# Physics Motivation and Status of the RENE Experiment

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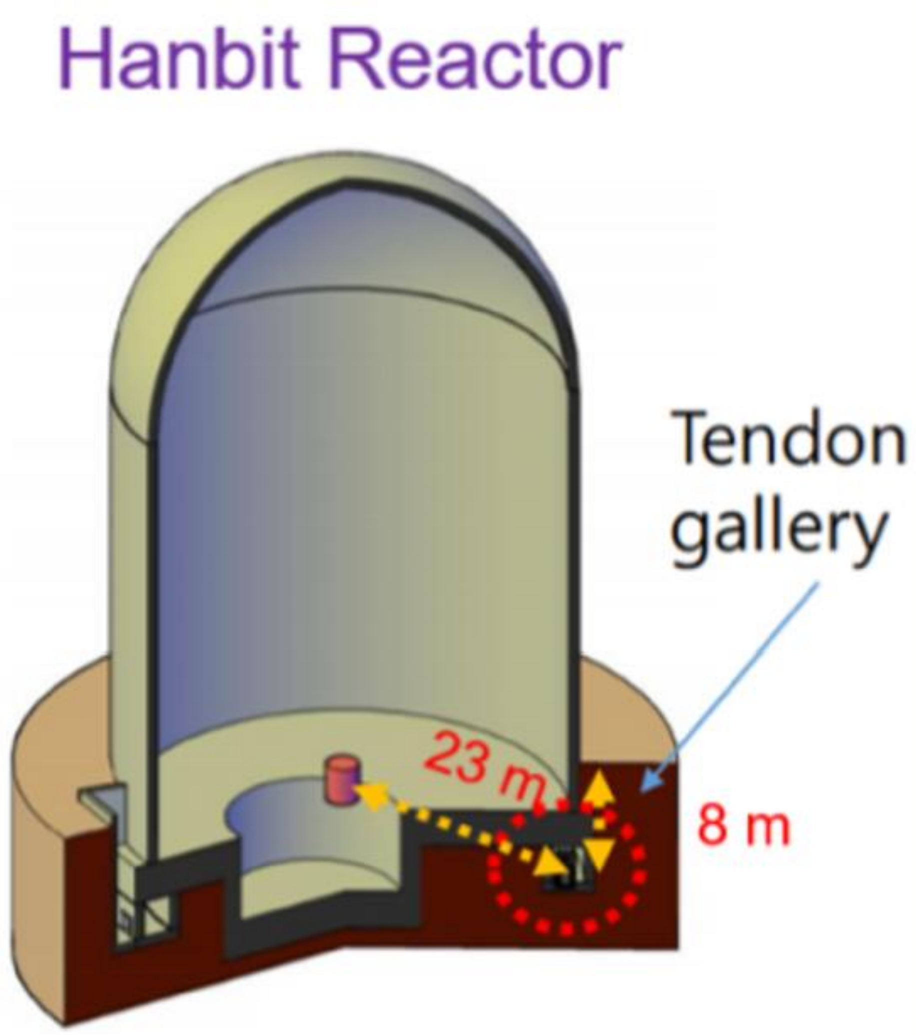
CPNR-OMEG Joint Workshop, May 22, 2026

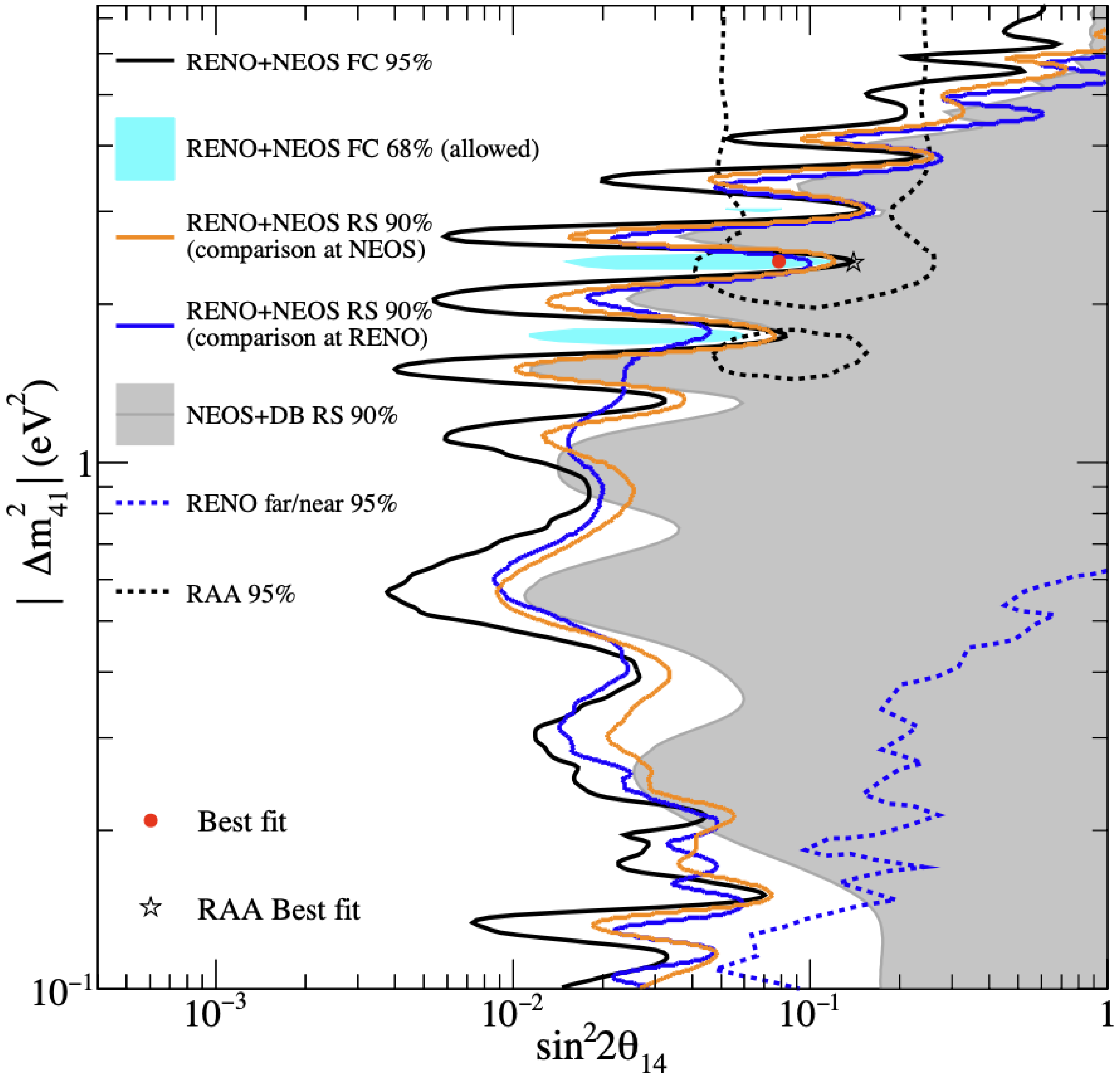
# Introduction

**RENE (Reactor Experiment for Neutrinos and Exotics)**

- **Aim to search for the sterile neutrino at $\Delta m^2_{41}$ ~2 eV².**
- **High-concentration 0.5% Gd-loaded Liquid Scintillator(LS) detector.**
- **The baseline of ~ 23 m is from the reactor core.**

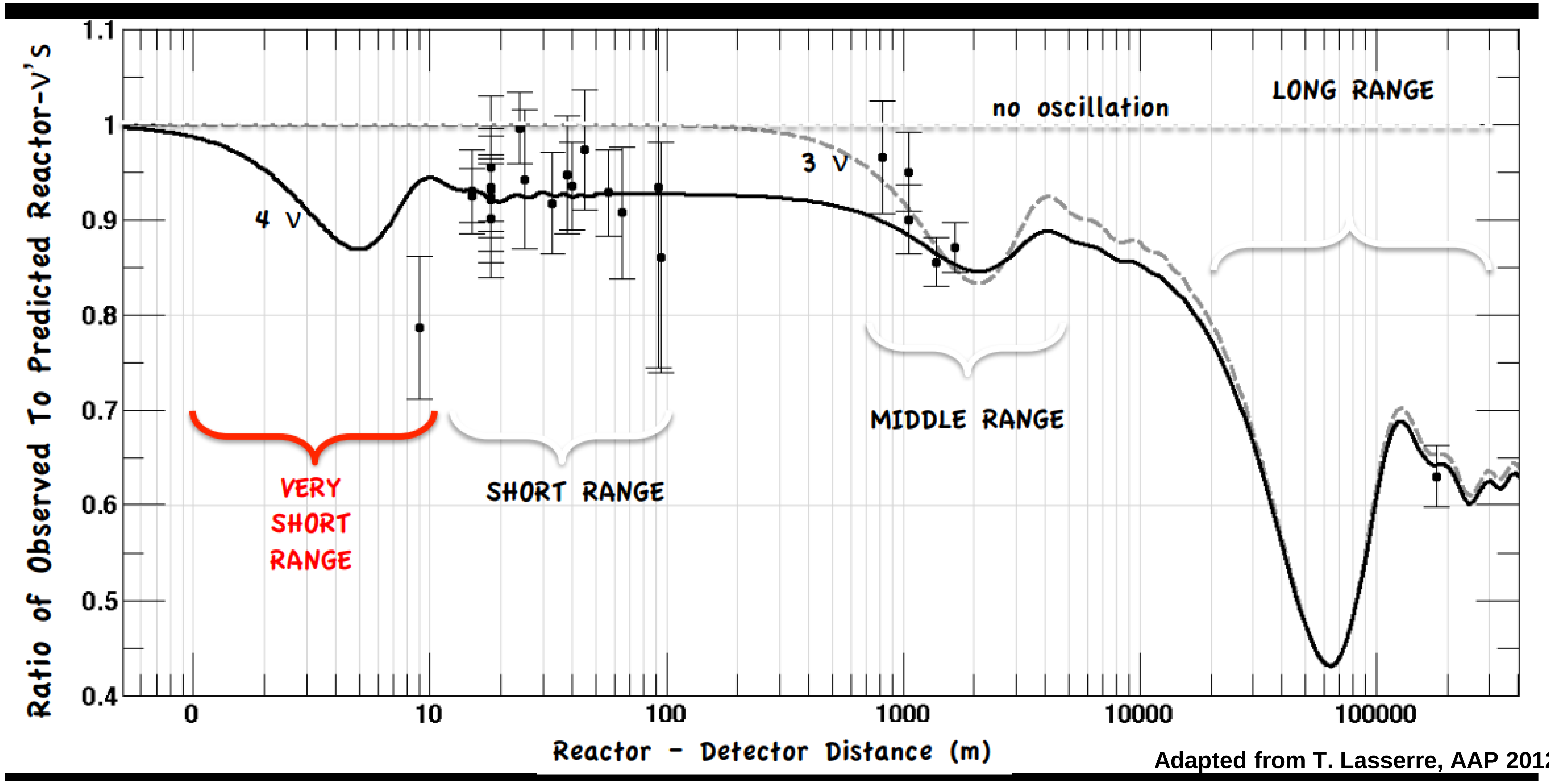






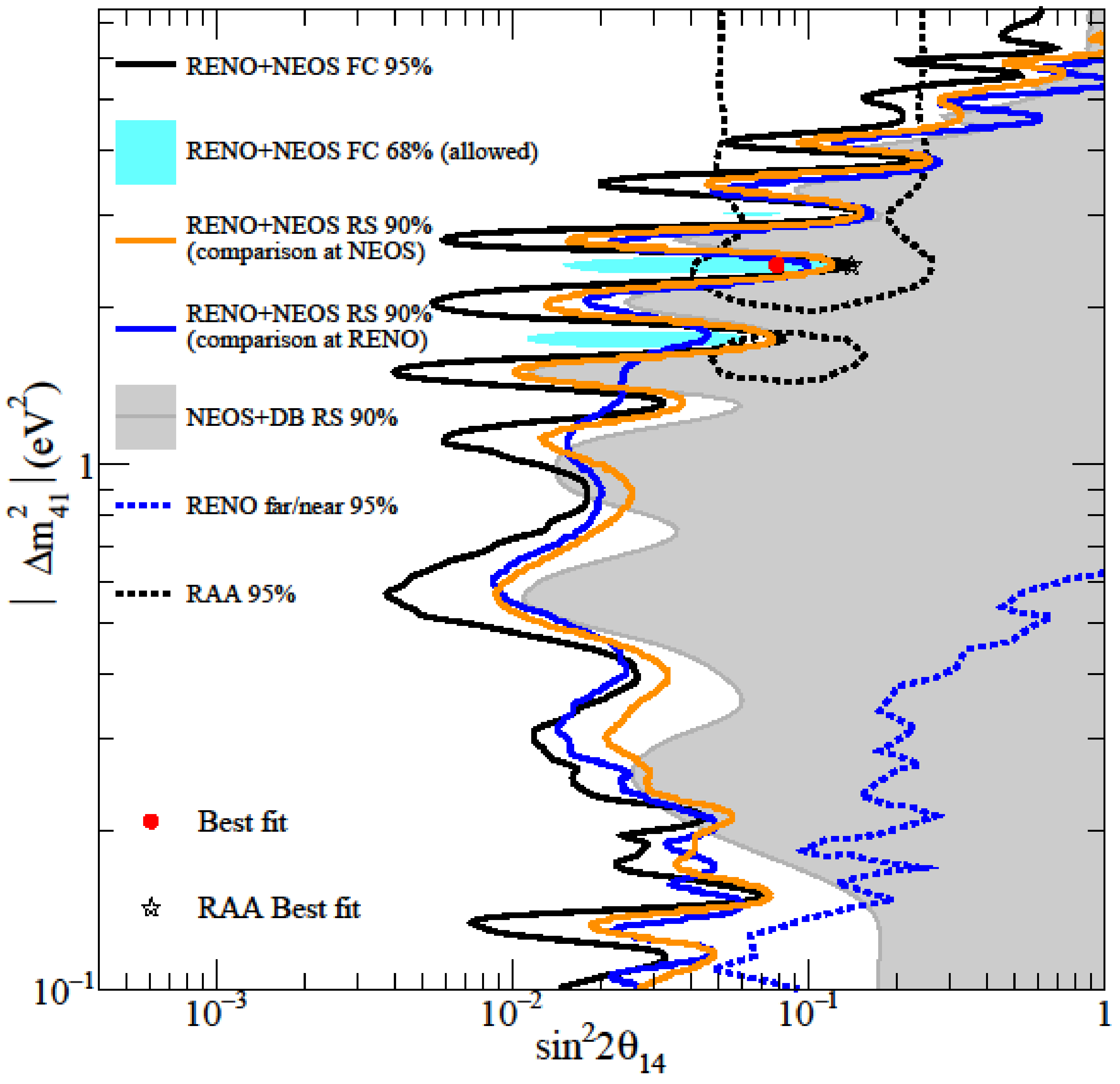
# Reactor Neutrino Anomalies and Sterile Neutrinos

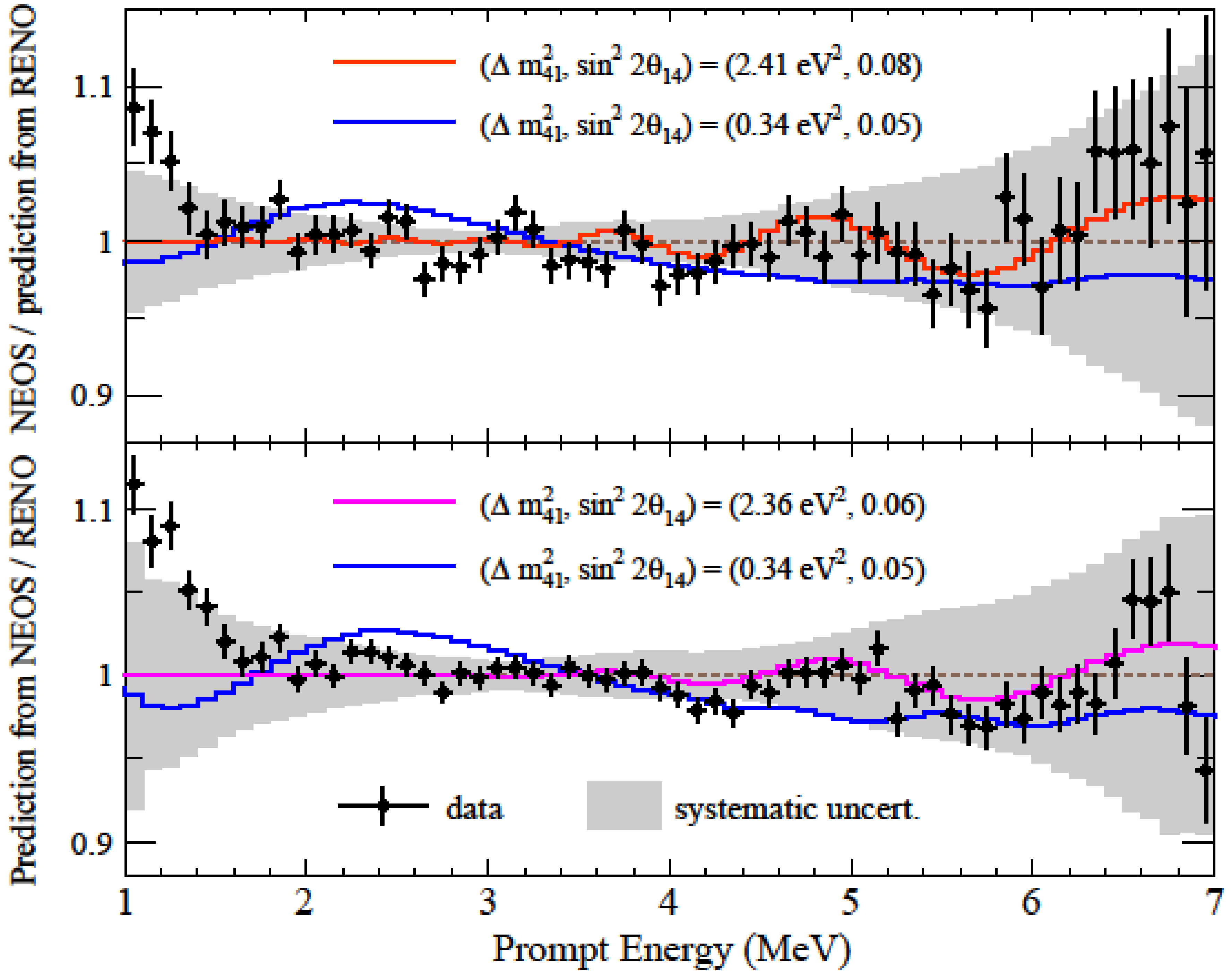
- In 2009, revision of the reactor neutrino spectrum prediction revealed an approximately 6% deficit in previous reactor data
- Sterile neutrinos were proposed as one possible explanation

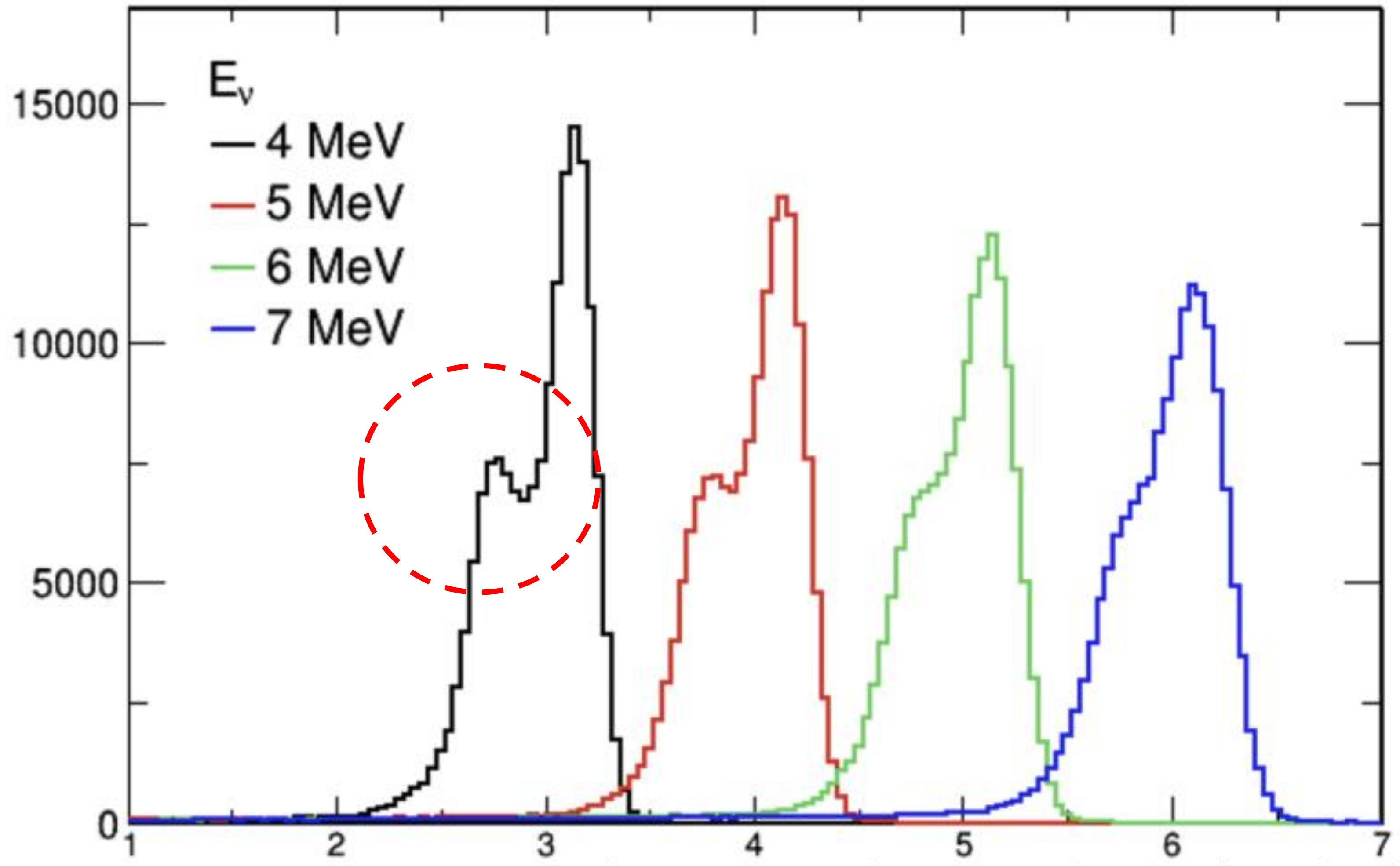



Adapted from T. Lasserre, AAP 2012

# Motivation for the RENE Experiment




Neutrino Experiment Oscillation at Short Baseline – Yoomin Oh, @The 39th ISNP (2017)


Conf. Series 1216(2019) 012004

- ***RENO-NEOS joint analysis*** **hint for the sterile neutrino at $\Delta m^2_{41} \sim 2\ eV^2$.**
- **To cross-check RENO-NEOS result, need to improve systematics.**
- **NEOS detector has 2nd peaks, which come from the escaping gammas, in the main peak.**
- **A gamma catcher is needed to improve energy resolution.**

# RENE Detector Overview

## Scintillator-Based Detector

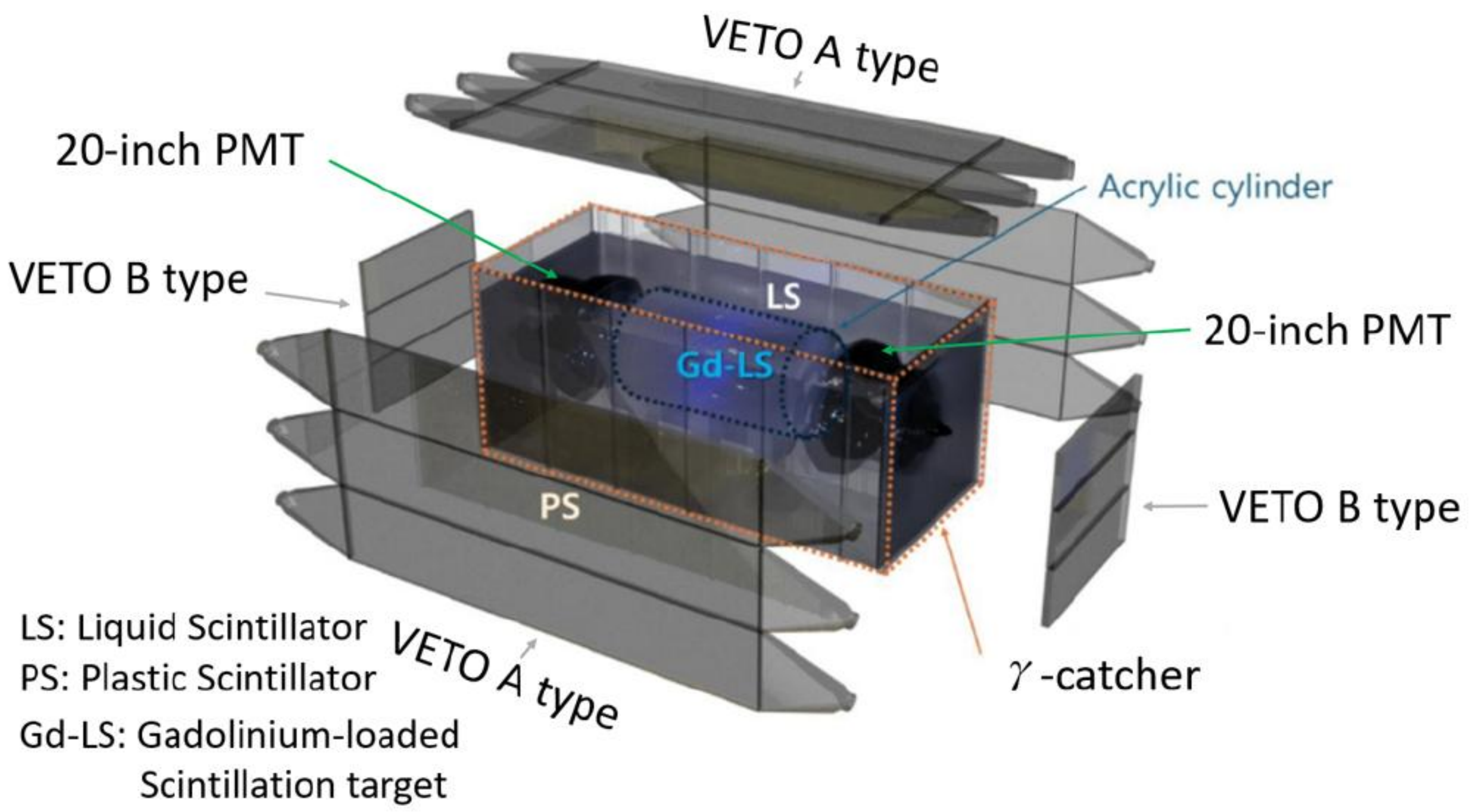
## Target

- Radius: 275 mm, Length: 1200 mm
- Gd-loaded LS (Gd 0.5%)
- Made of acrylic (8 mm thick)

## Gamma Catcher (GC)

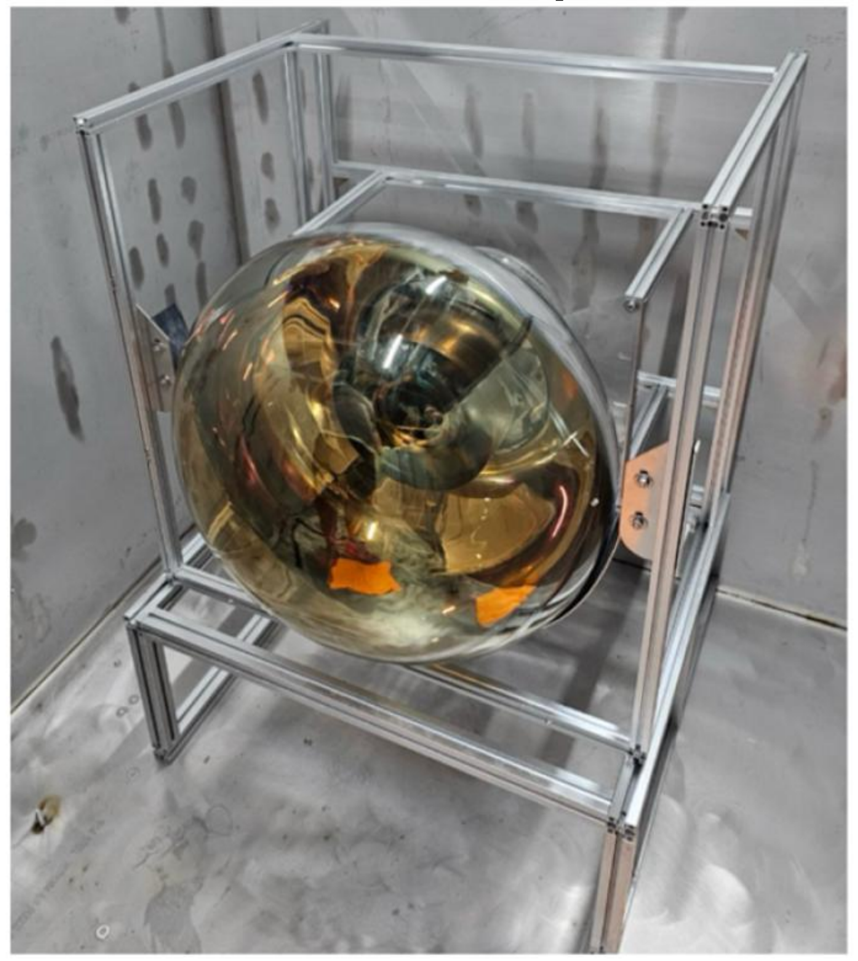
- 2800 mm × 1200 mm × 1200 mm
- Gd-undoped LS
- Made of stainless steel (5 mm thick)

## Veto System and Passive Shielding



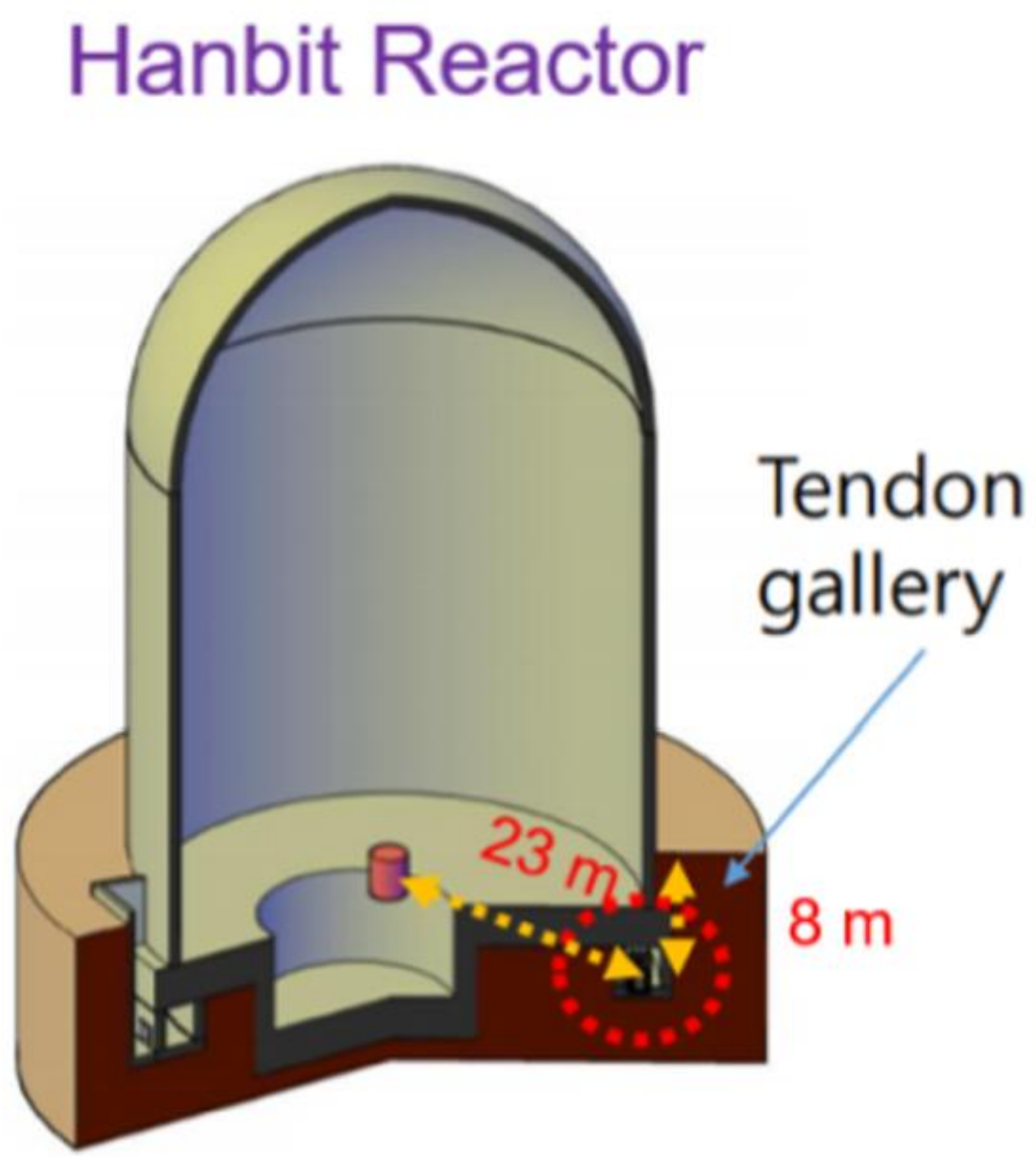

Target

20-inch PMT
(Hamamatsu R12860)



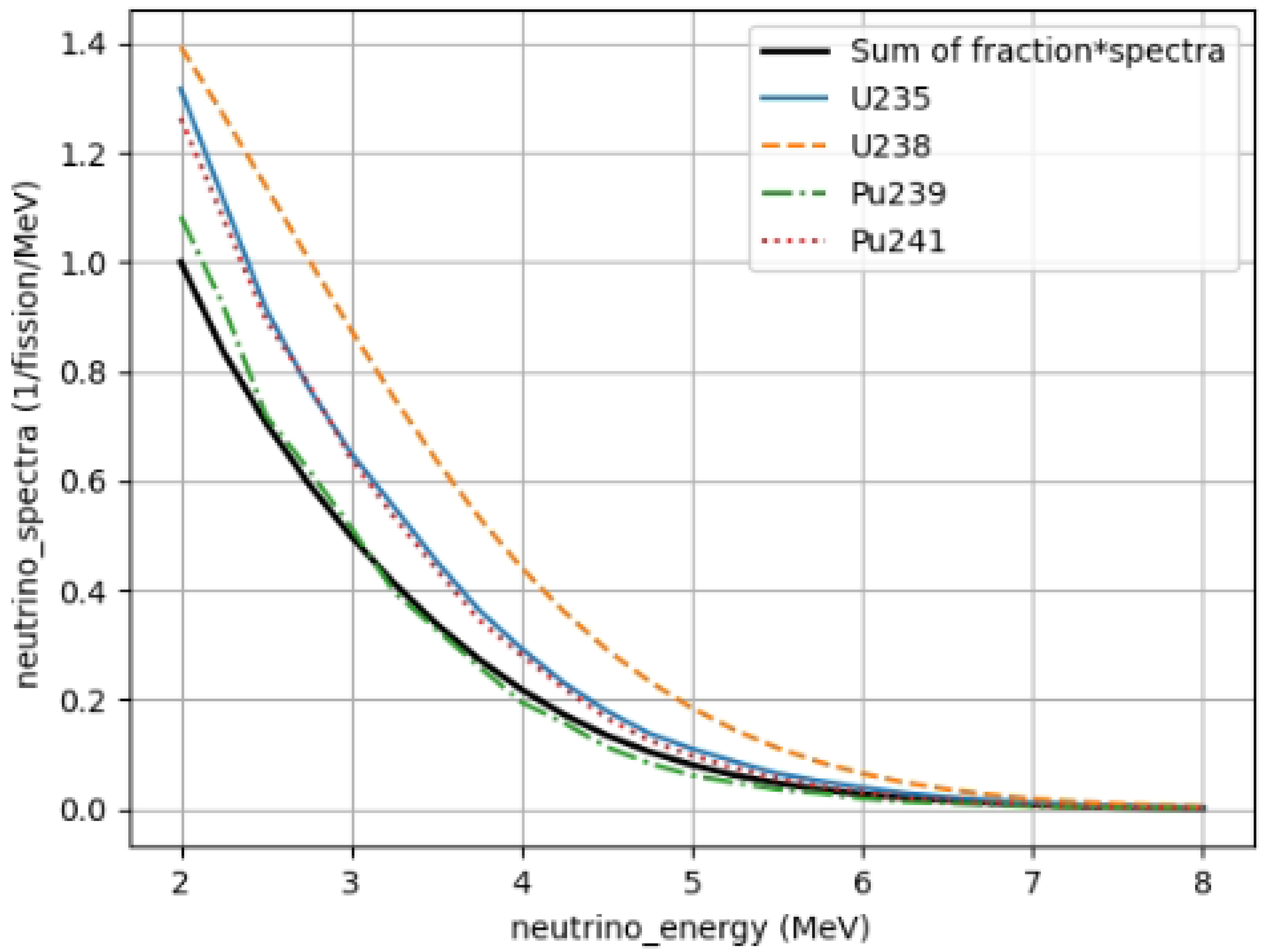
# Planned Detector Site

- **The RENE experiment is located in the tendon gallery of the Hanbit Nuclear Power Plant, Republic of Korea.**


# Reactor Antineutrino Flux Models

- **The Huber–Mueller model provided updated reference reactor antineutrino spectra in the 2–8 MeV range**
- **Based on the main fission isotopes: $^{235}$U, $^{239}$Pu, $^{241}$Pu, $^{238}$U**




$$S_{\text{tot}}(E) = \sum \alpha_k S_k(E)$$

**where $\alpha_k$ is the number of fissions of the *k*th isotope at the considered time**

$$S_{k,\text{fit}}(E_\nu) = \exp\left(\sum_{p=1}^{6} \alpha_{pk} E_\nu^{p-1}\right)$$

**Normalized antineutrino energy spectrum emitted per fission for each isotope**

# Neutrino Detection Principle

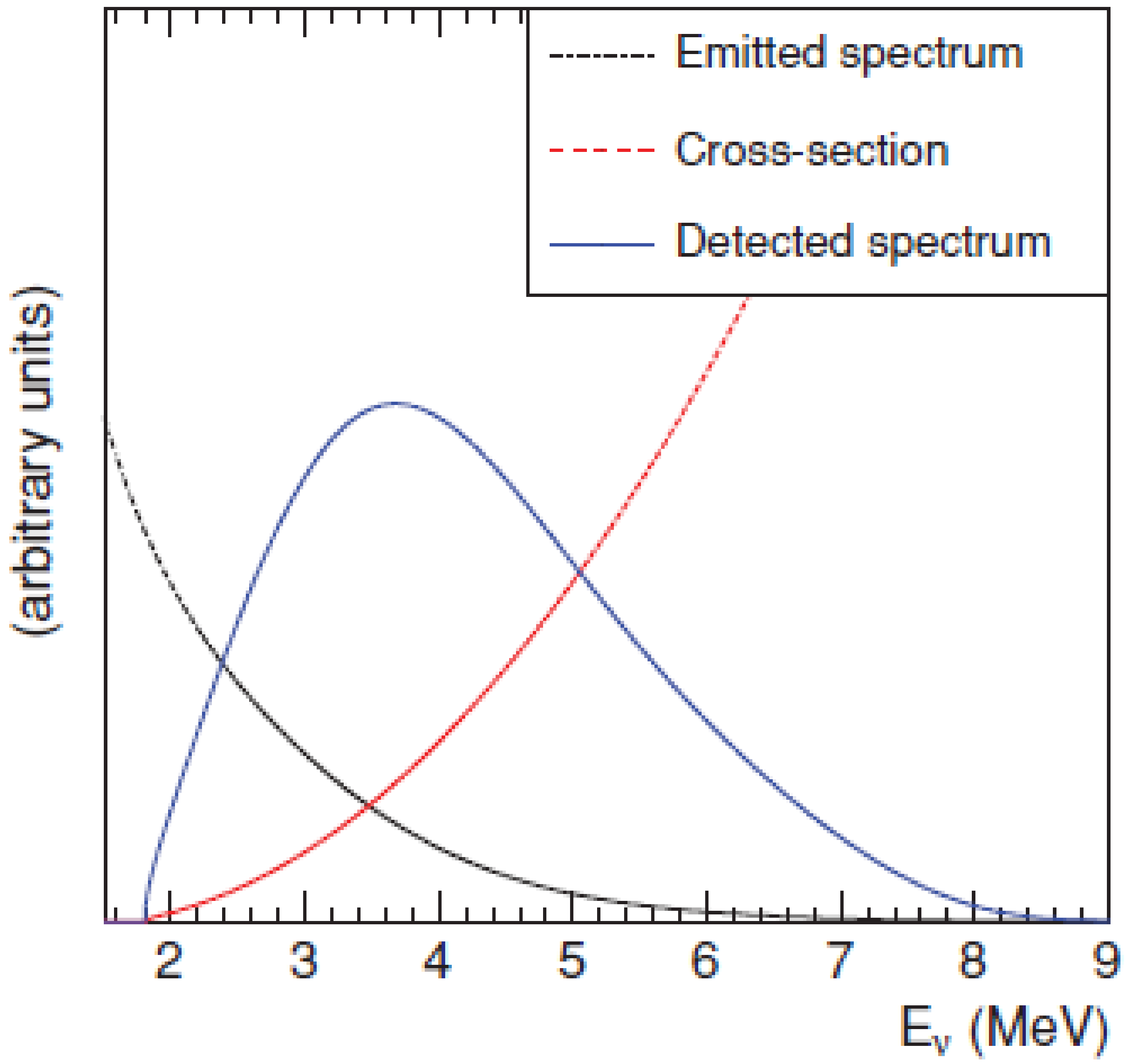
- **The RENE detector identifies antineutrinos via the Inverse Beta Decay (IBD) reaction:**

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

- **IBD Cross Section**
  - **The IBD cross section is based on the calculation by Vogel**

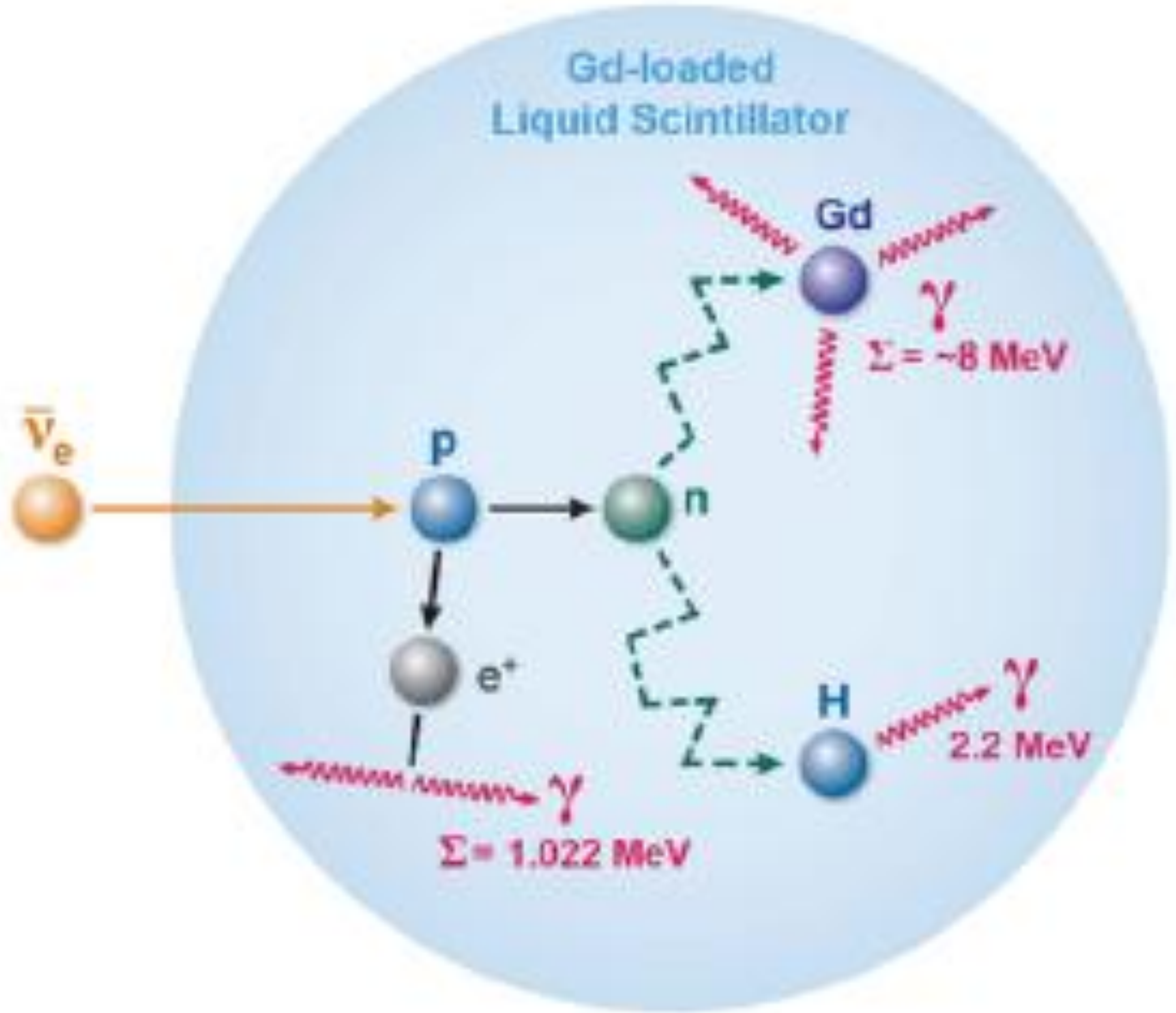
$$\sigma = \sigma_0 \left(1 + \delta_{\text{rec}} + \delta_{\text{WM}} + \delta_{\text{rad}}\right)$$

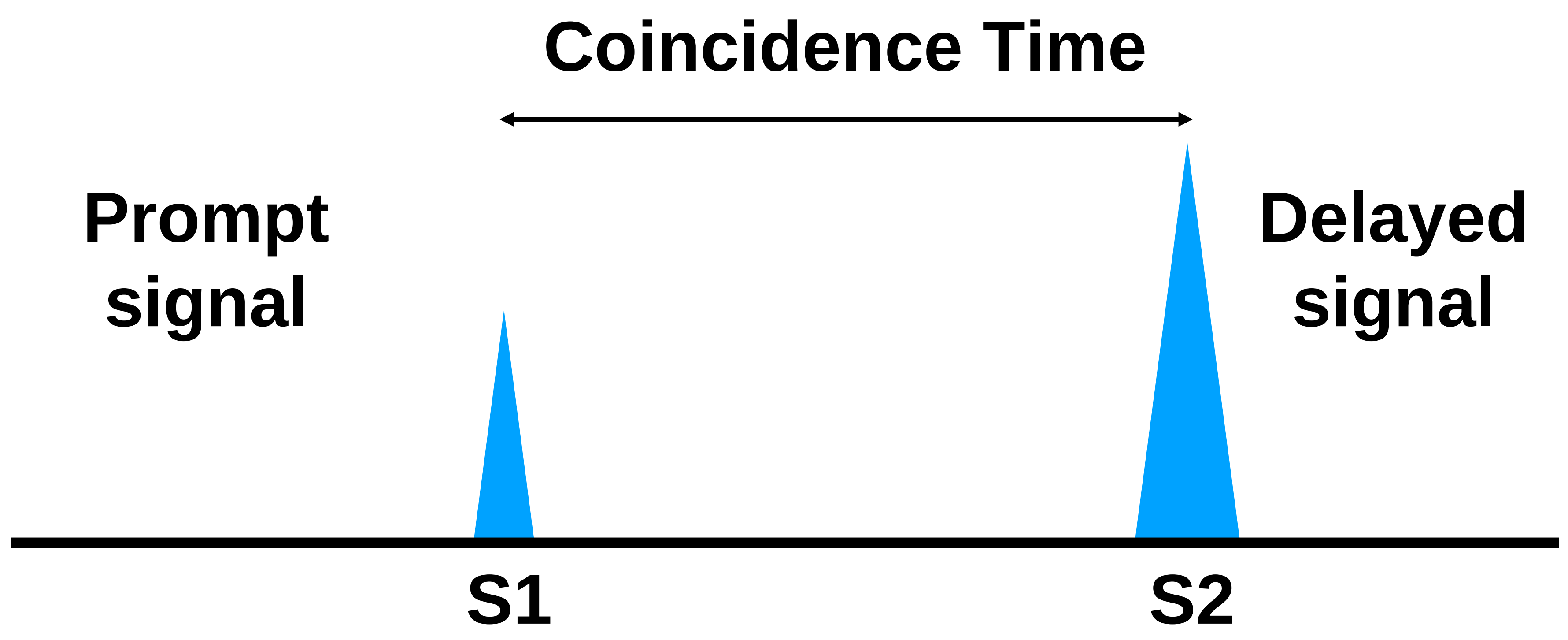
$$\sigma_0(E_e) = \frac{2\pi^2\hbar^3}{m_e{}^5 c^7 f \tau_n} p_e E_e$$



# IBD Selection Delayed Coincidence Signal

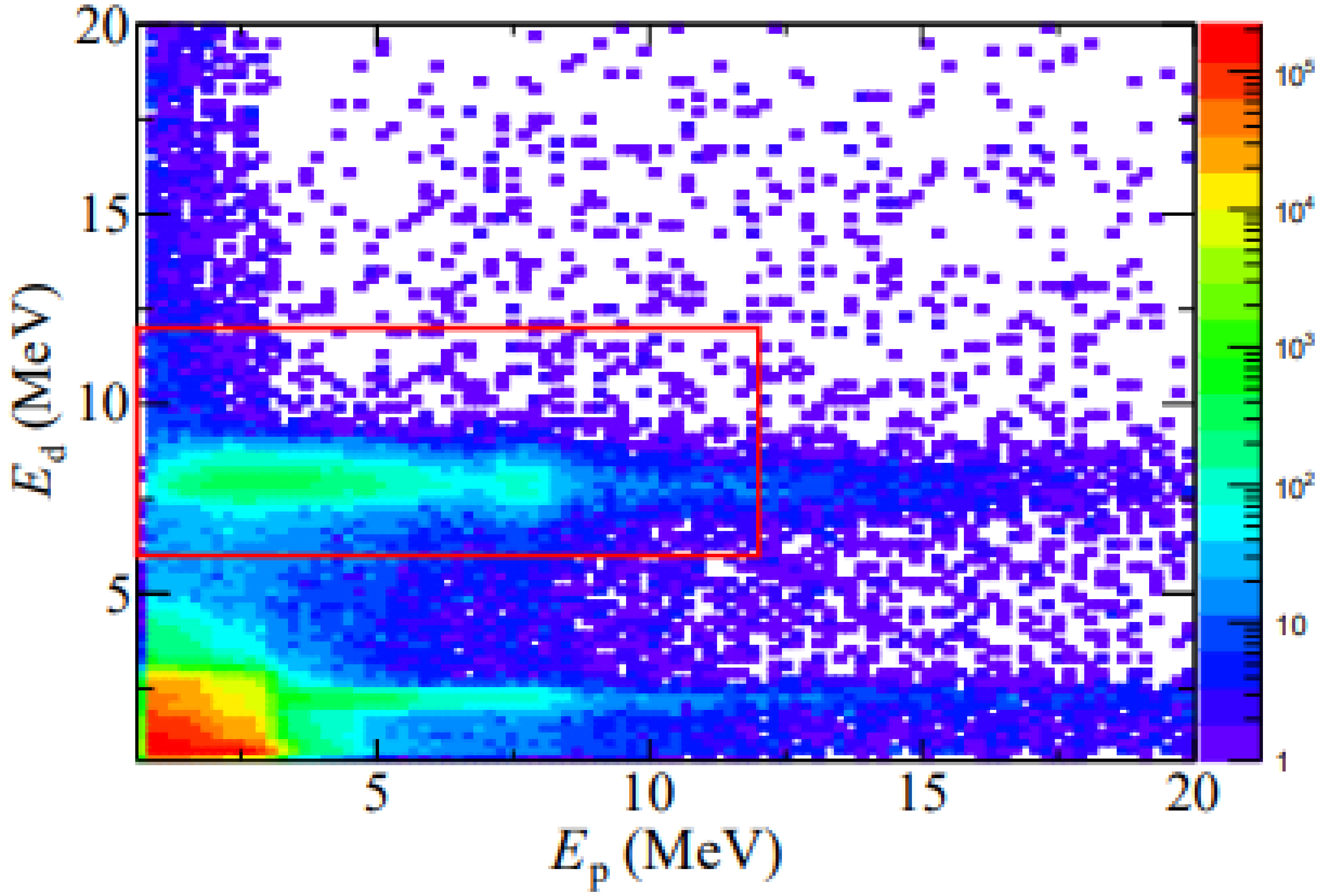
- IBD events can be identified as two signals with a coincidence time window.
  - Prompt signal: positron kinetic energy and annihilation
  - Delayed signal: neutron capture by nGd or H
  - Typical coincidence time:
    - H capture: ~200 μs
    - Gd capture with 0.1% Gd-LS: ~30 μs
    - Gd capture with 0.5% Gd-LS: ~8 μs



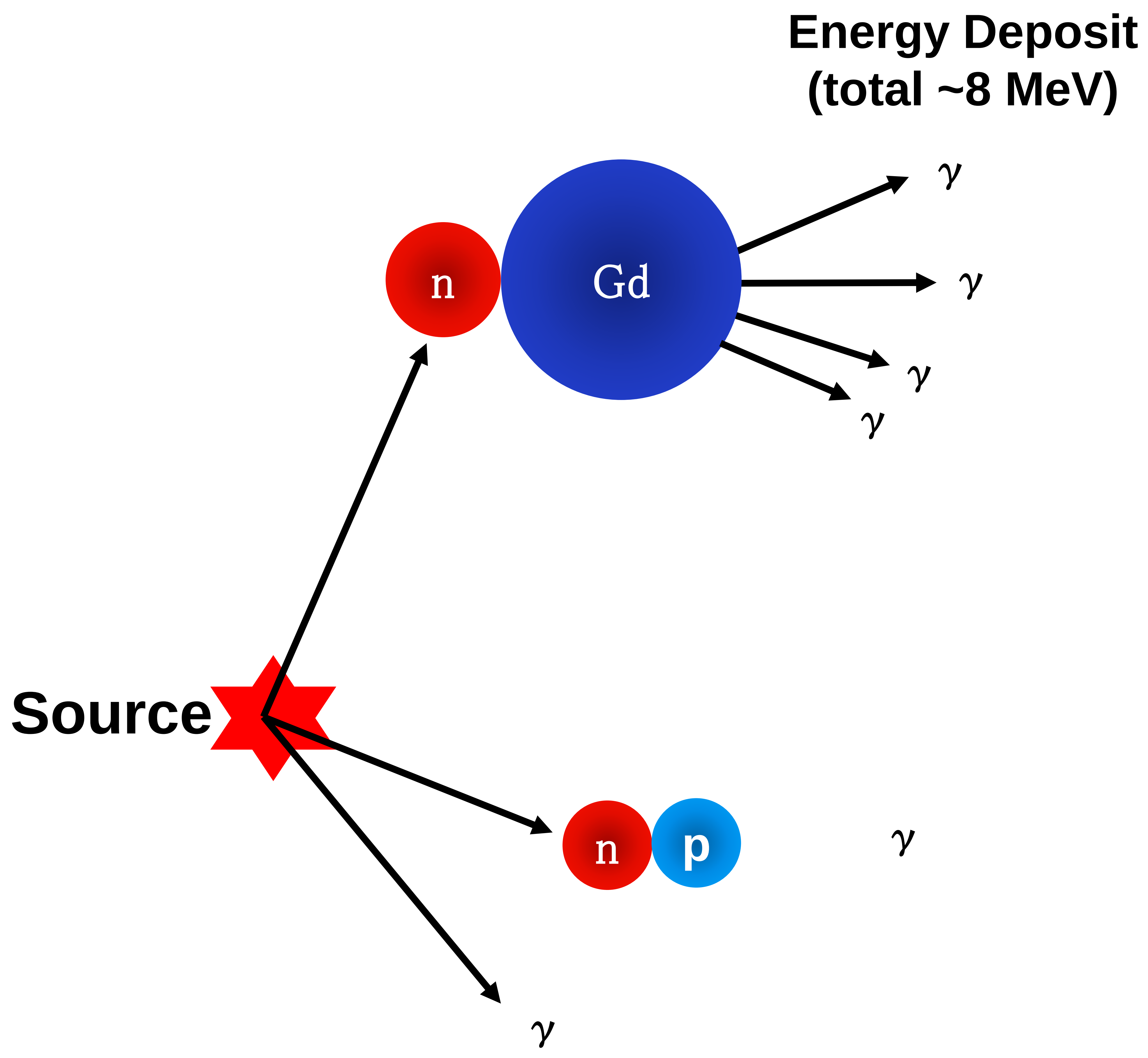
# IBD Selection Energy Criteria

- **IBD candidates are selected using prompt and delayed energy requirements to suppress background events**
- **Delayed energy: neutron capture on Gd (~8 MeV) or H (~2.2 MeV)**
- **Delayed energy selection suppresses accidental backgrounds**



# Simulation of Neutron Capture on Gd

**ANNRI-Gd model: improves the accuracy of γ-ray spectra following neutron capture on $^{155}$Gd and $^{157}$Gd.**



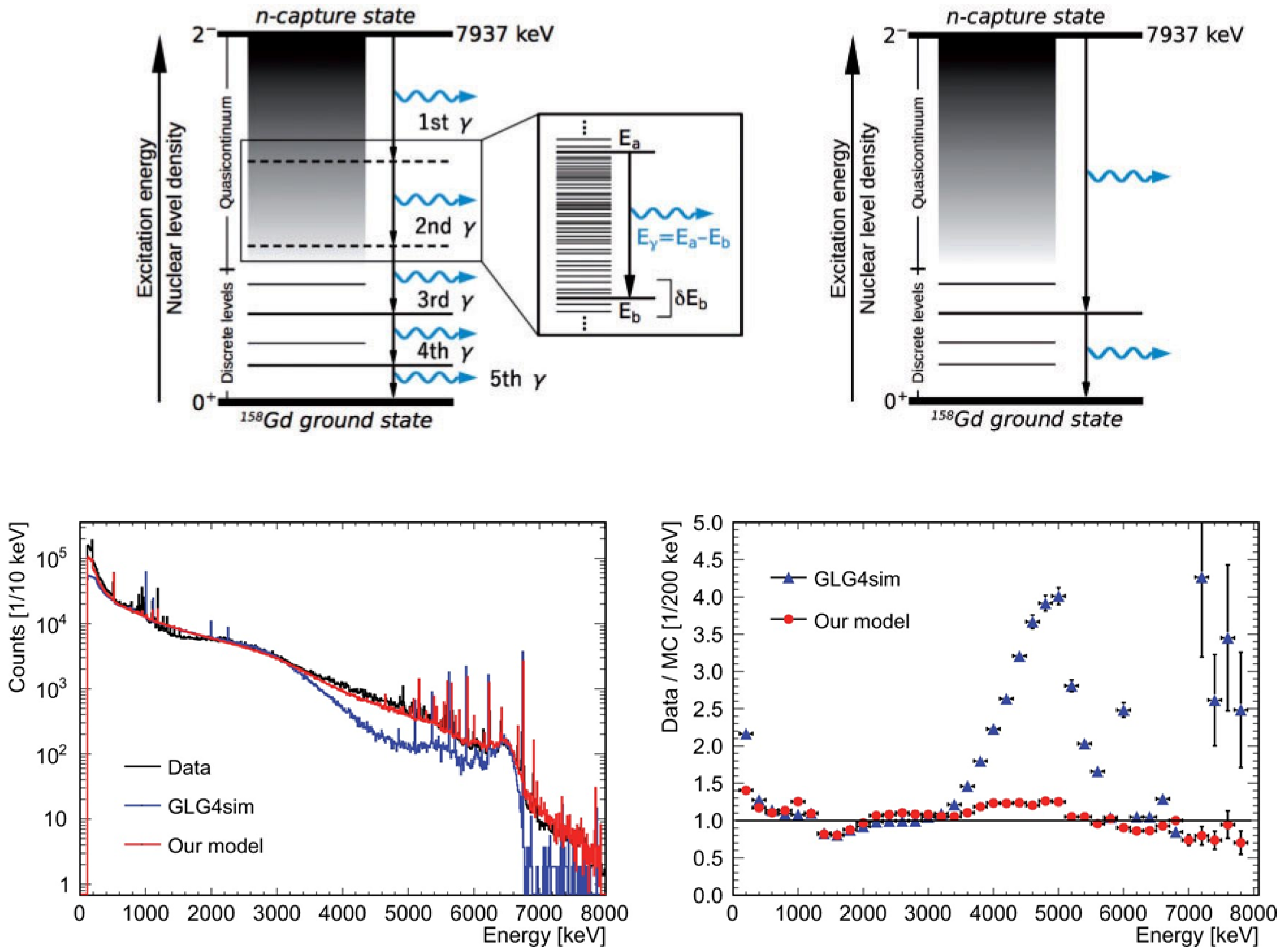
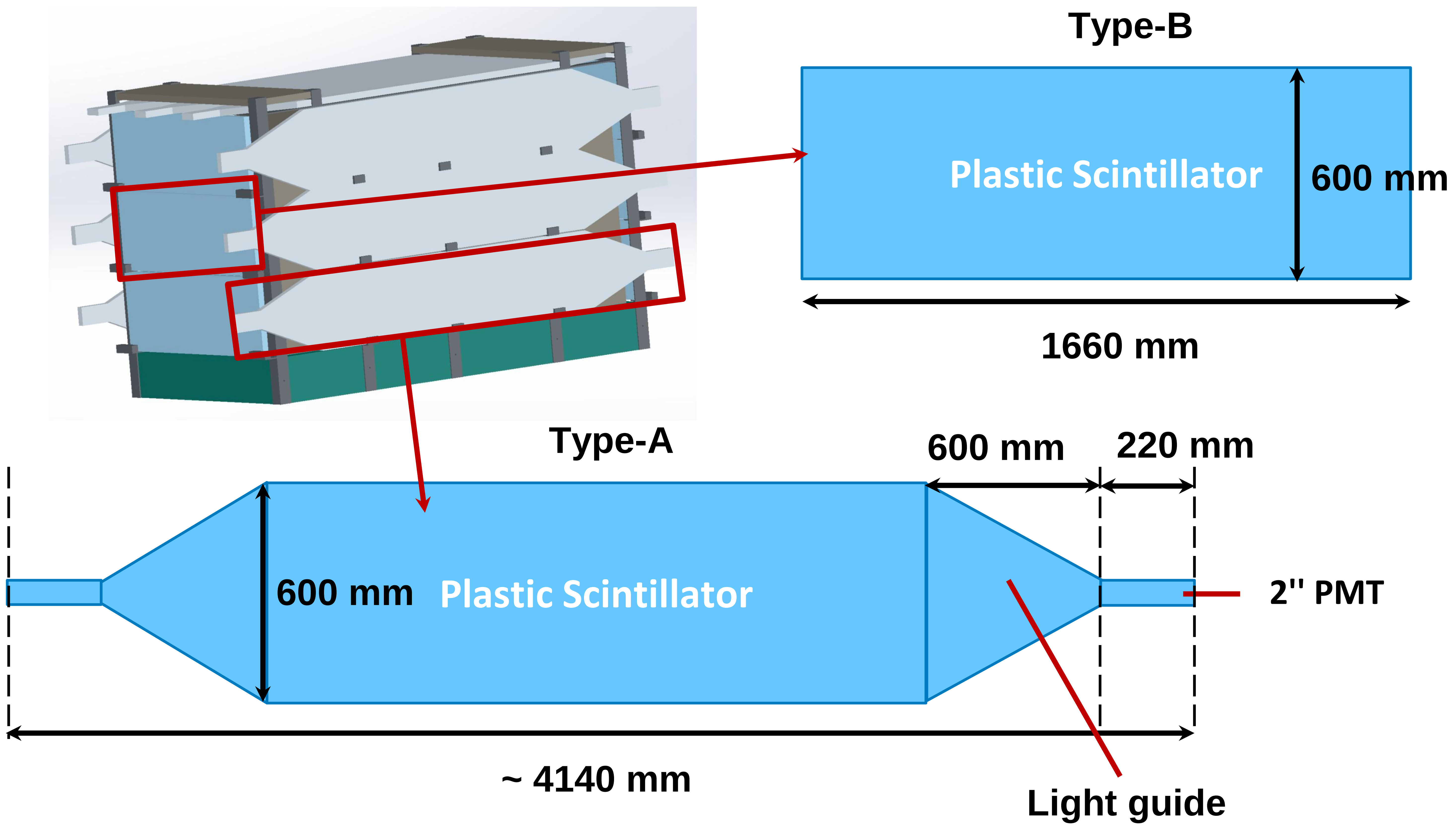




**Fig.** ANNRI-Gd model shows better agreement with data than GLG4sim (Prog. Theor. Exp. Phys. 2019, 023D01).

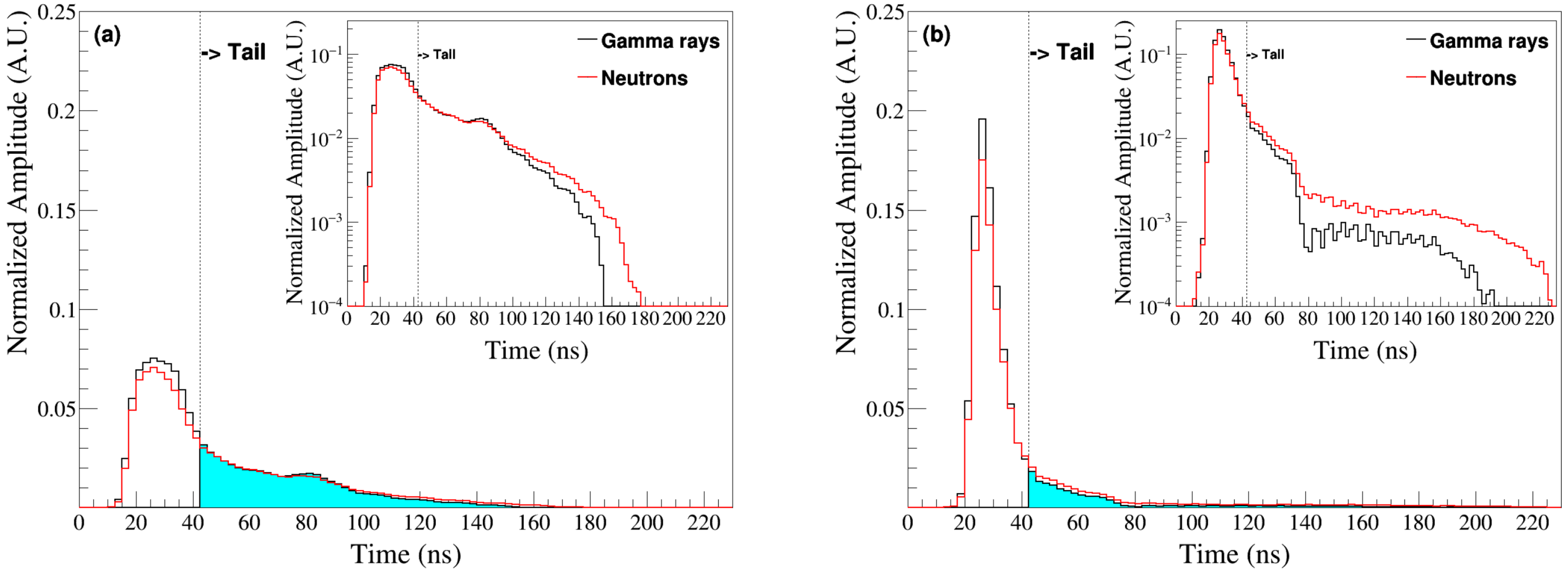
# Veto Detector

- The veto detector is used to identify and reject cosmic-ray muon events
- Surrounds the main detector to reduce cosmic-induced background signals

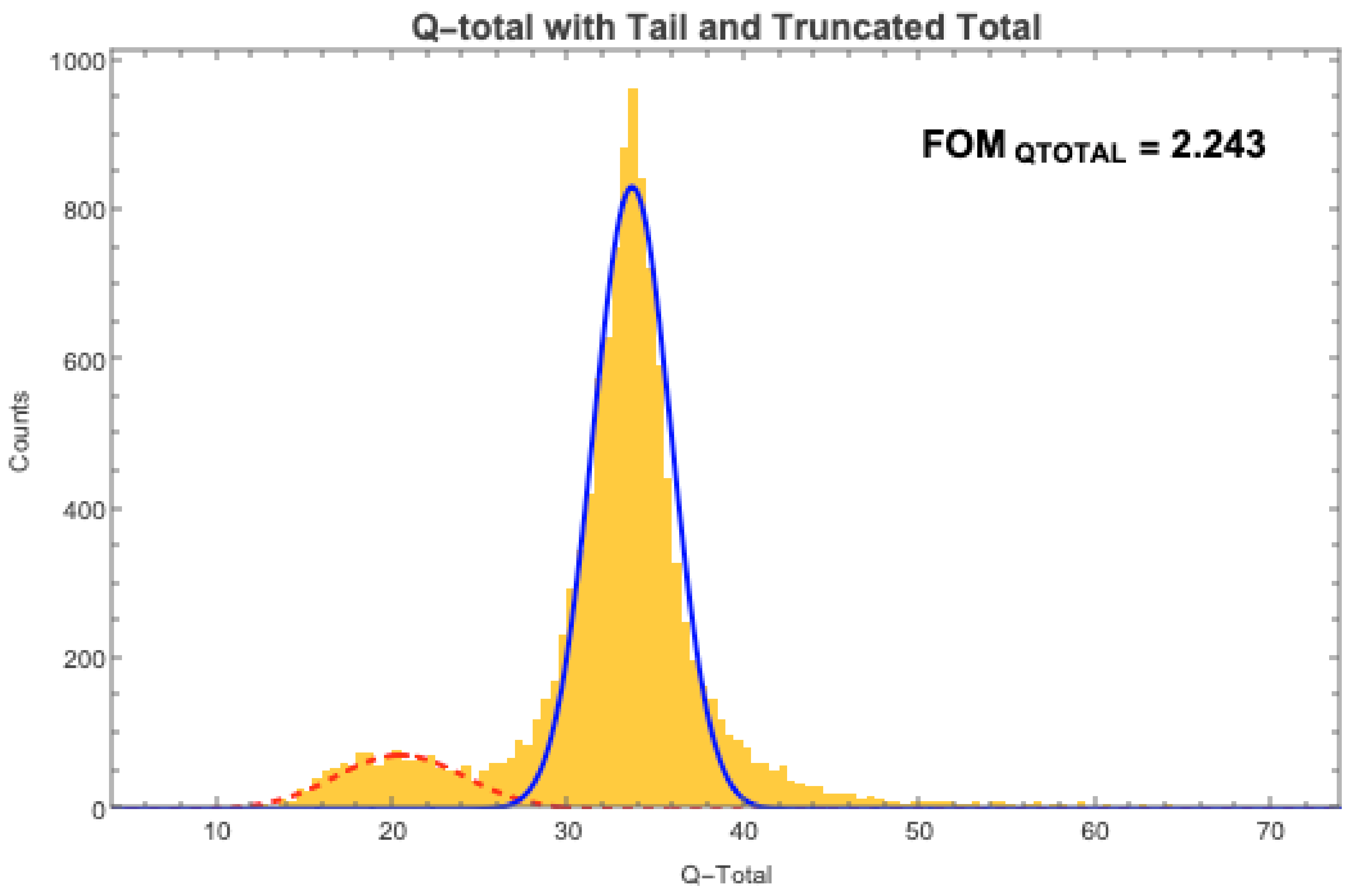


# Pulse Shape Discrimination (PSD)

- **Distinguishes particle types using waveform shape differences**
- **Useful for fast neutron background rejection**

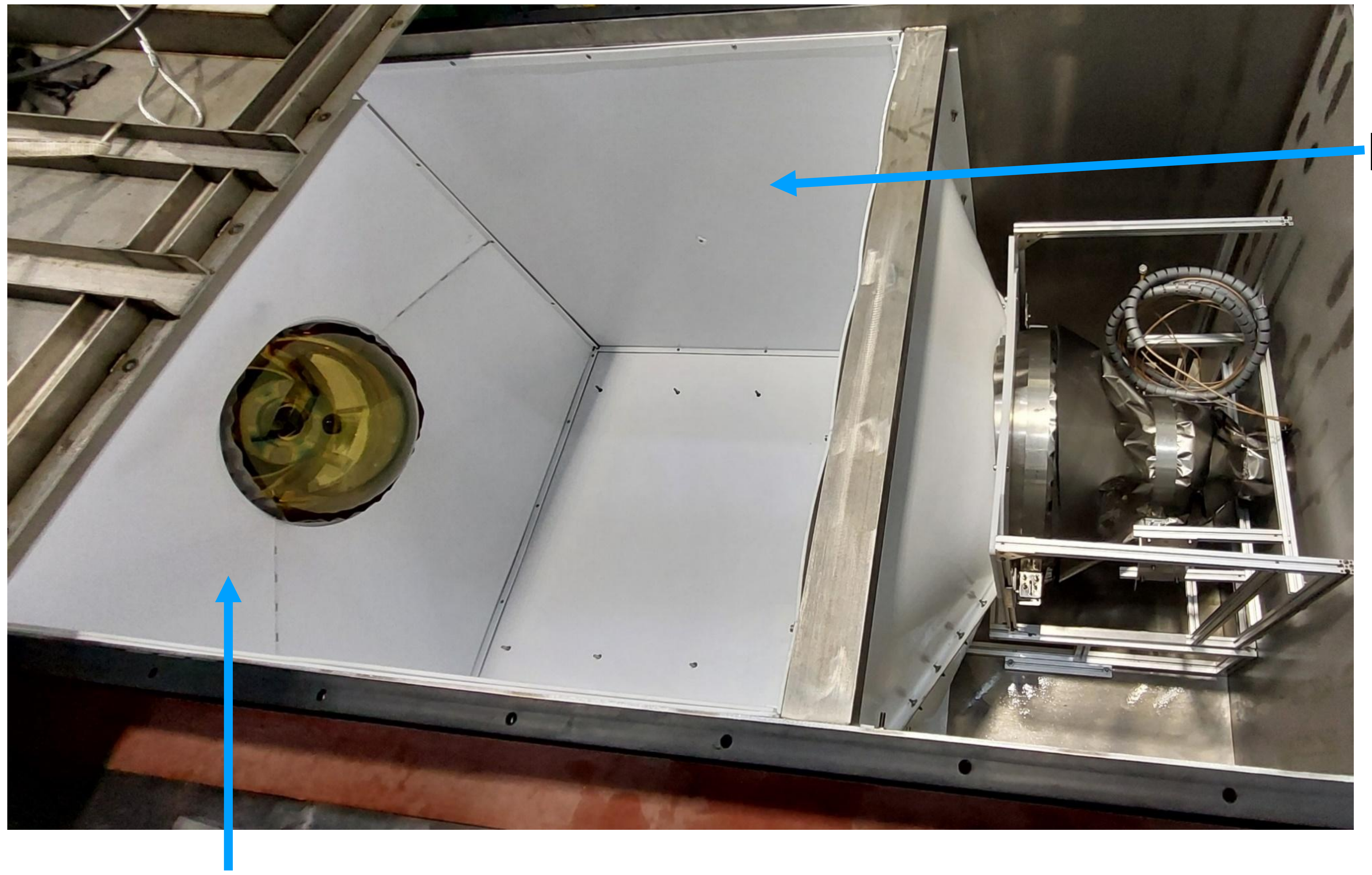


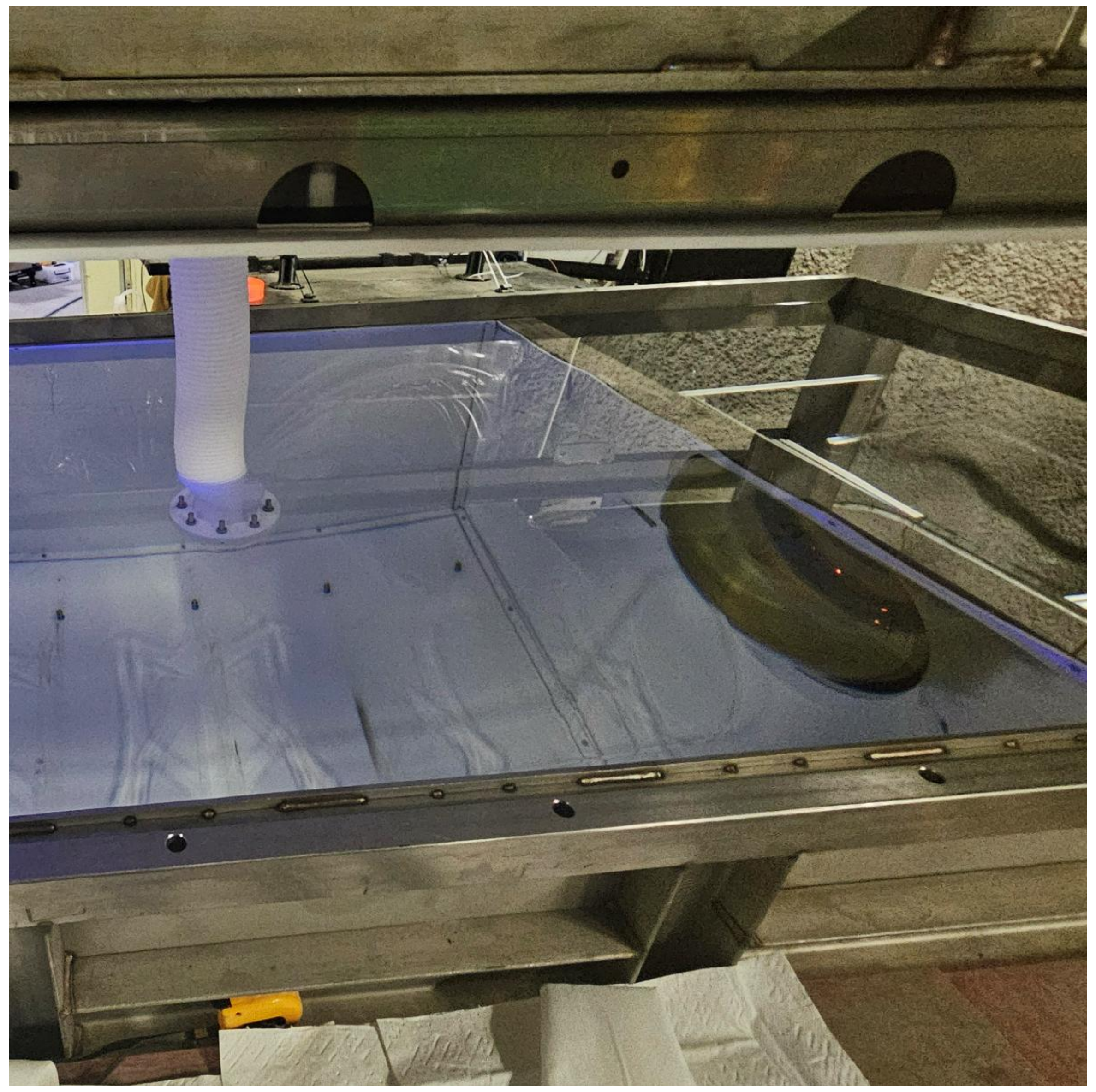

(a) (b)



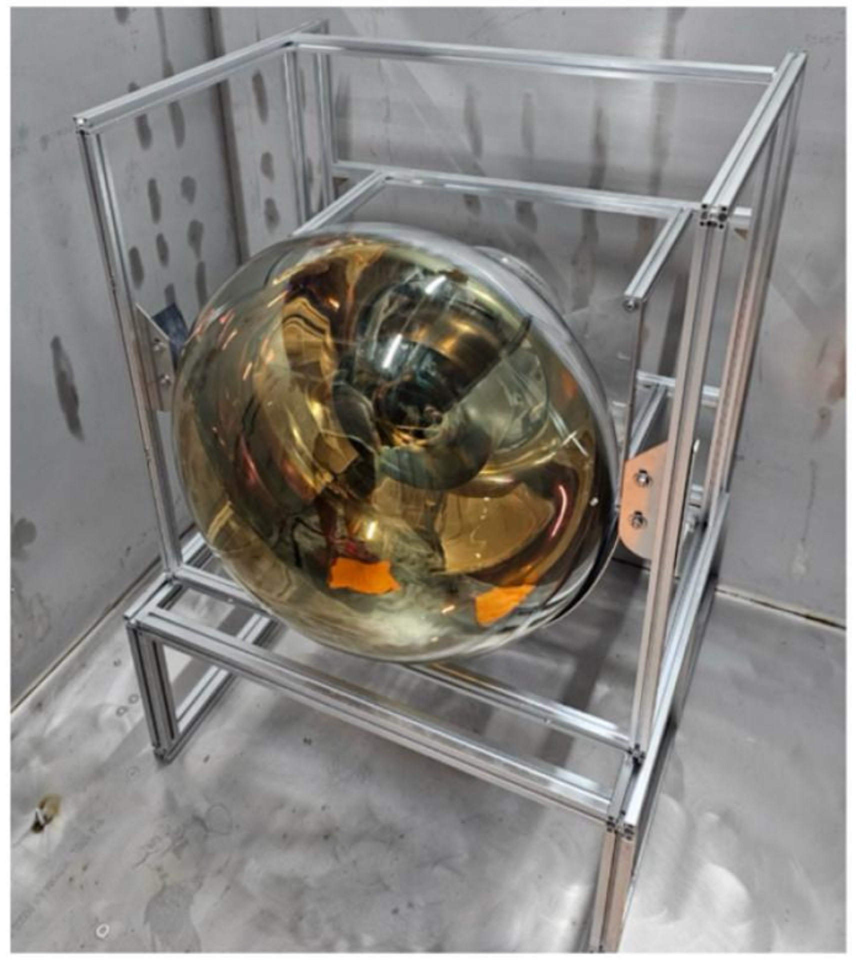
# Scintillation Process

- **Molecules excited by radiation emit scintillation photons during de-excitation**
- **Photomultiplier tubes (PMTs) detect the scintillation light signals**



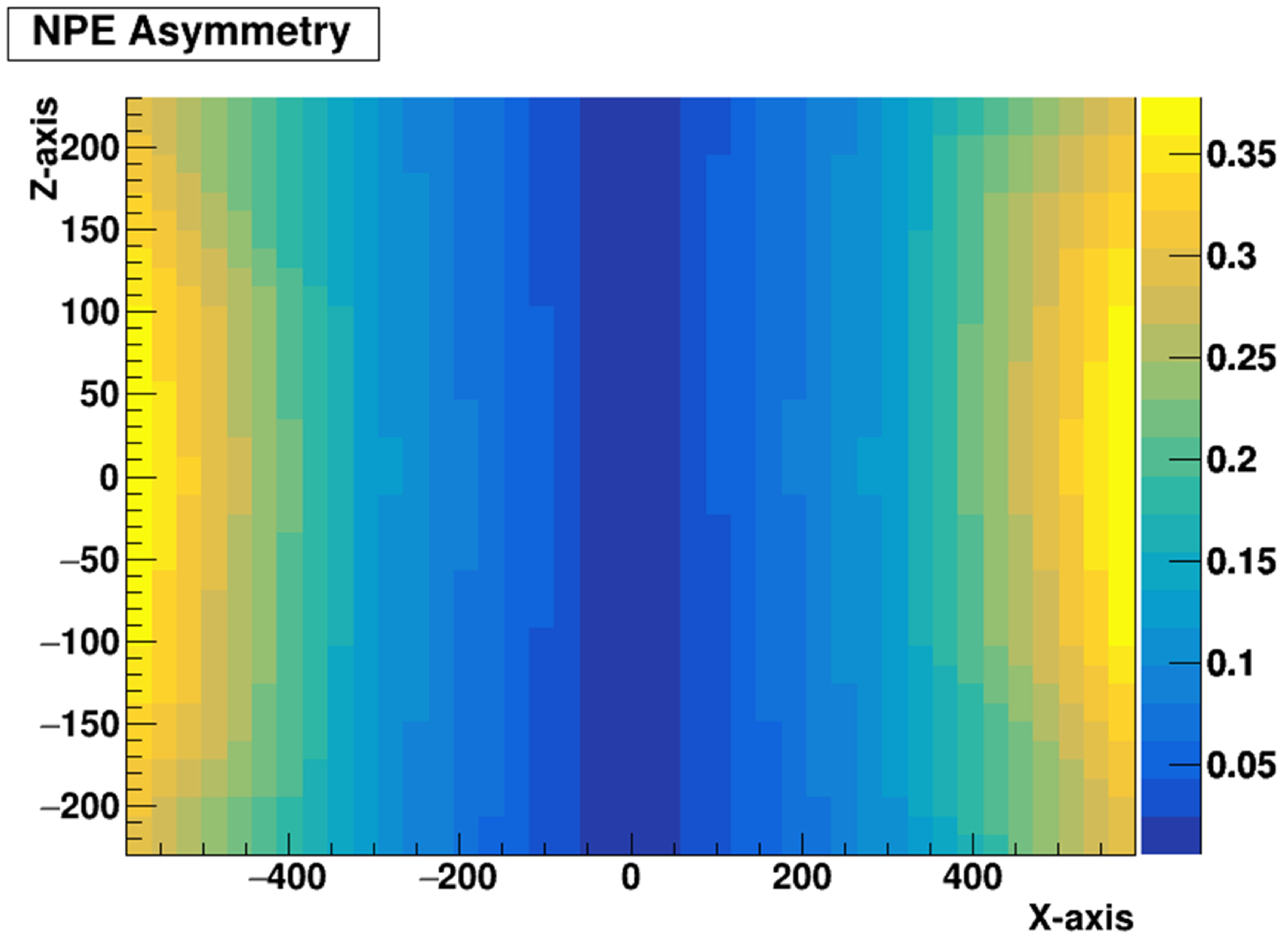



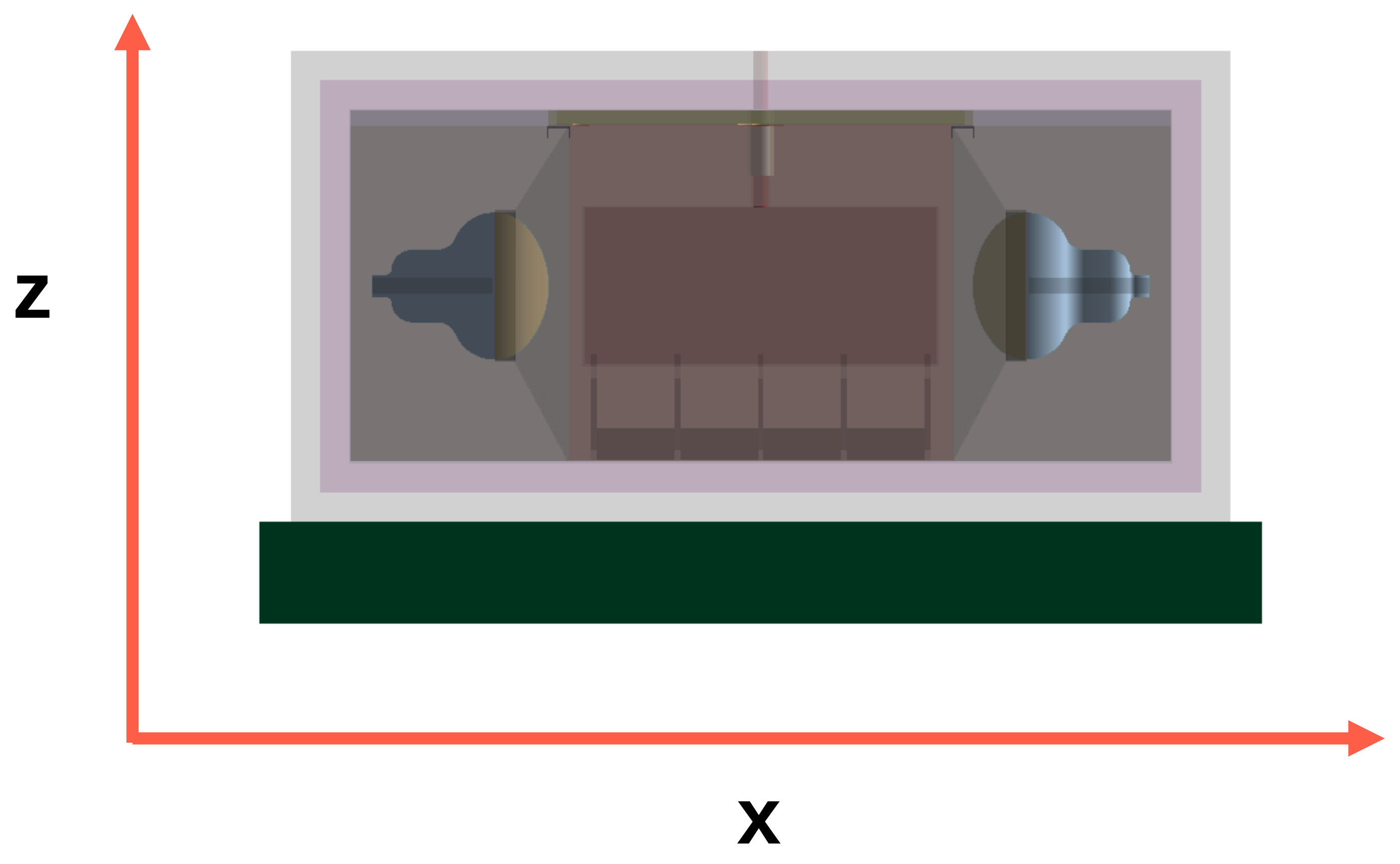
20-inch PMT
(**Hamamatsu R12860)**



# Position Correction Function

- Position-dependent variations affect the detector response
- A position correction function is applied to improve energy resolution
- Corrected signals provide more accurate energy reconstruction




$NPE = NPE_0 + NPE_1$ : *total # of PE*

$A_{PE} = \frac{|NPE_0 - NPE_1|}{NPE}$ : *NPE asymmetry*

$E_{dep}$ : *Deposited energy*

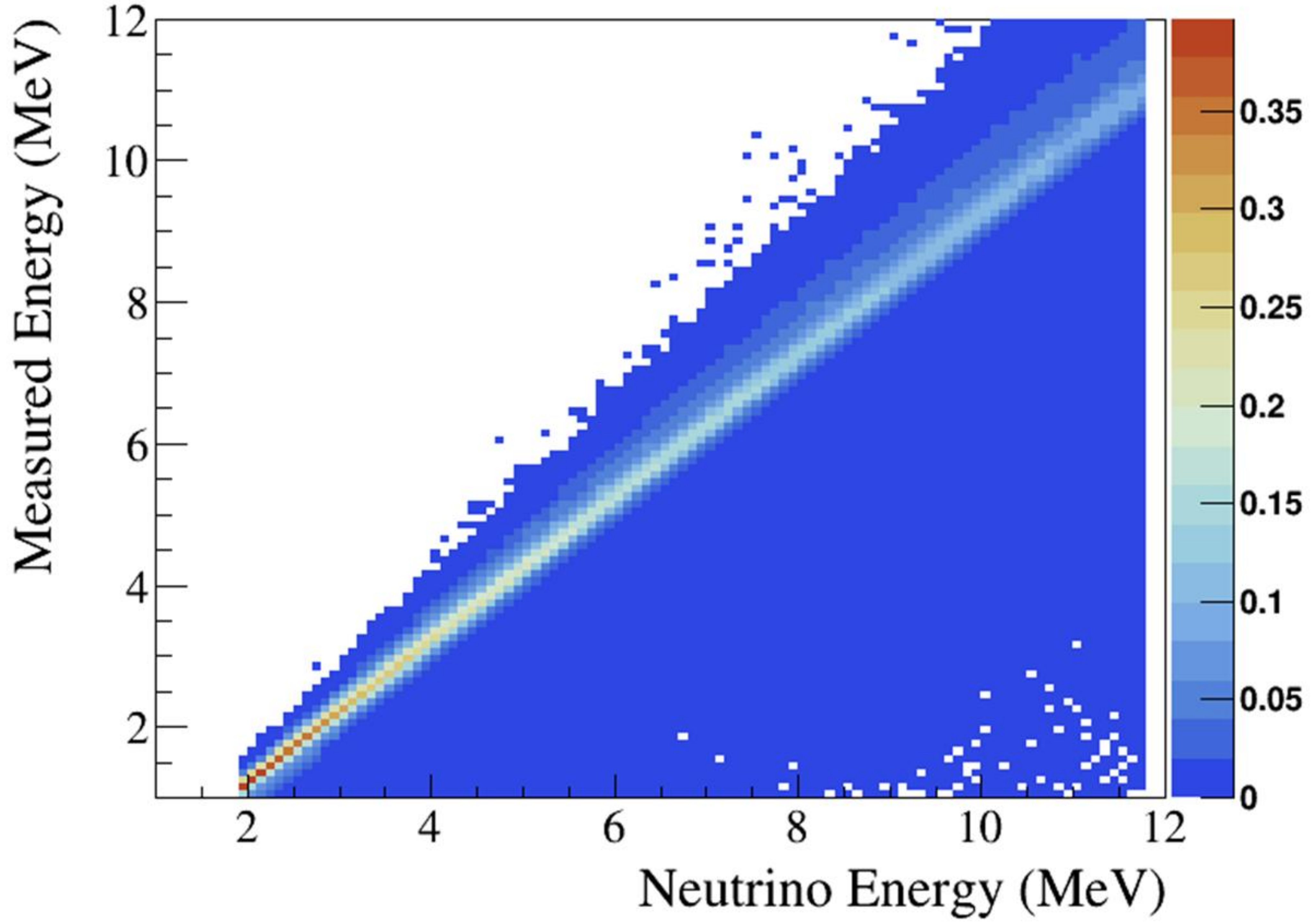
*2nd polynomial fitting*

$NPE/E_{dep} = \alpha A_{PE}^2 + \beta$ ( *fit result* $\alpha, \beta$ )

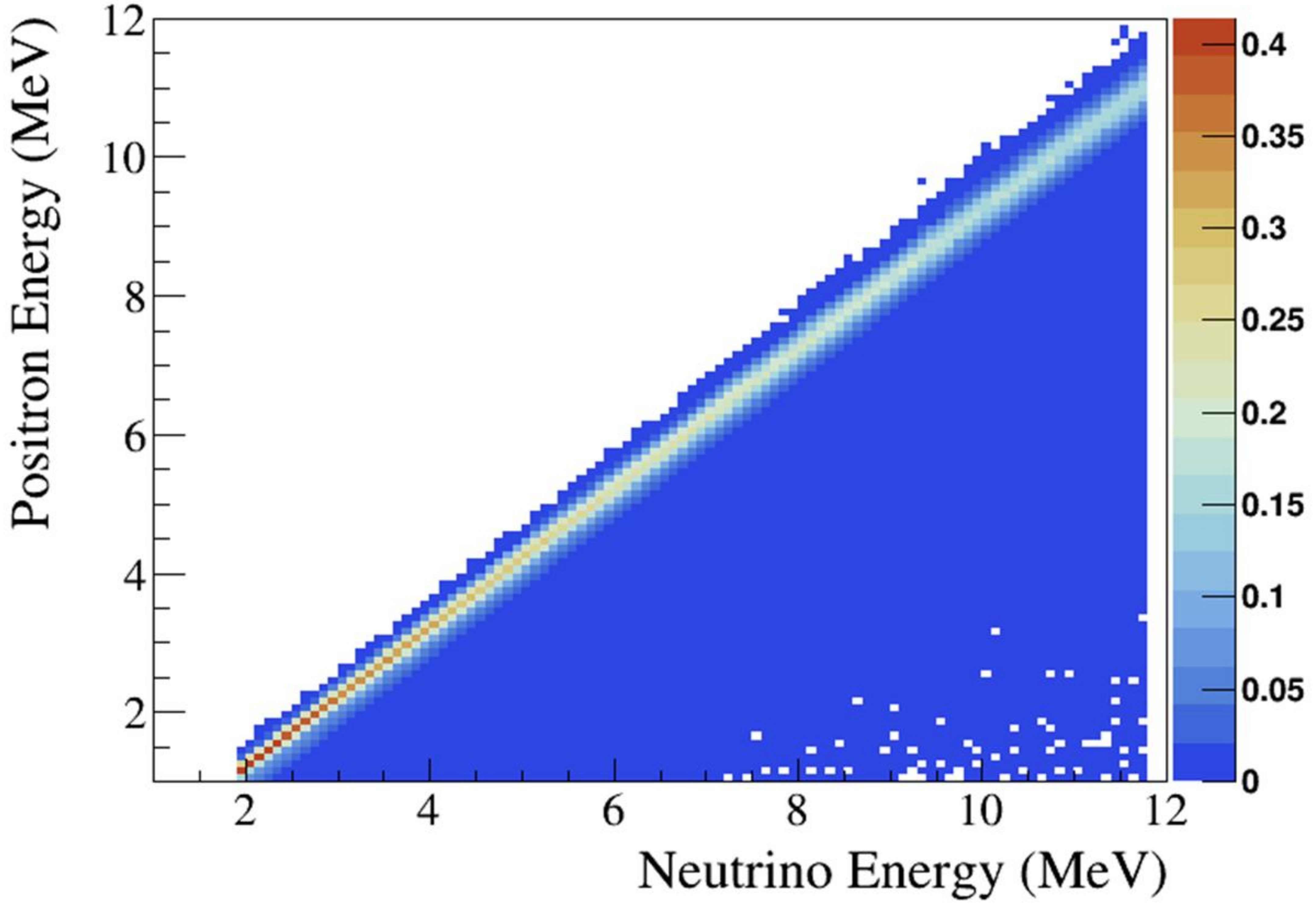
$\rightarrow \boldsymbol{Energy} = \frac{\boldsymbol{NPE}}{\boldsymbol{\alpha A^2 + \beta}}$

# Response Matrix

**A response matrix describes the detector response between true and reconstructed energy**



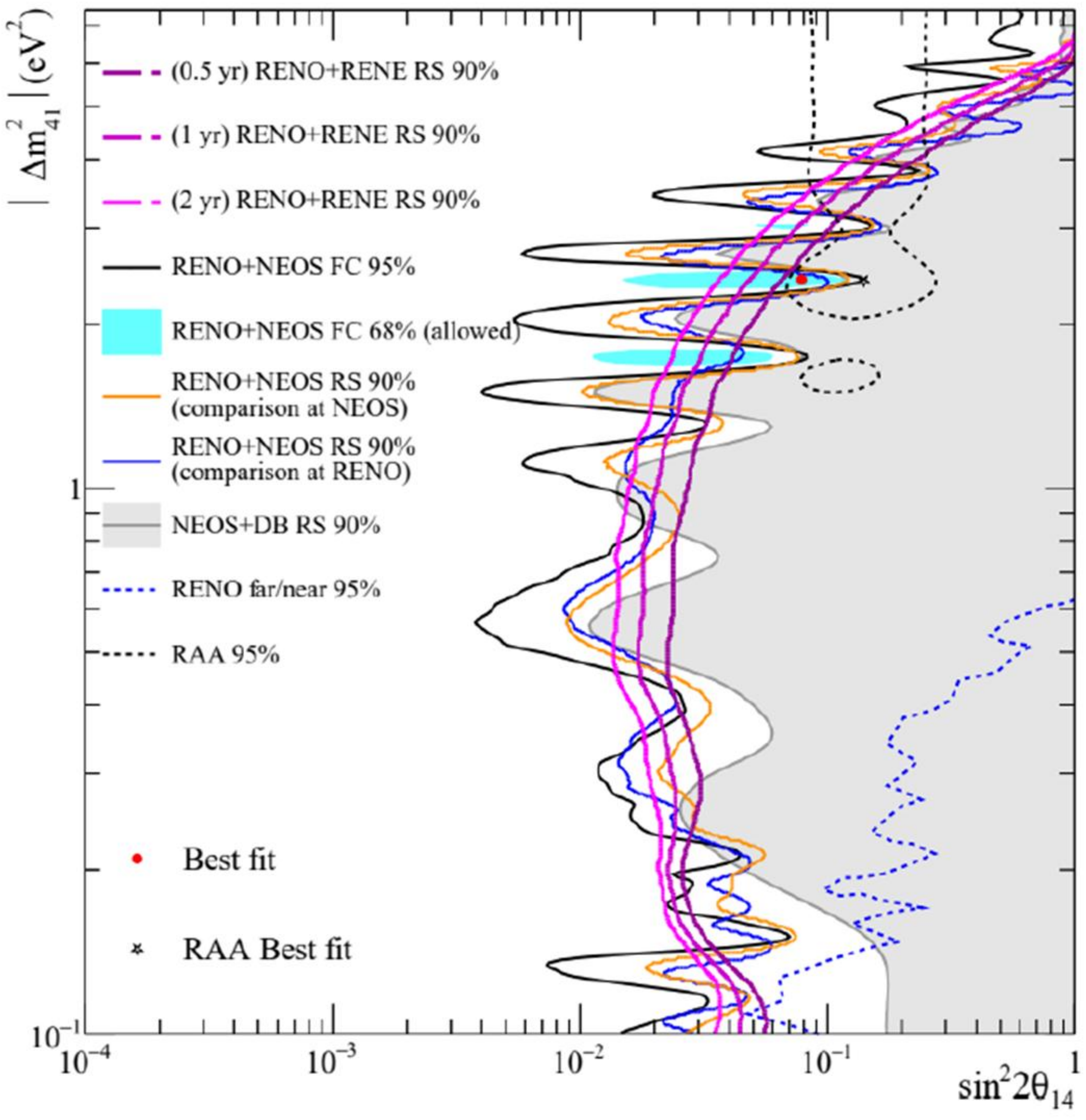

**Without Correction**




**NPE Asymmetry Correction**

# Sensitivity Plot

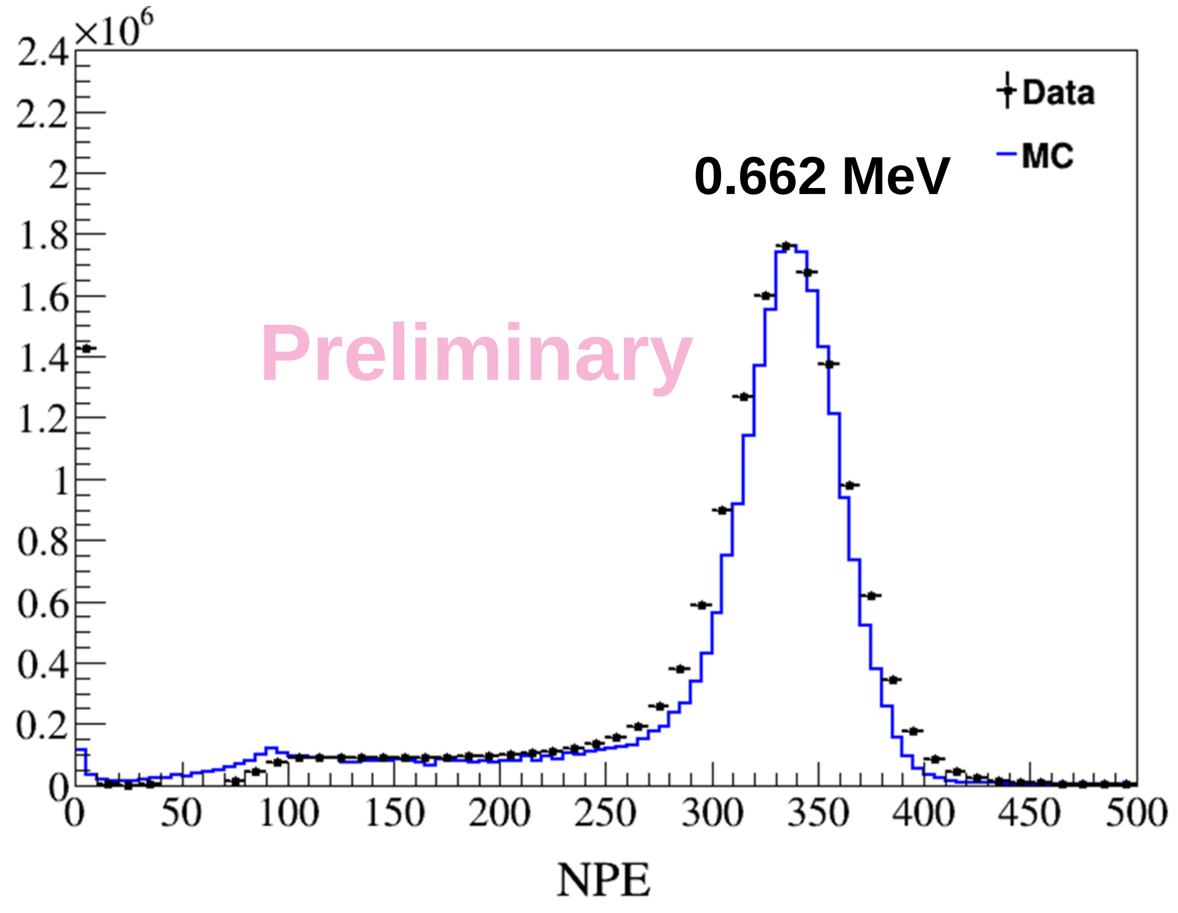
- **Sensitivity is estimated from the convolution of the theoretical neutrino flux and the detector response matrix**
- **The expected best-fit region can be probed within approximately 6 months of data taking**
- **The RENE experiment aims for a total data-taking period of about 2 years**



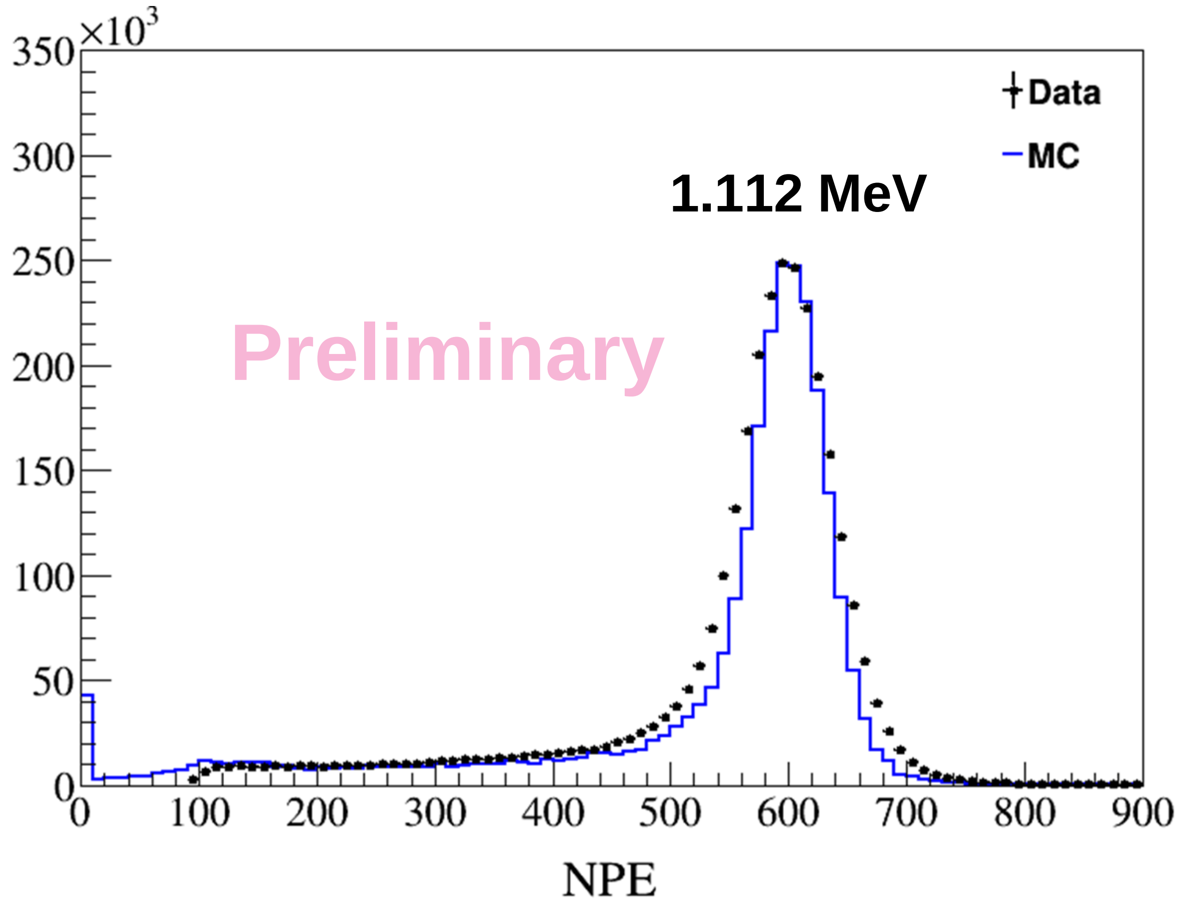
# Current Status of MC Tuning

## Comparison of Data and MC NPE spectra for calibration sources

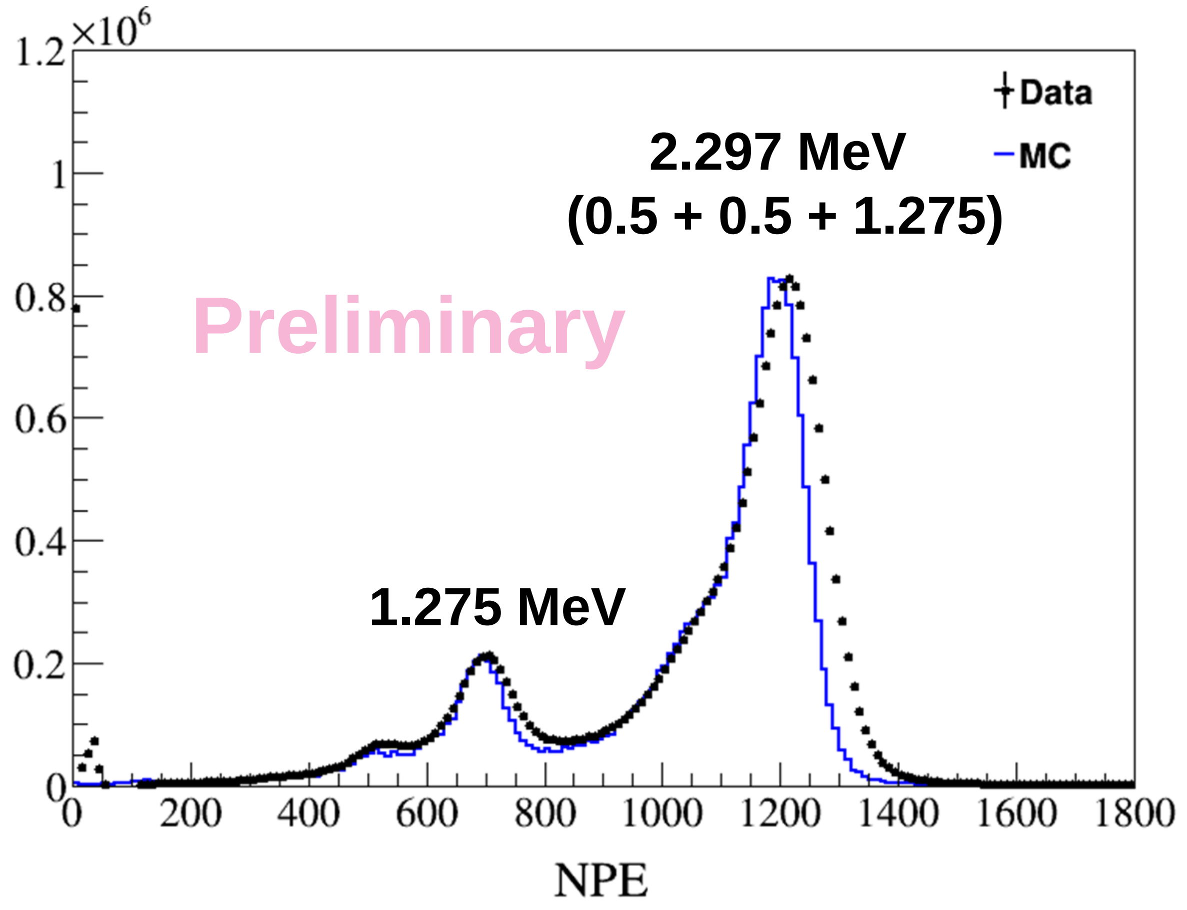
$^{137}$Cs



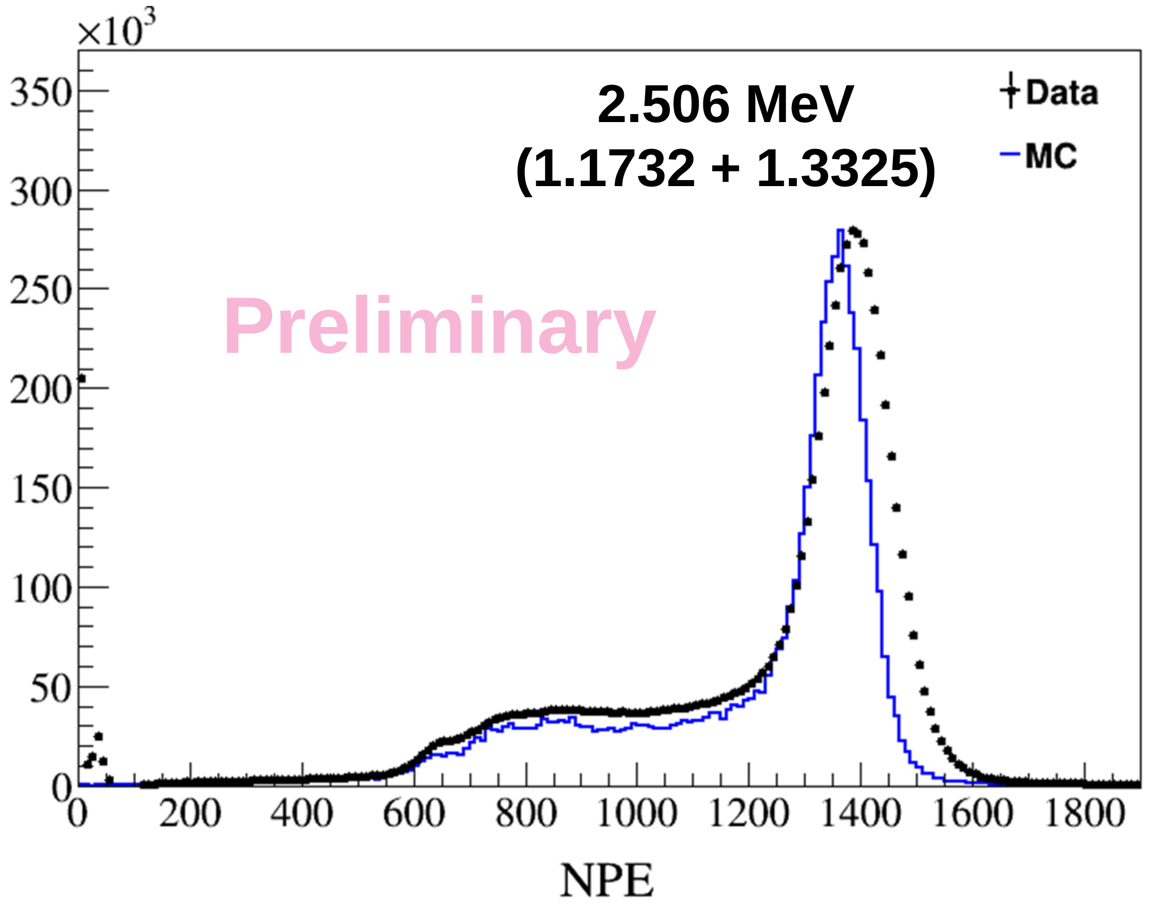

$^{65}$Zn



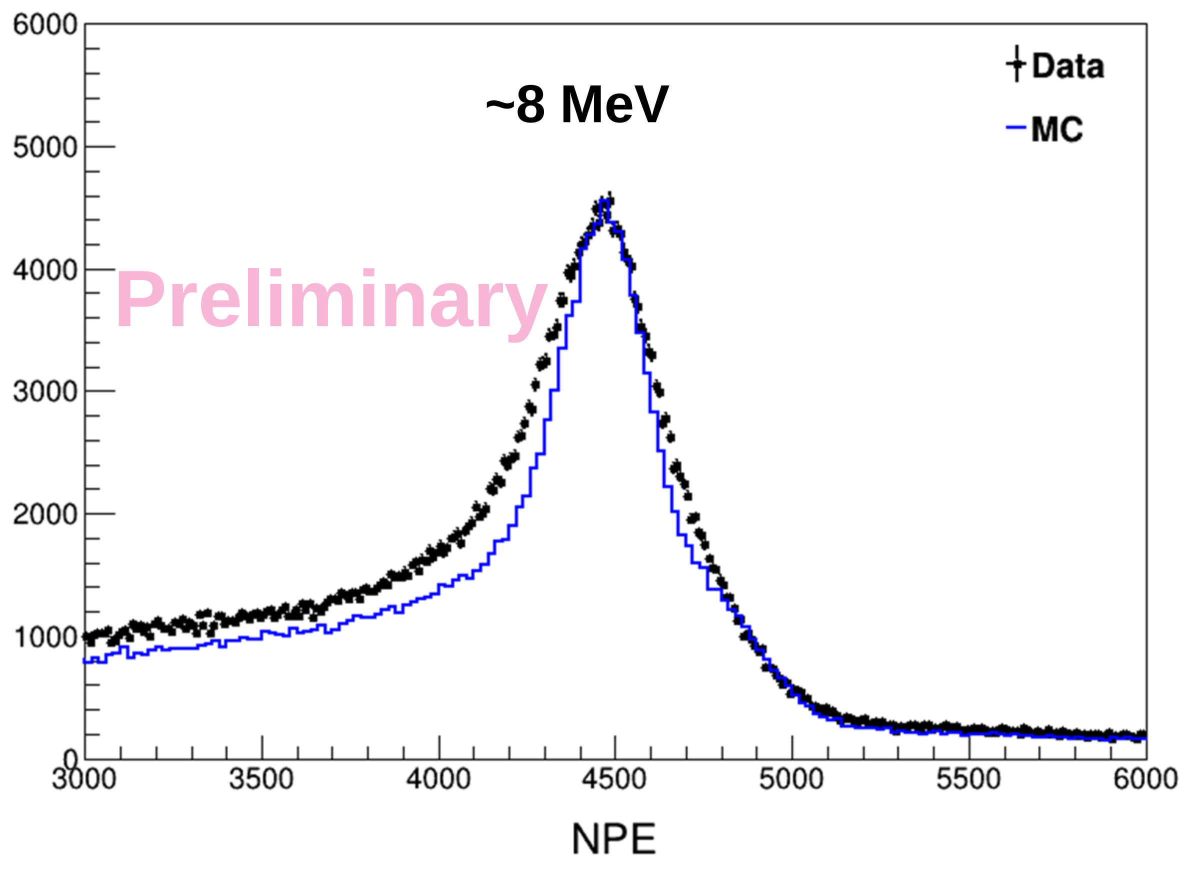

$^{22}$Na




$^{60}$Co

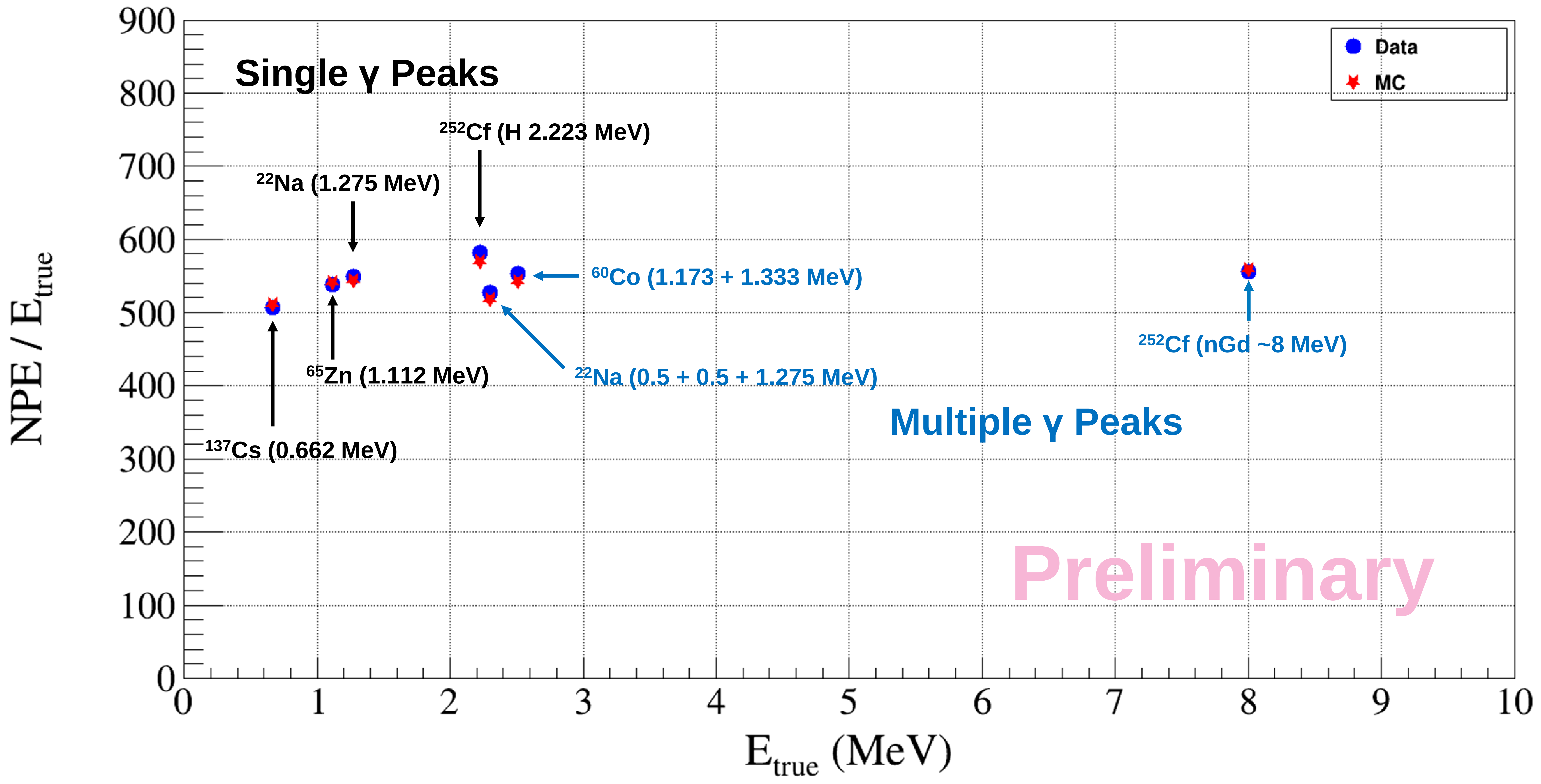



$^{252}$Cf (nGd)



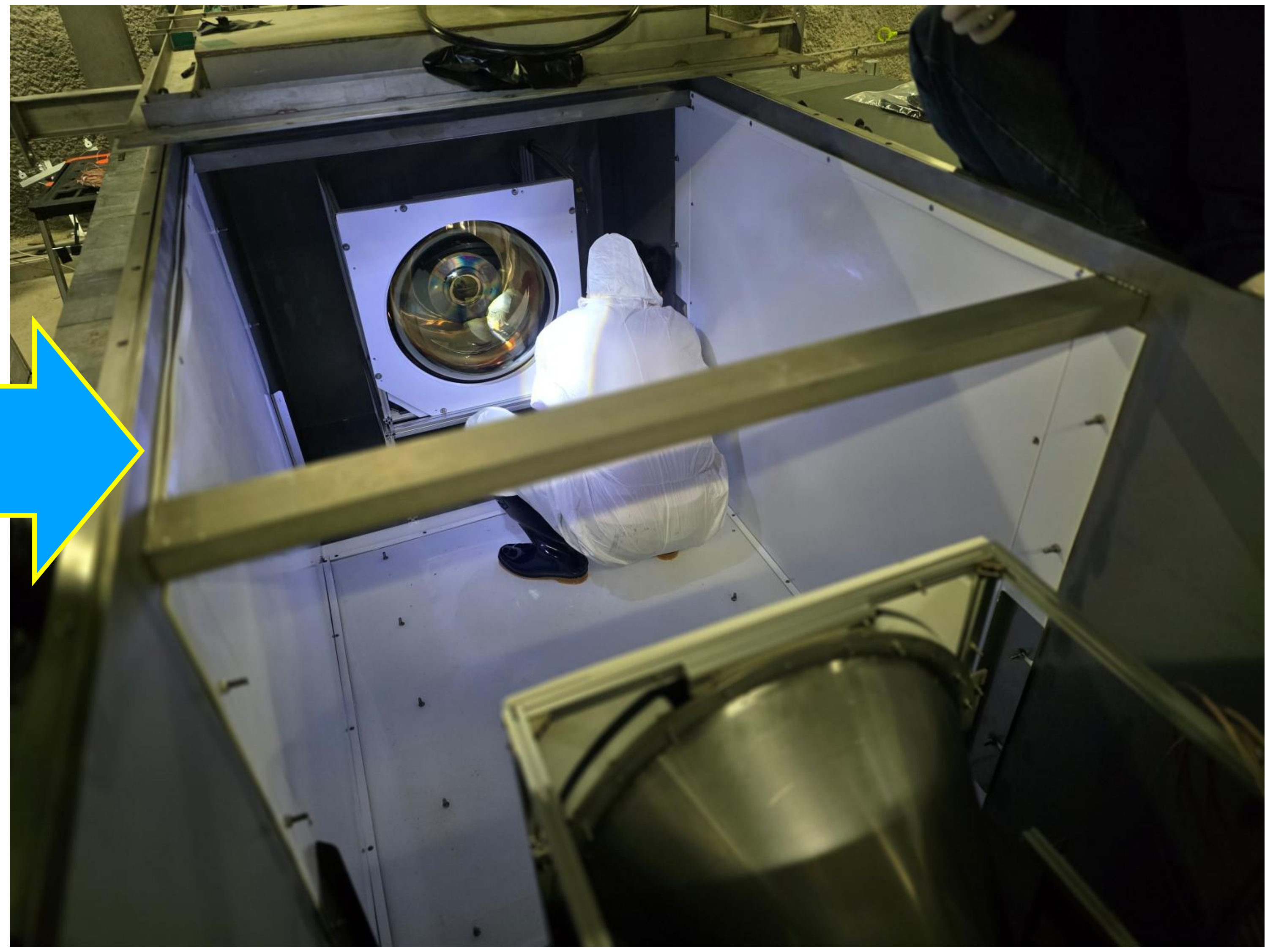
# NPE / True Energy vs True Energy

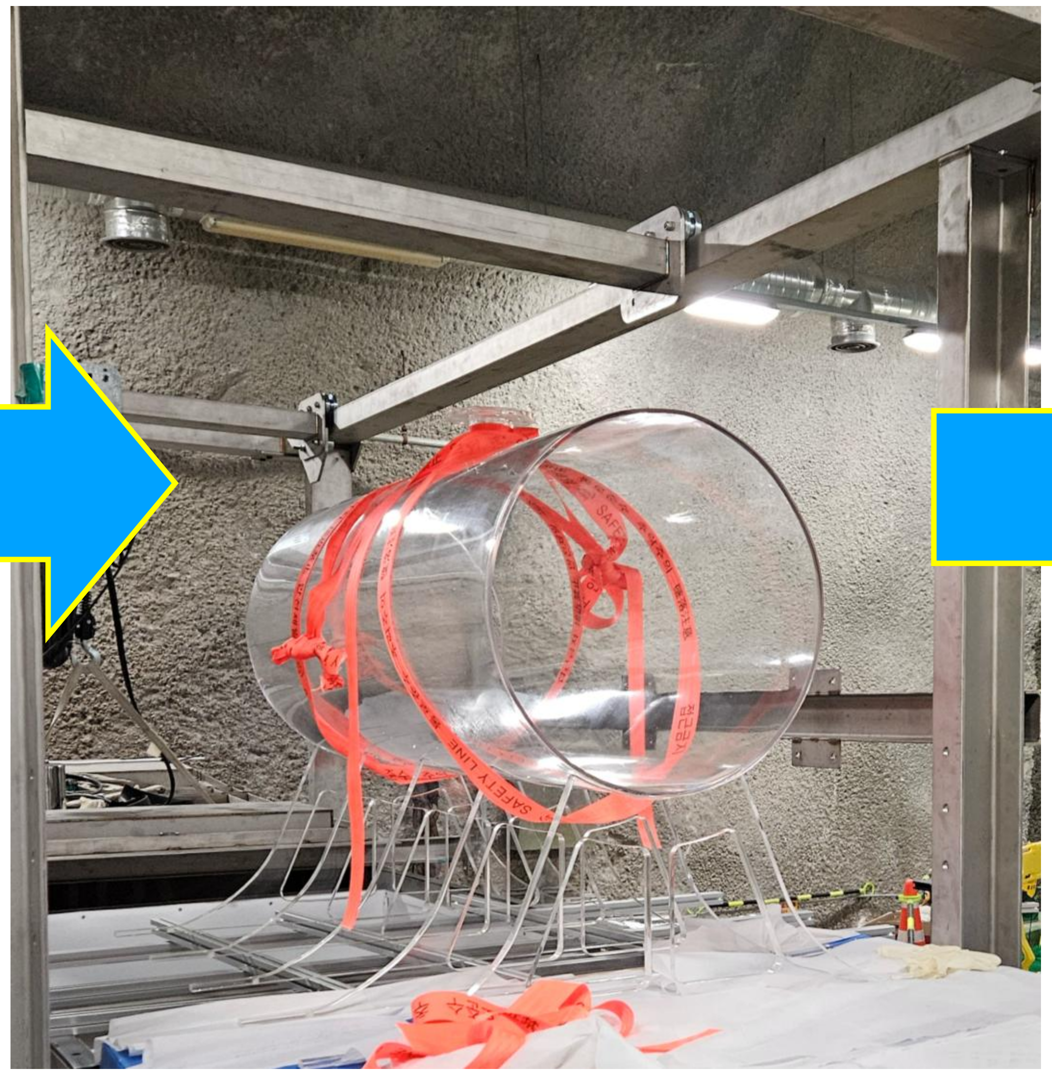
**Comparison of Data and MC: NPE / true energy as a function of true energy**

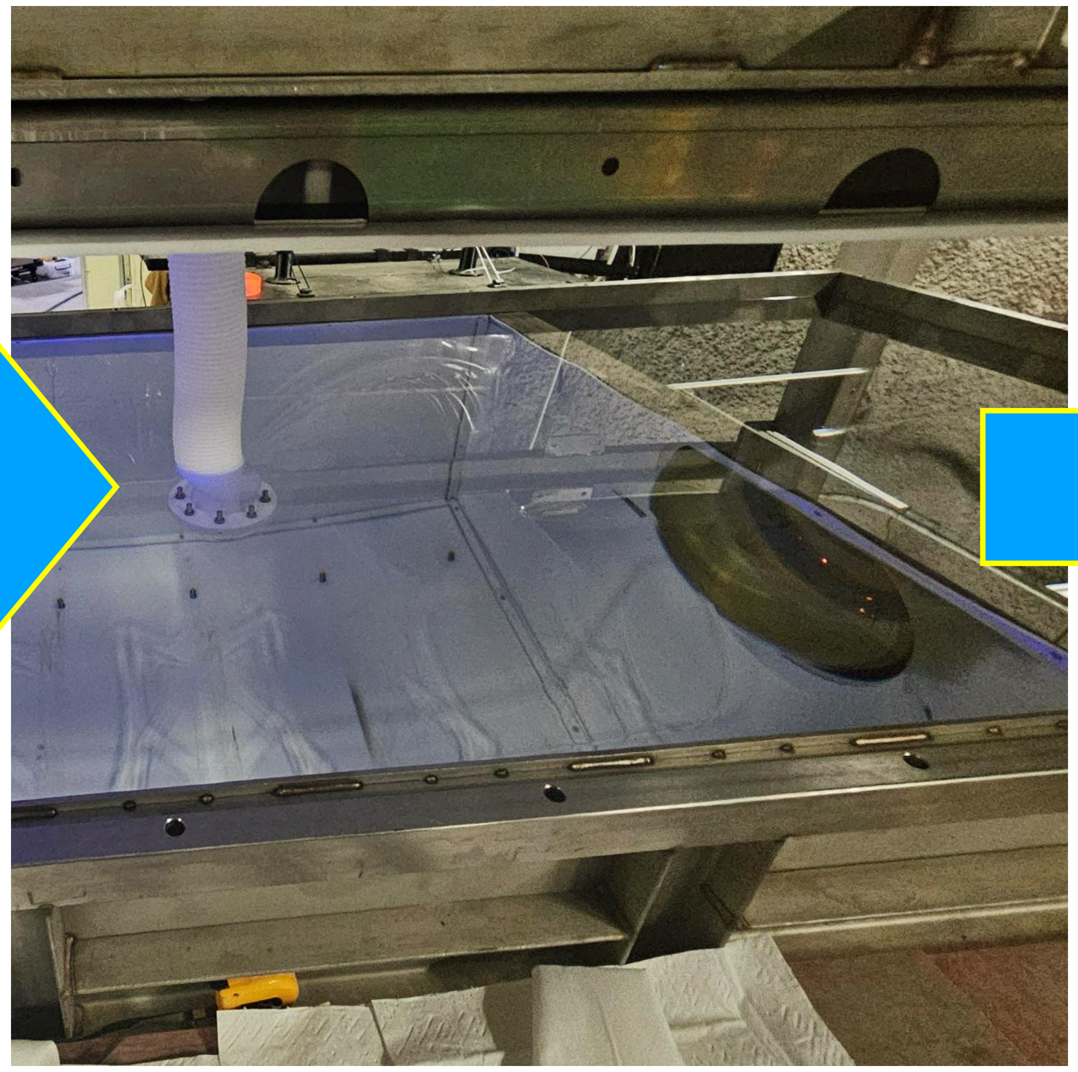


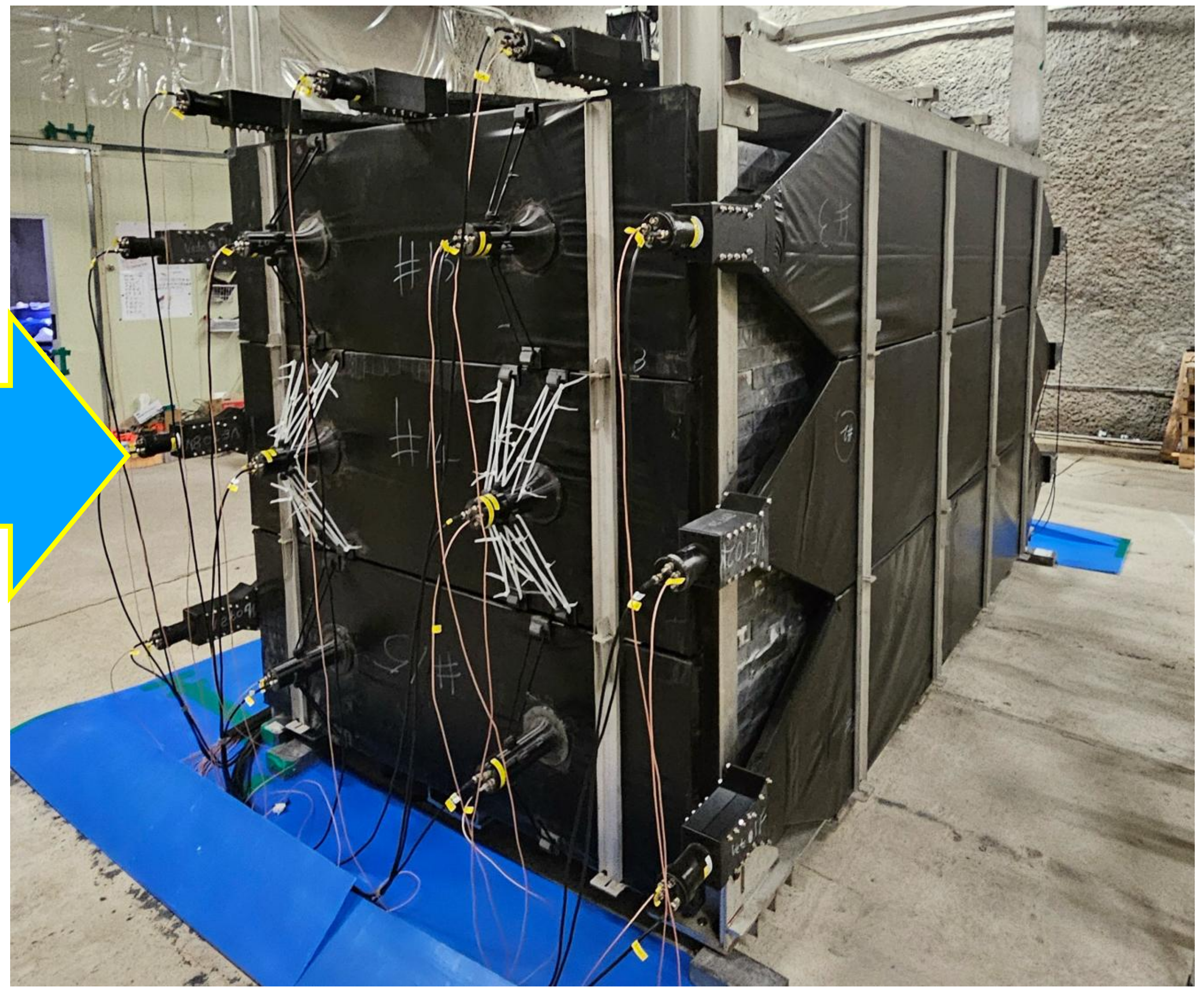

- **Single γ Peaks: Less light at low energy due to quenching, described by Birks' law**
- **Multiple γ Peaks: Also affected by quenching; ratio depends on individual γ energies, Data–MC trend consistent**

# Detector Construction









# RENE Collaboration

8th RENE collaboration meeting (2026.01.12)


**11 institutions & about 30 members**

# RENE Schedule

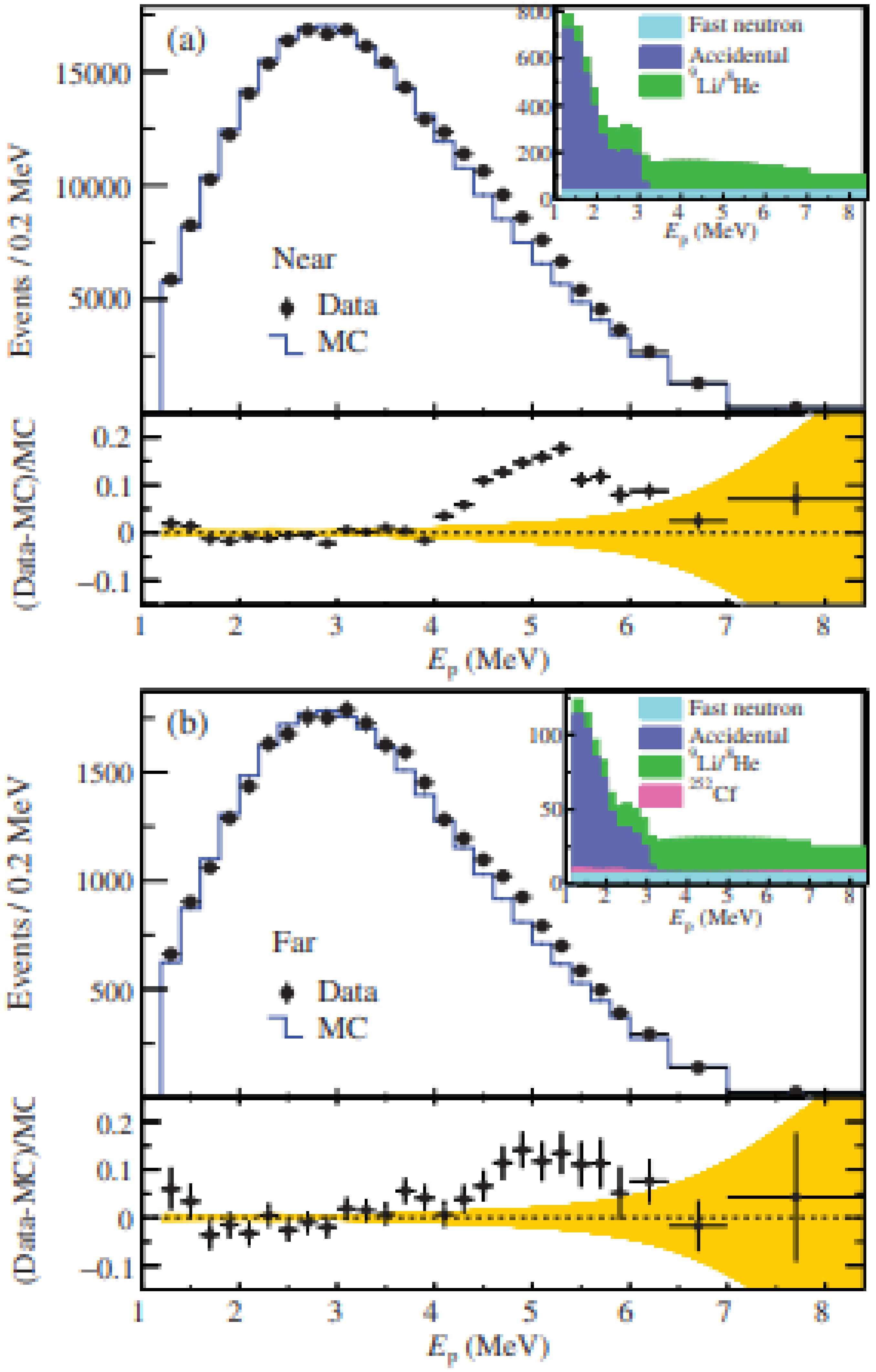

: RENE started

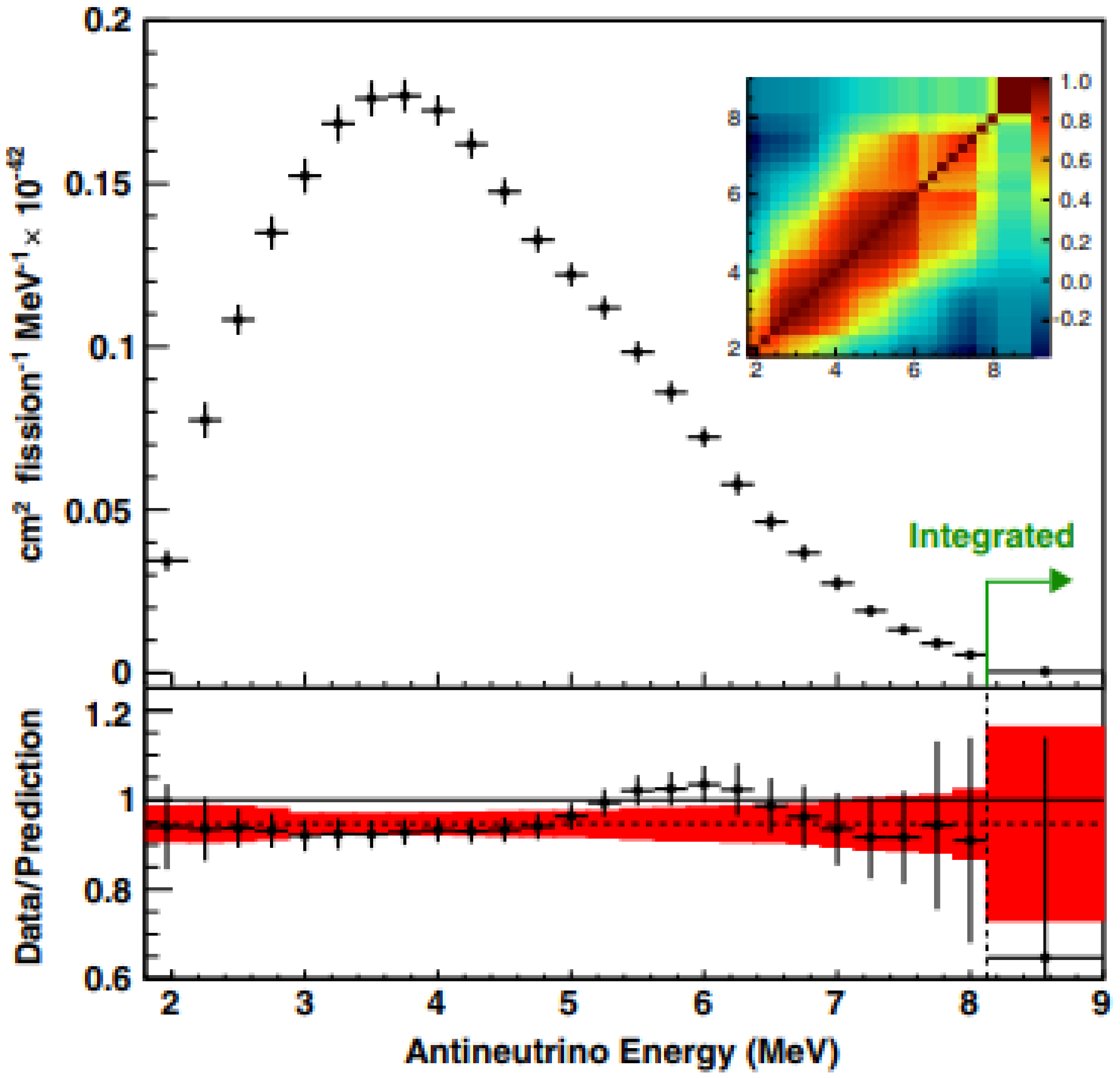
# Summary

- **RENE is a short-baseline reactor antineutrino experiment for sterile neutrino searches**
- **A 0.5% Gd-loaded LS detector with a gamma catcher is under development**
- **Detailed detector simulation and MC tuning are in progress**
- **The expected best-fit region can be probed within approximately 6 months of data taking**
- **Approximately 2 years of data taking are planned**

# Back Up

# Reactor Neutrino Anomalies and Sterile Neutrinos




$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) \approx 1 - \sin^2 2\theta_{14} \sin^2\left(1.27 \frac{\Delta m^2 L}{E_\nu}\left[\frac{eV^2 \cdot m}{MeV}\right]\right)$$

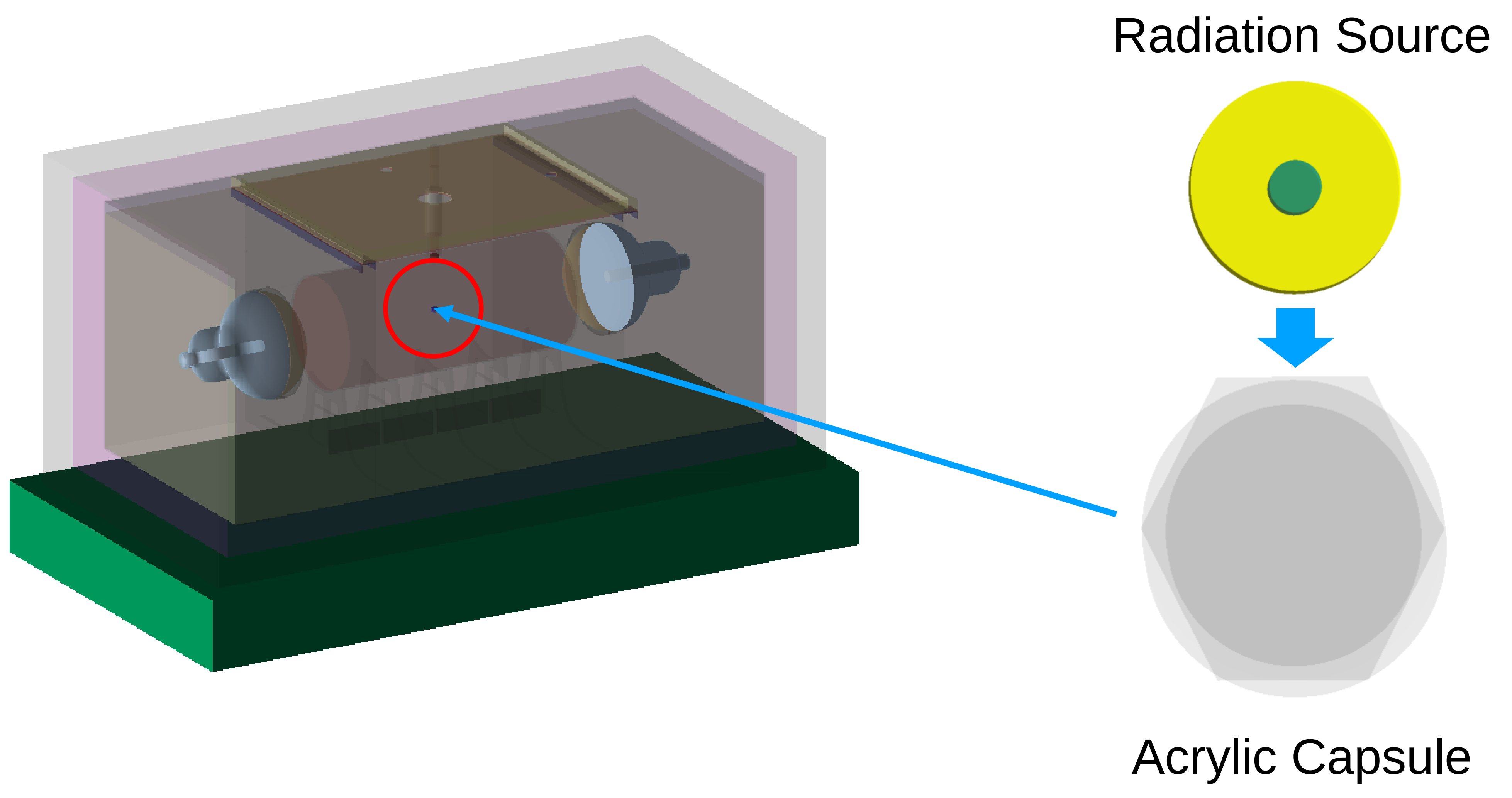
# Generator

**Generate various particles corresponding to calibration sources for comparison with experimental data.**

**Radiation Source Data**

| Source | Type | Energy (MeV) | Etc. |
|---|---|---|---|
| $^{137}Cs$ | γ | 0.662 | Single Gamma |
| $^{65}Zn$ | γ | 1.112 | Single Gamma |
| $^{22}Na$ | γ, $e^+$ | 1.275 | Single Gamma |
| | | 2.297 | Multiple Gamma |
| $^{60}Co$ | γ | 2.506 | Multiple Gamma |
| $^{252}Cf$ | γ, n | 2.223 | Single Gamma |
| | | ~8 | Multiple Gamma |

**Poster P1-pa.006 OH Junkyo**

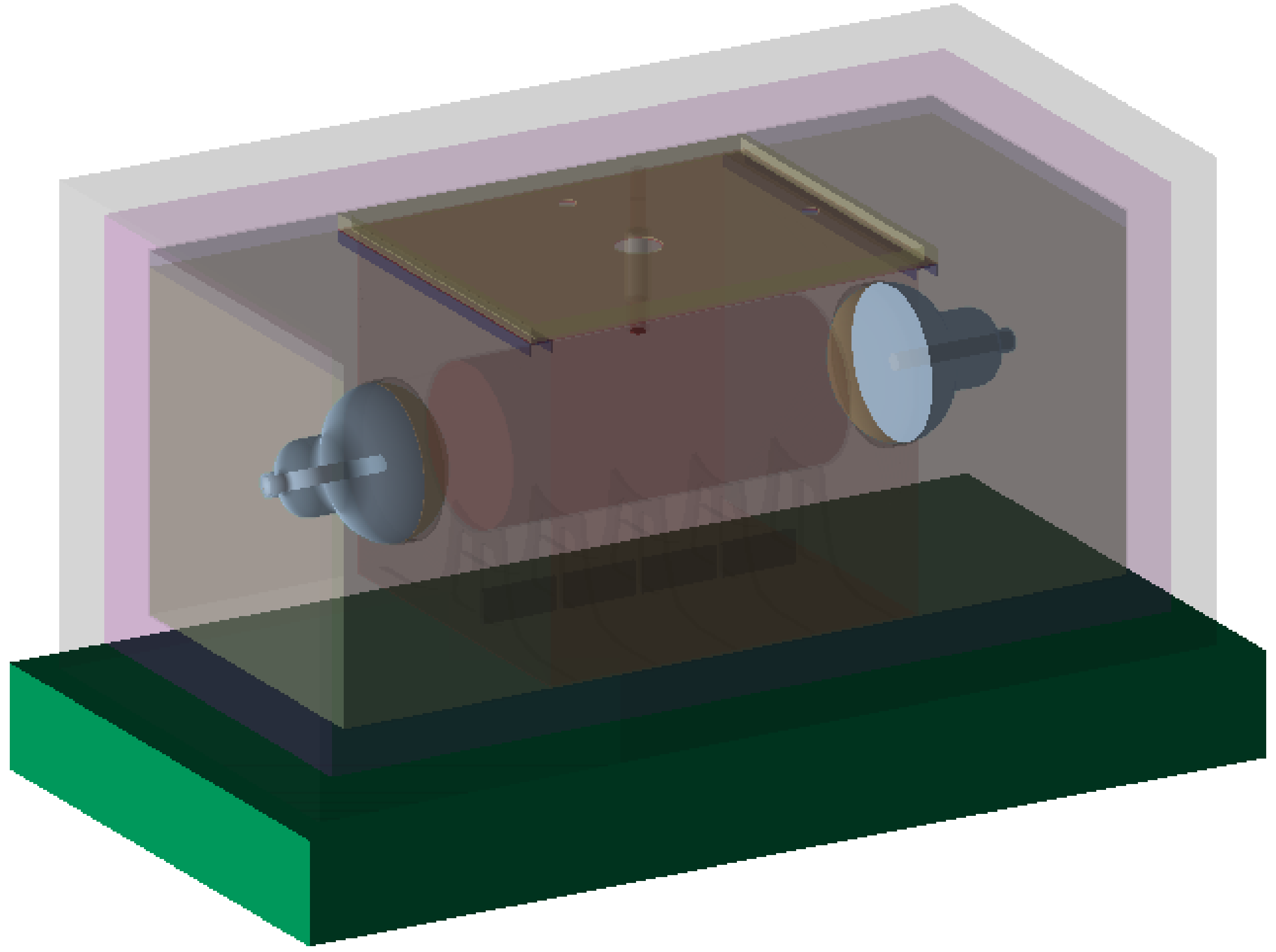


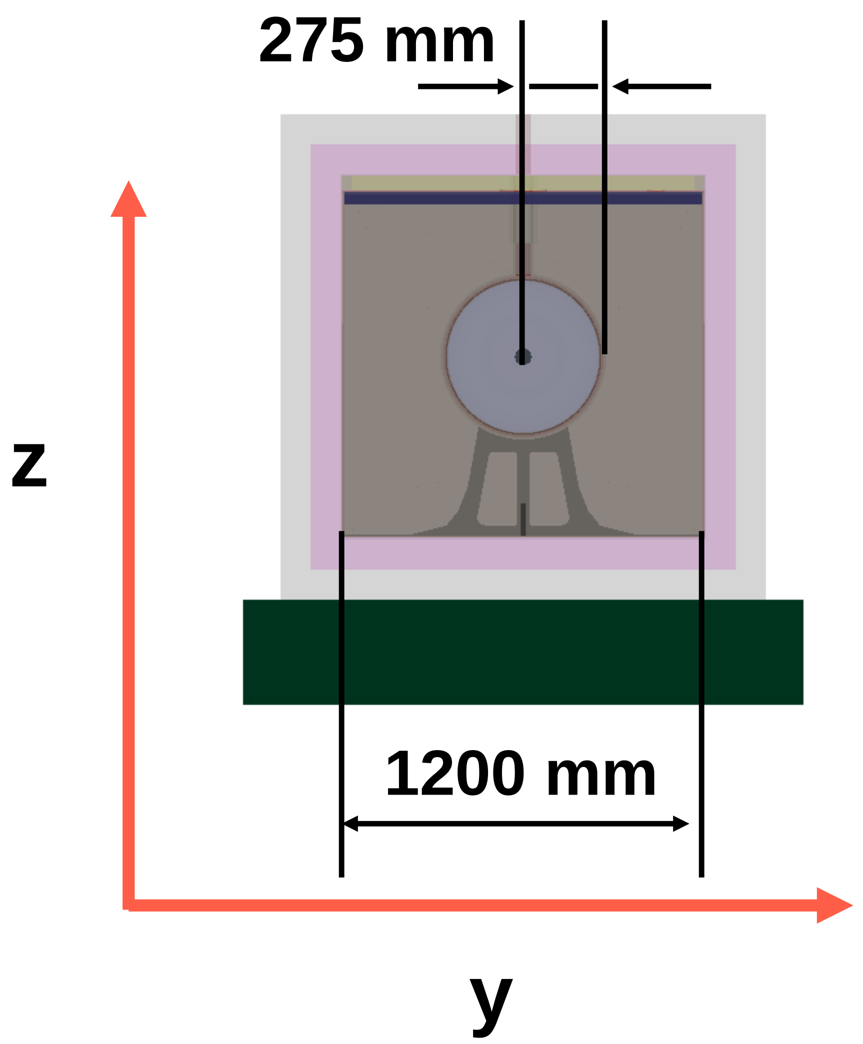

- **Acrylic Capsule**
  - **Blocks beta particles from calibration sources to prevent direct interaction with the scintillator.**
  - **Implemented identically in MC to reproduce experimental conditions.**

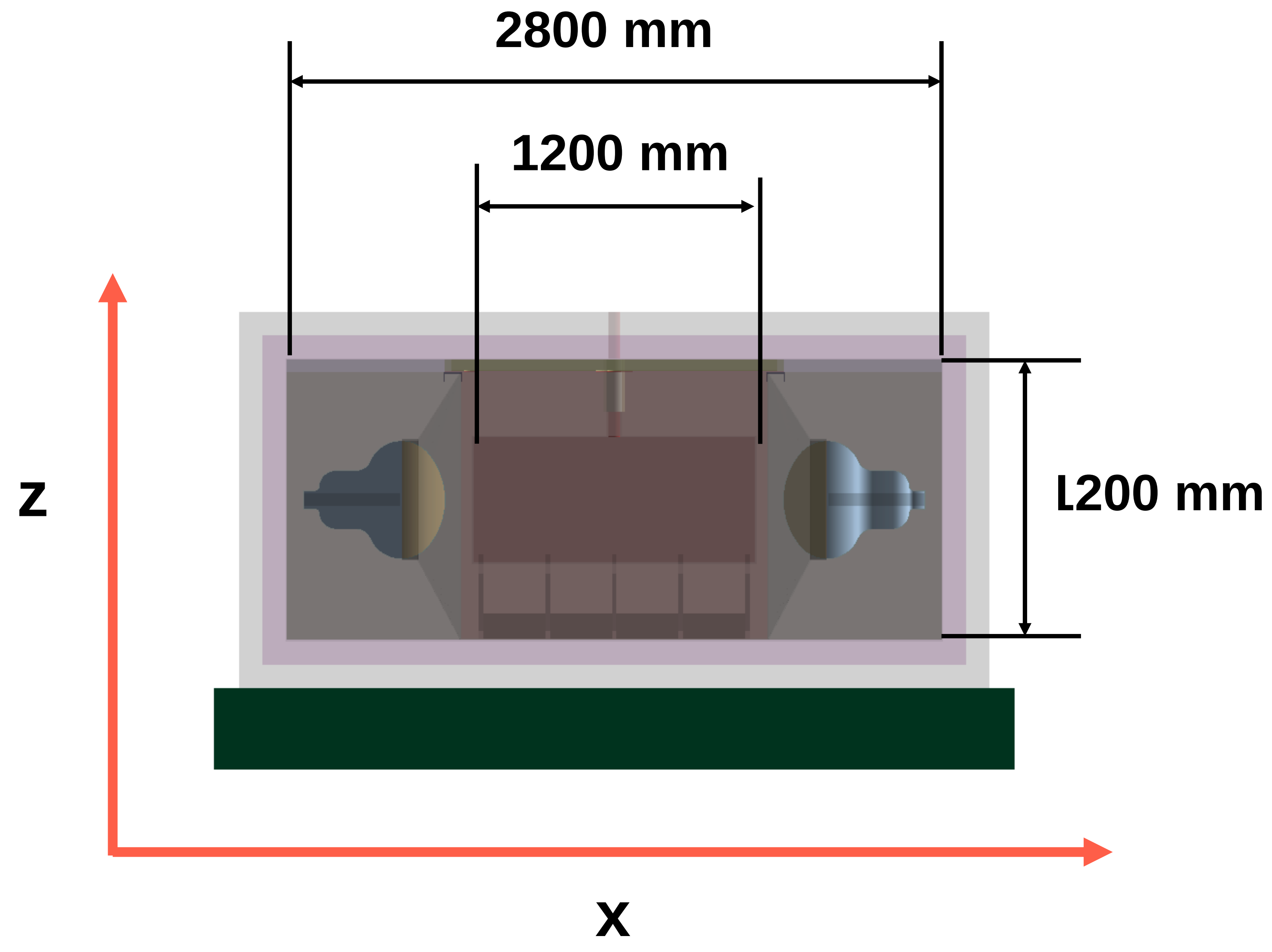
# RENE Simulation Outline

- **RATPAC-two framework has been adopted as our simulation software.**
  - **Reactor Analysis Tools Plus Additional Code (RAT-PAC) Two operates on the GLG4Sim framework and is compatible with Geant4 v11 and ROOT v6.25.**

- **Simulation Geometry**
  - **Target: Gd concentration 0.1% (commissioning)**



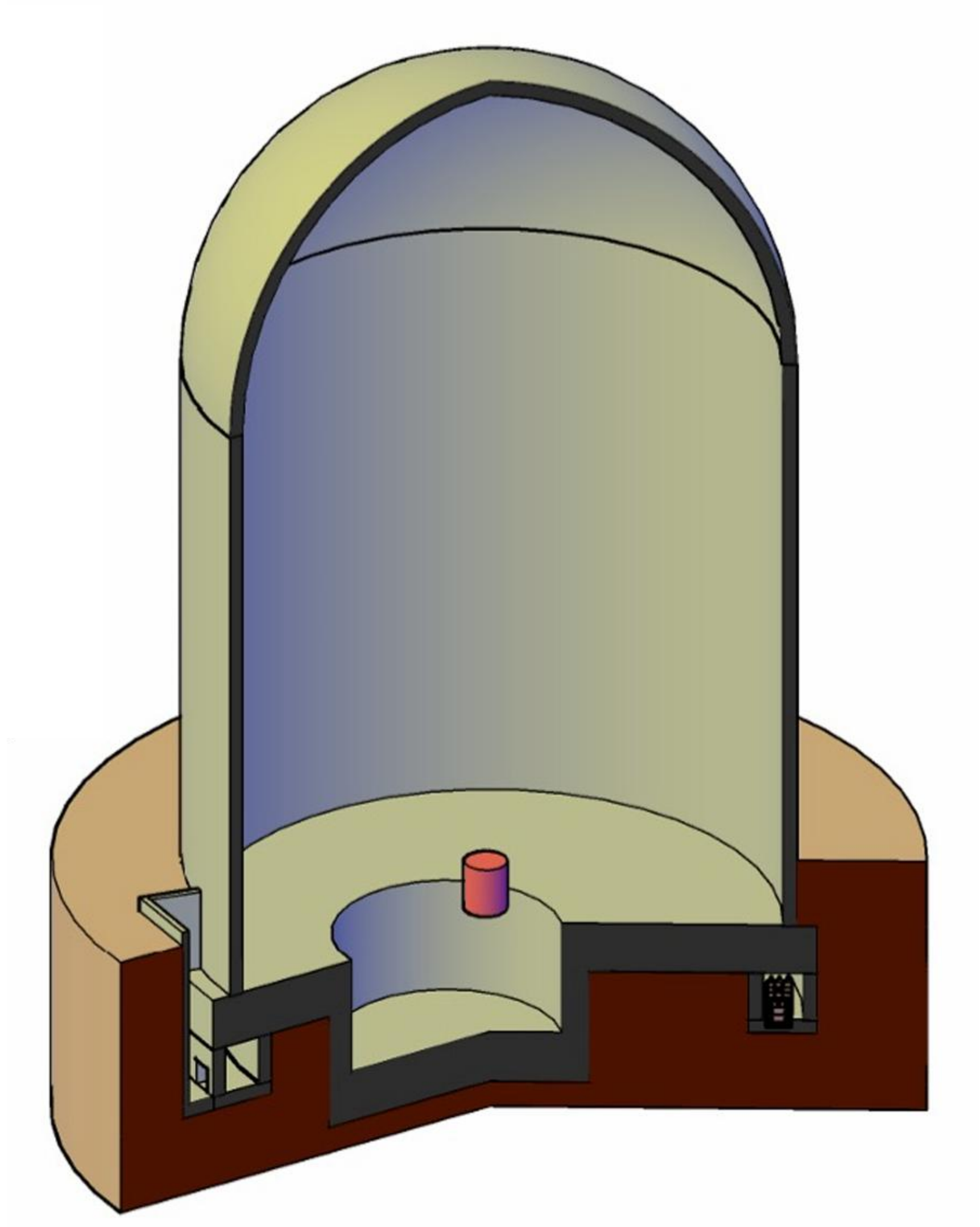


# Computing Status for RENE

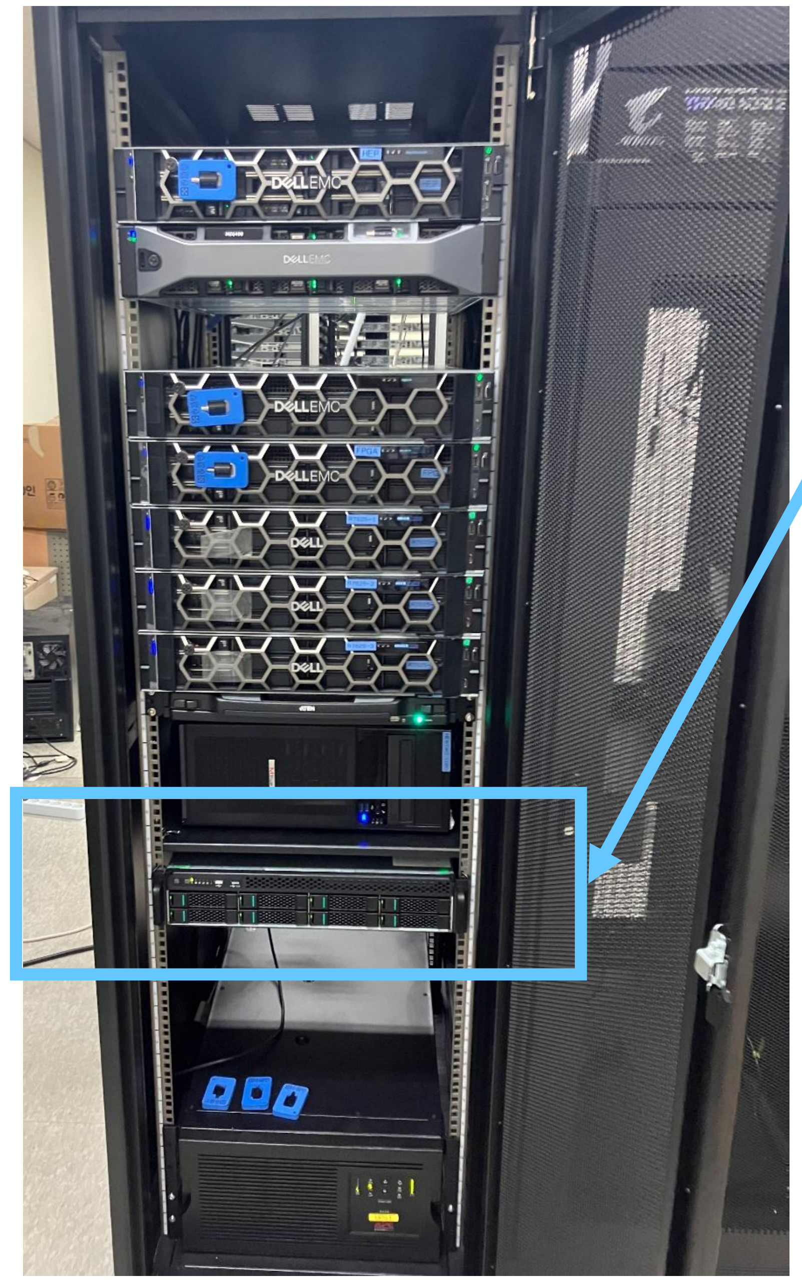
- **A computing farm has been established at Kyung Hee University (KHU) to support the RENE experiment.**

**Tendon Gallery**



**Transferred Manually**

**KHU**



**New Storages 144 TB (HDD 22 TB × 8, RAID 5)**

**Transferred via Network**

**Commissioning Site in CNU**

- **Due to security restrictions in the tendon gallery, raw data must be manually transferred via hard drives.**
- **Approximately 144 TB will be required over two years of data-taking.**
- **A total of 288 TB of storage capacity has been added for commissioning and data storage.**

# NPE Different for Data vs MC

- **Compared NPE values of source peaks**
- **Average difference: 1.26%**

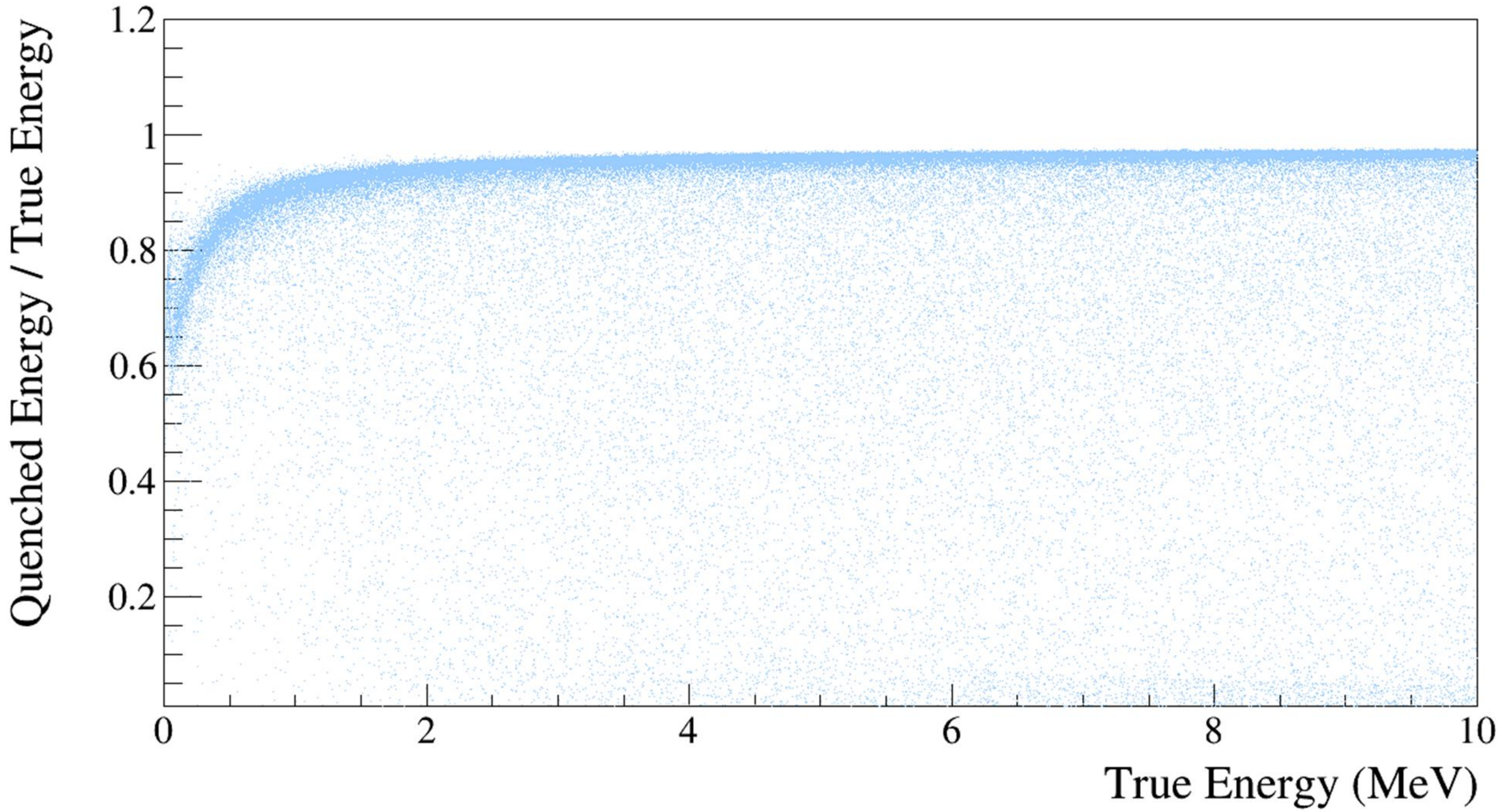
| Source | $E_{true}$ (MeV) | NPE (Data) | NPE (MC) | $\frac{\lvert Data-MC \rvert}{MC} \times 100\ (\%)$ |
|---|---|---|---|---|
| $^{137}$Cs | 0.662 | 335.62 ± 0.01 | 337.84 ± 0.12 | 0.66 |
| $^{65}$Zn | 1.112 | 598.43 ± 0.04 | 601.21 ± 0.21 | 0.46 |
| $^{60}$Co | 2.506 | 1387.92 ± 0.05 | 1360.82 ± 0.32 | 1.99 |
| $^{22}$Na | 1.275 | 701.07 ± 0.06 | 693.75 ± 0.61 | 1.06 |
| $^{22}$Na | 2.297 | 1213.03 ± 0.04 | 1190.06 ± 0.32 | 1.93 |
| $^{252}$Cf (nH) | 2.223 | 1294.63 ± 0.85 | 1265.81 ± 0.69 | 2.28 |
| $^{252}$Cf (nGd) | 8 | 4452.29 ± 0.91 | 4471.64 ± 2.31 | 0.43 |

# Scintillation

**Energy deposition in the scintillator produces optical photons via scintillation processes.**

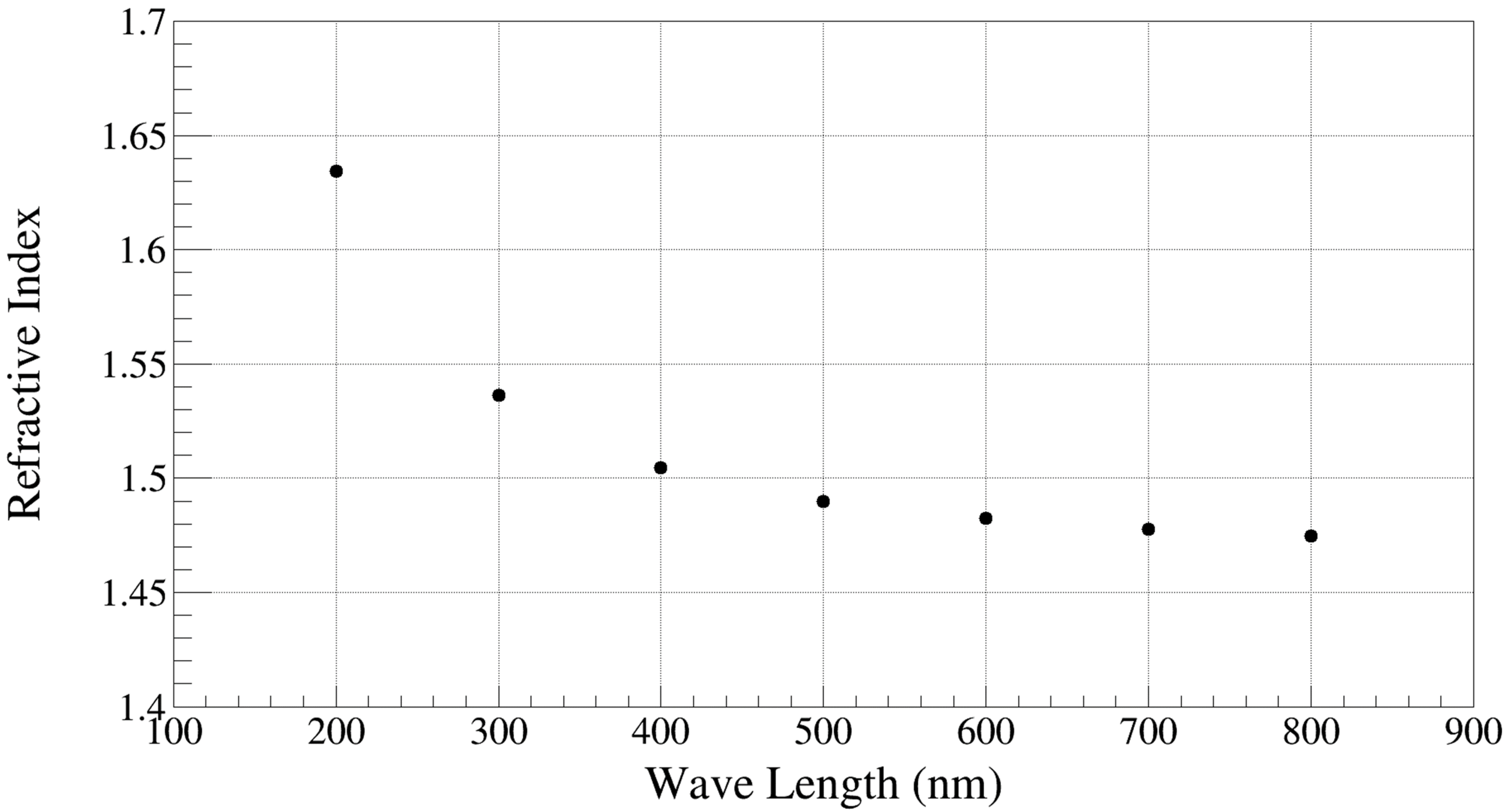
- **MC Simulation Conditions**
  - **Light Yield: 8360 pe / MeV**
  - **Birks' Constant ($kB$) [1]:**
    - **Gd-LS: 0.124 mm / MeV**
    - **LS: 0.117 mm / MeV**
    - **Birks' law is applied to account for quenching effects.**

$$\frac{dL}{dx} = \frac{S\cdot(dE/dx)}{1 + kB\cdot(dE/dx)}$$



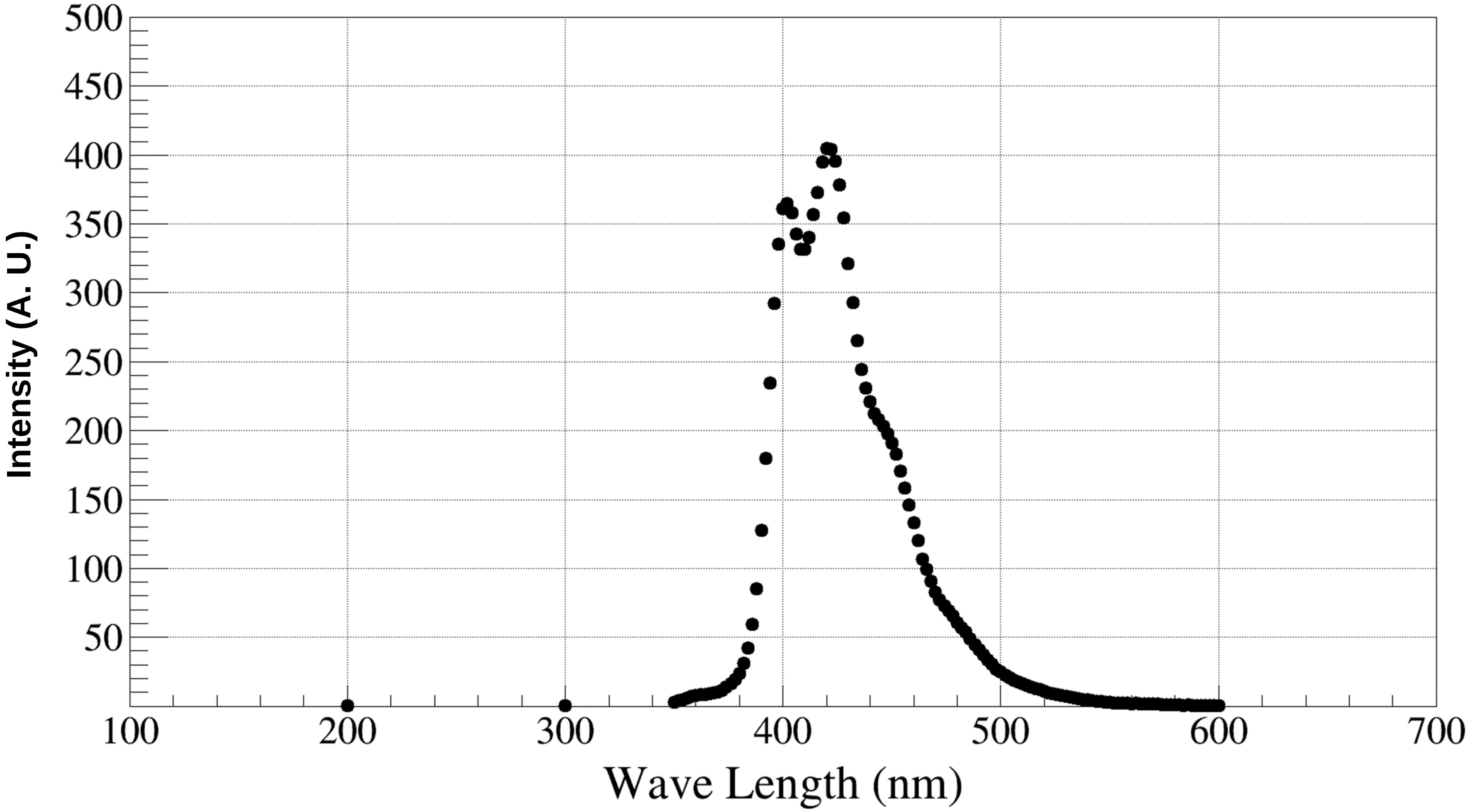
# Refractive Index

**This distribution is identically applied to both Gd-LS and LS.**



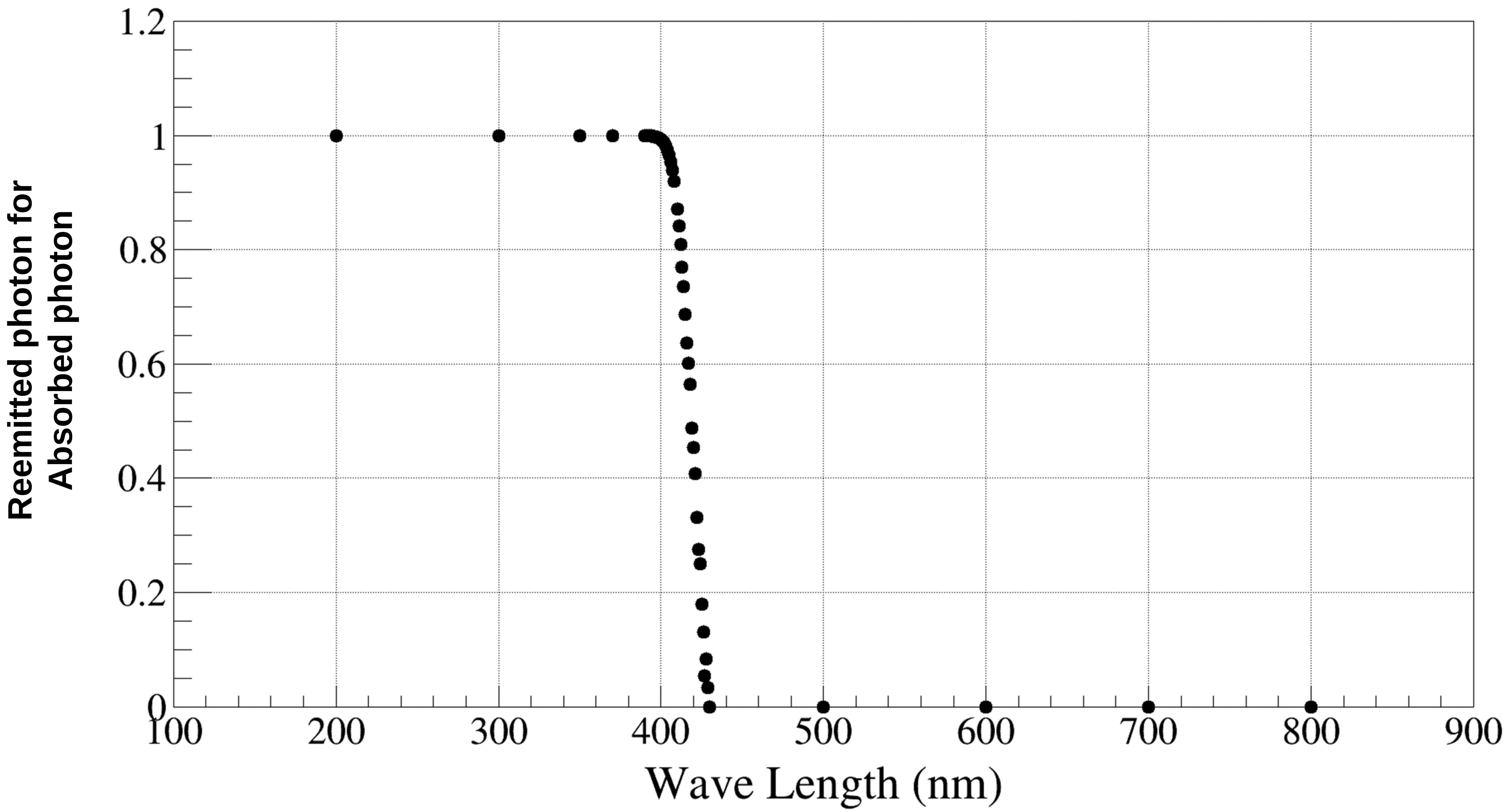
# Emission Spectra

**This distribution is identically applied to both Gd-LS and LS.**

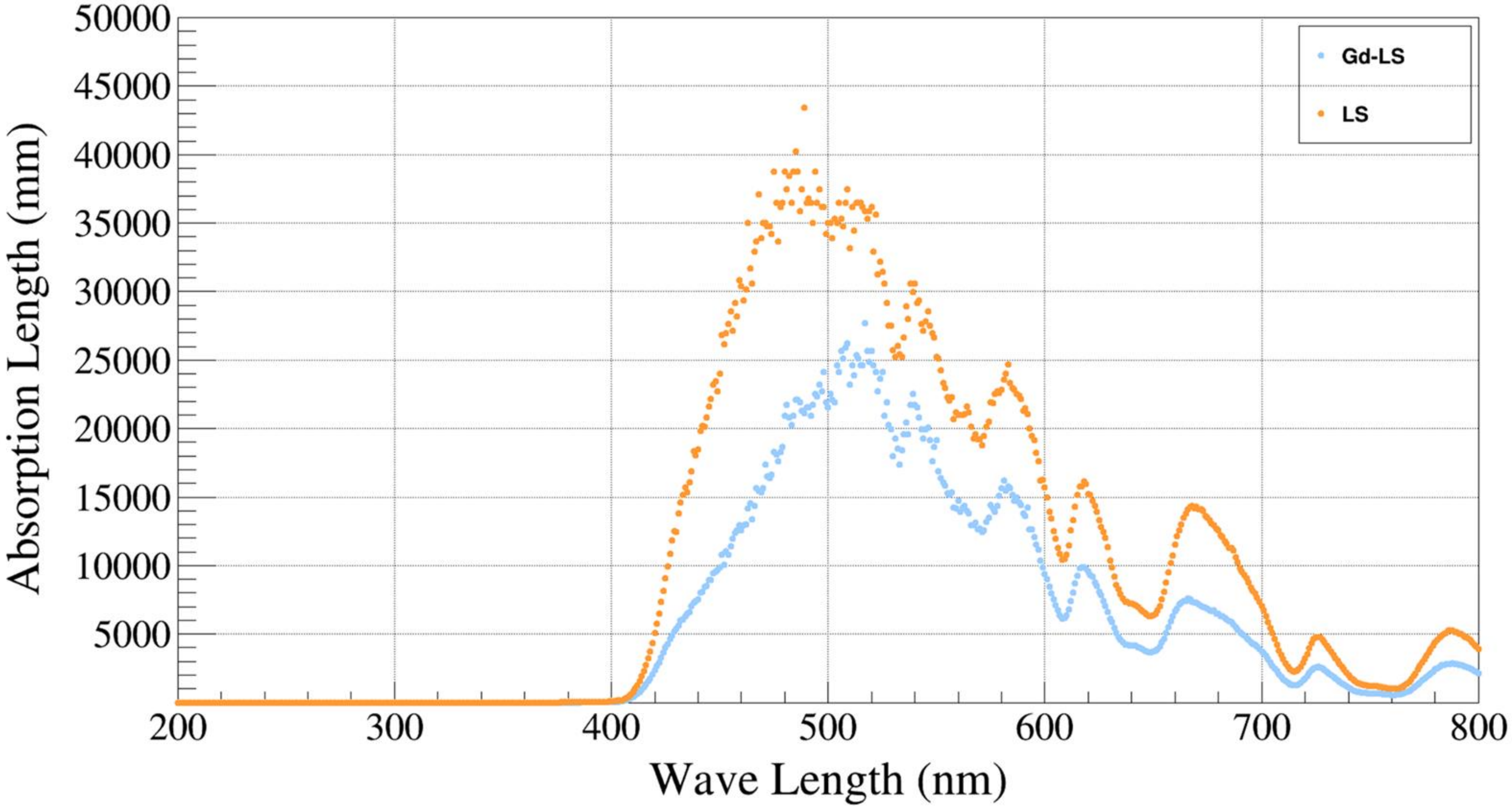


# Re-emission Probability

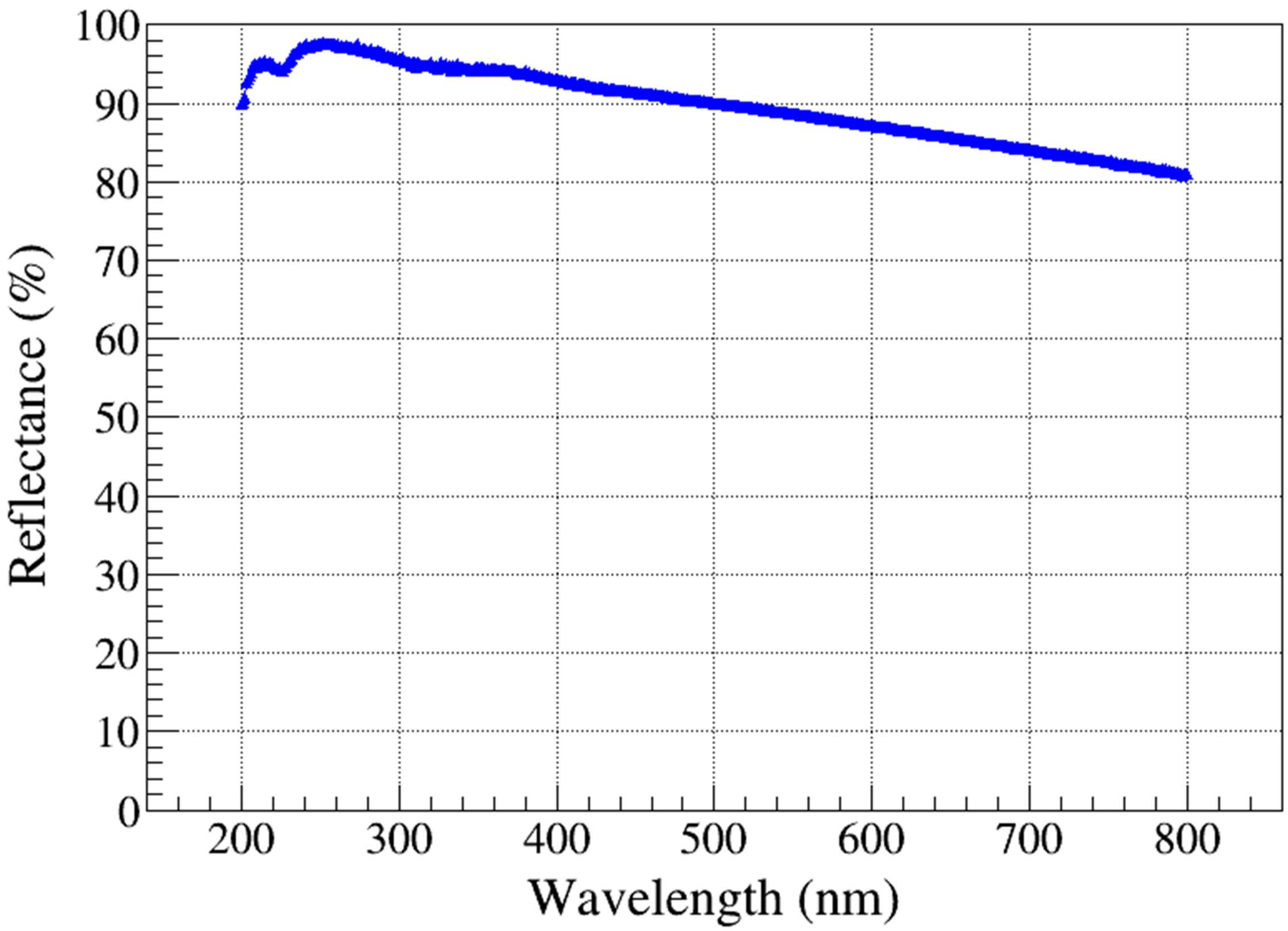
**This distribution is identically applied to both Gd-LS and LS.**

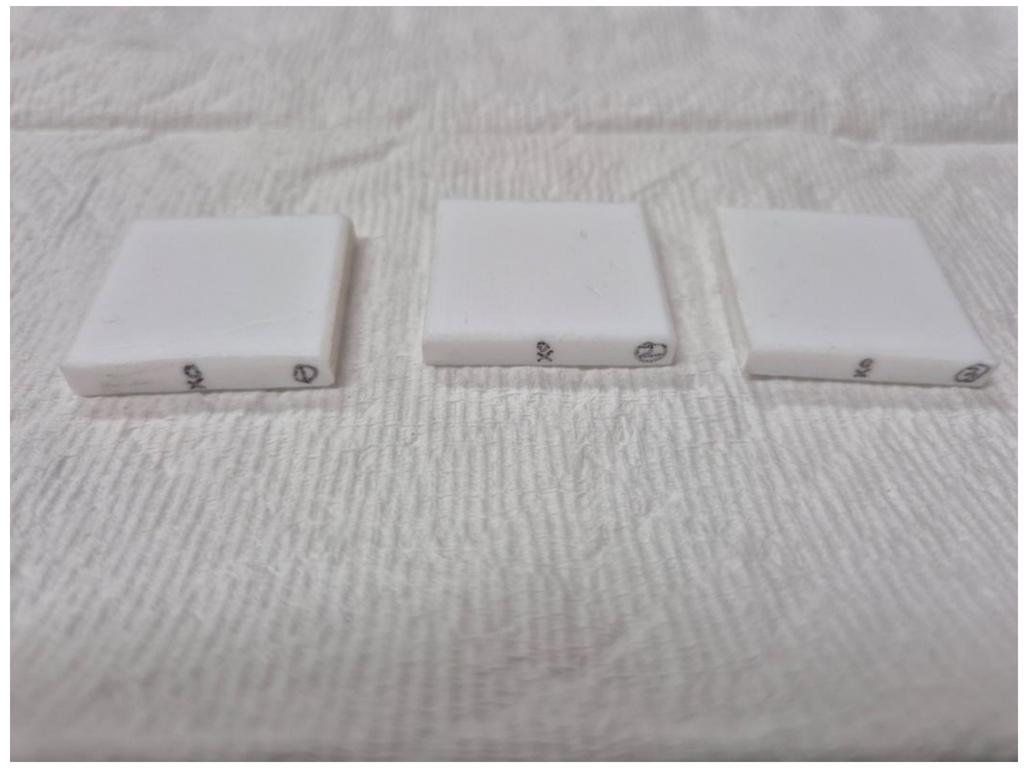


# Absorption Length



# Reflectance



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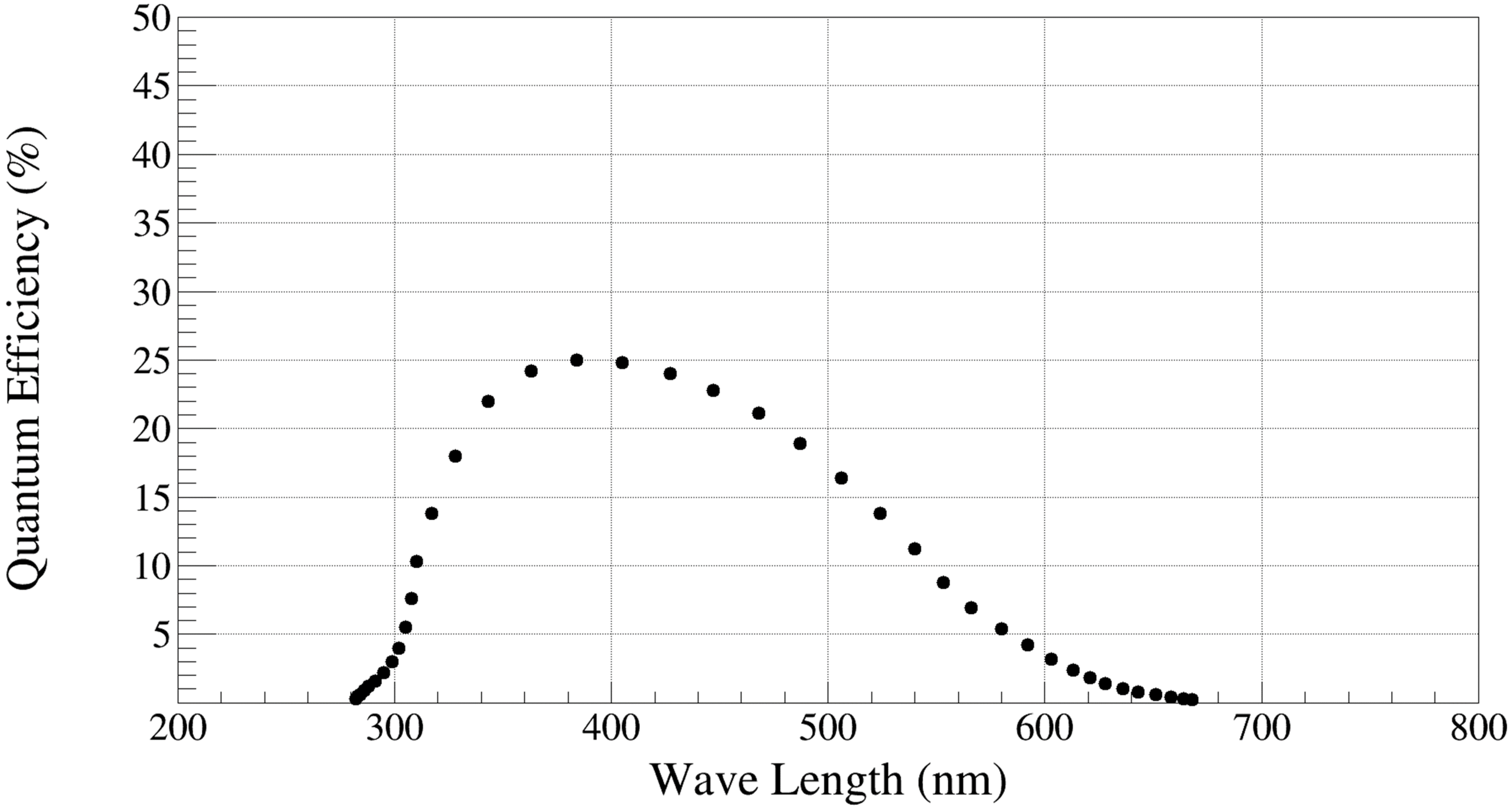
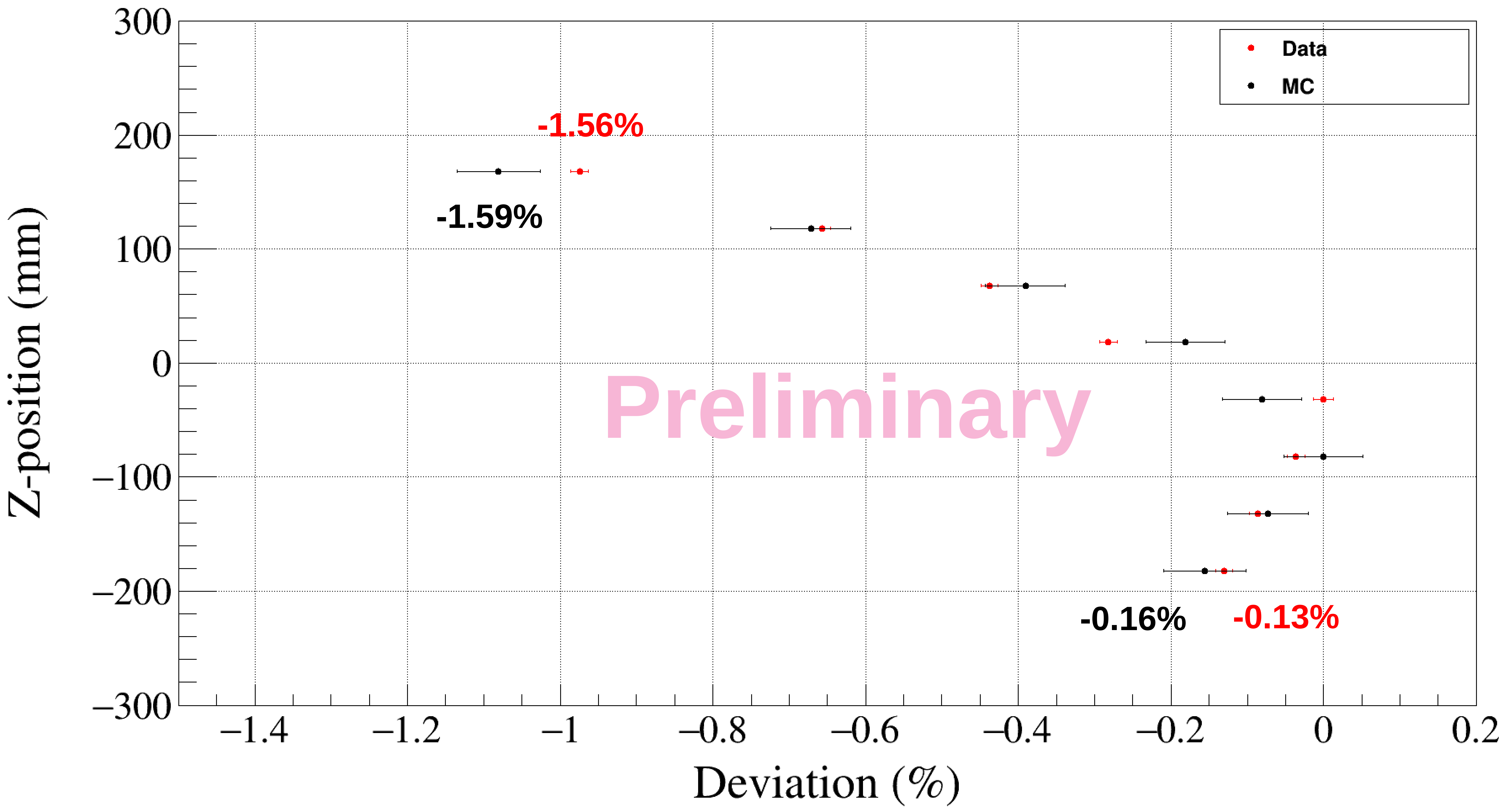
# PMT Quantum Efficiency



# Deviation Z-position Dependence Data vs. MC

$$\boldsymbol{Deviation}\ (\%) = \frac{\boldsymbol{NPE - NPE_{max}}}{\boldsymbol{NPE_{max}}} \times \mathbf{100}$$

**Data $NPE_{max}$: -32 mm**
**MC $NPE_{max}$: -82 mm**



| | 1 Event | 1 second (1 kHz) | 1 day | 1 week | 1 month |
|---|---|---|---|---|---|
| FADC (2-CH) | 2 kB | 2 MB | 172.8 GB | 1.21 TB | 4.84 TB |
| SADC (32-CH) | 0.5 kB | 0.5 MB | 43.2 GB | 302.4 GB | 1.21 GB |
| Total | 2.5 kB | 2.5 MB | 216.0 GB | 1.51 TB | 6.05 TB |

- According to the manuals of the equipment, the raw data size is expected to be **about 6 TB per month per kHz**.
- Data size needs to be measured during commissioning.
- RENE DAQ PC has 32 TB HDD.



# Data

# Reference

[1] J.S. Park, J. Lee, I.S. Yeo, W.Q. Choi, J.K. Ahn, J.H. Choi, ... & I. Yu, Production and optical properties of Gd-loaded liquid scintillator for the RENO neutrino detector. *Nuclear Instruments and Methods in Physics Research Section A*, 707, 45–53. (2013) https://doi.org/10.1016/j.nima.2012.12.121

# NPE Different for Data vs MC

- **Compared NPE values of source peaks**
- **Average difference: 1.26%**

| Source | $E_{true}$ (MeV) | NPE (Data) | NPE (MC) | $\frac{\lvert Data-MC \rvert}{MC} \times 100\ (\%)$ |
|---|---|---|---|---|
| $^{137}$Cs | 0.662 | 335.622 ± 0.009 | 337.84 ± 0.12 | 0.65623 |
| $^{65}$Zn | 1.112 | 598.43 ± 0.04 | 601.2 ± 0.2 | 0.4634 |
| $^{60}$Co | 2.506 | 1387.92 ± 0.05 | 1360.8 ± 0.3 | 1.9914 |
| $^{22}$Na | 1.275 | 701.07 ± 0.06 | 693.7 ± 0.6 | 1.056 |
| $^{22}$Na | 2.297 | 1213.03 ± 0.04 | 1190.1 ± 0.3 | 1.9302 |
| $^{252}$Cf (nH) | 2.223 | 1294.6 ± 0.9 | 1265.8 ± 0.7 | 2.2768 |
| $^{252}$Cf (nGd) | 8 | 4452.3 ± 0.9 | 4472 ± 2 | 0.4327 |

# NPE Different for Data vs MC

- **Compared NPE values of source peaks**
- **Average difference: 1.26%**

| Source | $E_{true}$ (MeV) | NPE (Data) | NPE (MC) | $\frac{\lvert Data-MC \rvert}{MC} \times 100$ (%) |
|---|---|---|---|---|
| $^{137}Cs$ | 0.6617 | 335.622 ± 0.009 | 337.84 ± 0.12 | 0.65623 |
| $^{65}Zn$ | 1.1116 | 598.43 ± 0.04 | 601.2 ± 0.2 | 0.4634 |
| $^{60}Co$ | 2.506 | 1387.92 ± 0.05 | 1360.8 ± 0.3 | 1.9914 |
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