University of Zurich[UZH]

LUX ZEPLIN Outer Detector Energy Calibration

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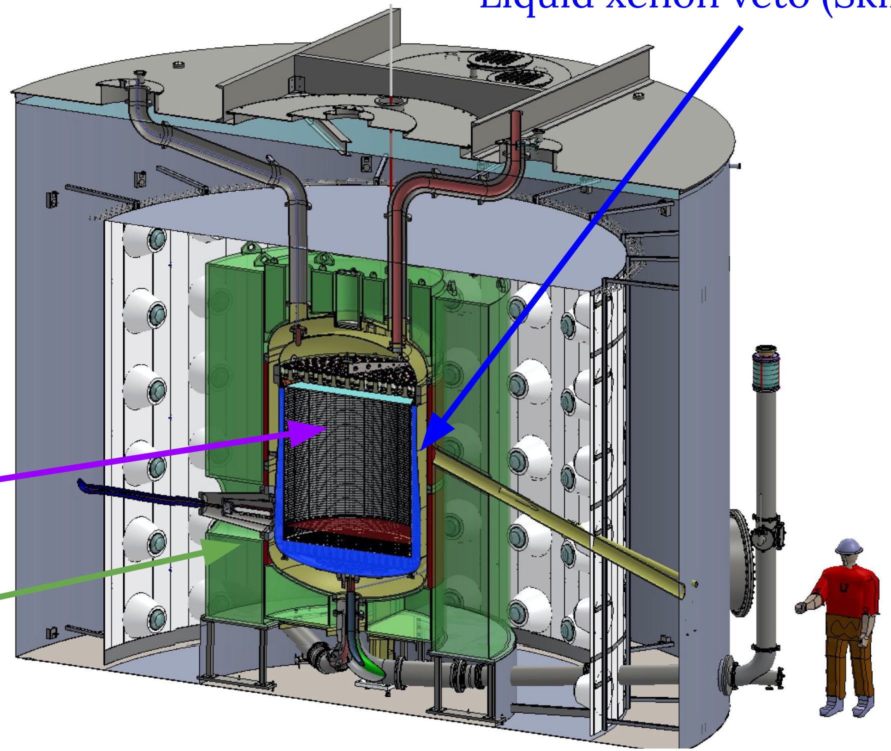
Outer Detector Energy Calibration

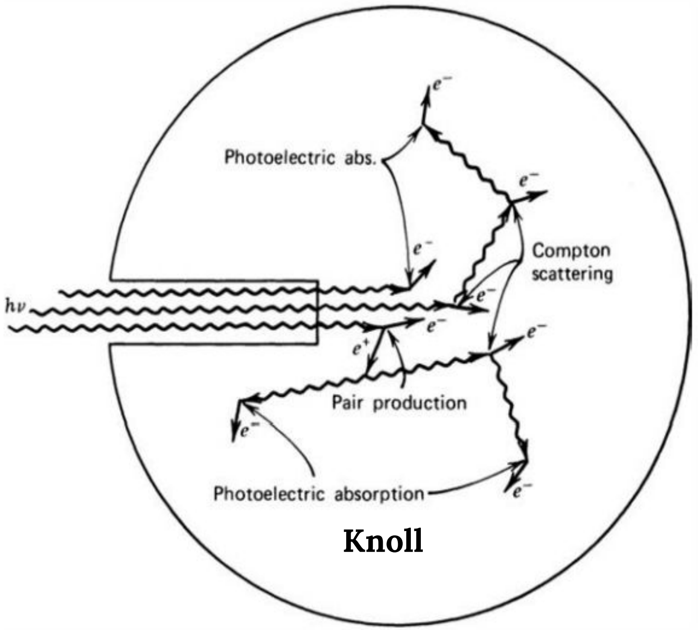
University of Zurich[UZH]

- Outer Detector (OD) is the primary neutron veto for LUX-ZEPLIN
  - Adds ability to distinguish primary WIMP NR background
  - Increases sensitivity
- Neutrons capture on gadolinium, generating gamma cascade
- OD was not designed to fully reconstruct energy



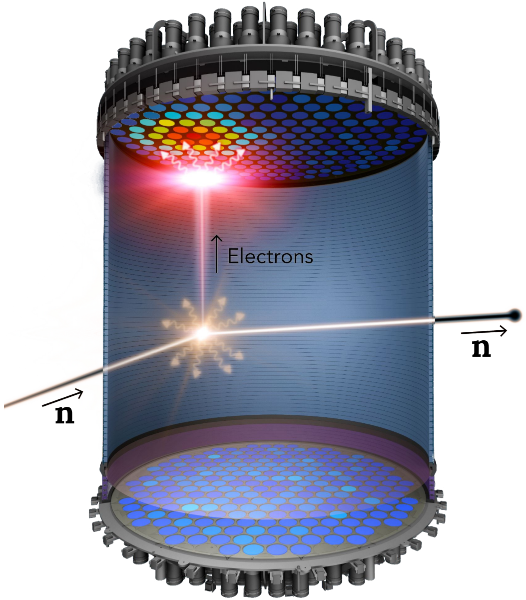
Gamma Interaction in Scintillators

- Gamma can't directly excite LS molecules to produce scintillation
  - Compton scattering
  - Pair production
  - Photoelectric effect
- Induced electrons, positrons excite LS, causing scintillation
- Above ~100 keV, compton scattering dominant process in organic scintillators



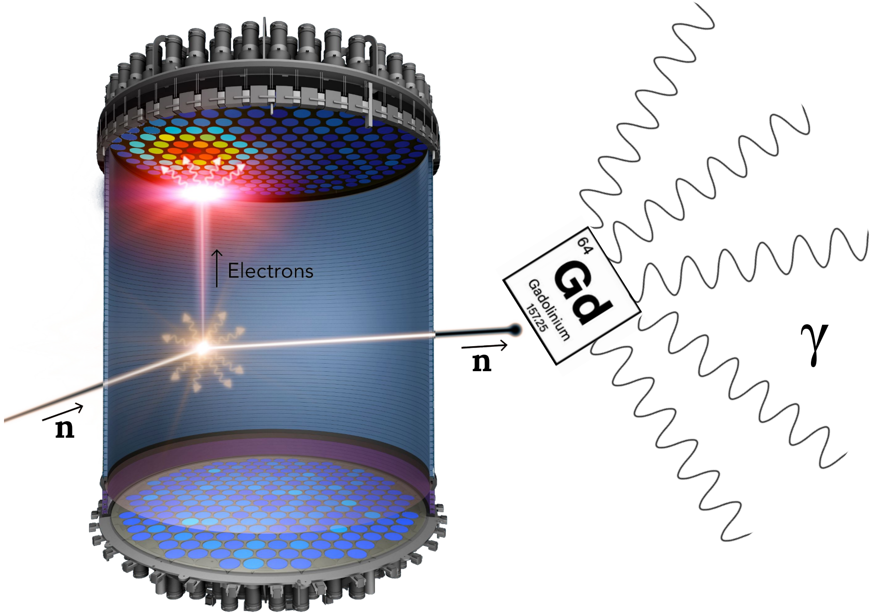
Knoll

Gd Cascade



Neutron scattering, leaving detector

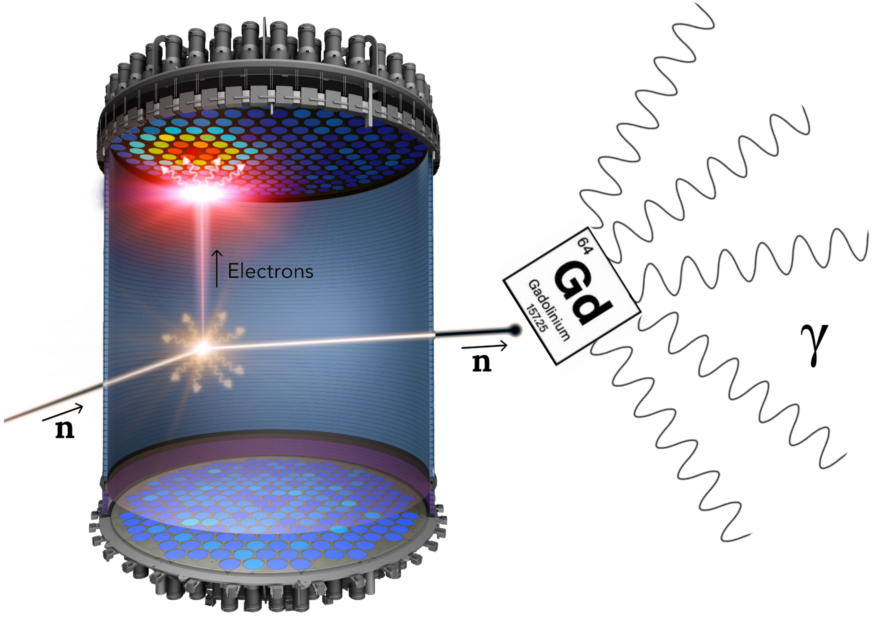
Gd Cascade

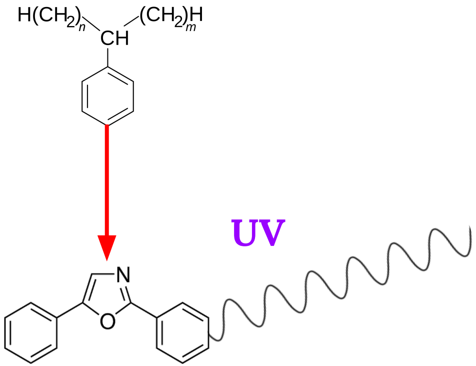


Neutron thermalizes, captures on $Gd^{155/157}$ releasing 8.5/7.9 MeV of γ, internal conversion e^-

Gd Cascade

γ compton, e^- excite
LAB -> PPO releasing UV





Gd Cascade

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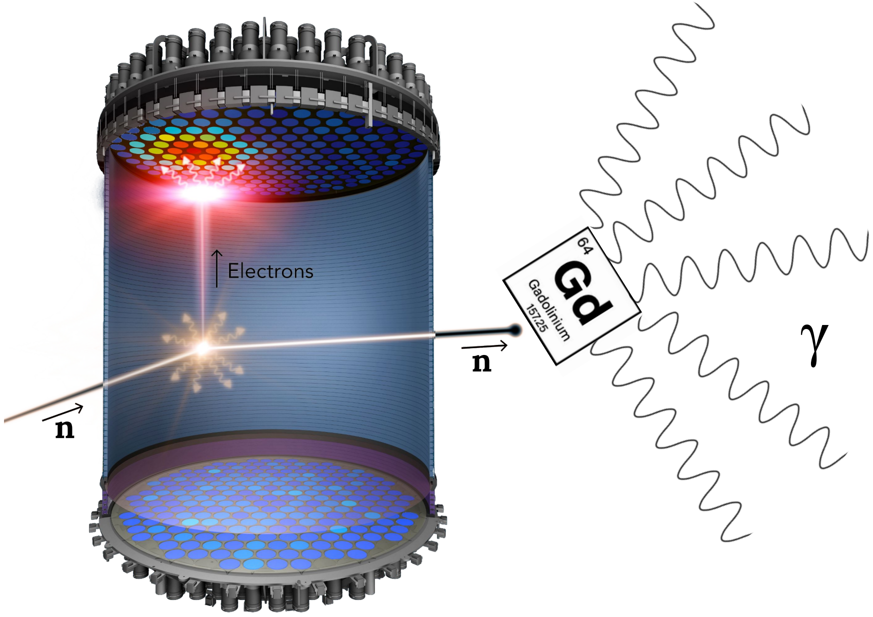
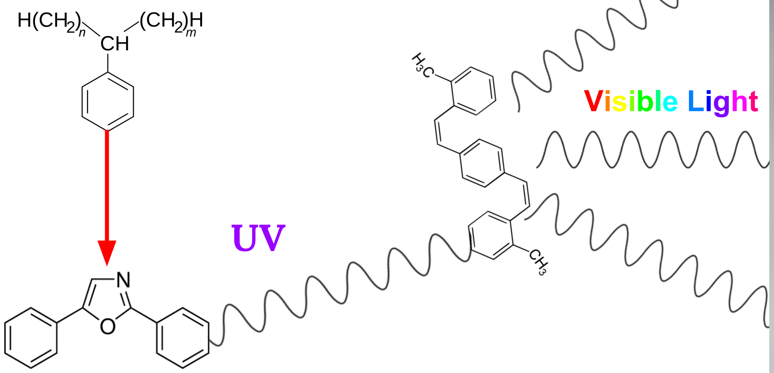
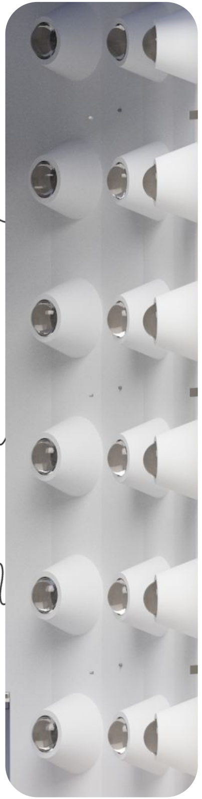


Bis-MSB shifts wavelength to VIS, captured on 8” PMTs





Birks' Law

- Excitation and de-excitation of fluor experiences non-linear quenching
- May de-excite non-radiatively, producing heat
- Dependent on particle type & stopping power
- Well described by Birks' Law

$$\frac{\mathrm{d}L}{\mathrm{d}x} = Y \frac{\frac{\mathrm{d}E}{\mathrm{d}x}}{1 + k_B \left(\frac{\mathrm{d}E}{\mathrm{d}x}\right) + C \left(\frac{\mathrm{d}E}{\mathrm{d}x}\right)^2}$$

TABLE III. Parameters used for various particles in production of scintillation photons in the GdLS of the Outer Detector.

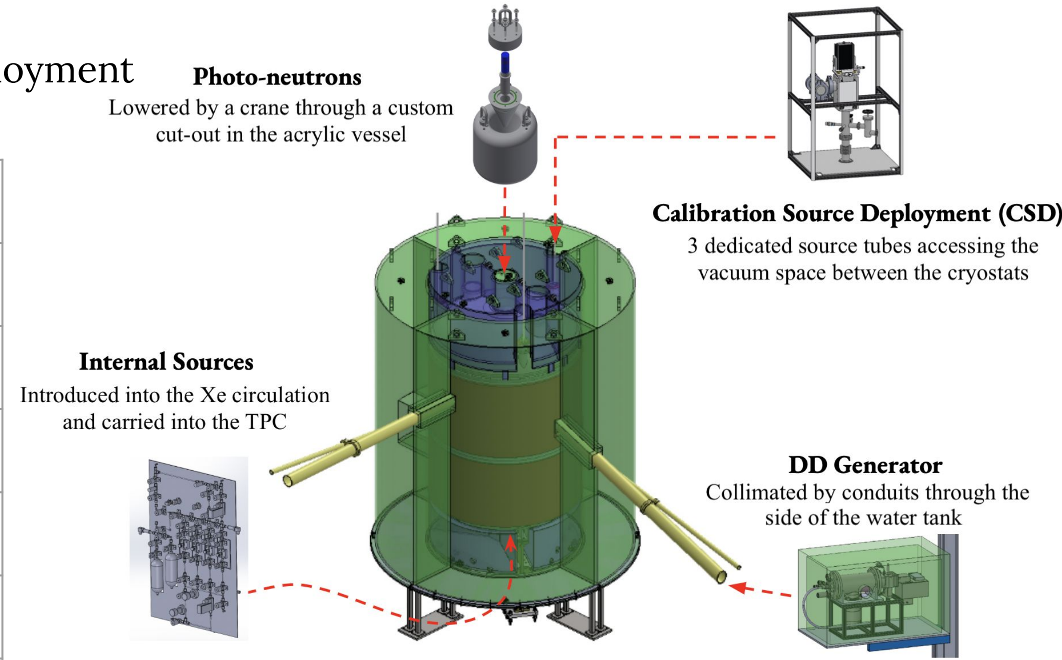
	Y (photons/MeV)	k_B (g/MeV/cm^2)	C (g/MeV/cm^2)^2
α		4.63E-3	1.77E-6
β/γ	9,000	0.03	0
Proton		8.26E-3	0

Astroparticle Physics 125. 102480

Calibration Sources

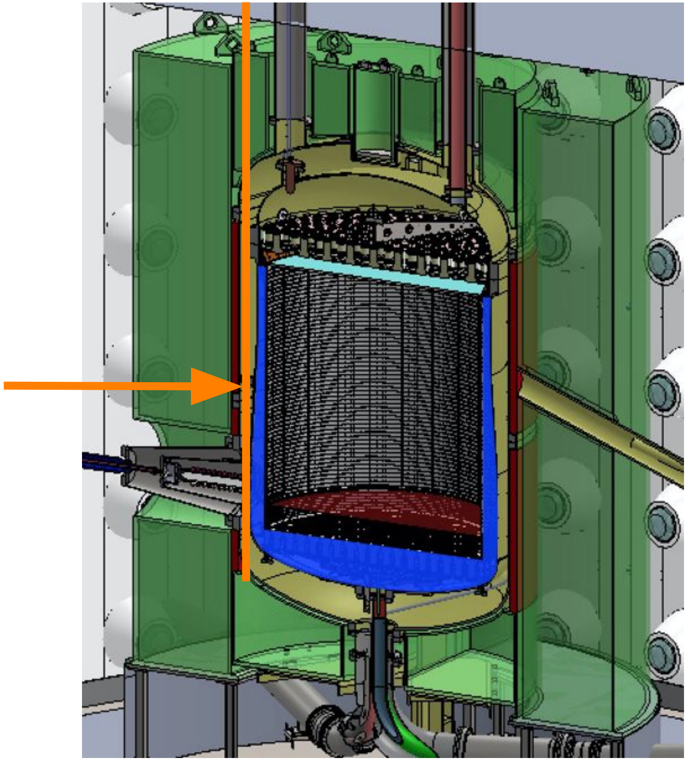
- Sources picked for wide coverage of gamma energies
- All deployed via Calibration Source Deployment (CSD) system

Source [Process]	Energy [keV]
^{57}Co	122
^{22}Na	511, 1275
^{54}Mn	835
AmLi [H(n, g)]	2223
^{228}Th	2614
AmBe [^{9}Be(a, ng)]	4438

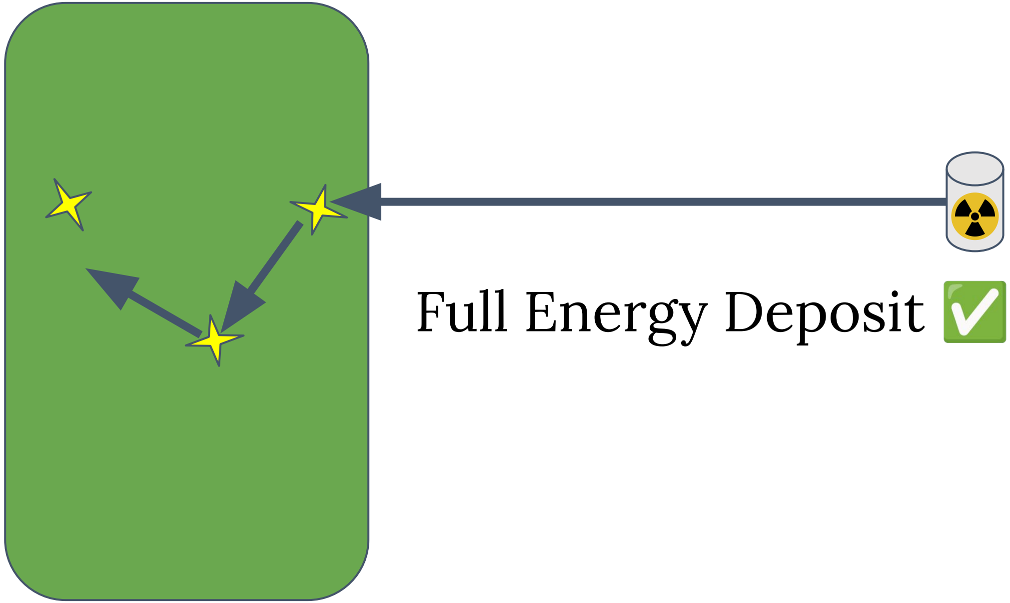


Calibration Strategy

- As a veto detector, compromises had to be made
  - Reflective interior, optimized for light collection to increase veto efficiency
    - Smears energy and position resolution
  - One deployment system for multiple detectors
    - Sources deployed between inner and outer cryostat
    - Several lays of titanium, acrylic, foam
    - Gamma often forward scatter before reaching OD, losing energy
    - External calibration, gamma often scatter out before depositing full energy in scintillator

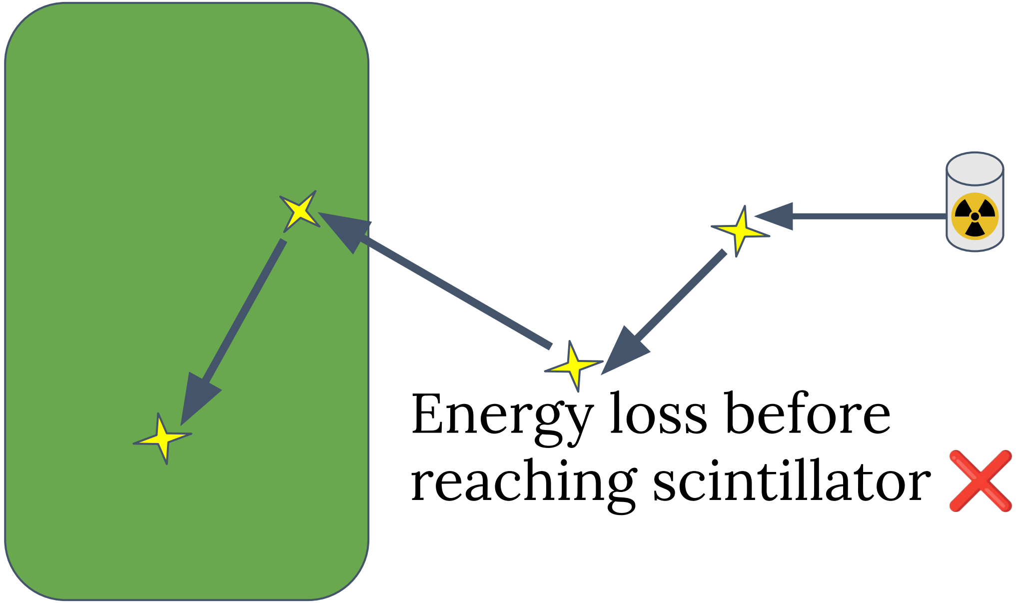


Ideal Event

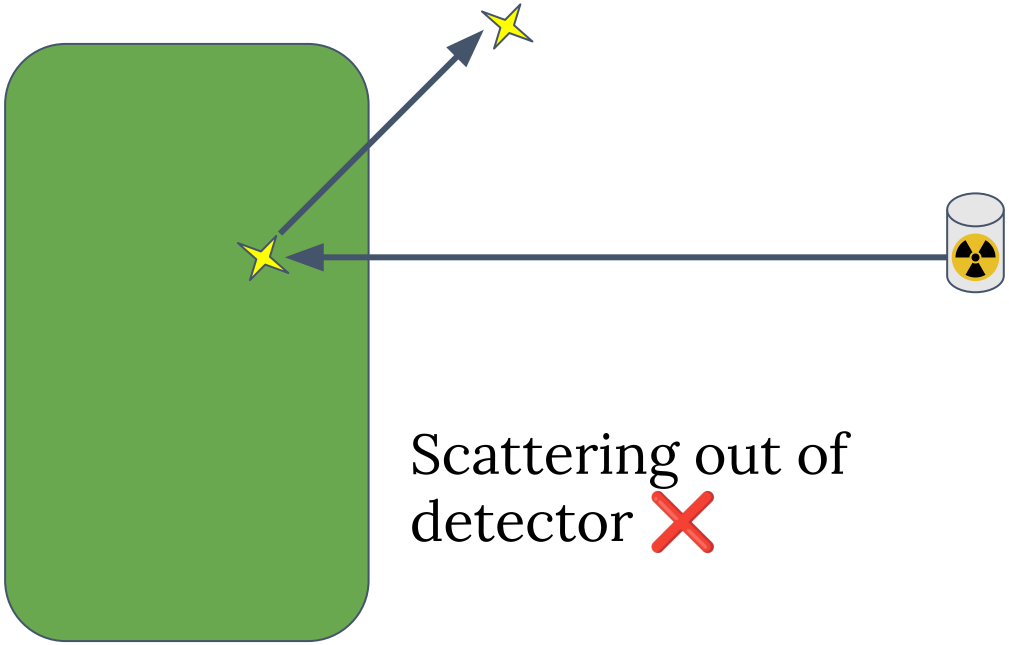


Full Energy Deposit ✅

Energy Loss

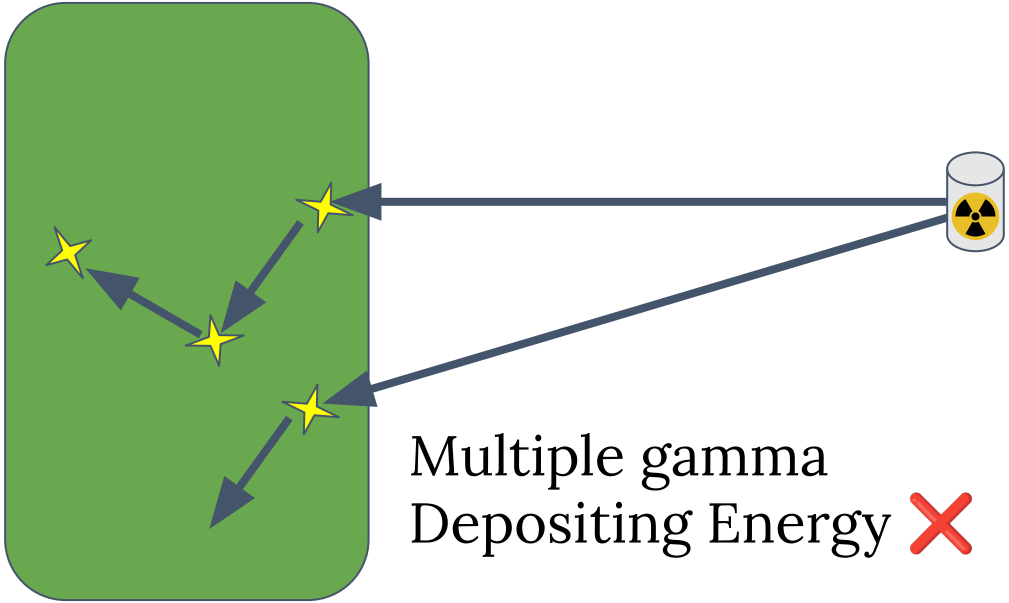


Compton Loss



Scattering out of detector ❌

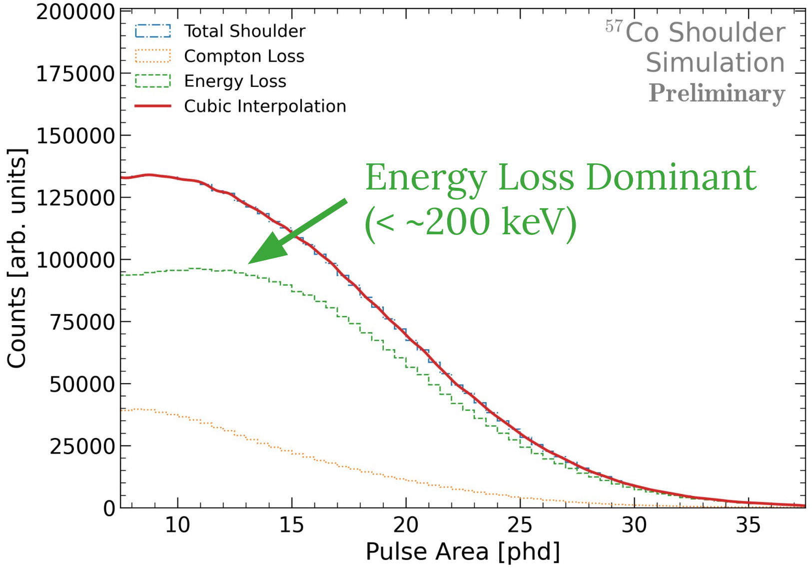
Multi-gamma

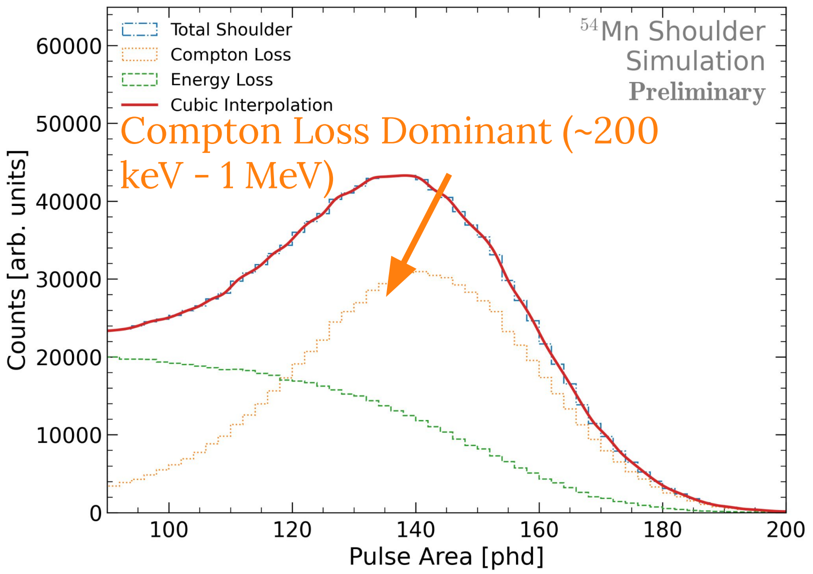


Multiple gamma
Depositing Energy ❌

Example Simulation Shoulders

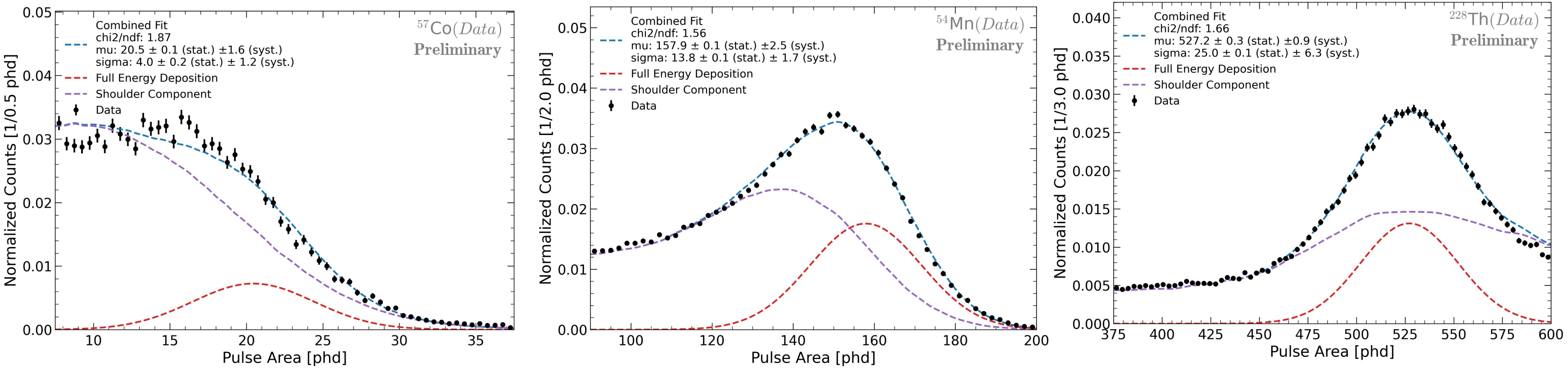
- Lower energy sources (< 200 keV) often forward scatter losing energy prior to entering OD
- Higher energy gamma often scatter out before depositing full energy





Template Fits

- Photopeak subdominant to shoulder across all sources, larger uncertainty at lower energies
- Fitting with shoulder reduces underestimation of resolution & bias on energy scale



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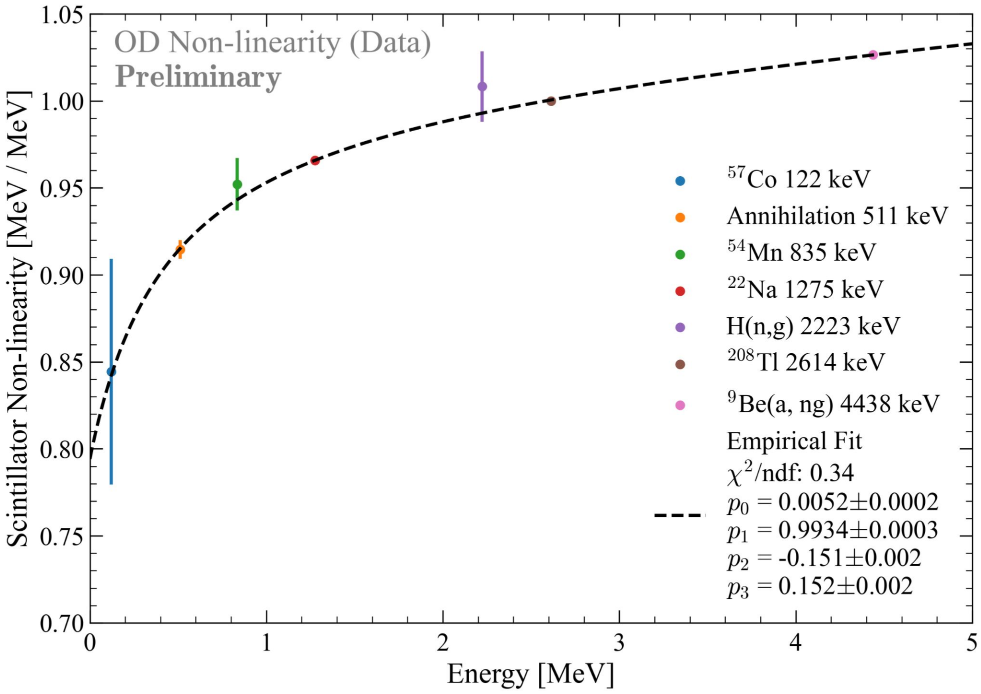
Non Linearity of Scintillator

- Well characterized through empirical function

$$NL(E) = \frac{p_0 + p_3 E}{1 - p_1 e^{p_2 E}}$$

- ^{208}Tl used for absolute energy scale
  - 202 photons / MeV



Energy Scale and Resolution

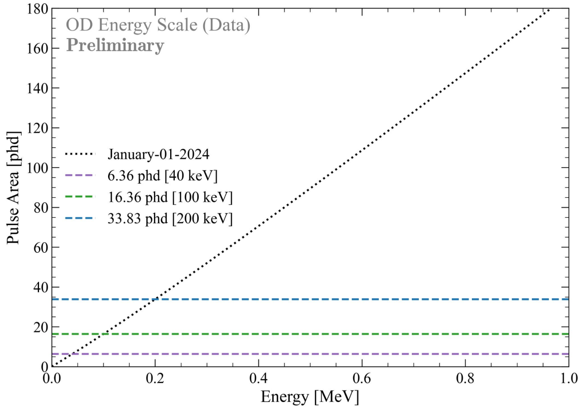
- Far exceeding design specification of 200 keV threshold
- Performance could allow for multi-detector analysis search
- Energy scale characterized by absolute scale and non-linearity as

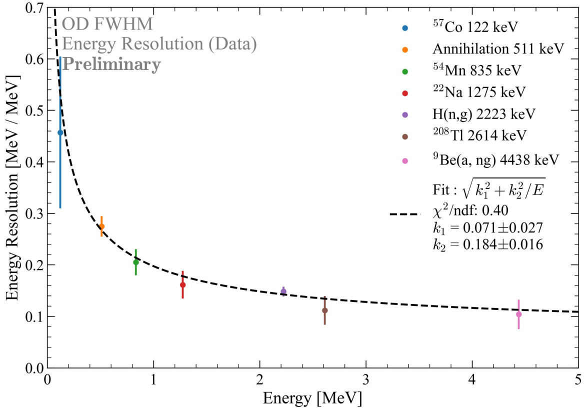
$$phd(E) = E_0 \cdot NL(E)$$

- FWHM resolution well described by

$$Resolution(E) = \sqrt{k_1^2 + k_2^2/E}$$

- ~14 ± 3% at 2.6 MeV





Summary

- Energy calibration allows for additional validation of OD veto response
- For LZ OD, calibration photopeaks subdominant to compton, energy loss shoulders
- Template fitting works well for decreasing bias on resolution, energy scale
- OD far exceeds initial design constraints for energy threshold
- Performance allows for additional usage in separate analysis searches

LZ (LUX-ZEPLIN) Collaboration, 38 Institutions

@lzdarkmatter

250 scientists, engineers, and technical staff

https://lz.lbl.gov/

- Black Hills State University
- Brookhaven National Laboratory
- Brown University
- Center for Underground Physics
- Edinburgh University
- Fermi National Accelerator Lab.
- Imperial College London
- King's College London
- Lawrence Berkeley National Lab.
- Lawrence Livermore National Lab.
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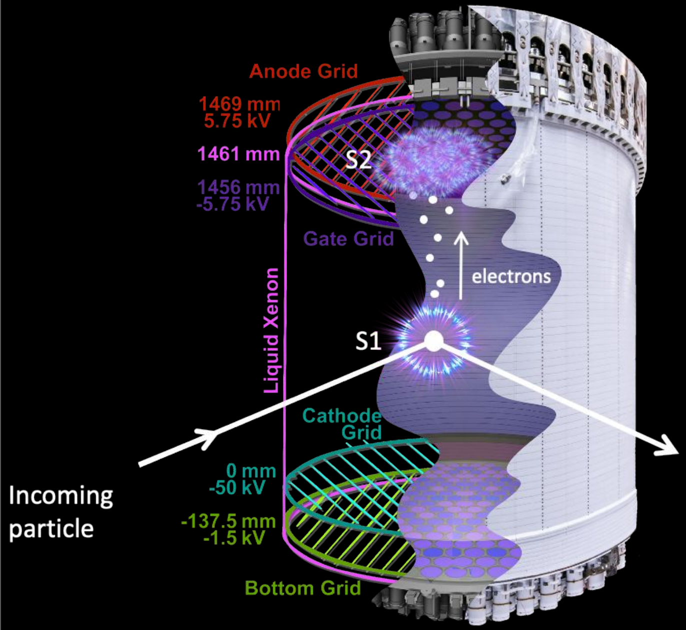

Image by Nicolas A. (Imperial College London)

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