

# Background simulation for AMoRE-II experiment using GEANT4 toolkit

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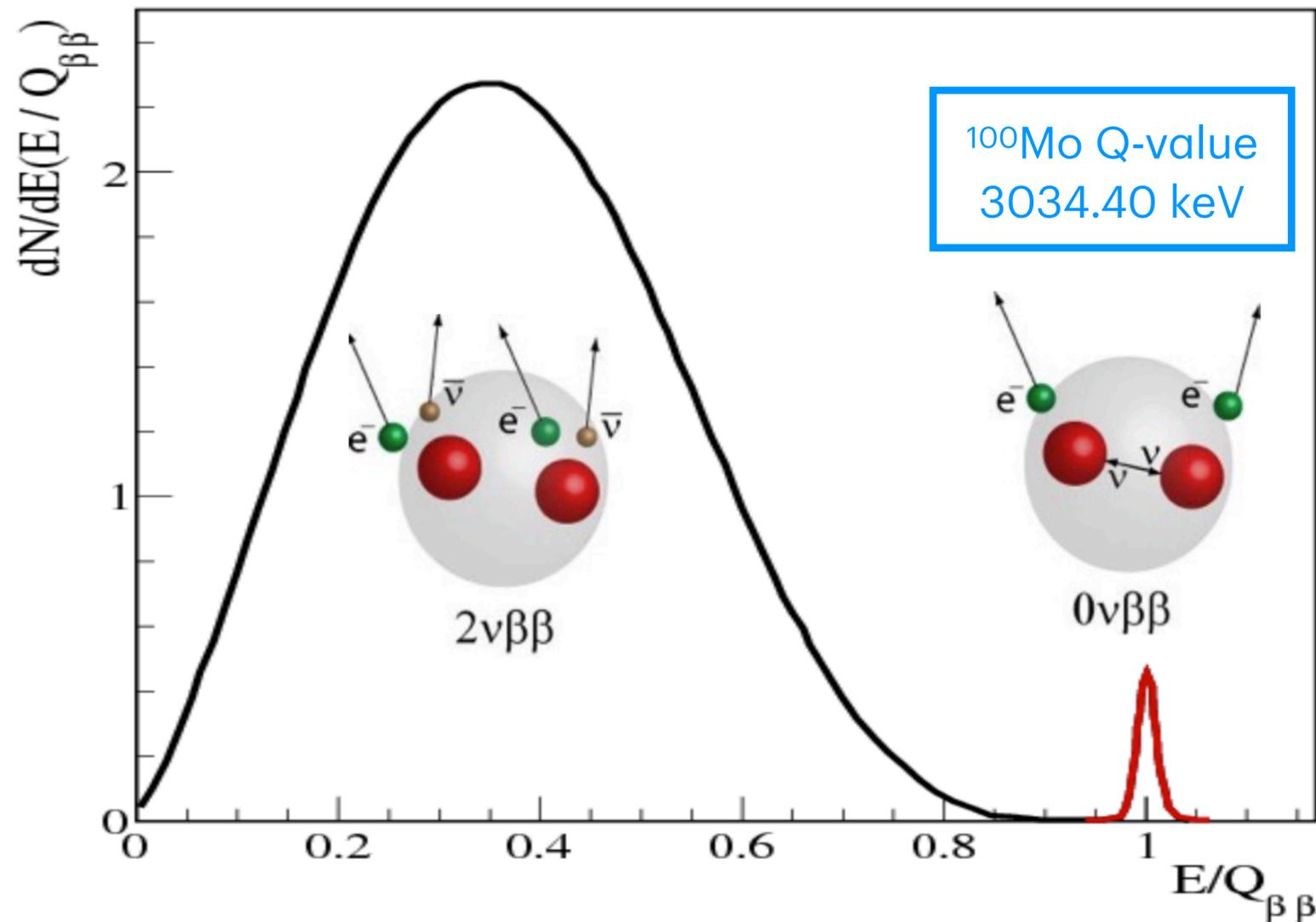
Jeju National University, Juju, Korea



CENTER FOR  
**UNDERGROUND PHYSICS**

# AMoRE: **A**dvanced **Mo**-based **R**are process **E**xperiment

It aims at searching for neutrino less double beta decay ( $0\nu\beta\beta$ )



- Direct measurement of the Majorana neutrino
- Existence of a lepton number violating process
- Estimation of the effective neutrino mass  $\rightarrow$  Neutrino mass hierarchy can be verified

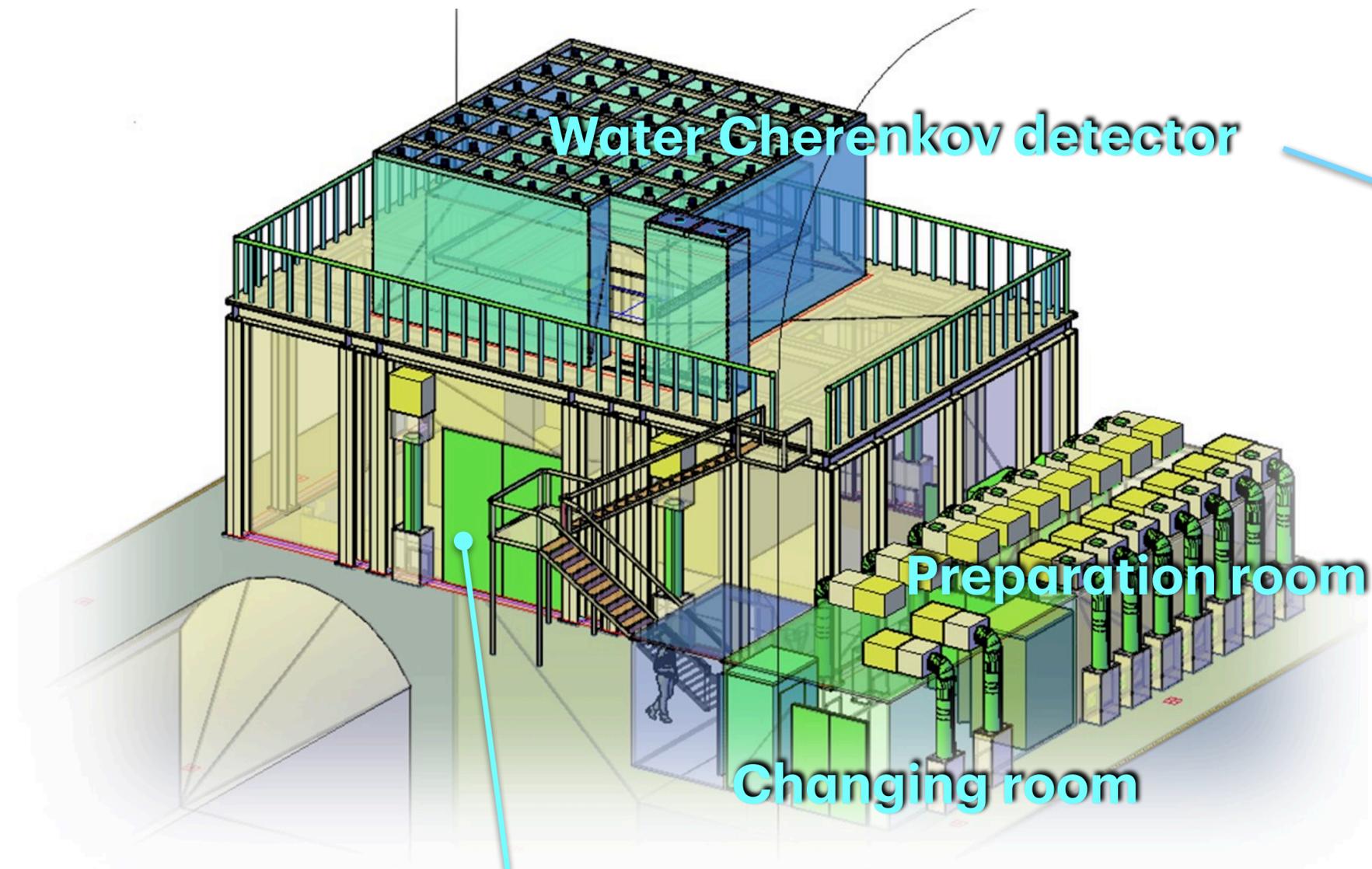
$$T_{1/2}^{0\nu} \propto \begin{cases} M \cdot T & \text{for zero background} \\ \sqrt{\frac{M \cdot T}{B \cdot \Delta E}} & \text{for finite background} \end{cases}$$

Measured half-life is related to the detector mass  $M$ , measurement time  $T$ , the number of background  $B$ , energy resolution  $\Delta E$

**A simulation study was conducted to estimate the background level of the AMoRE-II experiment.**  
Goal for zero background level in ROI:  $< 10^{-4}$  count/kg/keV/year

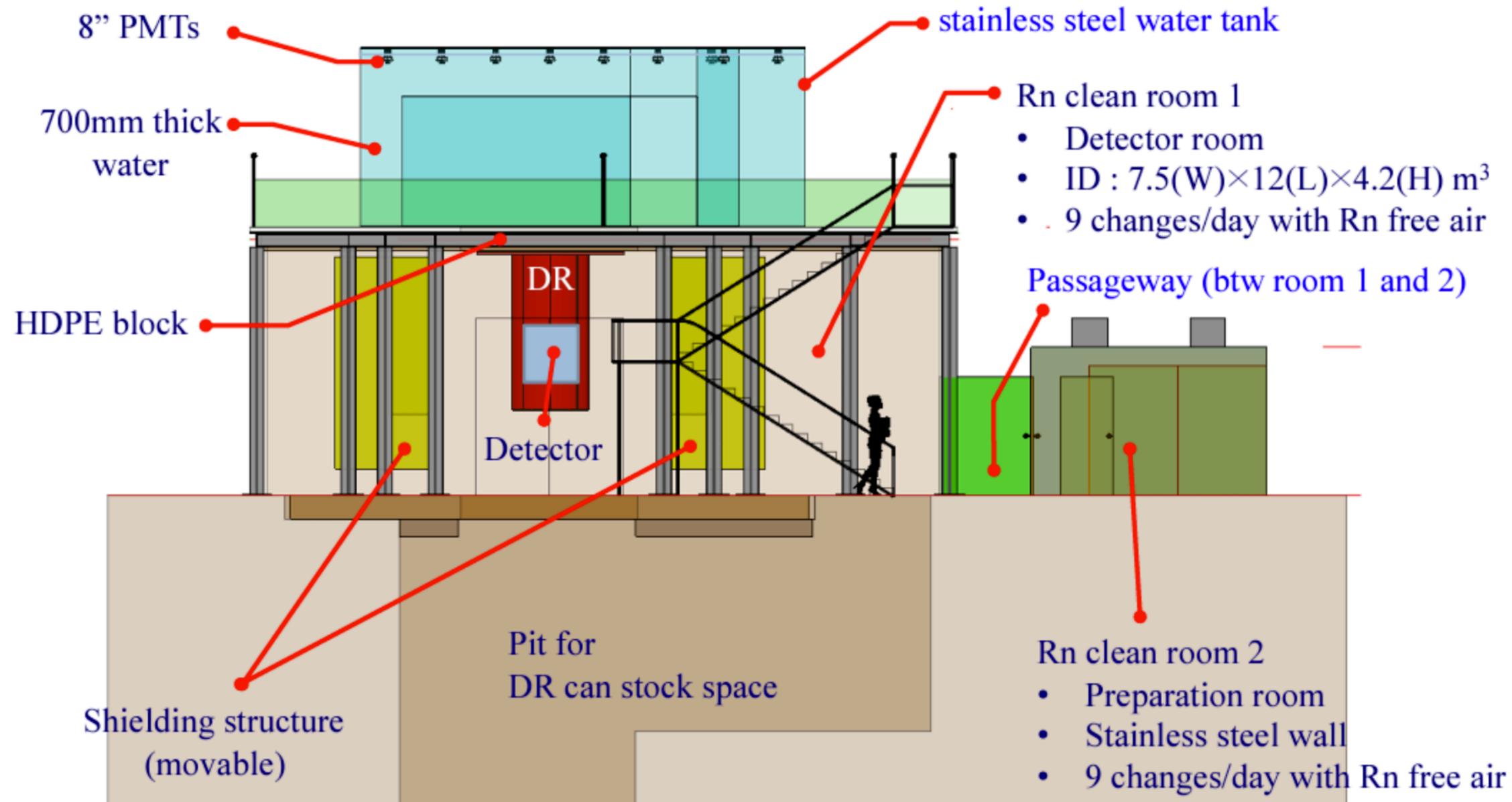
# AMoRE hall in Yemilab

Underground laboratory next to the Handuk mine at Jeongseon, Gangwon-do



Detector room

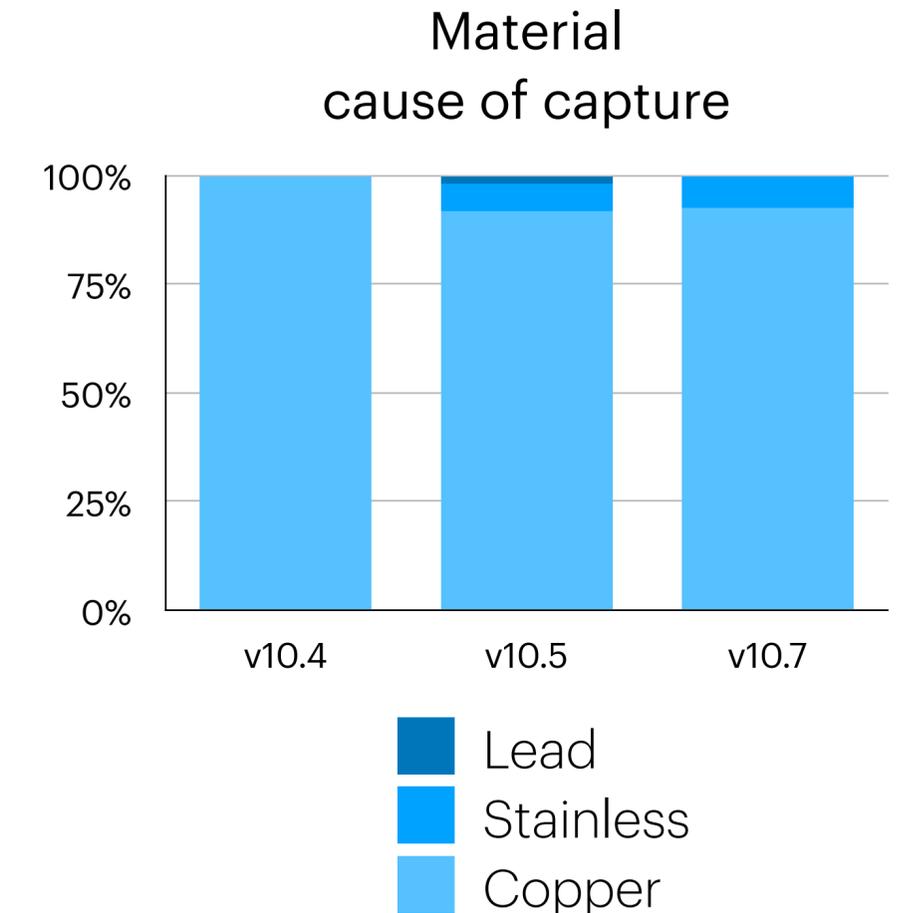
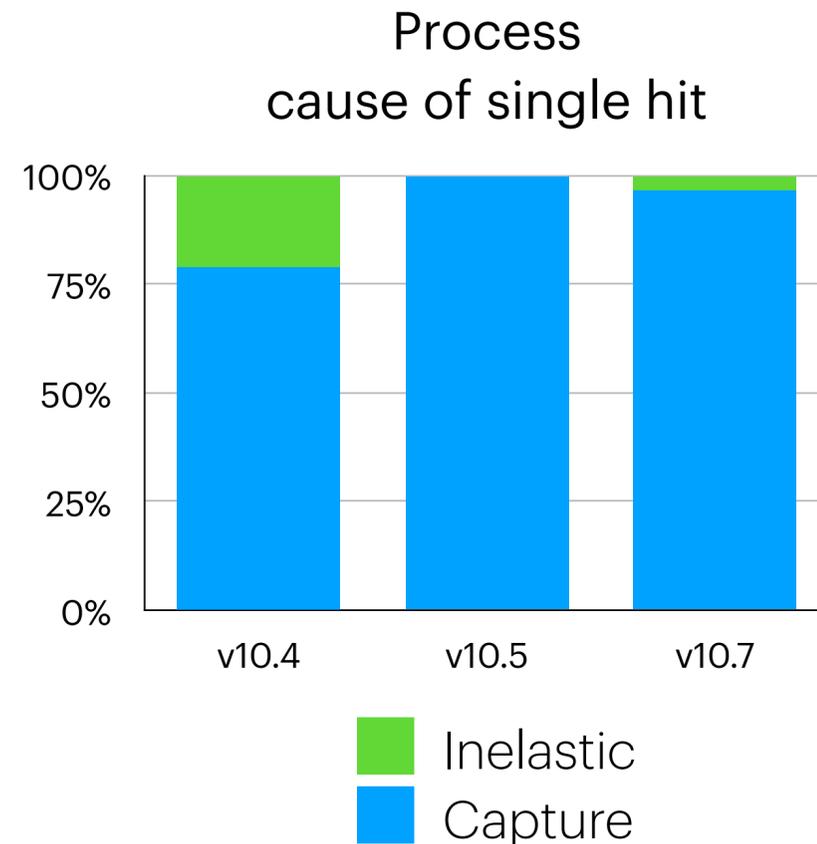
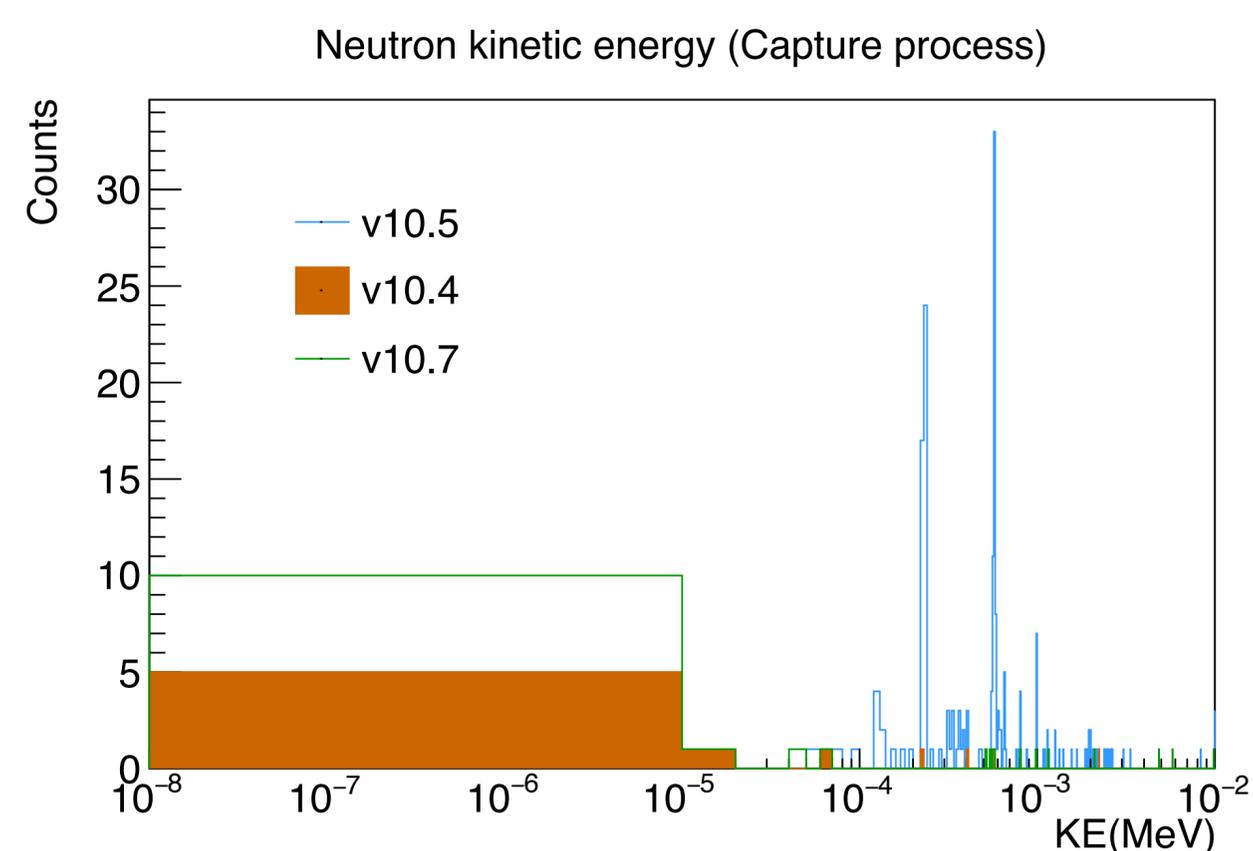
# AMoRE shielding structure



# Determination of the shielding layer

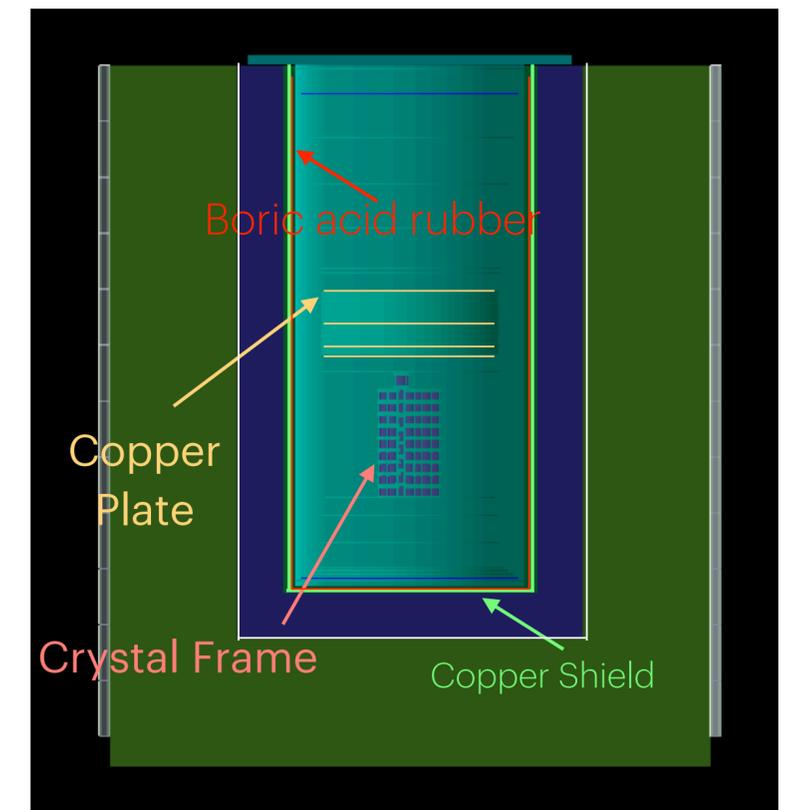
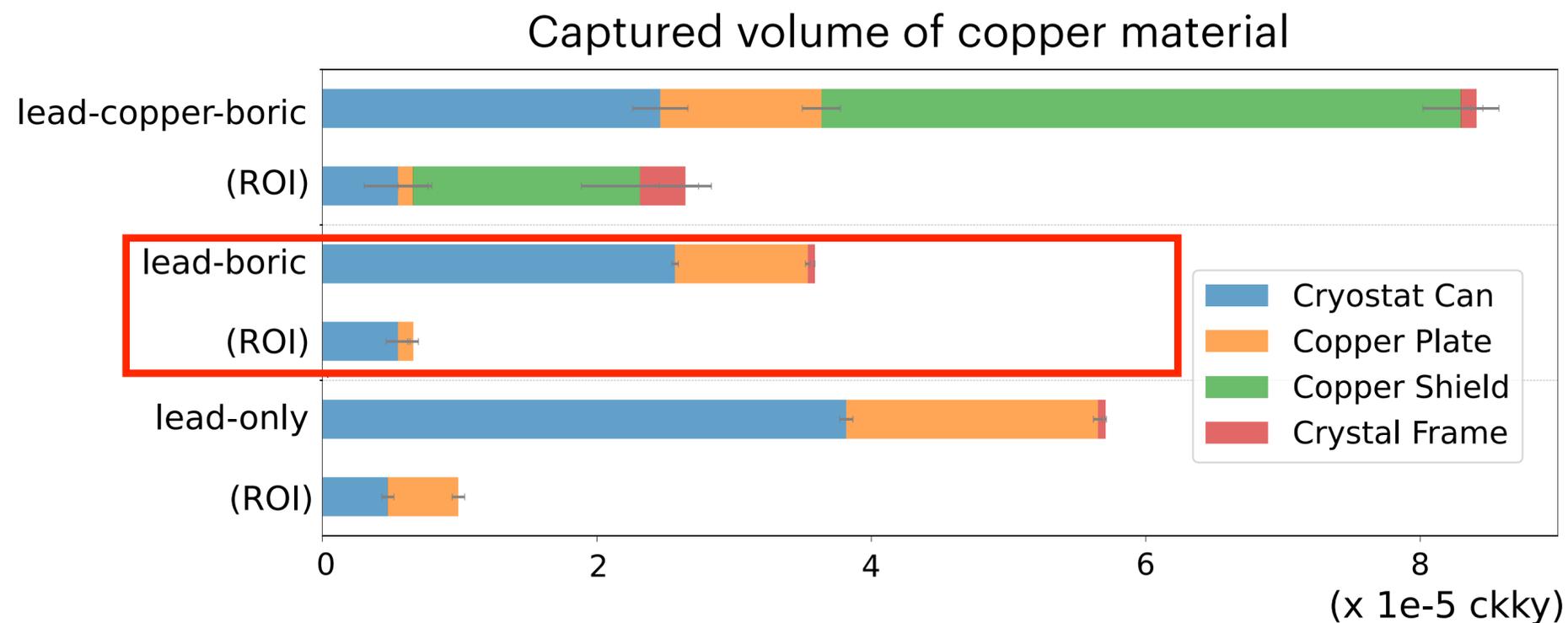
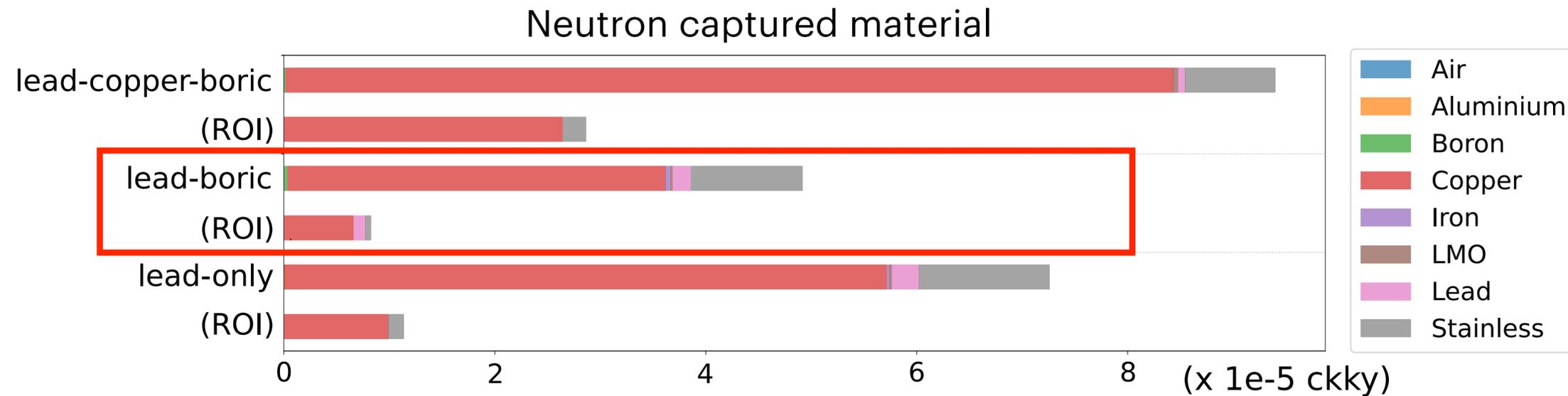
Difference between Geant4 version for neutron simulation

- Neutron simulations were performed with different versions of Geant4.
  - Neutron background was 10 times larger with the Geant4 10.5.1
- We have checked the neutron process and it seems that there is a problem with the neutron process cross-section in Geant4 10.5.1.



# Determination of the shielding layer

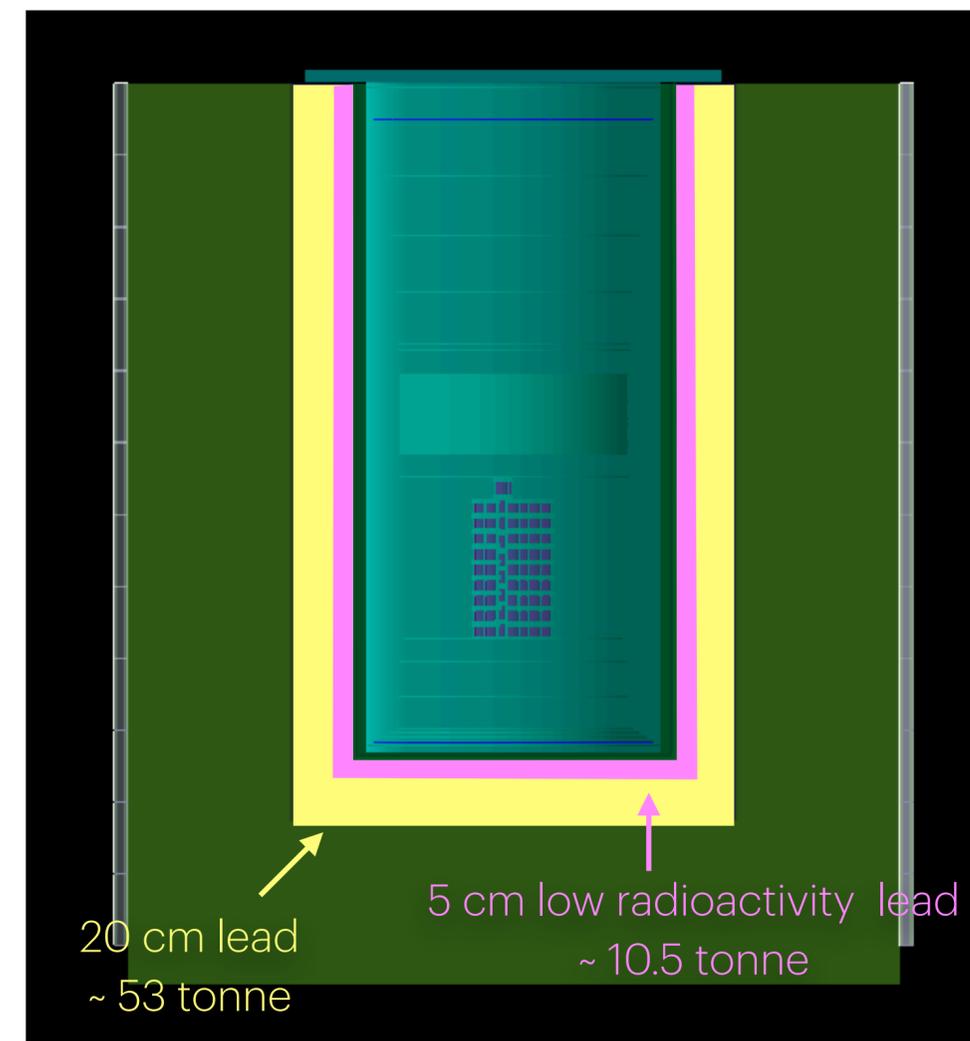
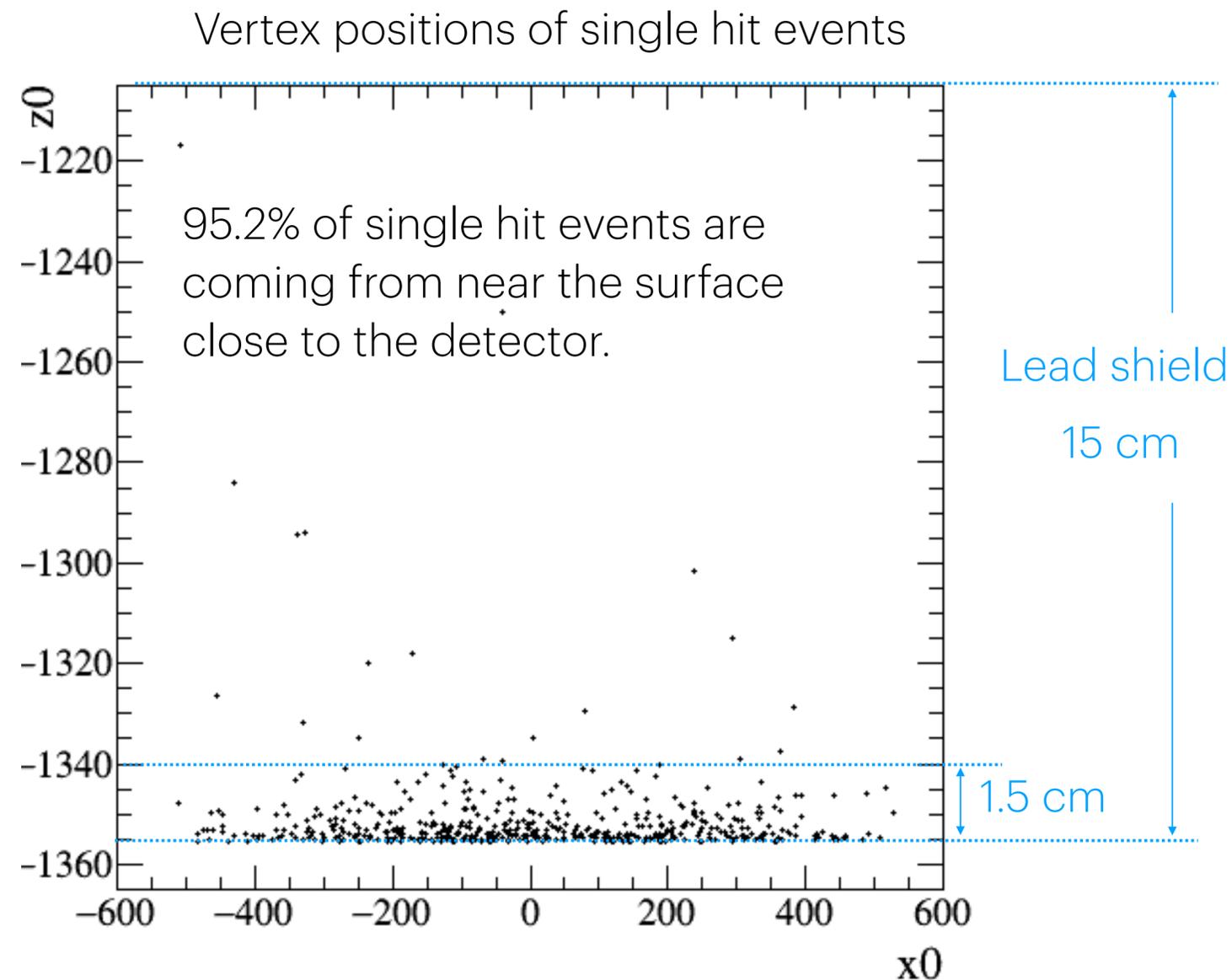
By neutron simulation



# Determination of the shielding layer

By lead simulation

- We found that the  $^{210}\text{Pb}$  background self-absorbs in lead shields with thicknesses greater than 5 cm.



# Background simulation using Geant4

QGSP\_BERT\_HP physics list with Geant4-v10.7.3

## Background sources on AMoRE experiment

Far components

### Environmental background

Cosmic muon, gamma from rock, radiogenic neutron, radon from the air

### Cryostat and shield materials

Copper plate, SC lead shield cryostat can, lead shield, neutron shield ...

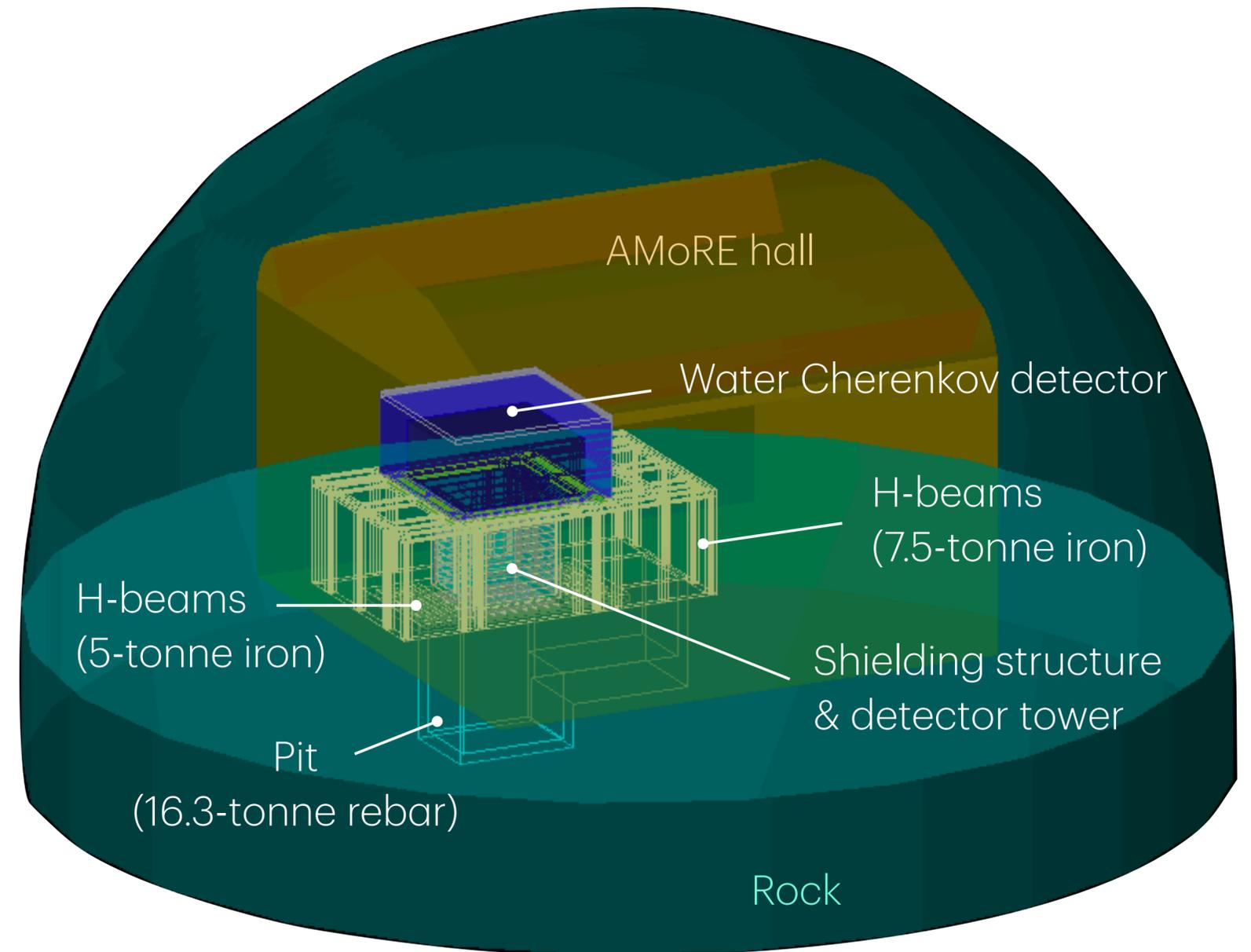
Near components

### Detector module components

Reflector, epoxy, solder, sensor, frame, bolts...

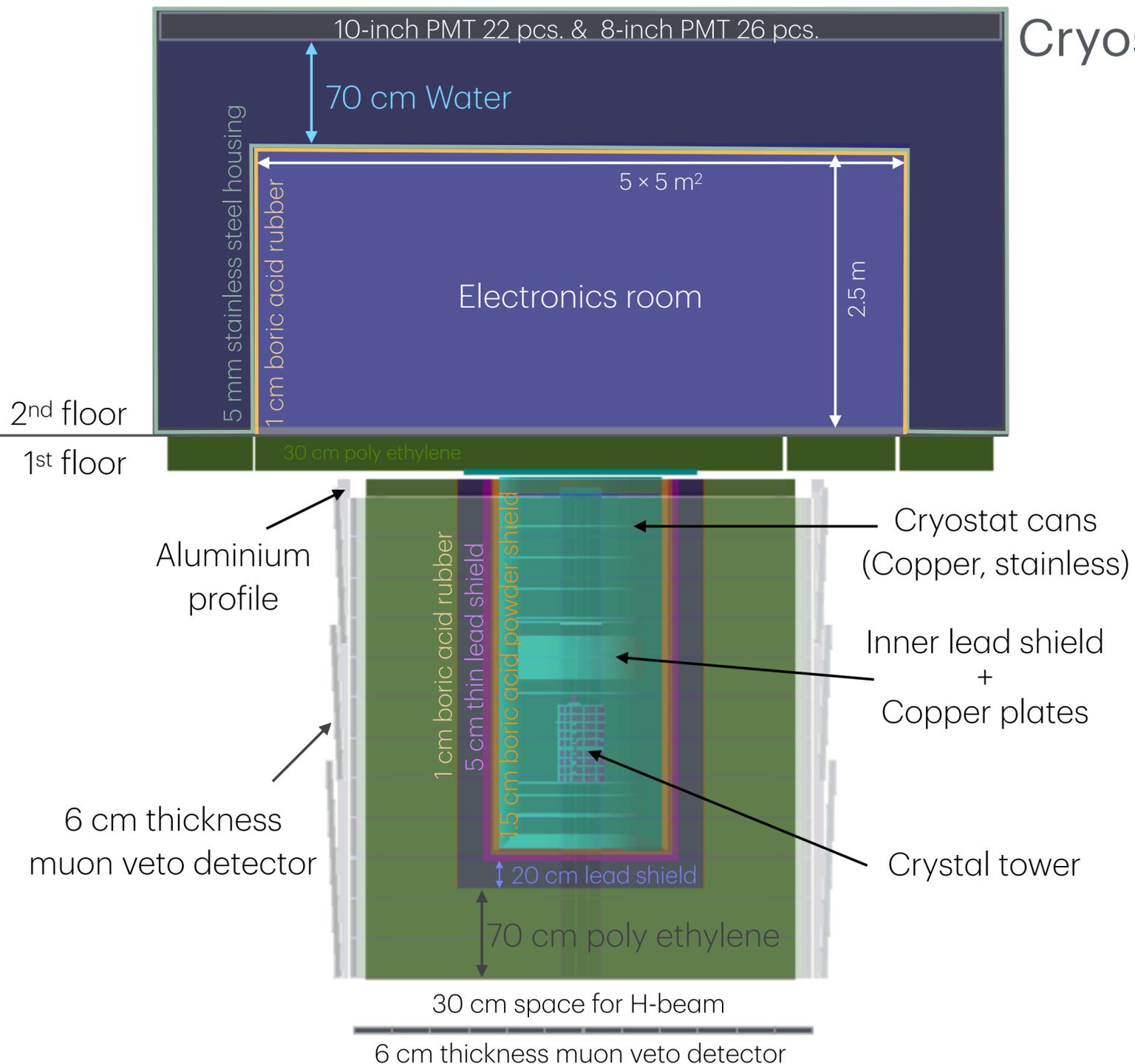
### Crystal internal background

$2\nu\beta\beta$  background

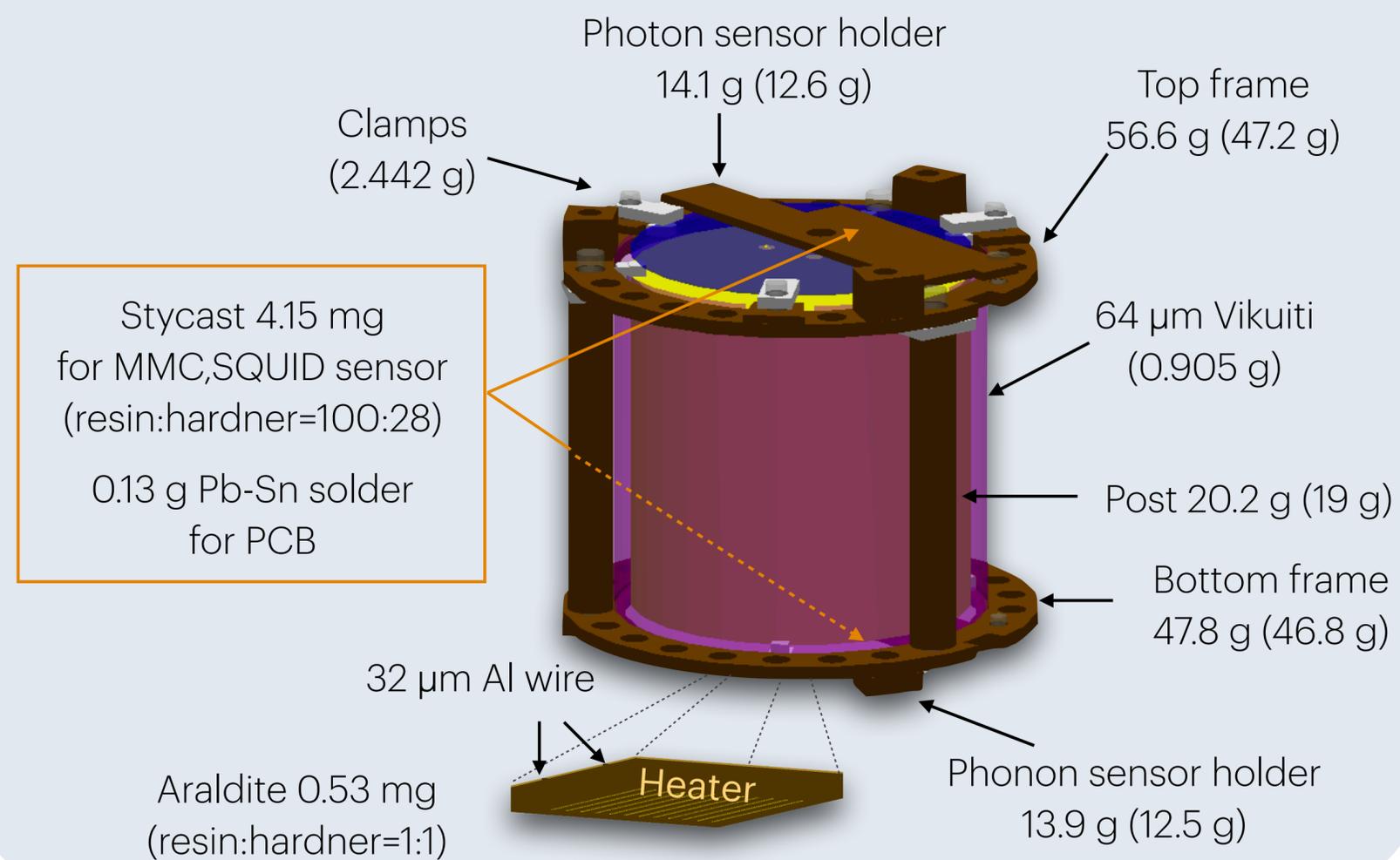


# Geometry in the simulation

Cryostat and shield material



Detector module components

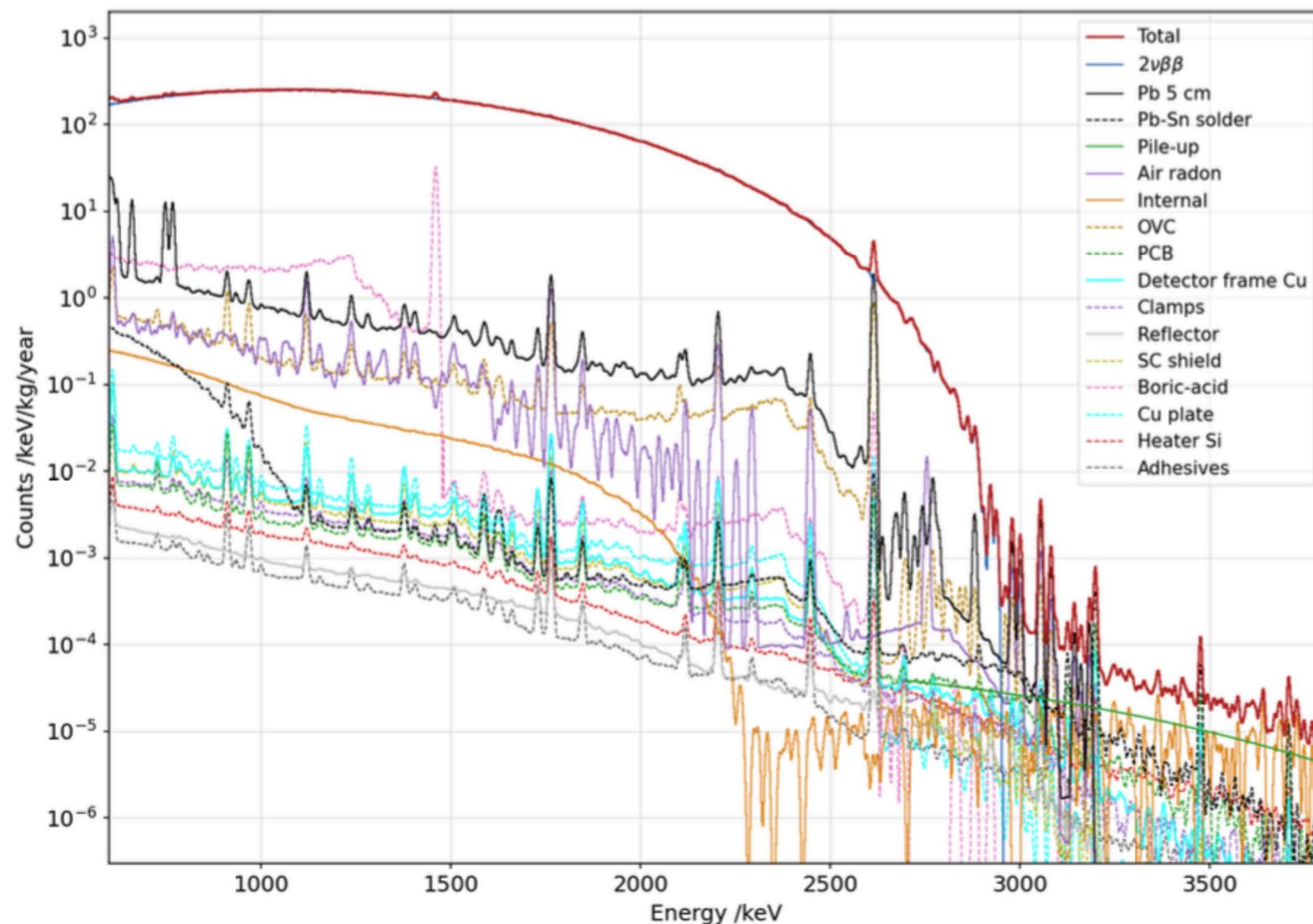


# Backgrounds of AMoRE-II

Radioassay and simulation

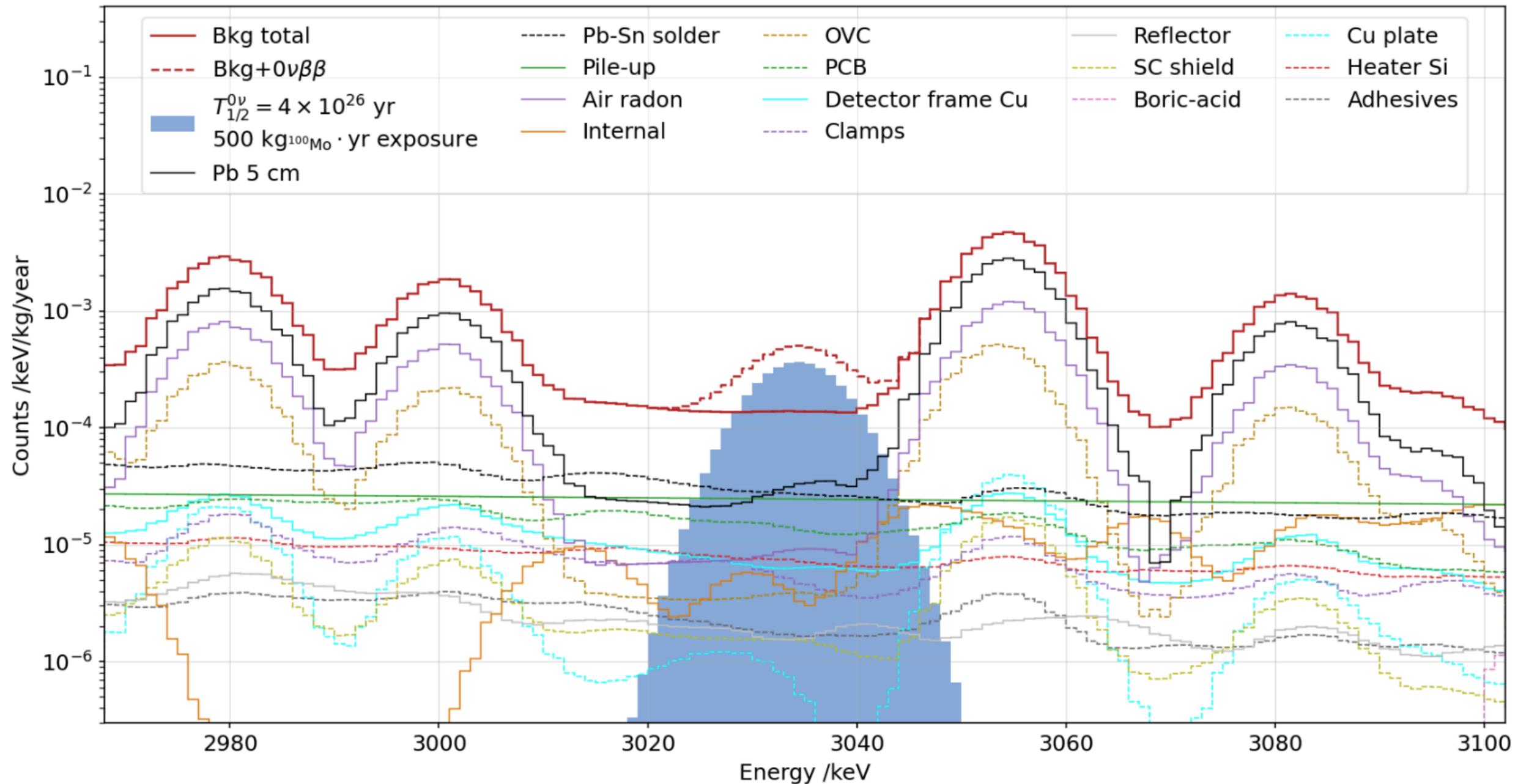
Source material	U-238 mBq/kg	Th-232 mBq/kg	Other mBq/kg	method
LMO internal	< 3.1E-3	< 1.9E-3	<1.8E-3 ( <sup>235</sup> U)	AMoRE-I
Vikuiti	4.2(37)E-2	1.3(9)E-3		ICP-MS
Araldite	2.21(75)	< 1.10		HPGe
Stycast	< 3.27	< 1.64		HPGe
Pb-Sn solder	< 0.88	< 2.19		HPGe
PTFE	< 0.12	< 0.04		ICP-MS
Kapton PCB	< 0.93	<0.93		HPGe
Cu (2022 NOSV)	3.5(7)E-3	1.10(4)E-3		ICP-MS
Heater Si	4.13	2.04		HPGe
Cu plate	< 1.24E-2	< 4.1E-3		ICP-MS
Si rubber	< 0.57	2.07(34)	4.90 ( <sup>40</sup> K)	HPGe
Boric acid	< 0.46	< 0.50	98(8) ( <sup>40</sup> K)	HPGe
Pb (Boliden)	0.44(8)	0.21(7)	12E+3 ( <sup>210</sup> Pb)	HPGe
Pb	0.76(21)	< 0.38	180E+3 ( <sup>210</sup> Pb)	ICP-MS
Rock	10.4E+3			ICP-MS

- Muon rate  $\sim 8.2\text{E-}8 \mu/\text{cm}^2/\text{s}$ ; neutron rate  $\sim 7.1\text{E-}6 n/\text{cm}^2/\text{s}$ .
- Rn-222 in air < 0.29(6) Bq/m<sup>3</sup>; OVC < 0.375 mBq/kg.
- Crystal and detector frame surface radioactivity to be controlled.



# Background estimation

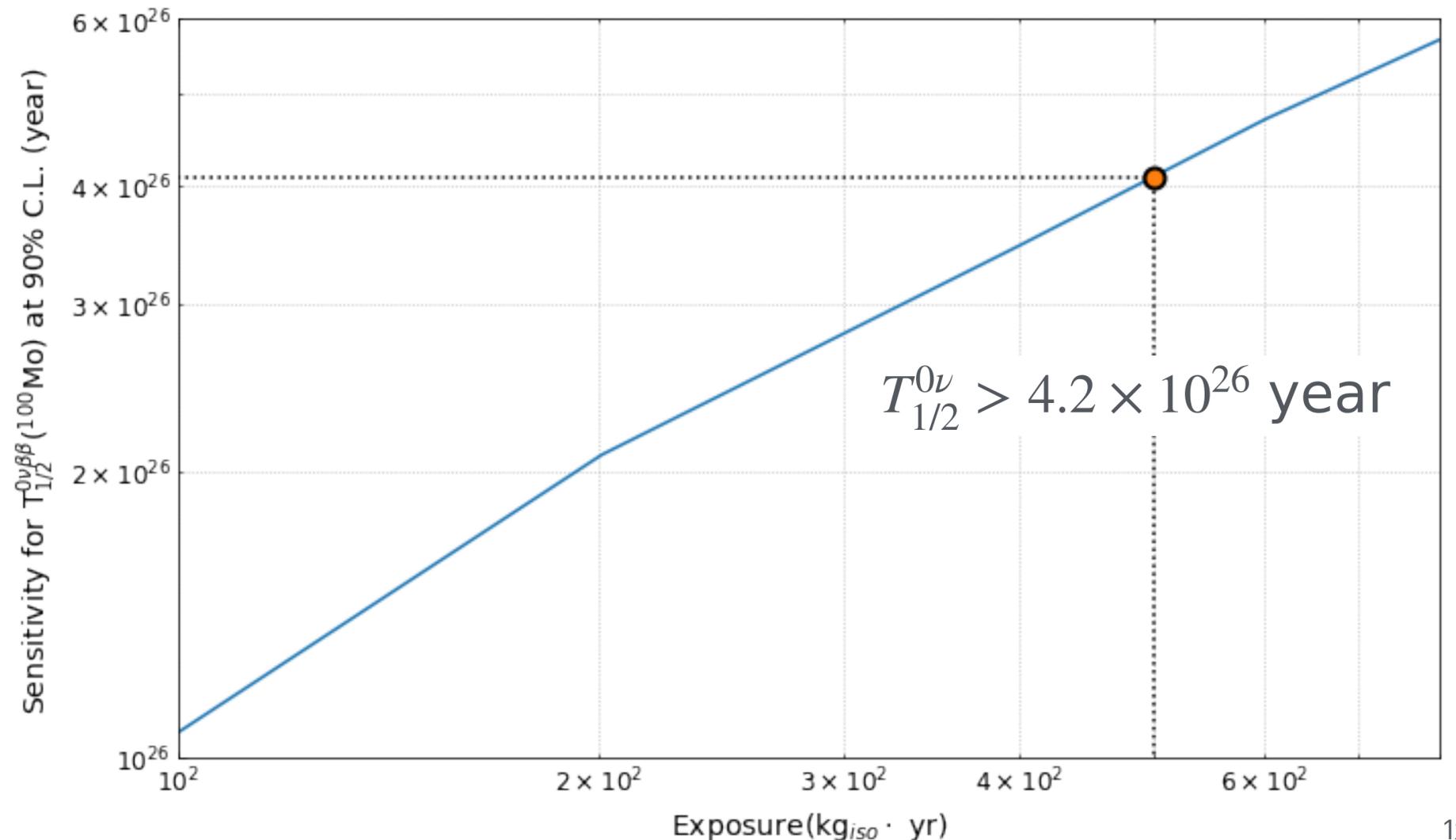
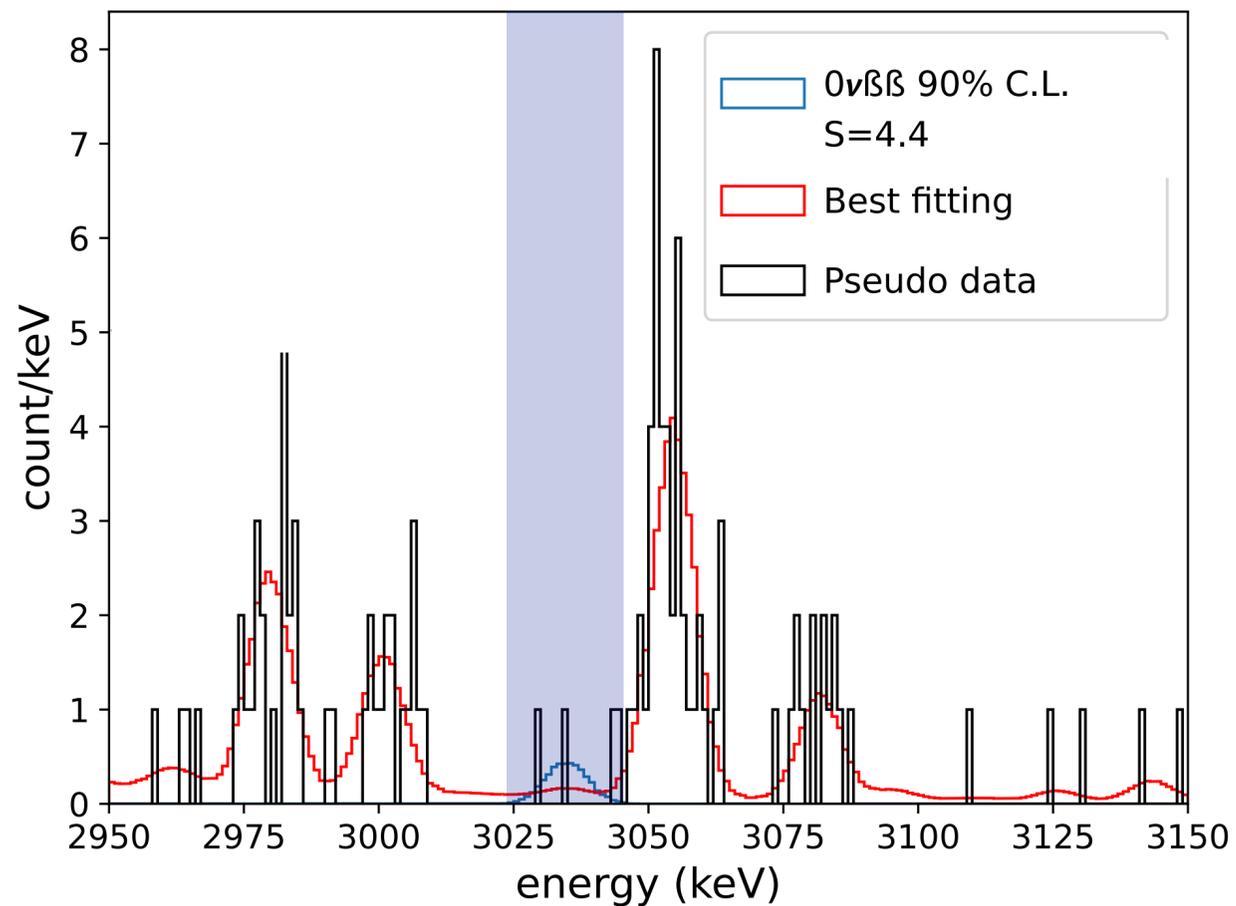
$B \sim 10^{-4}$  c/kg/yr,  $\Delta E = 10$  keV FWHM



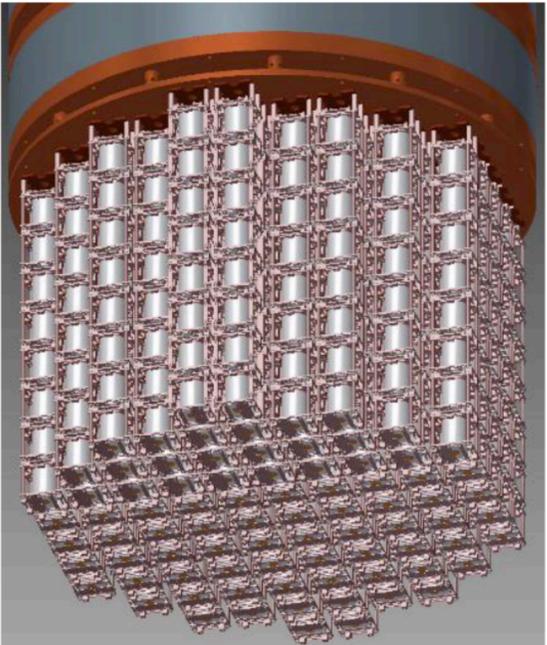
# Sensitivity estimation

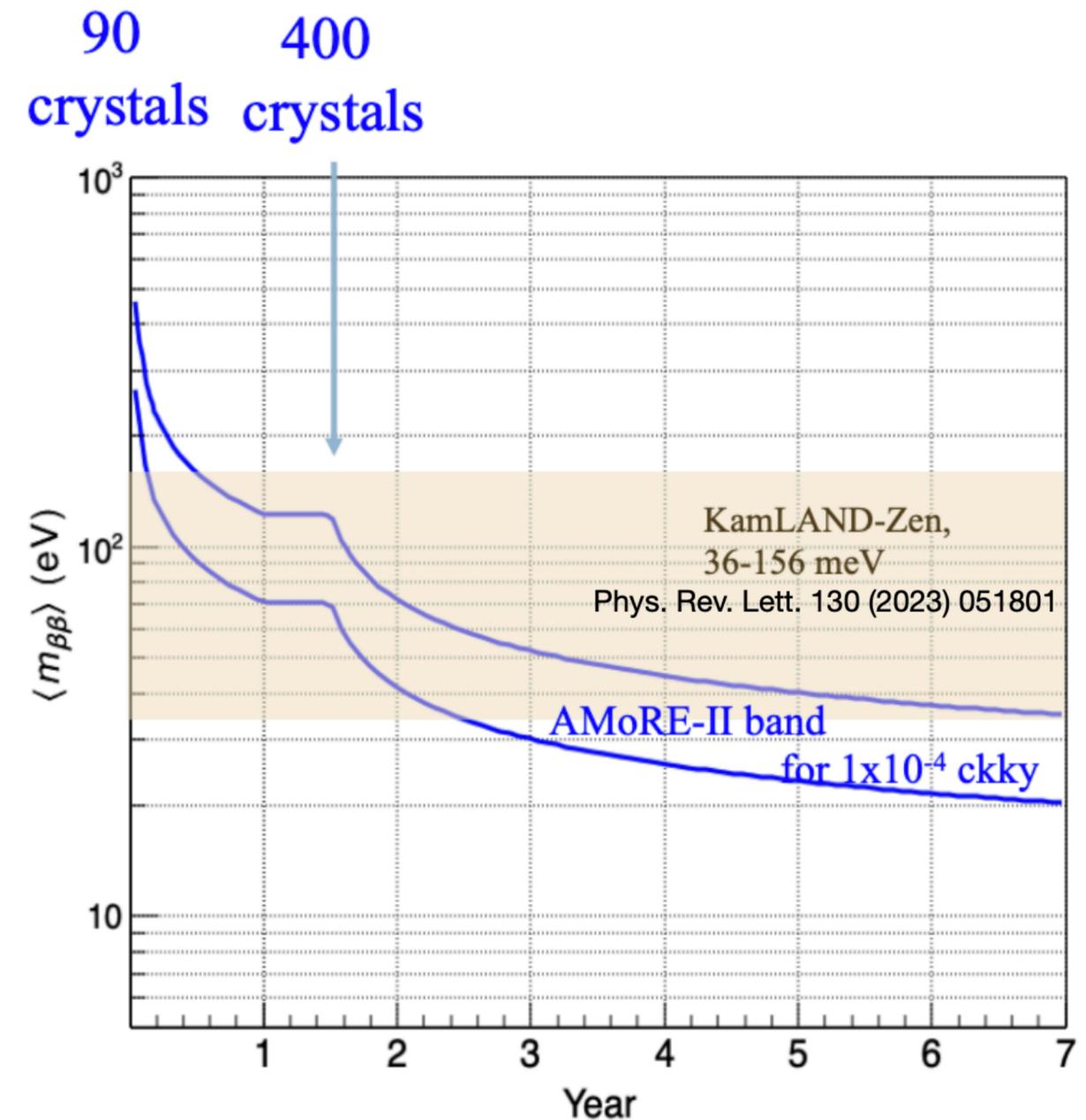
1000 pseudo experiments with 5 years of simulation data

$$\begin{aligned}
 \bullet L &= \prod \frac{(S+B)^N}{N!} e^{-(S+B)} \prod f(x) & \bullet N_{iso} &= N_A \cdot a \cdot M/A = 5.92 \times 10^{27} \\
 \bullet S &= \epsilon \Gamma^{0\nu} N_{iso} t = \epsilon \frac{\ln 2}{T_{1/2}^{0\nu}} N_{iso} t & \bullet T_{1/2}^{0\nu} &> \frac{\ln 2 \cdot \epsilon \cdot N_{iso} \cdot t}{S_{C.L.}} \\
 \bullet f(x) &= f \cdot pdf_s + (1-f) \cdot pdf_b & (\epsilon \sim 0.7, t = 5 \text{ years}) &
 \end{aligned}$$



# Stage of AMoRE-II

	Stage 1	Stage 2
		
Crystal towers	10 towers (90 crystals)	42 towers (~360 crystals)
Crystal Mass(kg)	~29 kg (81ea 5cm, 9ea 6cm)	~ 157 kg
Schedule	2024-	2025-



# Summary

- The shield layer was optimized through several simulation studies.
  - There were version issue with the neutron simulation.
- Most of the necessary background components have been considered.
  - The total background level in ROI is  $B < 1.77 \times 10^{-4}$  ckky.
- The sensitivity was evaluated by fitting on the pseudo-data.
  - Exclusive sensitivity is  $T_{1/2}^{0\nu} > 4.2 \times 10^{26}$  years
- We have plan to do the detailed simulation for AMoRE-II stage 1 run.