# Updated background simulation and detector design for AMoRE-II

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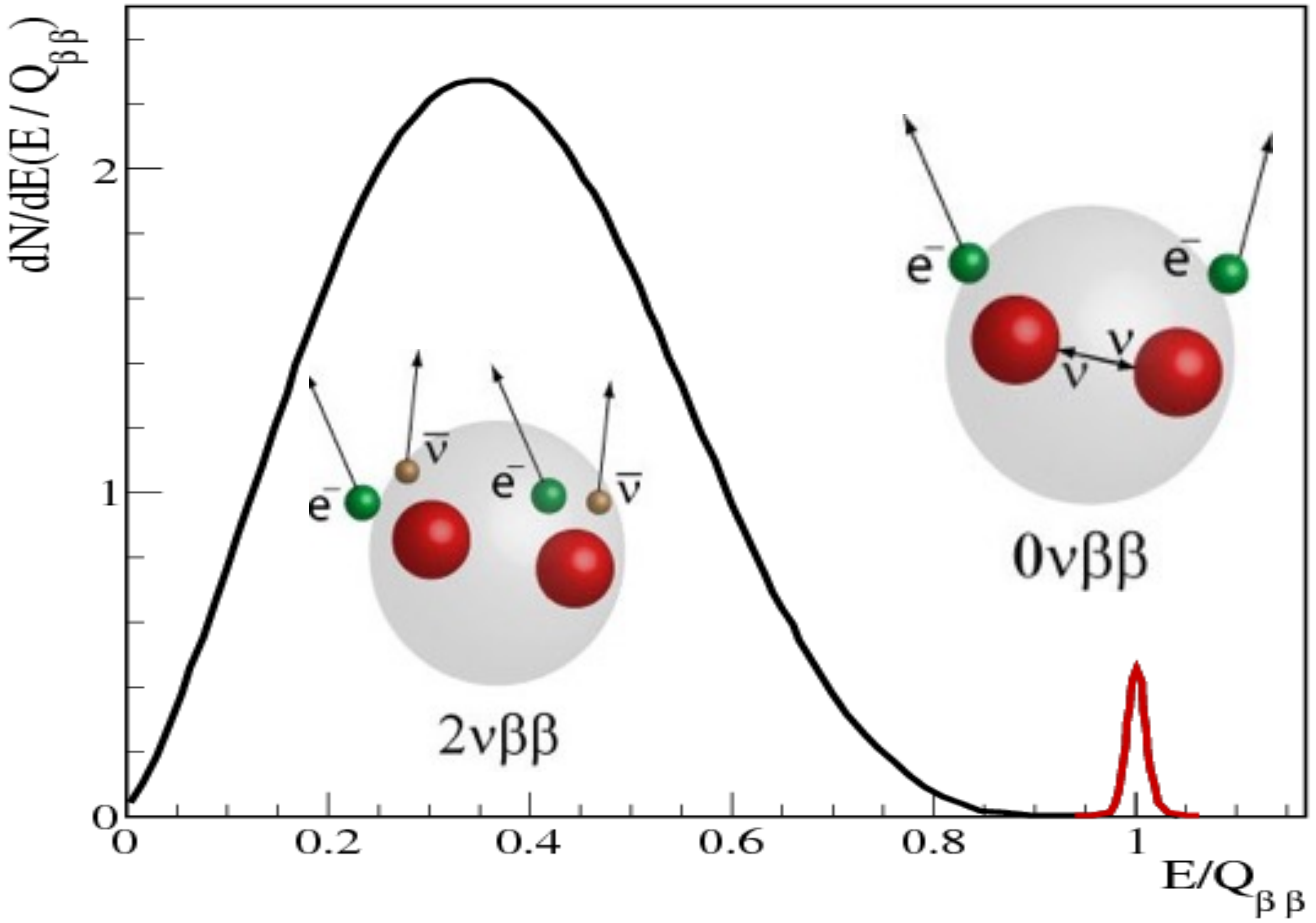
**TAUP 2025 @Xichang**

# AMoRE (Advanced Mo-based Rare process Experiment)

## It aims at searching for neutrinoless double beta decay (0νββ)




- To determine whether the neutrino is a Majorana particle
- To test the existence of lepton number violating process
- To estimate the absolute neutrino mass scale

For light neutrino exchange model:

$$[T^{0\nu}_{1/2}]^{-1} = G_{0\nu}\,|M_{0\nu}|^2 \left(\frac{m_{\beta\beta}}{m_e}\right)^2$$

Half-life measured; Phase factor; Nuclear matrix element; Effective 0νββ neutrino mass, < $m_{\beta\beta}$>

$$\langle m_{\beta\beta}\rangle = \left|\sum_{i=1}^{3} U_{ei}^2 m_i\right|$$

- If the decay rate of the 0νββ is precisely measured, the absolute neutrino masses can be calculated → It helps to determine neutrino mass hierarchy

(for zero background)

$$T^{0\nu}_{1/2} \propto M \cdot T$$

(for finite background)

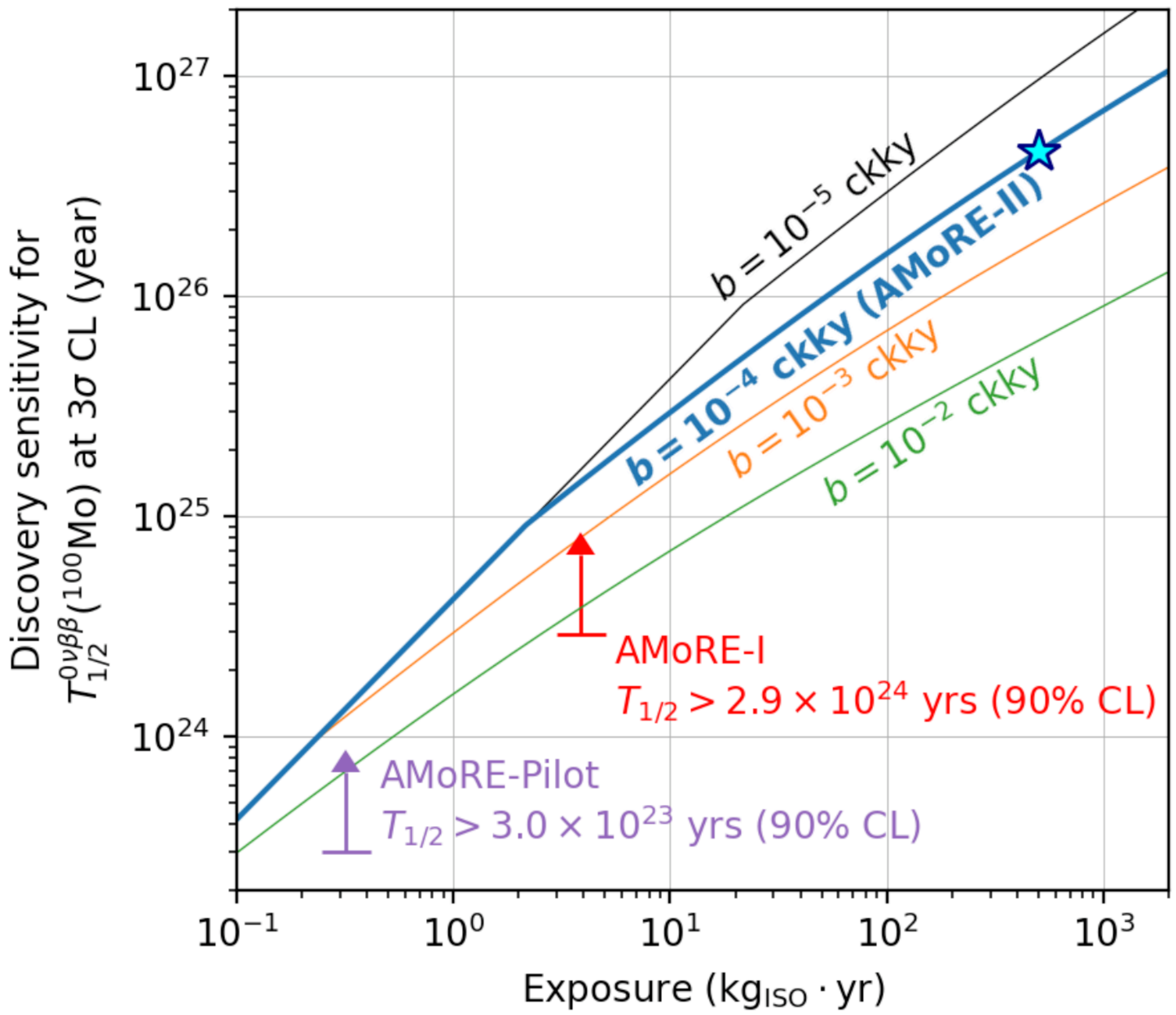
$$T^{0\nu}_{1/2} \propto \sqrt{\frac{M \cdot T}{B \cdot \Delta E}}$$

- Half-life limits are proportional to the detector mass M and DAQ time T, if finite background, sqrt(MT)
- To discover a sharp peak @ Q-value:
  - **Good energy resolution**
  - **Extremely low background**

# Projected backgrounds

## for experimental sensitivity

- Understanding and reduction of background
  - Careful selection of detector and shielding component materials
  - Heavy shielding strategies:
    - Deep underground installation
    - Pb, B, CH
    - Rn-free air supply
    - μ-veto system



# AMoRE-II experimental setup at Yemilab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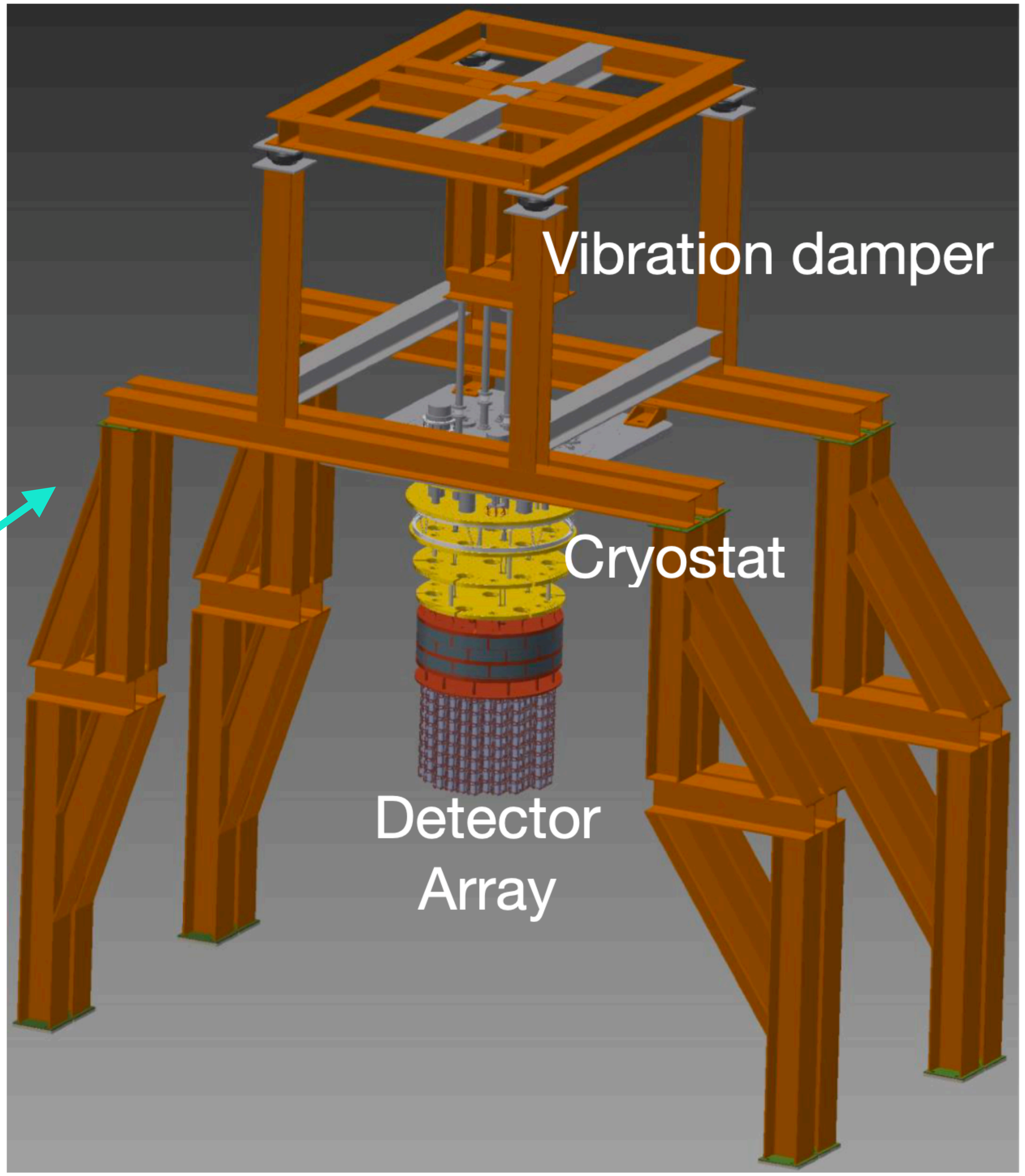
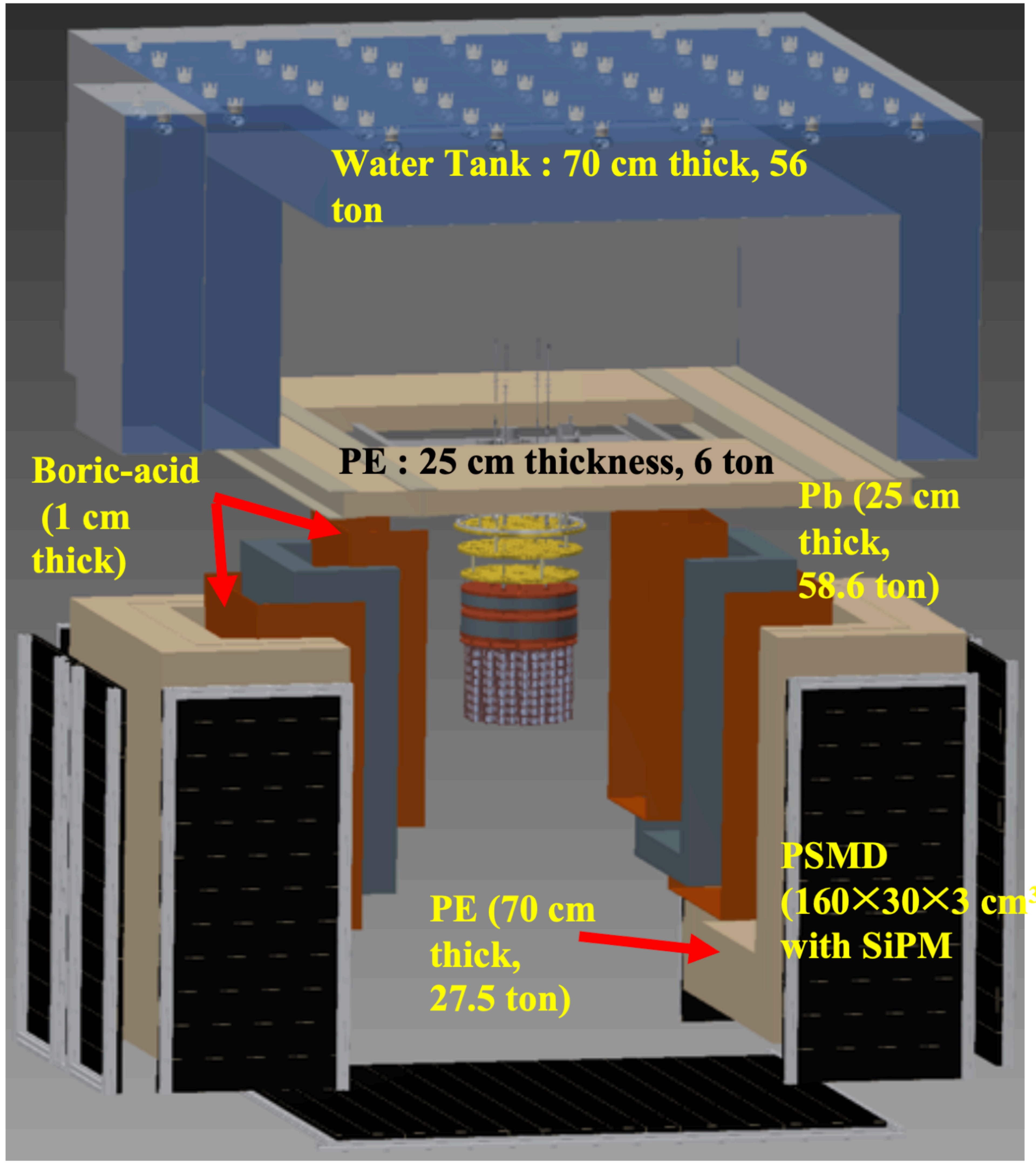


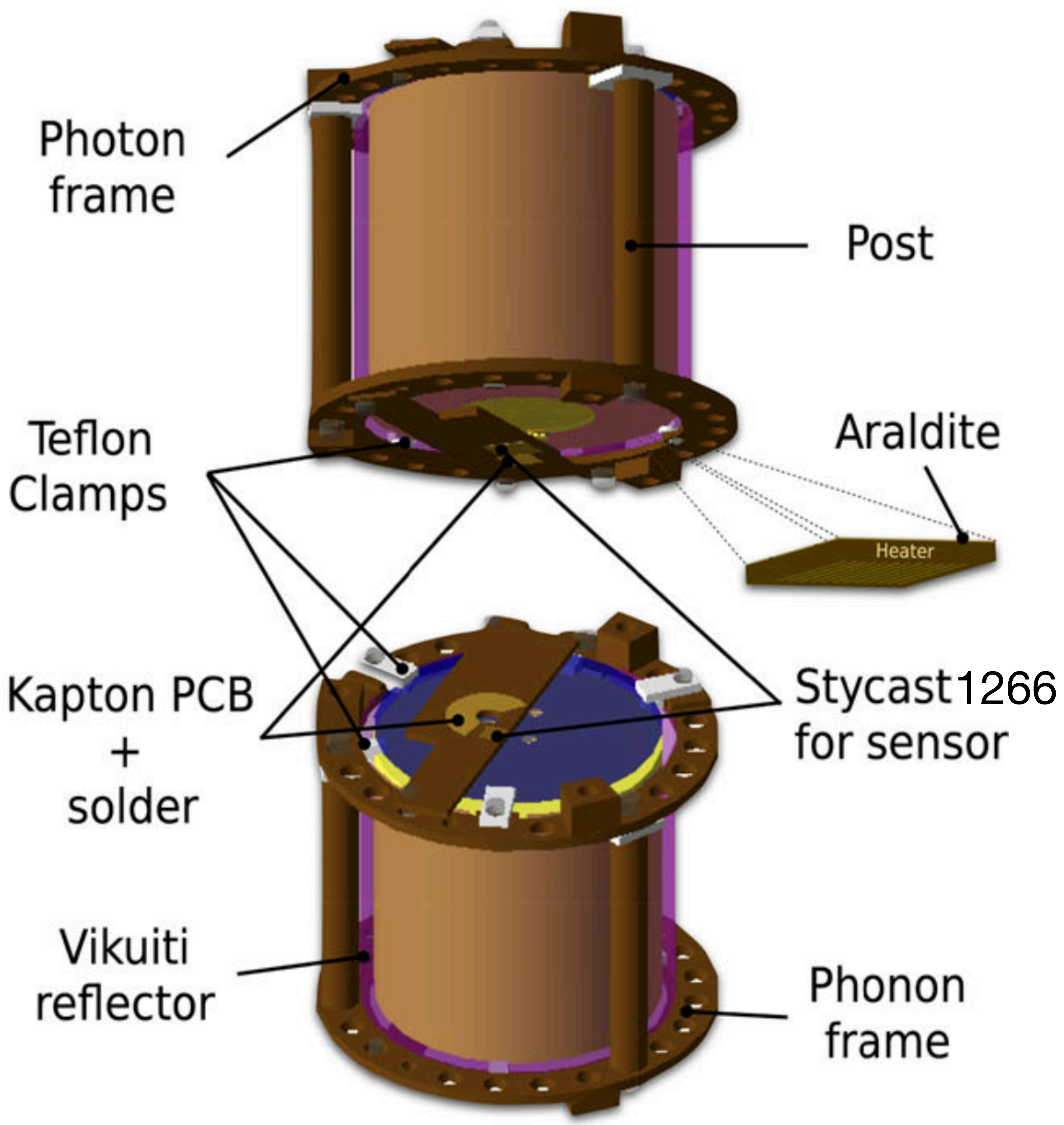
# Shielding structure and muon veto system

- Water Cherenkov detector with an active muon veto capability has been installed for the above part of the cryostat
- The plastic scintillator detector panels have been installed surrounding the cryostat on four sides and at the bottom

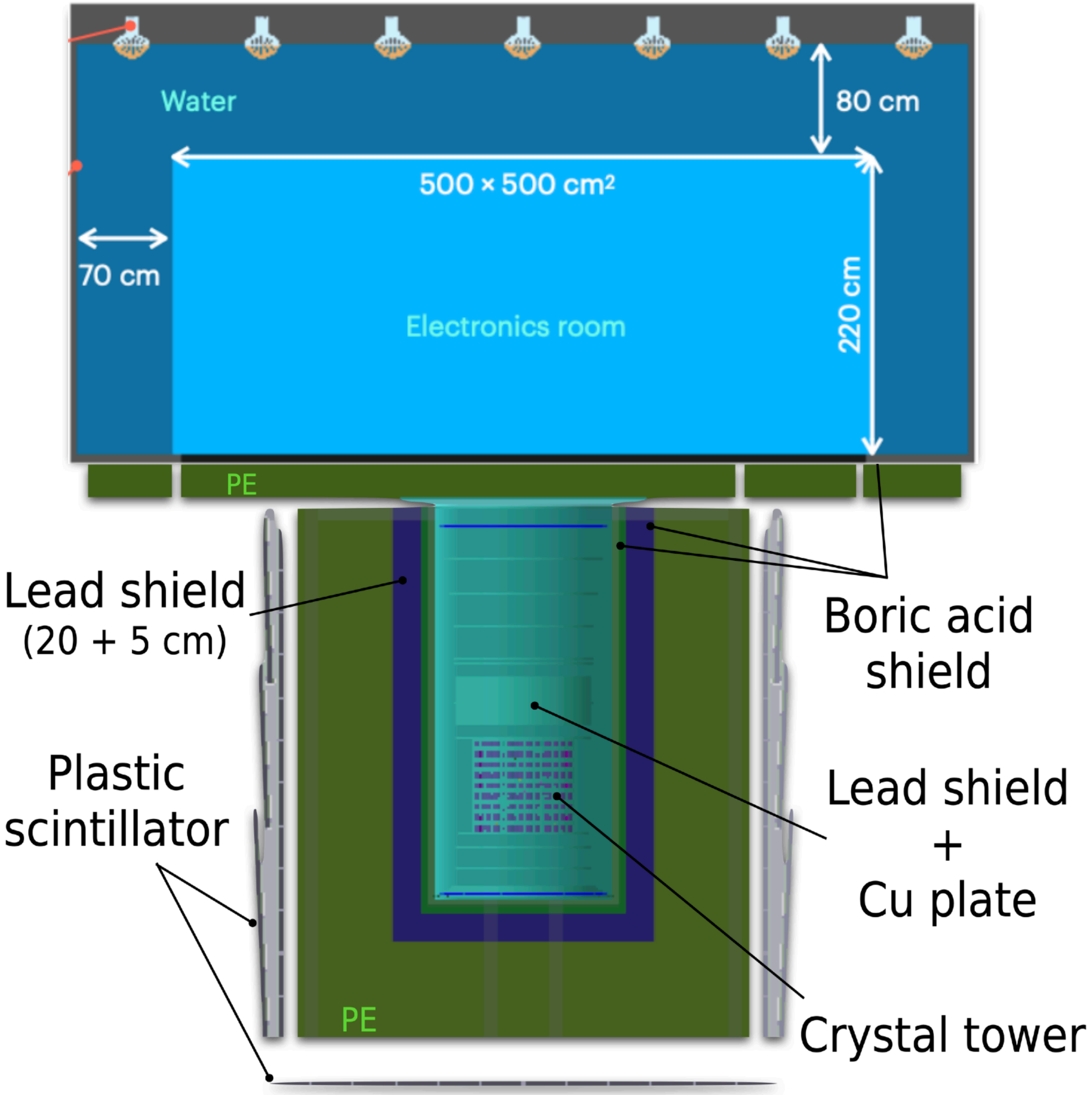



# AMoRE-II simulation geometry

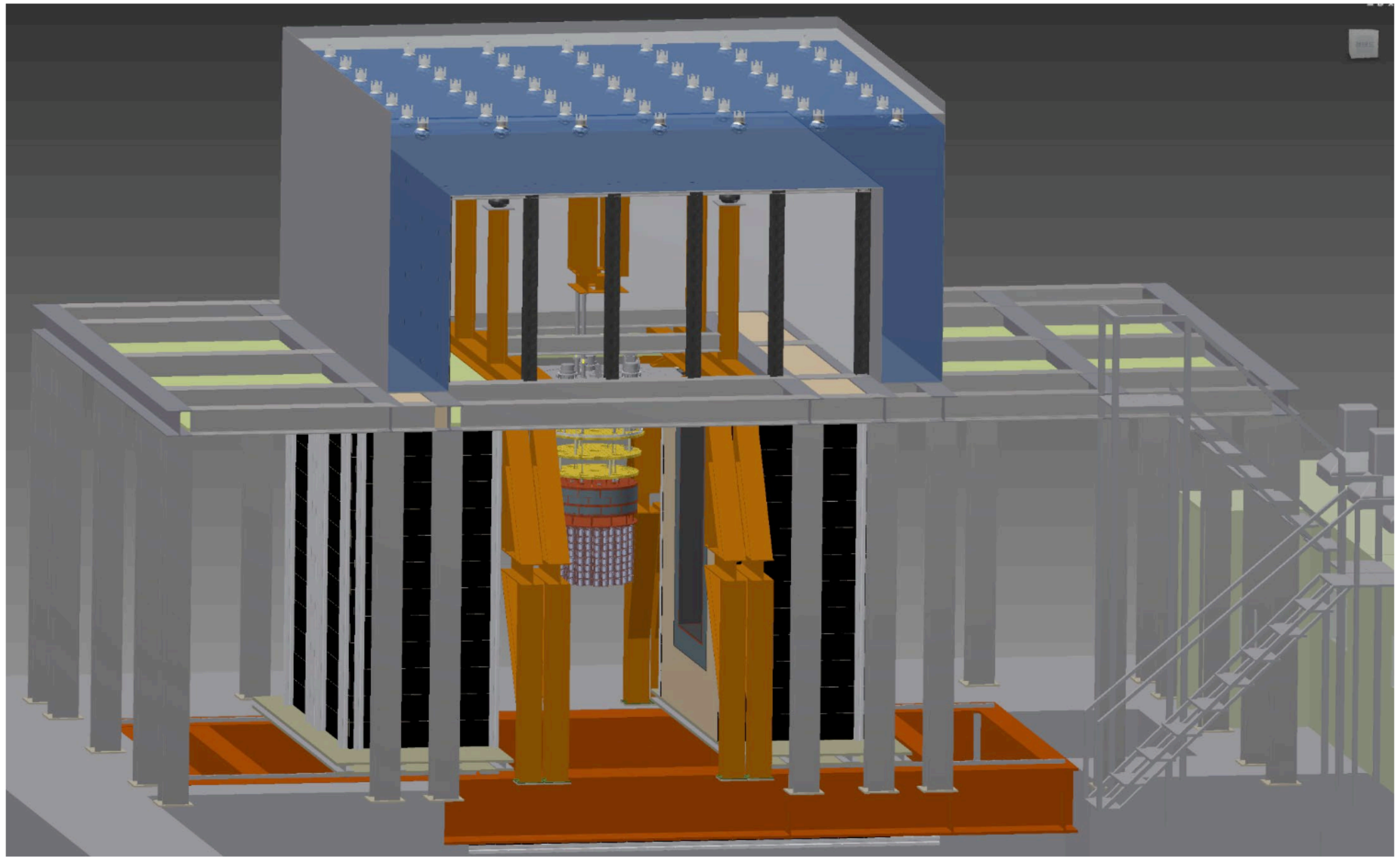
## Near components (G1)

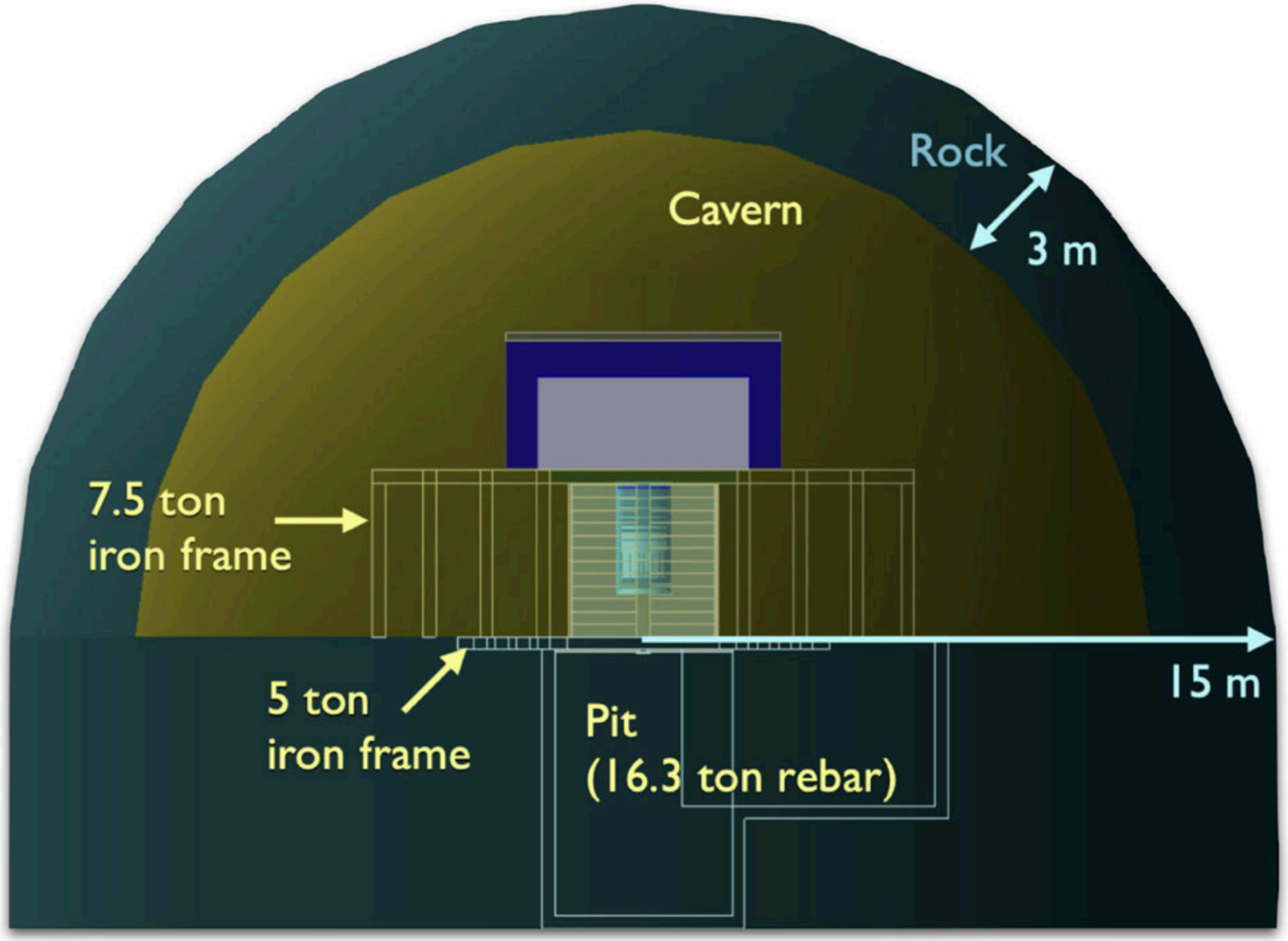



## Far components (G2)



# Structural materials



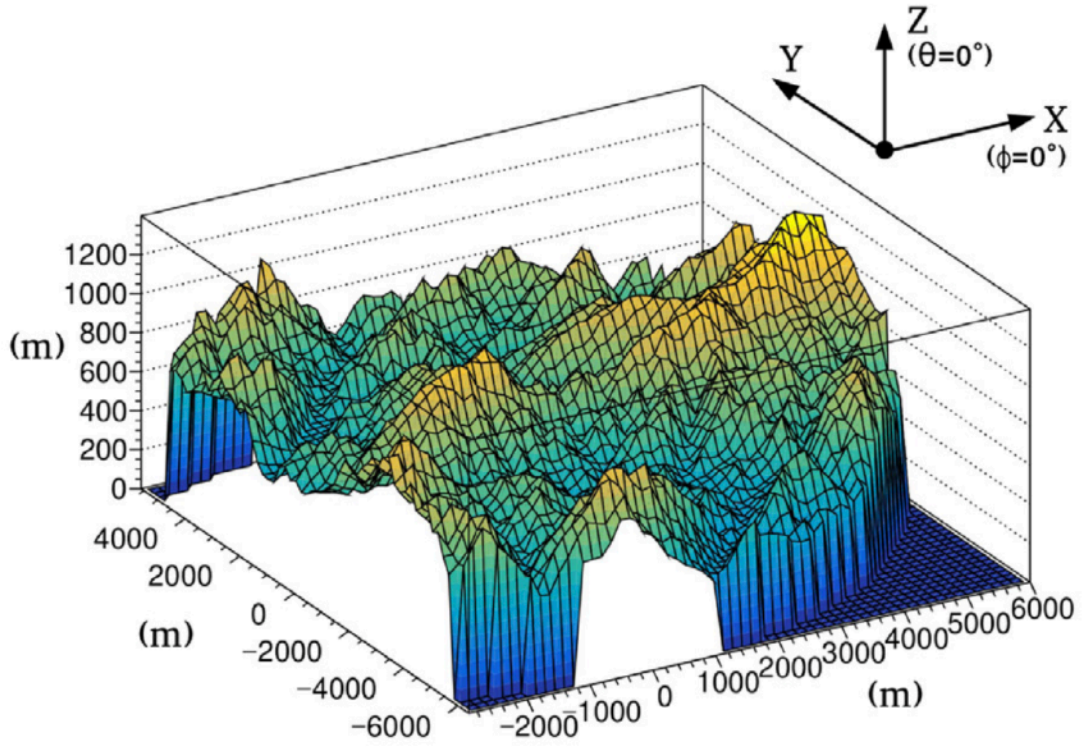


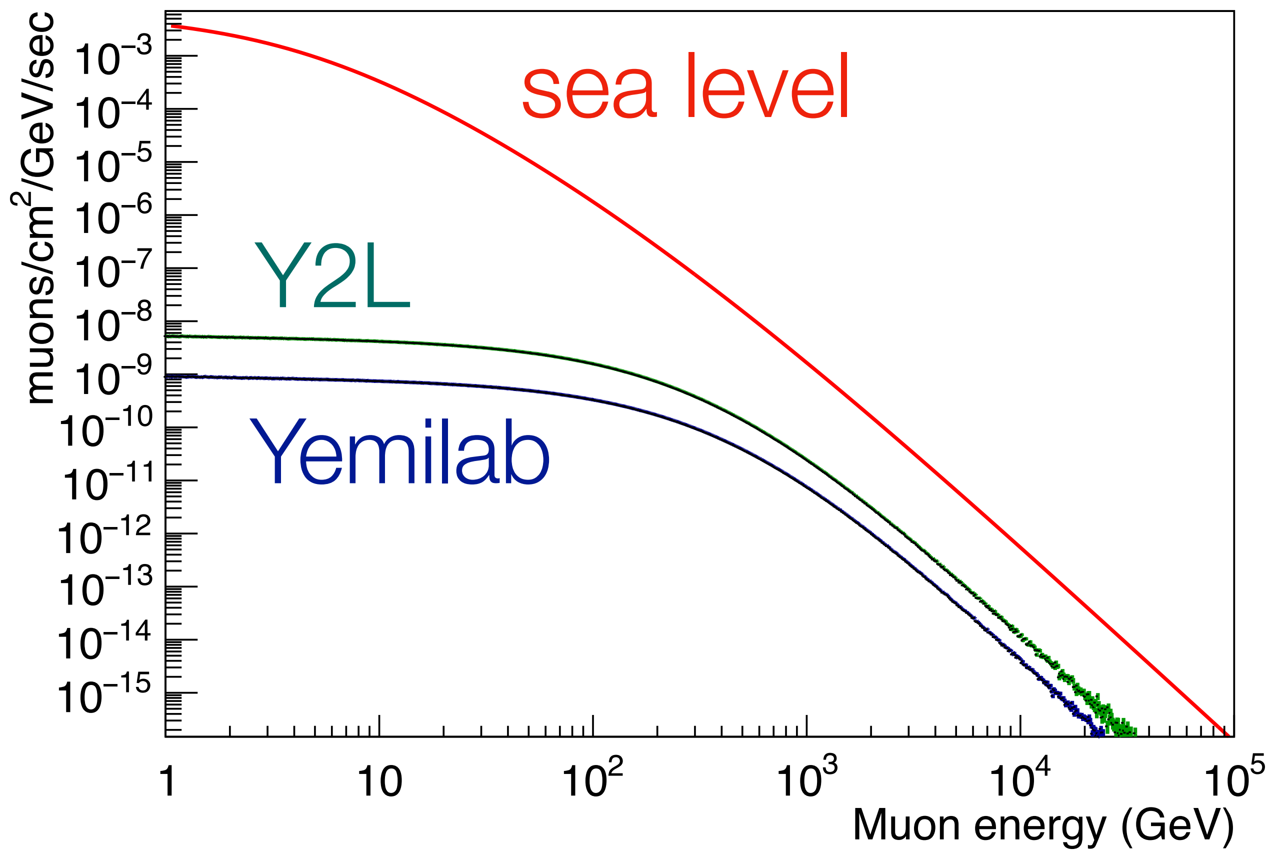
# Geant4-based background simulation

## Background sources considered

- Geant4 10.4.2
- Near componts (G1) and far components (G2)
- $2\nu\beta\beta$ using Decay0
- Internal radioisotopes
- Pileup events
- Neutrons and muons

# Neutron and muon-induced backgrounds

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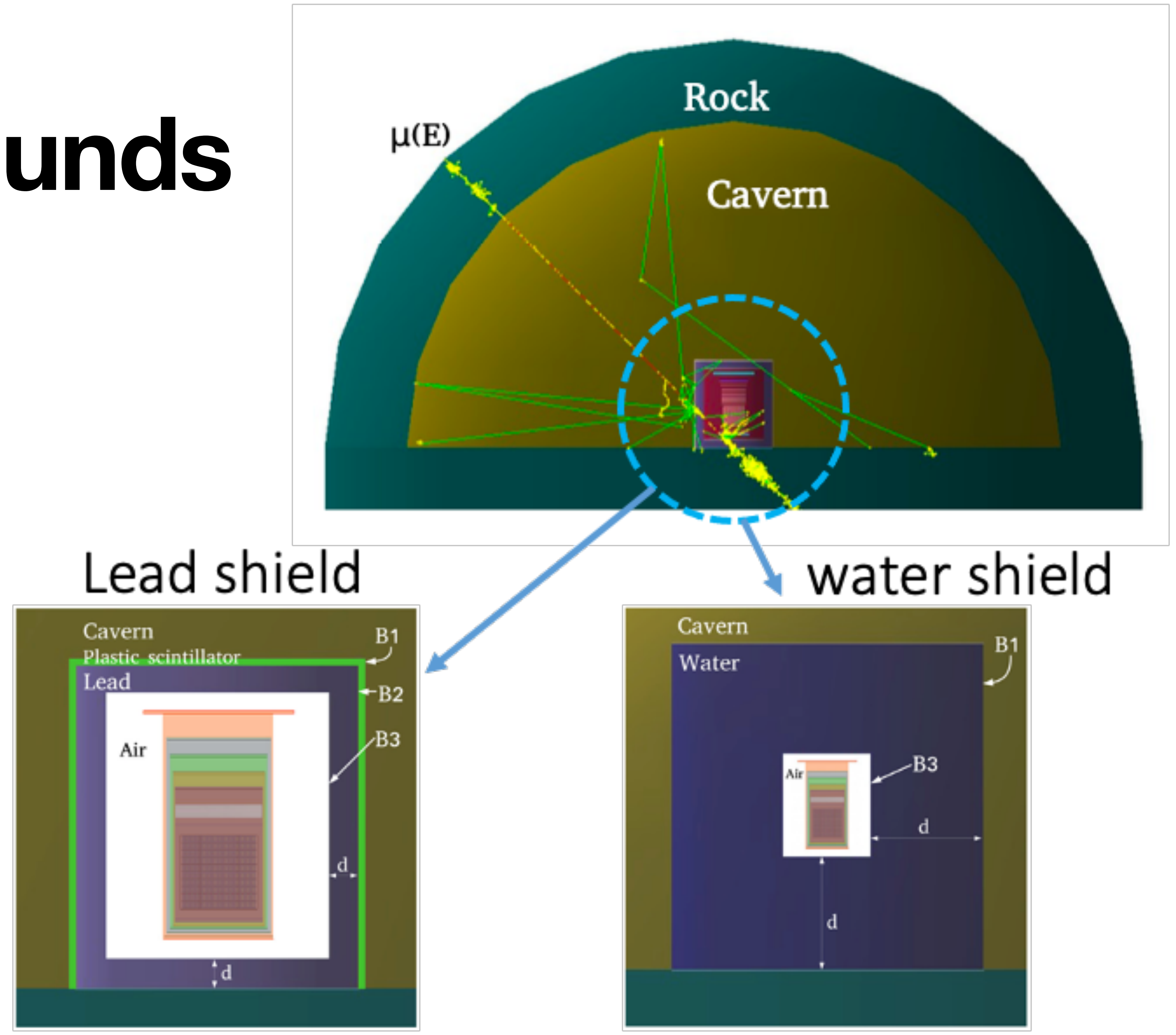
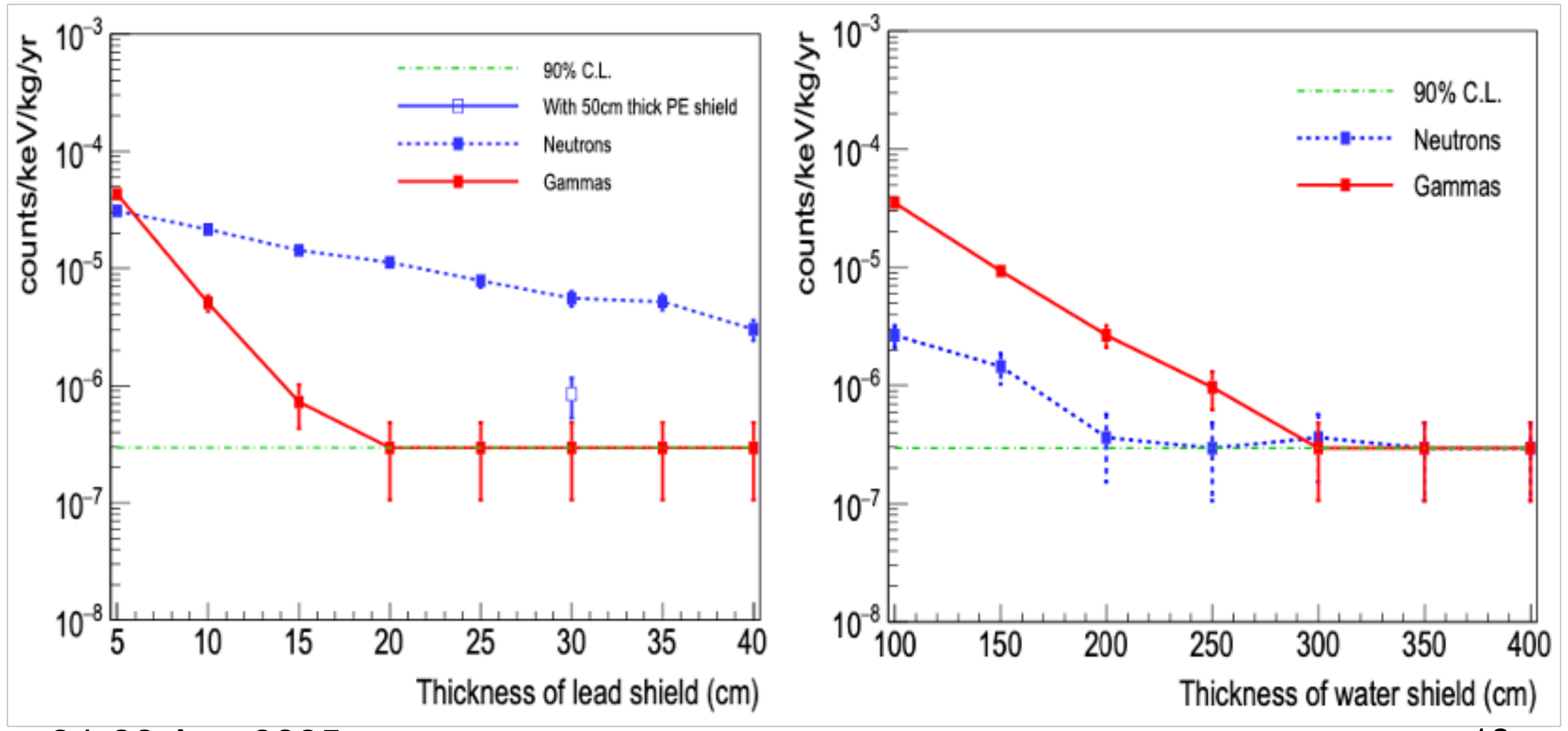



- We simulated cosmic muons and neutrons, taking the mountain contour into account
- We estimated the background event rate in the (2–8) MeV with various shielding thicknesses applied to both lead shielding and water tank shielding
- Thickness of shielding layers has been optimized



# Backgrounds of near (G1) and far (G2) components

G1

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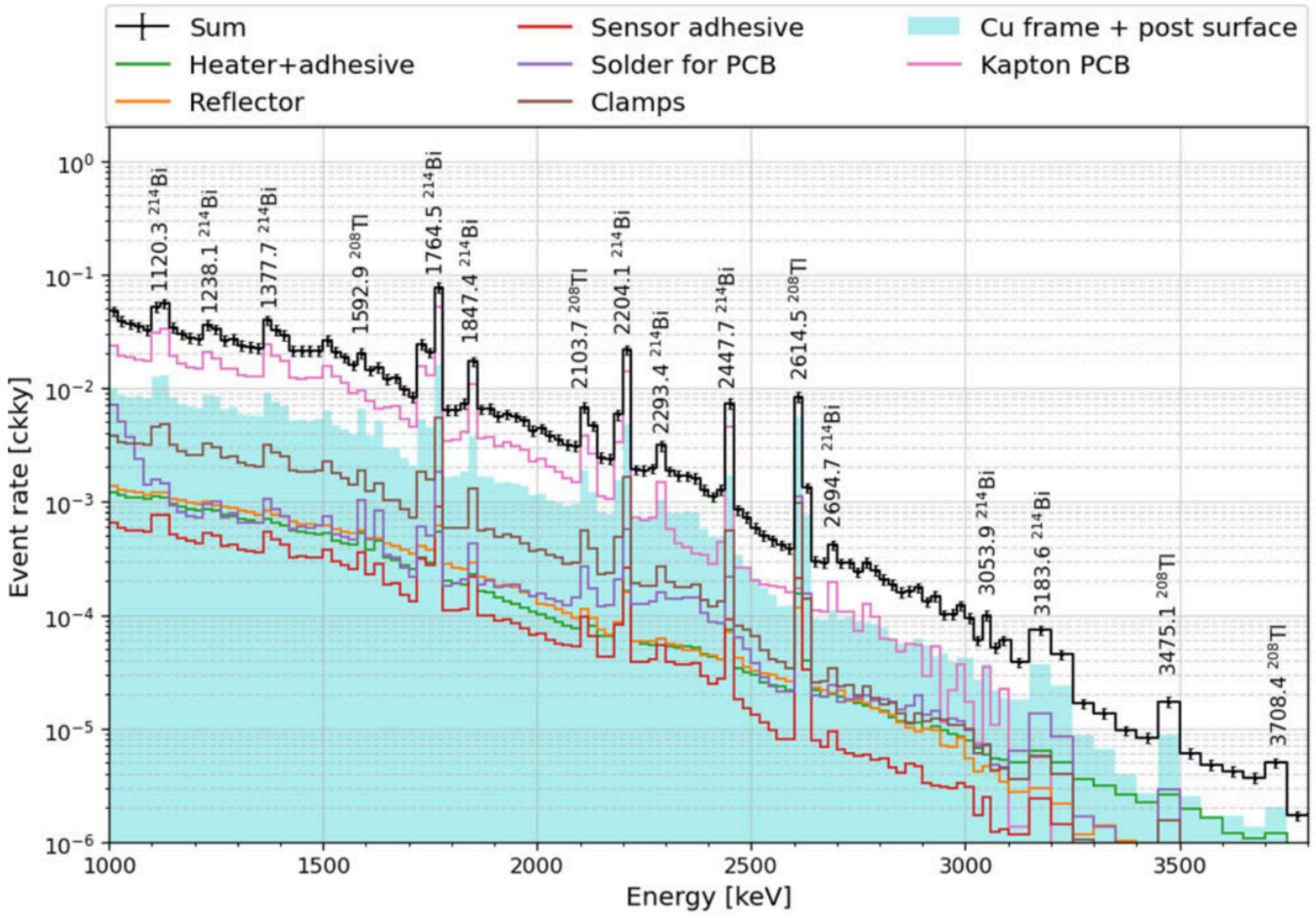
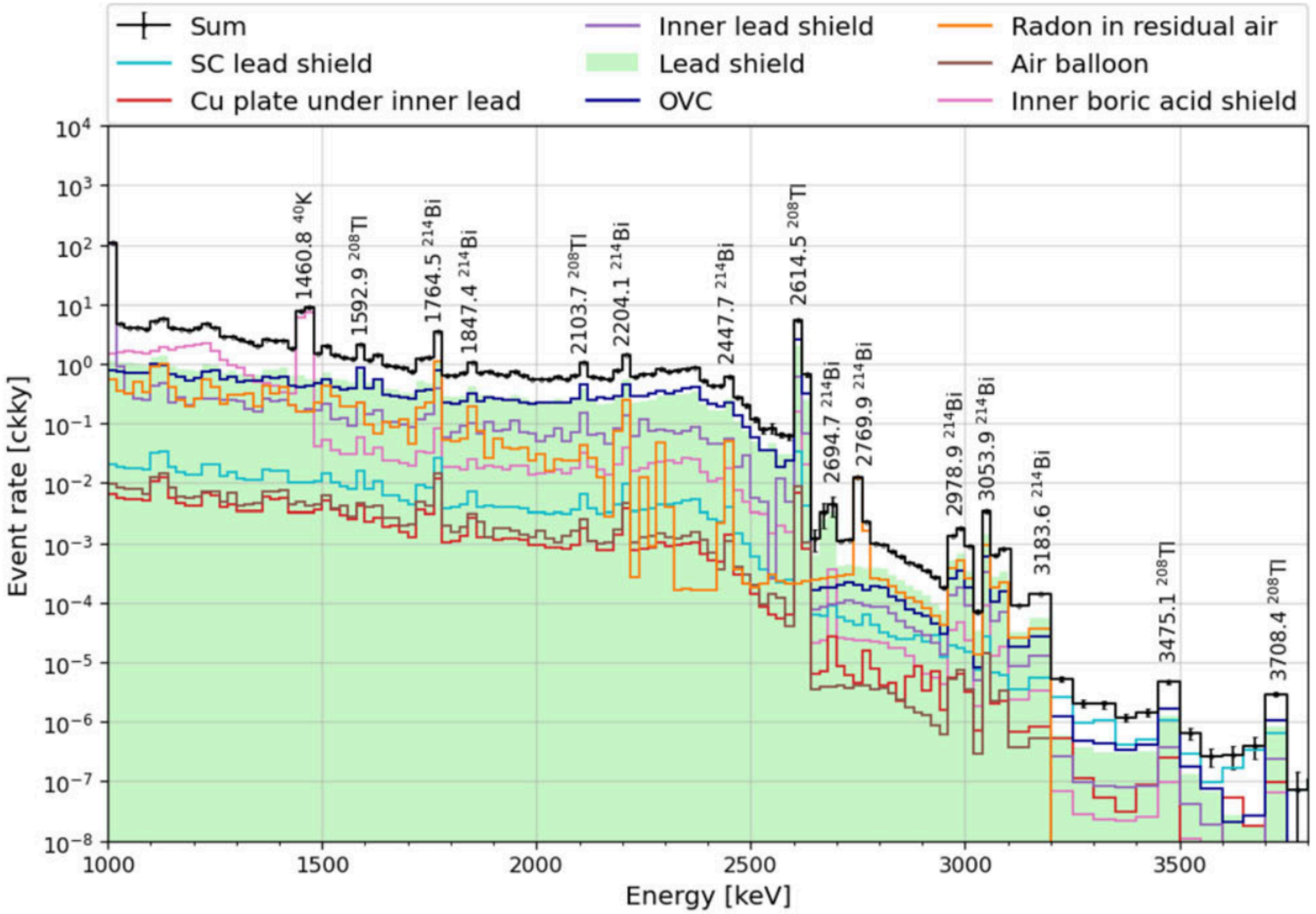
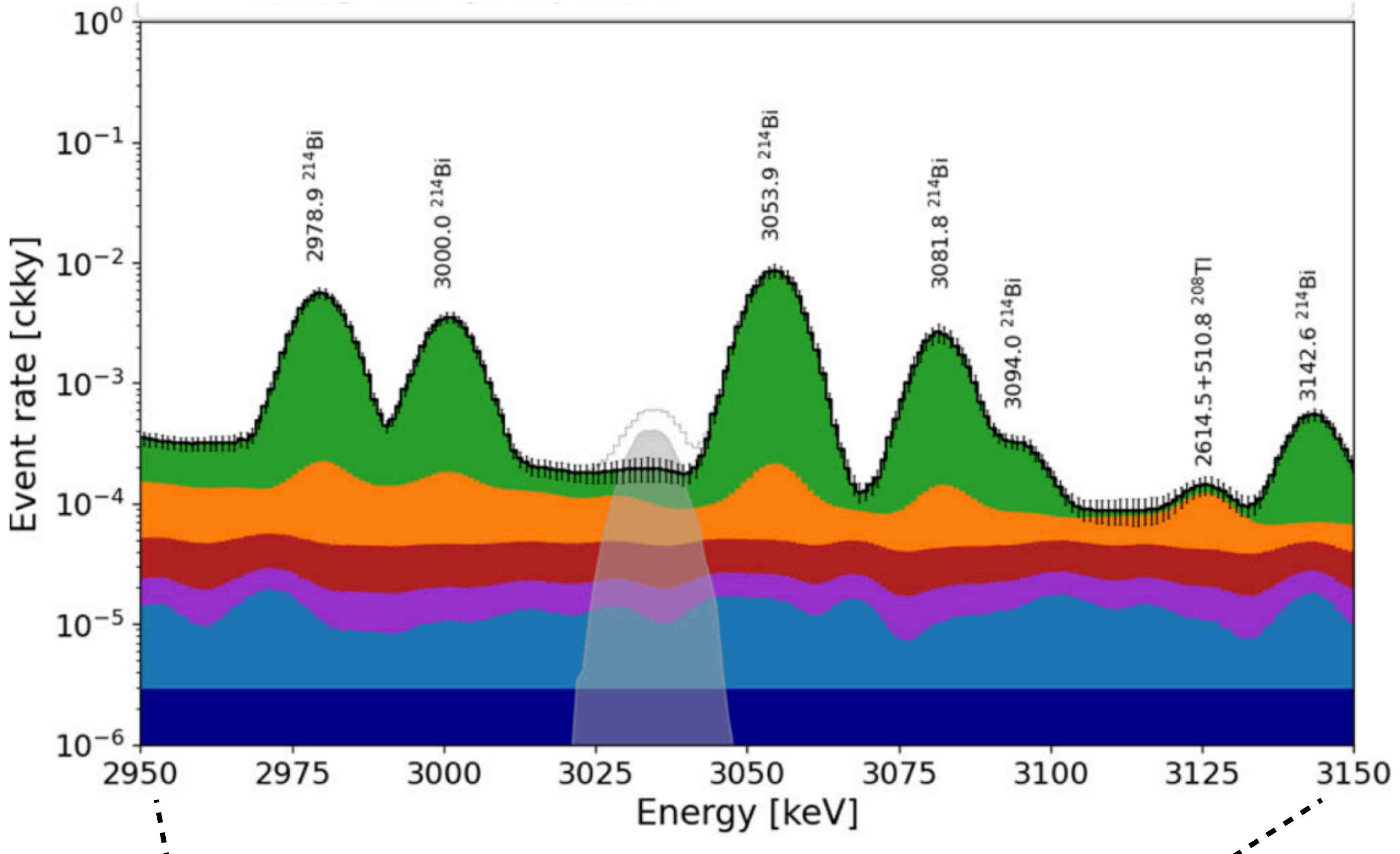
G2



# Projected Background

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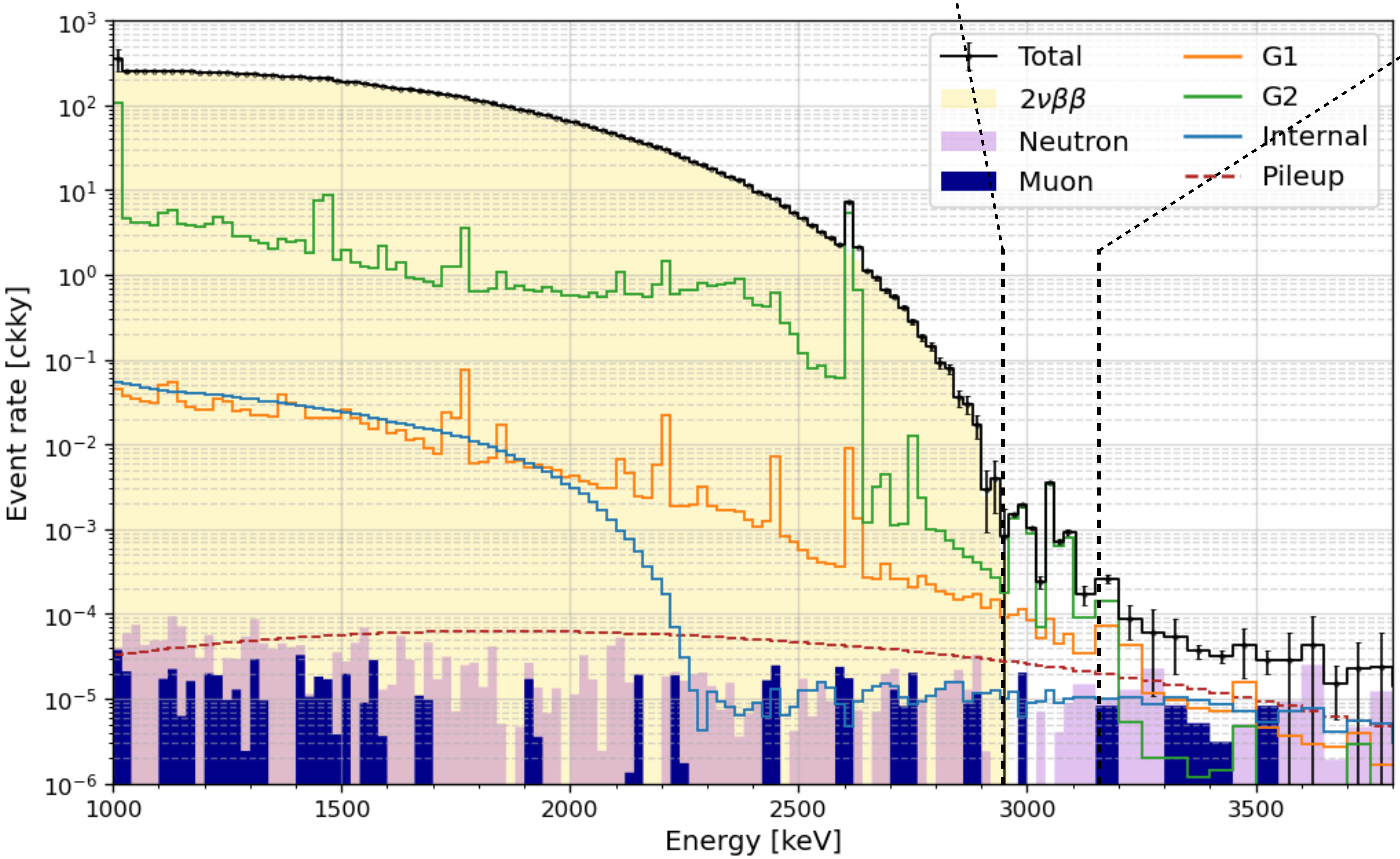
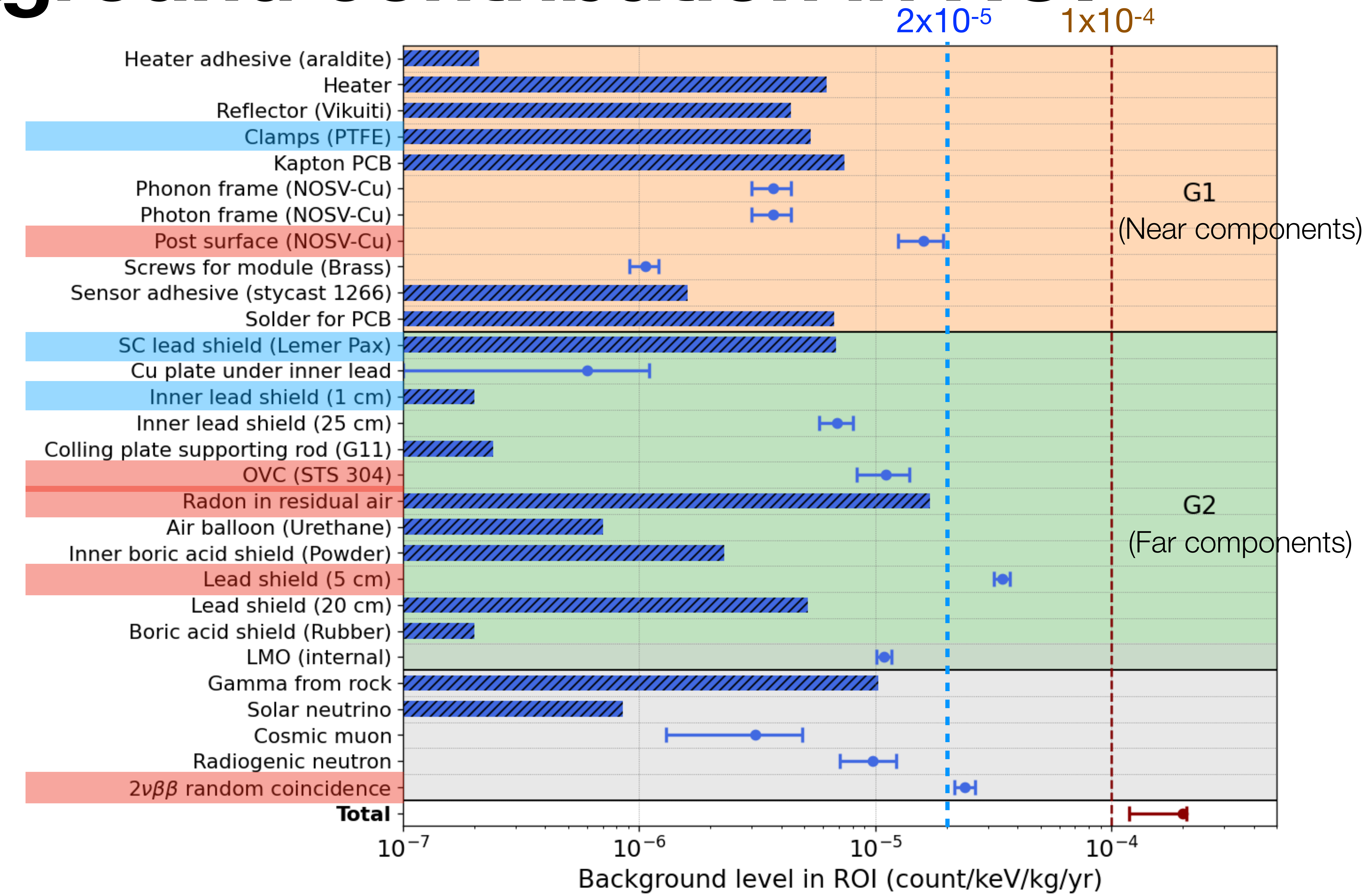


# Background contribution in ROI



# Lead shield design update

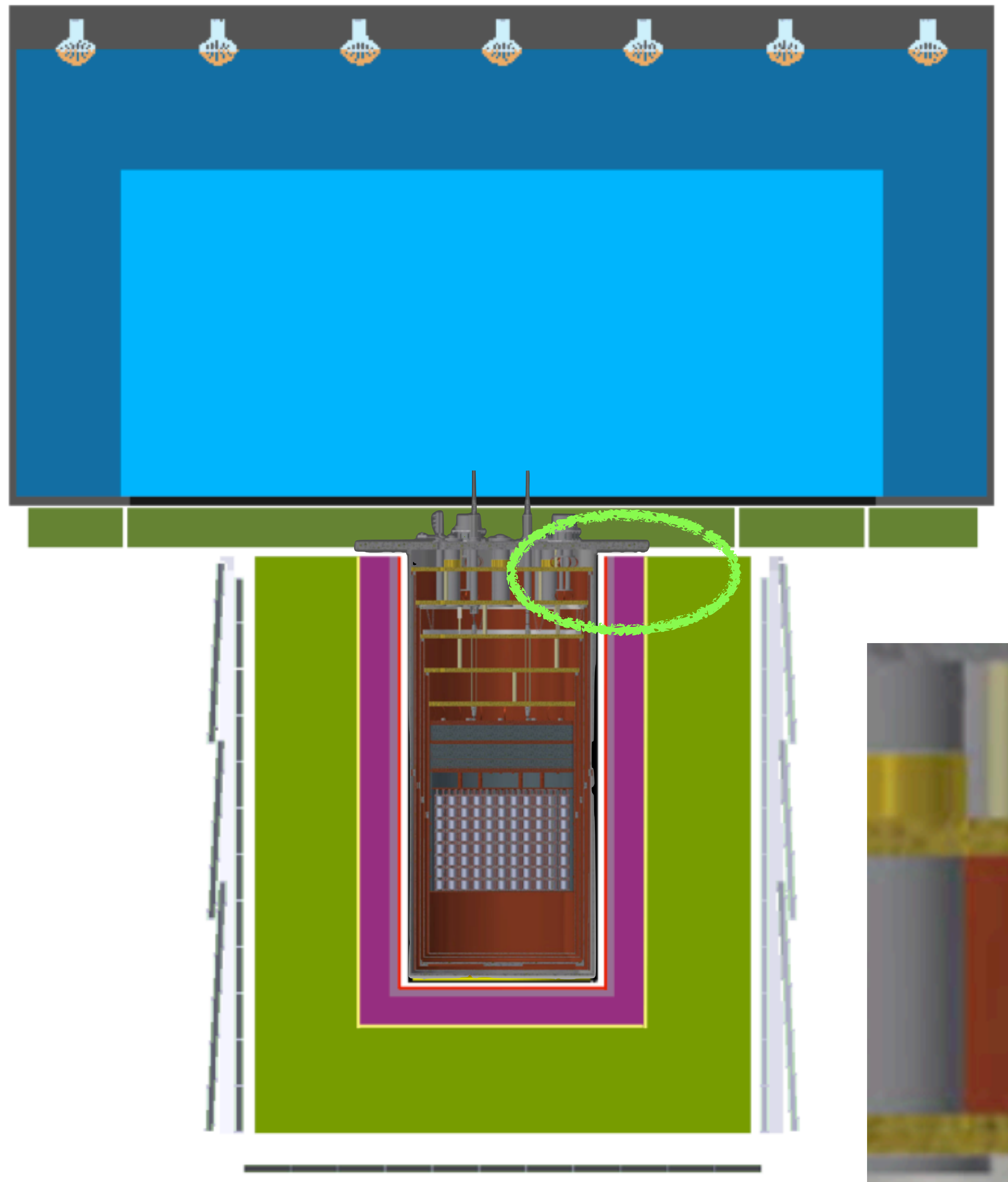
## To protect neutrons and gammas

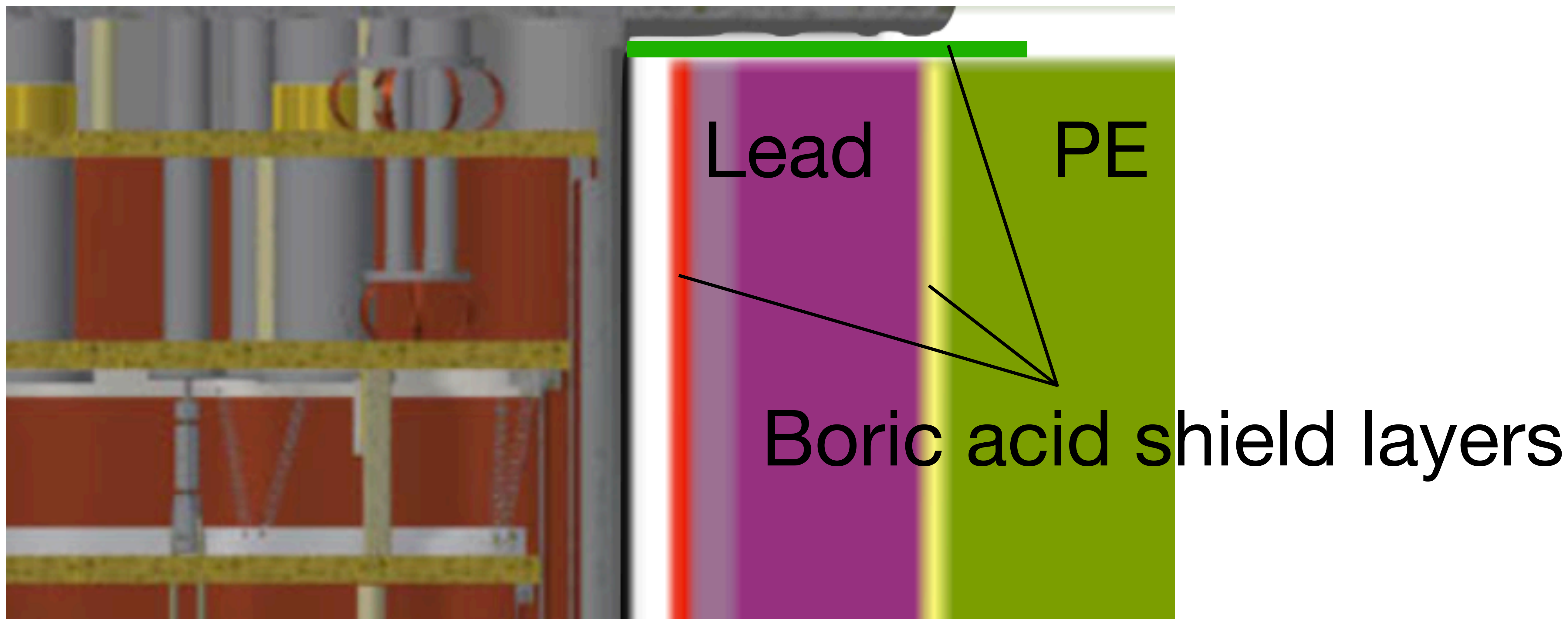
- 5 cm Boliden lead is replaced with 5 cm OFE copper for AMoRE-II stage 2

| | | Activities (mBq/kg) | | Background level (x10$^{-5}$ ckky) |
|---|---|---|---|---|
| Material | Supplier | Ra-226 (U-238) | Th-228 (Th-232) | 5 cm shield layer |
| Lead | Boliden | 0.48(12) | 0.45(11) | 3.44(28) |
| | | U-238 (pg/g) | Th-228 (pg/g) | |
| OFE Copper | Aurubis | 0.010(1) | 0.0040(6) | 0.08(1) |


# Filling gap with additional neutron shielding

## Supplementary shielding





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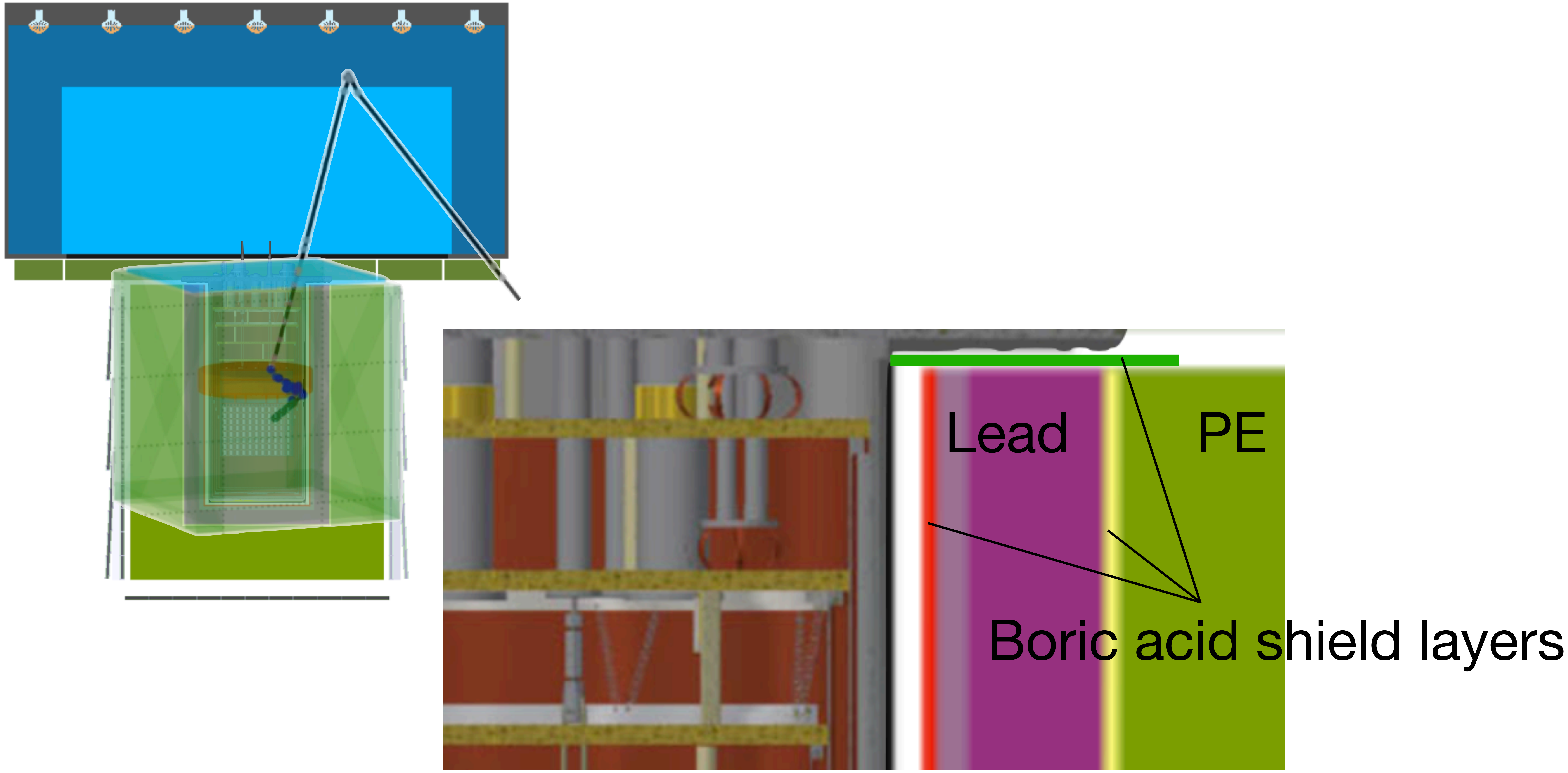

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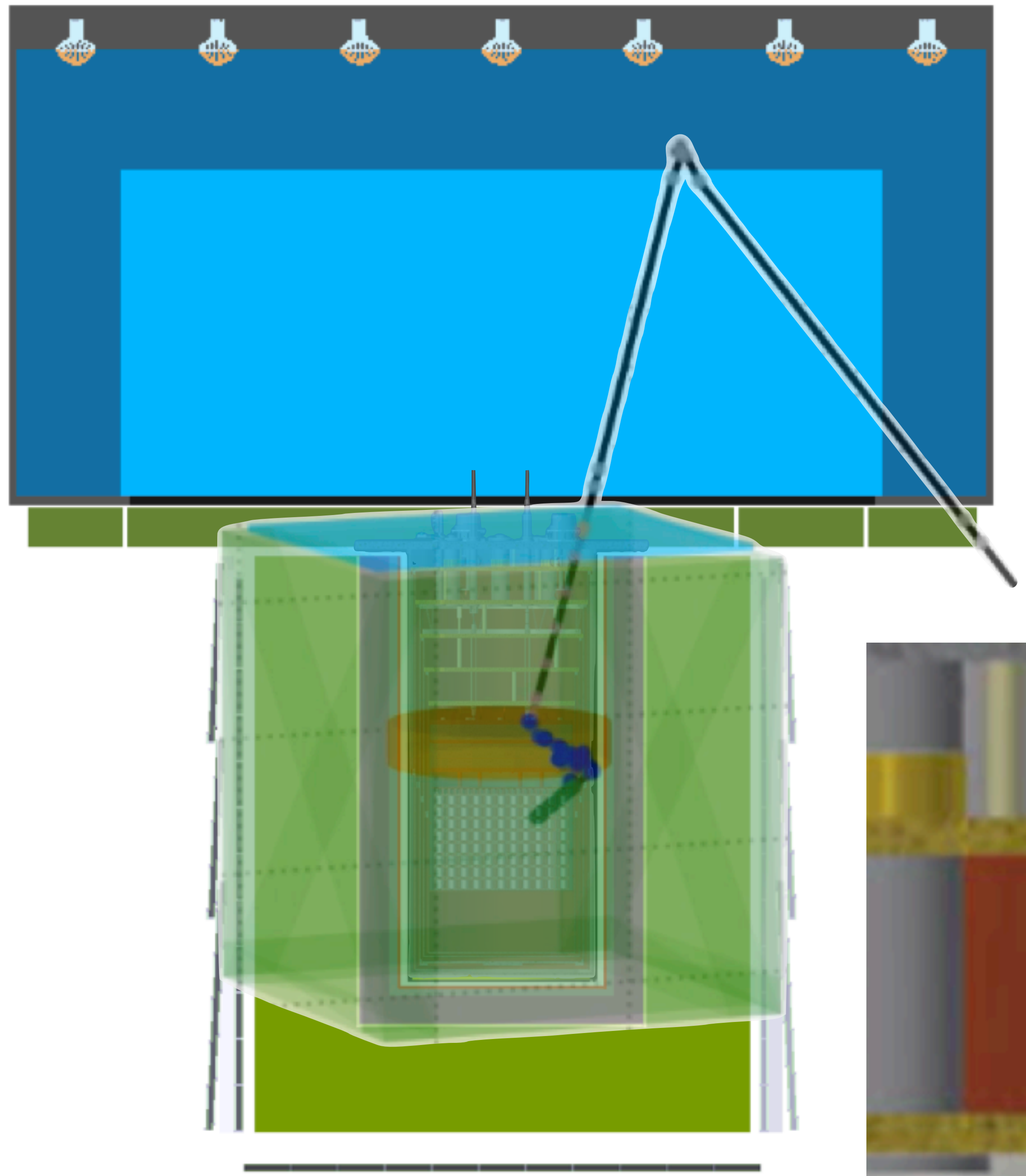
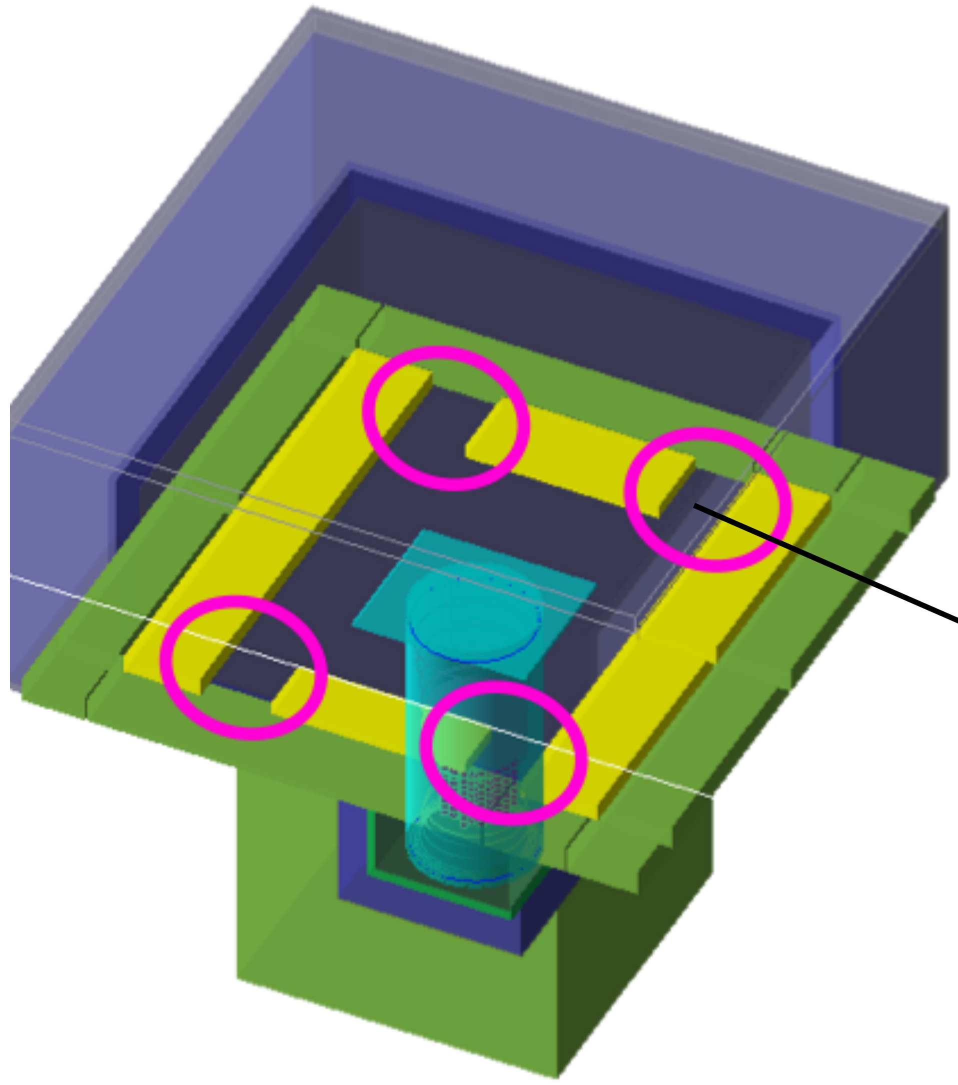
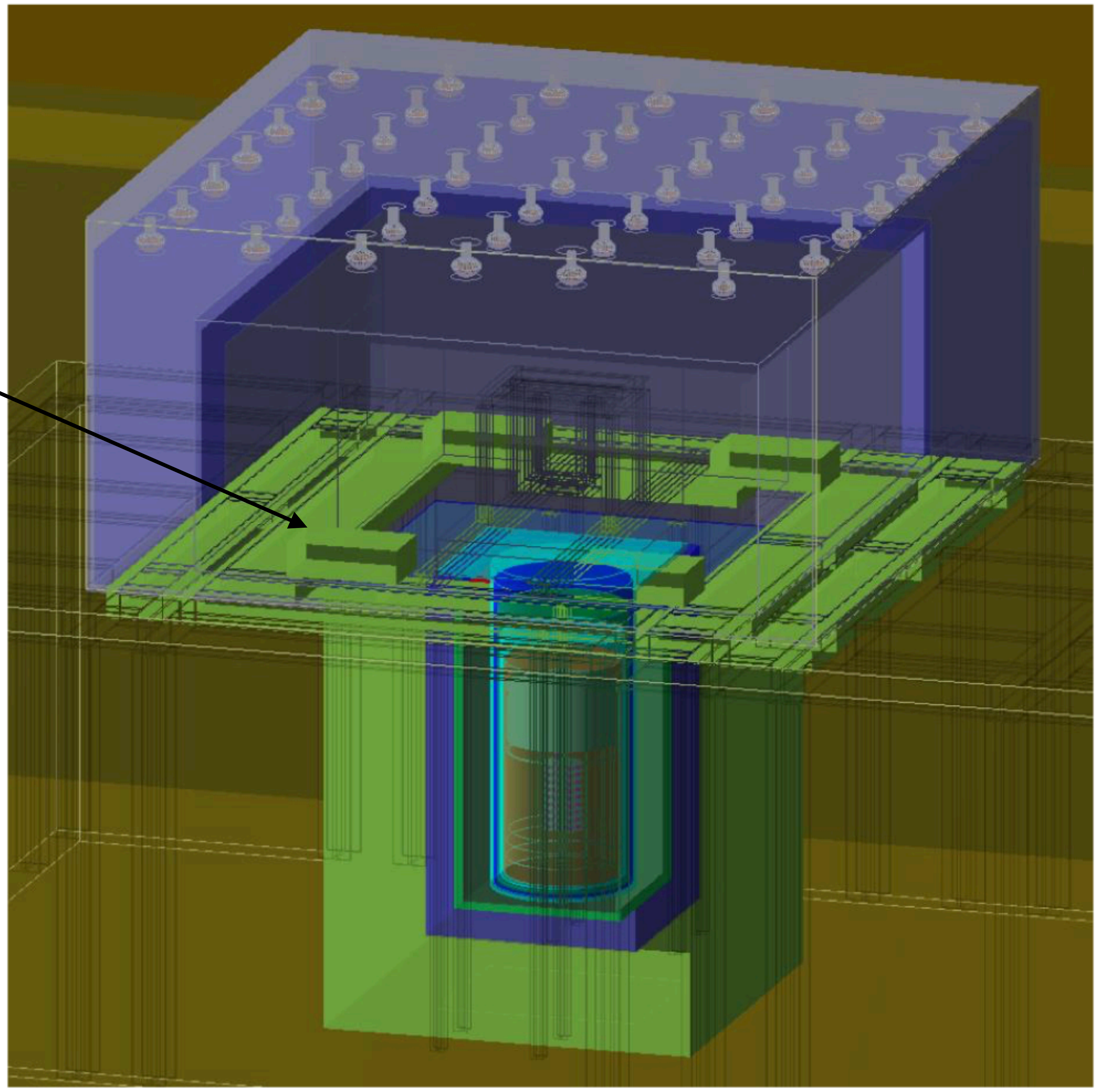
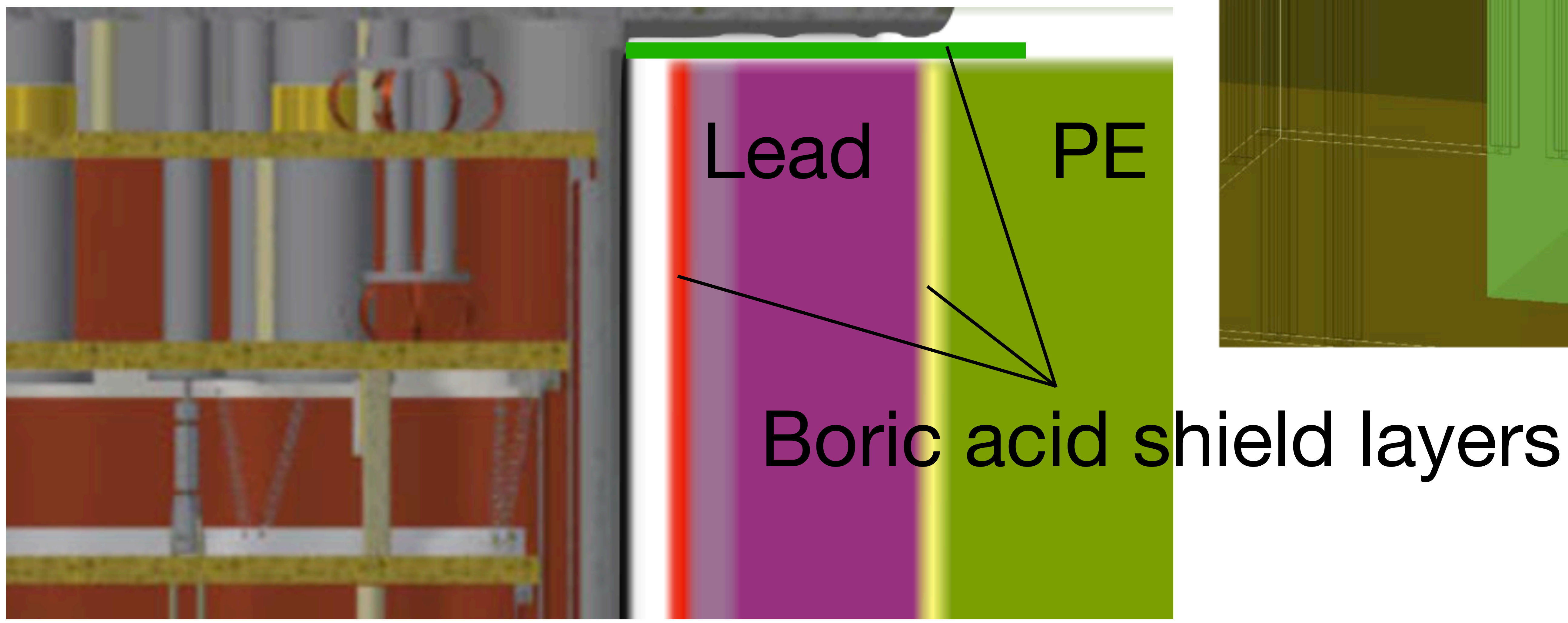




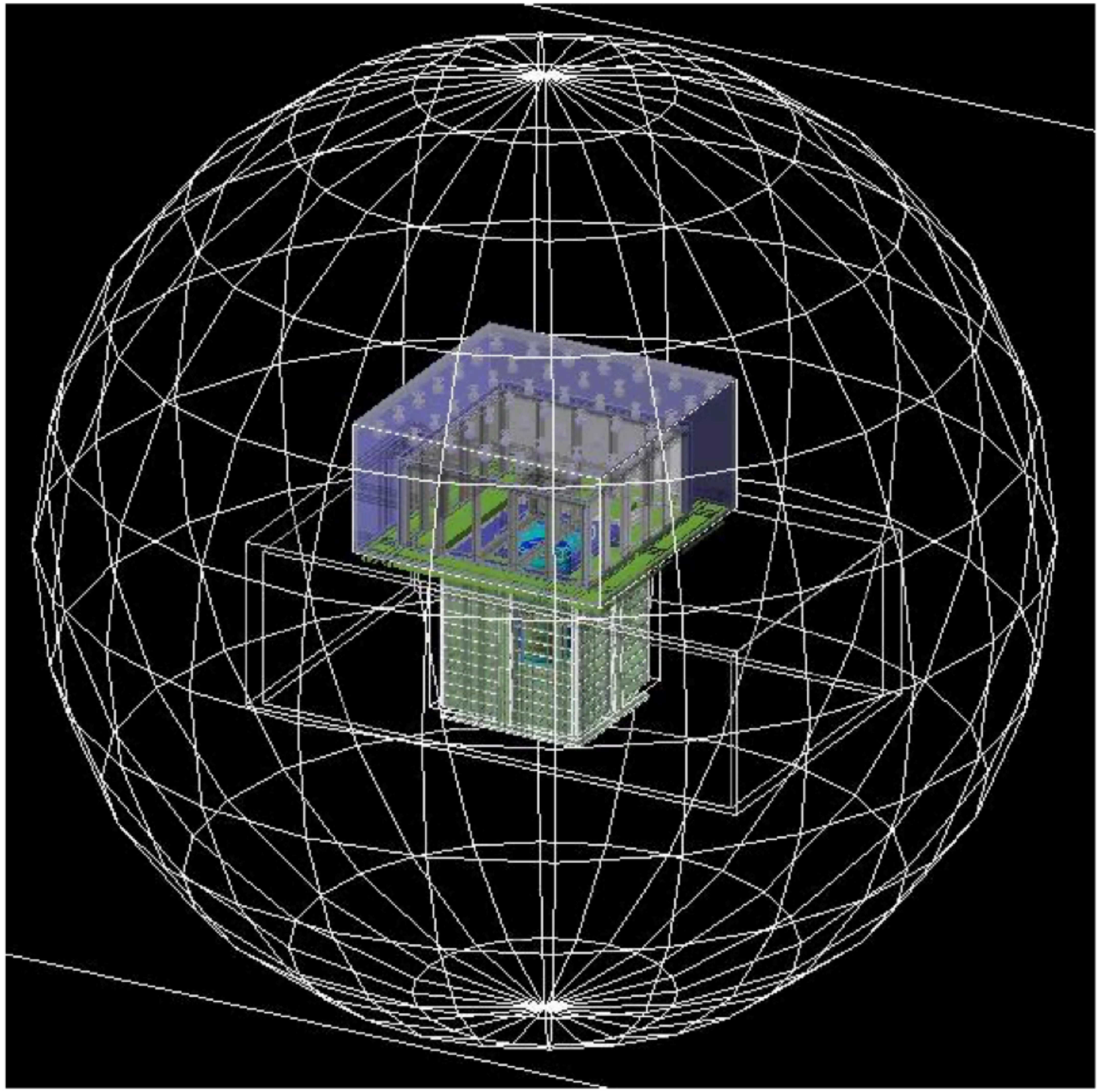




# Neutrons and rock gamma simulations

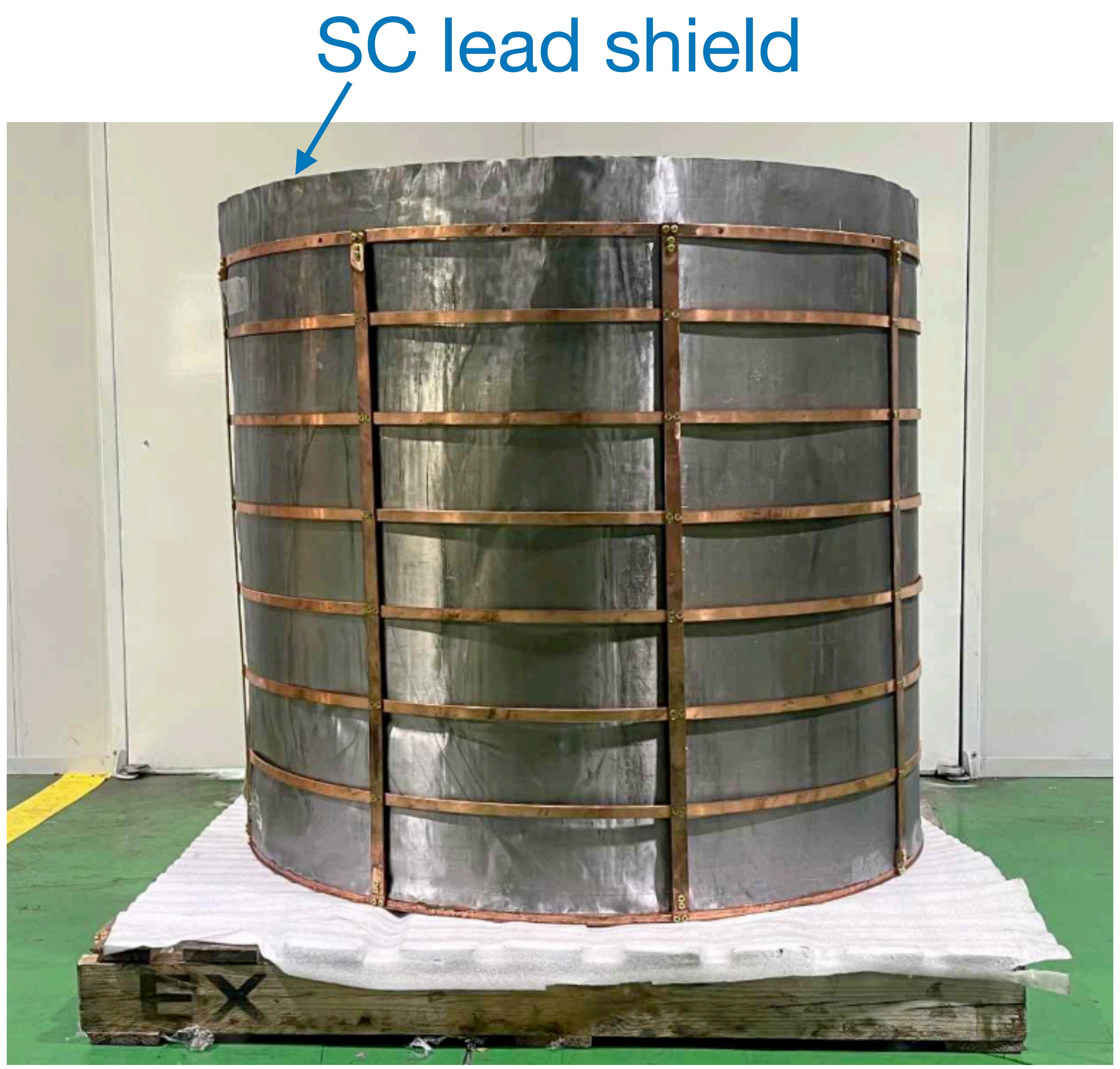
## With updated shield design

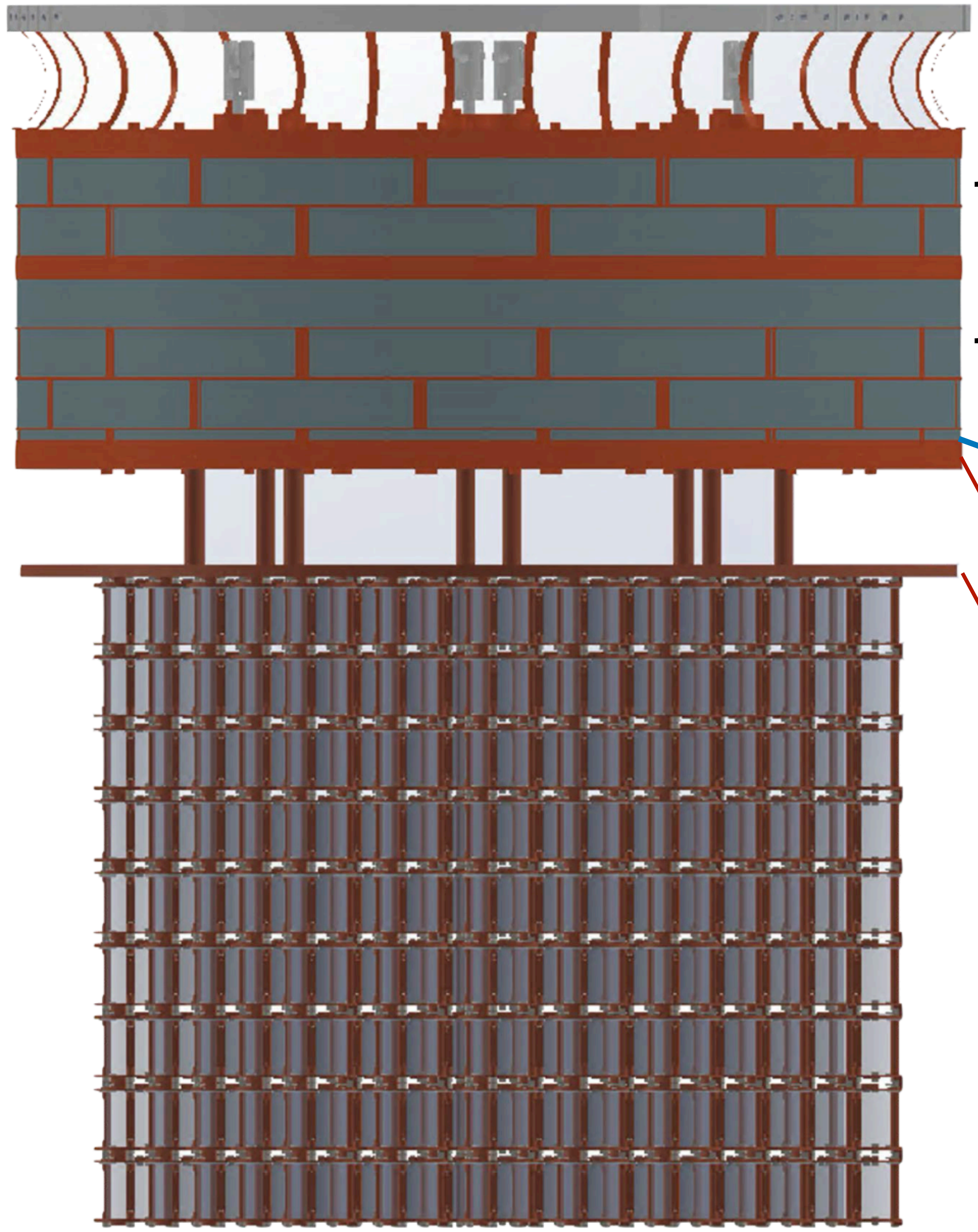
| | Background level (x10$^{-5}$ ckky) | |
|---|---|---|
| | Radiogenic neutrons | Rock gammas |
| Previous shield design | 0.97(26) | < 1.03 |
| Updated shield design | 0.51(8) | < 1 |



# Superconducting (SC) lead shield and inner lead shield

- Ultra-low Lemer Pax lead is used for them, with new measurements carried out at LNGS




| Background level ($\times10^{-5}$ ckky) | |
|---|---|
| SC lead shield | Inner lead |
| < 0.1 | < 0.13 |

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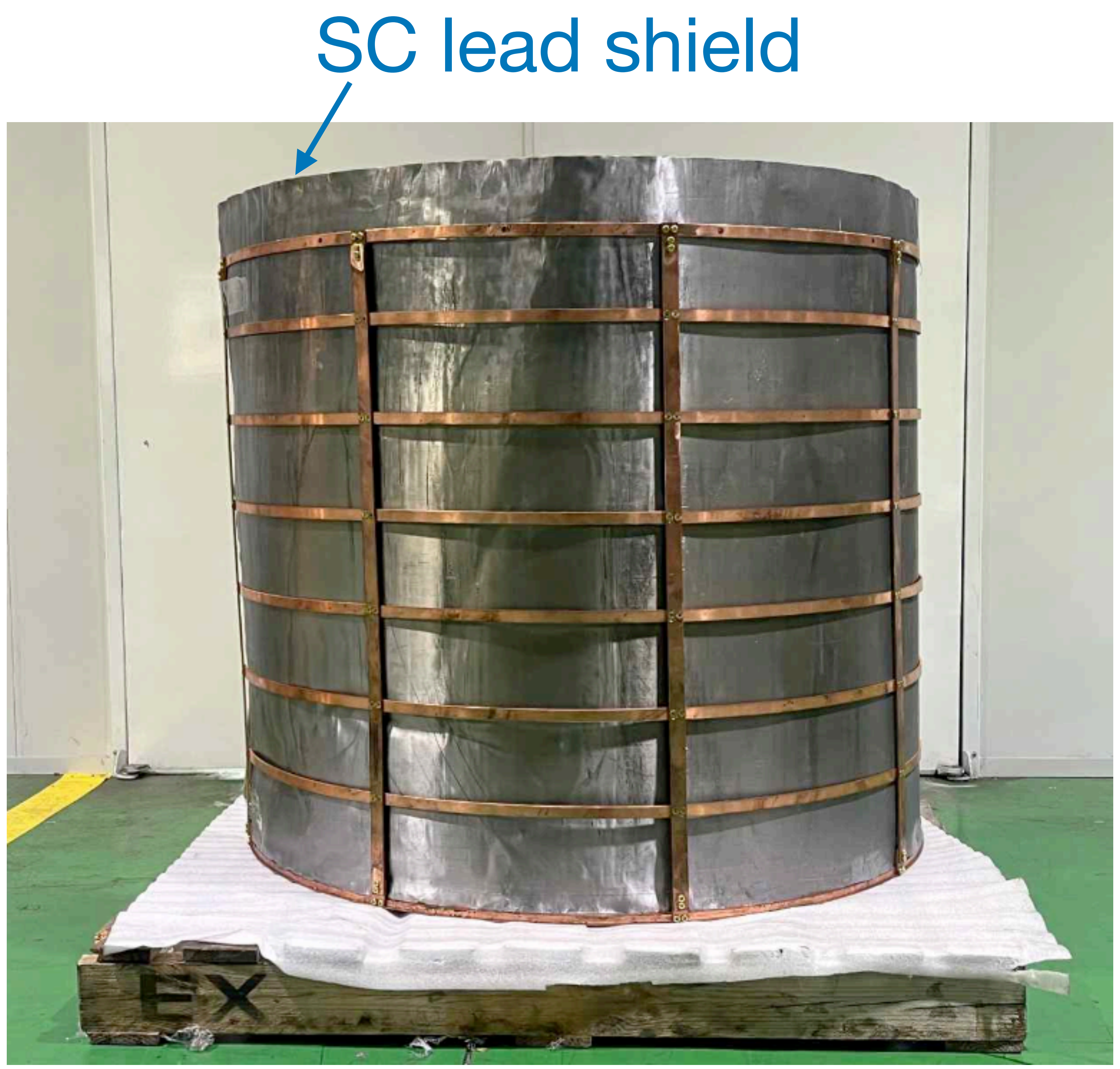
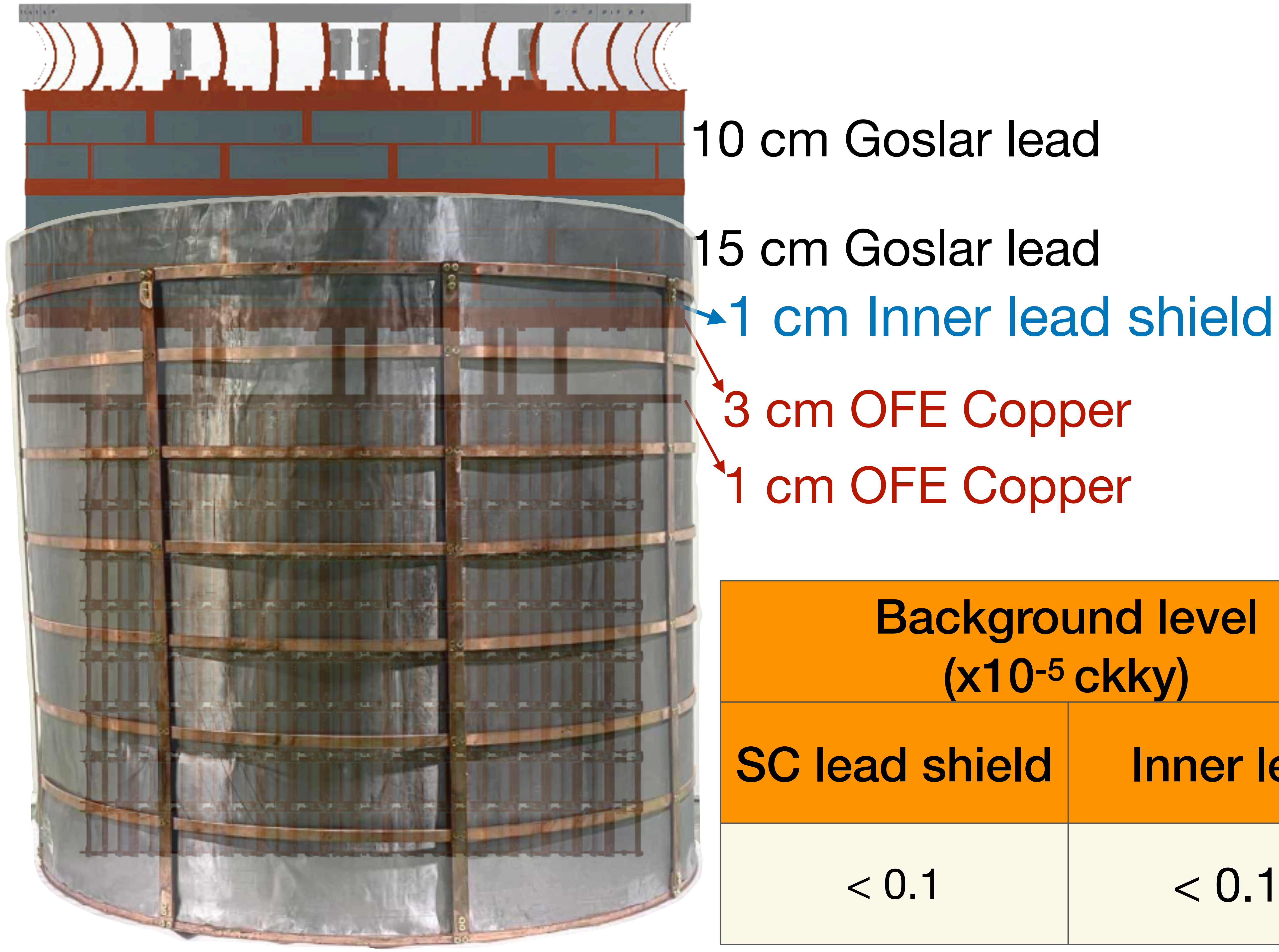



| Background level ($\times 10^{-5}$ ckky) | |
|---|---|
| SC lead shield | Inner lead |
| < 0.1 | < 0.13 |

# Outer vacuum chamber (OVC)

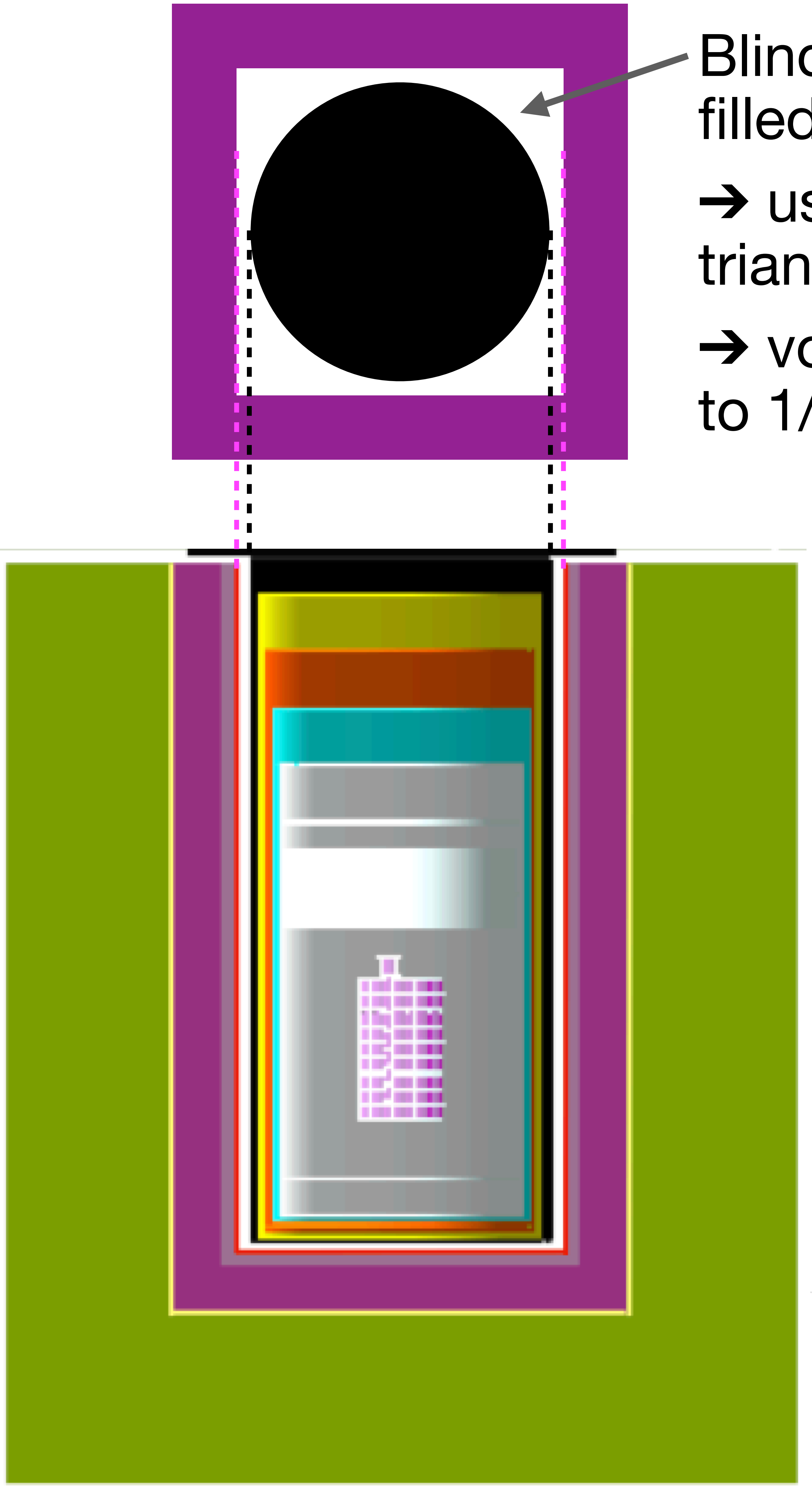
- Replace with a purer STS 316 type for AMoRE-II stage 2

| | | | Activities (mBq/kg) | | Background level ($x10^{-5}$ ckky) |
|---|---|---|---|---|---|
| | Material | | Ra-226(U-238) | Th-228(Th-232) | |
| OVC | STS 304 type | HPGe | 1.00(16) | 2.36(22) | 1.10(28) |
| | STS 316 type | XENON1T | < 0.55 | < 0.5 | < 0.6 |

# Rn-less air

- Background requirement for AMoRE-II:
  - 0.29+/-0.06 Bq/kg ➔ $10^{-5}$ ckky
- Rn-less air supply
  - < 150 Bq/m$^3$ for the summer season
  - < 50 Bq/m$^3$ for other seasons
- Can reach < 100 mBq/m$^3$
  - by reducing the volume to 1/5 and
  - by applying RRS in AMoRE Hall

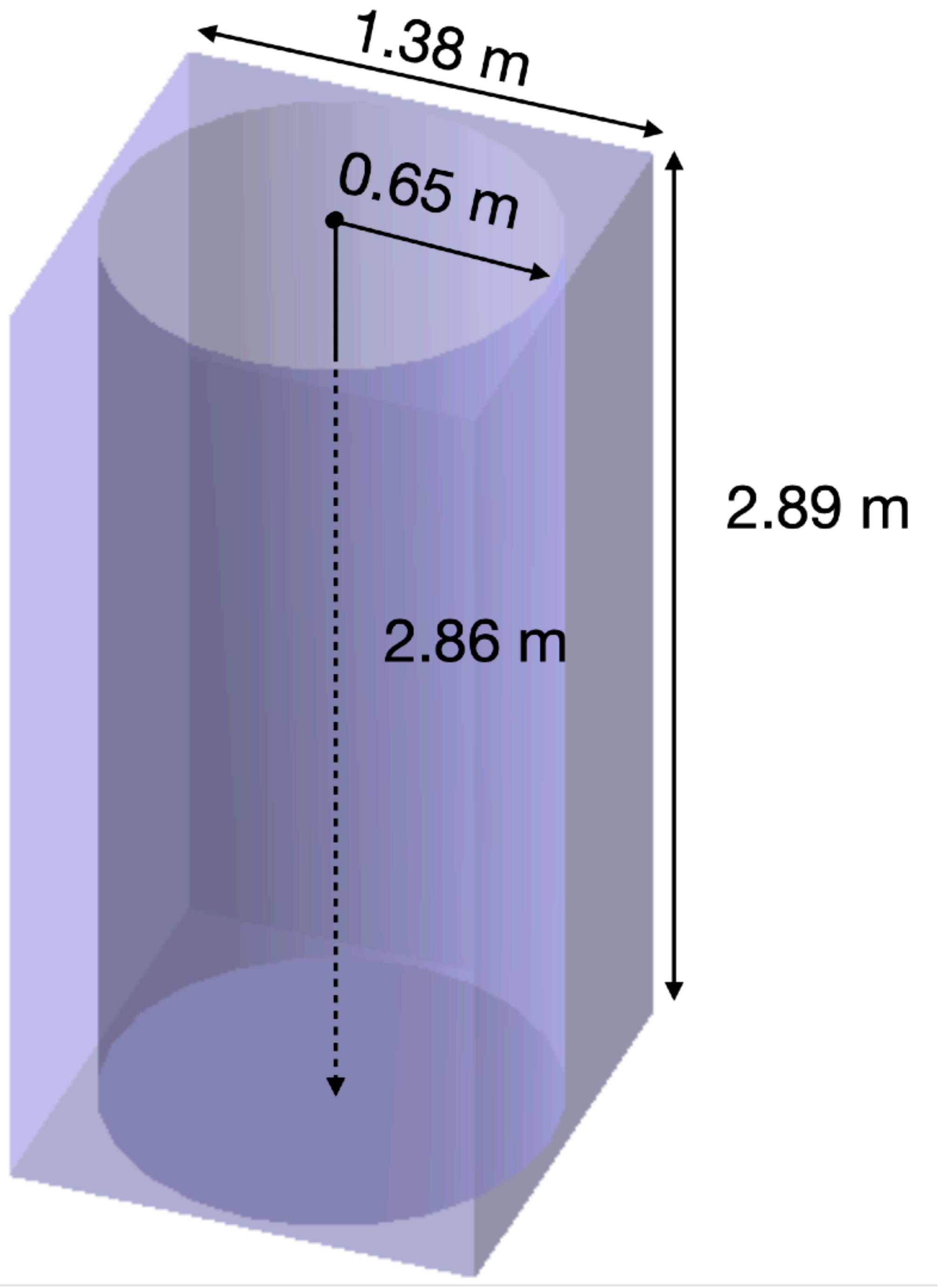
➔ background level reaches $3 \times 10^{-6}$ ckky



Blind spot in the shielding: filled with Rn-less air

➔ using an air balloon or a triangular prism, instead

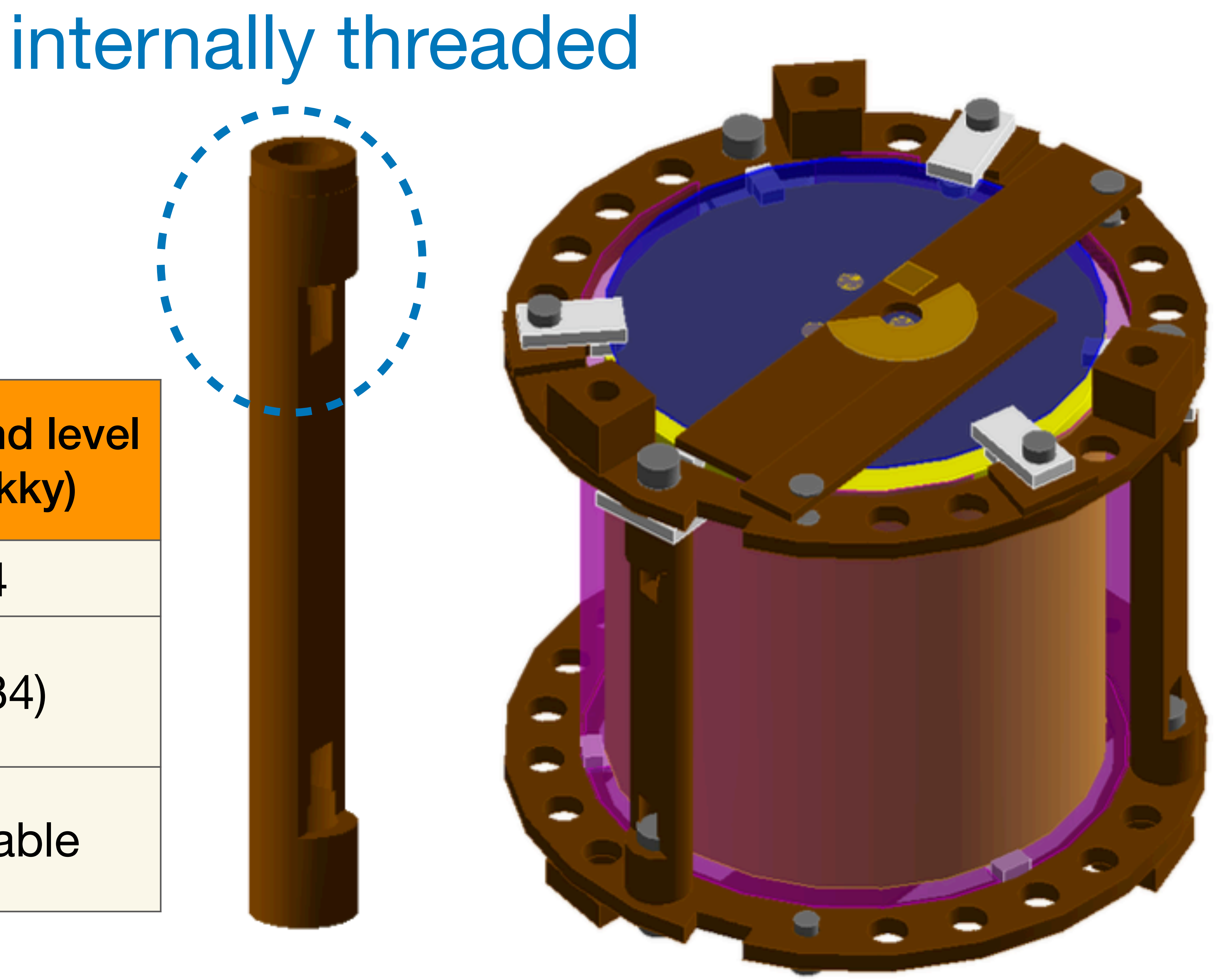
➔ volume will be reduced to 1/5



# Copper post

## Surface contamination

| | | Activities (pg/post) | | Background level ($\times 10^{-5}$ ckky) |
|---|---|---|---|---|
| Company | NOSV Copper | U-238 | Th-232 | |
| Taesung Tech | bulk (~15g) | 4.4(6) | 3.9(2) | 0.24 |
| | $HNO_3$ etching | 0.38(4) | 0.97(2) | 1.59(34) |
| | 9—12μm (0.055g) | 2.0(3) | 4.2(7) | acceptable |

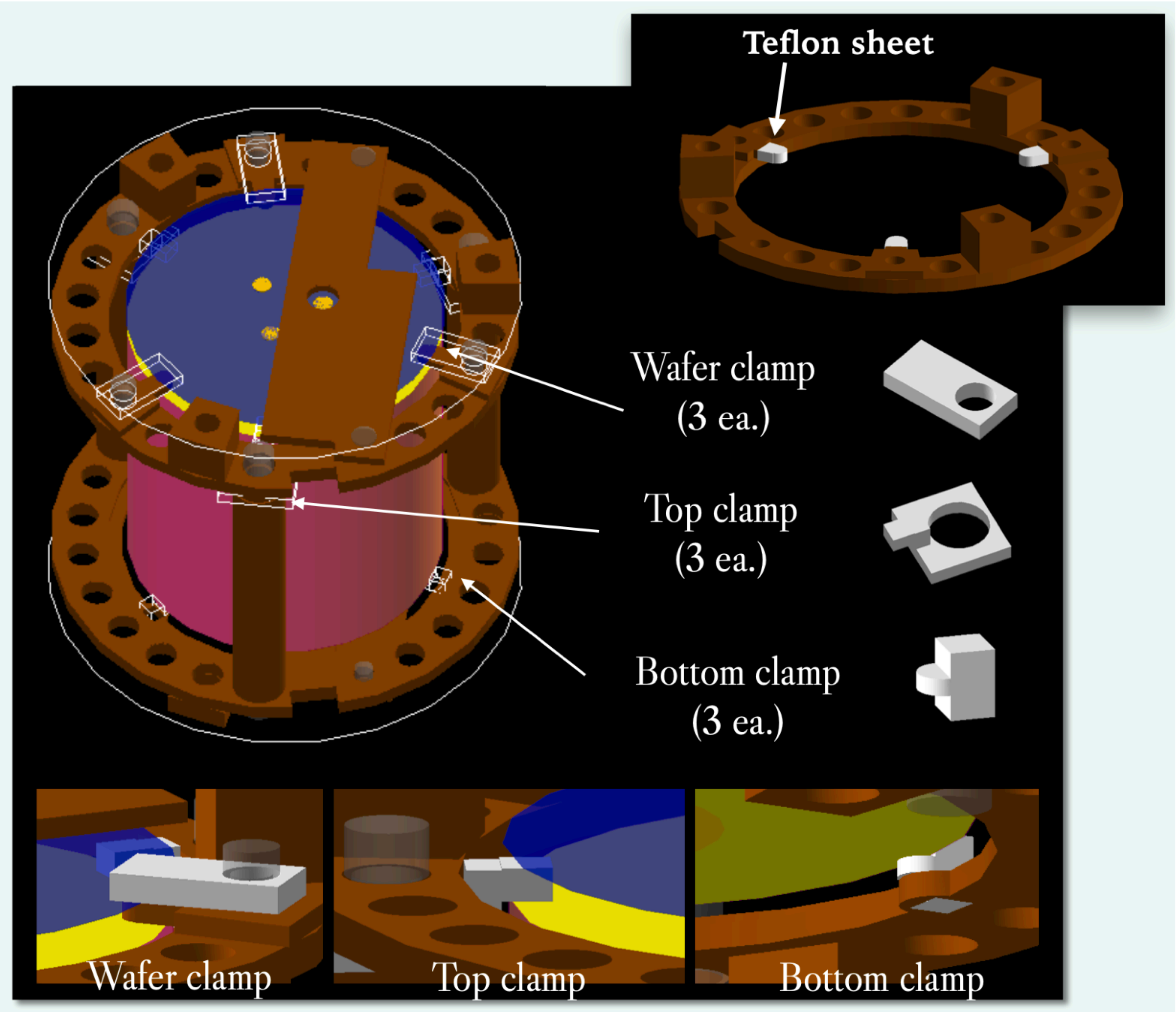



- Copper post-surface contamination occurred during the thread-making process, depending on the manufacturer
- Based on the R&D for the surface treatment, the material becomes acceptable after removing 12 μm from the surface through several purification steps, performed following manufacturing by the selected company

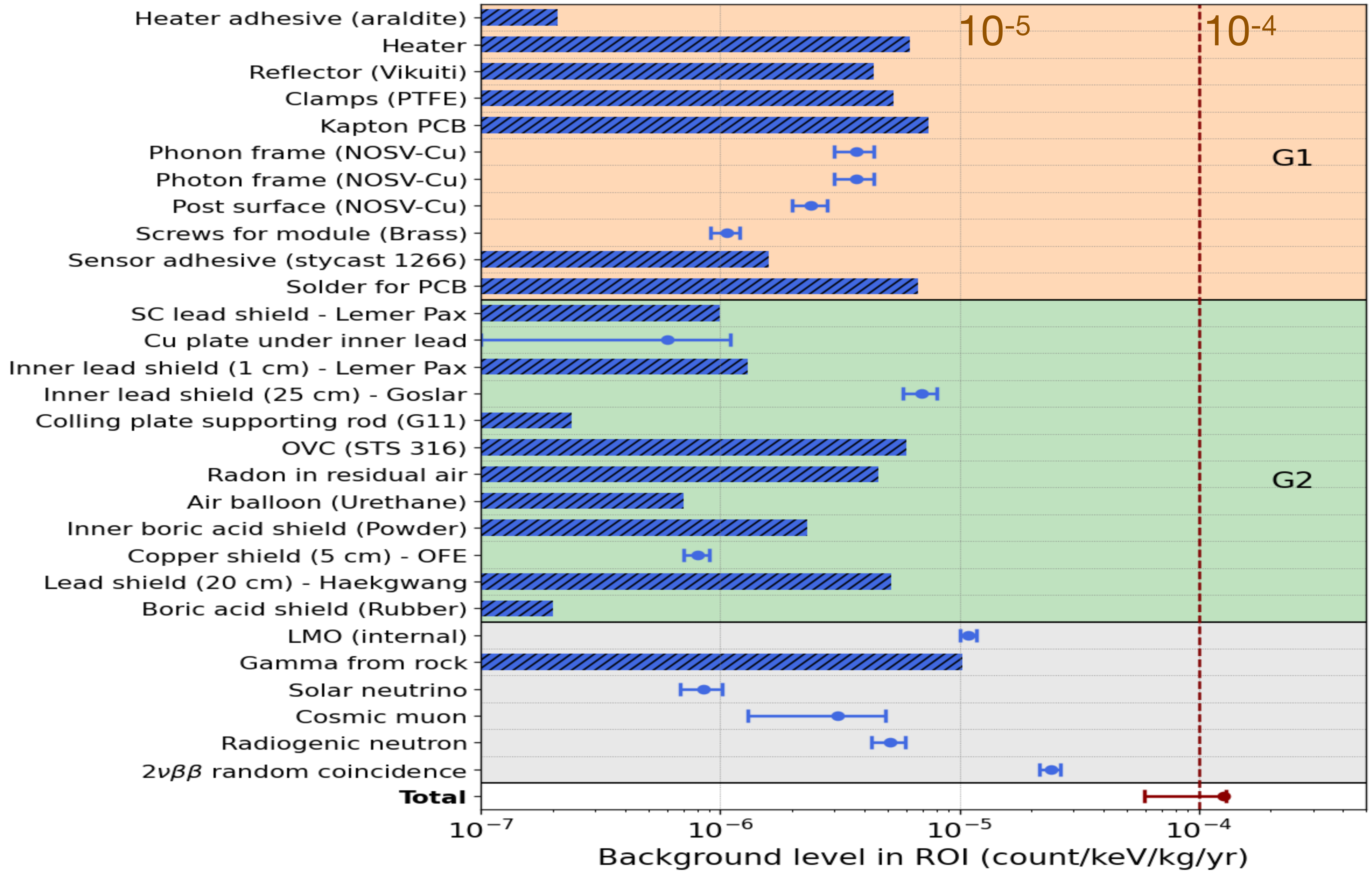
# PTFE clamps

- Currently, our measurement is at the detection limit
- To measure materials with very low activity, we require ultra-pure reagents and a crucible for sample preparation
- We will contact INFN to carry out the measurement

| | | | Activities (mBq/kg) | | Background level (x10$^{-5}$ ckky) |
|---|---|---|---|---|---|
| | Material | Techinque | U-238 | Th-232 | |
| Teflon Clamps | PTFE | ICP-MS (XENON1T) | < 0.12 | < 0.04 | < 0.53 |
| | | INAA | << 1.24 (DL) | << 0.82 (DL) | |



# Updated background contributions in ROI



# Summary

- We have updated the background projection for AMoRE-II to 1.3x$10^{-4}$ Counts/keV/kg/year (ckky), based on intensive background simulations performed with Geant4
  - Primary background source was $^{214}$Bi in the $^{226}$Ra-$^{210}$Pb decay sub-chain of $^{238}$U, located in the innermost layer of the outer lead shielding ➔ it will be replaced with OFE copper shielding layer
  - Copper post-surface contamination occurred during the thread-making process, depending on the manufacturer ➔ it becomes acceptable after removing 12 μm of the surface through several purification steps, performed after manufacturing by the selected company
  - We have measured ultra-low-activity lead and confirmed the background level of the shield layers made from it
  - Owing to the Rn-less air supply and the Rn Reduction System (RRS), the background level can be reduced to about $10^{-6}$ ckky in the ROI
- Currently, the main background source has been identified as pile-up events, which will be further studied and mitigated through machine learning analysis

# Backup

# Sensitivity of $T_{1/2}^{0\nu\beta\beta}$