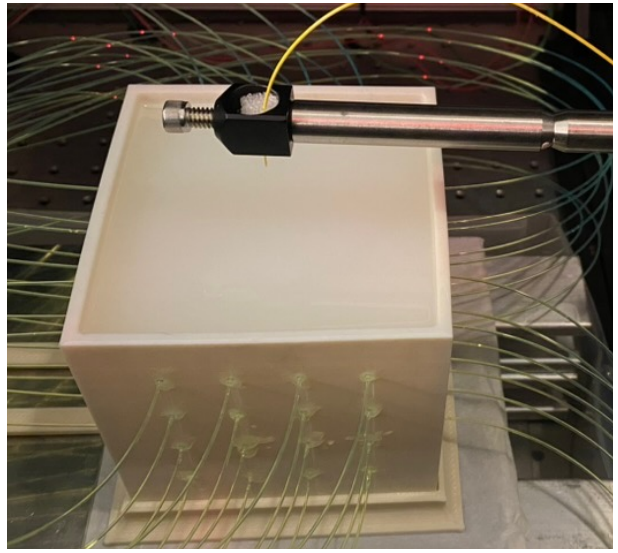


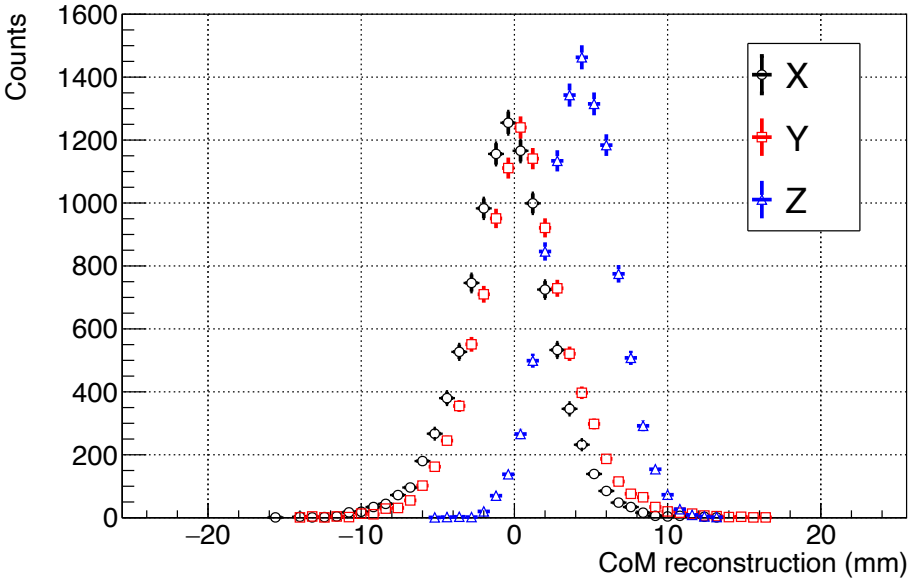
Results

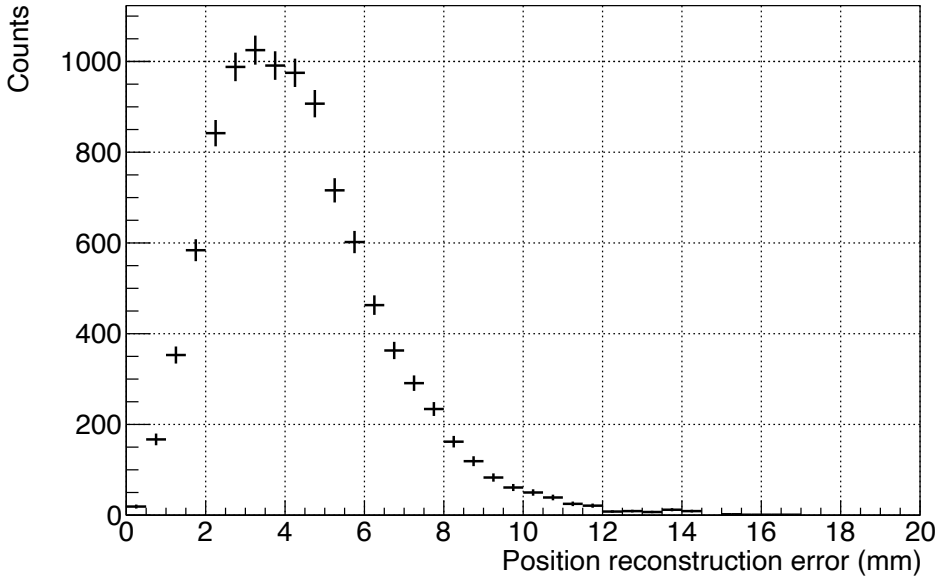
Reconstruction of event vertex using corrected CoM method

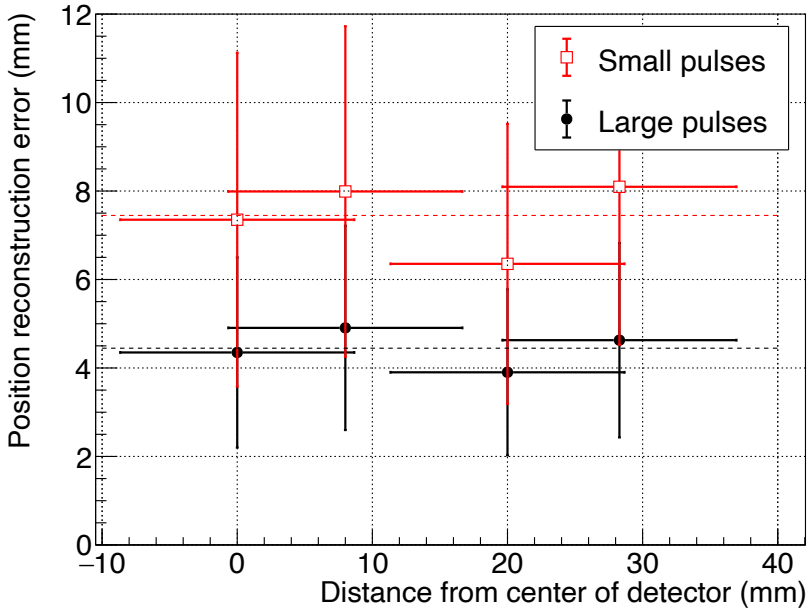
Mean reconstruction error

- Small pulses (10000 ± 1000 photons/pulse): 7.4 mm
- Large pulses (20000 ± 2000 photons/pulse): 4.4 mm



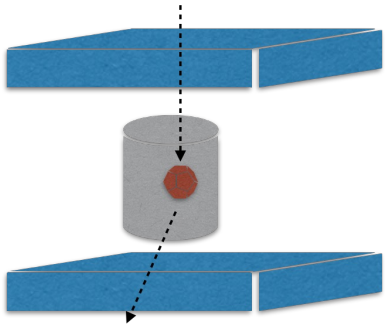


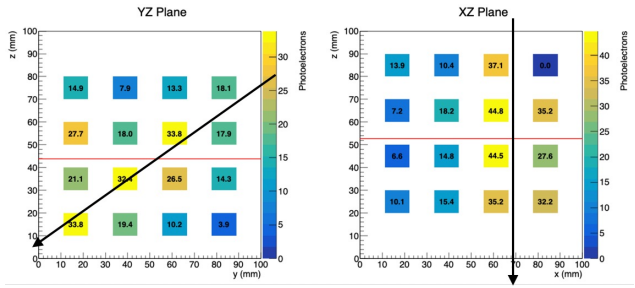




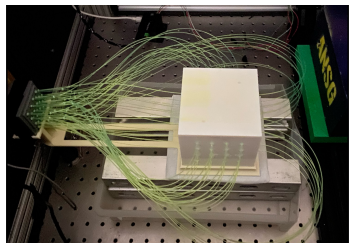
Relevance and Impact

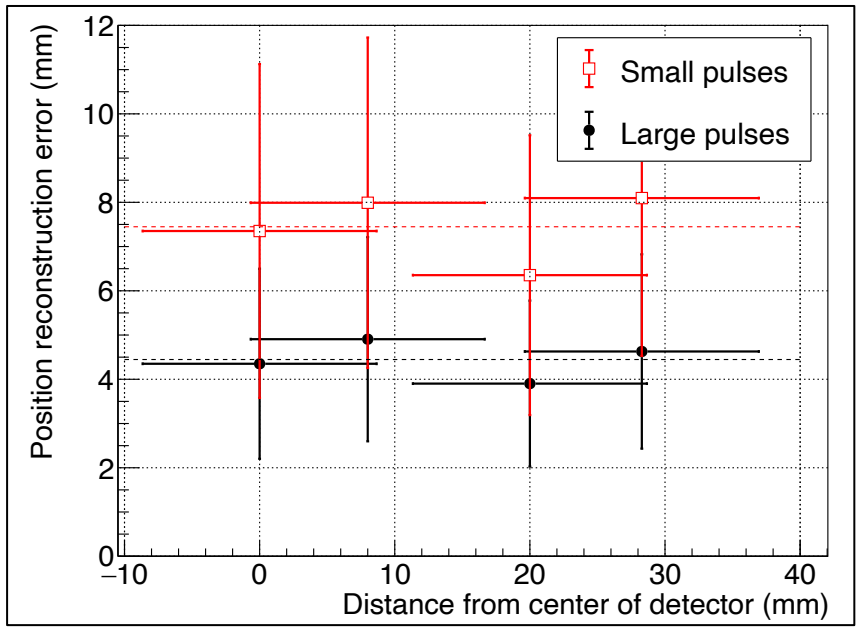
- Wide range of applications relevant to the NNSA mission
  - Muon scattering tomography for fuel cask monitoring
  - Dual-particle (neutron and gamma-ray) imaging for treaty verification, SNM detection, and radiological terror prevention
  - Compact, surface-level monitoring of reactor anti-neutrinos for nonproliferation
- Collaborations
  - Penn State University (Garrett Wendel and Doug Cowen)
  - Brookhaven National Laboratory (Minfang Yeh and Richard Rosero)
  - LiquidO Consortium (international group including members from France, the UK, Spain, Italy, Japan, and more)
- Potential future collaborations
  - Oak Ridge National Laboratory / Air Force Institute of Technology: opaque plastics
  - West Point / DTRA: Opaque dual-particle imaging prototype



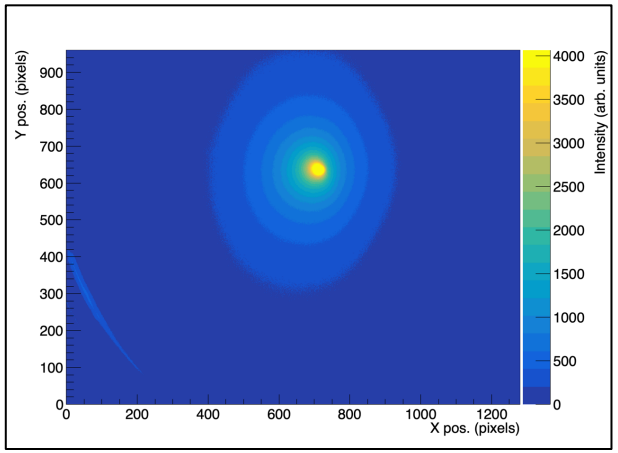


Conclusion and Future Work

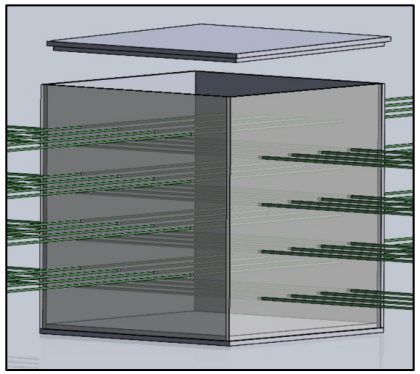




Reconstruction of topology for point-like events

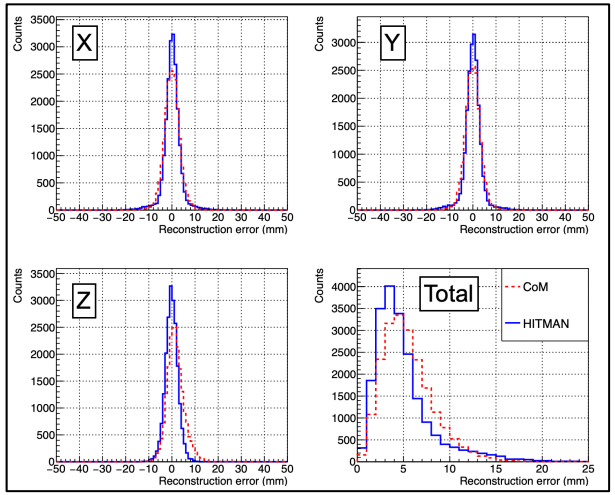


Direct optical characterization



Geometry and readout optimization

Novel materials



Reconstruction via machine learning

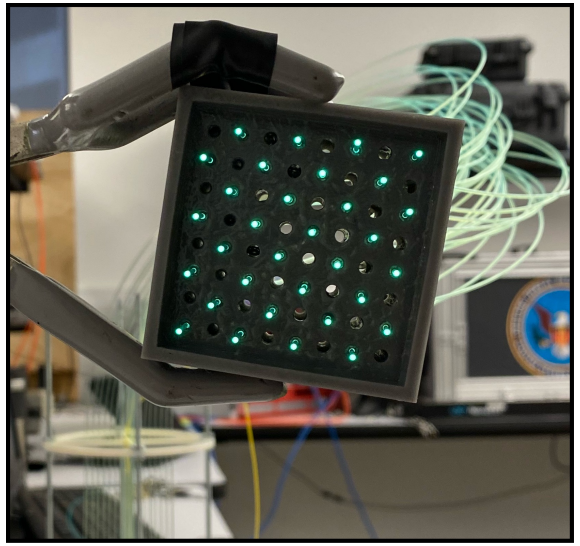
Acknowledgements

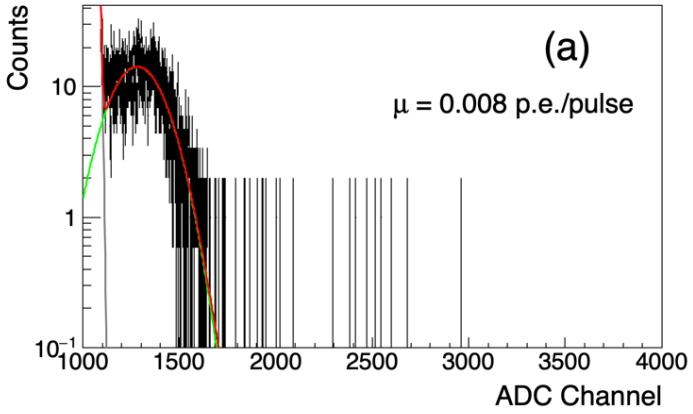
The Consortium for Monitoring, Technology, and Verification would like to thank the DOE-NNSA for the continued support of these research activities.

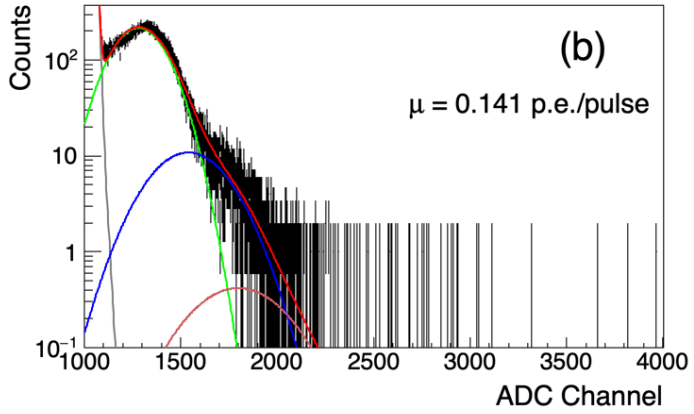
This work was funded by the Consortium for Monitoring, Technology, and Verification under Department of Energy National Nuclear Security Administration award number DE-NA0003920

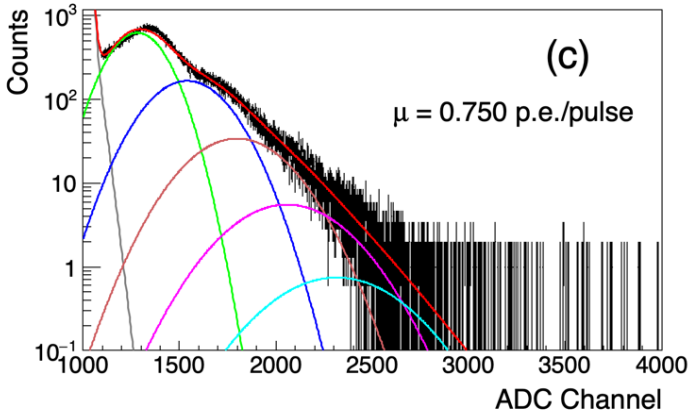
Backup slides

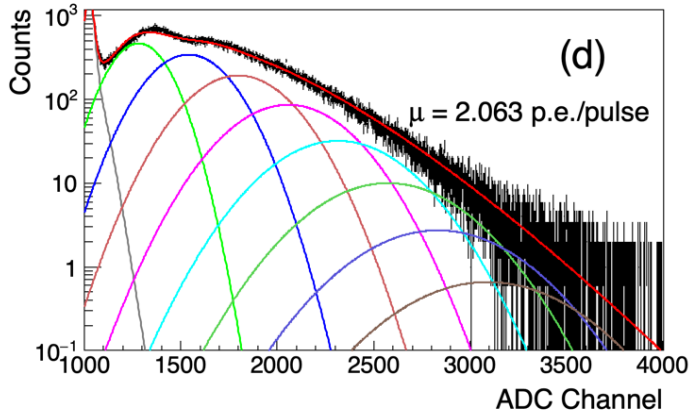
MAPMT Calibration

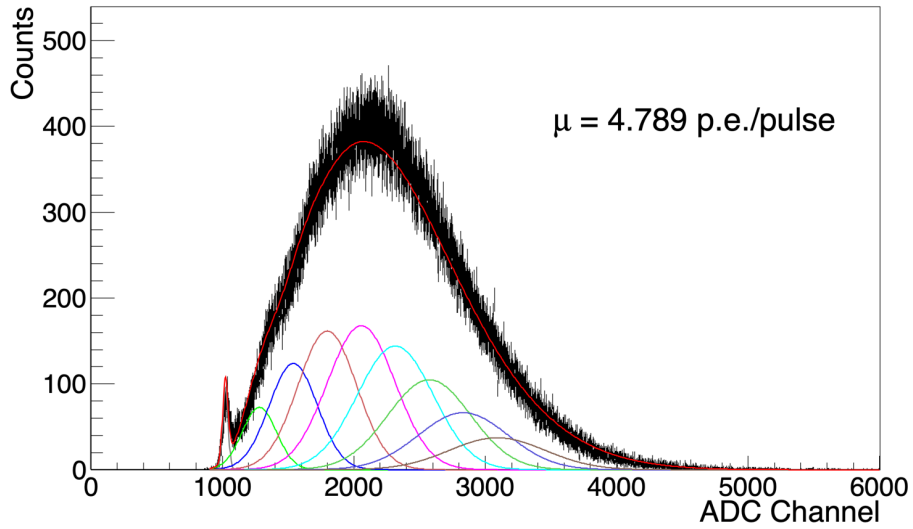




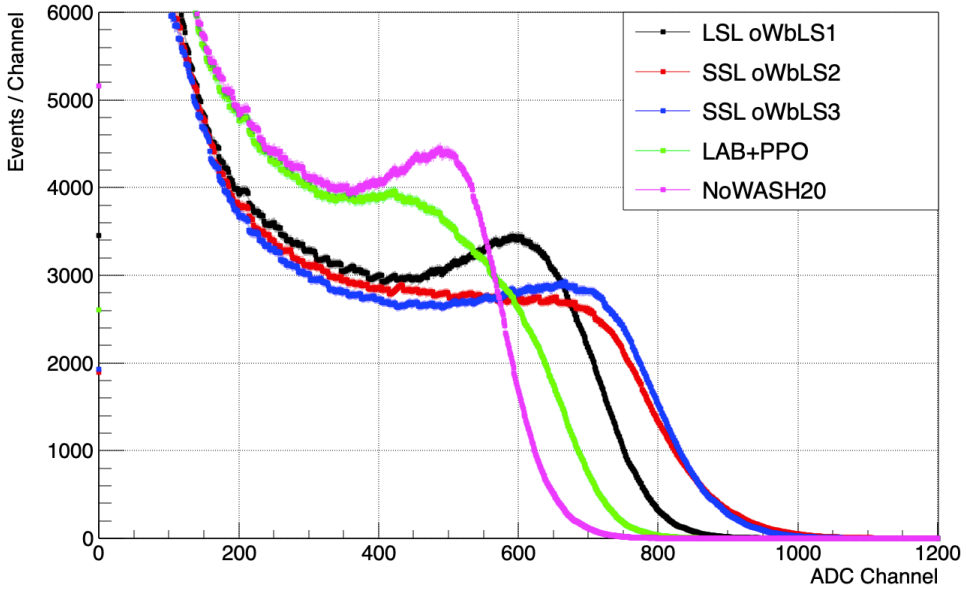


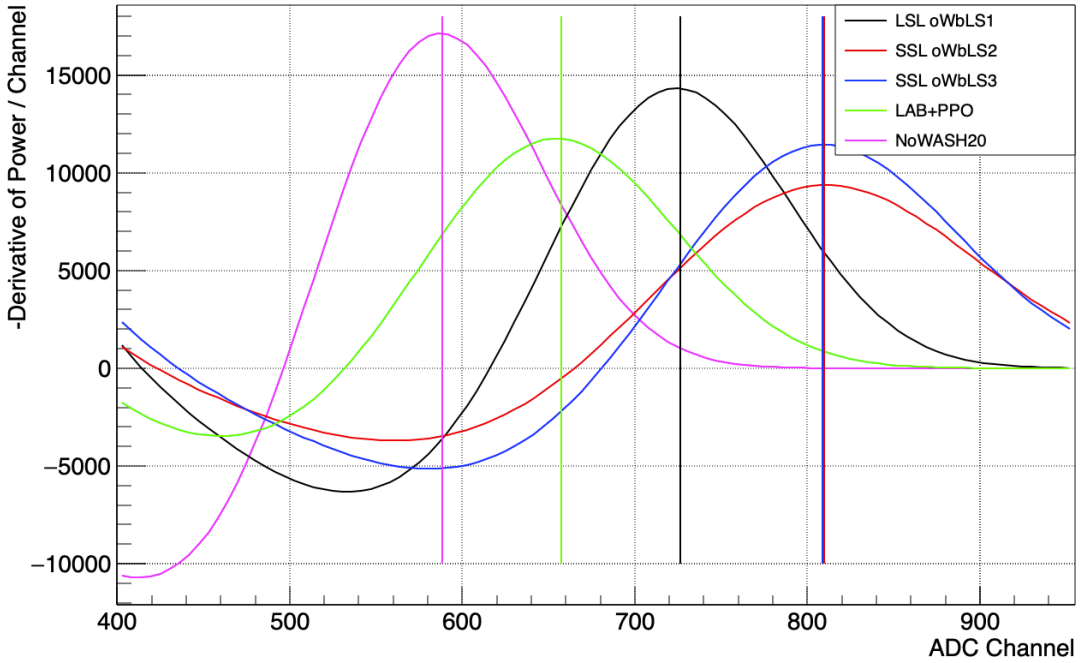




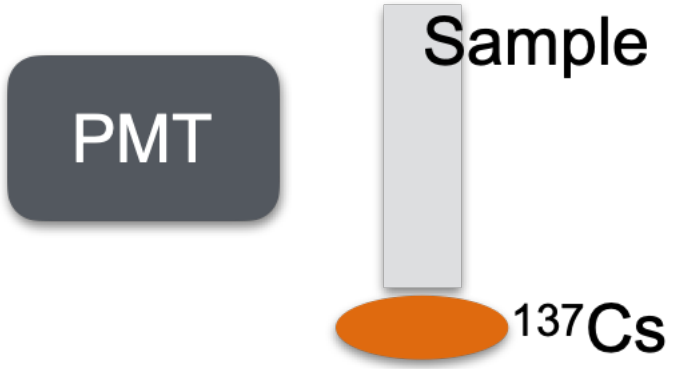


Light Yield Measurement



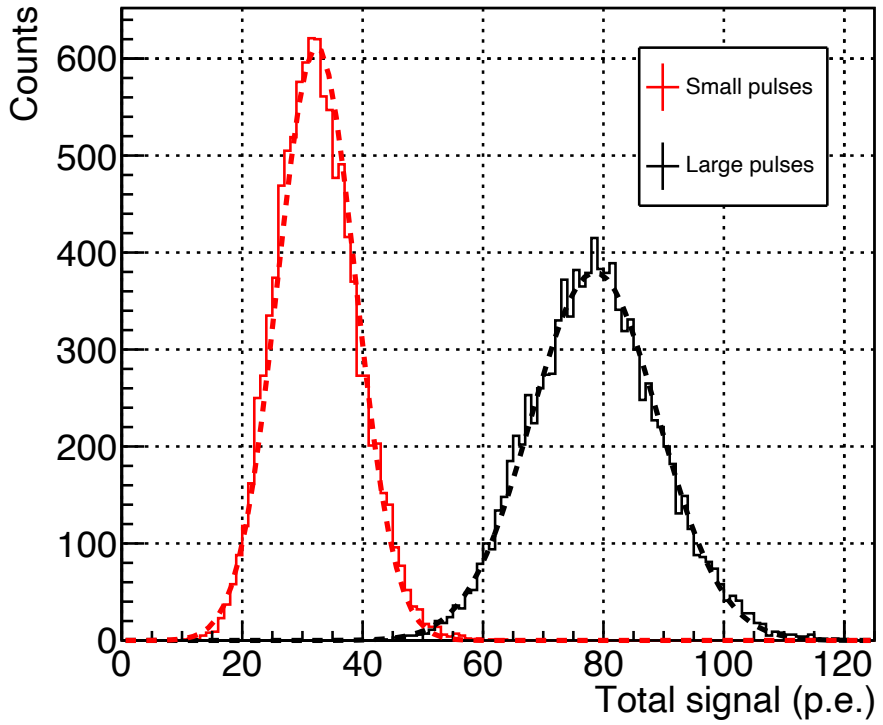


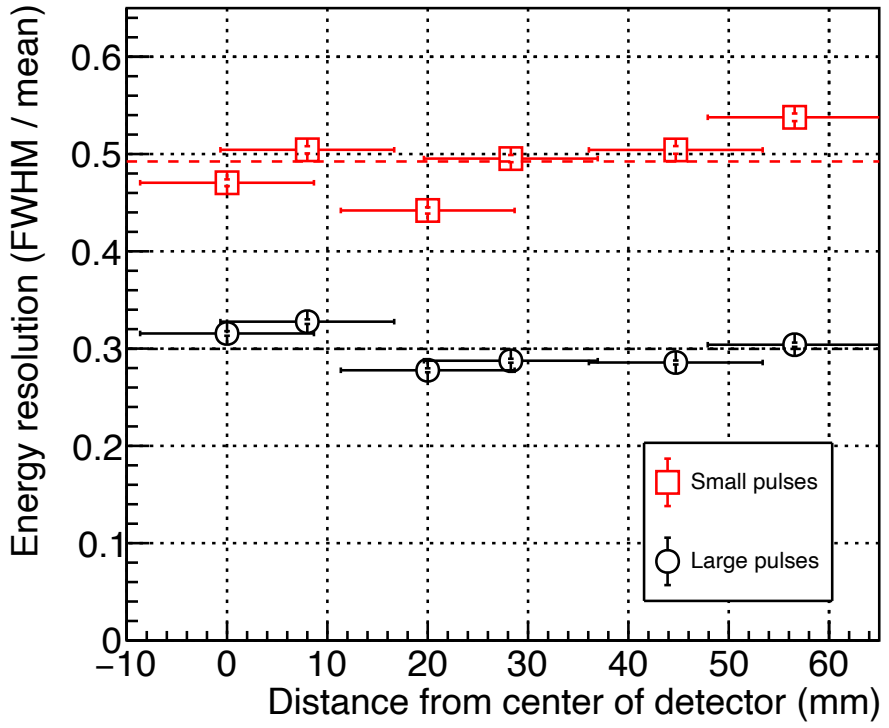
Material	LY (ph/MeV)	% LAB
LAB+PPO	10000+/-2000	100
NoWASH20	9000+/-2000	90
oWbLS 1 (LSL)	11000+/-2000	110
oWbLS 2 (SSL)	12000+/-2000	120
oWbLS 3 (SSL)	12000+/-2000	120



Energy resolution

$$\frac{\Delta E}{E} = \frac{2.35\sigma}{\mu}$$





Mean energy resolution across all positions
- Small pulses (10000 ± 1000 photons/pulse): 49 ± 3%
- Large pulses (20000 ± 2000 photons/pulse): 30 ± 2%

Light yield: 12000 ± 2000 photons / MeV
Small pulses ~ 0.8 MeV
Large pulses ~ 1.6 MeV