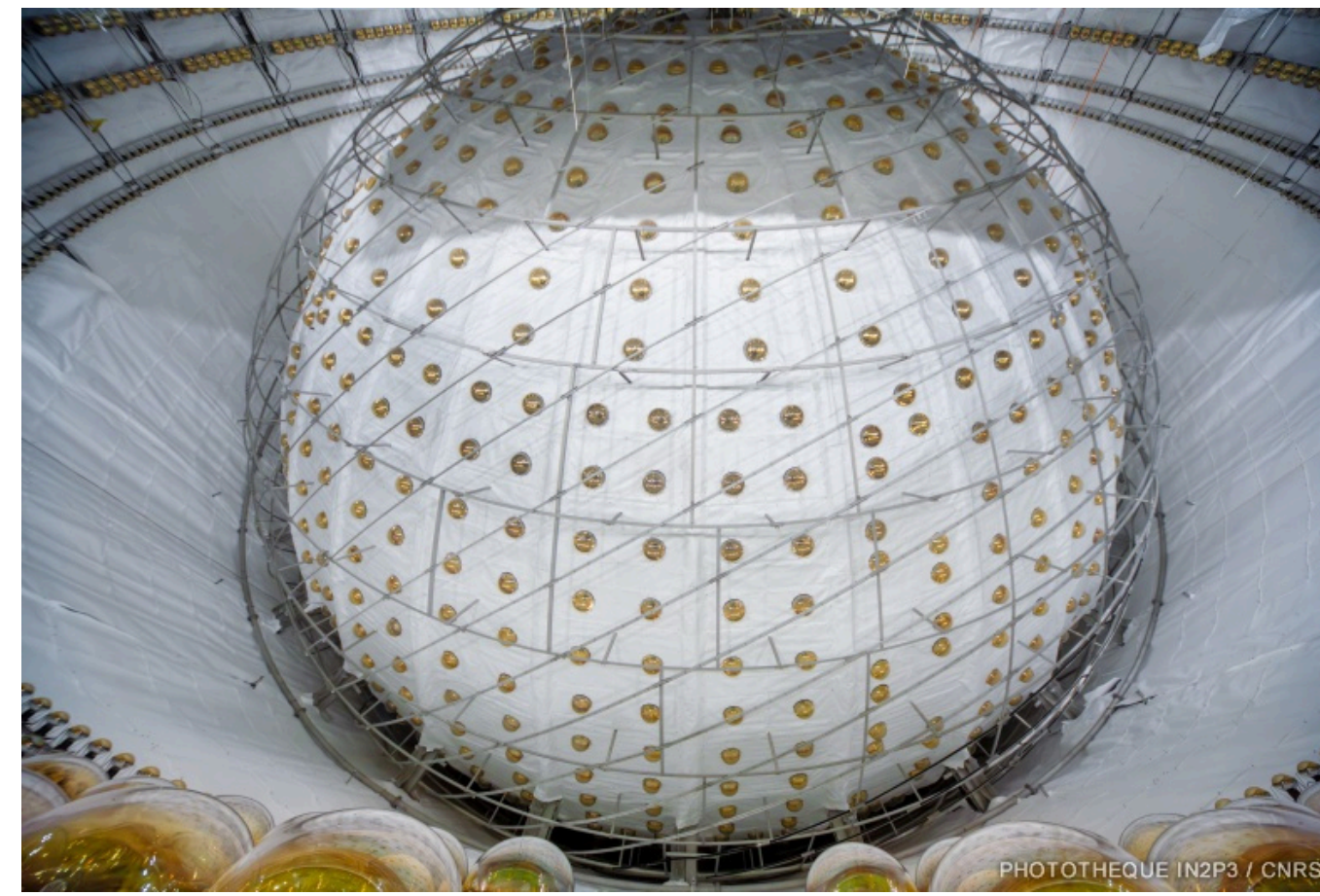
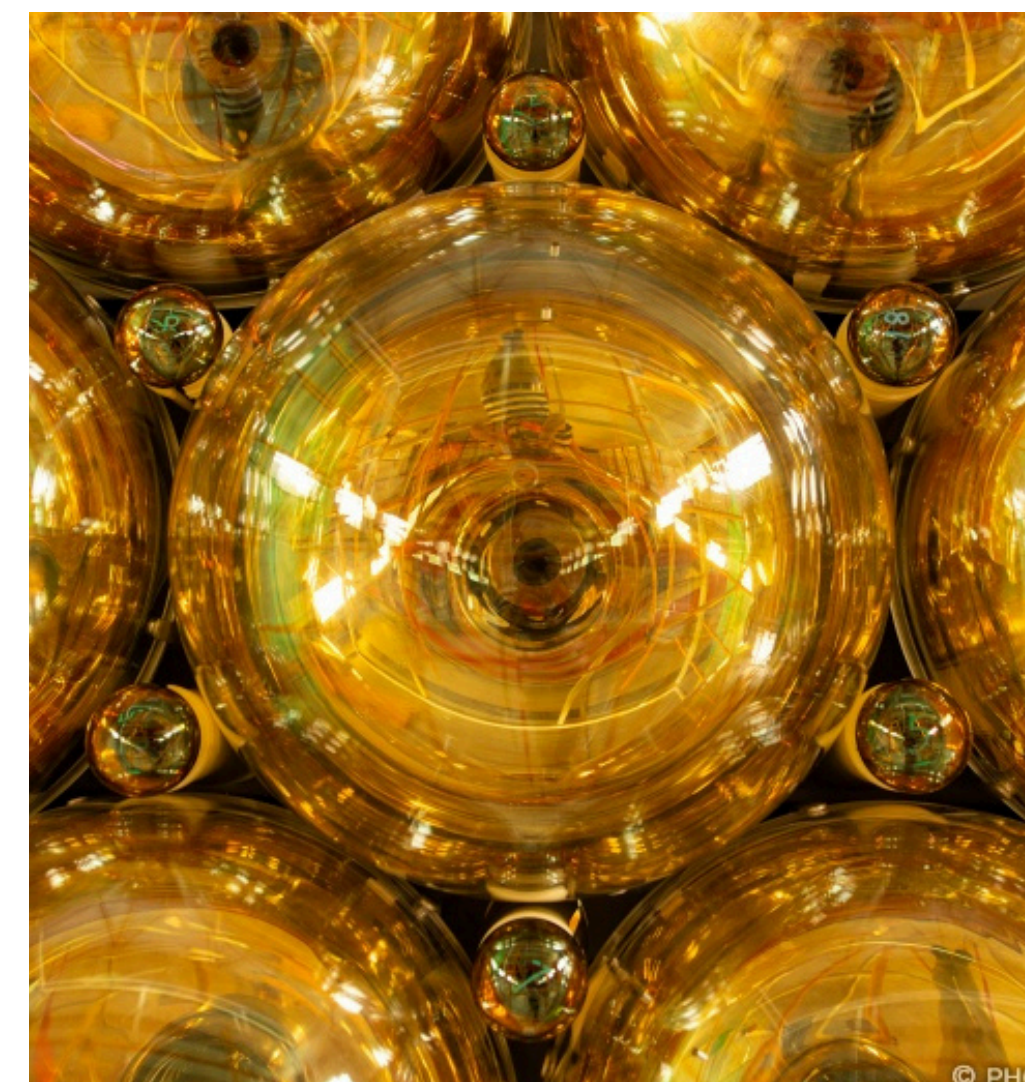


JUNO and the Small PMT system



JUNO :
20 kton Liquid Scintillator detector with high energy resolution for precision **reactor antineutrino** measurement



Light collection systems:

- **Large PMT (LPMT)**, 17596 20" PMTs, Integrated charge
- **Small PMT (SPMT)**, 25587 3" PMTs, single photo counting

Goal of the SPMT system:

To constrain the instrumental non-linearity of the energy response of the LPMTs

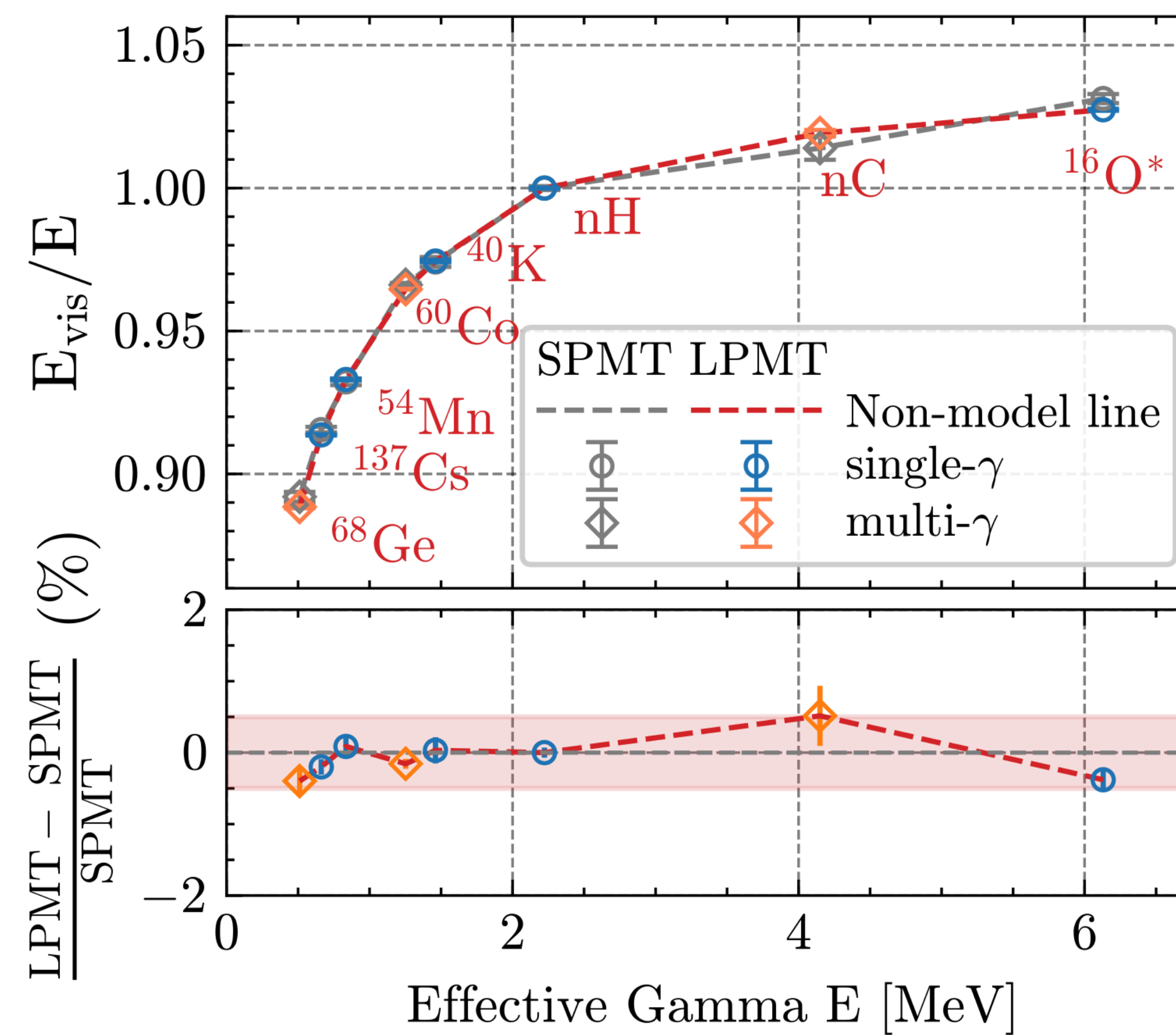
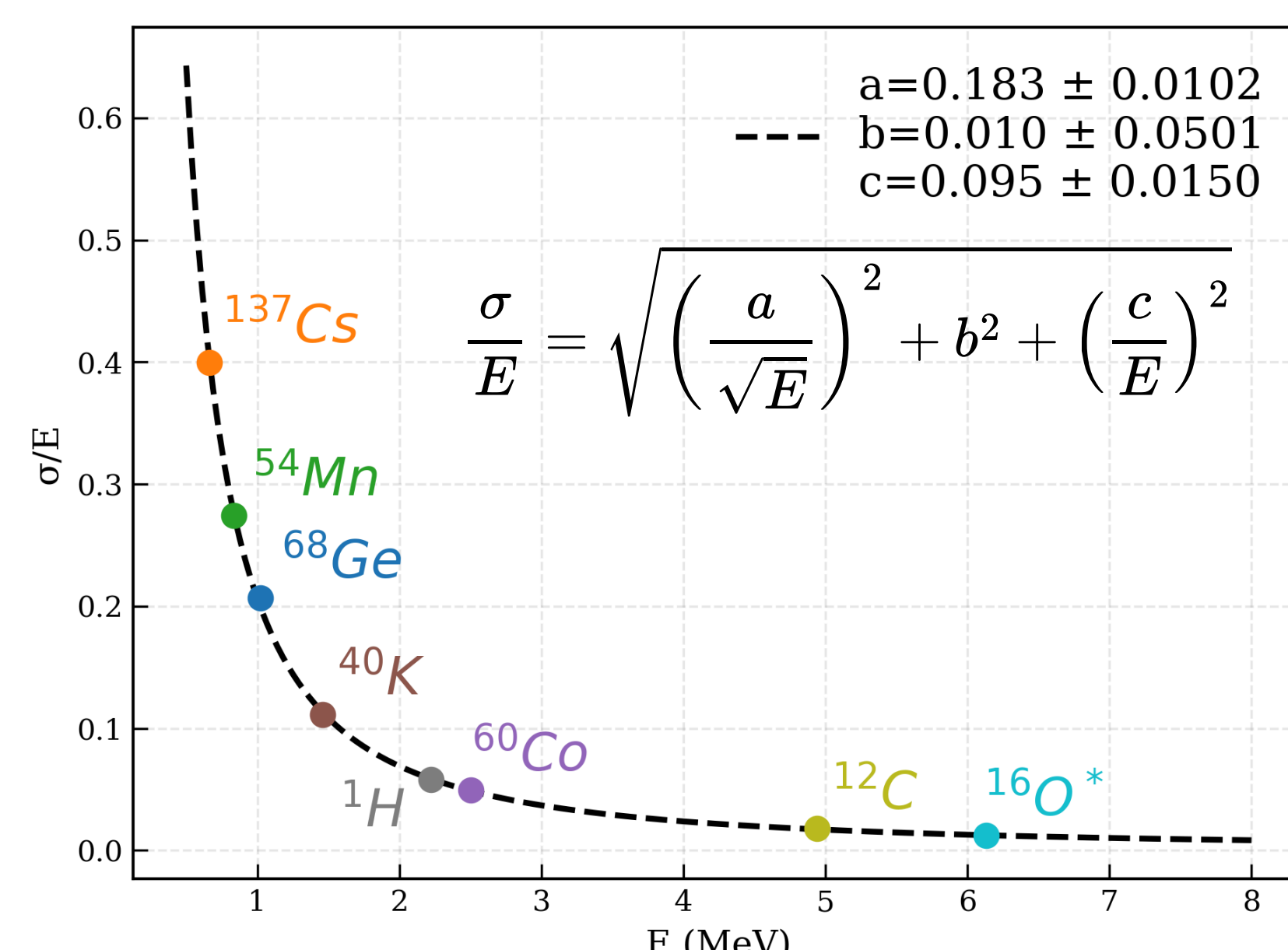
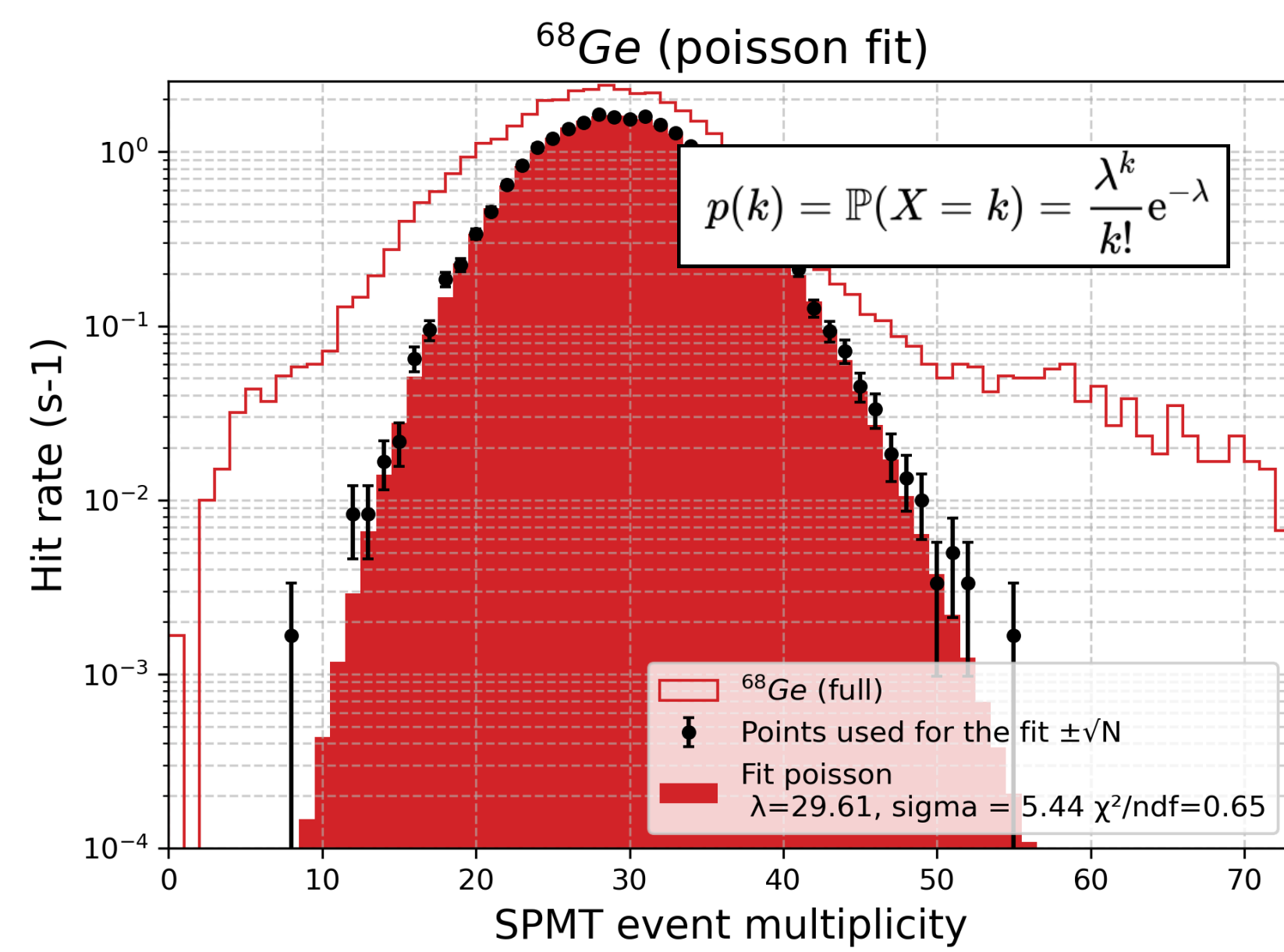
Energy Non-linearity and Resolution

Detector properties:

- Most of the energy deposited in a scintillator is re-emitted as light, but other processes can cause **non-linearities in measured energies**:
 - **Quenching**: Energy transferred non-radiatively in the scintillator
 - **Cherenkov light**: Not related to scintillation processes

Non-linearity measurement using calibration sources:

- **Radioactive γ sources** with different energies placed at the **center of the detector**
 - Acquisition is **triggered by the LPMT system** and gammas of interest are selected using LPMT charge measurements and reconstructed vertices
 - **Poissonian** fit applied to measure the visible energy with SPMTs
- ➔ Consistent energy non-linearity measurements with SPMTs and LPMTs within **0.5 %** level



Energy resolution with SPMTs :

- Energy resolution was measured using same calibration sources
- **~20%** energy resolution at 1 MeV
- 3 parameters impact the resolution :
 - a : Statistical term driven by **photostatistics**
 - b : **Non-uniformity**
 - c : **Dark Count Rate**

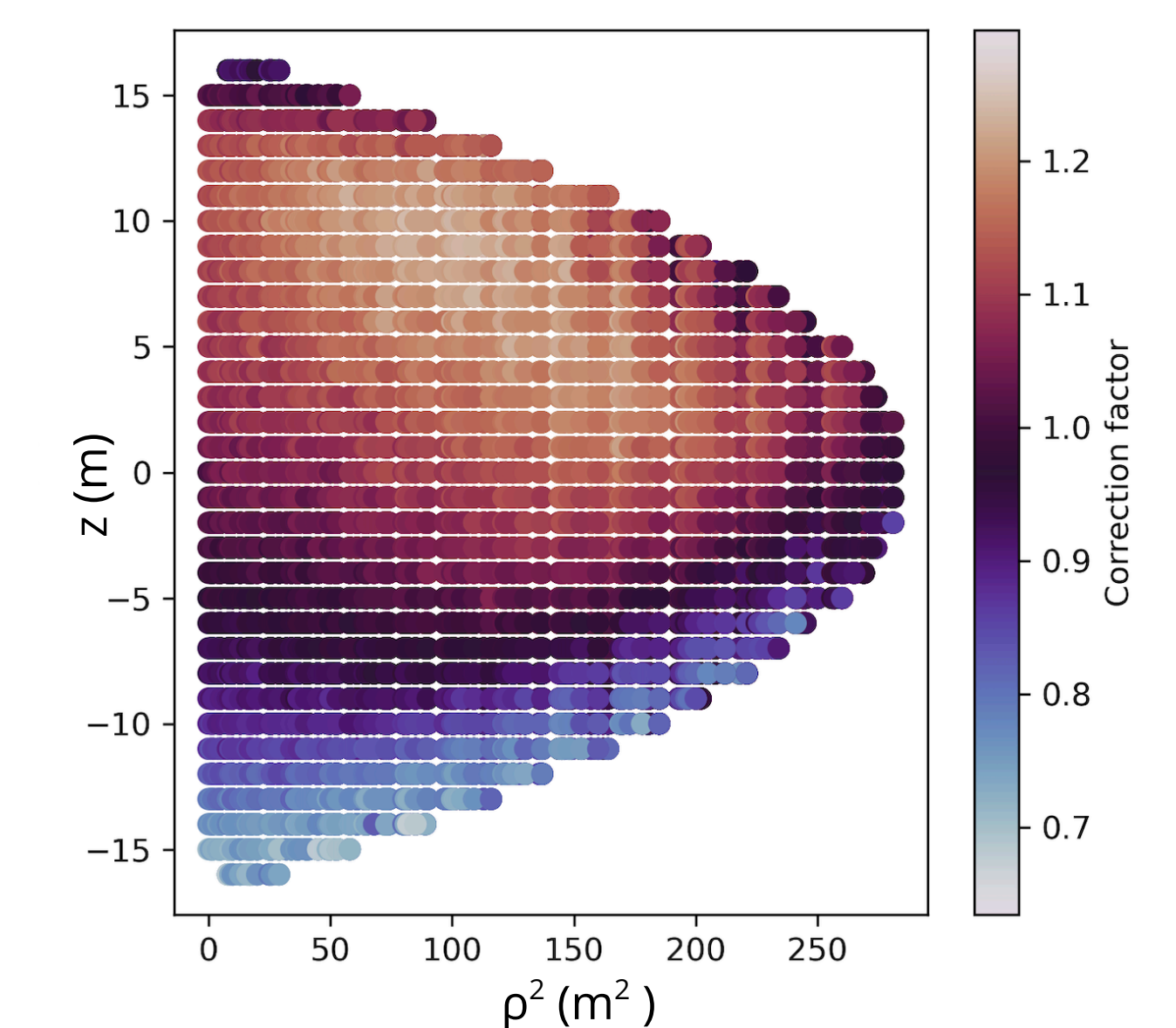
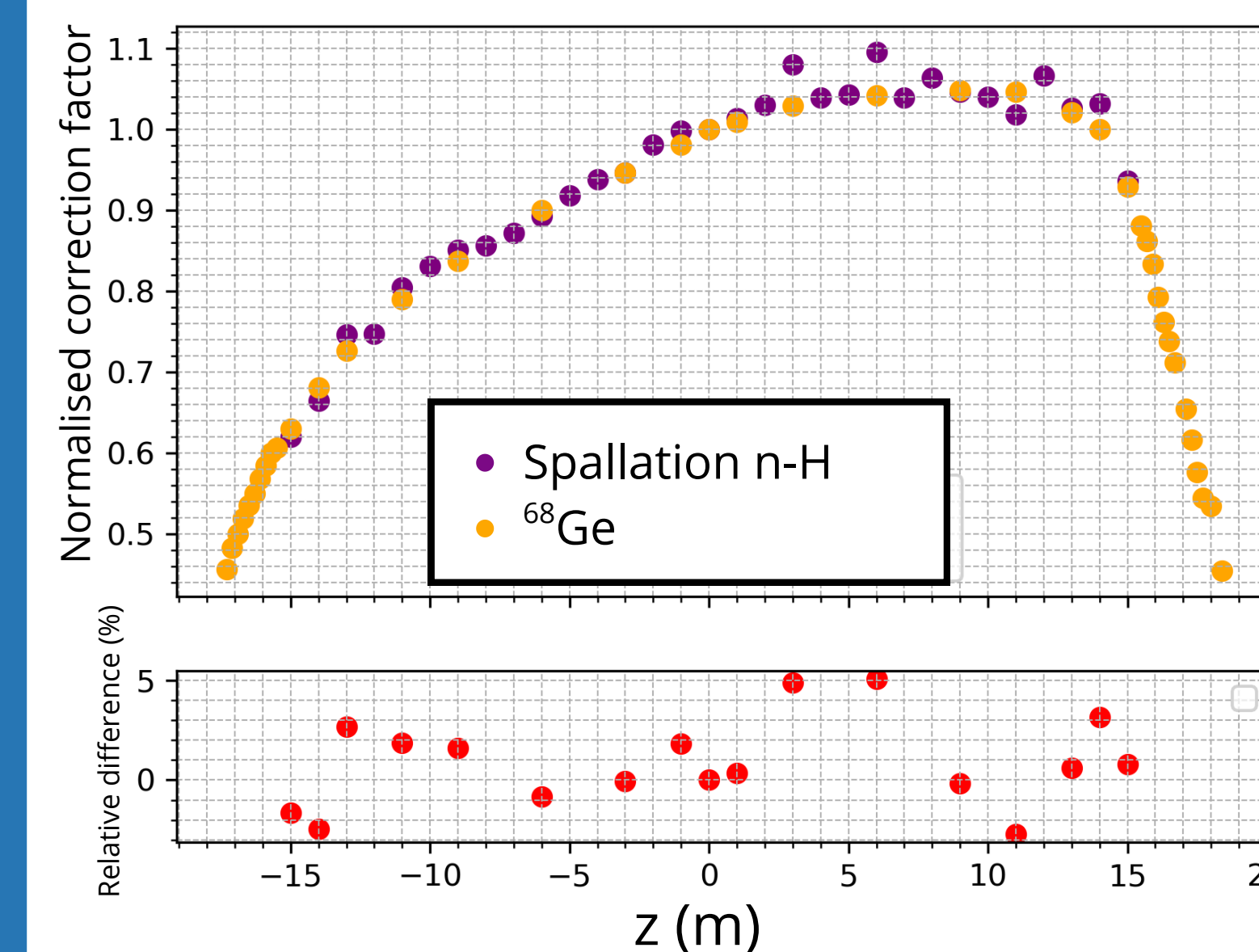
Spatial Non-Uniformity

Event vertex affects detector response:

- Collected light depends on **event vertex**
- In the first data taking phase, part of the SPMTs were turned off, mostly in the south hemisphere, leading to **z-axis asymmetry**

Correction using a non-uniformity map:

- Detector cut in **1m³ voxels**, 1 correction factor per voxel
- **Spallation neutrons**: 2.2 MeV gamma uniformly distributed
- Compared z axis correction with calibration ⁶⁸Ge runs



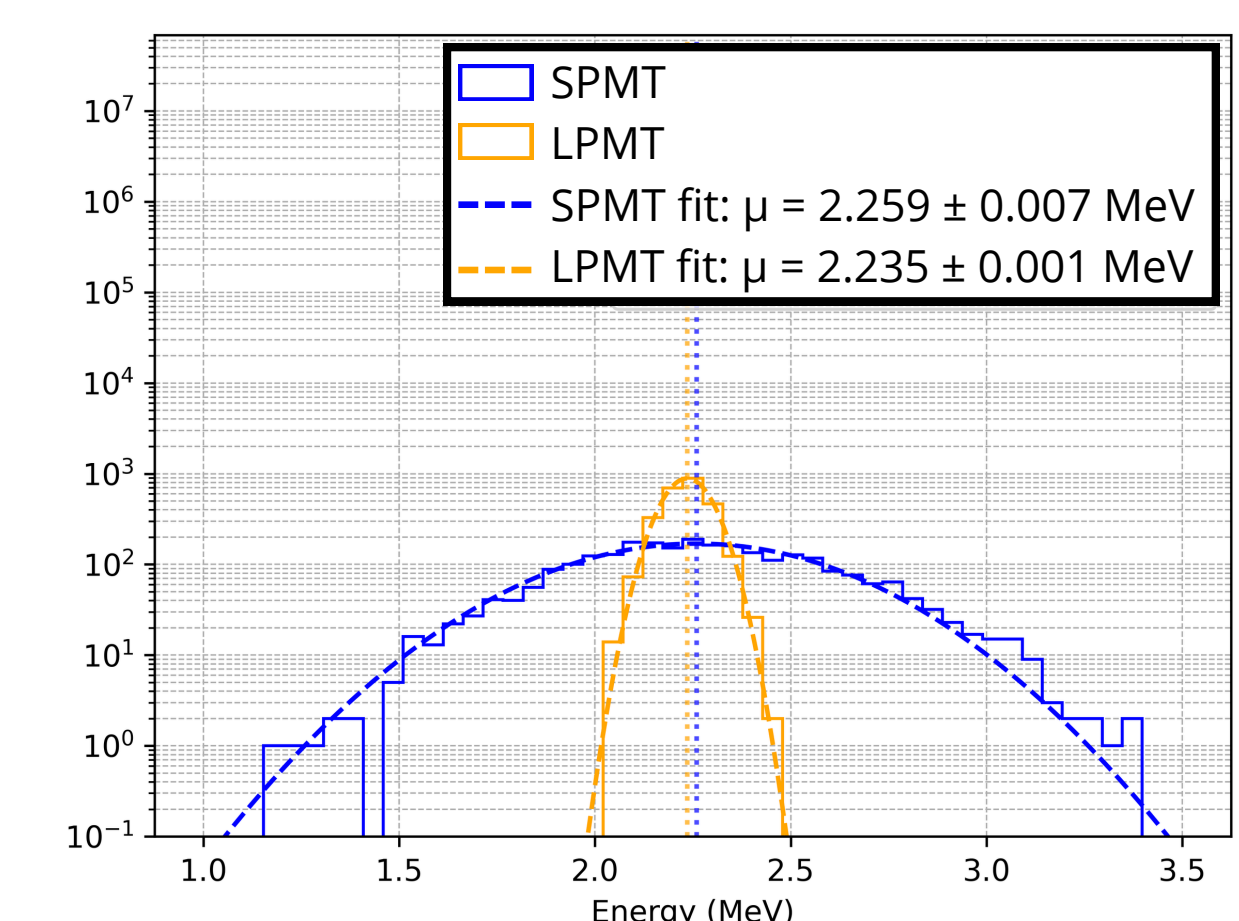
Correction factors from Spallation neutrons and ⁶⁸Ge **consistent within 5%** on the z-axis

Correction factor map in cylindrical coordinates

Energy Reconstruction

$$E_{SPMT} = \left(\frac{N_{hits} - DC_{hits}}{M_n(x, y, z)} \right) \times \frac{E_{n-H}}{N_{hits}^{n-H}(0, 0, 0)}$$

- $E_{n-H} = 2.22$ MeV
- $N_{hits}^{n-H}(0, 0, 0)$: Measured SPMT hits for **calibration source events** at detector center
- N_{hits} : Measured SPMT hits during **Physics events**
- DC_{hits} : SPMT **Dark count rate**
- $M_n(x, y, z)$: **Map correction factor**



Tested on IBD **Delayed** events (2.2 MeV gamma)
Energy reconstructed by SPMTs with **~1% bias** compared to LPMTs

JUNO Work in Progress. June 2026.