Monte Carlo Simulation of the RadioActive isotope Measurement Program at SNOLAB (RAMPS)

CASST 2026

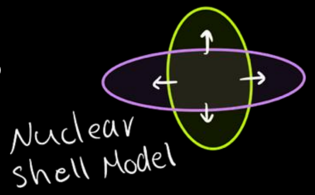
Diba Toyserkani

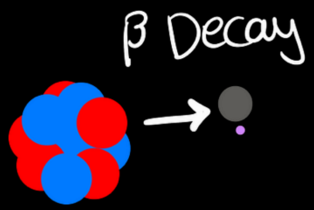
Supervisor: Dr. Matthew Stukel

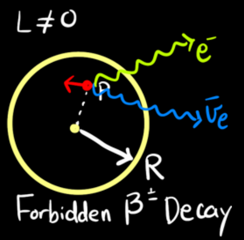
RadioActive isotope Measurement Program at SNOLAB (RAMPS)

Novel measurements of long-lived highly suppressed nuclear decays

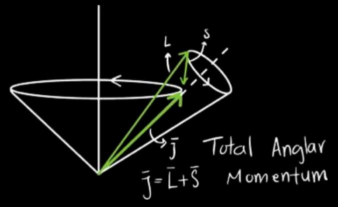
- Nuclear Physics

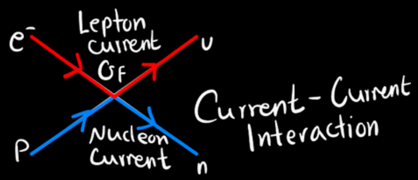


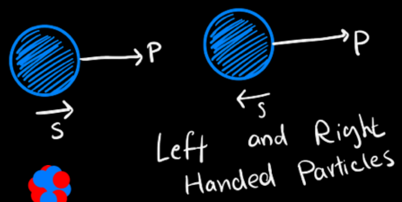




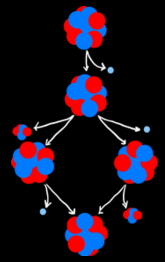
- Astro Particle Physics







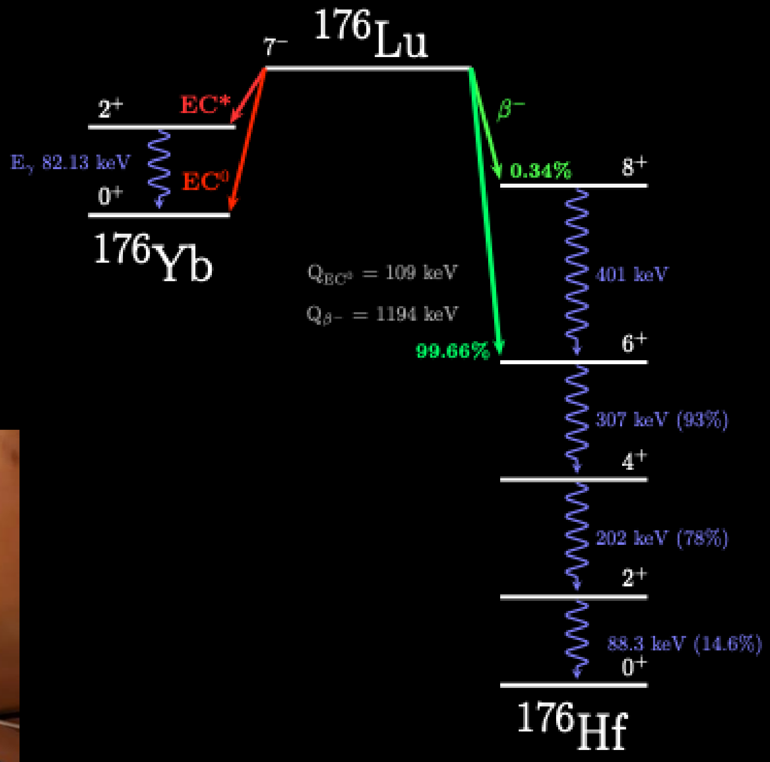
- Geochronology Radioactive Dating



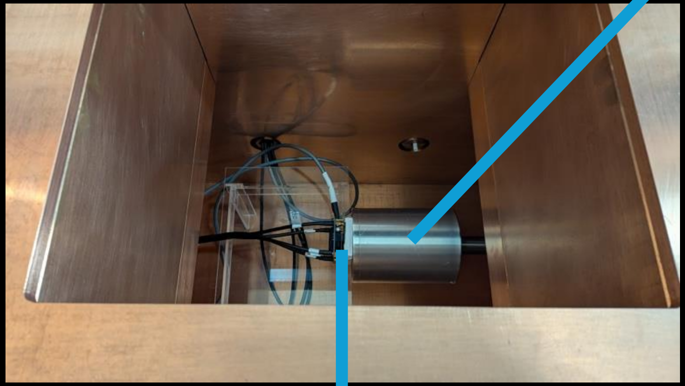
Utilizing already commissioned SNOLAB detector systems

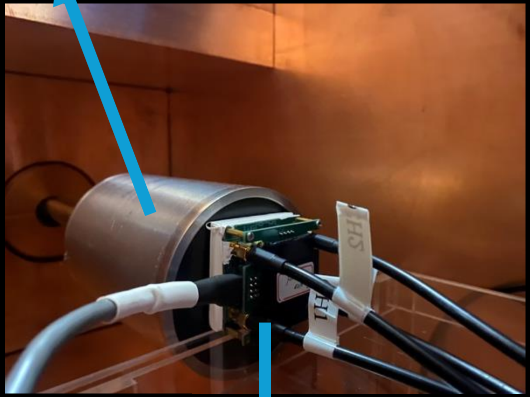
RadioActive isotope Measurement Program at SNOLAB (RAMPS)

- Pilot experiment focuses on $^{176}_{71}\mathrm{Lu}$ excited state electron capture



CTBT High Purity Germanium Detector (HPGe)





Silicon Photomultiplier (SiPM)

Why Doing Simulations?

First Science Run happened in Feb 2026, lots of data from HPGe and SiPM detectors

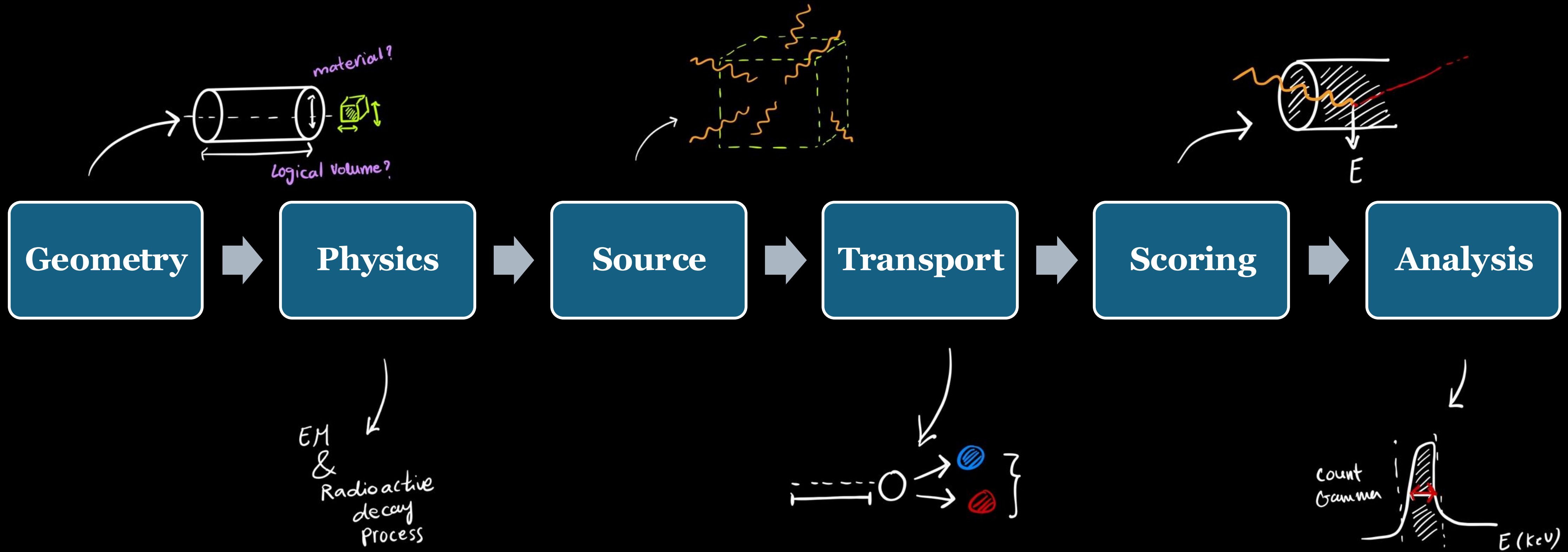
How efficient?

How well resolved?

How much of the signal does the source absorb in itself?

What do two detectors add?

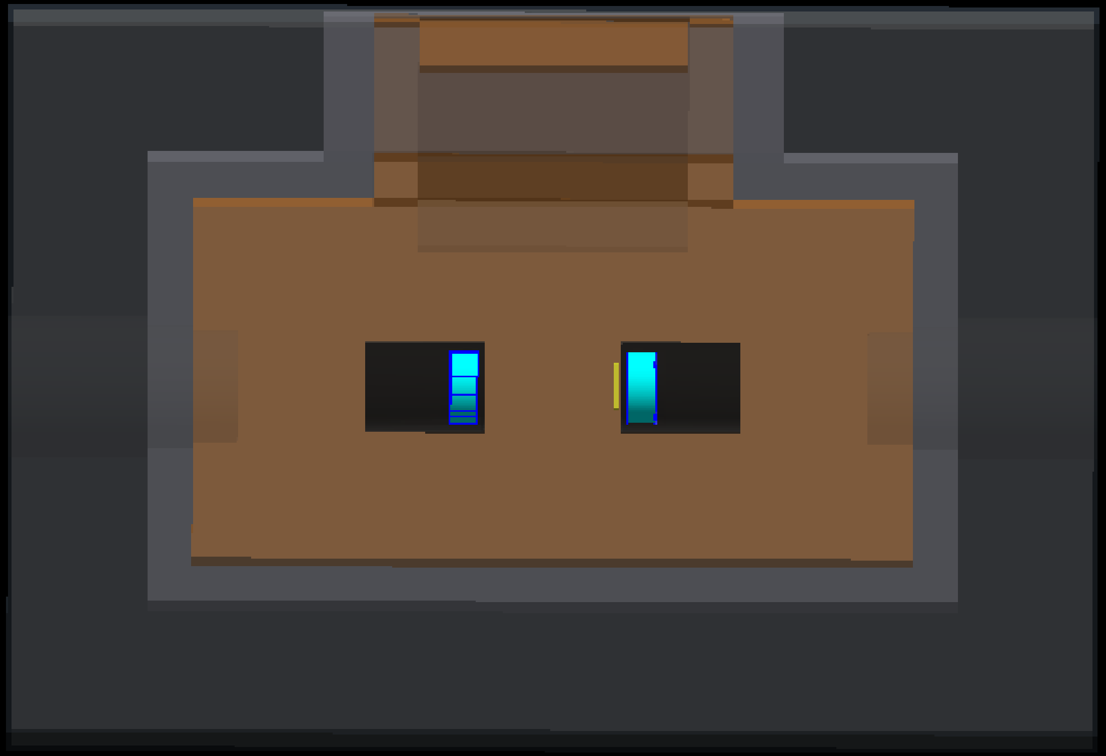
GEANT4

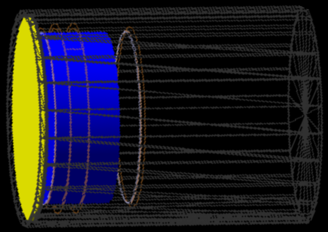


material?
Logical volume?
E
Geometry
Physics
Source
Transport
Scoring
Analysis
EM
&
Radioactive
decay
Process
count
Gamma
E (keV)

Geometry of RAMPS Setup

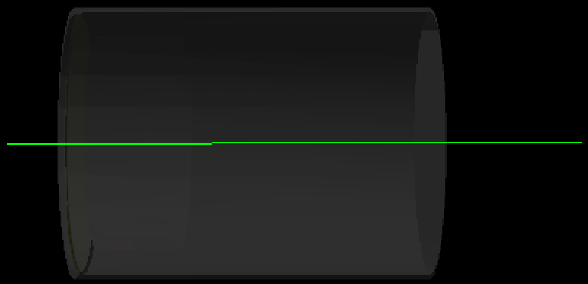
- HPGe crystal: germanium cylinder r = 40.15 mm × 30.6 mm, with dead layers, a 0.6 mm carbon entrance window and an aluminium end cap.
- LYSO target in front of the crystal; a graded Pb / Cu shield surrounds the assembly.



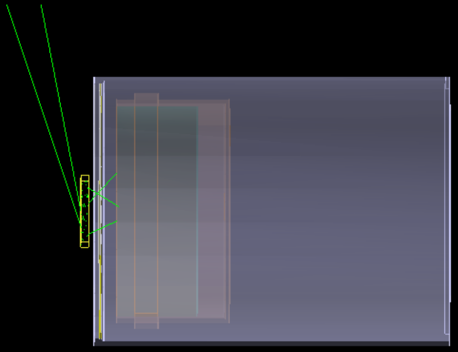


Event Generation

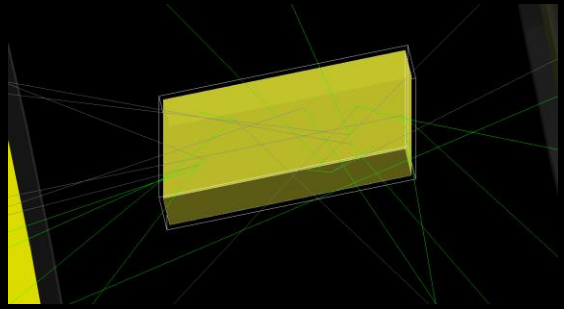
1. Pencil Beam: Mono-energetic γ fired on-axis into the bare detector crystal.
   - Isolates the detector's intrinsic response
   - No source, no solid-angle loss



2. Internal Source: γ generated uniformly & isotropically inside the source crystal.
   - Mimics activity spread through the scintillator
   - Shows self-absorption



3. Decay Cascade: True ^{176}Lu nuclei decayed in source crystal.
   - Full cascades, branching & coincidence summing



Some Definitions for Analysis

For N primary particle generated:

Total Efficiency $\varepsilon_{tot} = \frac{N_{detected}}{N_{emitted}}$

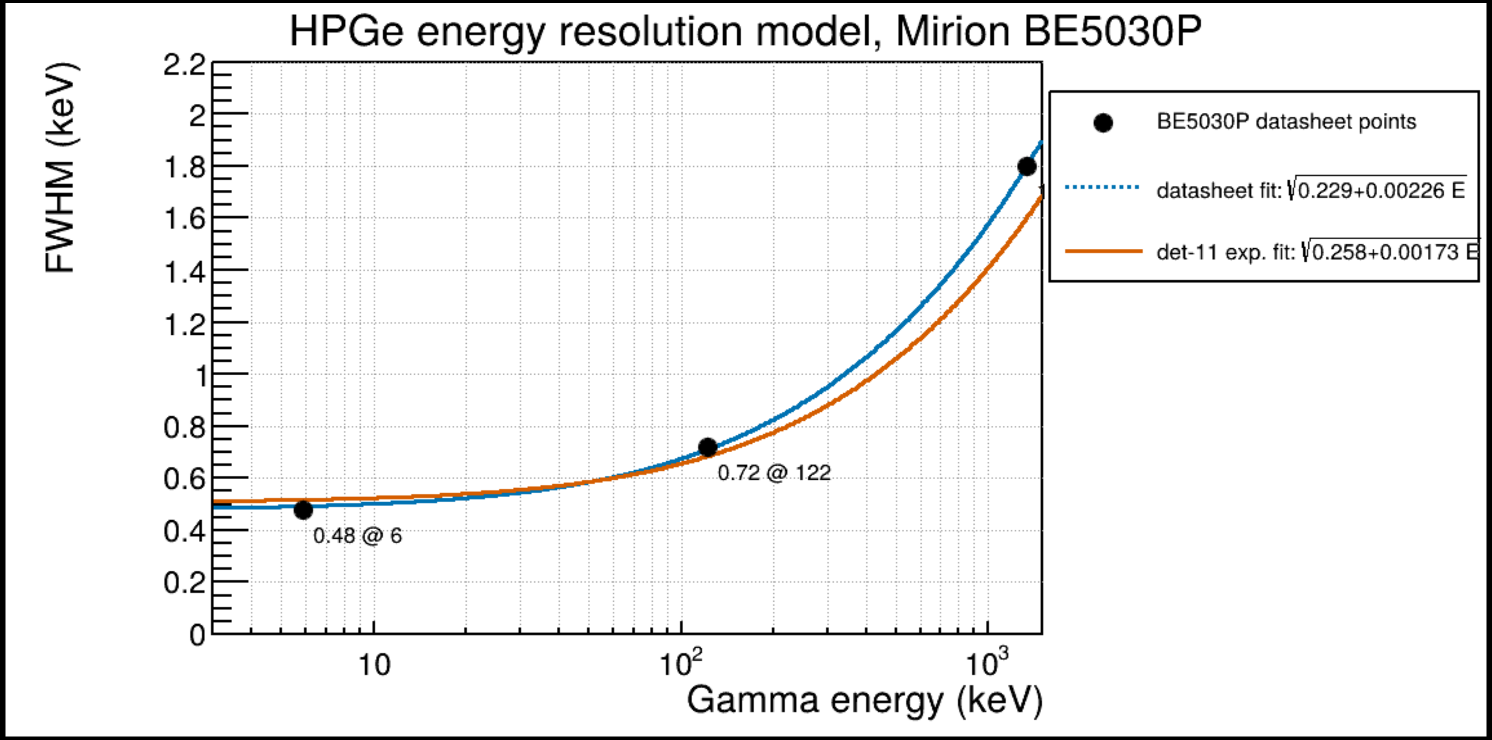
Full Energy Peak Efficiency $\varepsilon_{pk} = \frac{\int_{peak} \mathrm{H11}}{N}$

Detector Resolution

$$\text{FWHM}(E) = \sqrt{a + bE}$$

Datasheet-anchored fit to the BE5030P FWHM specifications

(0.48 keV at 5.9 keV, 0.72 keV at 122 keV, 1.80 keV at 1332 keV)



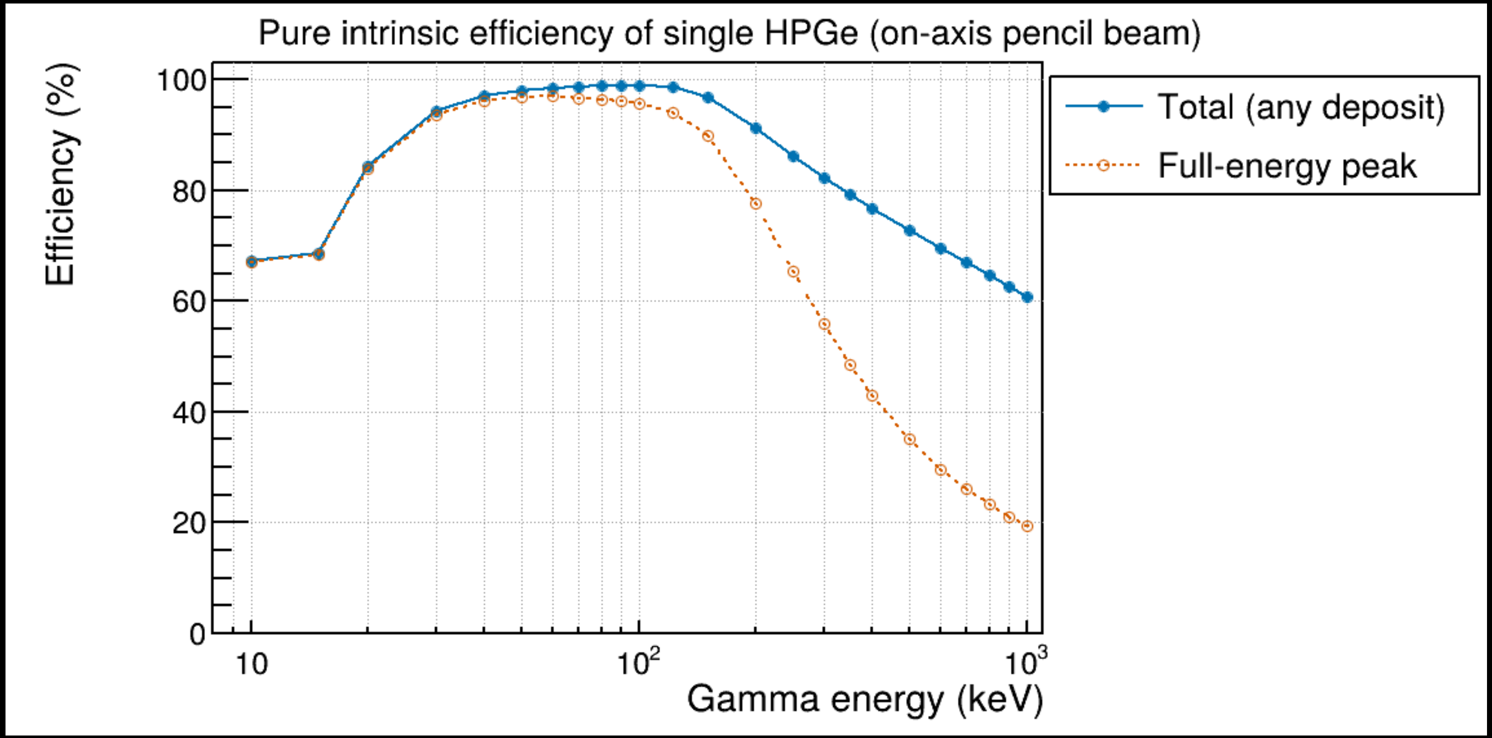
Intrinsic HPGe Detector Efficiency

Method: bare HPGe,

a mono-energetic pencil beam on-axis.

10 → 1000 keV

Peak efficiency maxes at ~97% at 50–60 keV; total stays 98–99% across 60–120 keV.

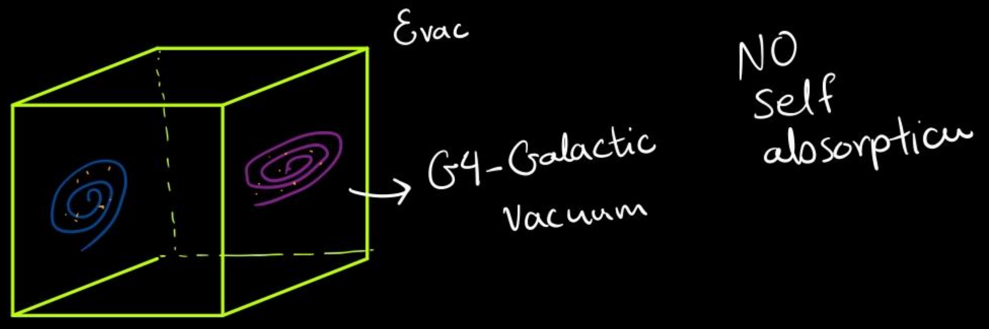


Absolute LYSO Efficiency

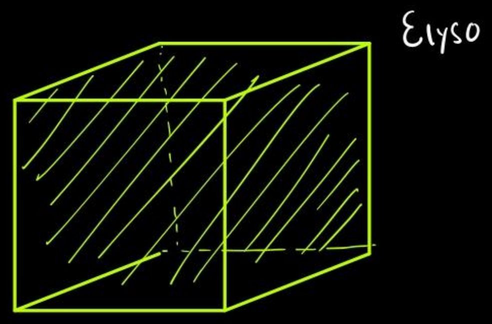
$$\varepsilon_{abs} = \varepsilon_{int} \times G \times S$$

ε_{int} : detector's intrinsic efficiency

Geometric Collection $G = \dfrac{\varepsilon_{vac}}{\varepsilon_{int}}$



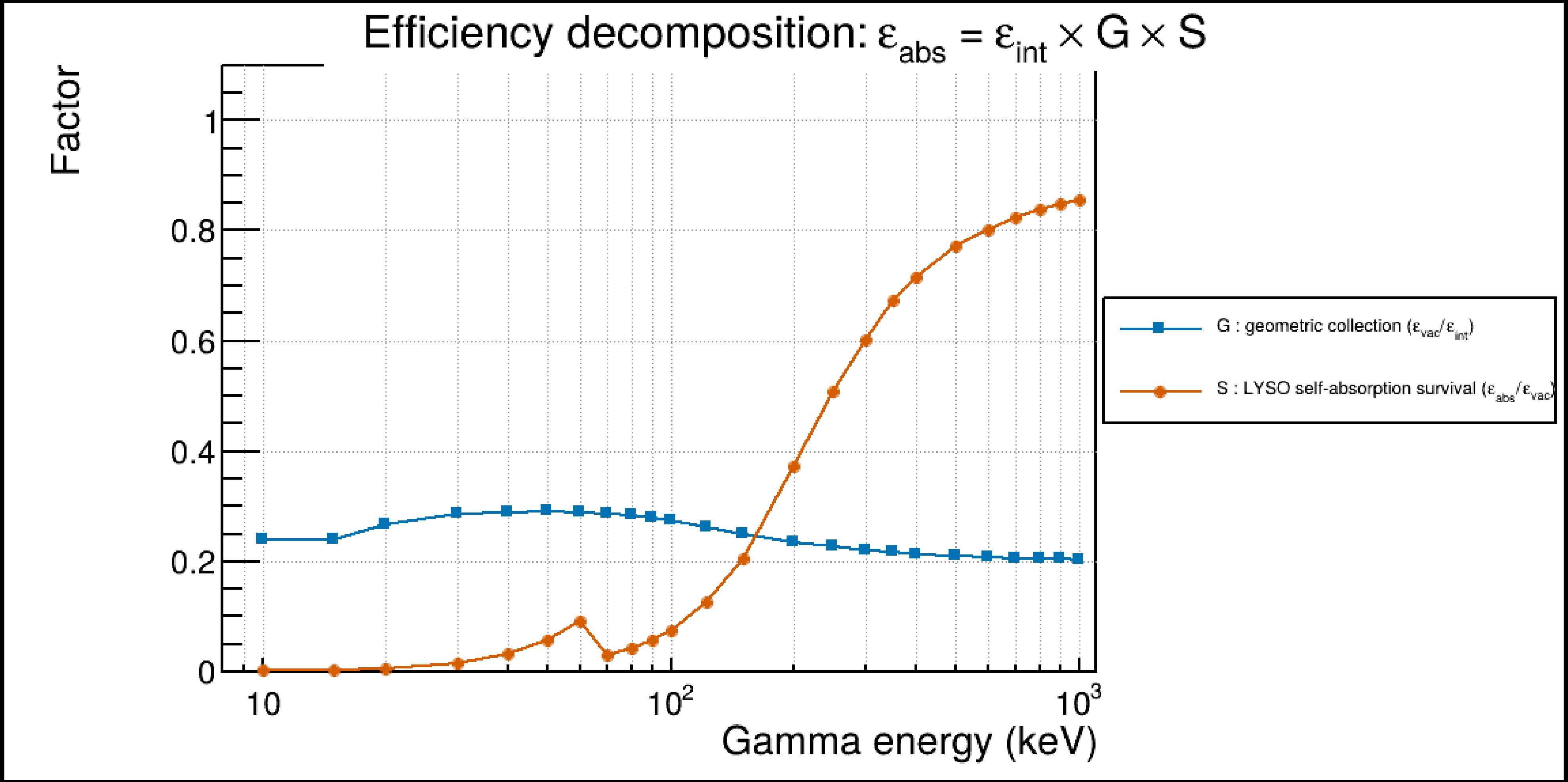
the fraction of isotropically emitted photons that the detector both intercepts and fully absorbs, relative to the on-axis intrinsic value



Self-absorption Survival $S = \dfrac{\varepsilon_{lyso}}{\varepsilon_{vac}}$

the probability that an emitted photon escapes the crystal without losing energy

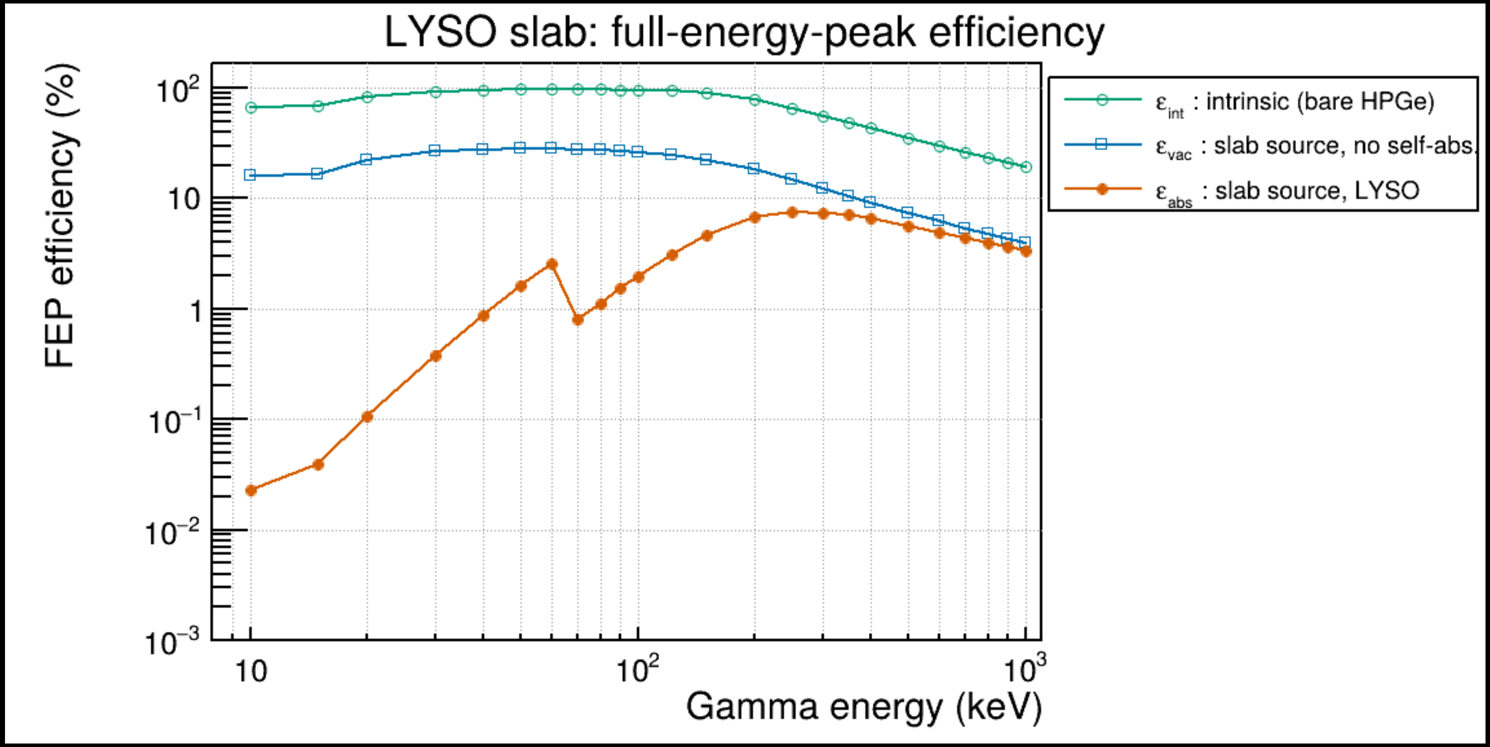
Absolute LYSO HPGe Efficiency



Absolute LYSO HPGe FEP Efficiency

geometric-only crystal source sits at~14 % (the solid-angle ceiling)

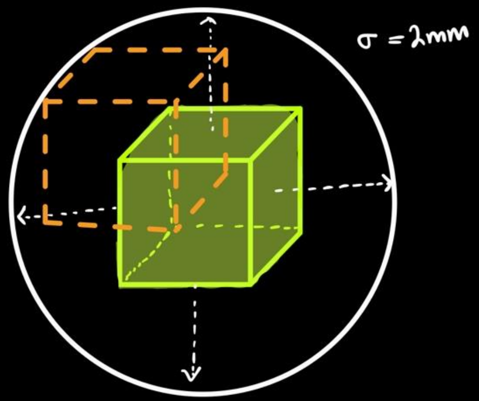
absolute LYSO efficiency is suppressed below 100 keV by self-absorption, peaking at only~1.1 % near 400 keV.



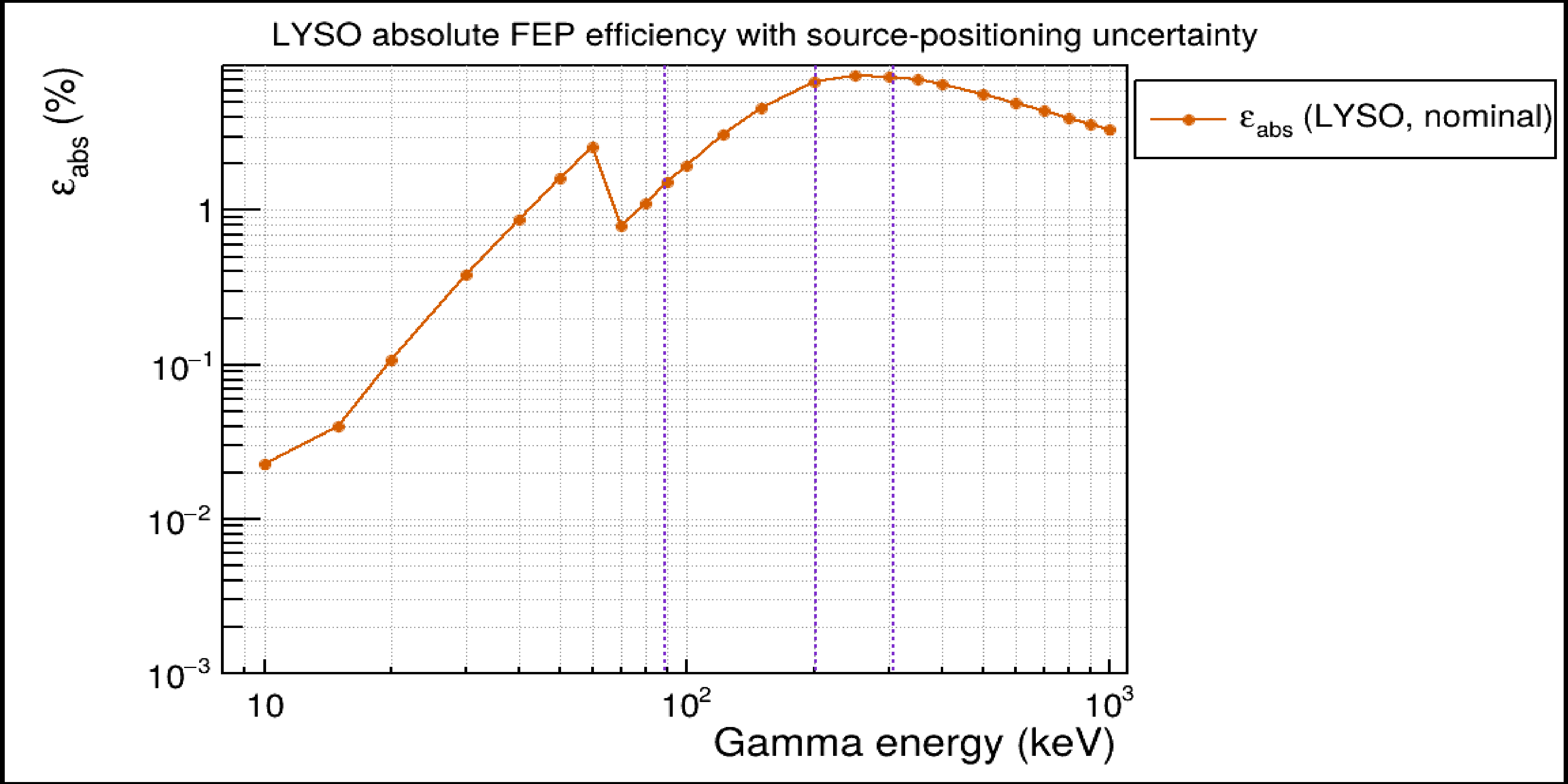
Absolute LYSO HPGe Efficiency Uncertainty

- Two scans: a random Gaussian cloud (σ = 2 mm per axis) and a controlled one-axis-at-a-time sweep.

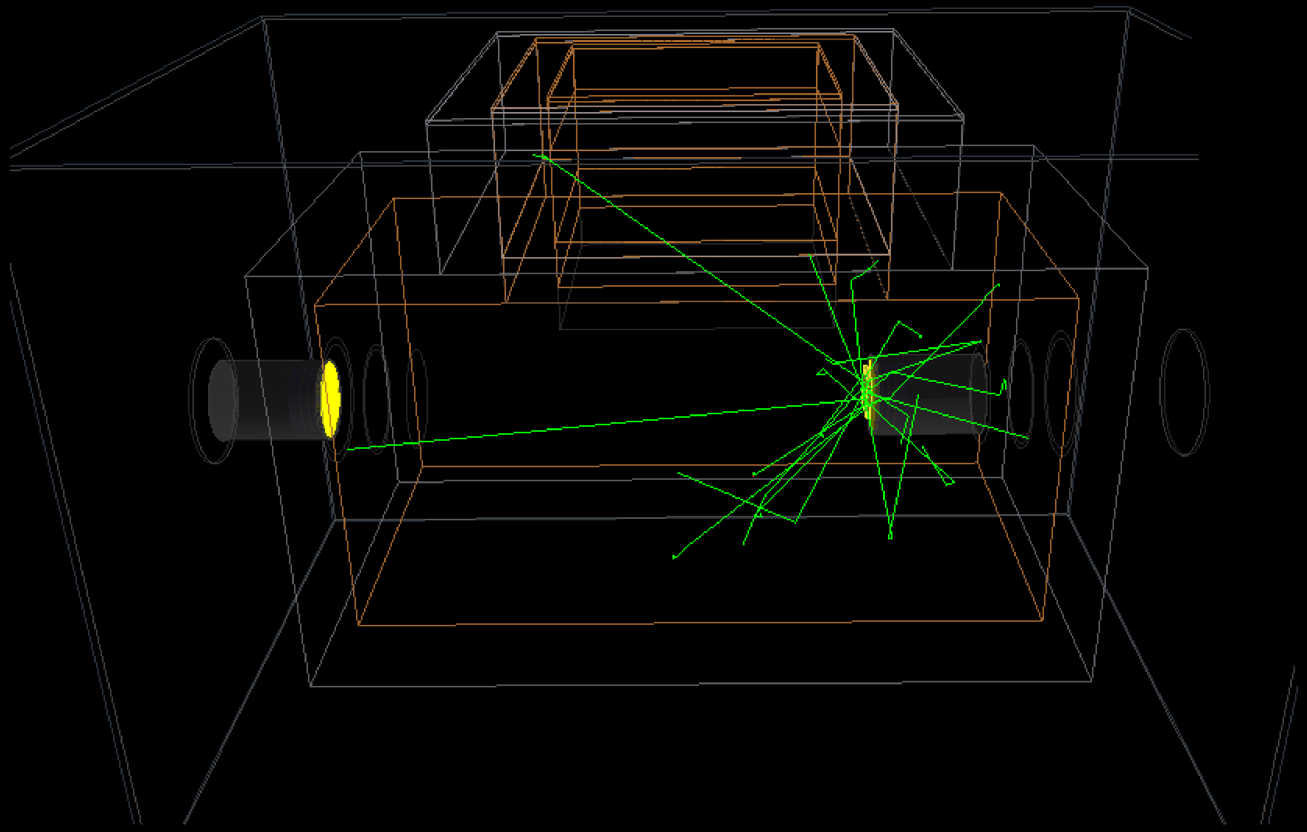
- The source–detector standoff (x) dominates; the transverse axes matter far less.

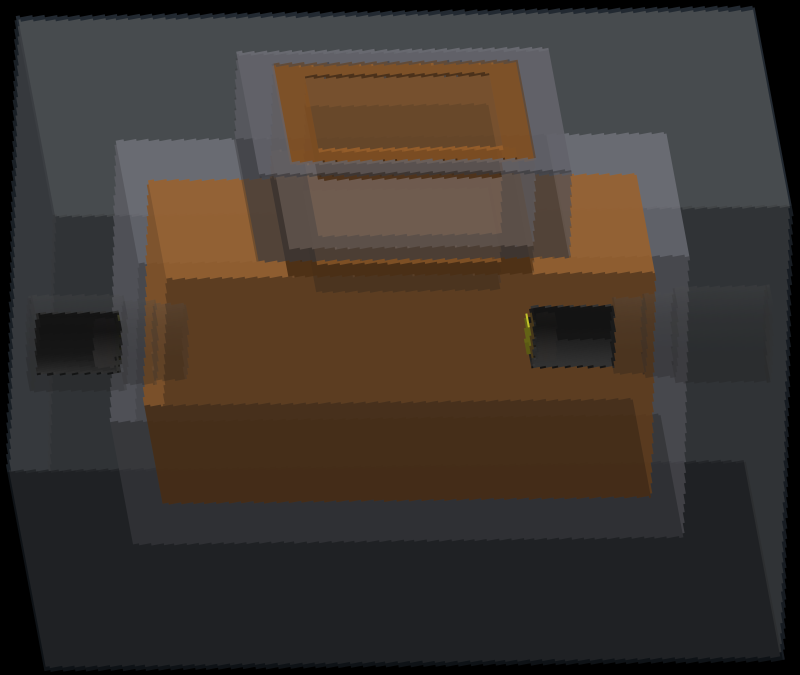


Absolute LYSO HPGe Efficiency Uncertainty

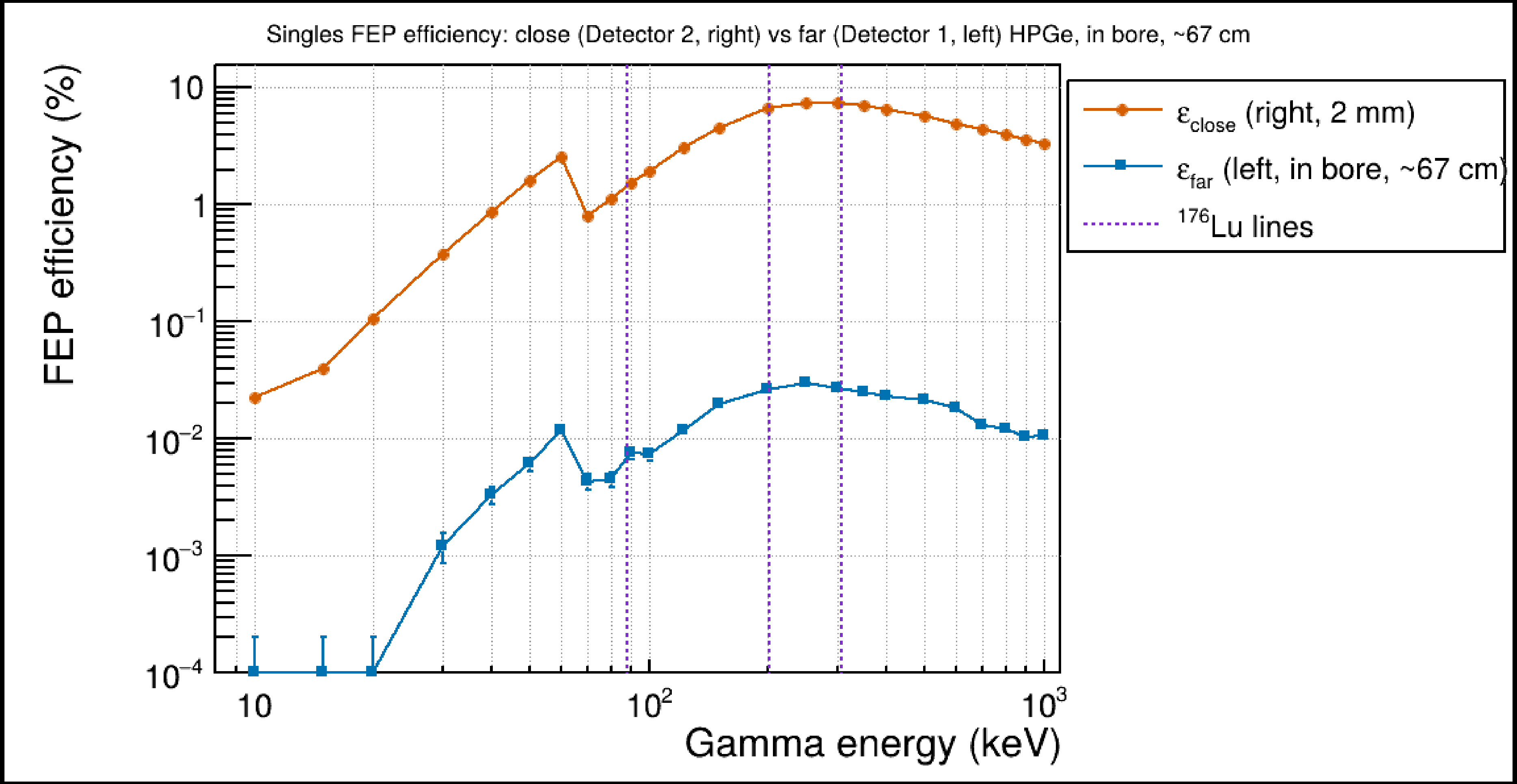


Two HPGe Detectors Coincidence Study





Two Detectors Coincidence Analysis



What Have Been Established So Far

- The geometry represents the BE5030P detector setup and LEMER Shielding around the system
- Intrinsic efficiency follows the expected HPGe shape, peaking near 97%.
- The low-energy response is self-absorption
- A datasheet-anchored resolution model is adopted, valid from 5.9 keV to > 1 MeV.

Future Work

Shield-background Study

- Use the graded-shield geometry to simulate radio-impurities (^{210}Pb) confined to each shield layer.

Optical Simulation of SiPM Response

Comparing Simulation with Experimental Data from Science Run 1

Thanks for listening!

I am eternally grateful to Dr. Matthew Stukel. For giving me the opportunity to continue working on this project and for all of the support and mentoring.

Thank you so much to Dr. Hector Herrera from Canadian Nuclear Laboratories for his continues support with optical simulations.

Thank you to Dr. Ian Lawson and Steffan Louma for their continues help.

Thanks to Sanjit for being so kind and doing measurements on my behalf underground .

References

Boshkova, T., & Minev, L. (2001). Corrections for self-attenuation in gamma-ray spectrometry of bulk samples. *Applied Radiation and Isotopes*, 54(5), 777–783. https://doi.org/10.1016/S0969-8043(00)00319-5

Jodłowski, P. (2006). Self-absorption correction in gamma-ray spectrometry of environmental samples - an overview of methods and correction values obtained for the selected geometries. *Nukleonika*, 51(Supplement 2), S21–S25.

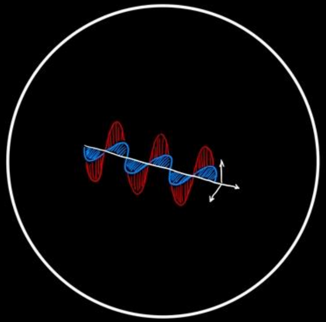
Khater, A. E. M., & Ebaid, Y. Y. (2008). A simplified gamma-ray self-attenuation correction in bulk samples. *Applied Radiation and Isotopes*, 66(3), 407–413. https://doi.org/10.1016/j.apradiso.2007.10.007

Geant4 Collaboration. *Geant4 User's Guide for Application Developers*. CERN. Retrieved from https://geant4-userdoc.web.cern.ch/UsersGuides/ForApplicationDeveloper/html/index.html

Backup: Monte Carlo Simulations

- Computational algorithms based on repeated random sampling for obtaining numerical results.
- Simulate the process thousands or millions of times with random inputs and look at the distribution of outcomes.
- Fire particles from a source, then follow each one and its secondaries step-by-step through the real geometry, sampling every interaction from measured cross-sections.
- Record the energy each particle leaves in each volume. Millions of histories → the histogram a real detector would build.

Backup: Physics List

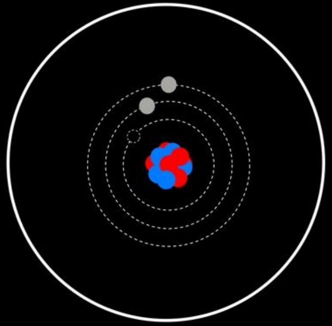


Electromagnetic physics

G4EmStandardPhysics_option4 (Livermore / Penelope): photoelectric cross-sections and absorption edges, essential near the Lu K-edge at 63.3 keV that governs the 88 keV line.

Radioactive decay

Full Geant4 radioactive-decay treatment (biased): β^- spectra, γ cascades, internal conversion and coincidence summing.



Atomic relaxation

Fluorescence, Auger and PIXE enabled: needed for the characteristic X-rays and for the graded shield, whose Cu liner absorbs Pb K X-rays (75–88 keV).

Back up: Scoring the Hits

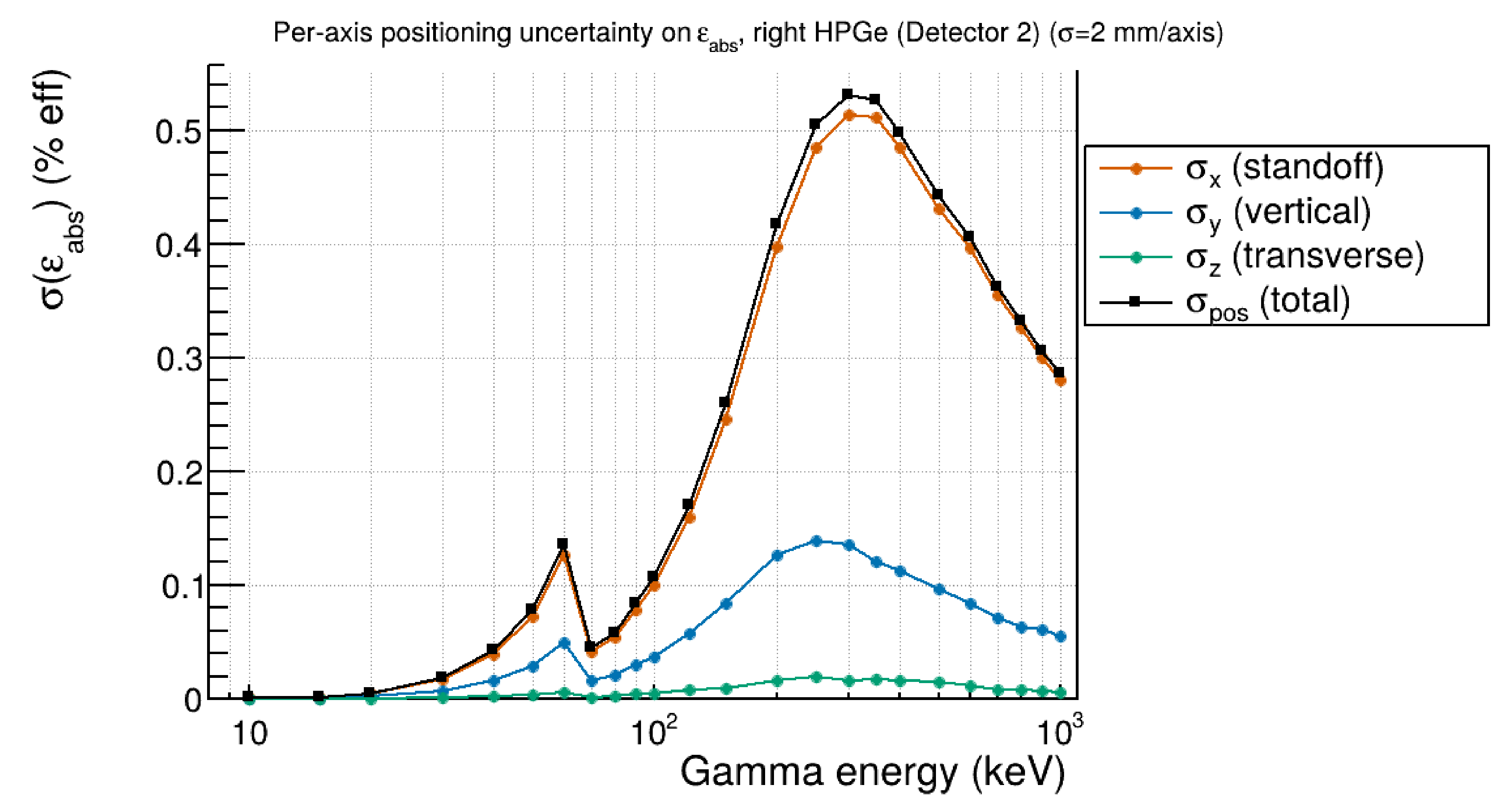
Energy deposited per event is histogrammed per volume:

H10 = target (LYSO)

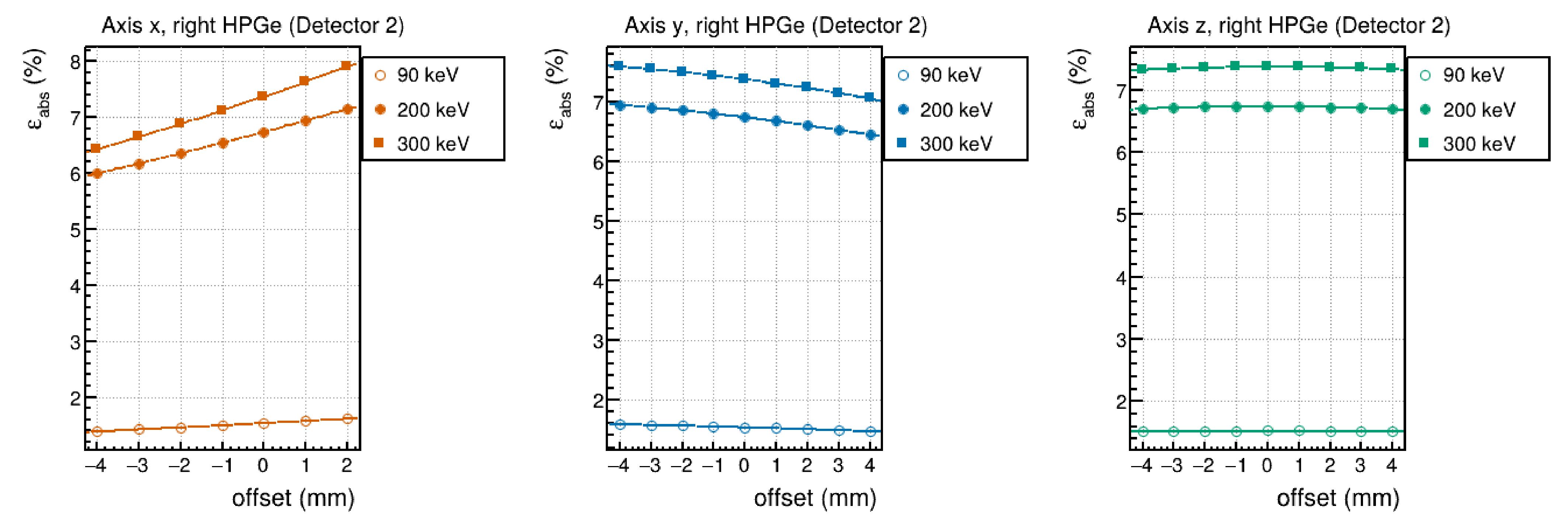
H11 / H12 = detector 1 / 2.

```
#
## Configure histograms
/analysis/h1/set 0  350 0. 3.5 MeV     # H10 - Target spectrum
#/analysis/h1/set 1  350 0. 3.5 MeV     # H11 - Detector 1 spectrum
#/analysis/h1/set 2  350 0. 3.5 MeV     # H12 - Detector 2 spectrum
#/analysis/h1/set 3  350 0. 3.5 MeV     # H13 - Combined detectors
#/analysis/h1/set 4  350 0. 3.5 MeV     # H14 - Total energy
#
## Coincidence spectra
#/analysis/h1/set 5  350 0. 3.5 MeV     # H15 - Target-Det1 coincidence
#/analysis/h1/set 6  350 0. 3.5 MeV     # H16 - Target-Det2 coincidence
#/analysis/h1/set 7  350 0. 3.5 MeV     # H17 - Det1 in Det1-Det2 coinc
#/analysis/h1/set 8  350 0. 3.5 MeV     # H18 - Det2 in Det1-Det2 coinc
#/analysis/h1/set 9  700 0. 7.0 MeV     # H19 - Sum energy in coinc
#/analysis/h1/set 10 700 0. 7.0 MeV     # H20 - Triple coincidence
#
## Anti-coincidence spectra
#/analysis/h1/set 11 350 0. 3.5 MeV     # H21 - Target only
#/analysis/h1/set 12 350 0. 3.5 MeV     # H22 - Detector 1 only
#/analysis/h1/set 13 350 0. 3.5 MeV     # H23 - Detector 2 only
#
## Decay emission spectra - HIGH RESOLUTION
#/analysis/h1/set 14 700 0. 3.5 MeV     # H24 - Full spectrum (5 keV/bin)
#/analysis/h1/set 15 1000 0. 1.0 MeV    # H25 - Low energy (1 keV/bin)
#/analysis/h1/set 16 5000 0. 0.5 MeV    # H26 - Very low energy (0.1 keV/bin)
#
```

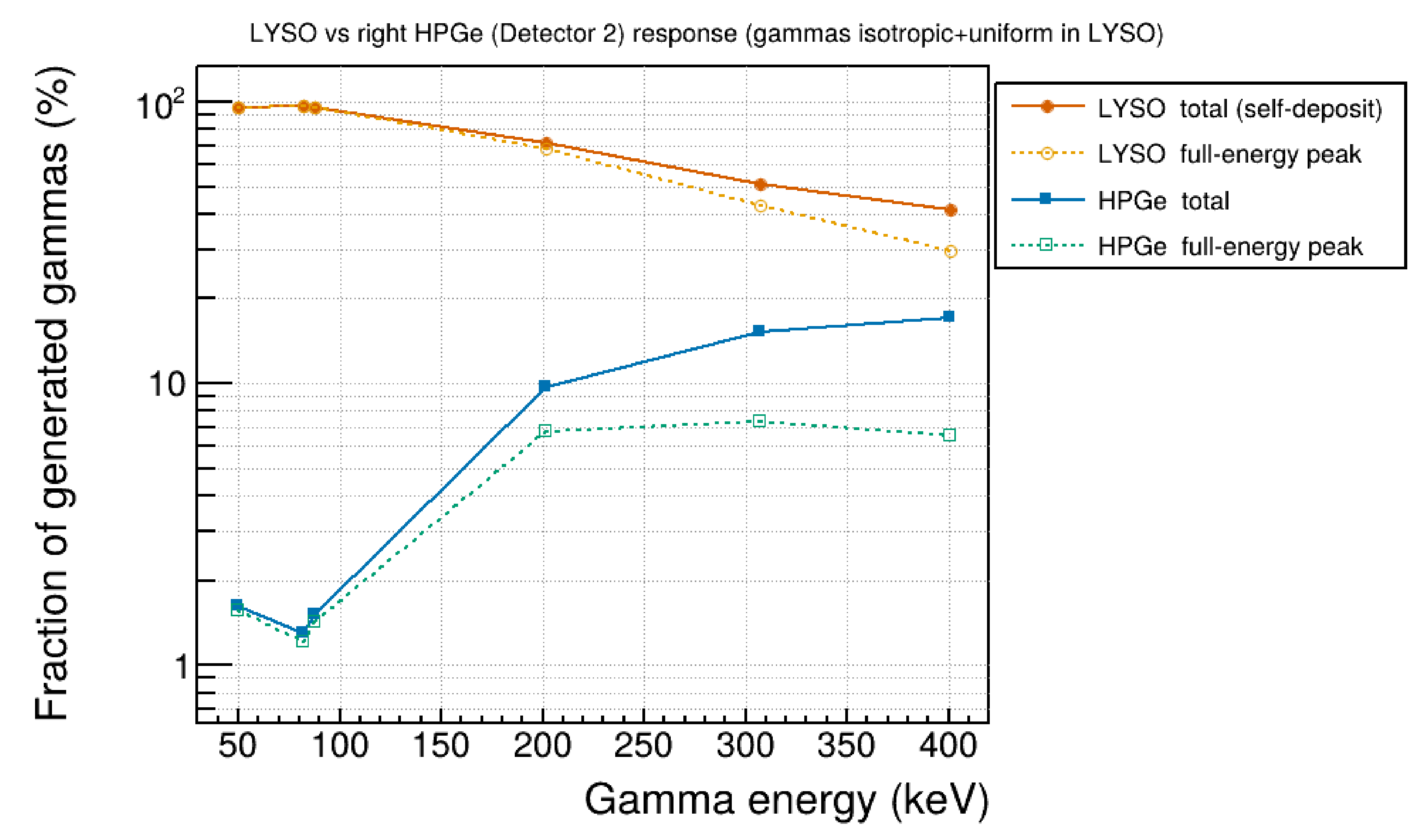
Backup: Absolute LYSO Efficiency Uncertainty



Backup: Absolute LYSO Efficiency Uncertainty



Backup: Target vs Detector



Backup: Coincidence Spectra