# Energy Response Model of the JUNO Central Detector

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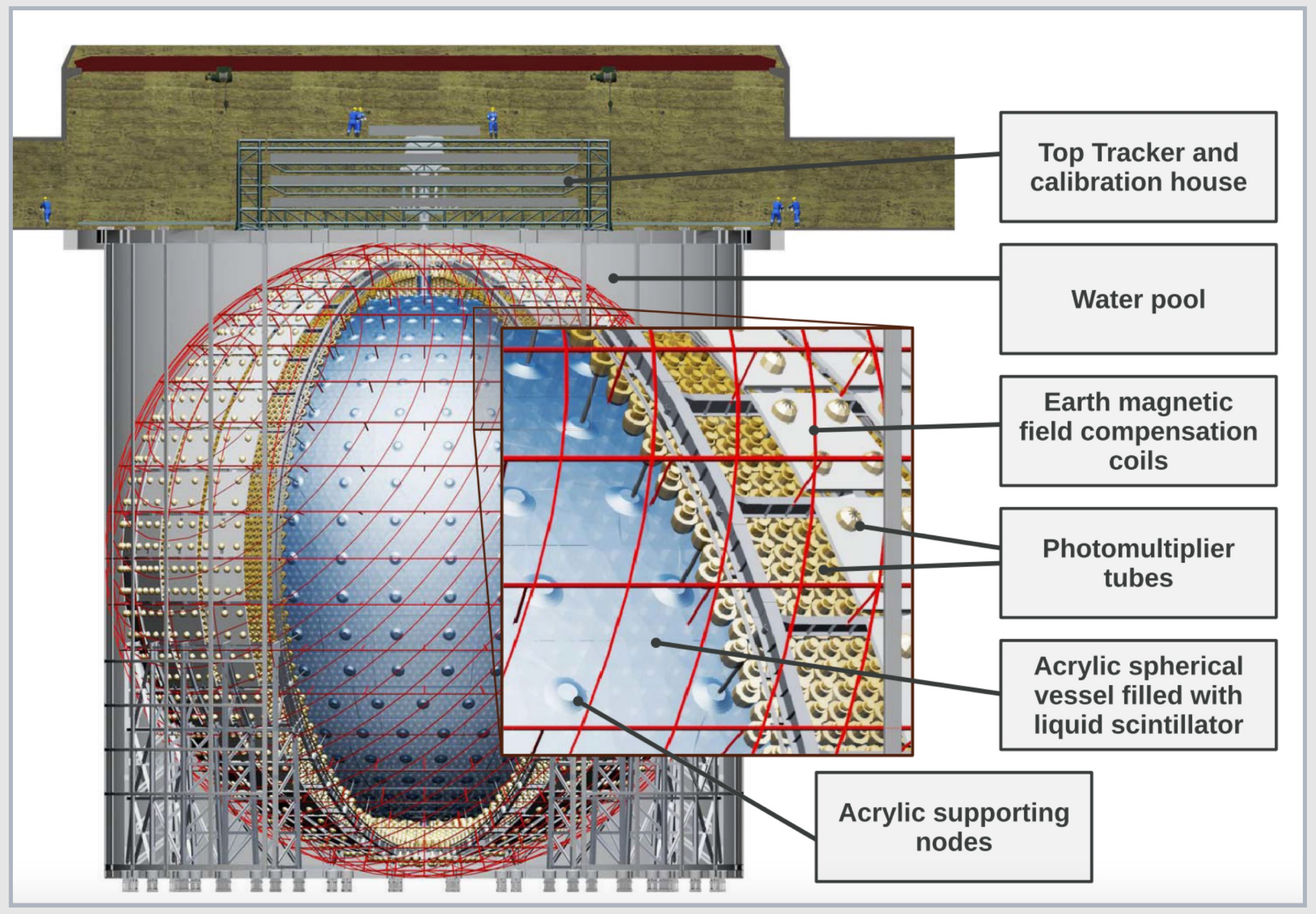
*(on behalf of the JUNO collaboration)*

## 1. Jiangmen Underground Neutrino Observatory [1]

- Located in Southern China next to multiple reactors providing large $\bar{\nu}_e$ flux
- 20 kton of liquid scintillator instrumented with 2 sets of PMTs reaching ~78% photocoverage
- Primarily designed for neutrino mass ordering determination through precise measurement of the $\bar{\nu}_e$ energy spectrum



## 2. Antineutrino Detection

Reactor antineutrinos detected through Inverse Beta Decay (IBD)

**Prompt**: $e^+e^-$ annihilation $\gamma$

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

**Delayed**: n capture on H

Spatial-temporal coincidence of prompt and delayed events provide IBD signal of high purity

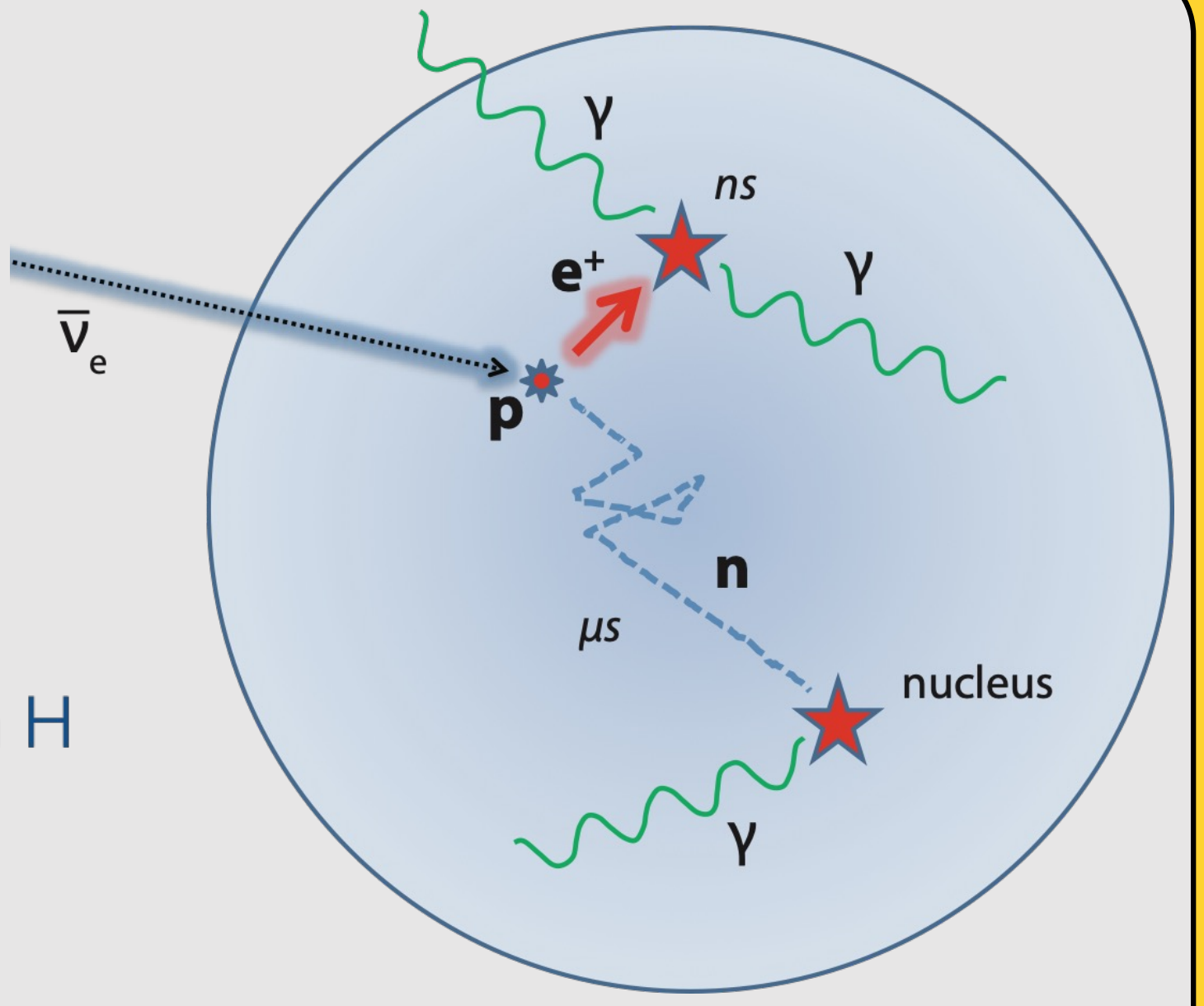


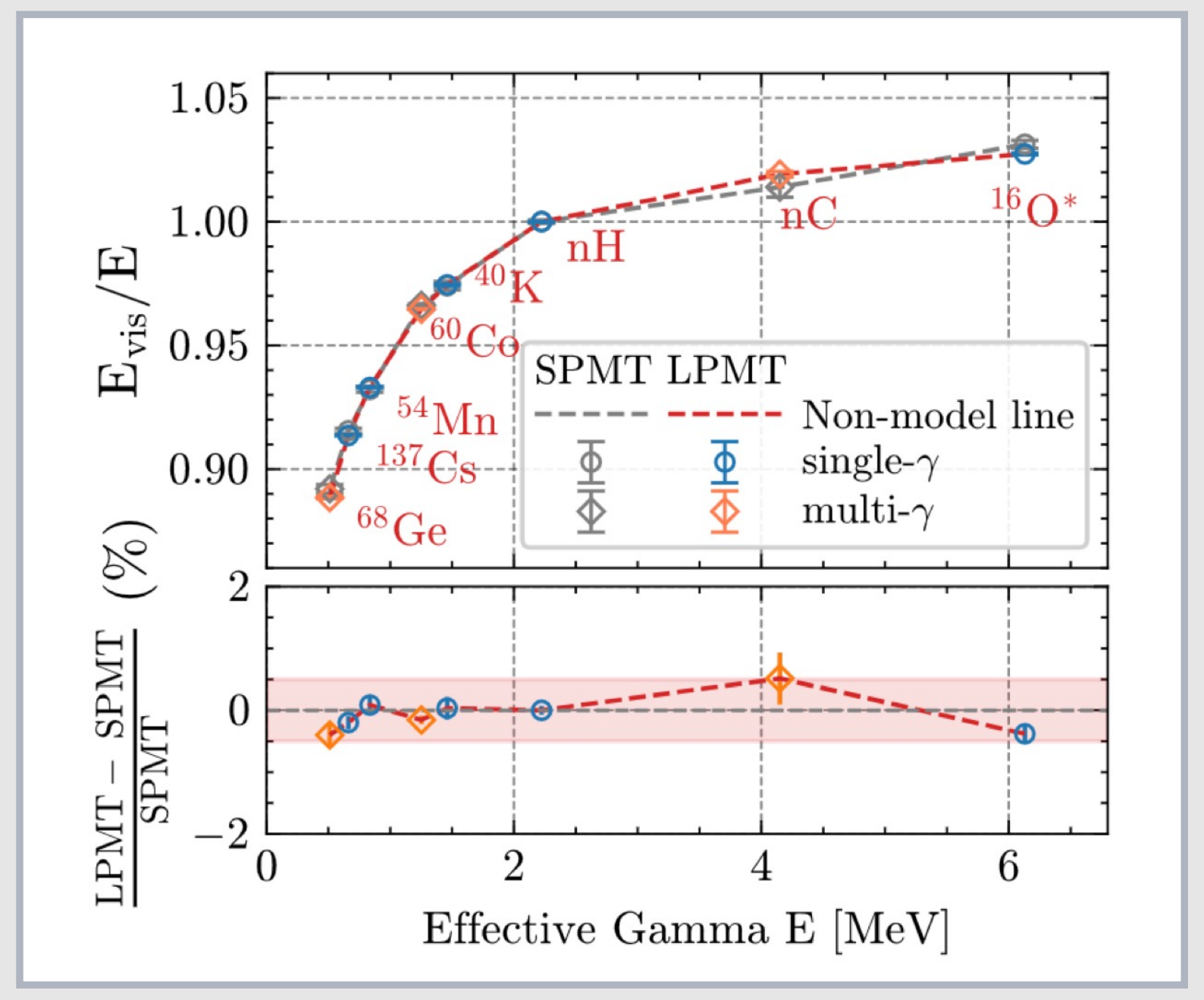
Figure of IBD process

## 3. Energy Non-linearity [1]

Since $E_{e^+} \propto E_\nu$, mapping the non-linear relationship between $E_{vis}$ & $E_{dep}$ is key to JUNO's oscillation program

Energy non-linearity depends on:

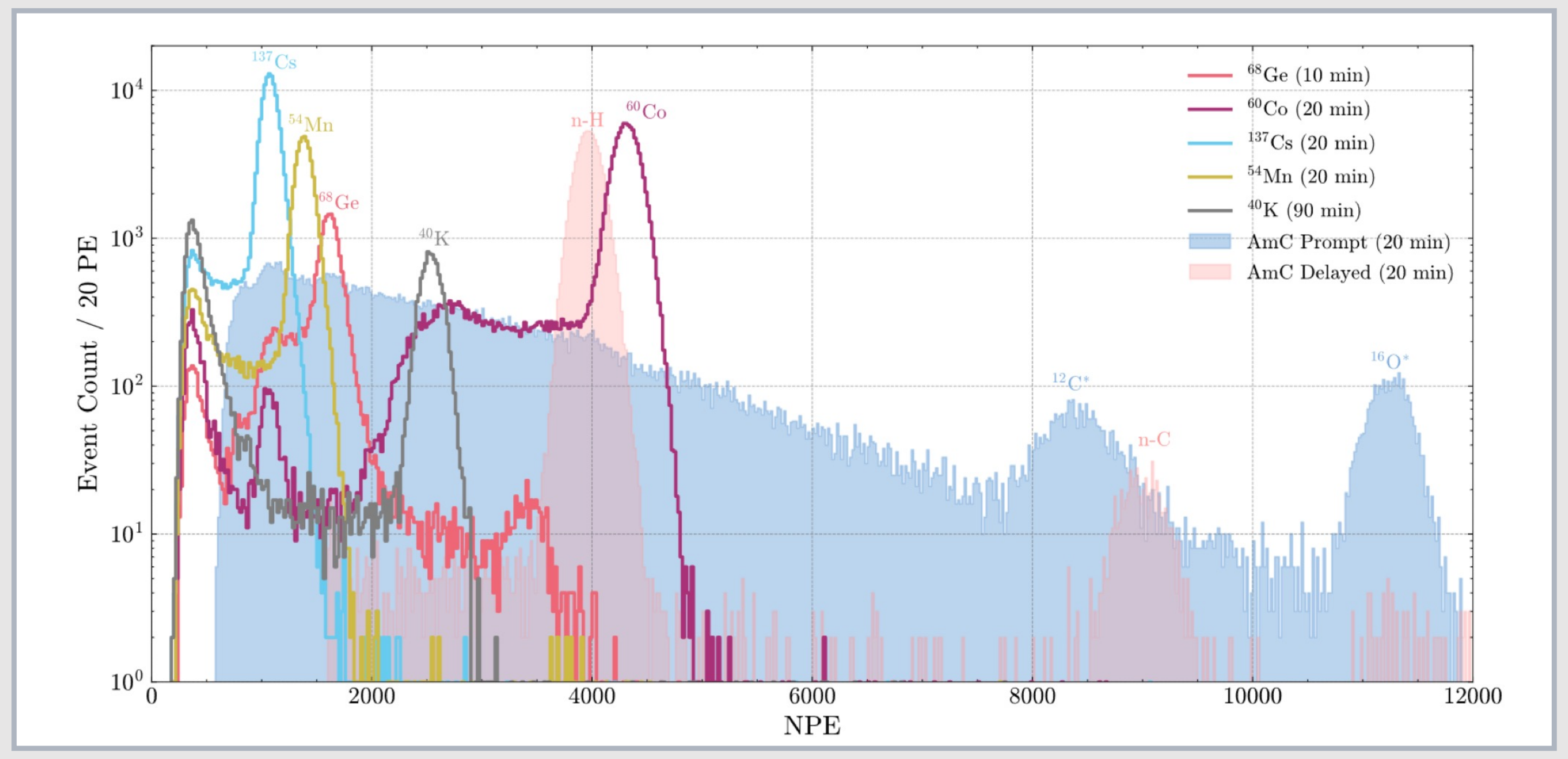
- Quenching (low energies)
- Cherenkov light (high energies)
- Instrumental Response



## 4. Calibration Sources [1,5]

- Deployed radioactive gamma sources cover energies from 1-8 MeV
- Cosmogenic isotopes from muon spallation directly constrain e±
- 16.5 m radius fiducial volume chosen

| Cosmogenic Isotope | Emission |
|---|---|
| $^{10}$C | e+ |
| $^{11}$C | e+ |
| $^{12}$B | e- |
| $^{12}$N | e+ |



Charge spectrum of gamma calibration sources

## 5. Modeling [2,3,4,5]

We present 2 models used to describe the JUNO detector response:

**a. COMEER**: Uses $dE, dx, \beta$ step information from Geant4 to calculate the number of photoelectrons (PE) in an event for different particles:

$$NPE = S * \Sigma_{step}\left(\frac{dE}{1 + k_B * \frac{dE}{dx}} + p * \frac{1}{1 - n^2 * \beta^2}\right) dx$$

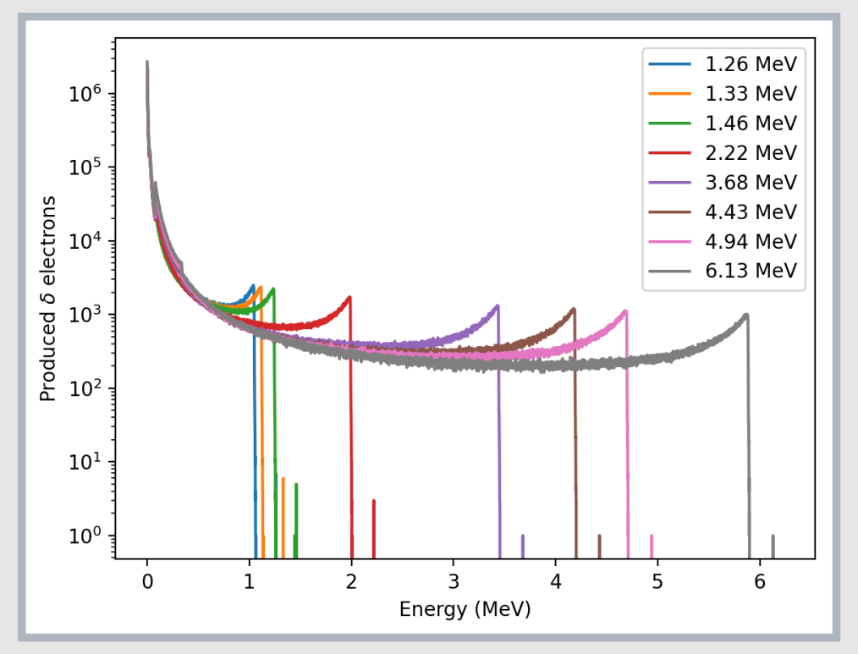
and a statistical resolution term : $Reso_{stat} = \sqrt{a^2 * NPE + NPE_{dark}}$

**b. GEPRiS: G**amma-**E**lectron-**P**ositron **R**esponse in **S**cintillator calculates the electron non-linearity $f^e_{NL}$ as:

$$f^e_{NL} \equiv \frac{E_{vis}}{E_{dep}} = \underbrace{f_{quench}\left(E, \frac{dE}{dx}, kB\right)}_{\text{Analytical (ESTAR)}} + \underbrace{f_{cherenkov}(E)}_{\text{Geant4}} + \underbrace{f_{instNL}}_{\text{Data-driven}}$$

Gammas are described as a function of their delta electron production P(E$^e$), simulated in Geant4:

$$\frac{E^\gamma_{vis}}{E^\gamma_{dep}} = \frac{\int_0^{E^e_{max}} P(E^e) \times E^e \times f^e_{NL} dE^e}{\int_0^{E^e_{max}} P(E^e) \times E^e dE^e}$$



Simulated delta electron energy distributions for gammas of various energies

## References

[1] Abusleme et al, Initial performance results of the JUNO detector. Chinese Phys. C 50 (2026) 043001
[2] https://github.com/robx97/GEPRiS
[3] Mougeot, X. BetaShape: Calculation of Beta and Neutrino Spectra, Mean Energies and Log ft values . Laboratoire National Henri Becquerel (LNE-LNHB), CEA-Saclay.
[4] Berger, M. J. ESTAR, PSTAR, and ASTAR: Computer Programs for Calculating Stopping-Power and Range Tables for Electrons, Protons, and Helium Ions. NISTIR 4999, National Institute of Standards and Technology.
[5] The JUNO collaboration., Abusleme, A., Adam, T.et al..Calibration strategy of the JUNO experiment. J. High Energ. Phys.2021, 4 (2021）

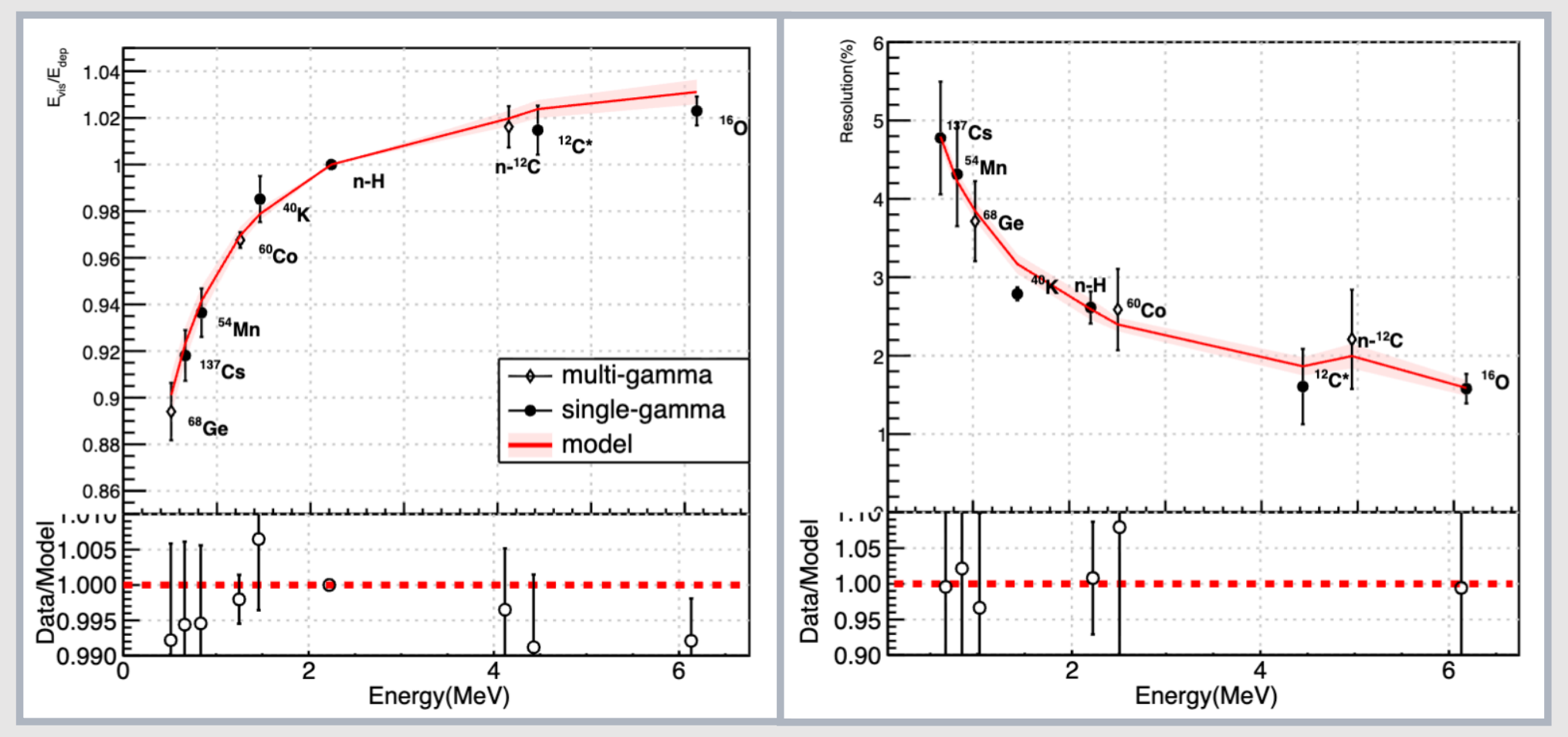
## Acknowldgements

We would like to acknowledge the support for this work from:
- National Key Research and Development Program of China
- National Science Foundation in the United States

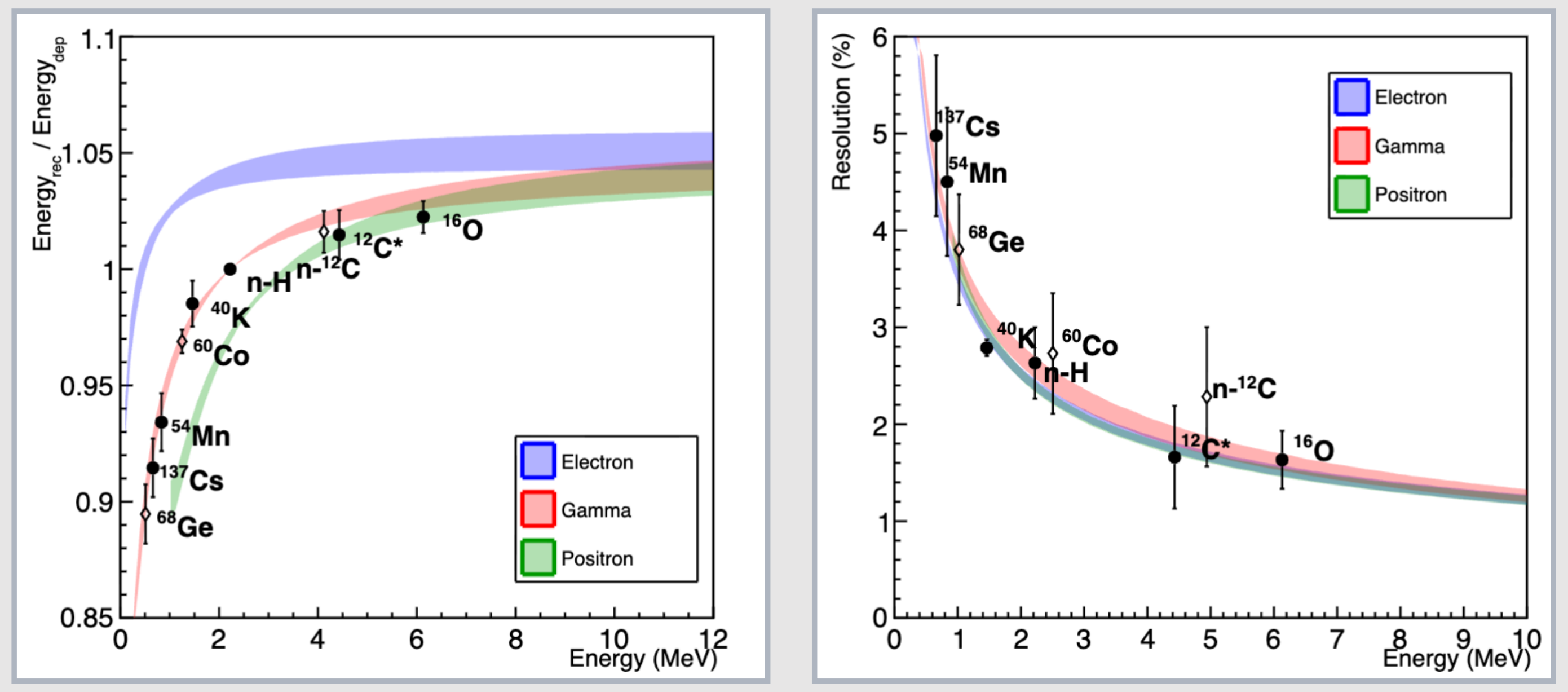
## 6. COMEER Results [5]

- Volume weighted average of resolutions was calculated
- Fits to calibration data at different detector positions were performed separately

JUNO Work In Progress. June 2026.



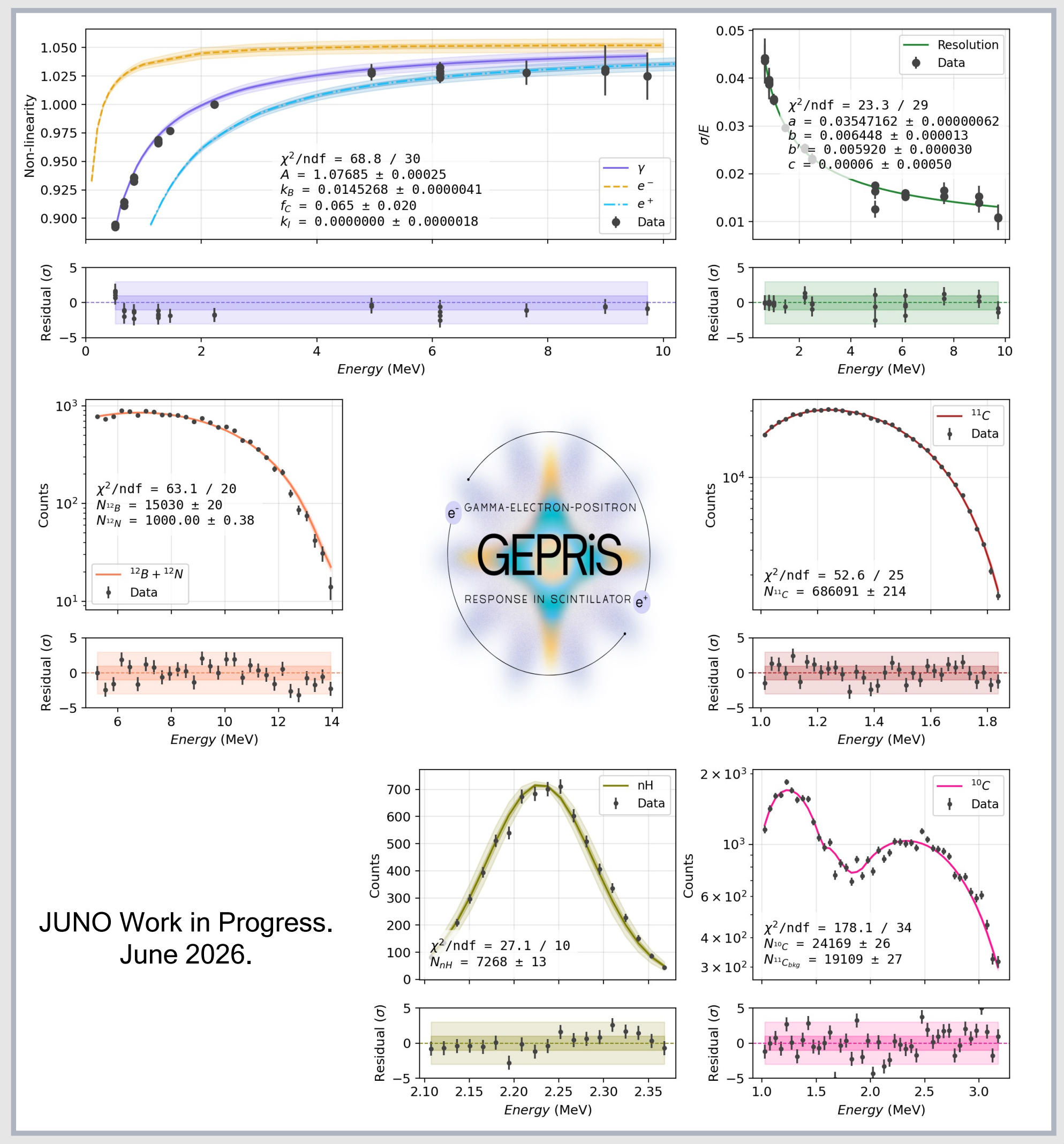
Discrepancy between model and data is within 1%



COMEER predictions for gammas, positrons and electrons

## 7. GEPRiS Results [2,3,4]

- Joint fit of gamma points, their resolution and several cosmogenic beta spectra taken between August 2025 and May 2026
- Additional parameter b' added to capture larger resolution in uniformly distributed samples
- Gamma points from different rounds of calibration fit concurrently



## 7. Comparison and Outlook

- Positron energy non-linearity is the main focus, mapping positron to neutrino energy in oscillation analysis
- Positron results between models agree within 1σ
- Further study to include larger fiducial volume (within 17.2m) planned in the future