Search for 0νββ decay at AMoRE

October 22-25 @ PIC 2024, Athens

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Center for Underground Physics, Institute for Basic Science

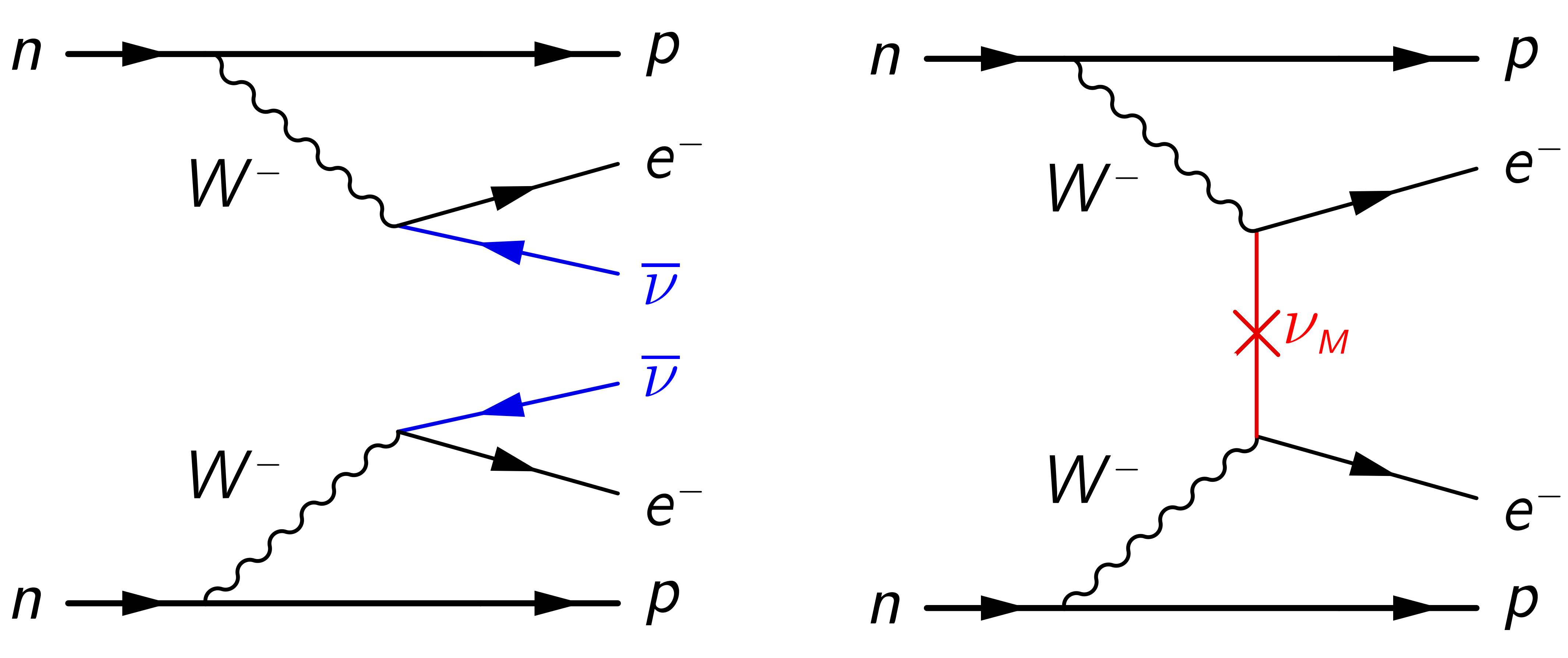
Outline

Advanced ^{100}Mo-based Rare Process Experiment

- Double beta (ββ) decay and neutrinoless double beta (0νββ) decay.
- The AMoRE project.
- Detector principle and performances.
- AMoRE-pilot, AMoRE-I results.
- AMoRE-II preparation status.

Neutrinoless double beta decay

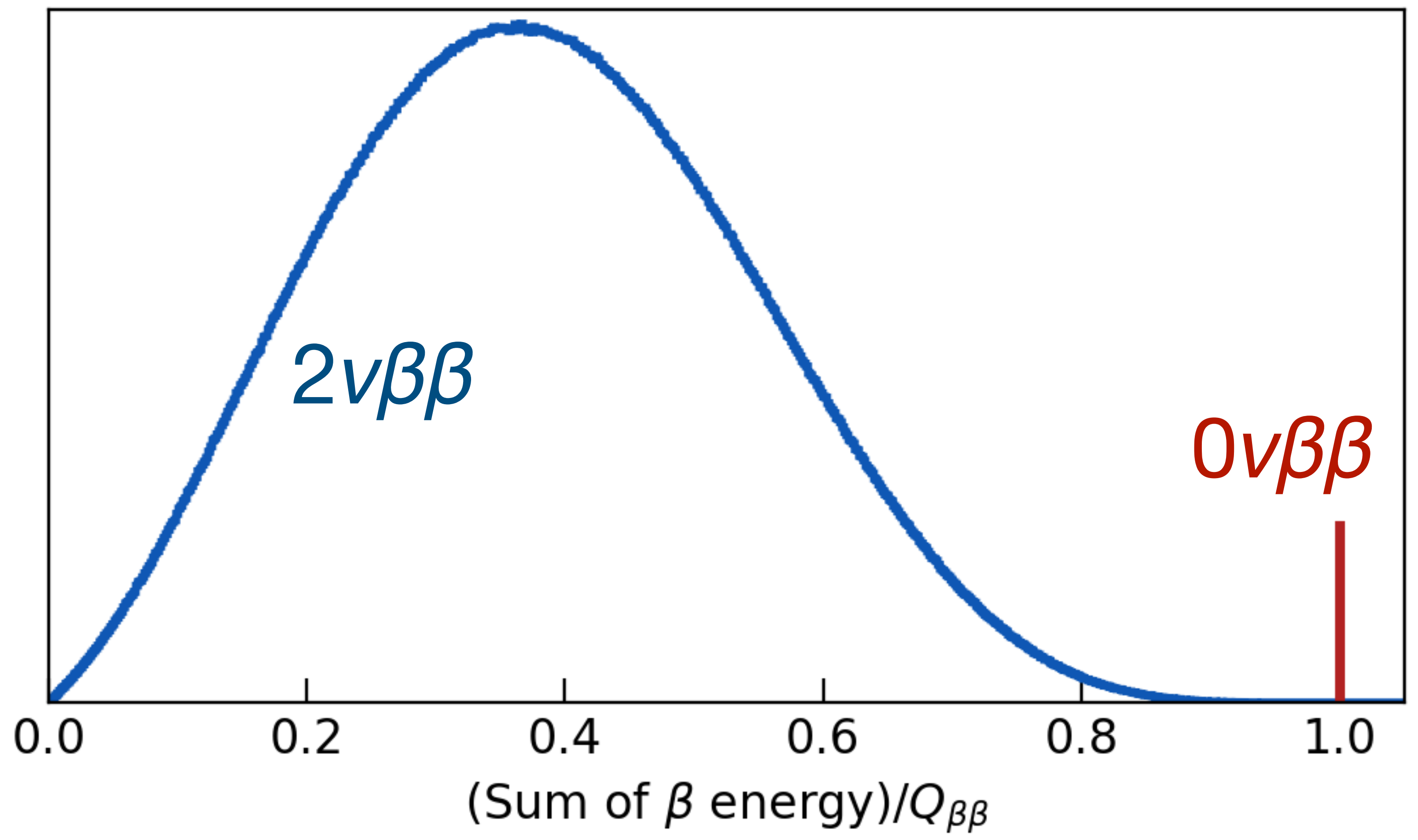
- $\nu = \overline{\nu}$?
- Majorana/Dirac nature.
- Matter-antimatter asymmetry.
- Lepton number violation: ΔL=2.
- Absolute mass of neutrino.



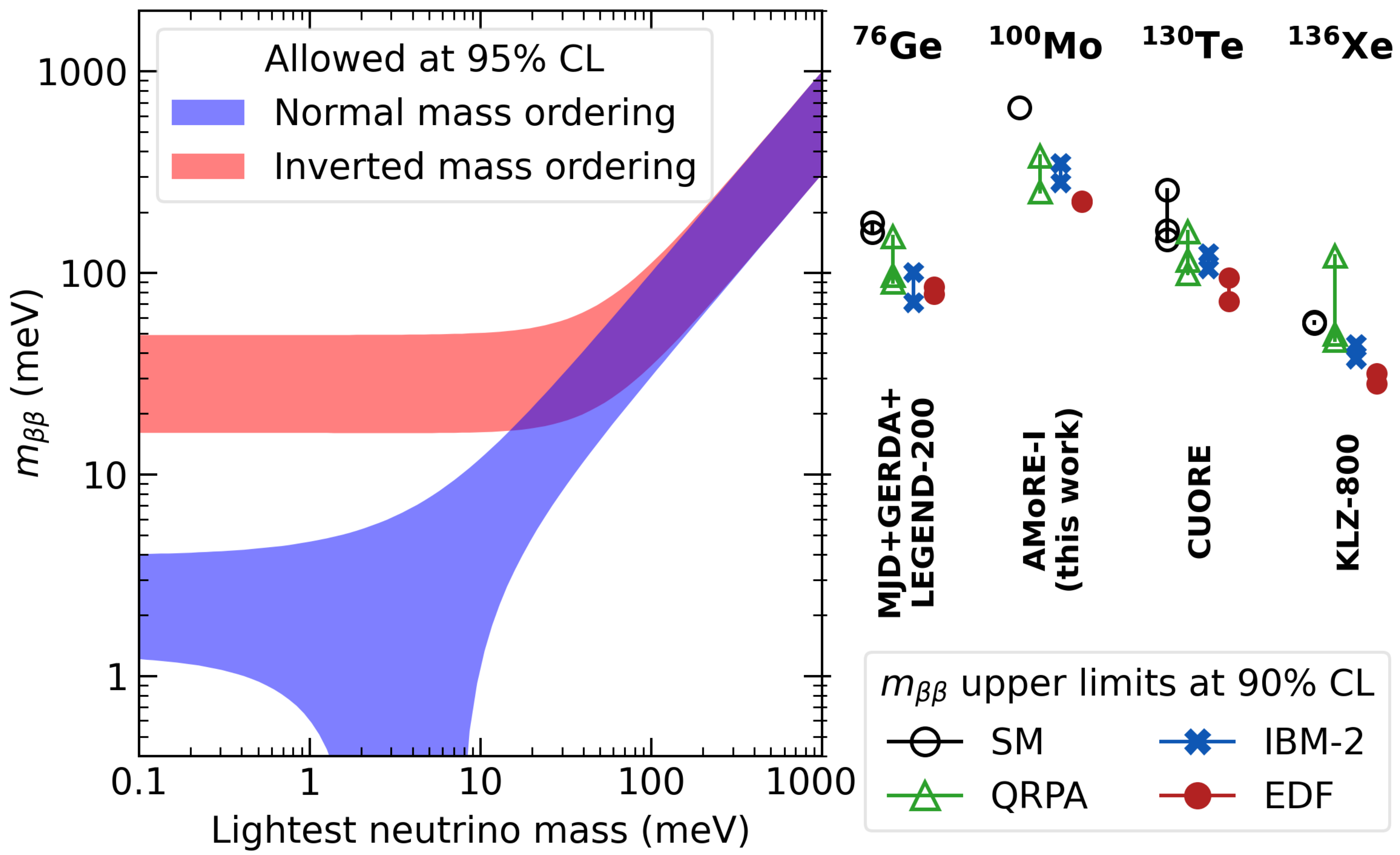
$$\frac{1}{T^{0\nu}_{1/2}} = G^{0\nu}\left(M^{0\nu}\right)^2 \frac{m^2_{\beta\beta}}{m^2_e}, \quad m_{\beta\beta} = \left|\sum_{i=1}^{3} U^2_{ei} m_i\right|$$

Nuclear Matrix Element

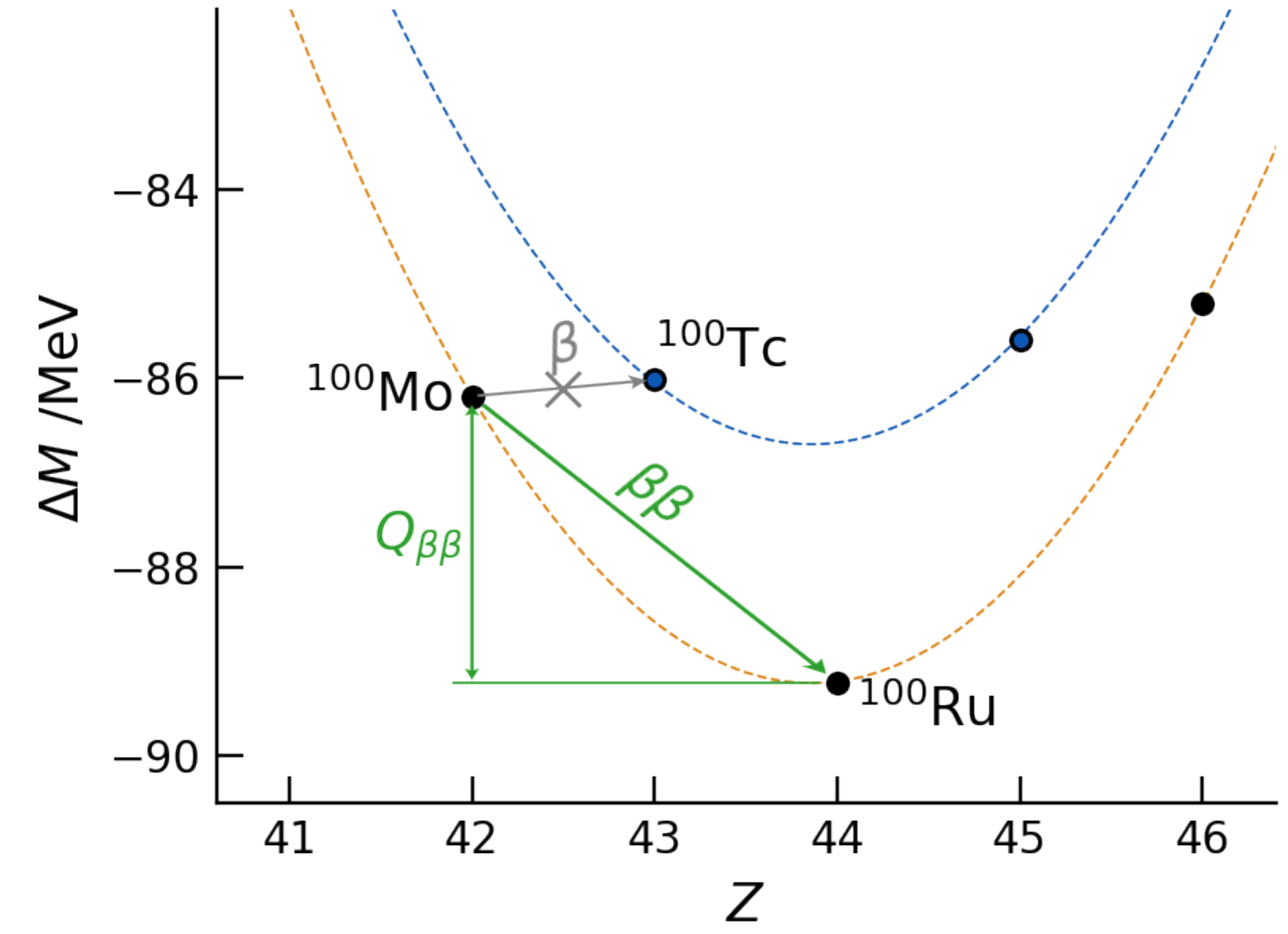
PMNS matrix



$^{100}_{42}Mo$



- Decay modes: $2\beta^-$ 100%, $Q_{\beta\beta}$ = 3034 keV.
- $T_{1/2} = 7.1\times10^{18}$ y.
- BR(0ν) < 4×10^{-6}:
  - $T^{0\nu}_{1/2} > 1.8\times10^{24}$ yr at 90% CL by CUPID-Mo.
- Natural abundance = 9.74%.
- Scintillation crystal in the form of $\mathbf{X}_a\mathbf{Mo}_b\mathbf{O}_c$ (XMO):
  - X: **Li**, Na, **^{48dep}Ca***, Pb, …



* ^{48}Ca is also a $\beta\beta$-decaying isotope with Q=4.27 MeV.

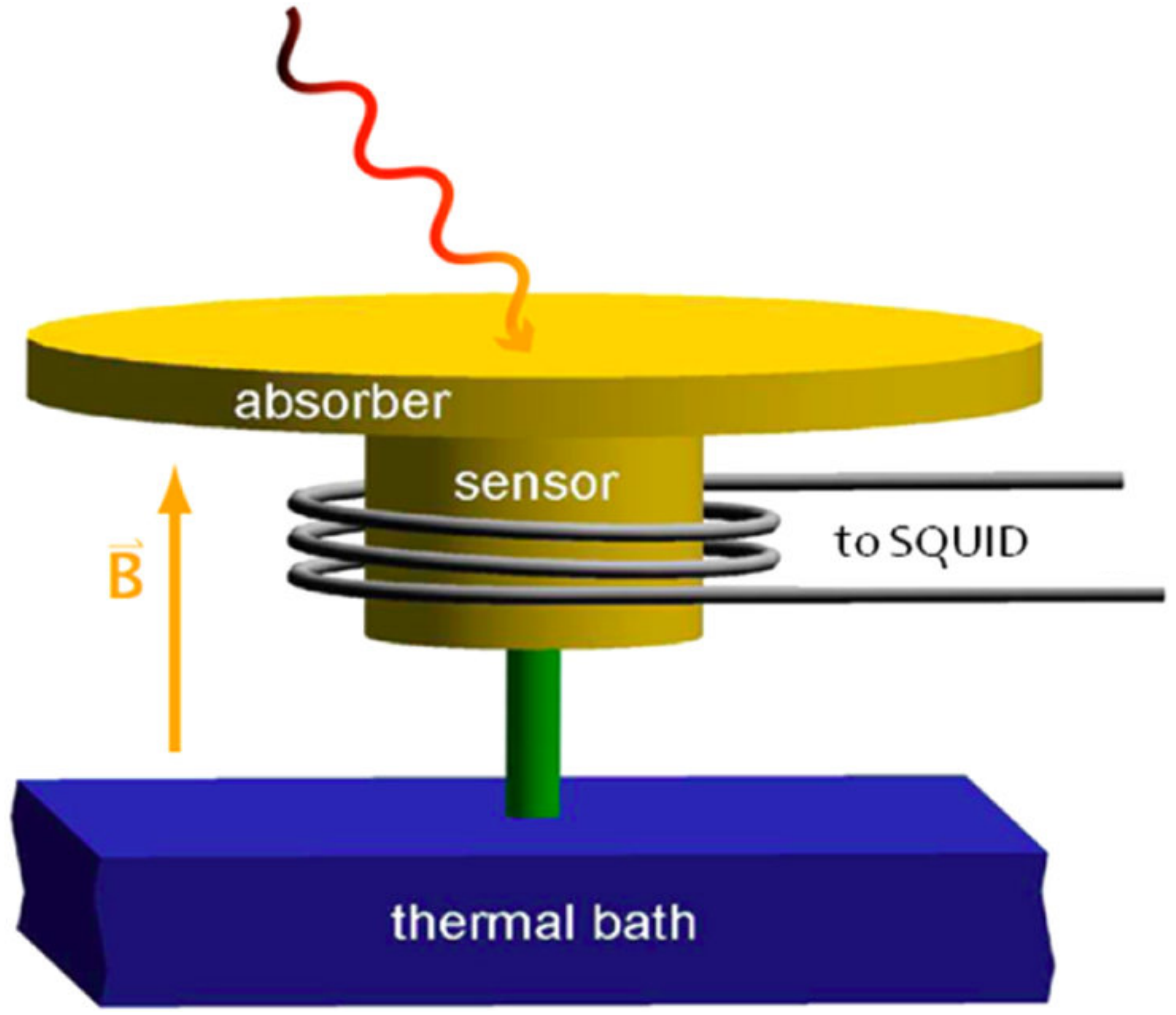
AMoRE key features

- $0\nu\beta\beta$ decay search.
- $T^{0\nu}_{1/2}$ experimental sensitivity↑:
  - mass·time exposure↑, ROI background level↓, energy resolution↑.
- Using ^{100}Mo in the form of scintillation crystal.
- Low temperature (T~10 mK) detector technique.
  - Metallic magnetic calorimeter (MMC).
- Radioassay and purification.
- Deep underground laboratory.

Detection principle

Heat and light signals at low temperature

- Mo-100 based scintillation crystal (XMO) as source and target at 10–20 mK.

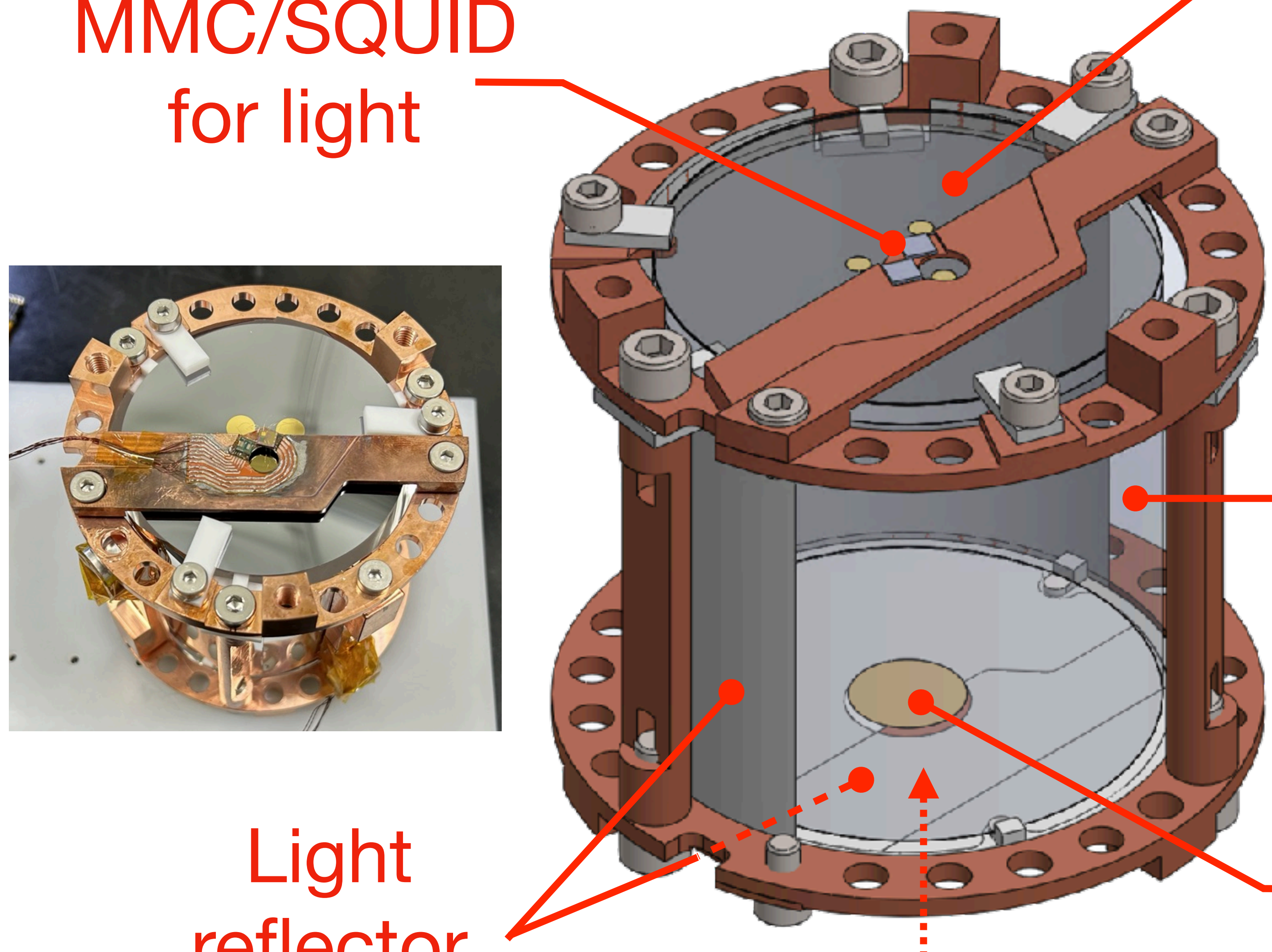


Metallic Magnetic Calorimeter (MMC)

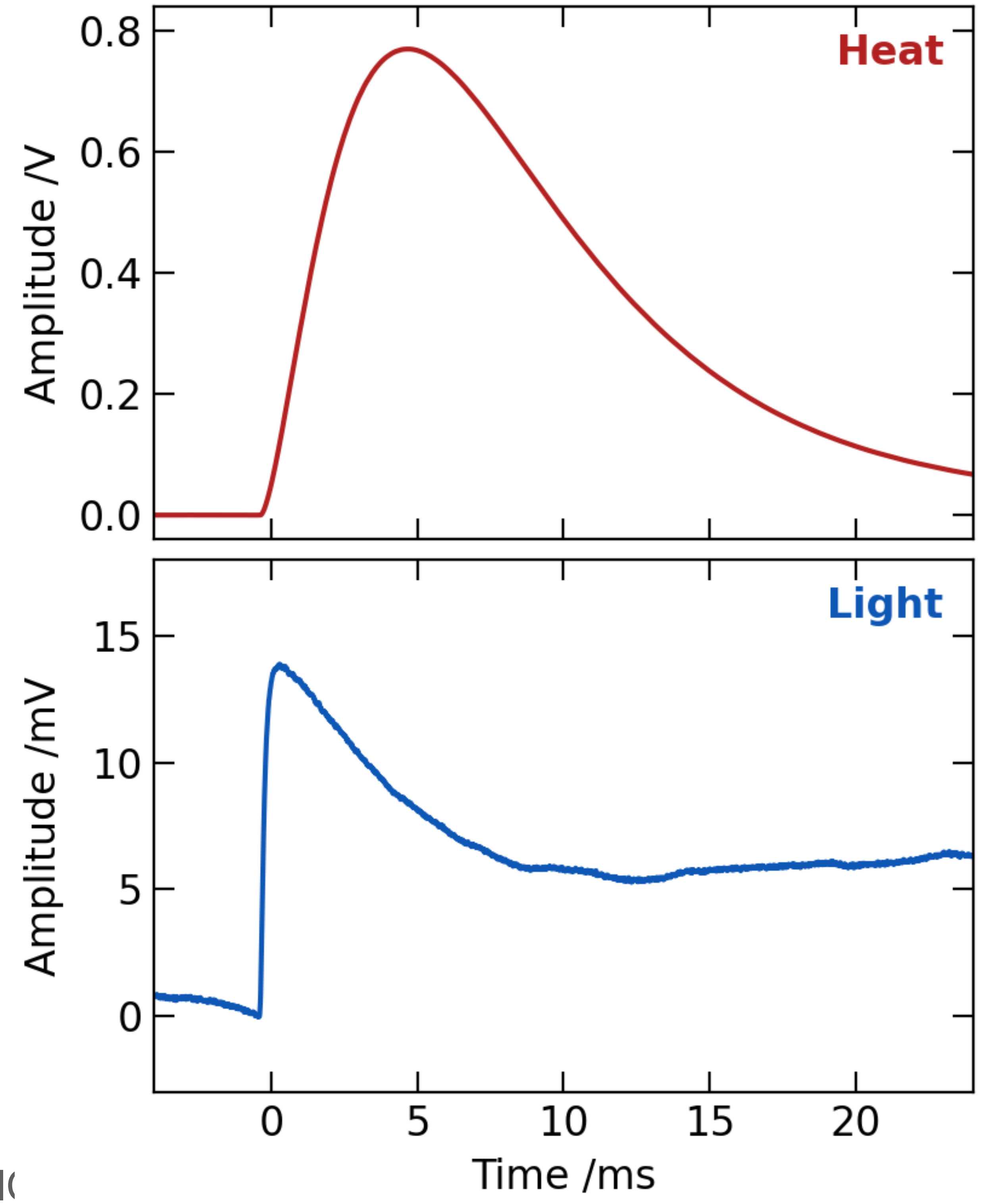
Figure courtesy of D. Hengstler et al (2015)

AMoRE-II detector module

arXiv:2407.12227, EPJC accepted



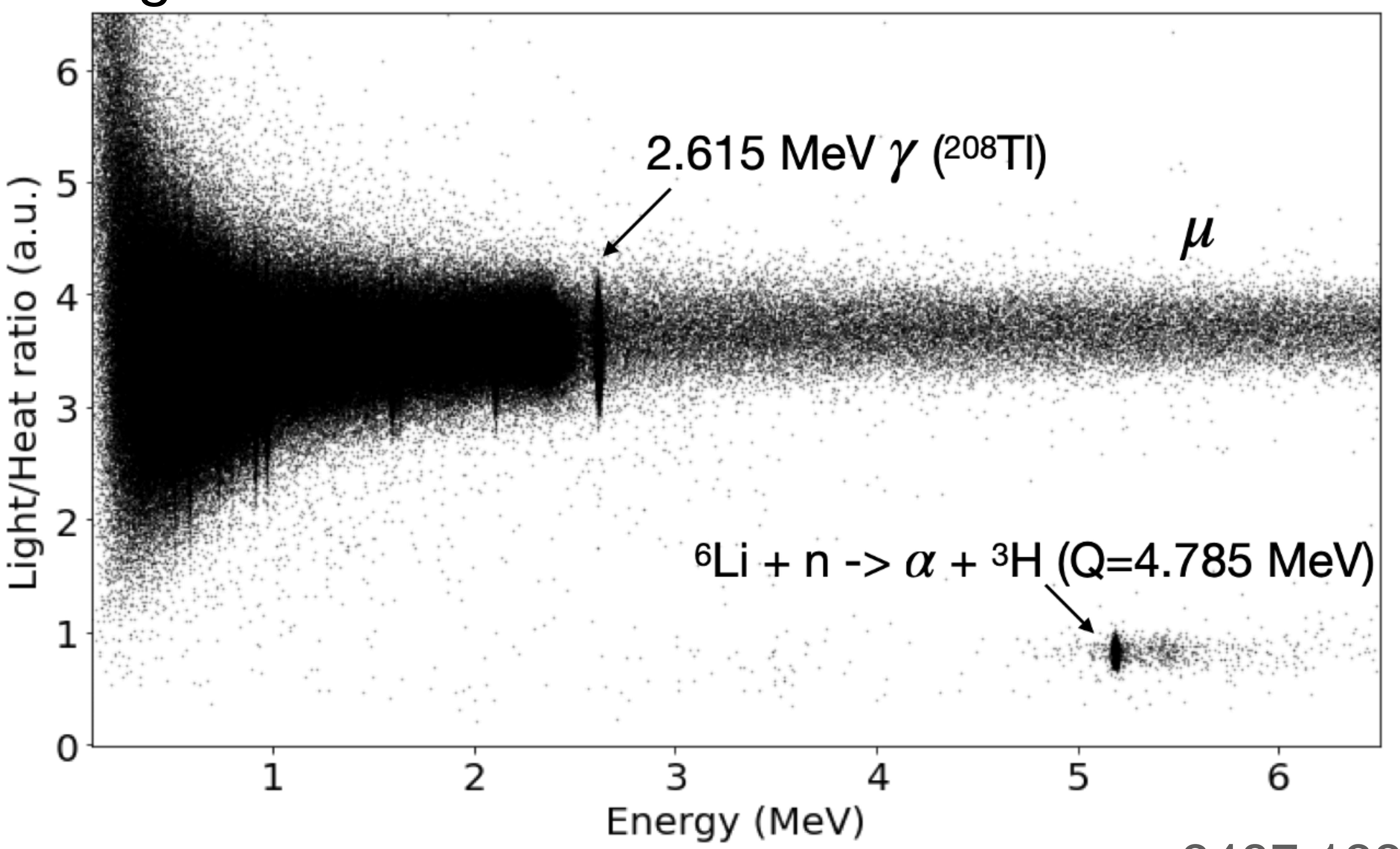
Averaged 2.6 MeV-γ signals of an LMO detector in AMoRE-I



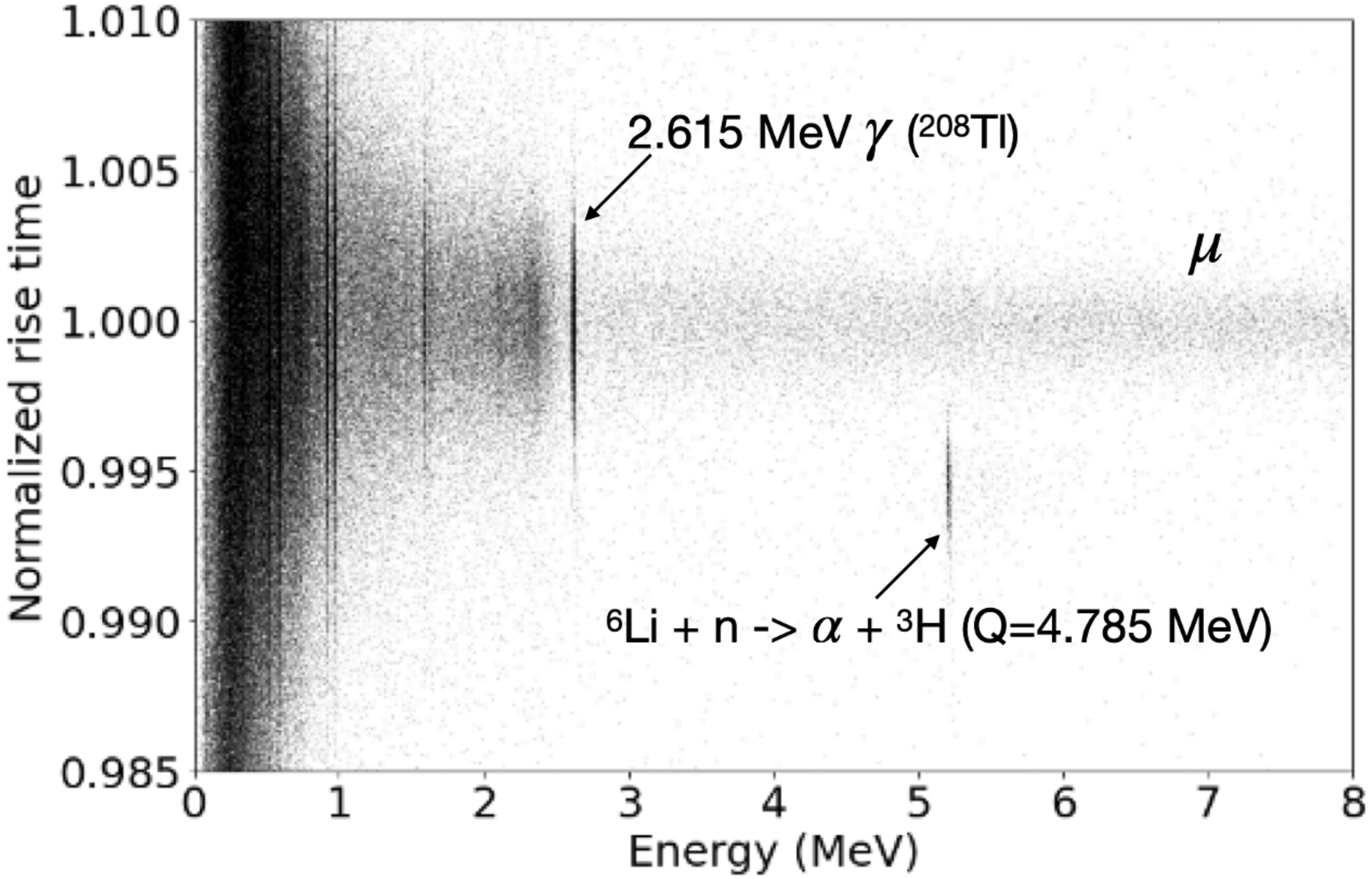
Detector performance I

Discrimination of β/γ and α events for background rejection

Light/heat



Rise-time



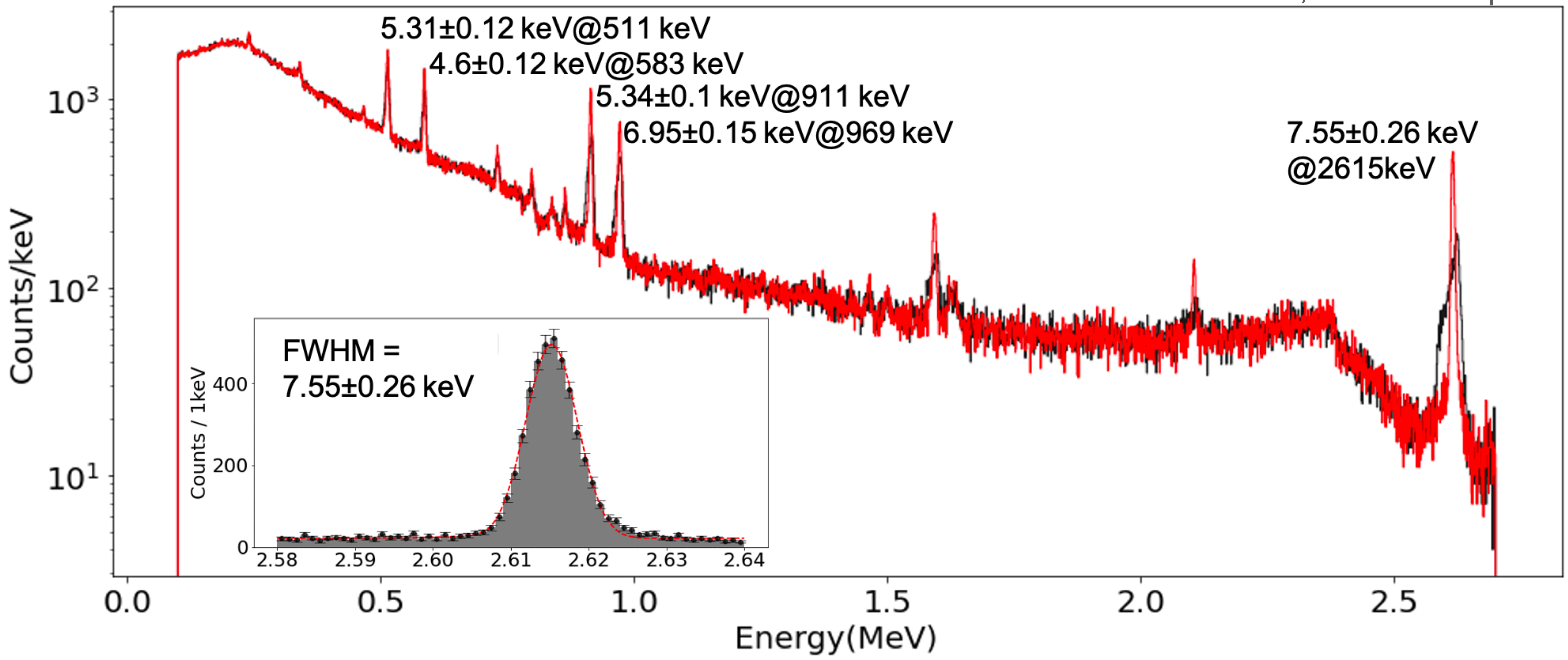
2407.12227, EPJC accepted

- Surface α: contributes the background at ROI.
- Discrimination utilizing difference in scintillation light quenching.

Detector performance II

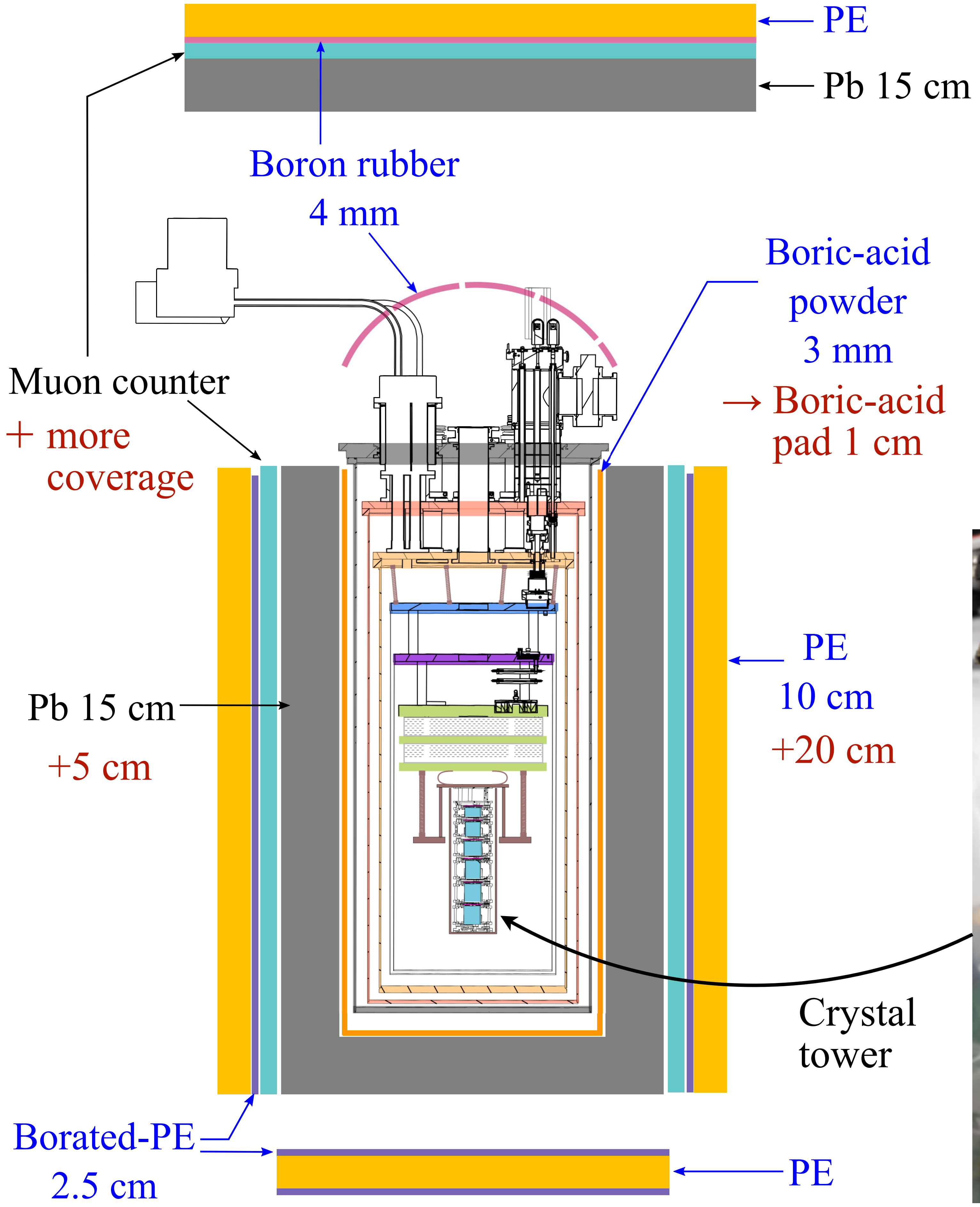
Energy resolution < ~10 keV FWHM at 2.6 MeV

2407.12227, EPJC accepted

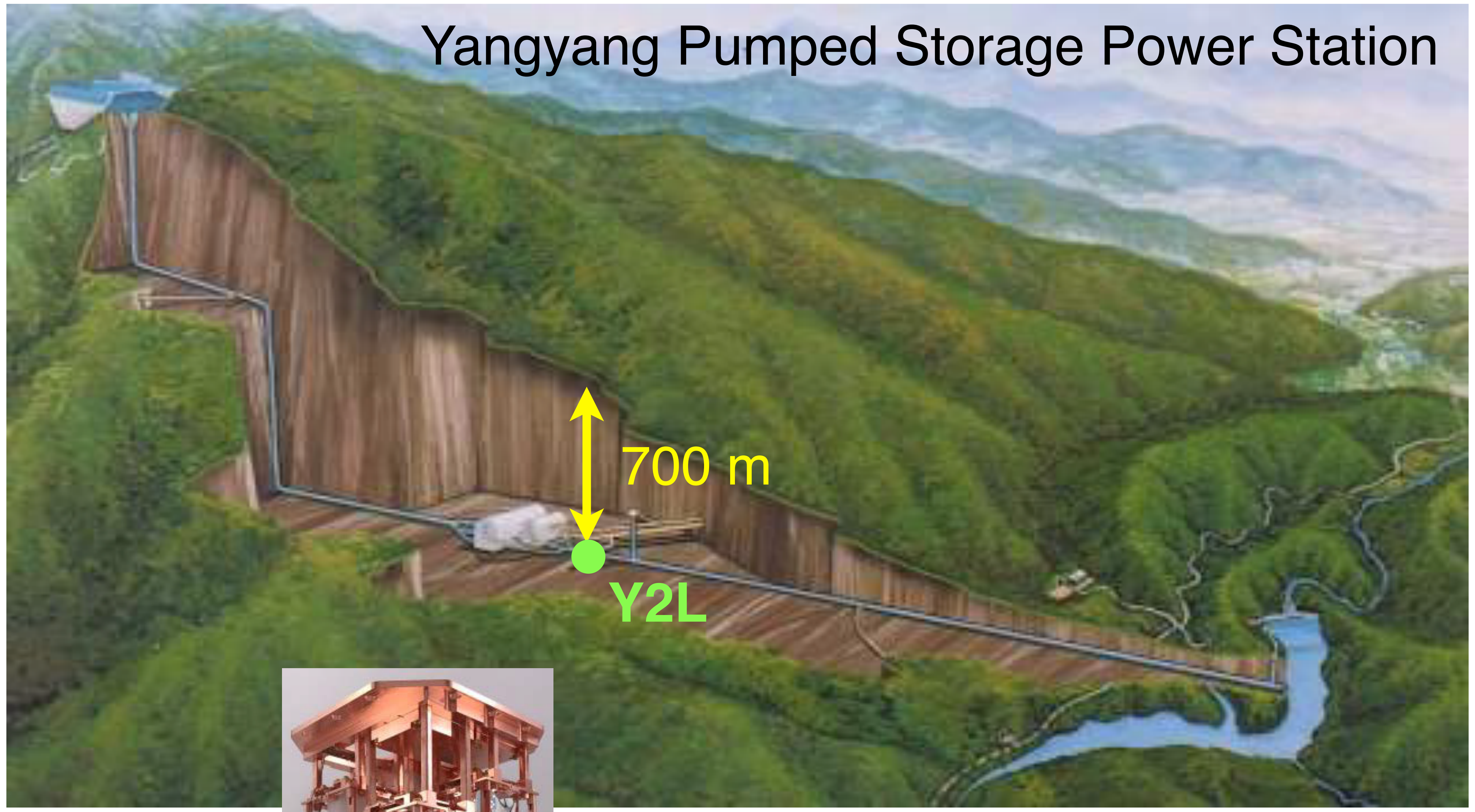


In Yangyang Underground Lab (Y2L)

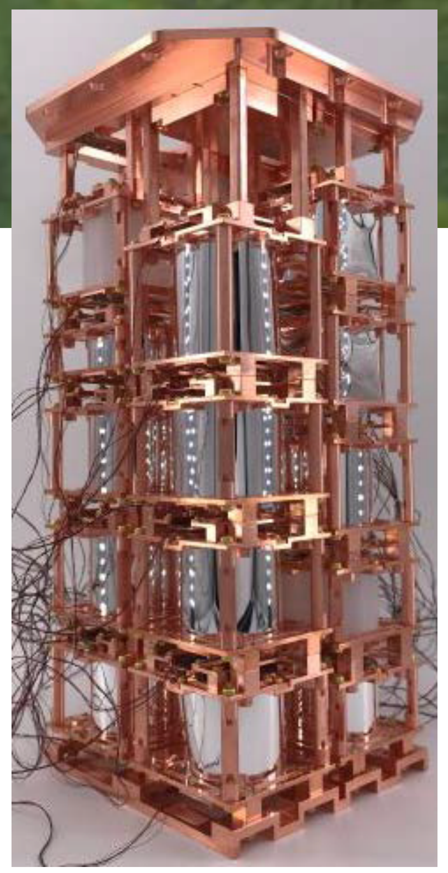
AMoRE-pilot (2015–18) and AMoRE-I (2020–23)



AMoRE
-pilot



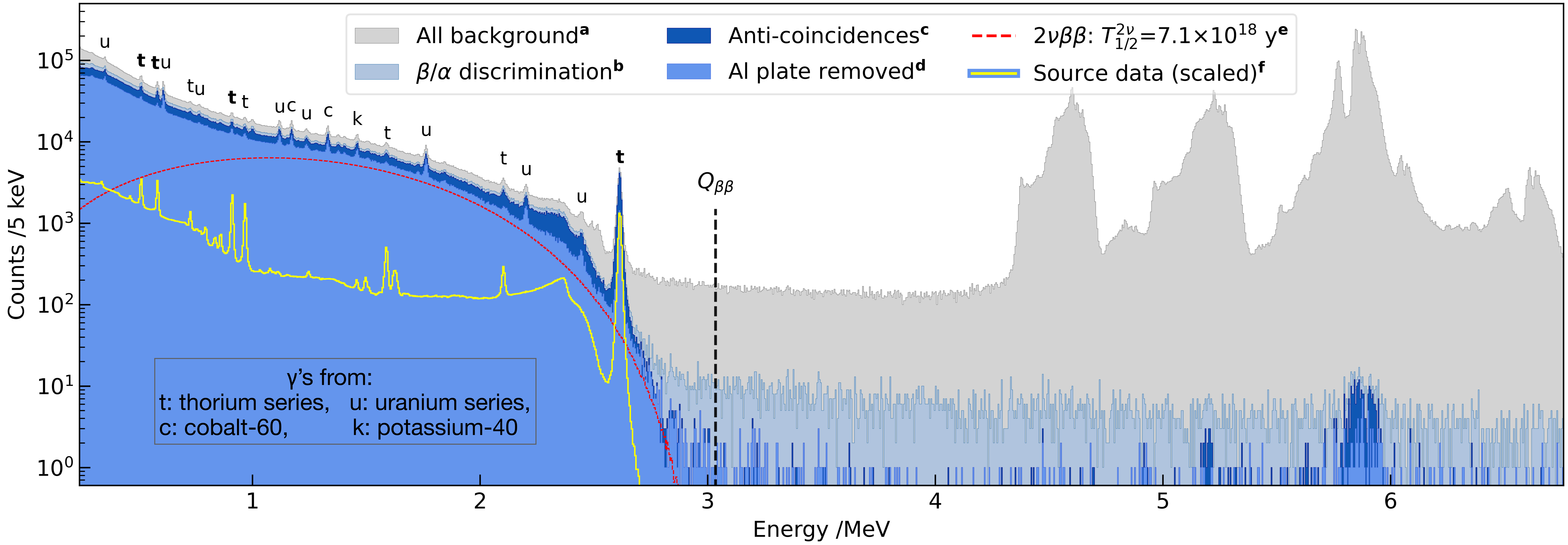
AMoRE-I



- At the beginning of AMoRE-pilot
- Shield upgrade for AMoRE-pilot Config-3
- More upgrade for AMoRE-I

Data analysis and selections

AMoRE-I, 2407.05618

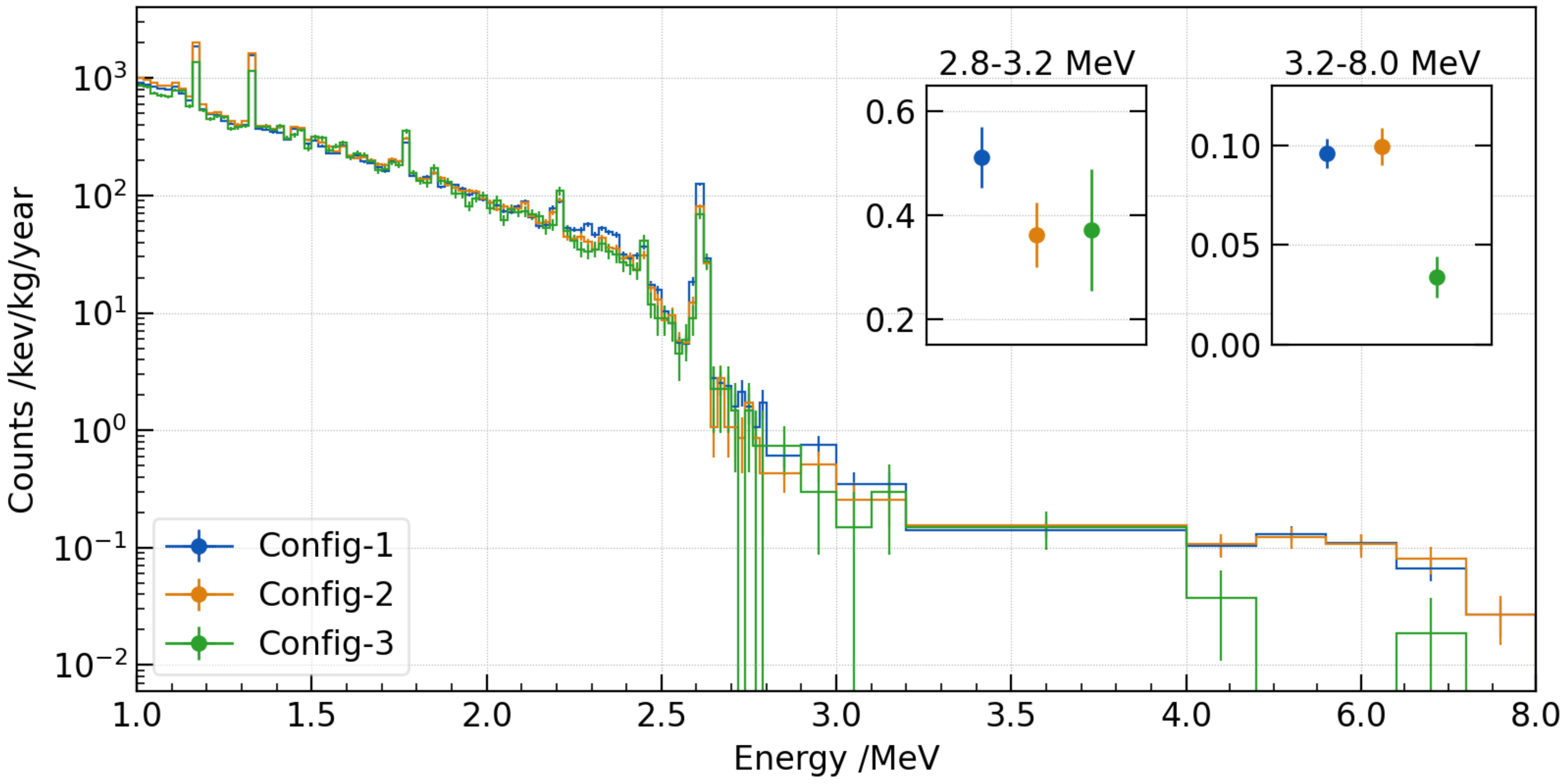


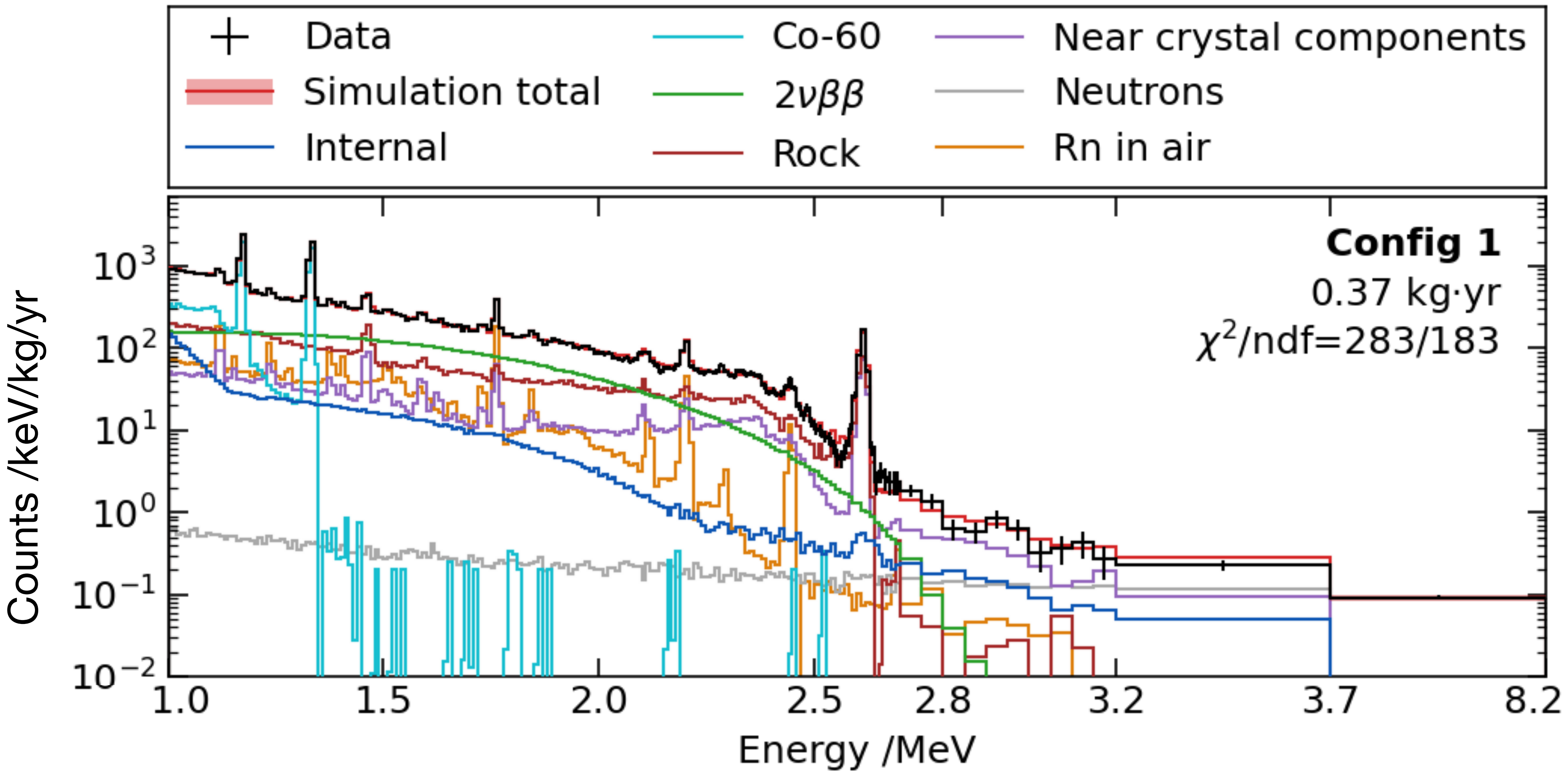
- Energy calibration using γ source (Th-contained welding rods).
- β/γ, α discrimination: pulse shape (PSD), light/heat ratio.
- Anti-coincidences: between crystals, with muons, or with tagged α's (^{212}Bi).

AMoRE-pilot

EPJC 79 (2019) 791
Astropart. Phys. 162 (2024) 102991

- Demonstration of detection principles and background reduction.
- Data taking using 6 $CaMoO_4$ crystals.
- Data analyzed for 0.32 $kg_{Mo\text{-}100}$·yr live exposure.
- Background modeling for 3 different detector/shielding configurations.

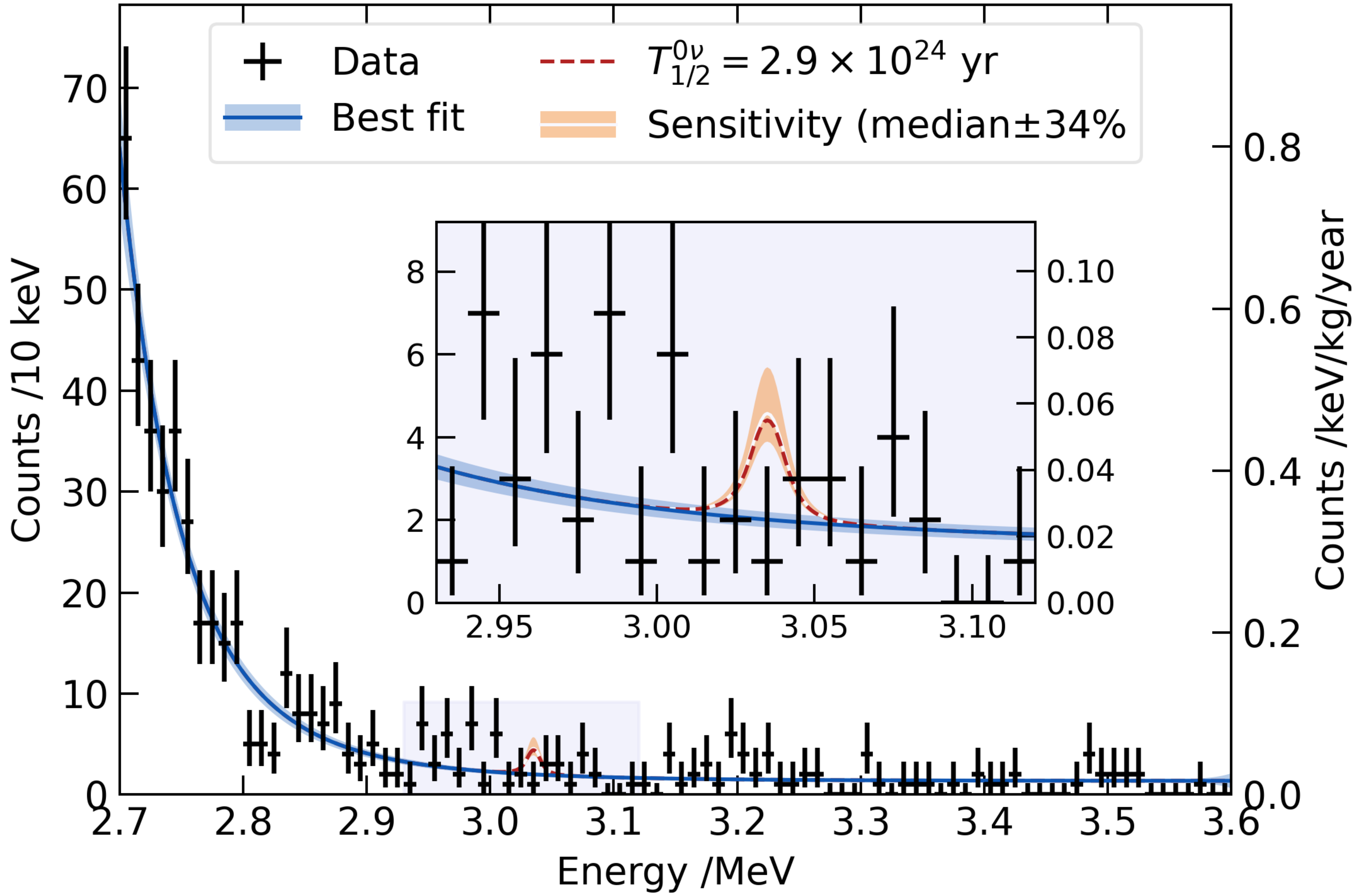




AMoRE-I

Improved Mo-100 0νββ decay half-life

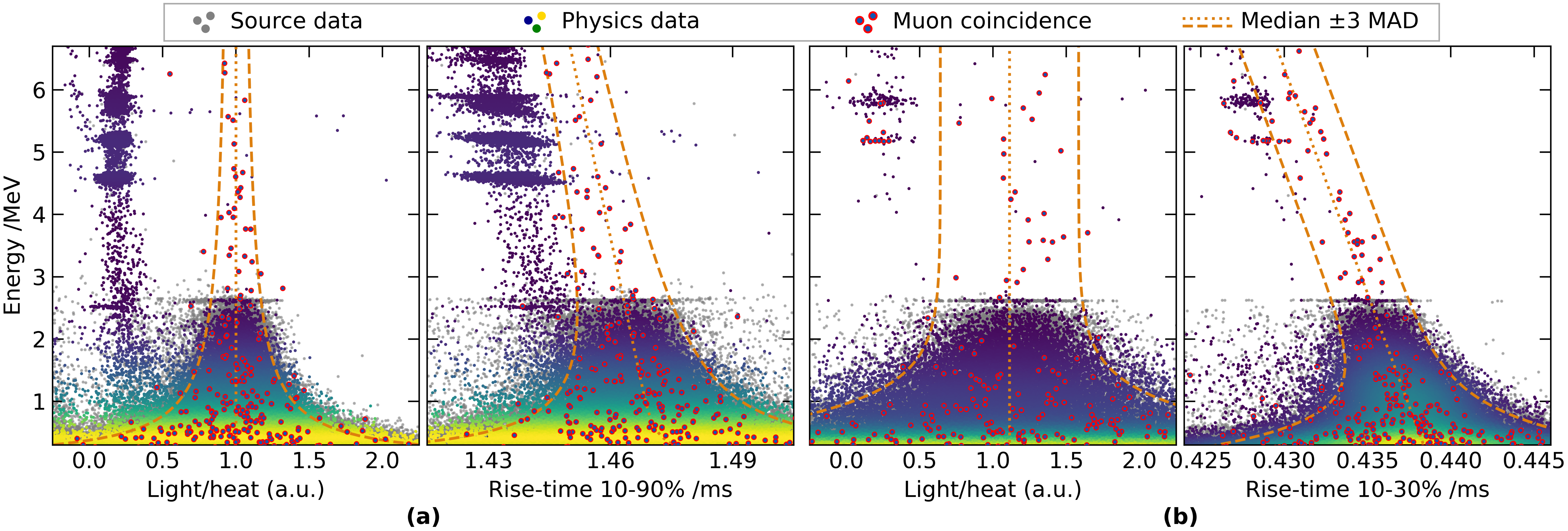
2407.05618



- Scalability, stability for long-term operation.
- 18 (13 CMO+5 LMO) crystals.
- Live exposure ~ 4 $kg_{Mo\text{-}100}$·yr.
- Exponential+flat background around ROI.
  - Detailed background modeling is in progress.
- b_{ROI} ~0.025 counts/keV/kg/yr.
  - Reduction from Pilot (×1/12) thanks to shielding enhancements.
- $T^{0\nu}_{1/2} > 2.9 \times 10^{24}$ yr at 90% CL.

CMO vs LMO

2407.05618

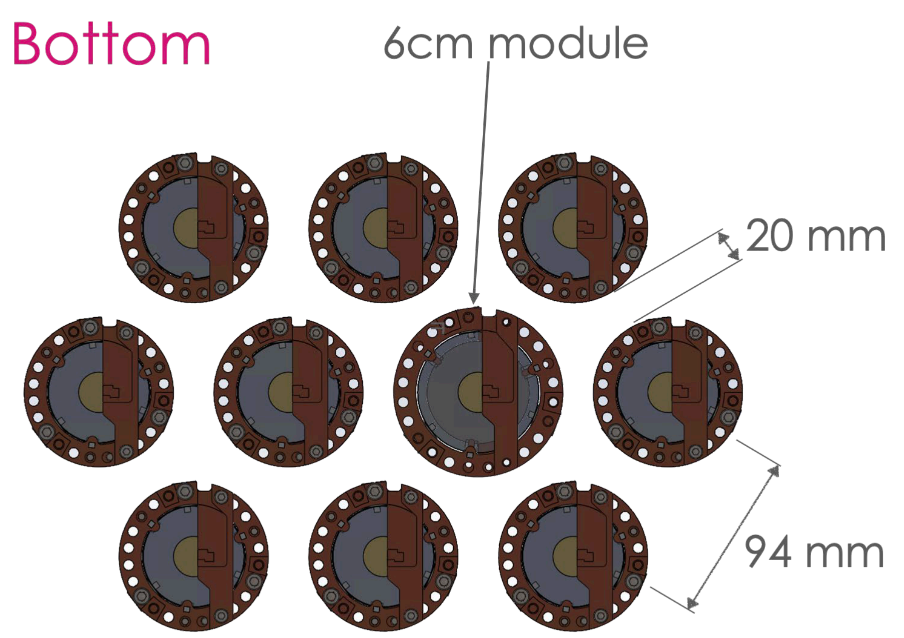


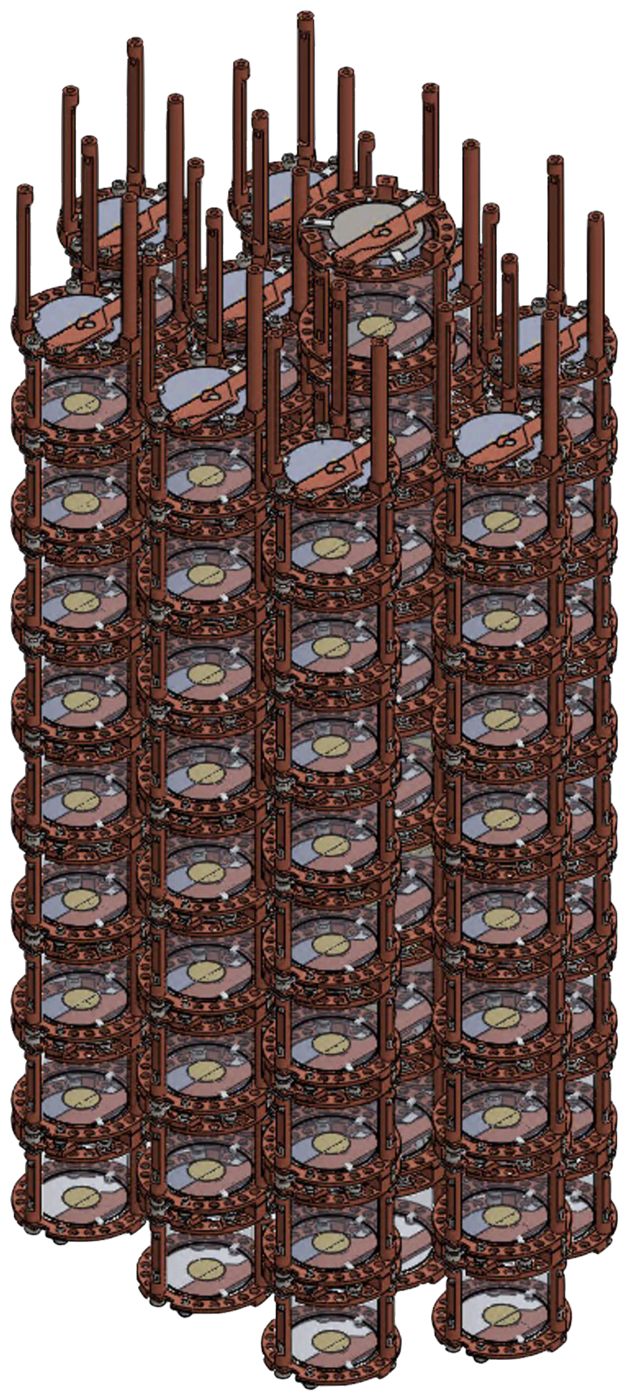
(a) $CaMoO_4$ outperforms for β/α discrimination by means of PSD and L/H ratio.

(b) Li_2MoO_4 shows much less internal radioactive contaminations.

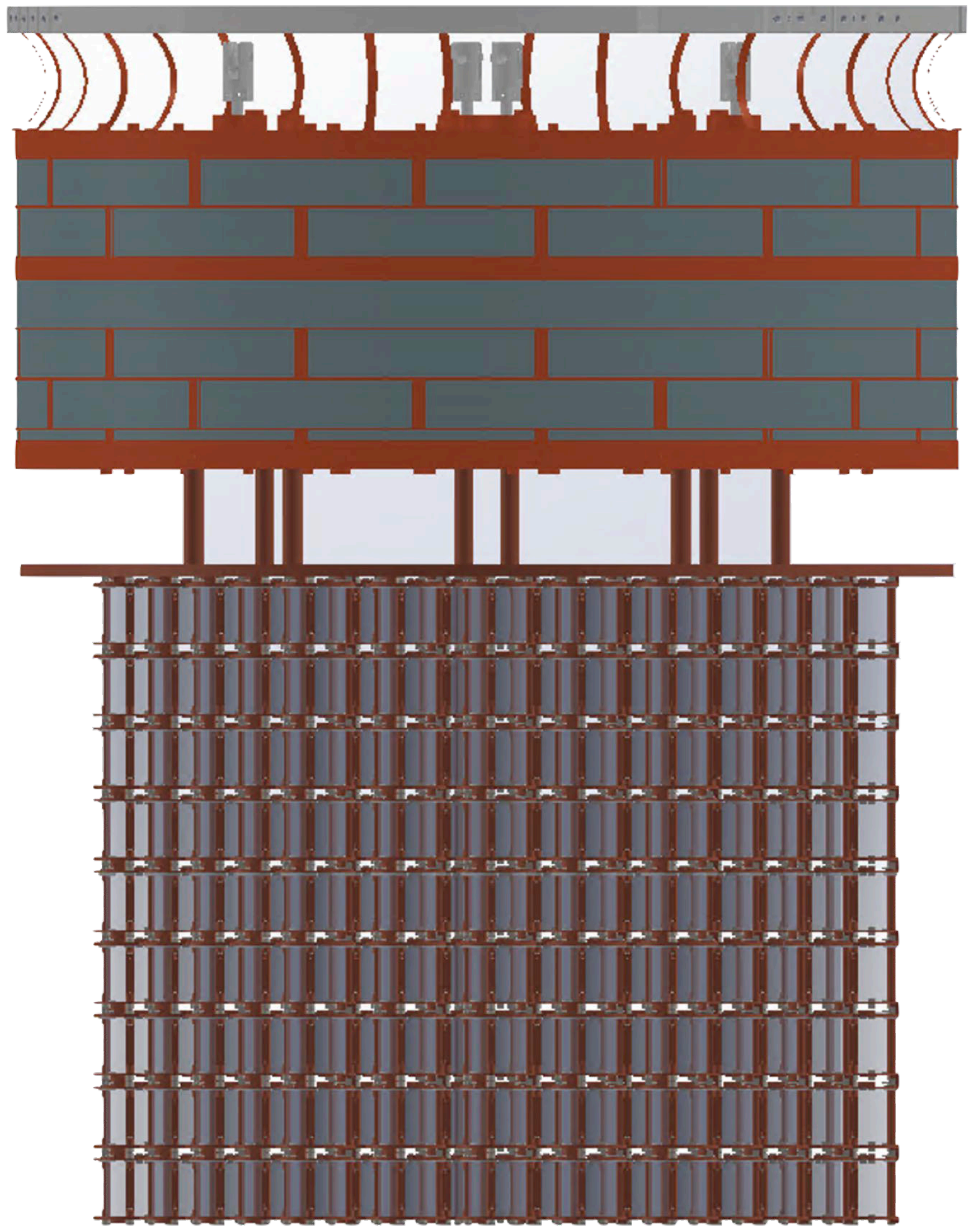
AMoRE-II under preparation

- Stage 1 using 90 crystals.
  - Data taking for no longer than a year, starting from 2025.
- Stage 2 using 360 crystals.
  - 157 (84.4) kg of crystal (^{100}Mo) mass.
  - Exposure goal >500 $kg_{Mo\text{-}100}\cdot yr$.
- In Yemi Underground Laboratory.





Detector towers in stage 1

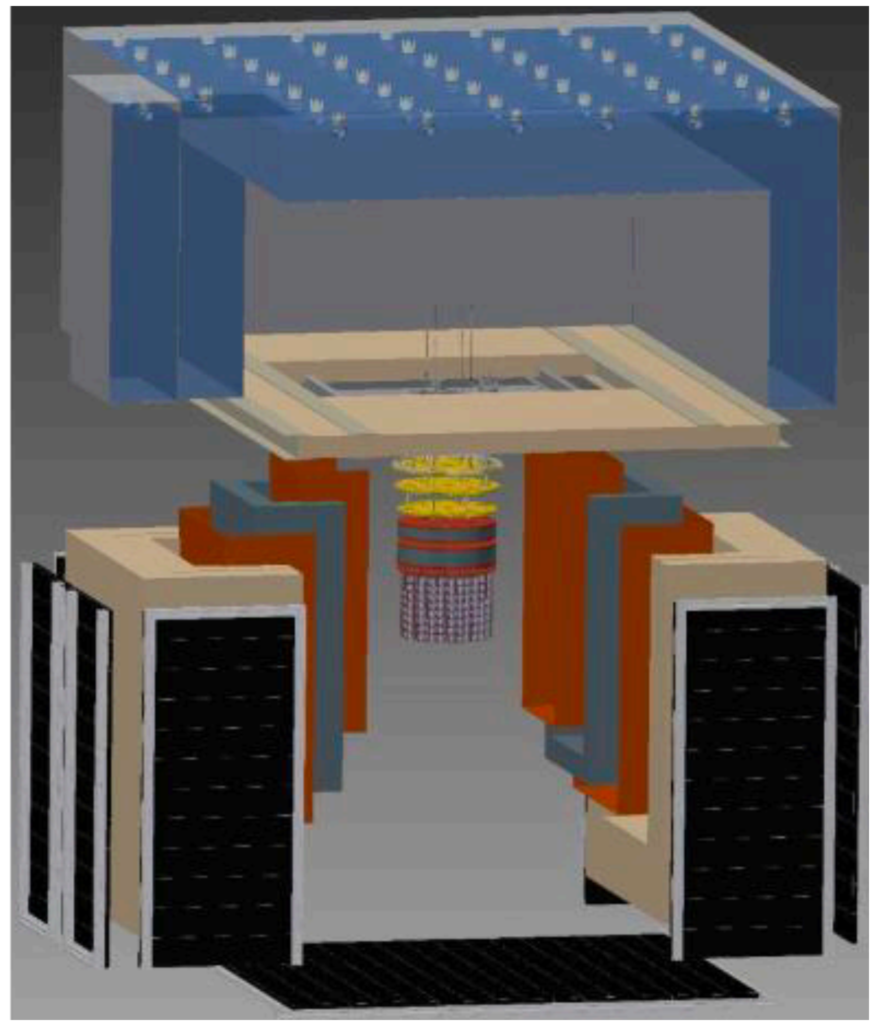


Detector towers in stage 2

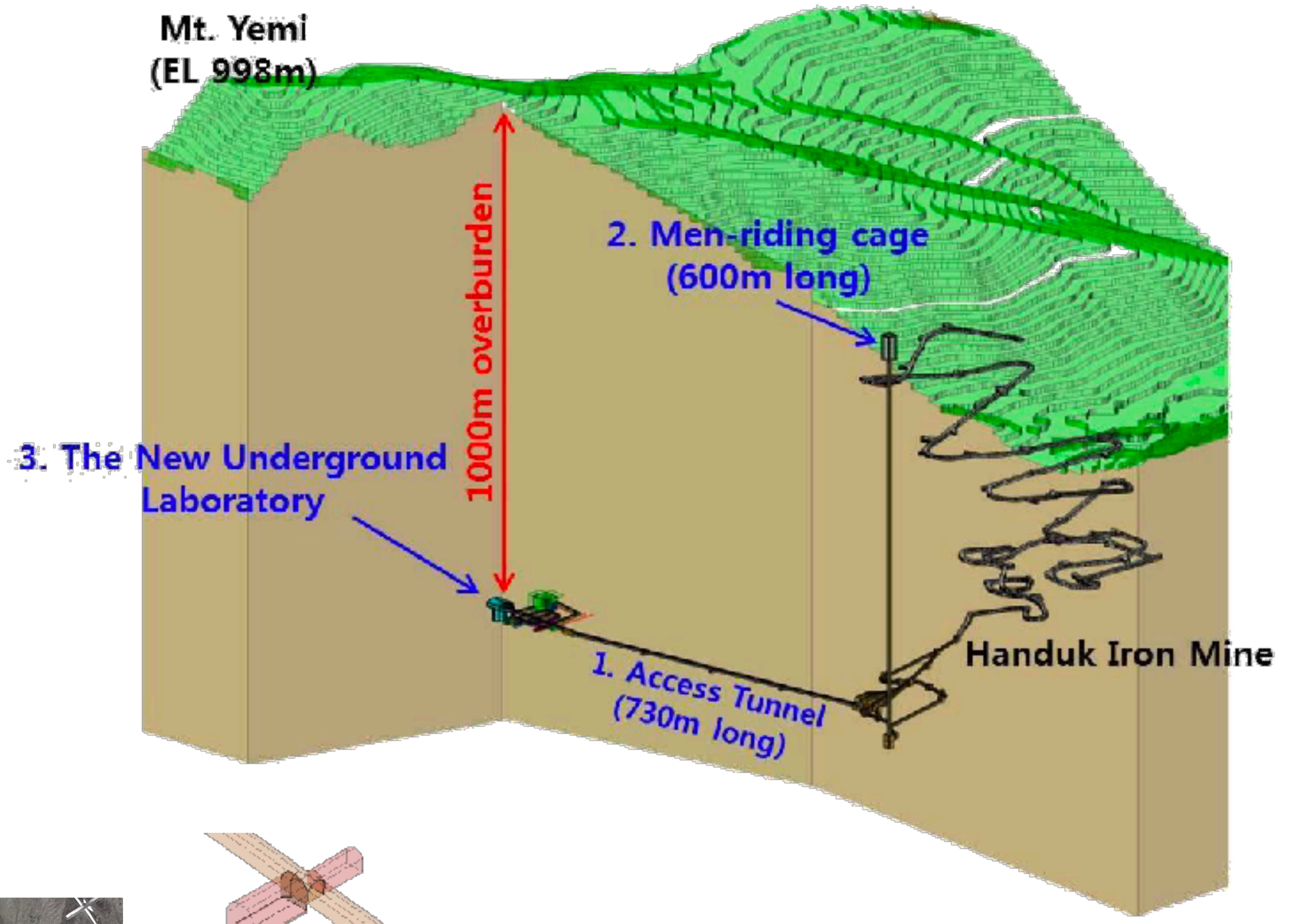
AMoRE-II under preparation in Yemilab

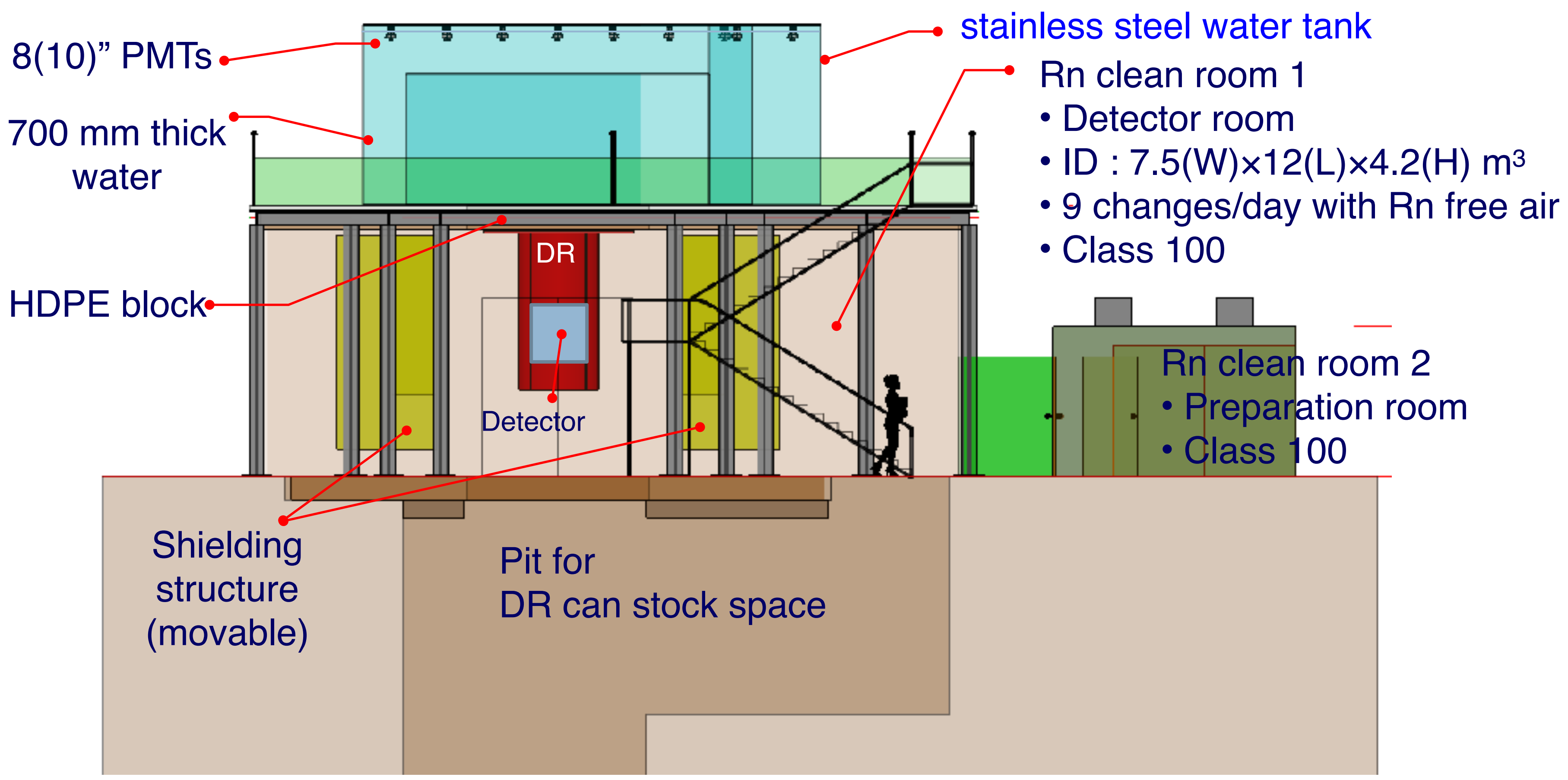
DR started moving
from the surface lab

DR installed in Yemilab

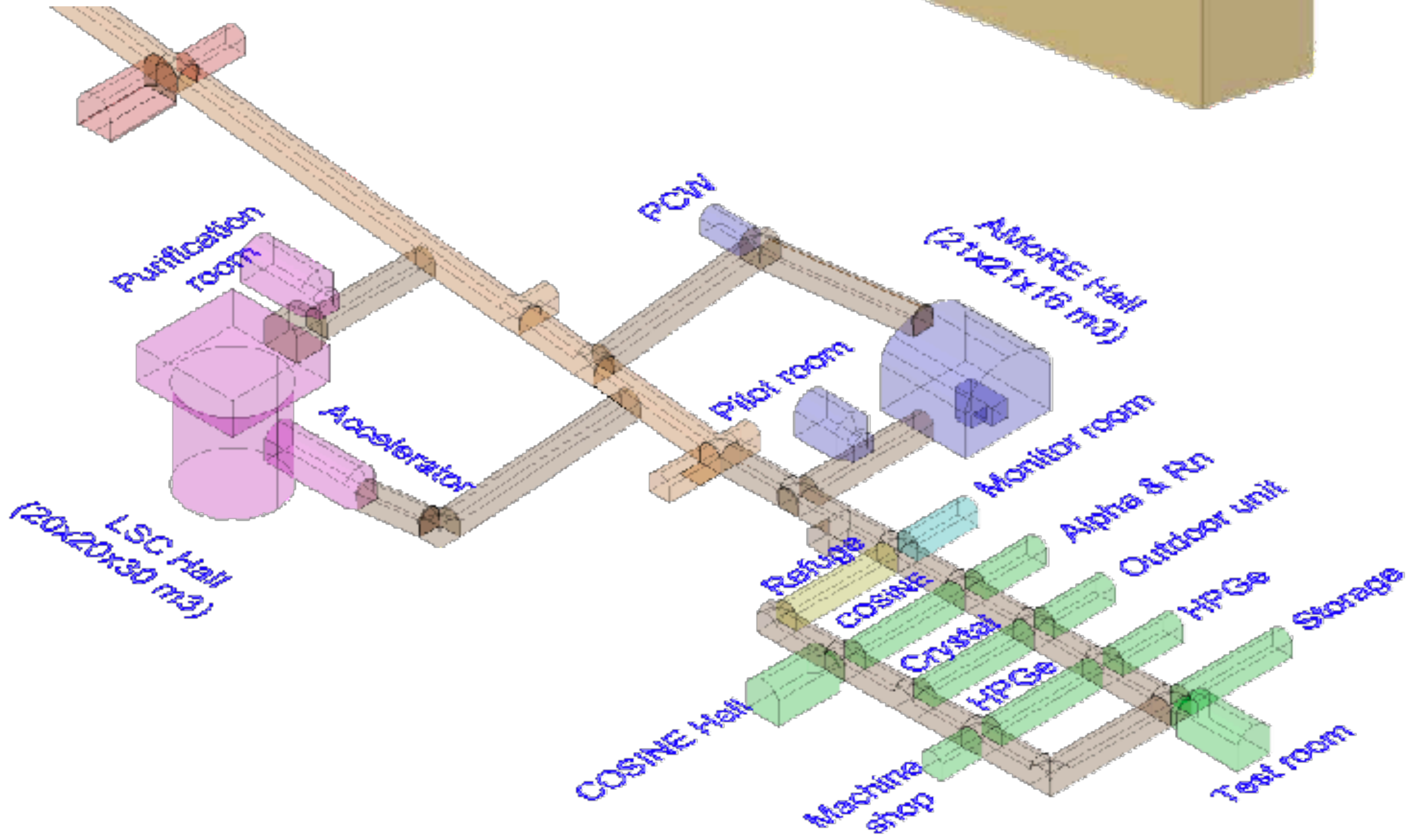


Detector/shielding scheme





AMoRE Hall in Yemilab

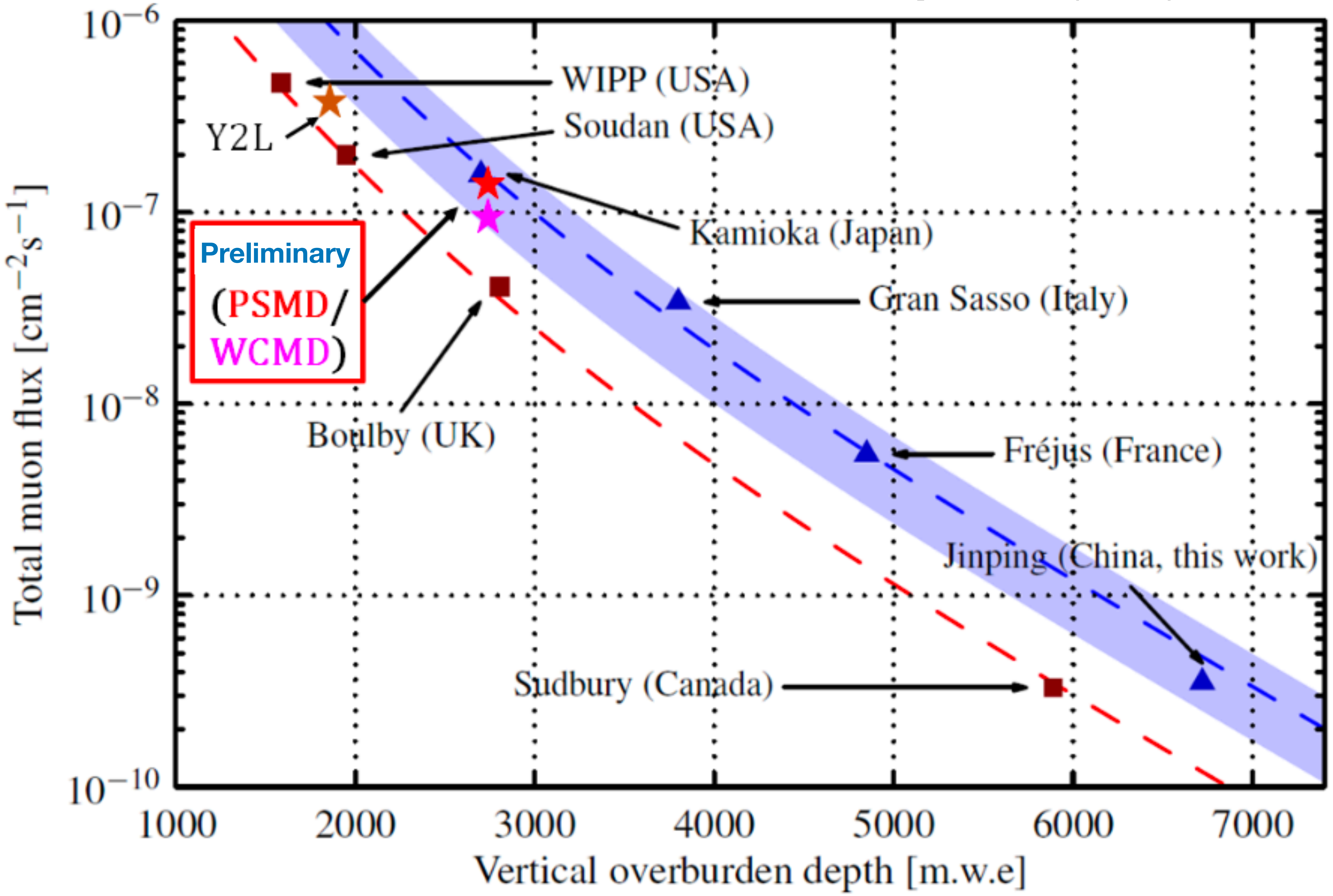


AMoRE-II: muon counter

↑ Water Cherenkov at the top: 70 cm thick (60 tonnes), 8, 10 inch PMTs

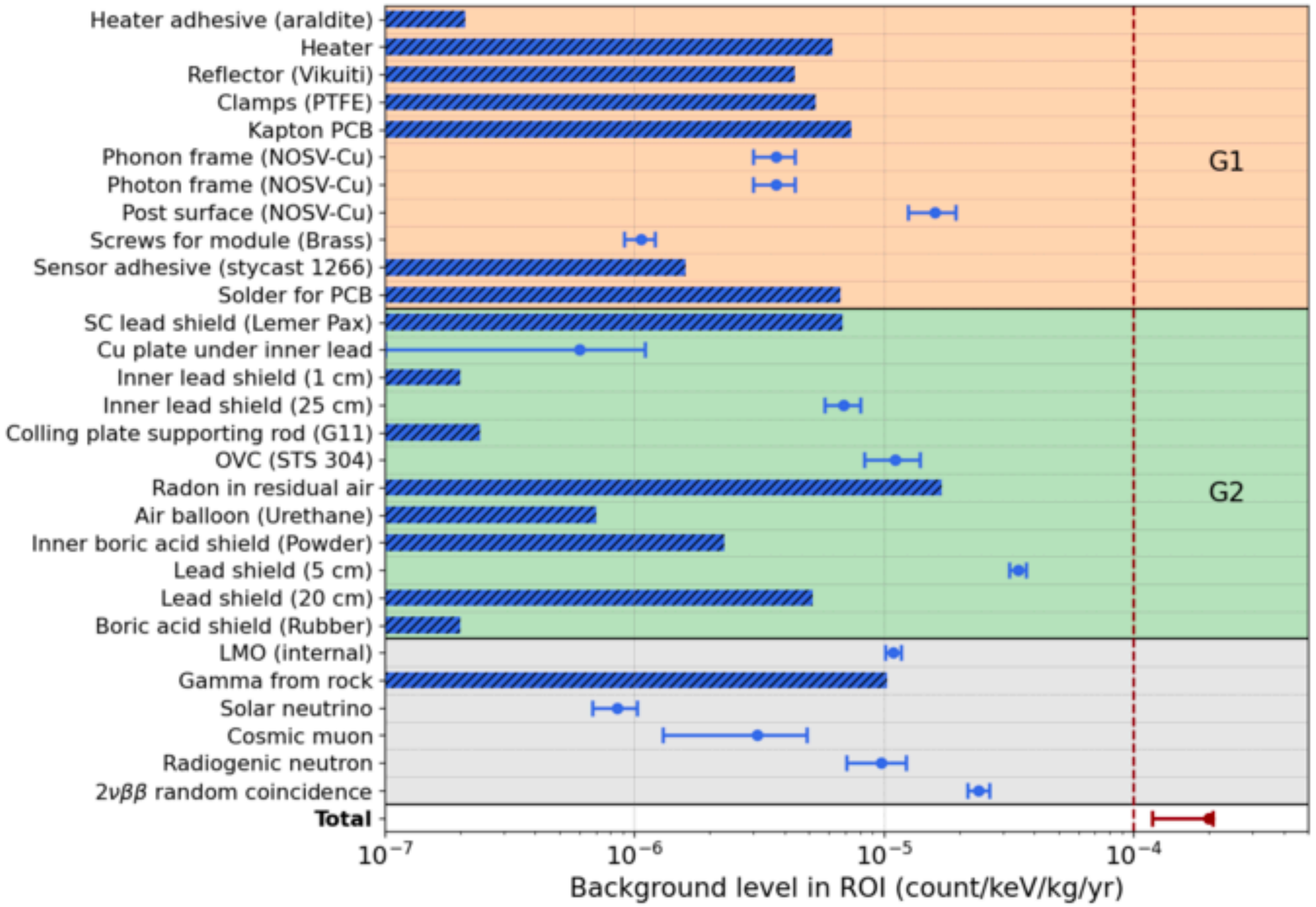
← Bottom plastic scintillator: 130 modules × 2 PS panels × (WLS fibers+2 SiPM)

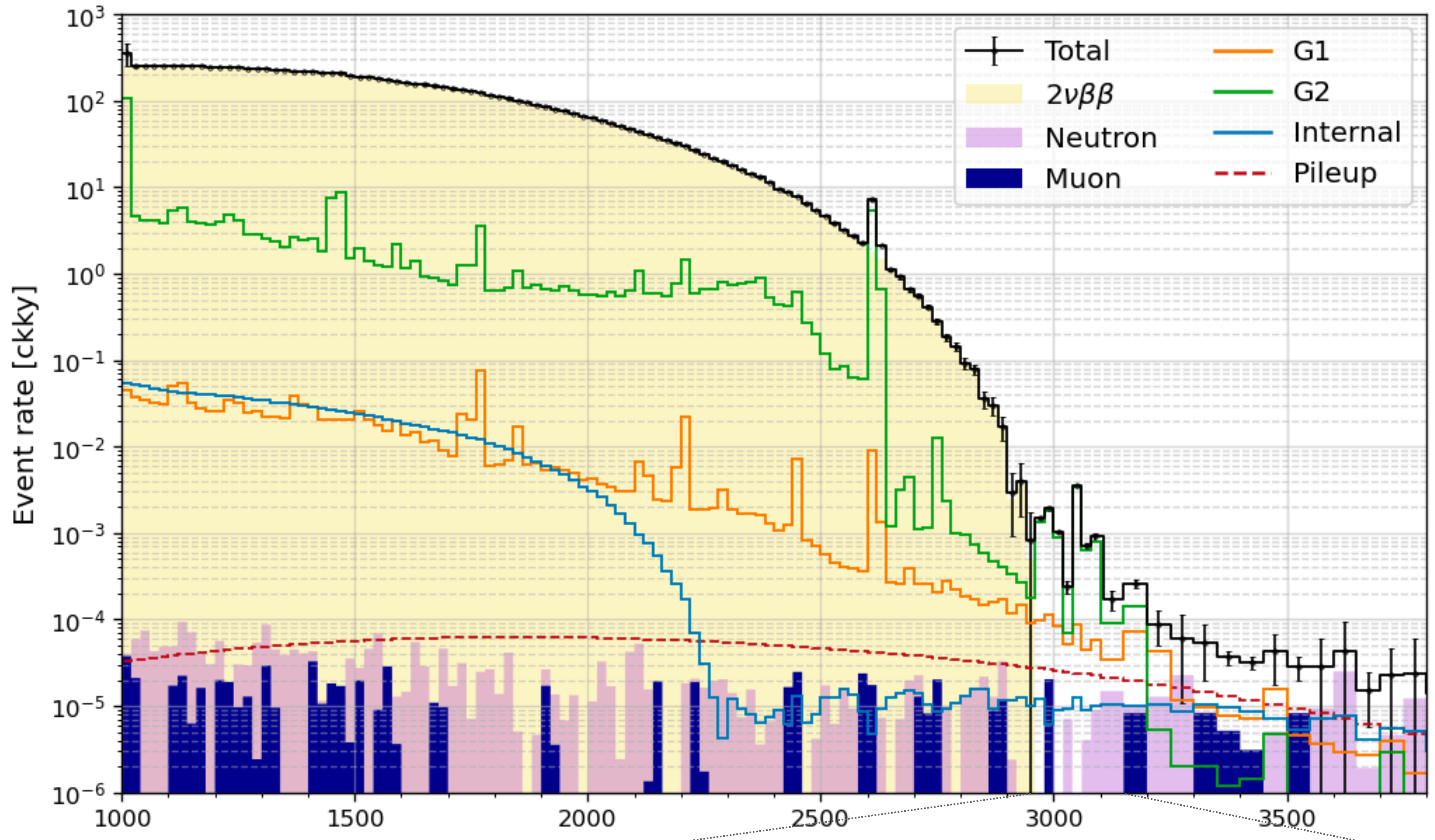
Modified from: Chinese Phys. C 45 (2021) 025001

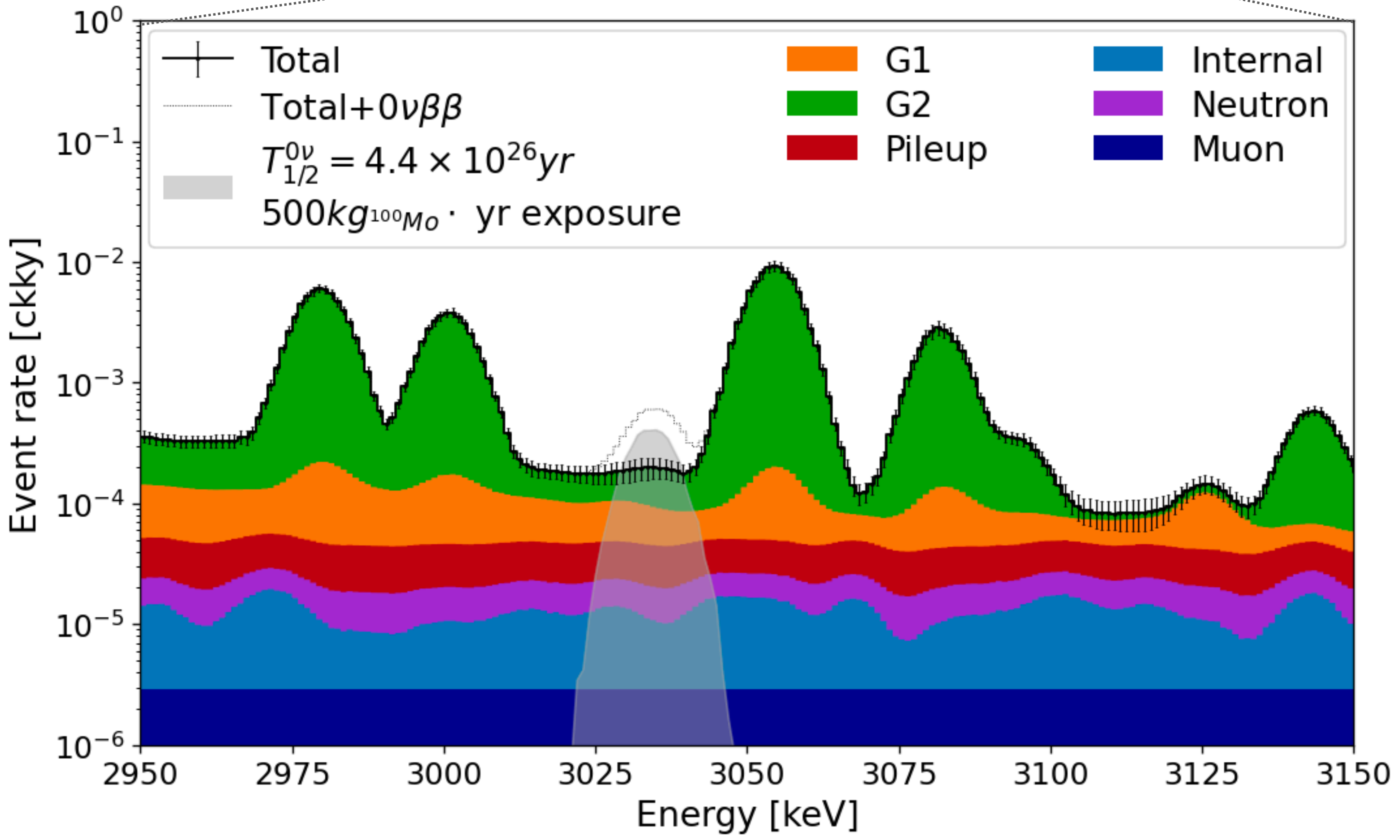


AMoRE-II background and sensitivity

2406.09698
EPJC accepted







- $b < 10^{-4}$ counts/keV/kg/yr, ΔE_{FWHM}~10 keV at ROI.
- $T^{0\nu}_{1/2}$ sensitivity > 4×10^{26} yr at 90% CL.
    - $m_{\beta\beta}$ sensitivity covers inverted mass ordering.

Summary

- Search for $0\nu\beta\beta$ decay with ^{100}Mo-based scintillation crystals using low temperature detector technique.
- Data taking completed for the first two phases, AMoRE-pilot and AMoRE-I.
  - AMoRE-I result: $T^{0\nu}_{1/2} > 2.9 \times 10^{24}$ yr at 90% CL.
- AMoRE-II in preparation.
  - Detector is being ready in Yemilab.
  - Data taking for the 1st stage starts in 2025.

Thank you

And others...