

Status of AMoRE Experiment

Go Woon Kim (CUP, IBS)

On behalf of the AMoRE Collaboration

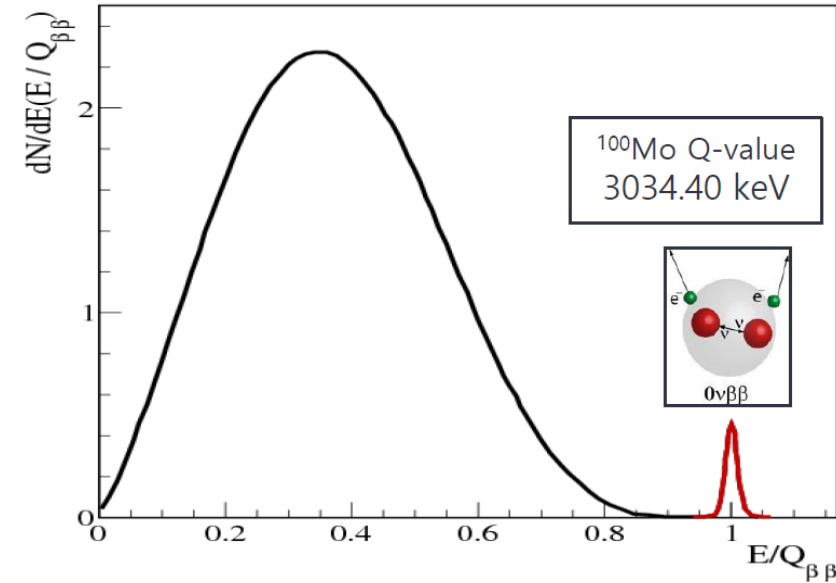
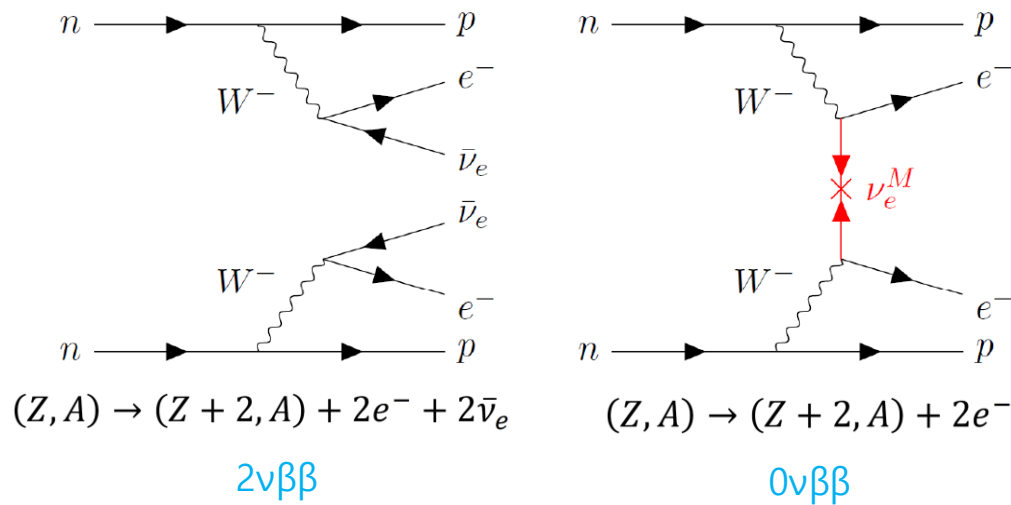
LLWI2024, Chateau Lake Louise, Canada

Feb 18th-24th, 2024



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

an experiment to search for $0\nu\beta\beta$ decay of ^{100}Mo using molybdate scintillation crystals and low-temperature sensors.



$0\nu\beta\beta$ decay of ^{100}Mo

Observation of $0\nu\beta\beta$

- Direct measure of Majorana nature of neutrino.
- Lepton number violation process.
- Effective neutrino mass.

^{100}Mo

- $Q_{\beta\beta} = 3034$ keV
- Natural abundance : $\sim 9.7\%$
- Current best limit of $T_{1/2}^{0\nu} : > 1.8 \times 10^{24}$ yr (CUPID-Mo)

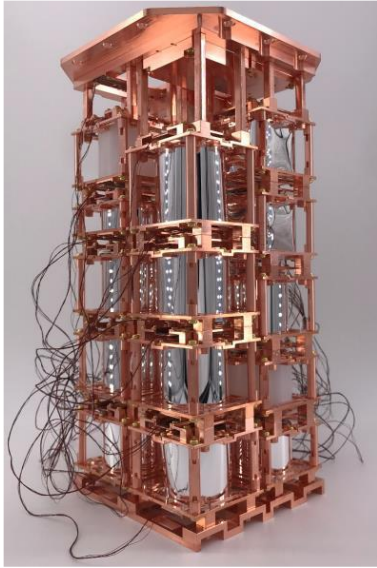
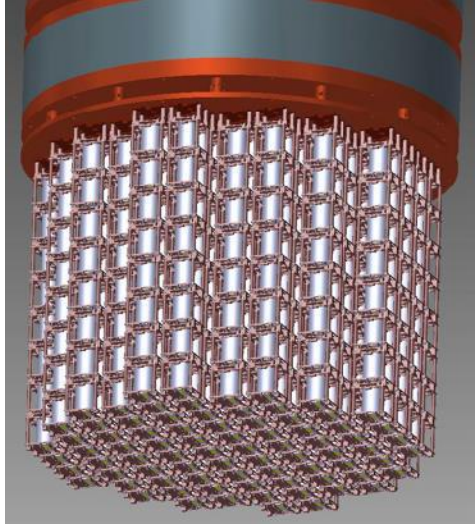
AMoRE Collaboration

10 Countries, 26 Institutions

Korea, Germany, Ukraine, USA, Russia, China, Thailand, Indonesia, India, Pakistan

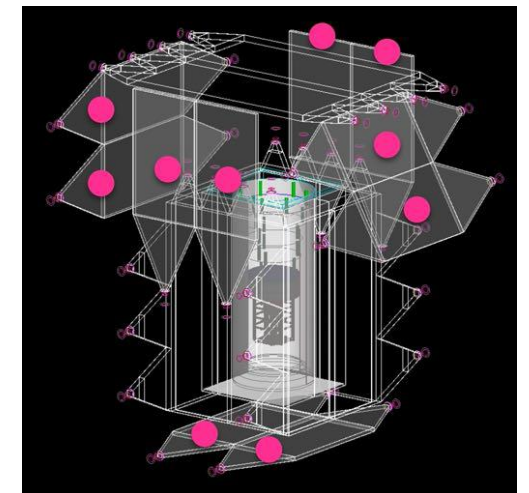
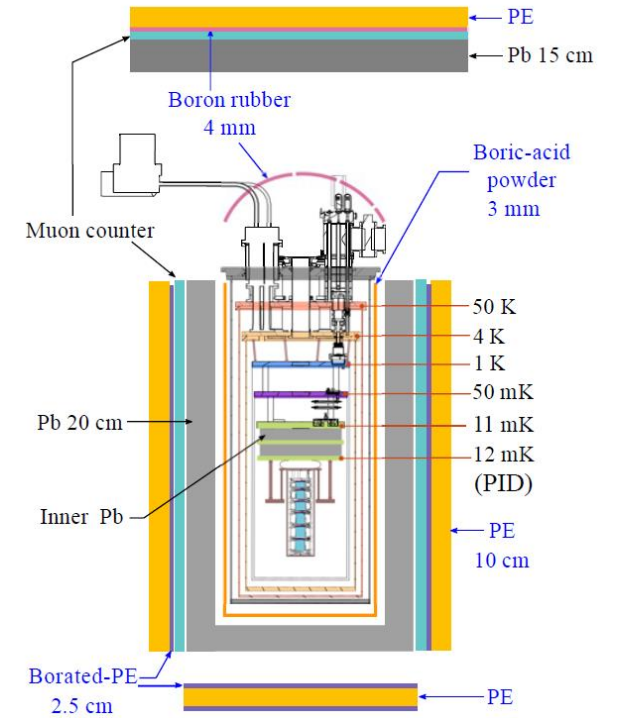
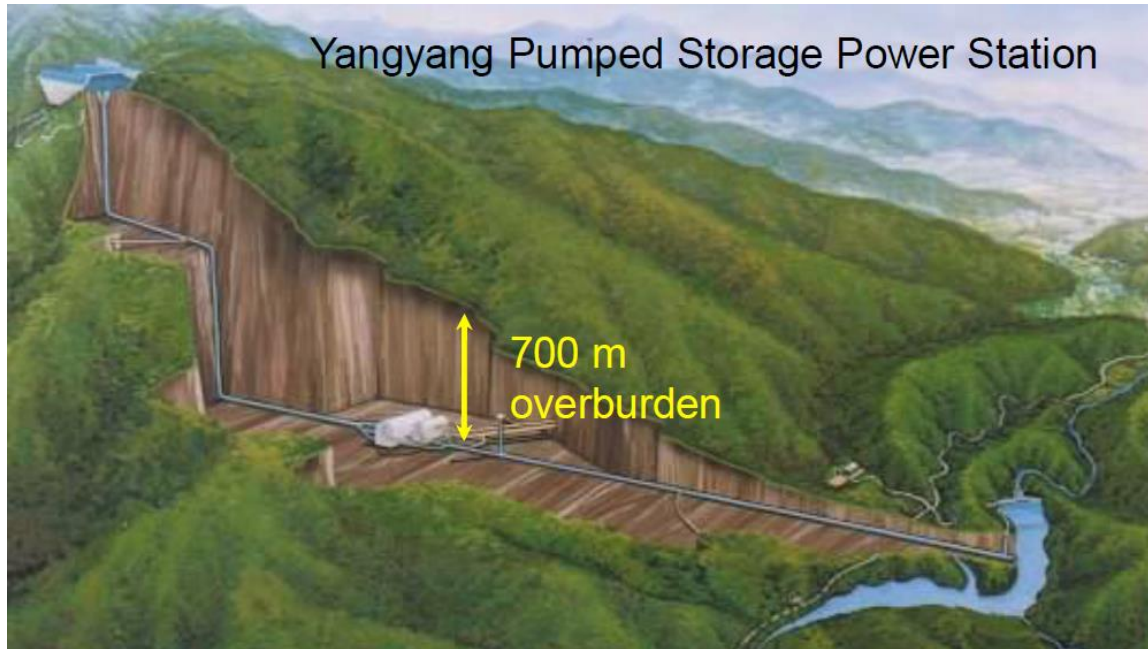


Phases of AMoRE

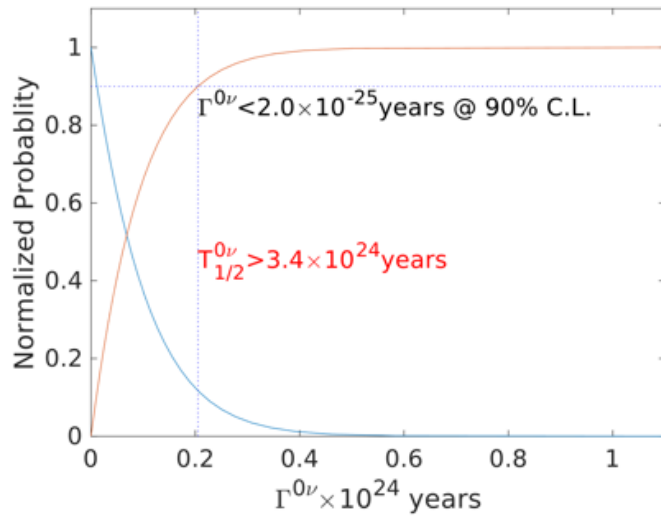
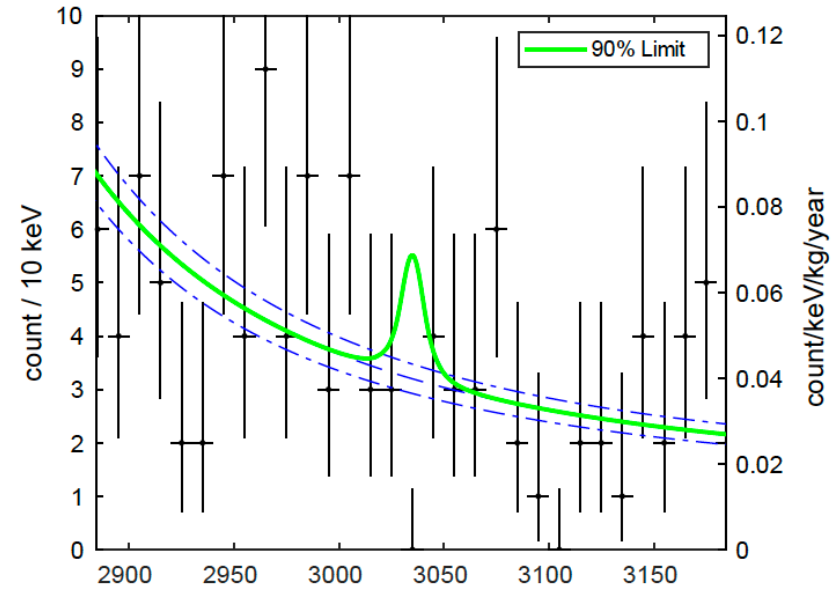
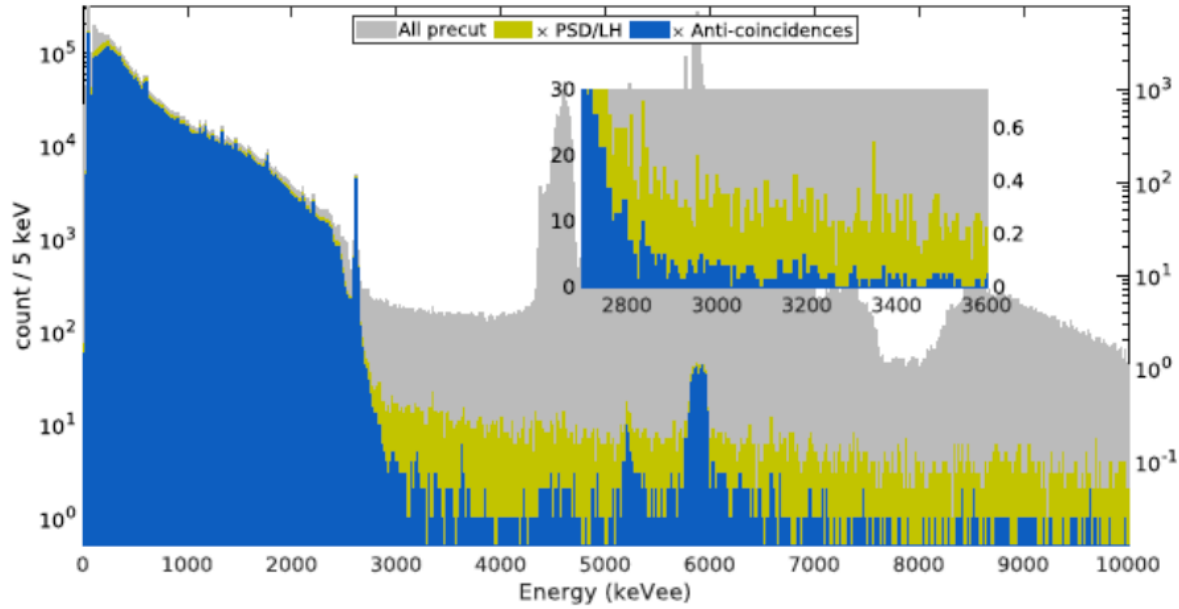
Phase	AMoRE-Pilot	AMoRE-I	AMoRE-II
			
Crystal	CMO	CMO, LMO	LMO
Crystal Mass(kg)	1.9 kg	6.2 kg	157 kg
Background Goal (ckky)	4×10^{-1}	3×10^{-2}	$< 10^{-4}$
Expected $T_{1/2}$ sensitivity(yr)	3.2×10^{23}	3.4×10^{24}	8.0×10^{26}
Expected $\langle m_{\beta\beta} \rangle$ (meV)	630-1100	140-270	13-23
Location	Y2L	Y2L	Yemilab
Schedule	2015-2018	2020-2023	2024-

AMoRE-I

- YangYang Underground Laboratory (Y2L) at 700 m depth
- Run period : ~900 days (2020.12~2023.05)
- 13 CMO crystals (4.6 kg) and 5 LMO (1.6 kg) crystals = 3.0 kg ^{100}Mo
- 20cm Pb shielding + neutron shields (boric acid+PE+b.PE), plastic scintillator for muon veto
- Cryogen-free dilution refrigerator operating at 12 mK ($\Delta T < 1 \mu\text{W}$)



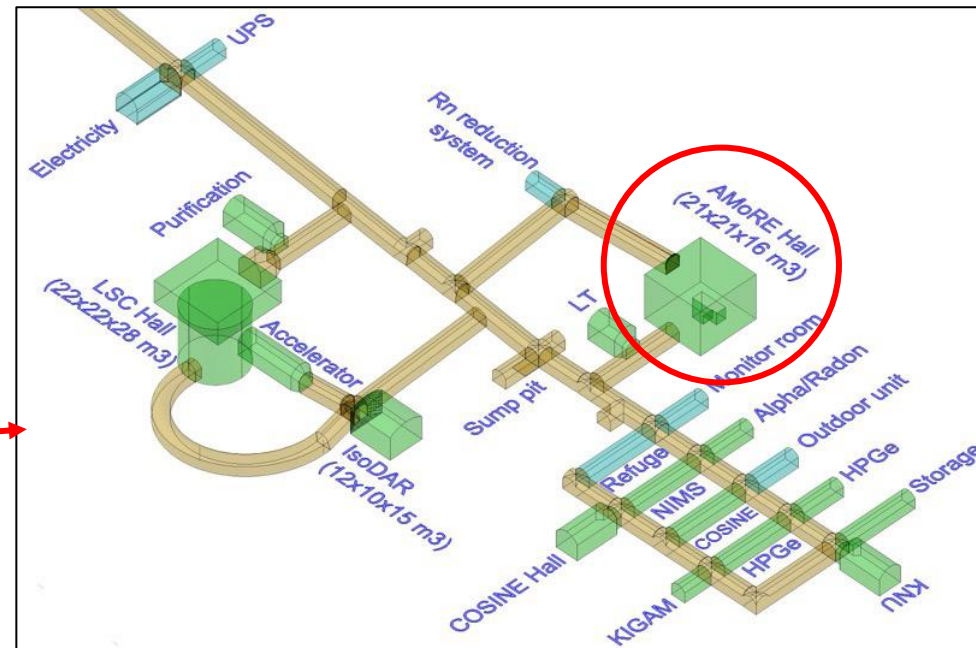
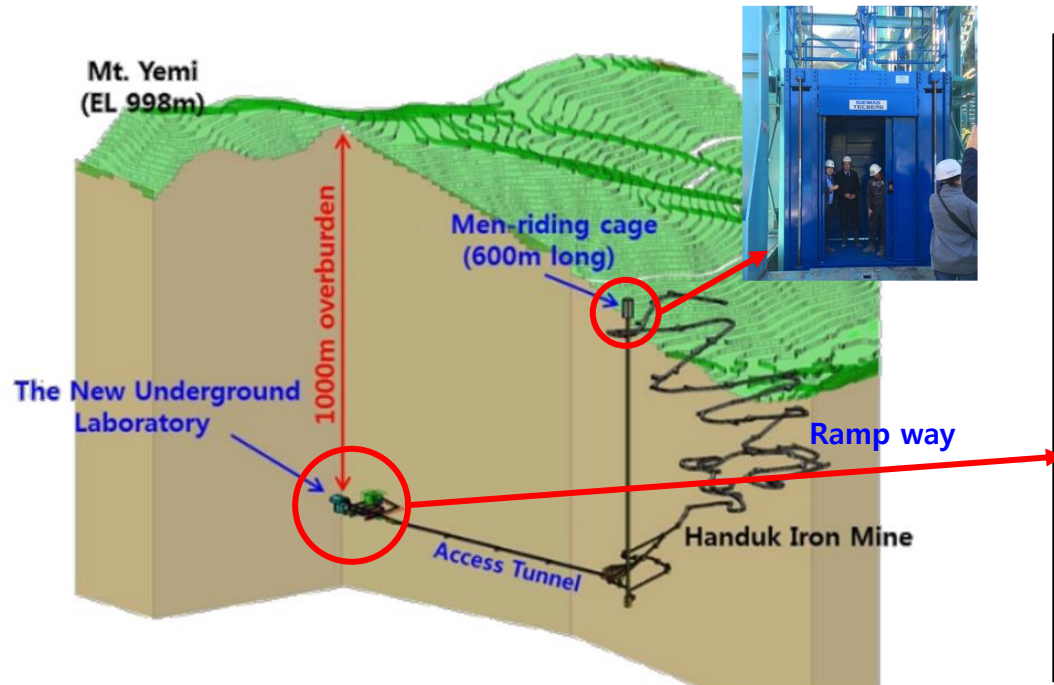
AMoRE-I result



- $\text{ROI} = |E - Q_{\beta\beta}| < 2.5 \Delta E_{\text{FWHM}}$
- Background = 0.032 ± 0.003 ckky, from ROI side-band
- Exposure = $8.02 \text{ kg}_{\text{MoO}_4} \cdot \text{yr}$ ($3.88 \text{ kg}_{100\text{Mo}} \cdot \text{yr}$)
- $T_{1/2}^{0\nu} > 3.4 \times 10^{24}$ years (90% C.L.) **Preliminary**

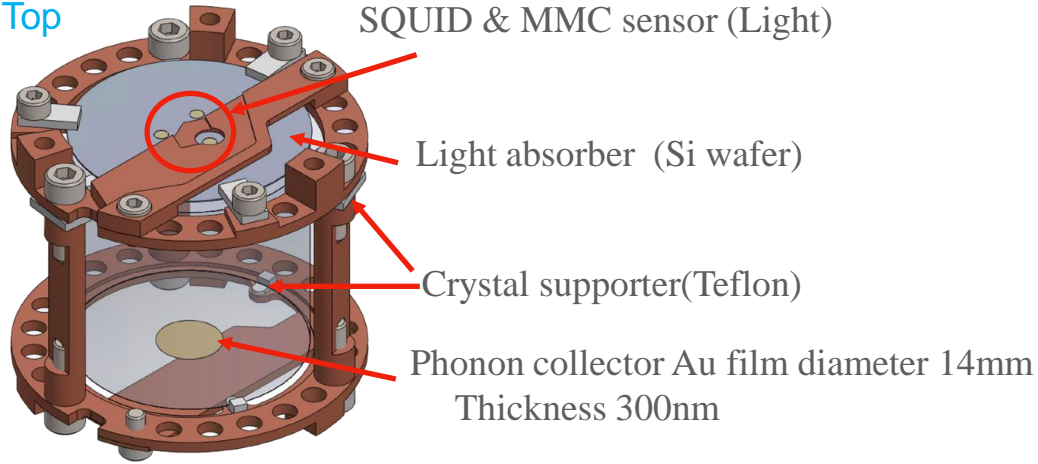
AMoRE-II

- Third phase of AMoRE experiment using about 360 ea LMO crystals (157kg)
- **Yemilab**
 - New underground laboratory of CUP, IBS
 - 1000 m depth, over 3000 m² lab space
 - Access way : ramp-way (by car), men-riding cage (4m/s speed)

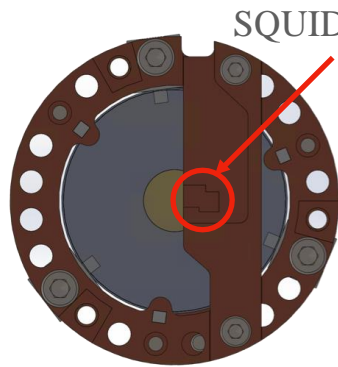


AMoRE-II detector module & tower

Top



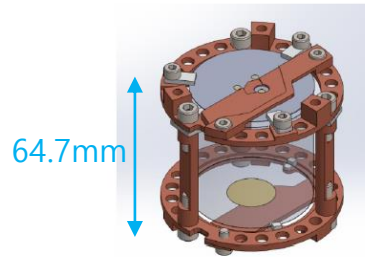
Bottom



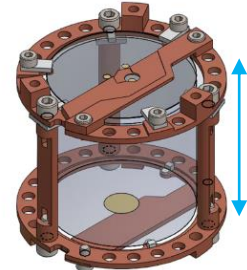
designed for 5cm and 6cm LMOs

5cm module

6cm module

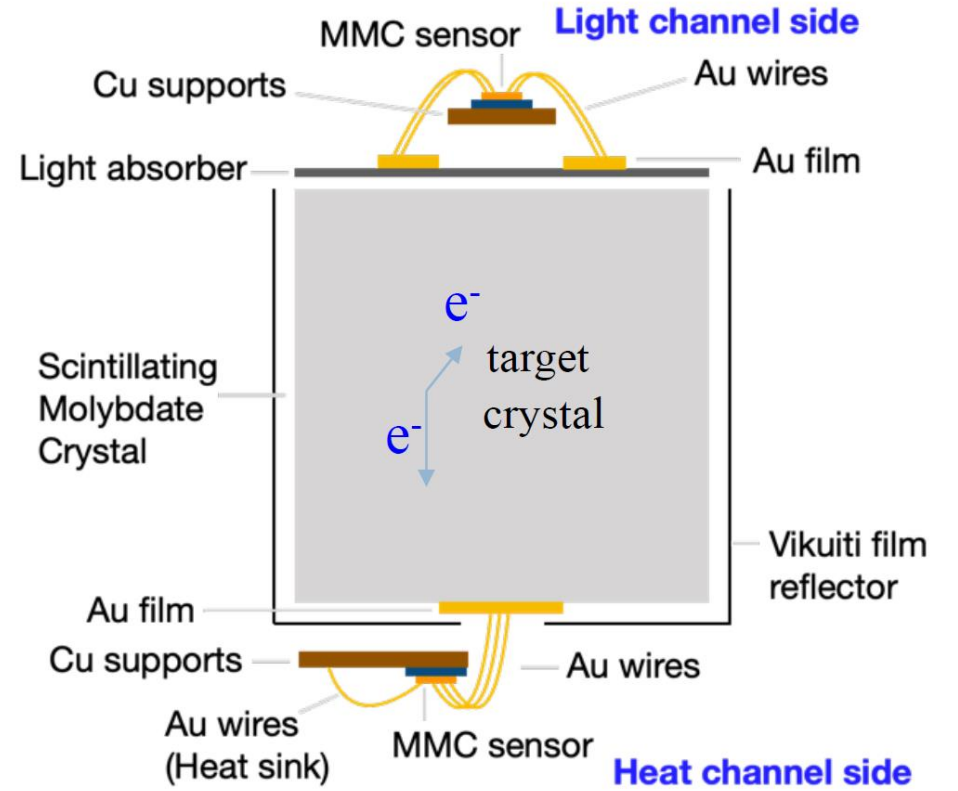


64.7mm



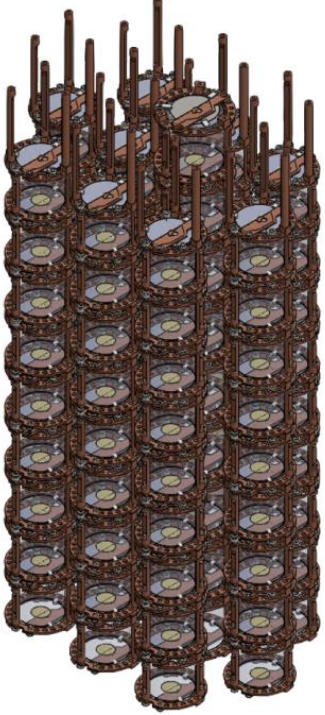
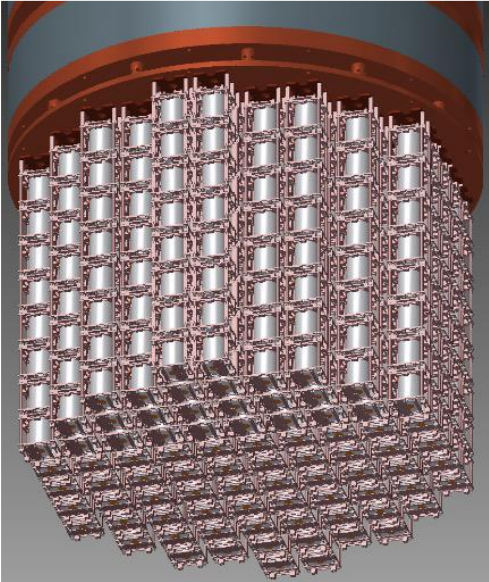
74.7mm

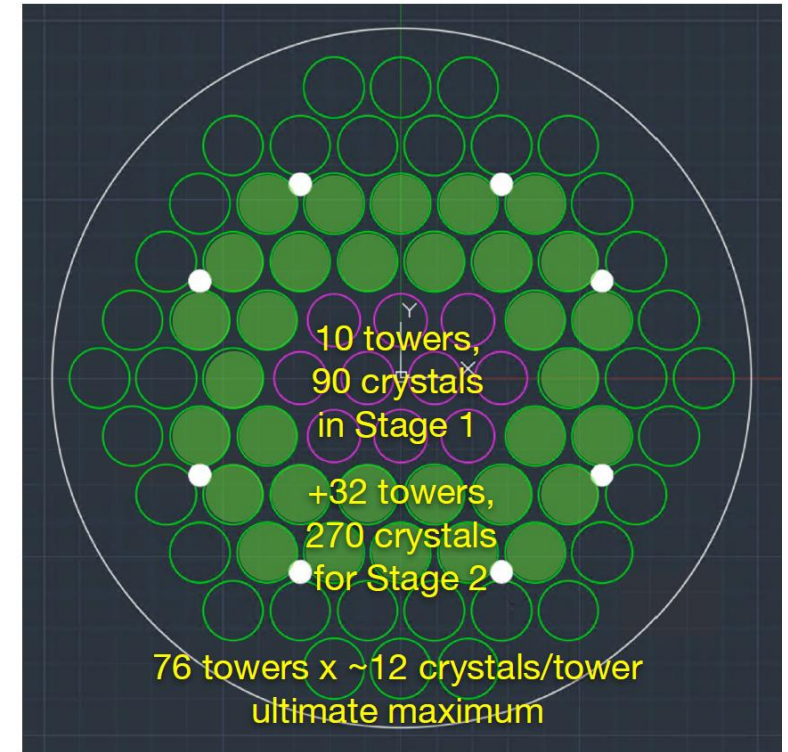
Detector module



- Operating at 10-20 mK
- MMC+SQUID for heat and light signal detection

Stage of AMoRE-II

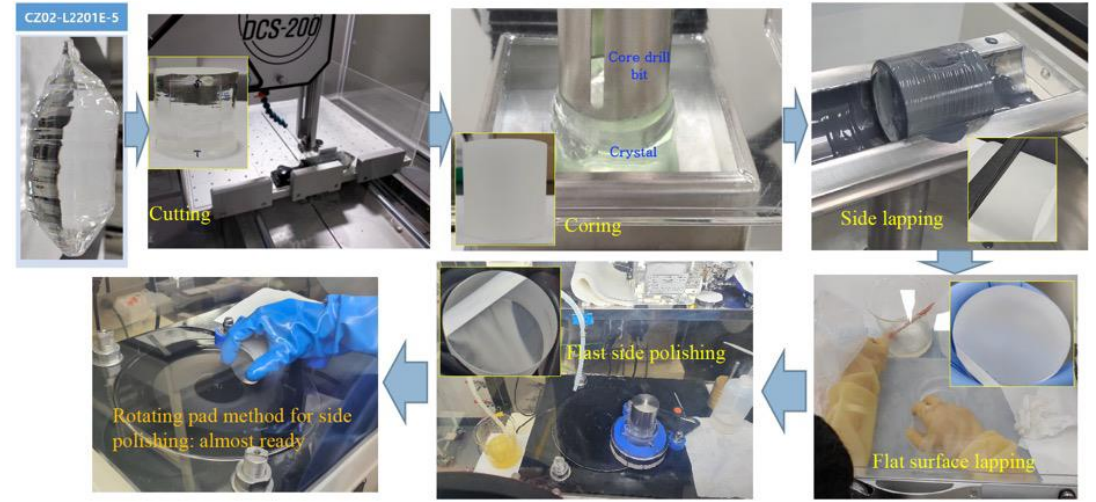
	Stage 1	Stage 2
		
Crystal towers	10 towers (90 crystals)	42 towers (~360 crystals)
Crystal Mass(kg)	~29 kg (81ea 5cm, 9ea 6cm)	~ 157 kg
Schedule	2024-	2025-



Top view of tower structure

LMO crystals for AMoRE-II

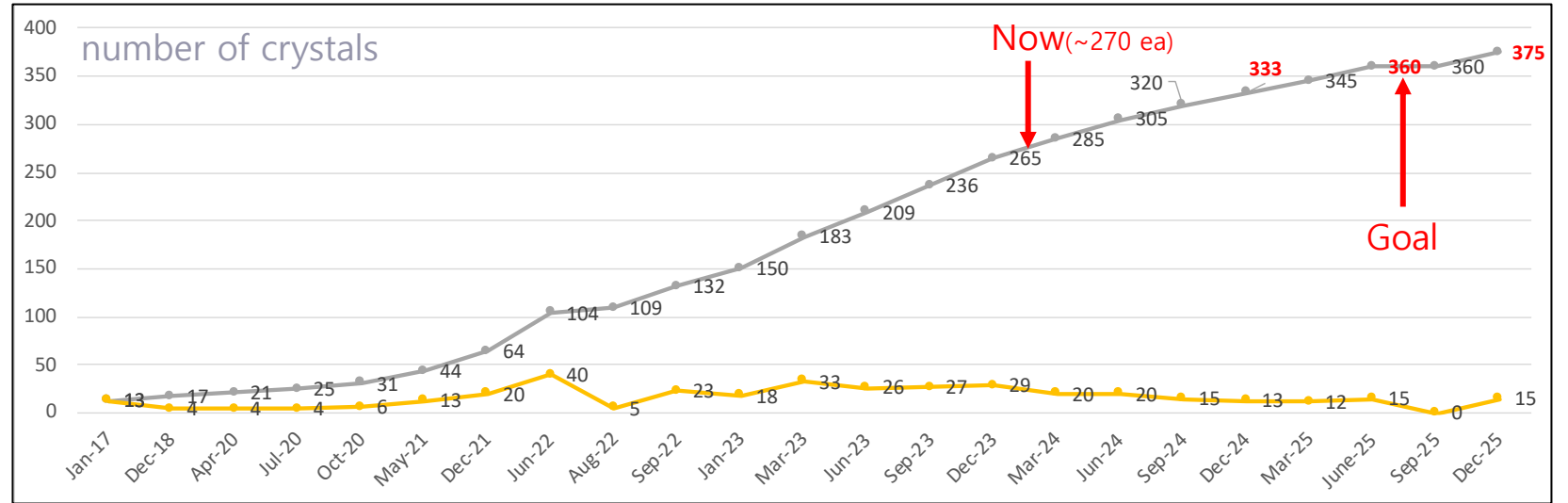
- LMO crystal produced at CUP & NIIC (Nikolaev Institute of Inorganic Chemistry)
- ^{100}Mo enrichment = 95%
- Powder purification is ongoing at CUP
- For 1st stage : 24 ea (5cm) crystals from CUP,
66 ea (5cm 57 ea, 6cm 9 ea) crystal from NIIC



Crystal growing at CUP

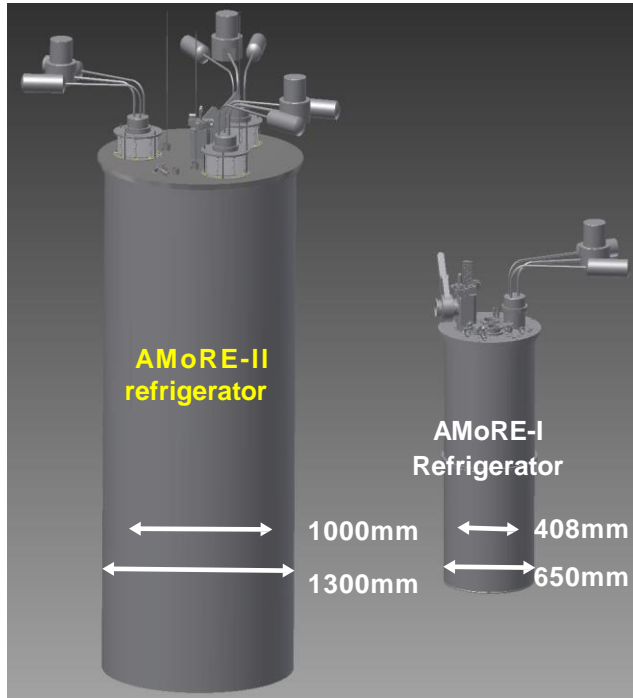
MoO ₃ powder \ Activity (μBq/kg)	Raw	Purified
Ac-228	260 ± 50	< 27
Th-228	210 ± 50	< 16
Ra-226	260 ± 50	110 ± 30
K-40	8500 ± 1400	1700 ± 340

Yeon H., et al. Front. Phys. 11, 1142136 (2023)



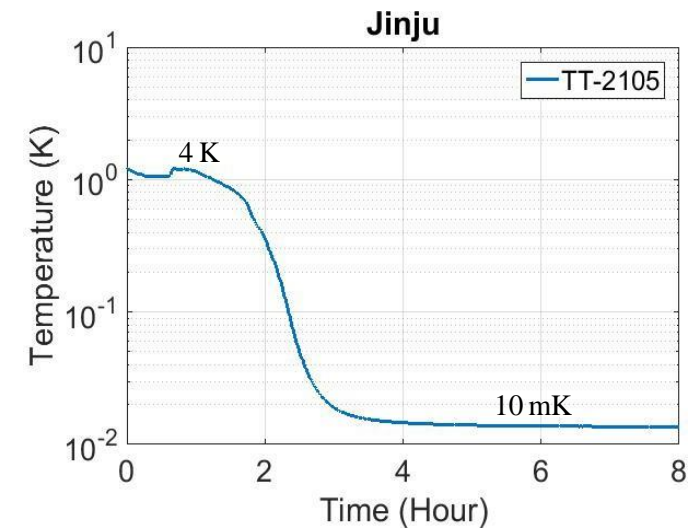
Crystal production schedule

AMoRE-II Dilution Refrigerator (DR): Jinju



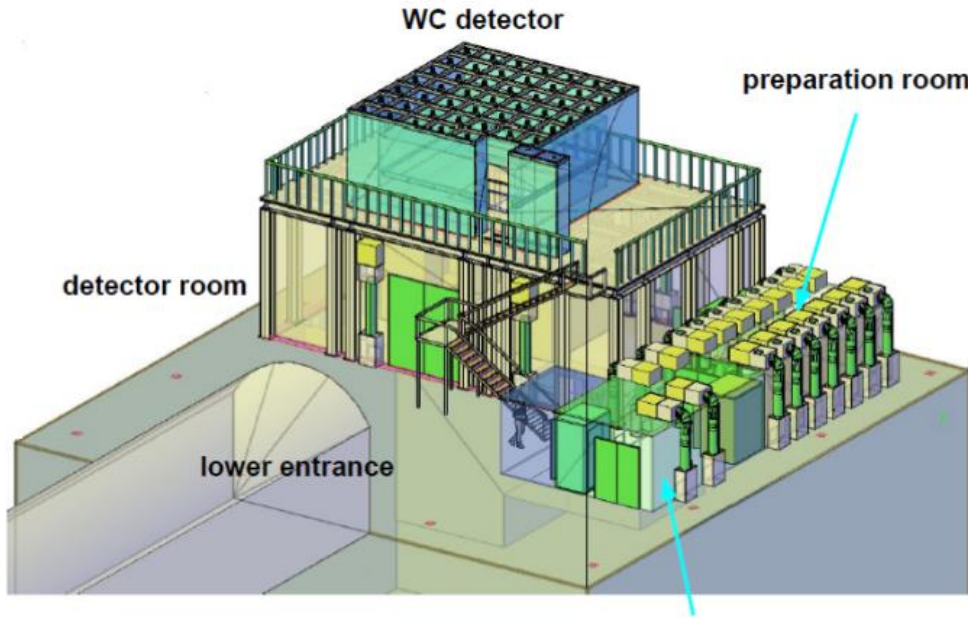
DR for AMoRE-II

- Large dilution refrigerator from Leiden.
 - Three PTR (Pulse Tube Refrigerator)
 - Cooling power : 1 mW @ 100 mK, 7 μ W @ 10 mK
- With heavy LN₂ supply(pre-cooling 77 K), it takes 8 days to reach 4 K.
- ~ 7 hours to reach 10 mK

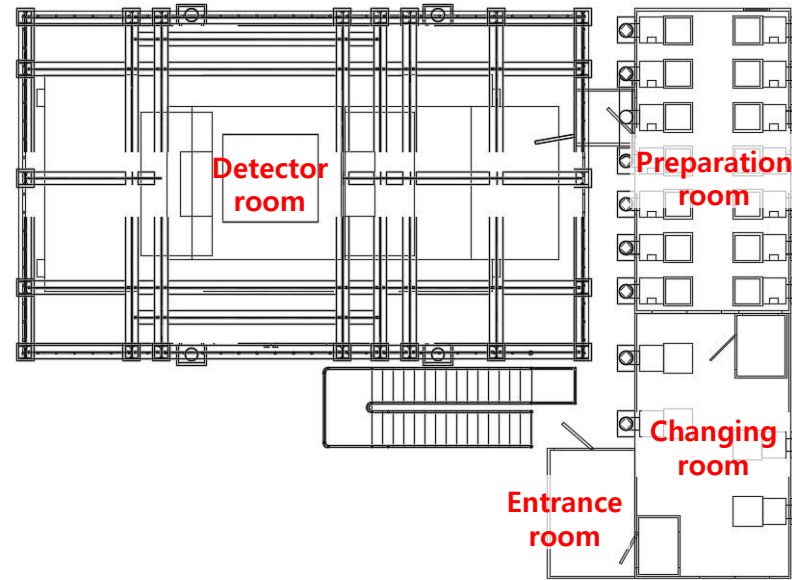


AMoRE Hall

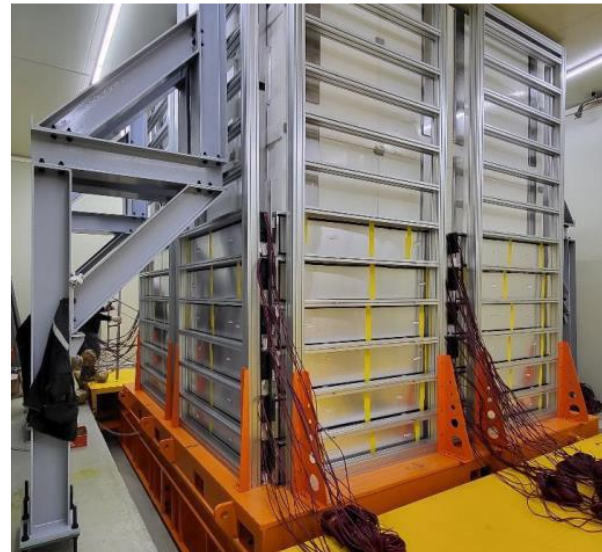
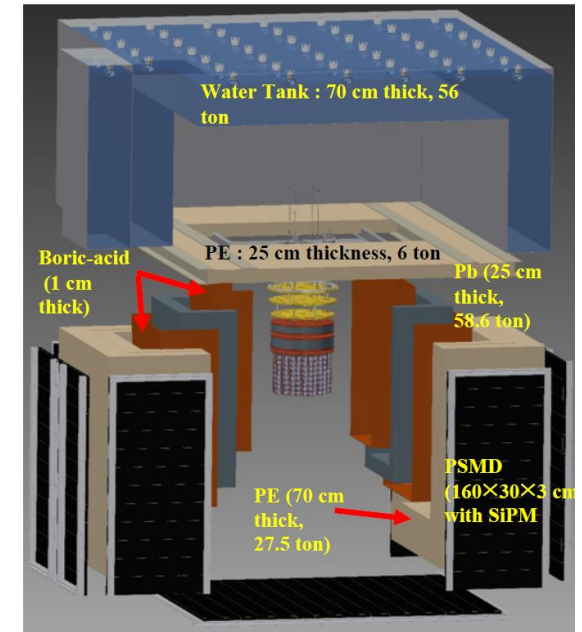
Overview of AMoRE Hall construction



Top view of construction in AMoRE Hall

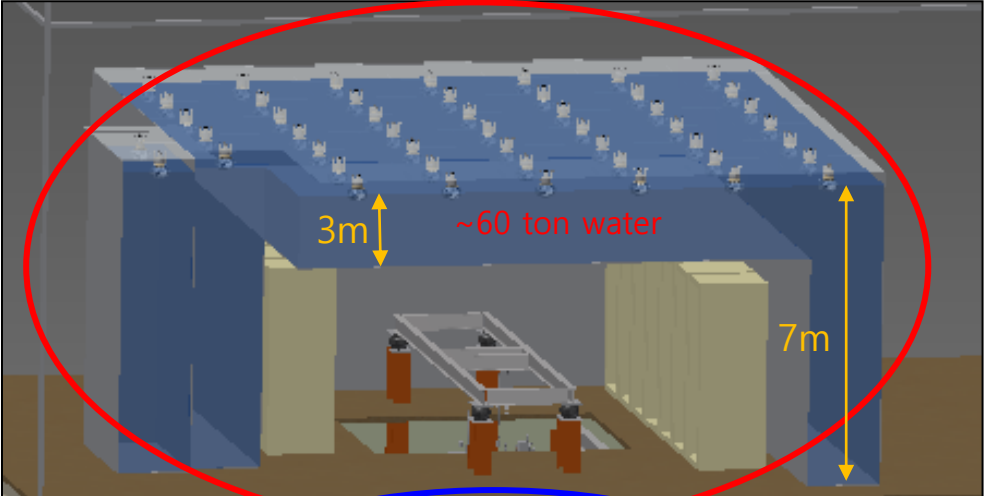


AMoRE-II structure



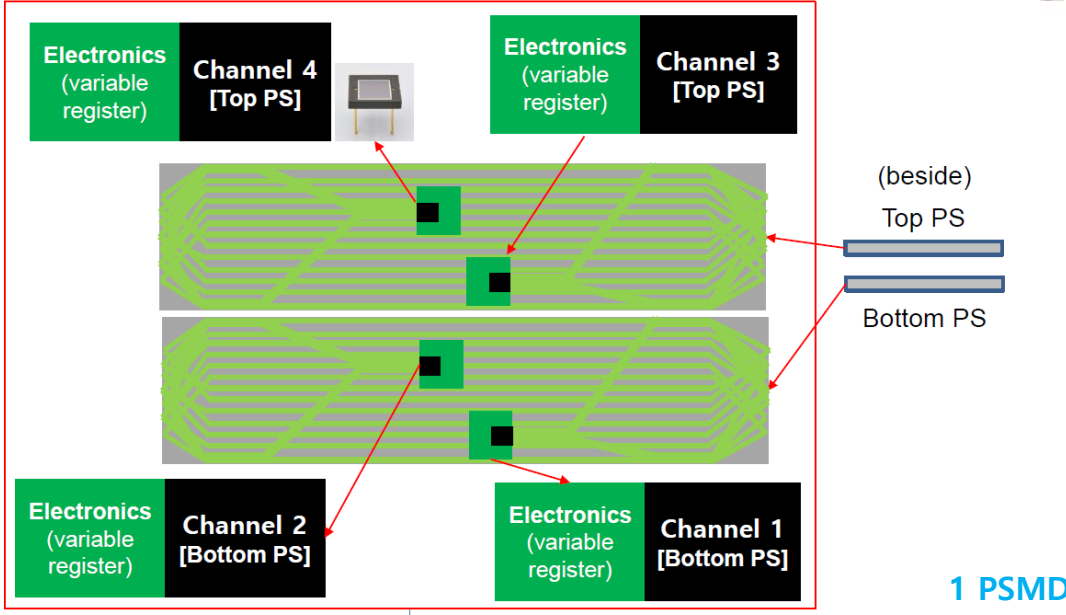
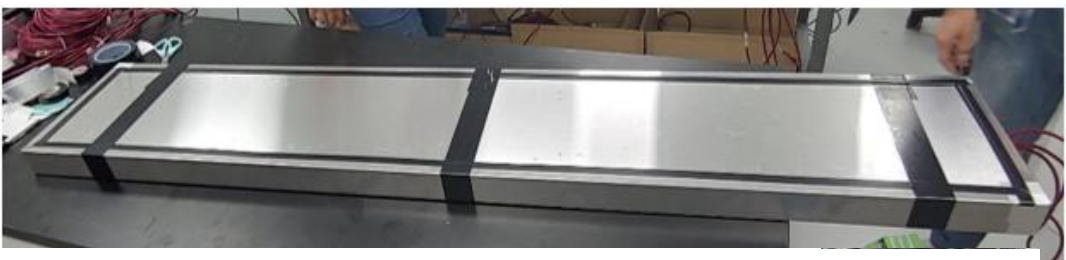
AMoRE-II muon veto detector

Water Cherenkov Muon Detector (WCMD)



PMTs for WCMD

Plastic Scintillator Muon Detector (PSMD)



1 PSMD

AMoRE-II muon veto detector

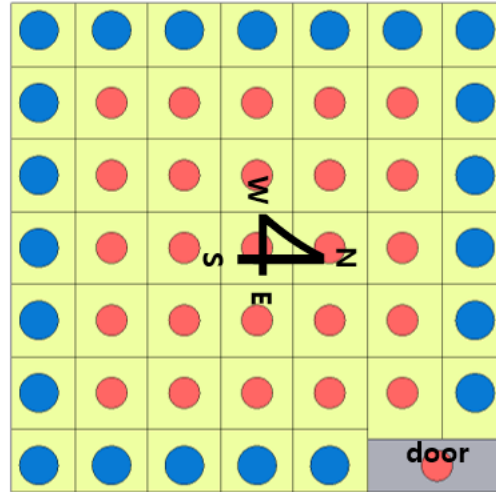
Water Cherenkov muon detector(WCMD)



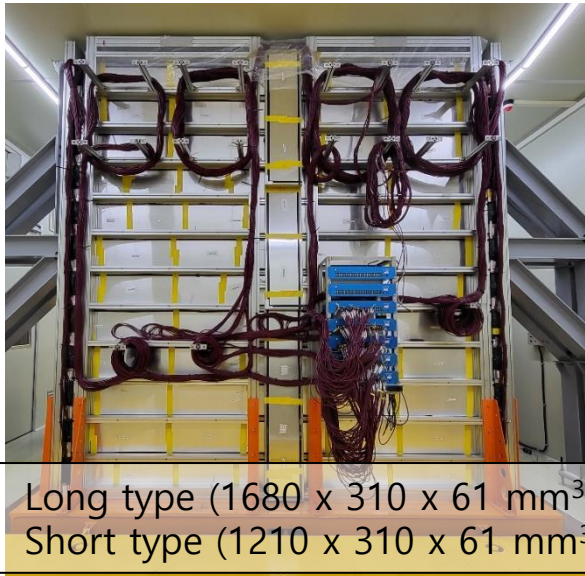
48 PMTs

- 10 inch PMT 22ea
- 8 inch PMT 26ea

[PMT for WCD(Top view)]

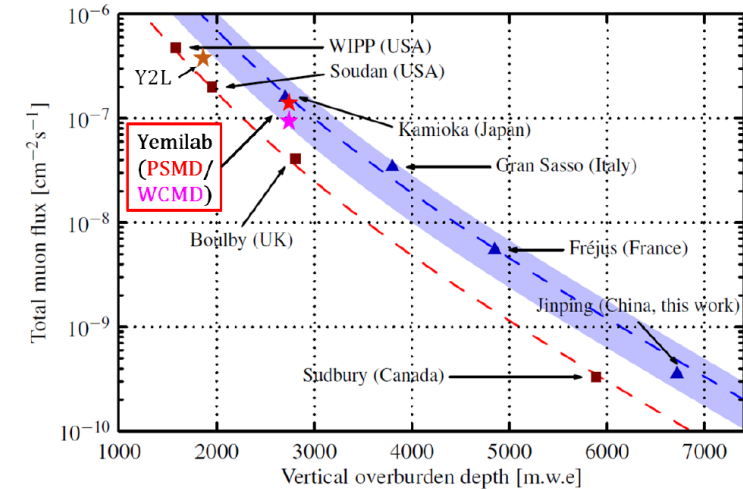
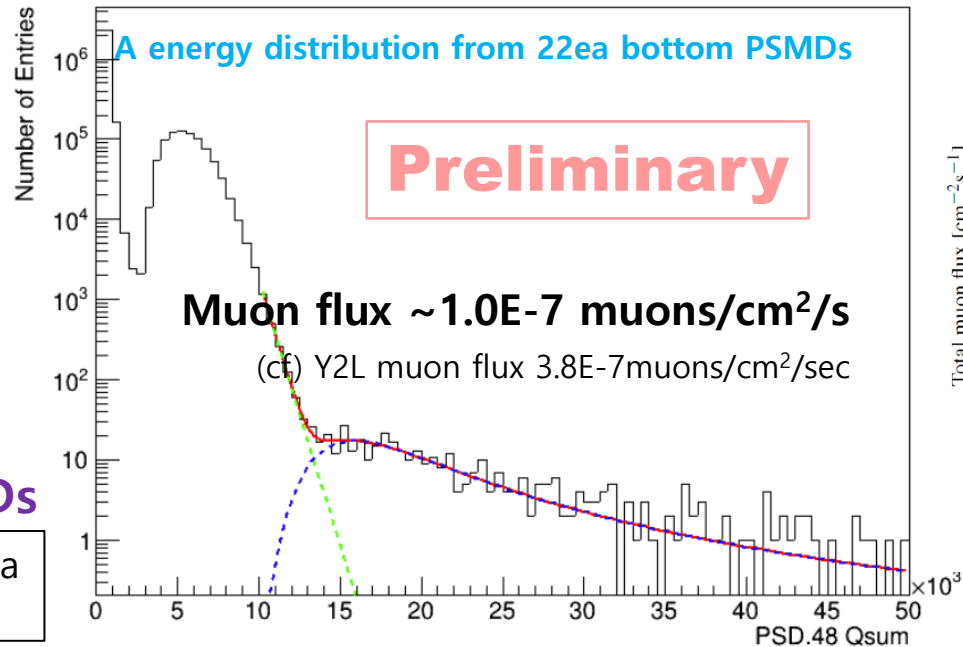


Plastic scintillator muon detector(PSMD)

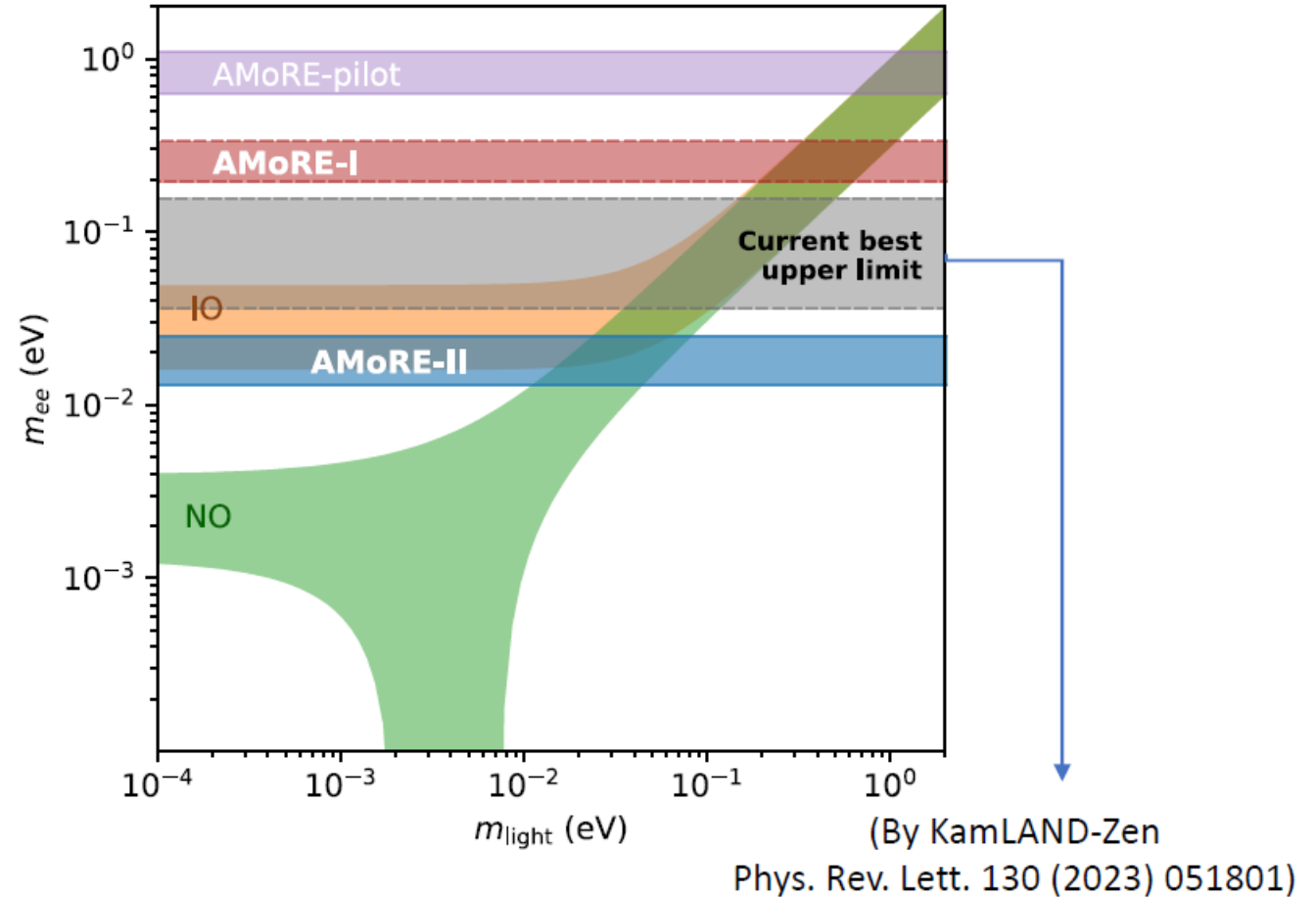
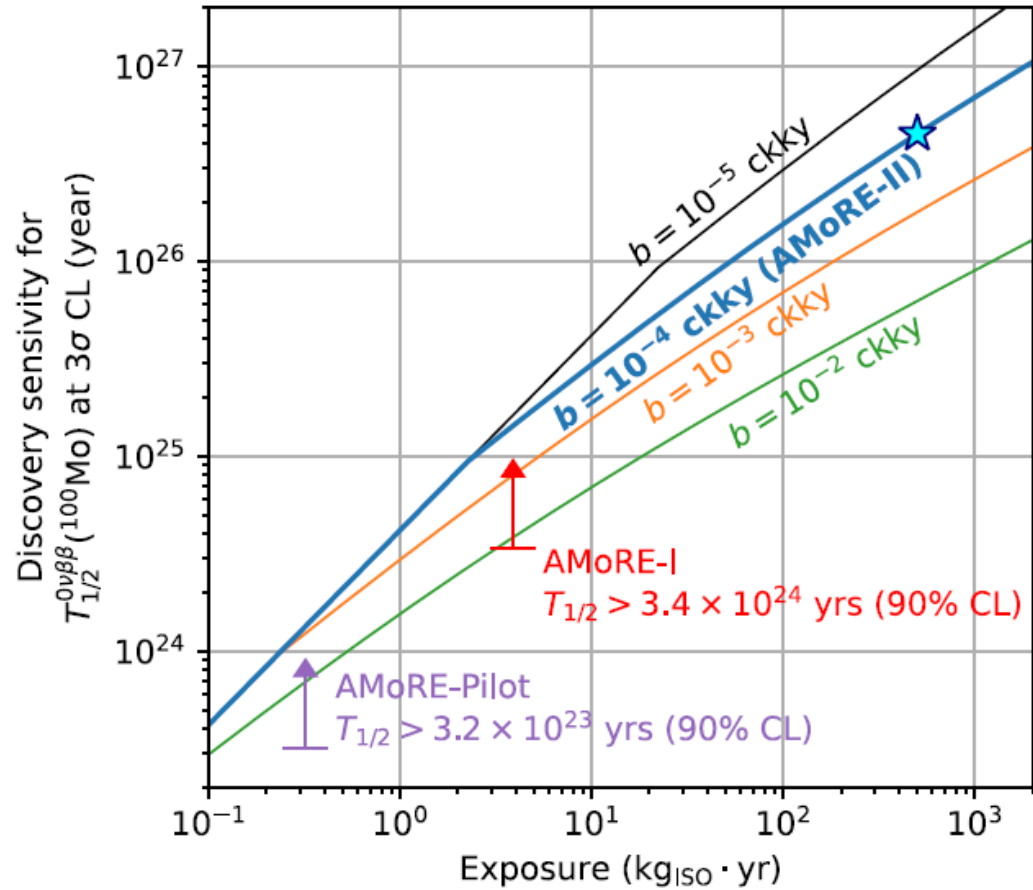


130 PSMDs

- Long type (1680 x 310 x 61 mm³) PSMD 126ea
- Short type (1210 x 310 x 61 mm³) PSMS 4ea



AMoRE-II goals



Sensitivity of AMoRE-II

- Background level $< 10^{-4}$ ckky.
- $T_{1/2}^{0\nu} \sim 4 \times 10^{26}$ years with 100 kg of ^{100}Mo with 5 years exposure

Summary & Plan

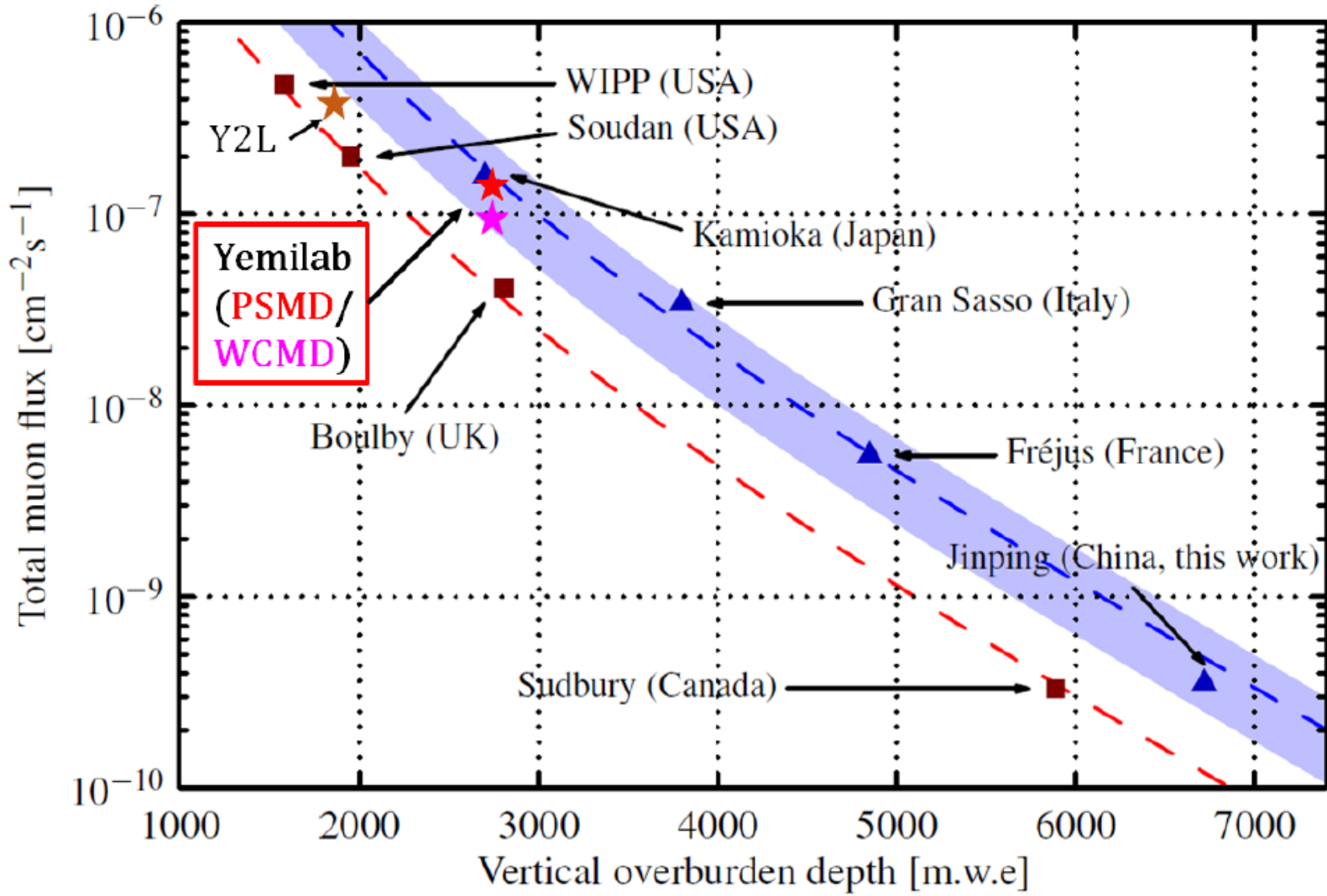
- AMoRE is an experiment to search for $0\nu\beta\beta$ decay of ^{100}Mo using molybdate scintillation crystals.
- AMoRE-I, the first phase using about 6 kg of CMO & LMO, is completed its operation at the Y2L.

The result of $T_{1/2}^{0\nu} > 3.4 \times 10^{24}$ years (90% C.L.) and AMoRE-II will be start soon, in this year.

- Goal of background level for AMoRE-II is $< 10^{-4}$ ckky, and all components are meet the requirements according to simulation study. Discovery potential of $0\nu\beta\beta$ is expected $T_{1/2}^{0\nu} \sim 4 \times 10^{26}$, with 500 kg ^{100}Mo · yr exposure.
- AMoRE-II, the second phase, will be divided into two stage depending on the crystal production status. The experiment will be operated in AMoRE Hall, at the Yemilab, and the 1st stage using 90 LMO crystals will started in middle of 2024. The 2nd stage with full scale will be started in 2025.

BACK UP

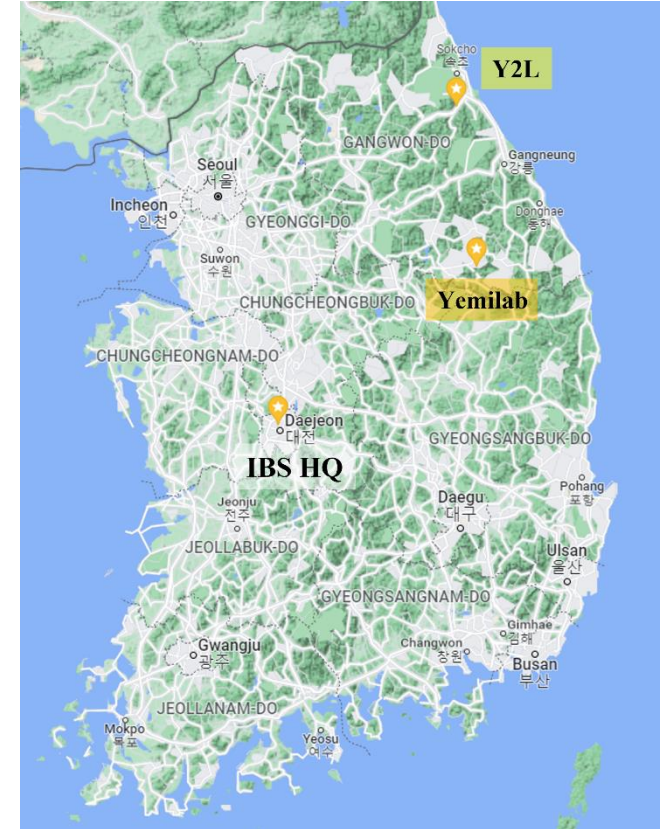
Estimated muon fluxes



Modified from Zi-yi Guo *et al* 2021 *Chinese Phys. C* **45** 025001

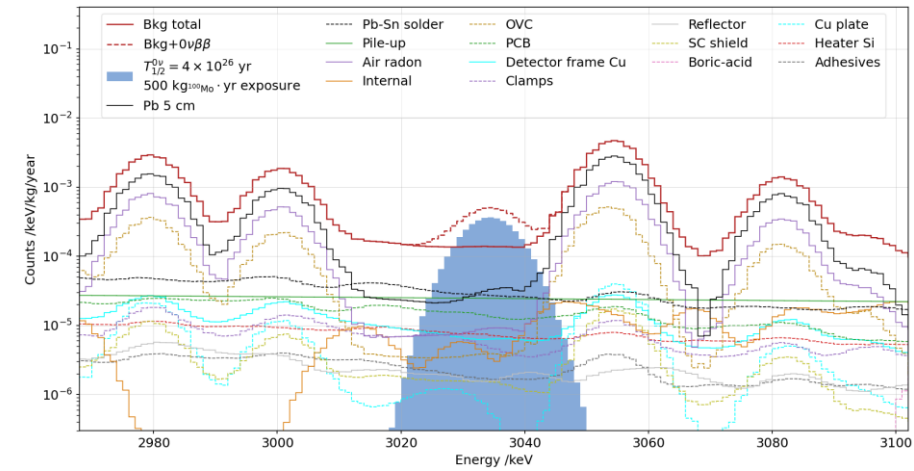
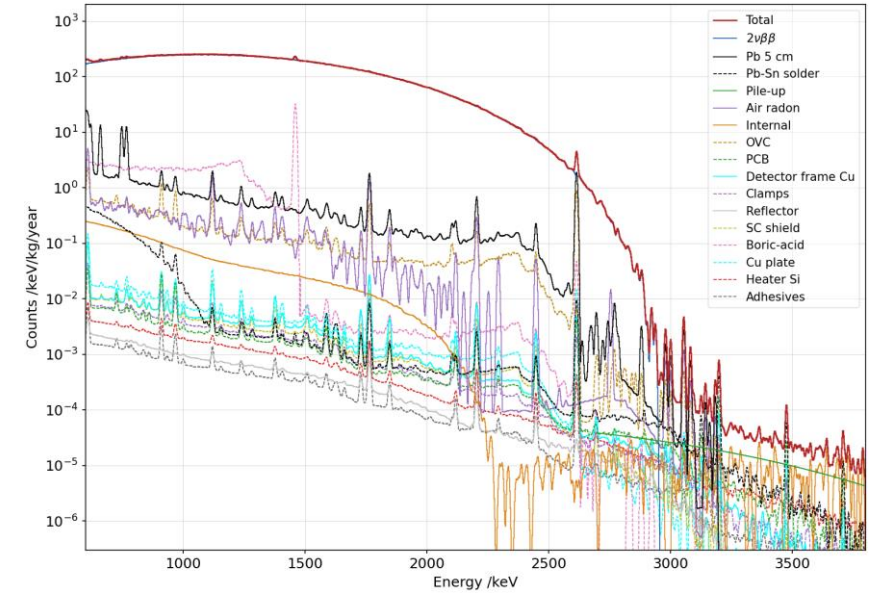
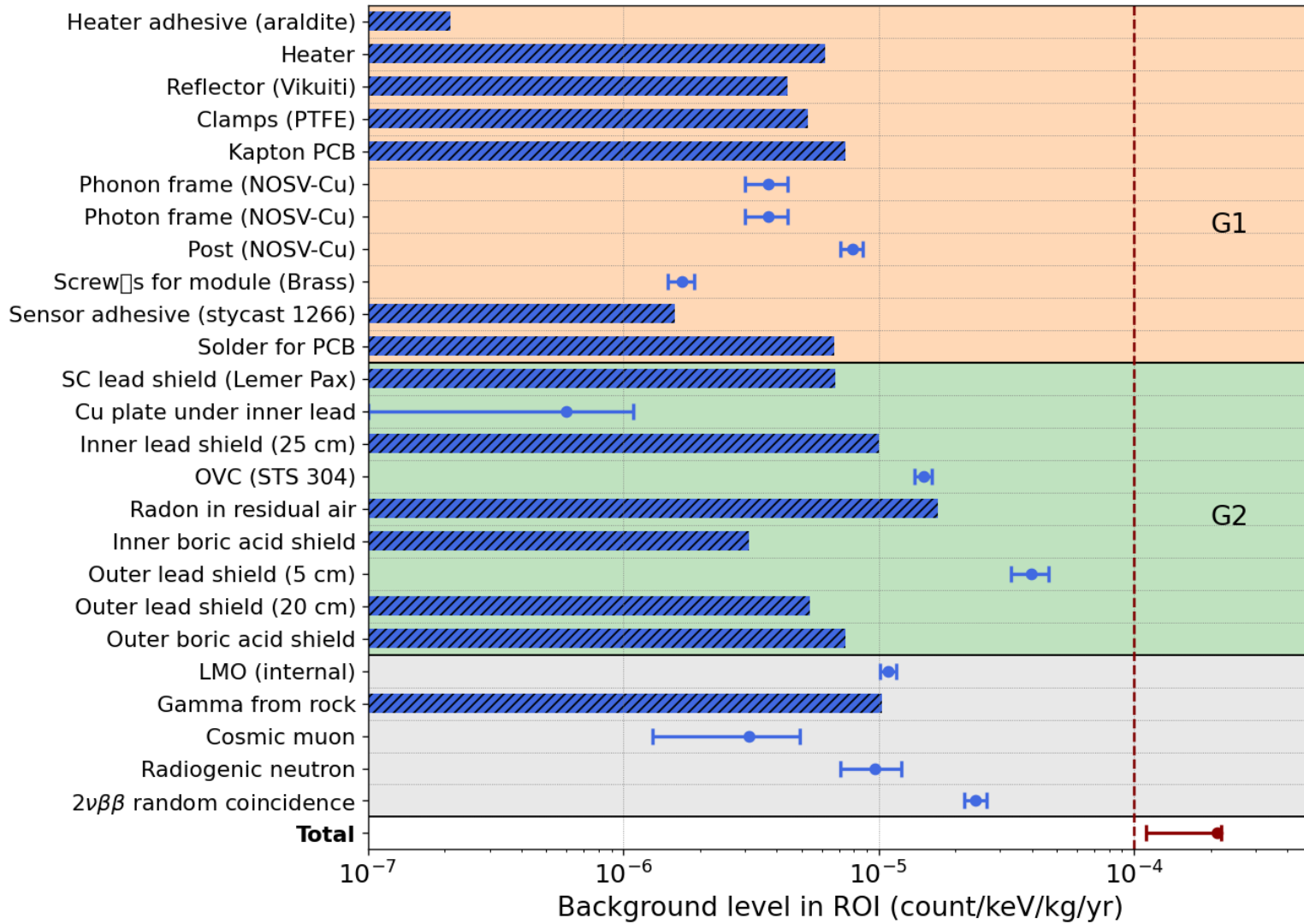
Underground Laboratories of CUP

	Y2L (Yangyang underground laboratory)	Yemilab
Location	Yangyang	Jeongseon
Depth (m)	700	1000
Area (m ²)	350	~3000
Rock Radioactivity (ppm)	U: 3.9(14) Th: 10.5(65) K: 40000	U: 0.8(3) Th: 3.3(4) K: 11800
Experiments	AMoRE-I COSINE-100	AMoRE-II COSINE-200



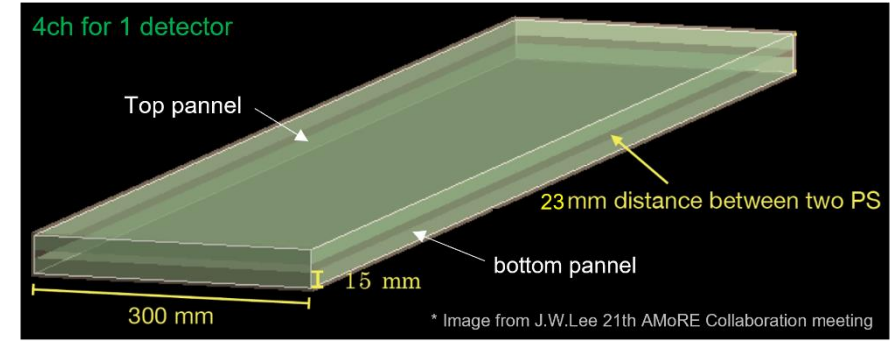
- 2003: Y2L constructed for KIMS dark matter search experiment
- 2013: CUP established
- 2022: Yemilab construction complete
- 2023: Y2L experimental facilities will be moved to Yemilab

AMoRE-II background estimation

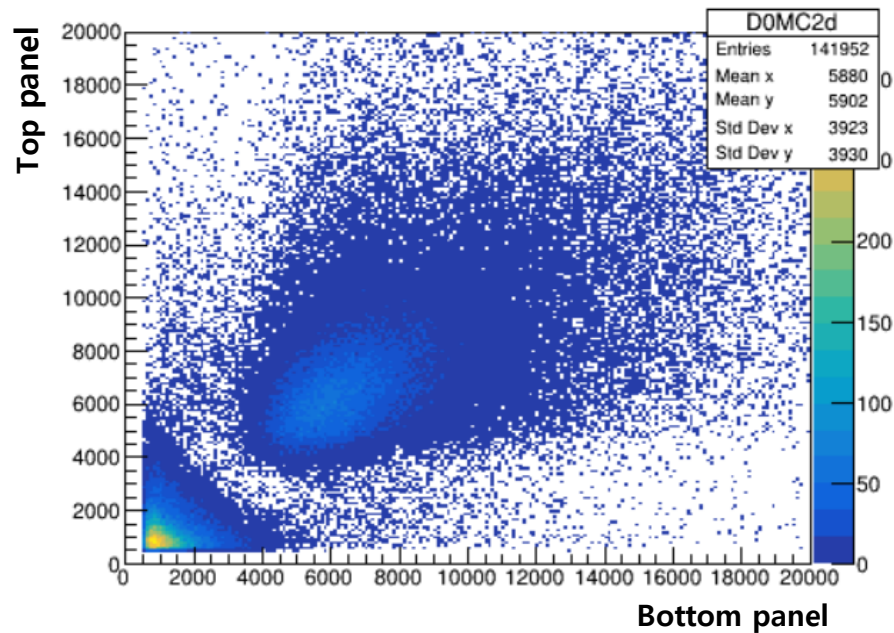


PS detector development & quality test

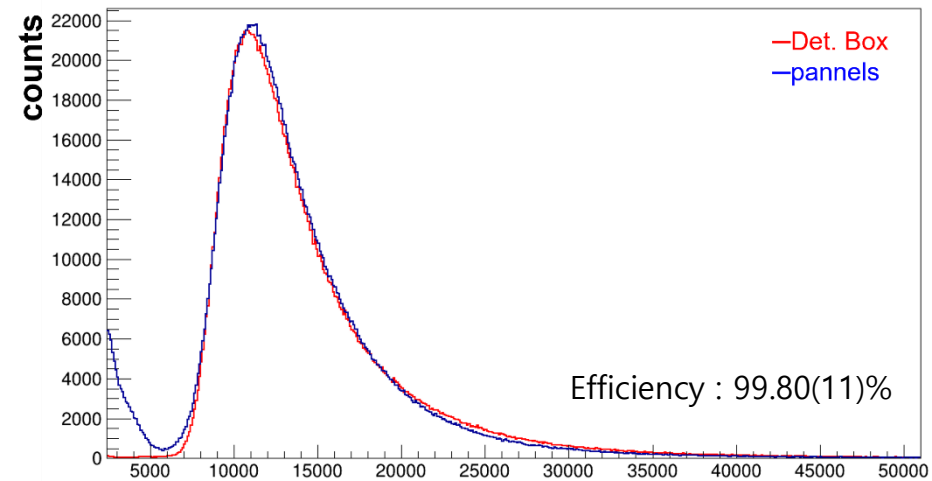
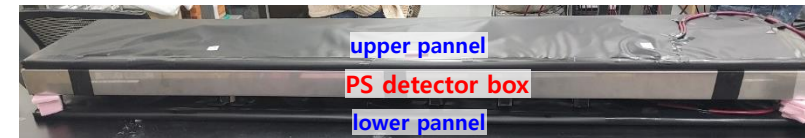
- 1 PS detector(box) is made using stacked 2 PS panels with a 23mm gap.
- PS panel
 - ▶ size : **1670mm** x 303mm x 15mm (Long), **1200mm** x 303mm x 15mm (Short)
 - ▶ 1 panel has 16 grooves on its surface for wavelength-shifting(WLS) fiber install.
- Design details
 - ▶ WLS fiber: **32 fibers** are installed **1 panel** (2 fibers in 1 groove)
 - ▶ Wrapping: each panel is wrapped by **Tyvek sheet** (reflector) at first, a black sheet used for 2nd wrapping to block light



[Inside geometry of PS detector box]



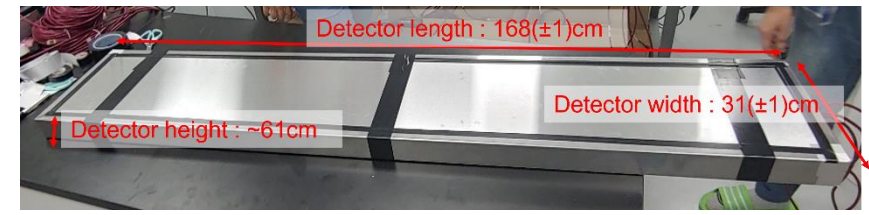
[2D charge distribution plot between top & bottom panels]



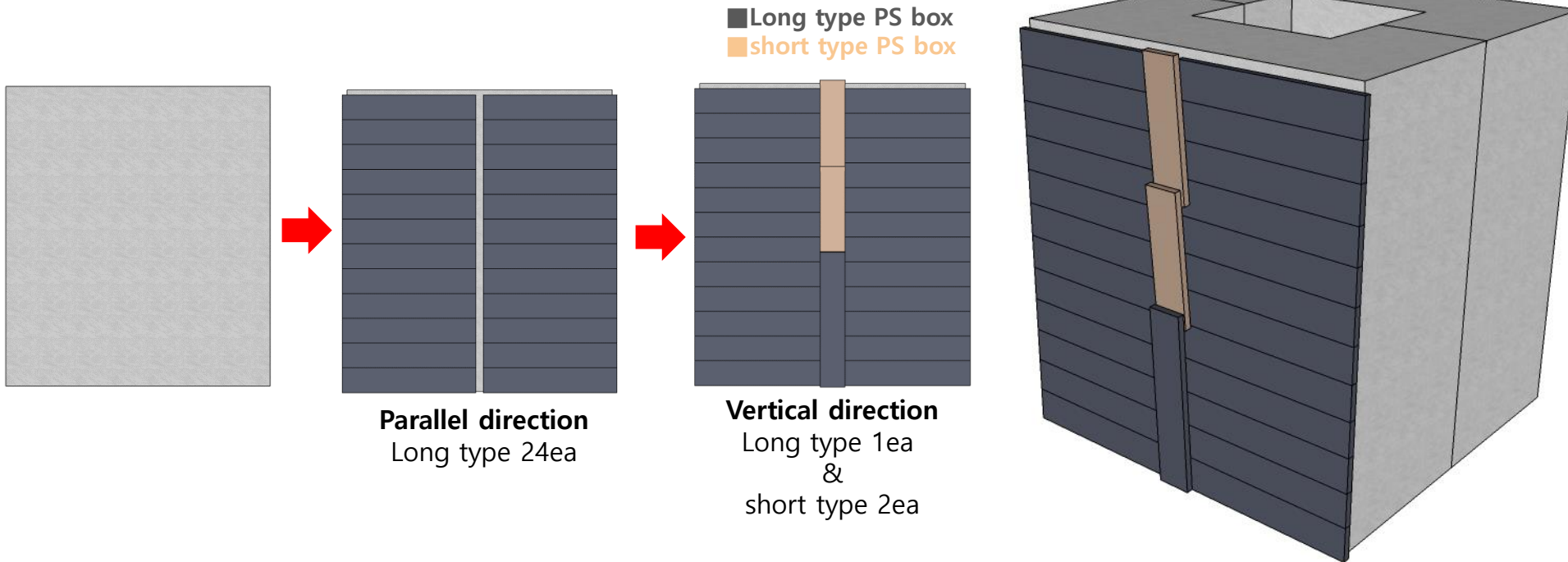
[efficiency test for one PS detector box]

PS detector installation structure

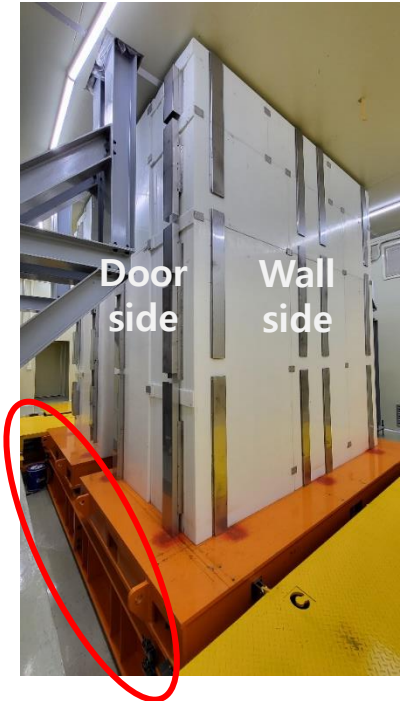
- PS box size
 - ▶ Long type : 1680mm x 310mm x 61mm
 - ▶ Short type : 1210mm x 310mm x 61mm
- Side part : 27ea PS boxes(long type 25ea, short type 2ea) will be used for one side of AMoRE-II shielding
- Bottom part : 24ea long type PS boxes will be used for Bottom part of AMoRE-II shielding



[Long PS box size]



[structure of PS detector (side part)]

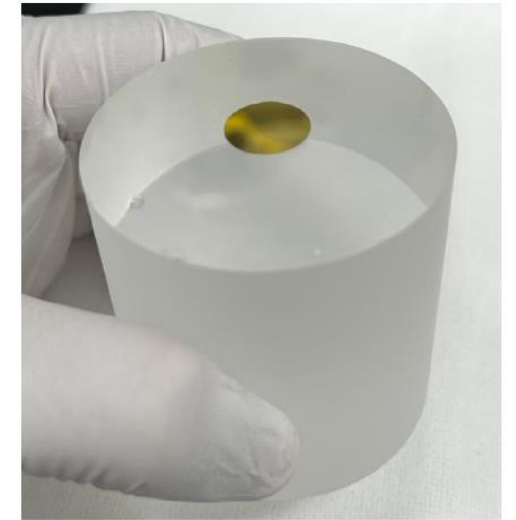
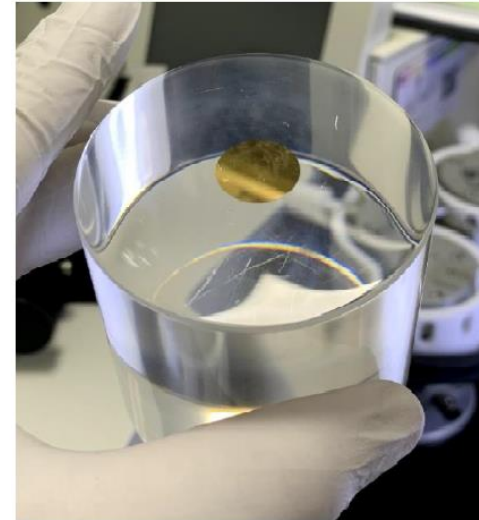
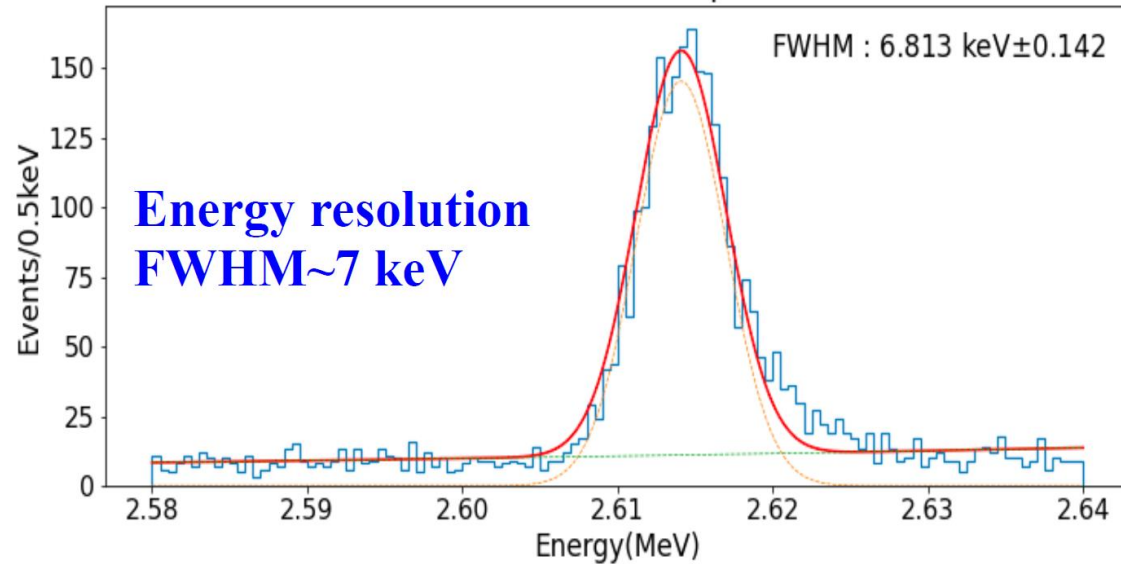


[location of bottom part of PS detector]

Detector R&D

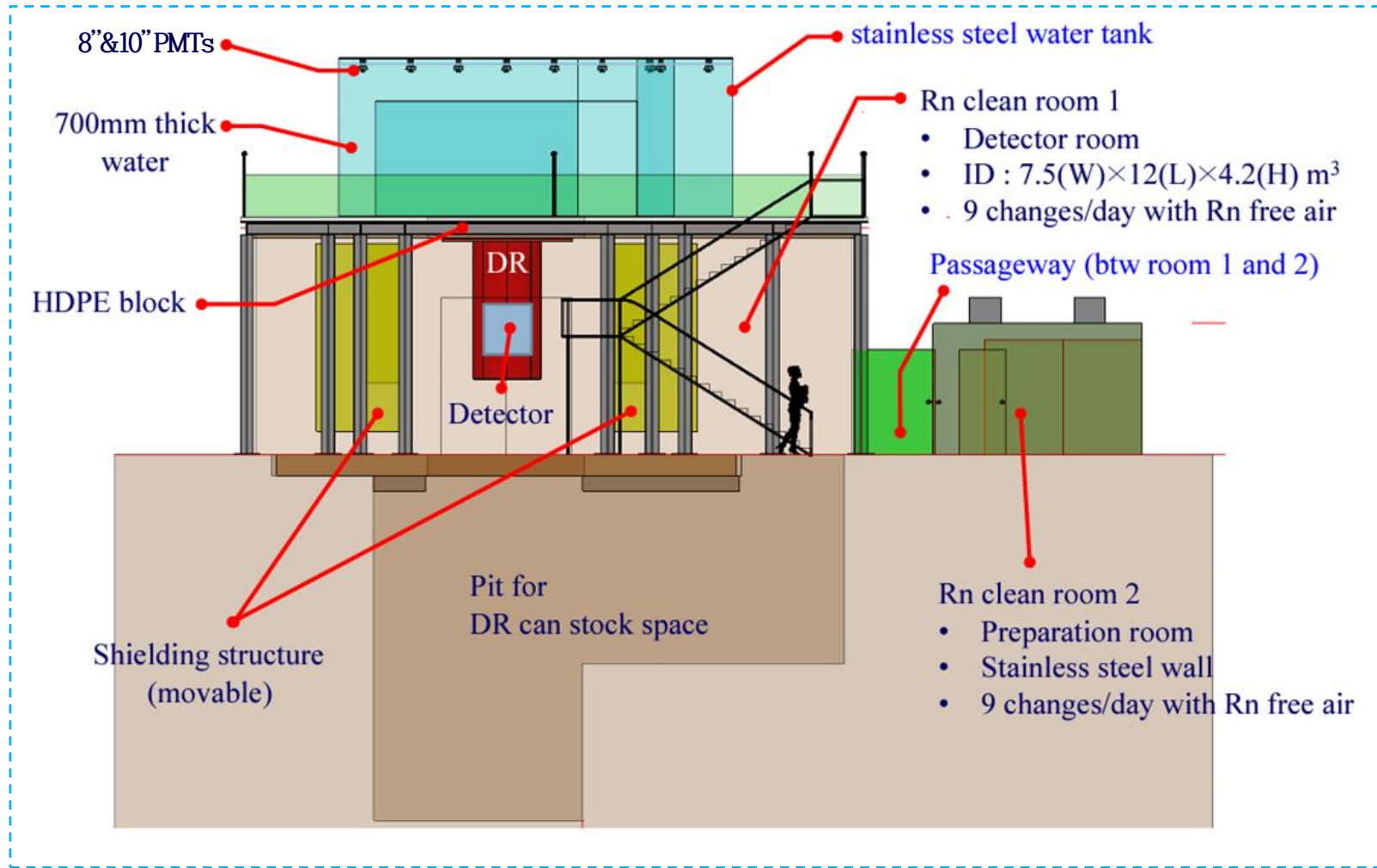
*TAUP2023, Y.M Oh, AMoRE-II preparation status
* WT Kim, JINST 17, p07034(2022)

- Crystal size[$\phi \times H$] : 5 \times 5 (98 cm³), 6 \times 6 (170 cm³)
- Pile-up background at ROI can be below 3×10^{-5} counts/keV/kg/year.
- $\Delta E = 7\text{-}9$ keV FWHM at 10 mK.
- β/α discrimination power > 10 .



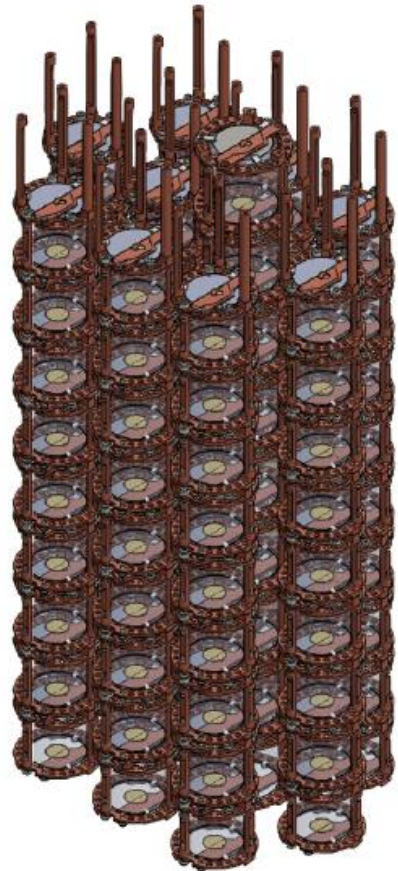
AMoRE Hall

[Drawing of AMoRE Hall]

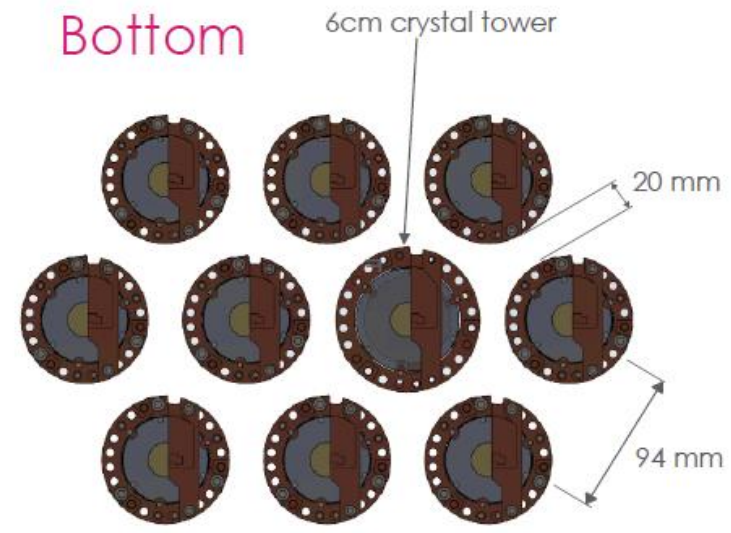


- Space dimensions: 21 m (w) x 21 m (d) x 16 m (h), 441 m² area
- Construction: Detector room, monitoring room, preparation room, changing room, Water Cherenkov (WC) tank...
- Radon reduced air will be supplied to the detector and preparation rooms (clean areas)

AMoRE-II Detector Tower



Bottom



Side

