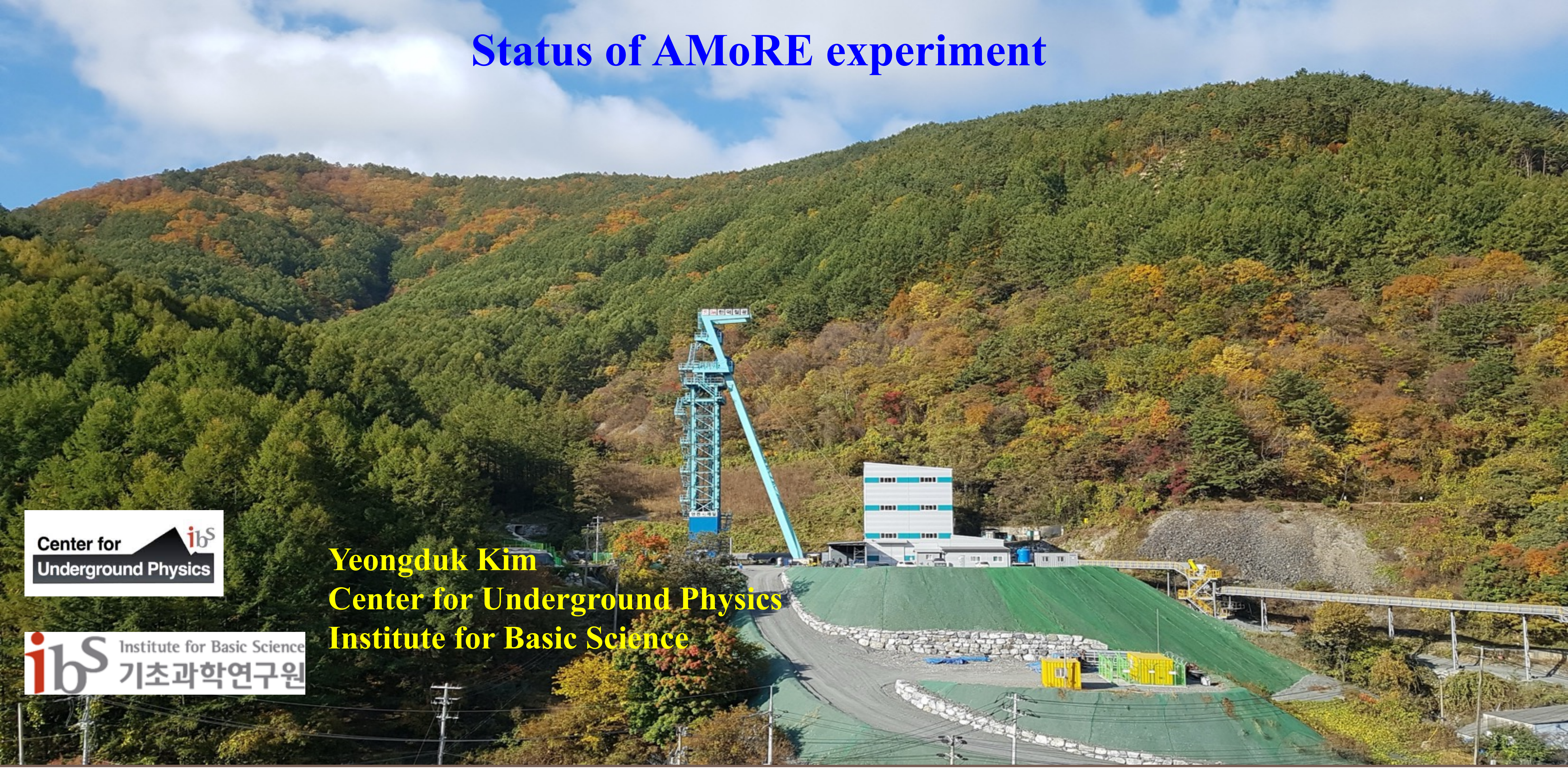
Status of AMoRE experiment



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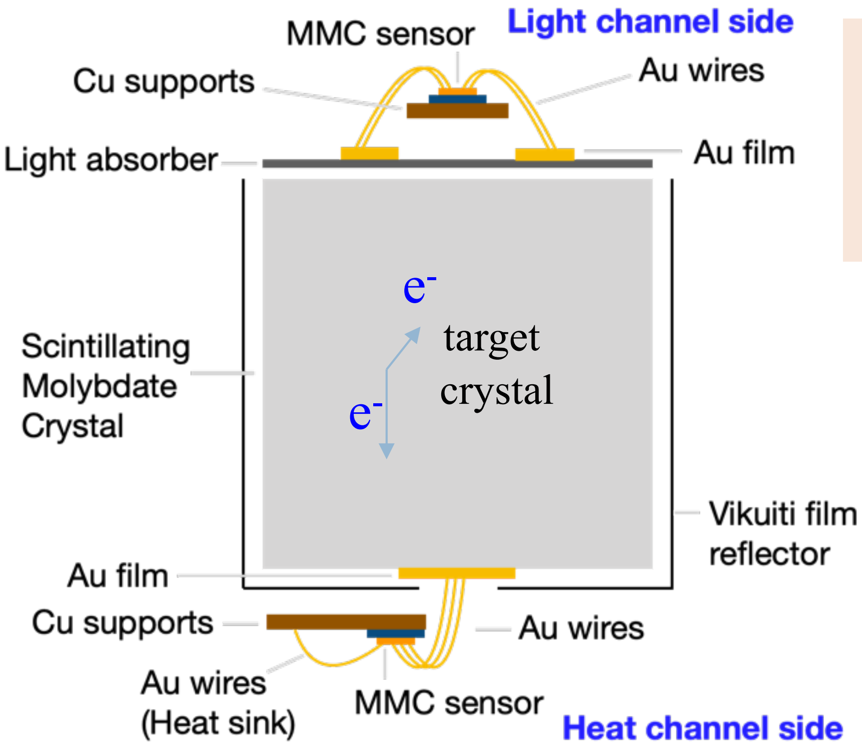
2024. 2. 20.

NPB 2024, HKUST, Hong Kong

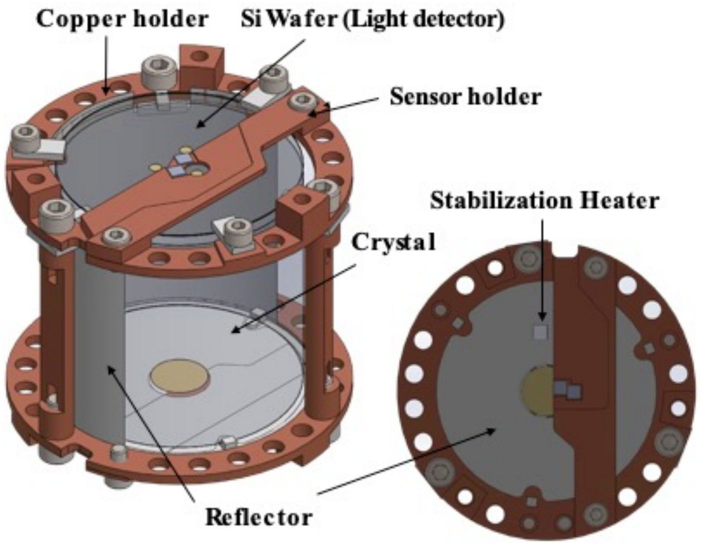
AMoRE Collaboration

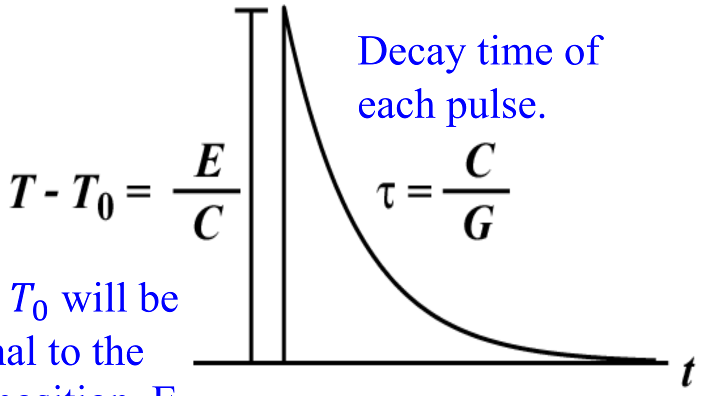
10 Countries, 26 Institutions - Korea, Germany, Ukraine, USA, Russia, China, Thailand, Indonesia, India, Pakistan

Overview of AMoRE detector



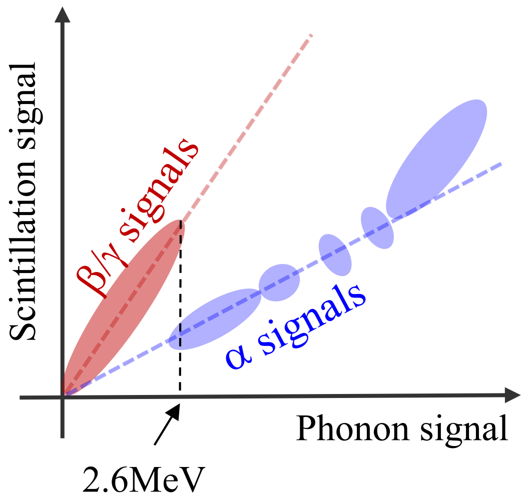
- ^{100}Mo (Q = 3.034 MeV, Natural abundance : 9.74%).
- Use scintillating bolometer with $^{40}Ca^{100}MoO_4$(CMO) and $Li_2{}^{100}MoO_4$(LMO) to have good energy resolution (<10 keV (FWHM))





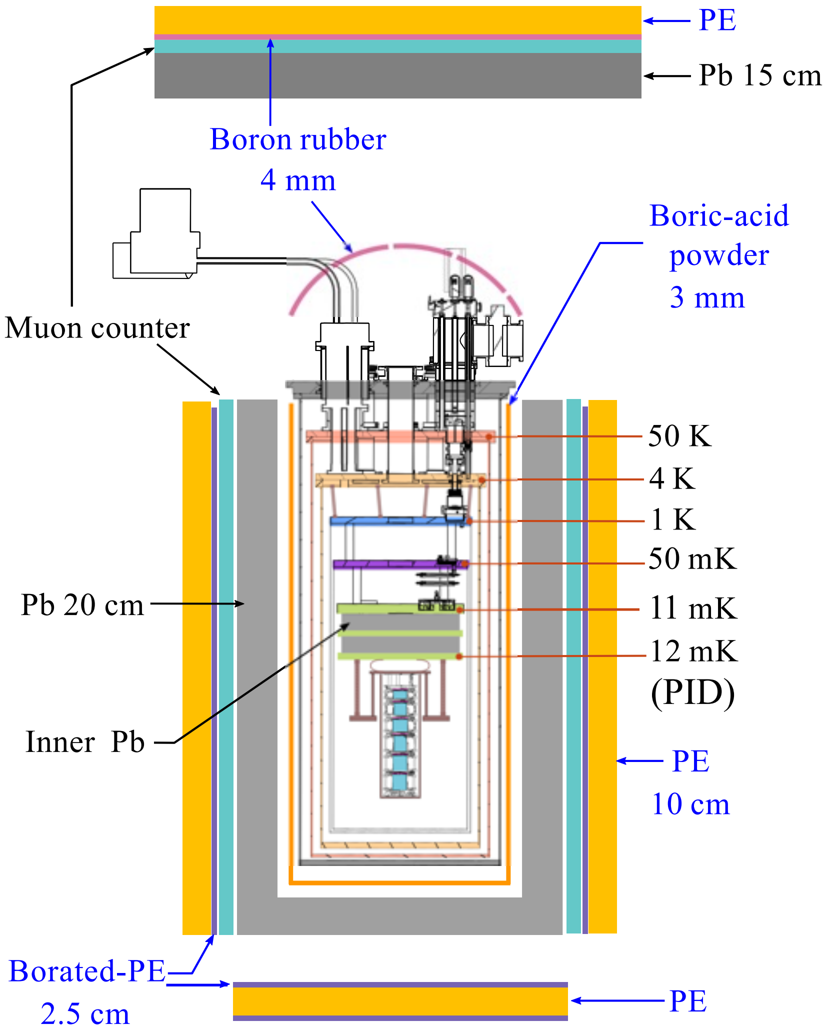
$\Delta T = T - T_0$ will be proportional to the energy deposition, E

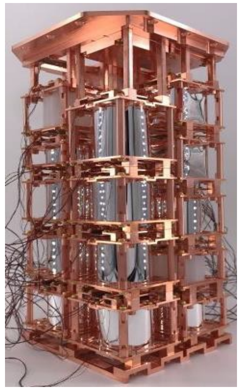
Surface alphas are continuous in energy and can be rejected by scintillation measurement.

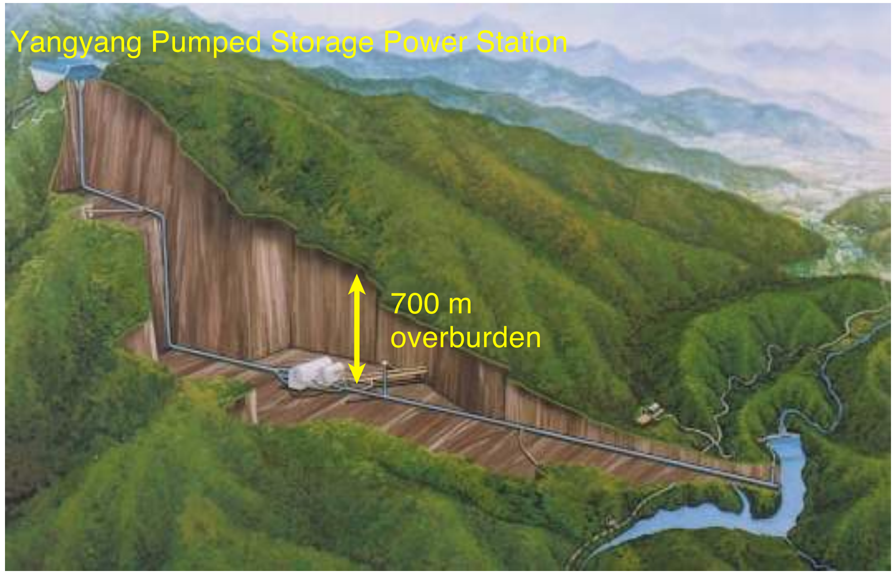


AMoRE-I @ Y2L : (2020.12-2023.5, ~ 900 days)

- To check detector performance & backgrounds.

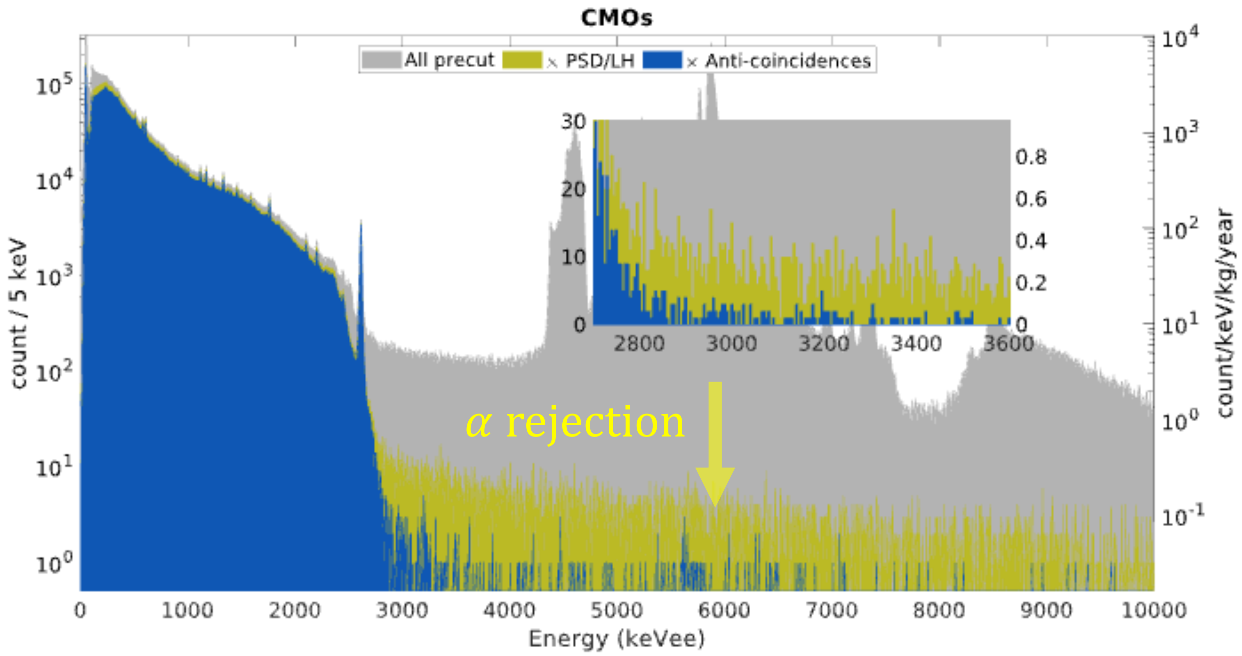


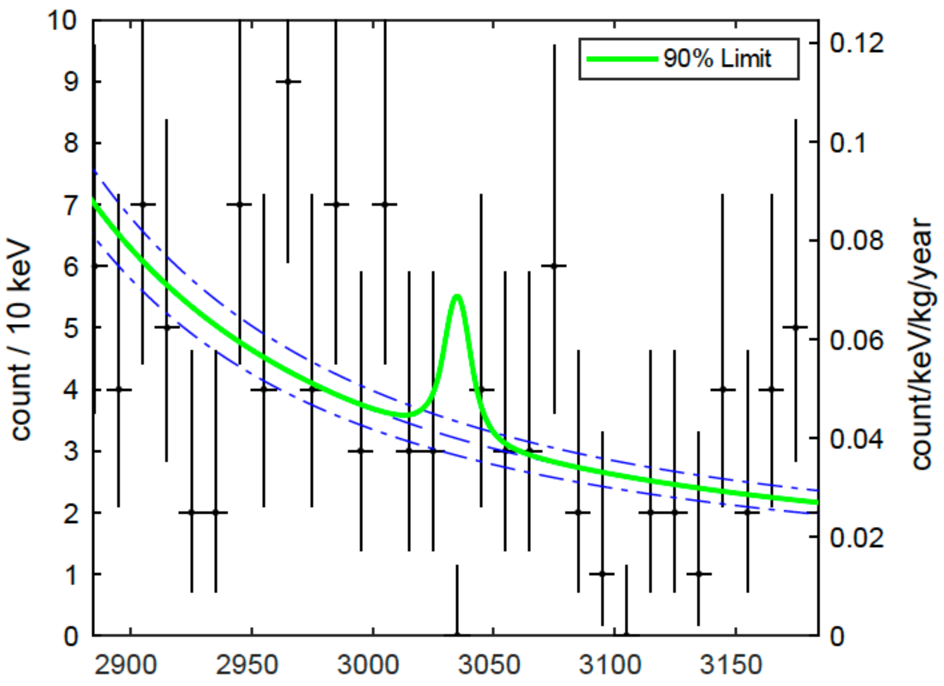




- Run @ Yangyang Underground Laboratory (Y2L)
- Cryogen-free dilution refrigerator @12 mK
- Detectors: 13 CMO crystals (4.6 kg) and 5 LMO (1.6 kg) crystals
- 20cm Pb shielding + neutron shields (boric acid+PE+b.PE)
- Confirmed stable operation of MMC+SQUID system.

Background spectra after alpha background rejection





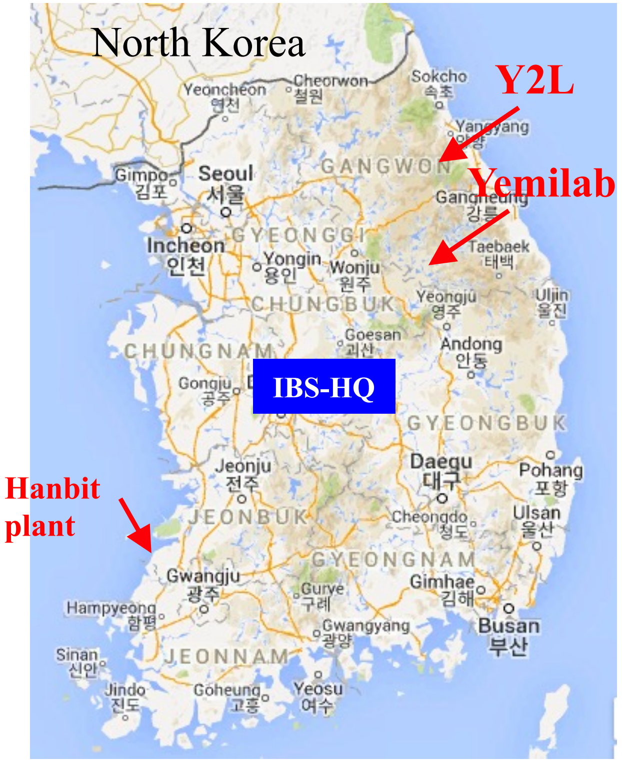
- 17 crystals excluding one LMO (for very poor β/α discrimination power)
  - Exposure = 8.02 $kg_{XMoO_4}\cdot$ yr = 3.88 $kg_{^{100}Mo}\cdot$ yr.
  - CMO has higher alpha backgrounds and rejection power is high.
  - LMO has lower alpha backgrounds and rejection power is low.
  - ~ 3 × CUPID-Mo exposure (1.48 $kg_{Mo\text{-}100}\cdot yr$).

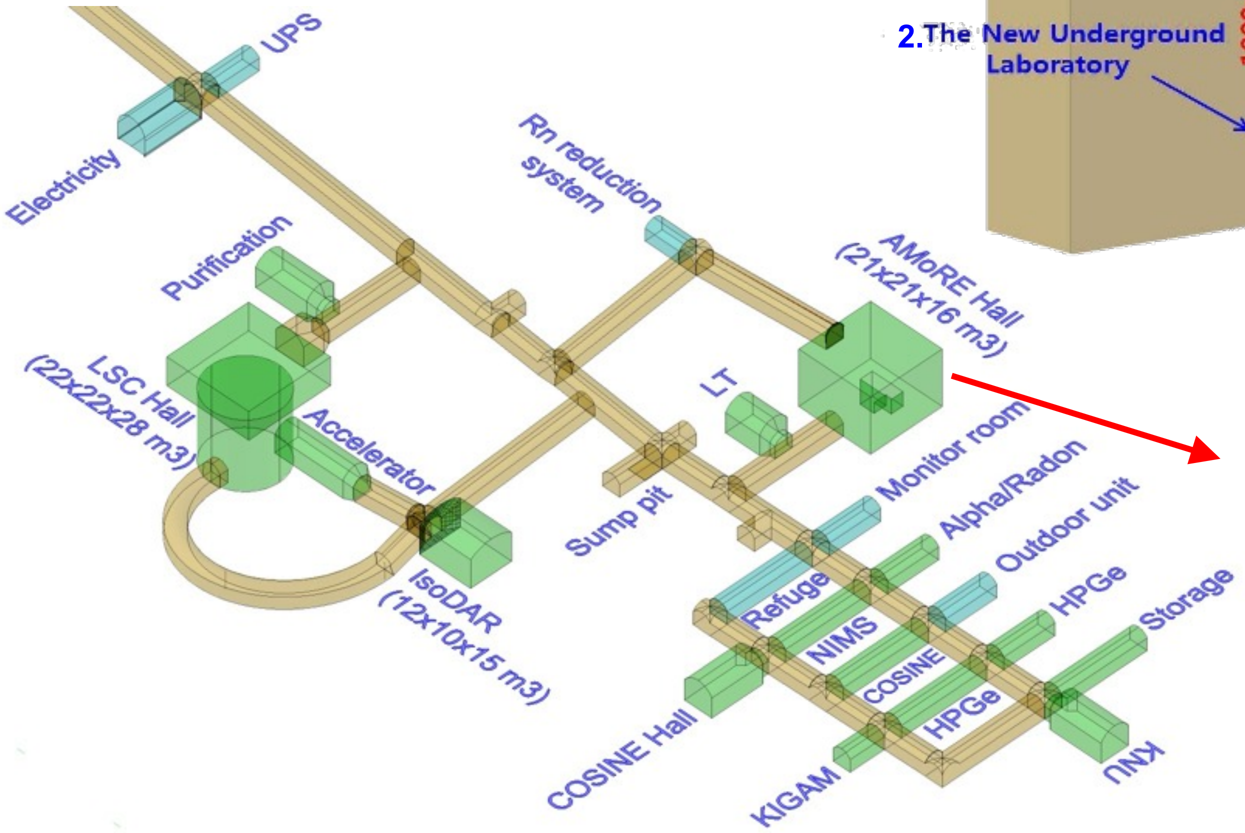
→ $T^{0\nu}_{1/2} > 3.4\times10^{24}$ *years*

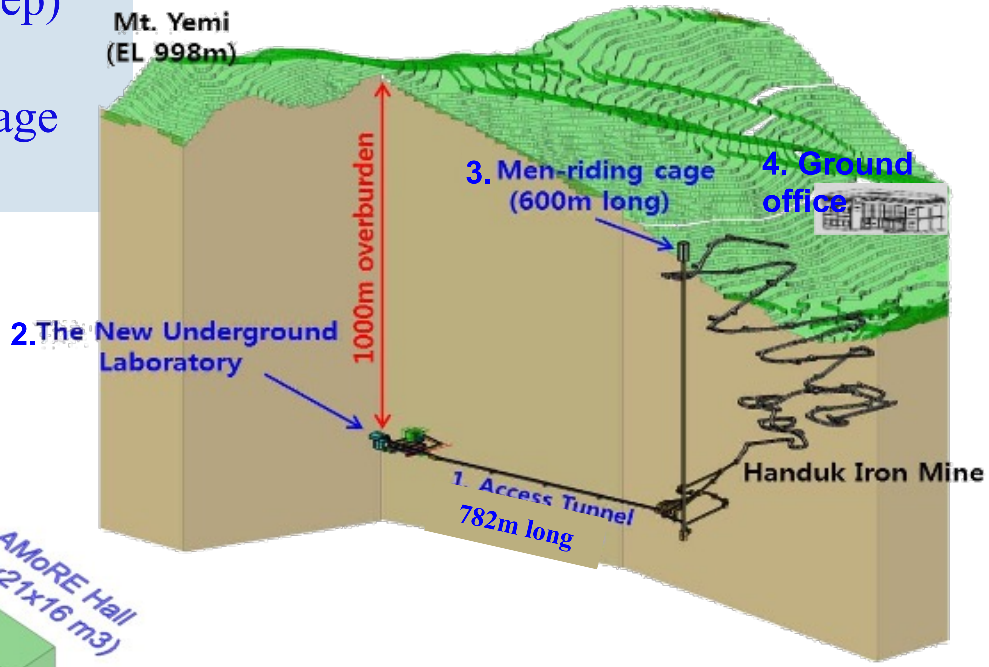
Cf. Current best limit 1.8×10^{24} *years* by CUPID-Mo

AMoRE-II @Yemilab Yemi (禮美)

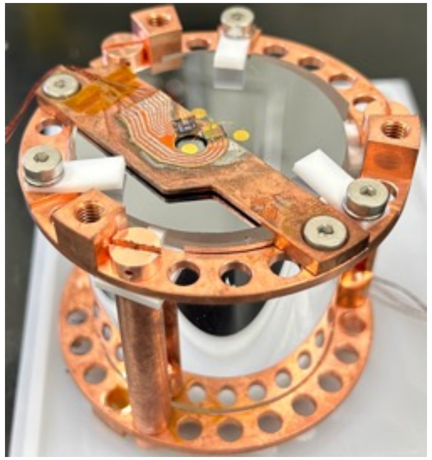
- Yemilab is constructed in 2022. (1000m deep)
- Lab space > 3000 m², 2.5 MW electricity.
- Two access ways: ramp-way, men-riding cage
- Open to other researchers IBS.







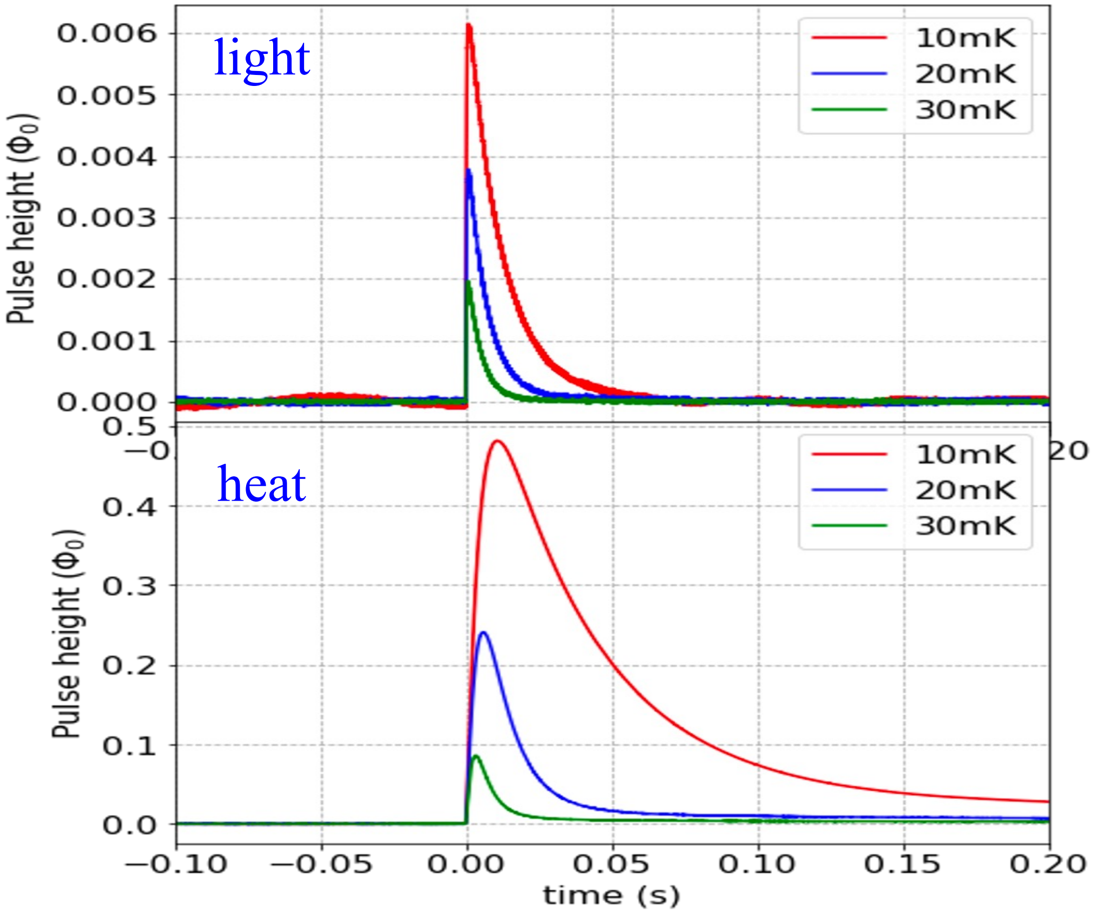
Detector R&D @ ground lab



- Signal pulses for 2.615 MeV gamma-rays at different temperatures. (LMO)
- Fast signals thanks to MMC sensor reading

  $\tau_{rise}(10\ \text{mK}) \sim 3.8 - 5.9\ ms$ for heat signal

  $\sim 0.5 - 0.9\ ms$ for light signal

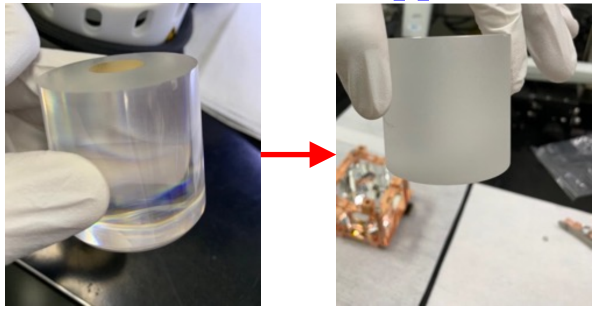


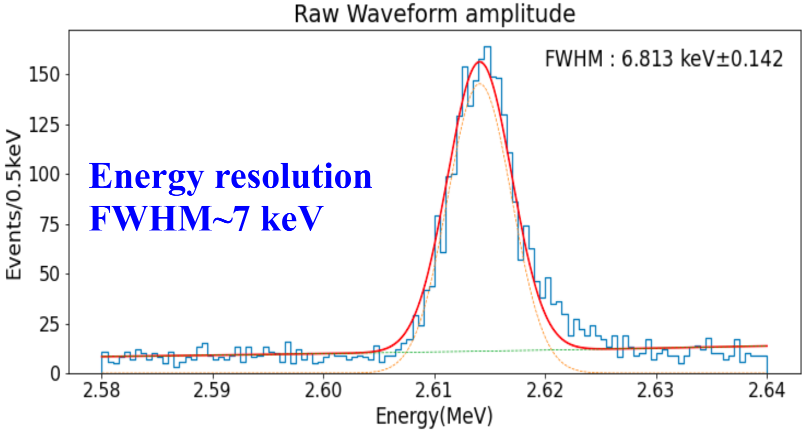
Energy resolution and particle identification.

JINST 17, p07034(2022)

(1) Polishing vs lapping(roughening)

Polished surface Lapped surface

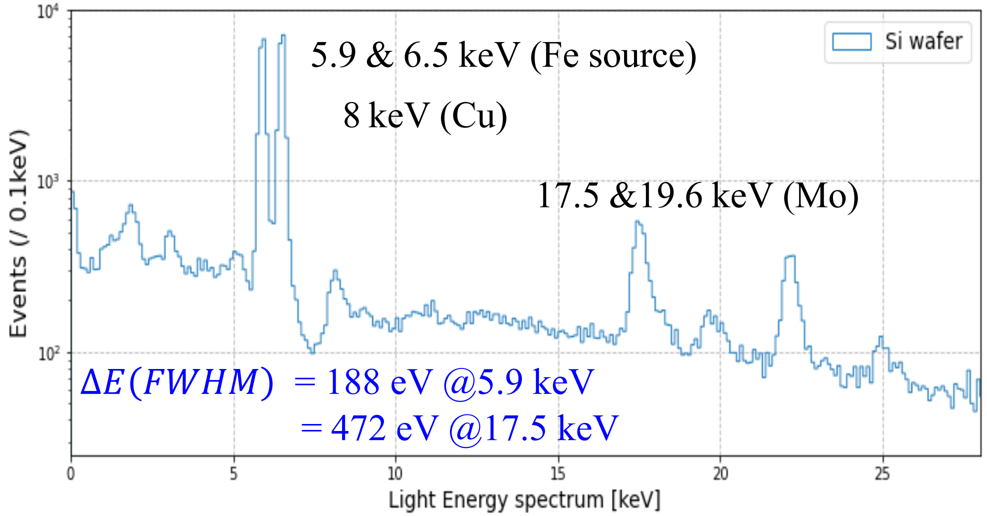


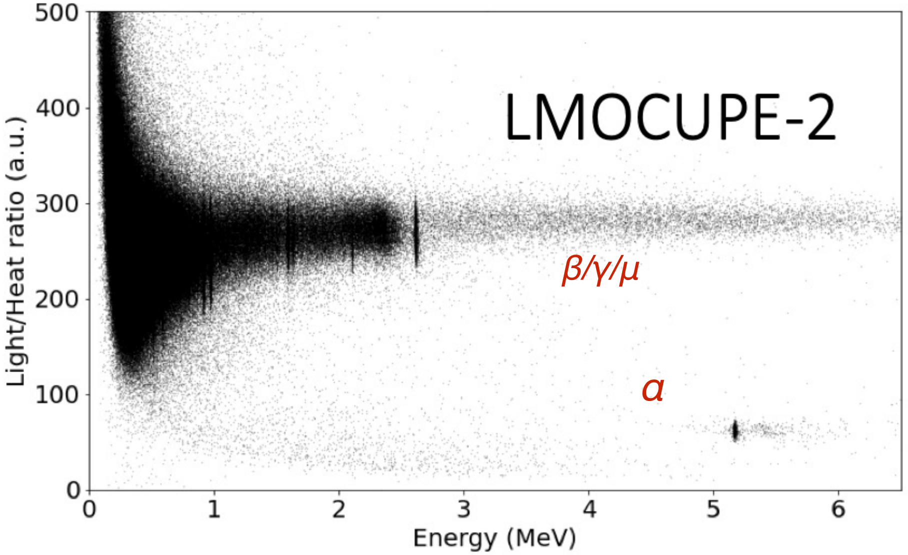


- Better energy resolution ~ 7 keV FWHM.
- Signal slower, rising time 3.2 ms → 4.8 ms.

Satisfactory energy resolution keeping the fast rise time.

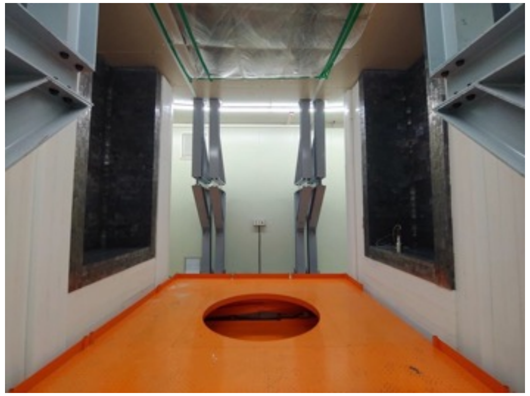
(2) Si wafer for light detector

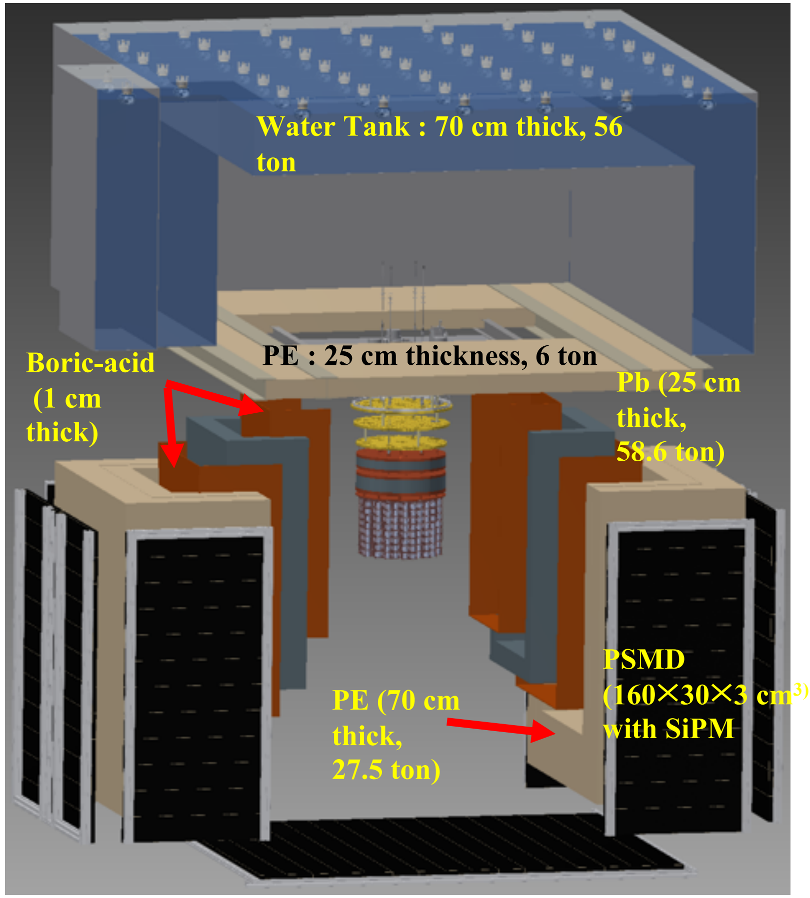


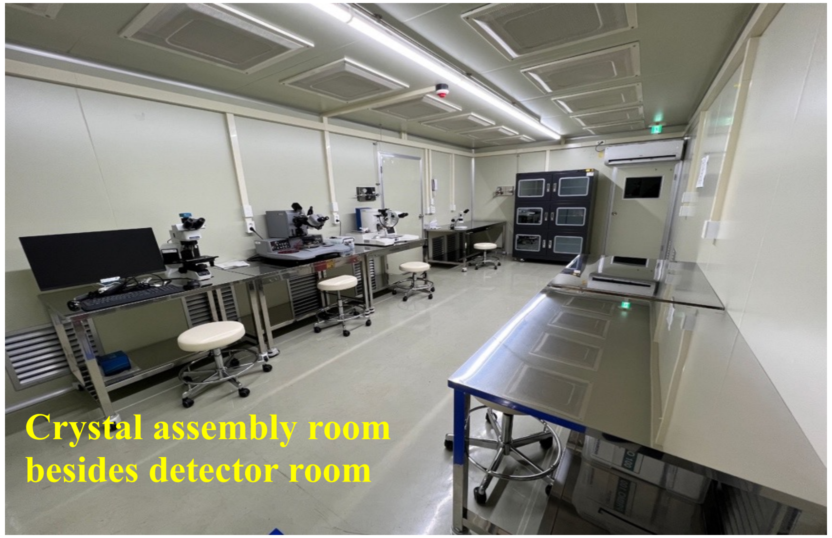


Better PID →
DP factor > 10.

AMoRE-II installation







Crystals are assembled in copper holder and tower

- Class 100
- Humidity<1%
- Rn < 200mBq/m^3

Signal readout

Cabling:

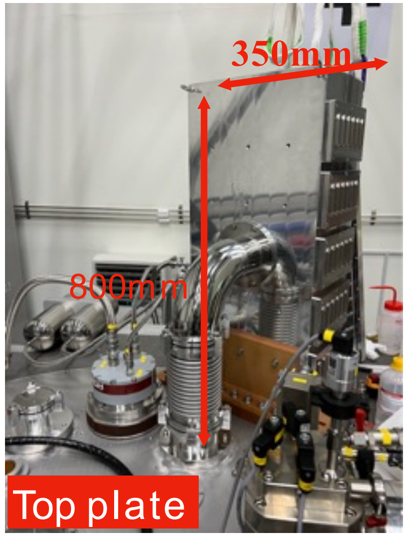
- 360 detectors, 24 wires for each detector (phonon/photon, heater)
- Ribbon cables between top plate and MC
  - TEKDATA CuNi alloy30, D=0.16 mm with NOMAX wire
  - SQUID: 63 wires, MMC: 36 wires

AMoRE-II SQUID electronics:

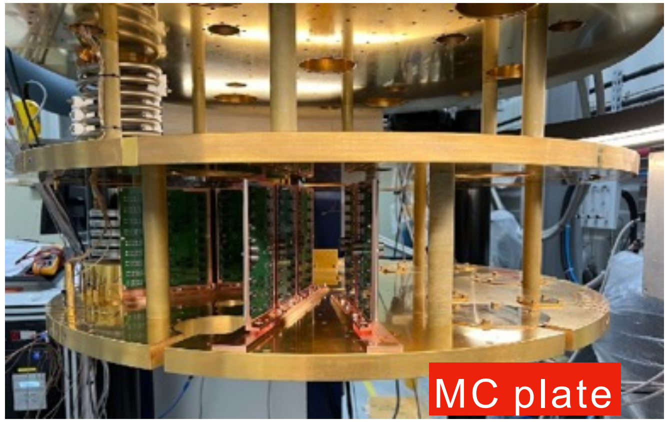
- Compact electronics for large number of SQUIDs by Magnicon.
- 9 SQUID channels / module.
- Similar noise performance compared to current small unit controller.
- Low power consumption, reasonable costs.

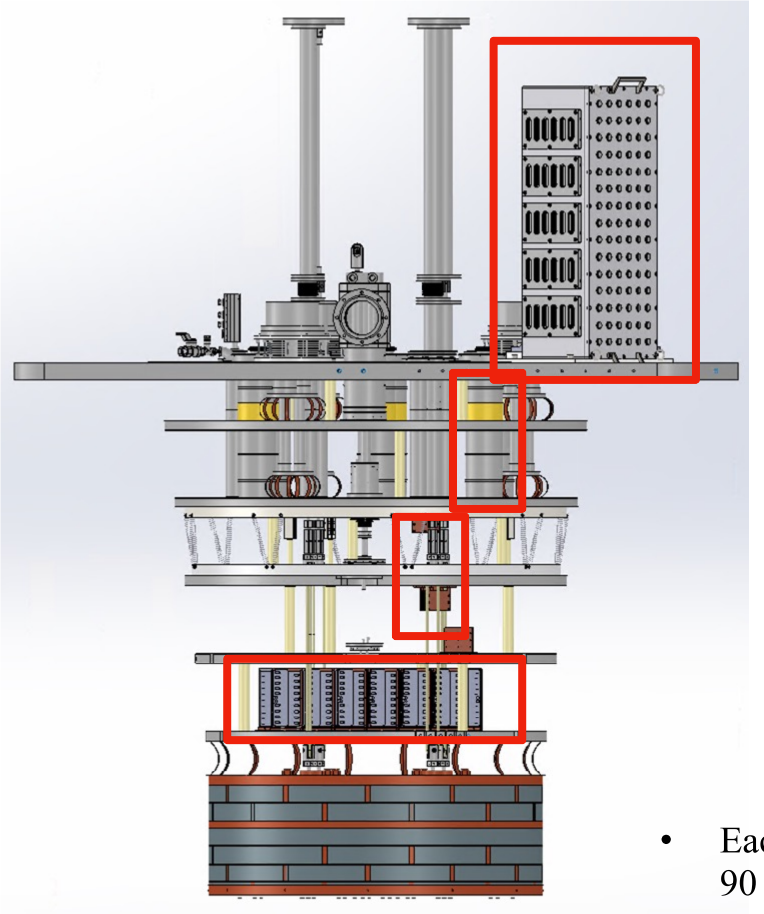
Vacuum Feedthrough & Wiring

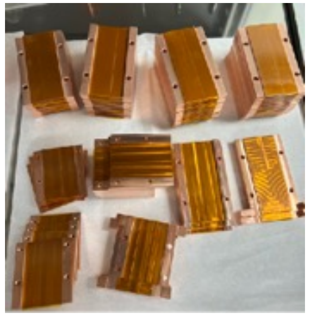
- Installed 270 SQUID & MMC channels for phase-1.
- After cooling test, will install DR at Yemilab.

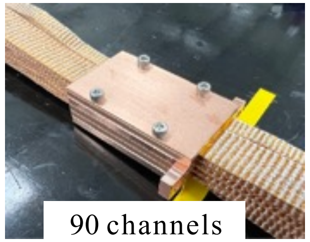


- **PCBs for MMC & Stabilization's filter circuits.**
- **ribbon wires ←→ detector wires.**

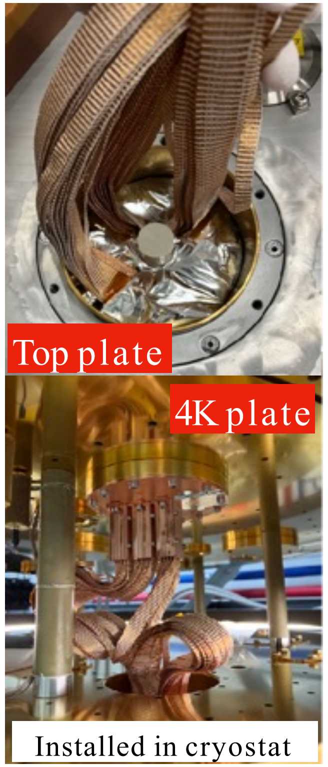







90 channels

50K anchoring part with ribbon cable



Installed in cryostat

- Each bundle consists 90 channels of MMCs and SQUIDs

Crystals

Purification

- Purification of both powders, $^{100}MoO_3$ and Li_2CO_3 to produce pure $Li_2{}^{100}MoO_4$ crystals.
- 120 kg of enriched MoO_3 powder is purified in wet chemistry: 150 kg at CUP and 30 kg at NIIC.
- Repurification of crystal melts and wastes is going on.

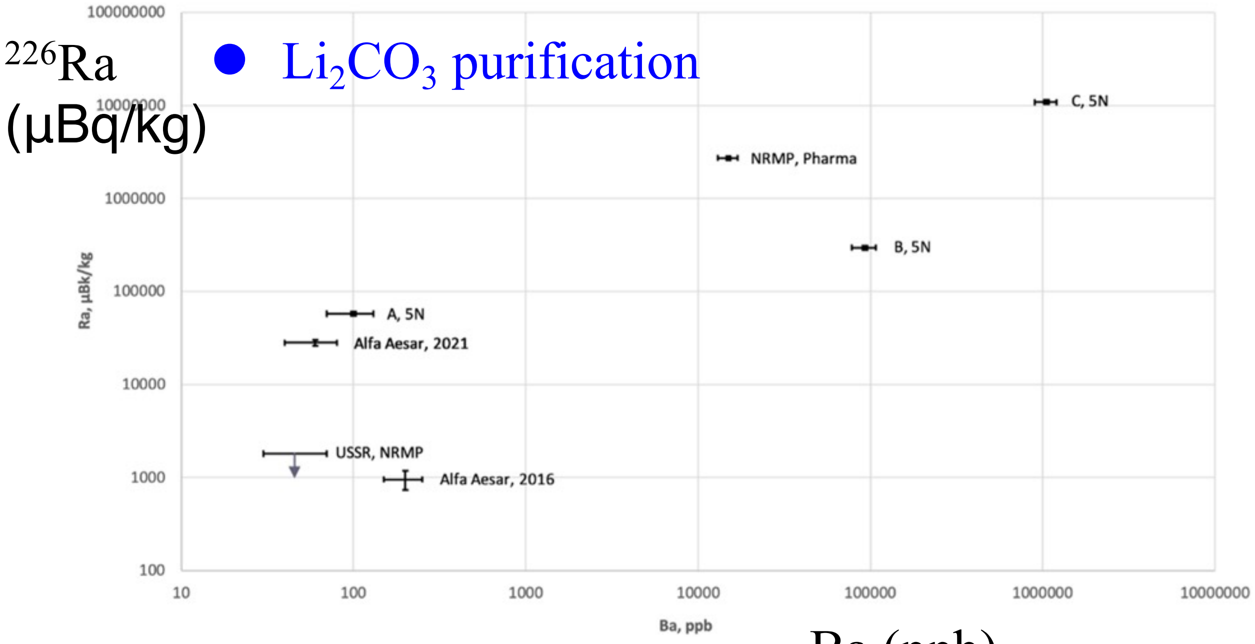
In press in Front. Phys.

- $^{100}MoO_3$ purification (µBq/kg)

	^{228}Ac	^{228}Th	^{226}Ra	^{40}K
Raw $^{100}MoO_3$	260 ± 50	210 ± 50	260 ± 50	8500 ± 1400
Purified $^{100}MoO_3$	<27	<16	110 ± 30	1700 ± 340

Front. Phys. 11:1142136.

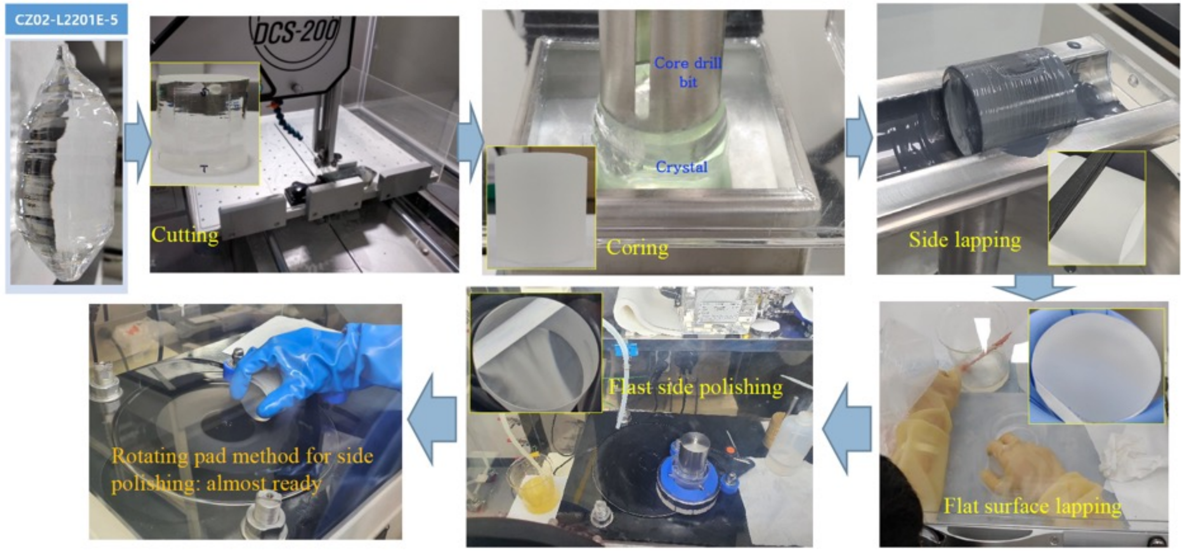
- Li_2CO_3 purification



Decontamination factor:
~20 for K
~10 for Th
~50 for Ra-226 in synthesized Li_2CO_3 powder

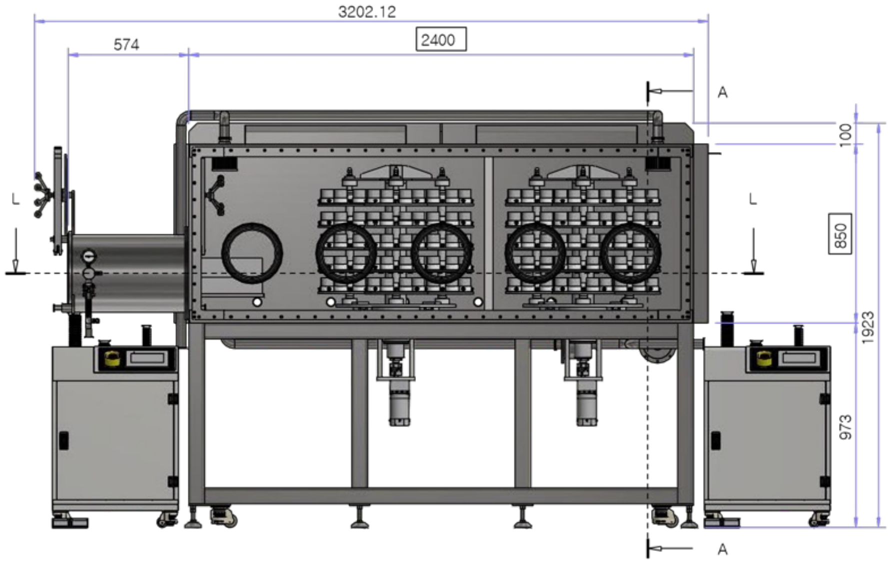
Crystal growing

- Crystals are grown at both CUP (Czochralski) and NIIC (Low temp. gradient).
- Growing speed gets slower due to the recycling of crystal melts and wastes.

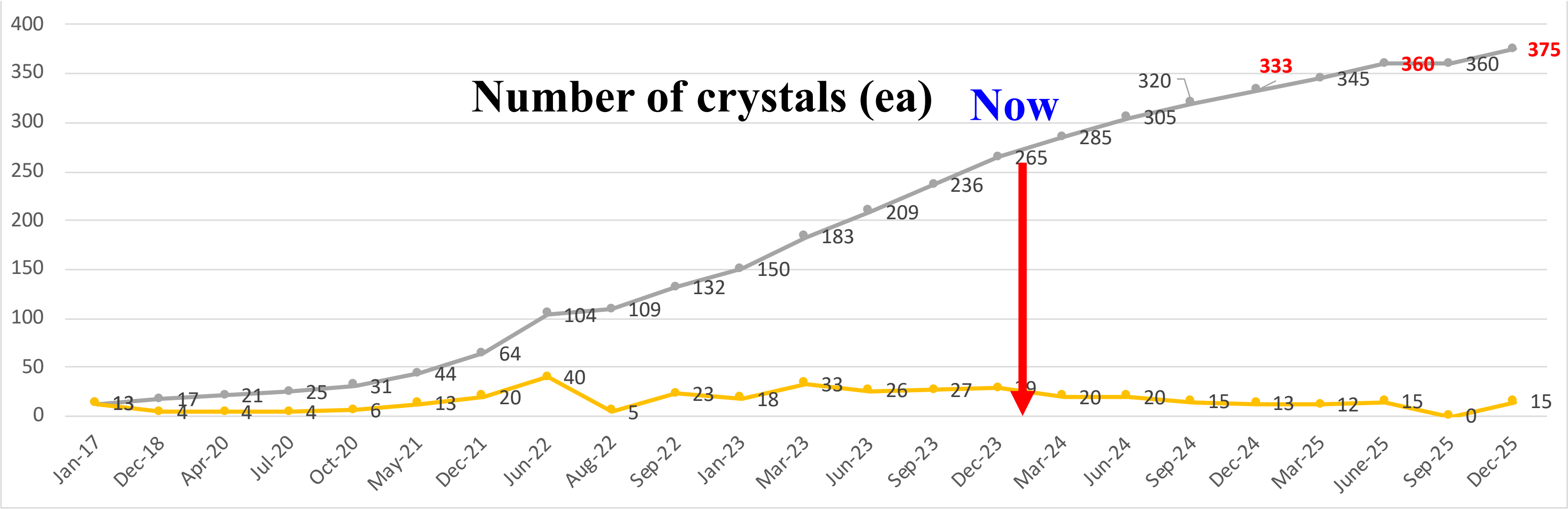


Lapping @ polishing compounds and pads are selected.

- Dry box for crystal storage



Crystal production schedule

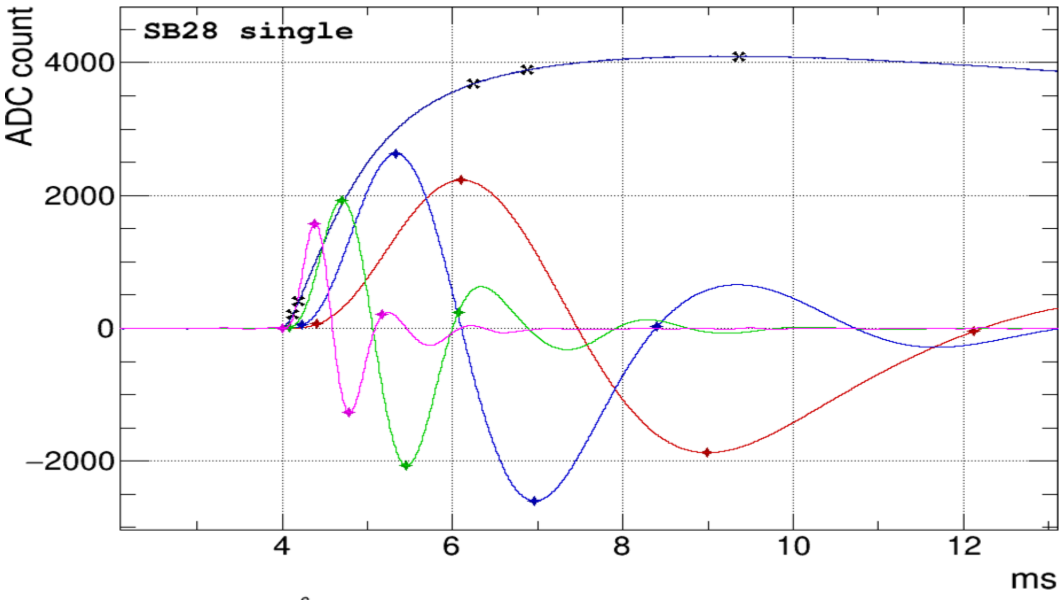


15 CMO, 113 (5 cm) & 141 (6 cm) LMO
-> 269 ea, 109.6 kg (58.9 kg Mo-100)

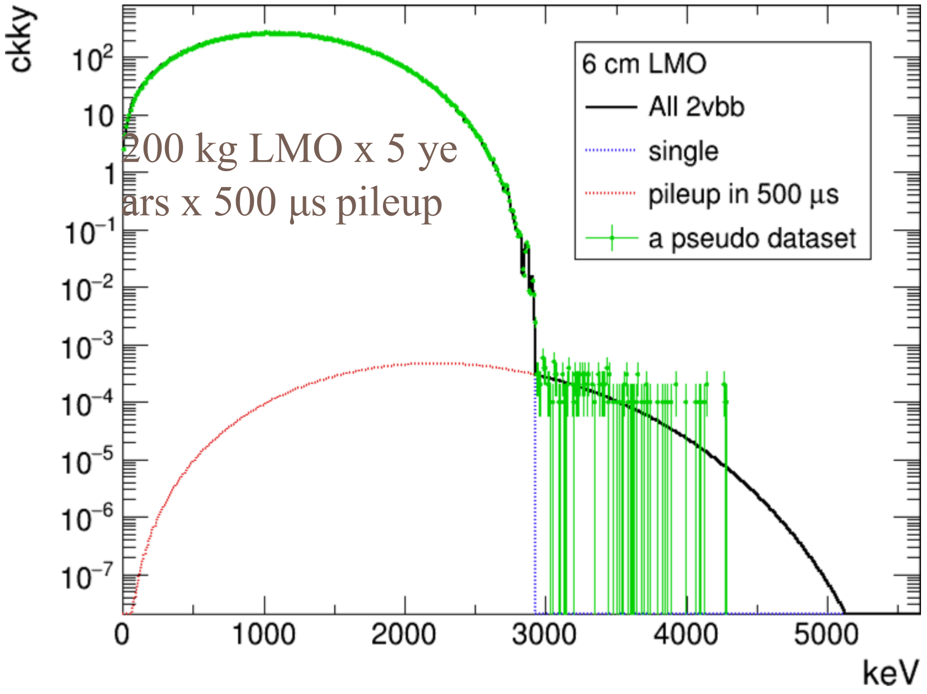
- **By mid 2025:**
  157 kg (84.4 kg Mo-100), 360 crystals will be grown.

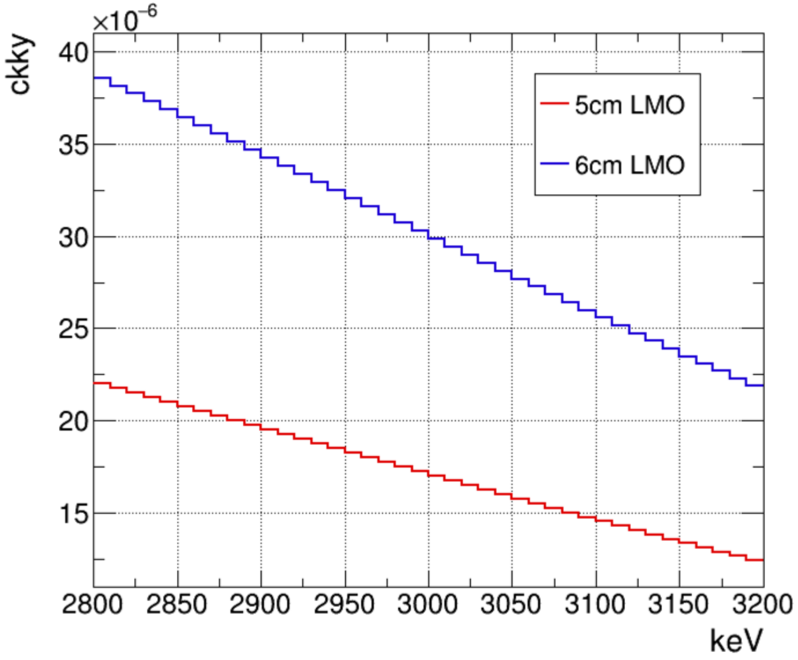
Pileup rejection in AMoRE-II

- Significant due to short lifetime of two neutrino lifetime of ^{100}Mo. (20 mBq/kg)
- Thanks to fast timing response of MMC, the pileup background of AMoRE-II is within the experimental requirement even with ~ 500g detector.
- Need multi-variable analysis to obtain the rejection efficiency high.



Pile-up backgrounds

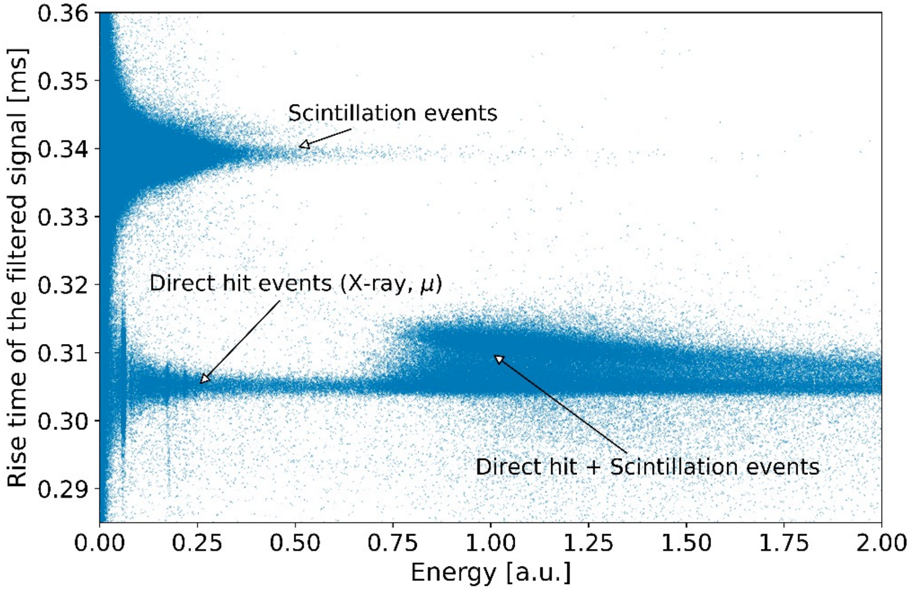


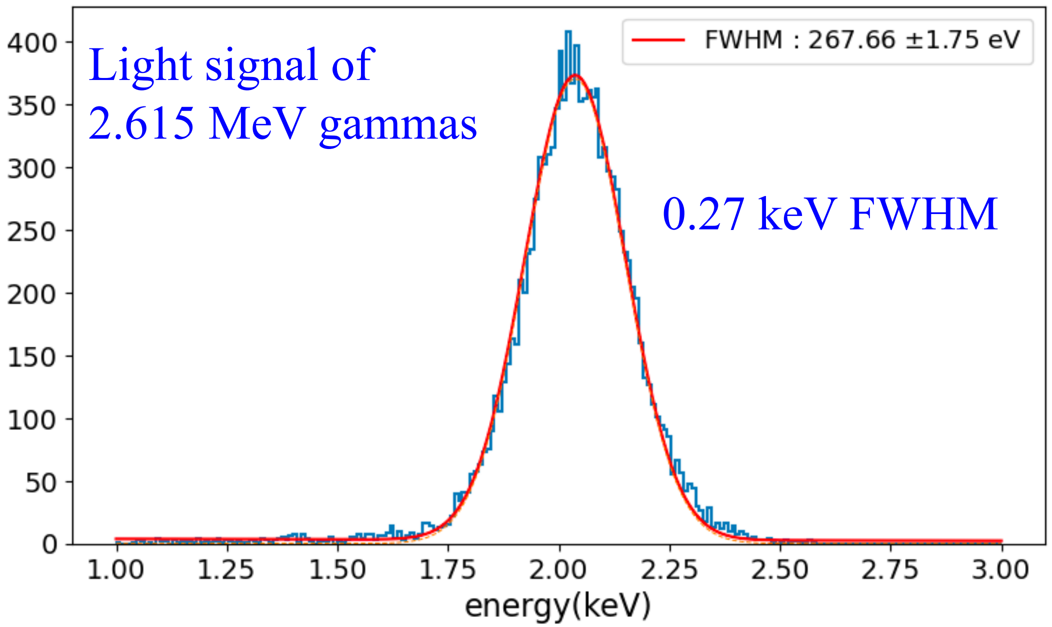


Light detector

- Fast rise time of light detector, $\tau_{rise} \sim 0.5 - 0.9\ ms$
  - LMO scintillation decay time ~ 0.1 ms. (Fast 0.04 ms, slow ~ 0.5ms)
- ~ 0.9 keV/MeV scintillation light measured.
  - 0.27 keV FWHM resolution with 2.615 MeV gammas.

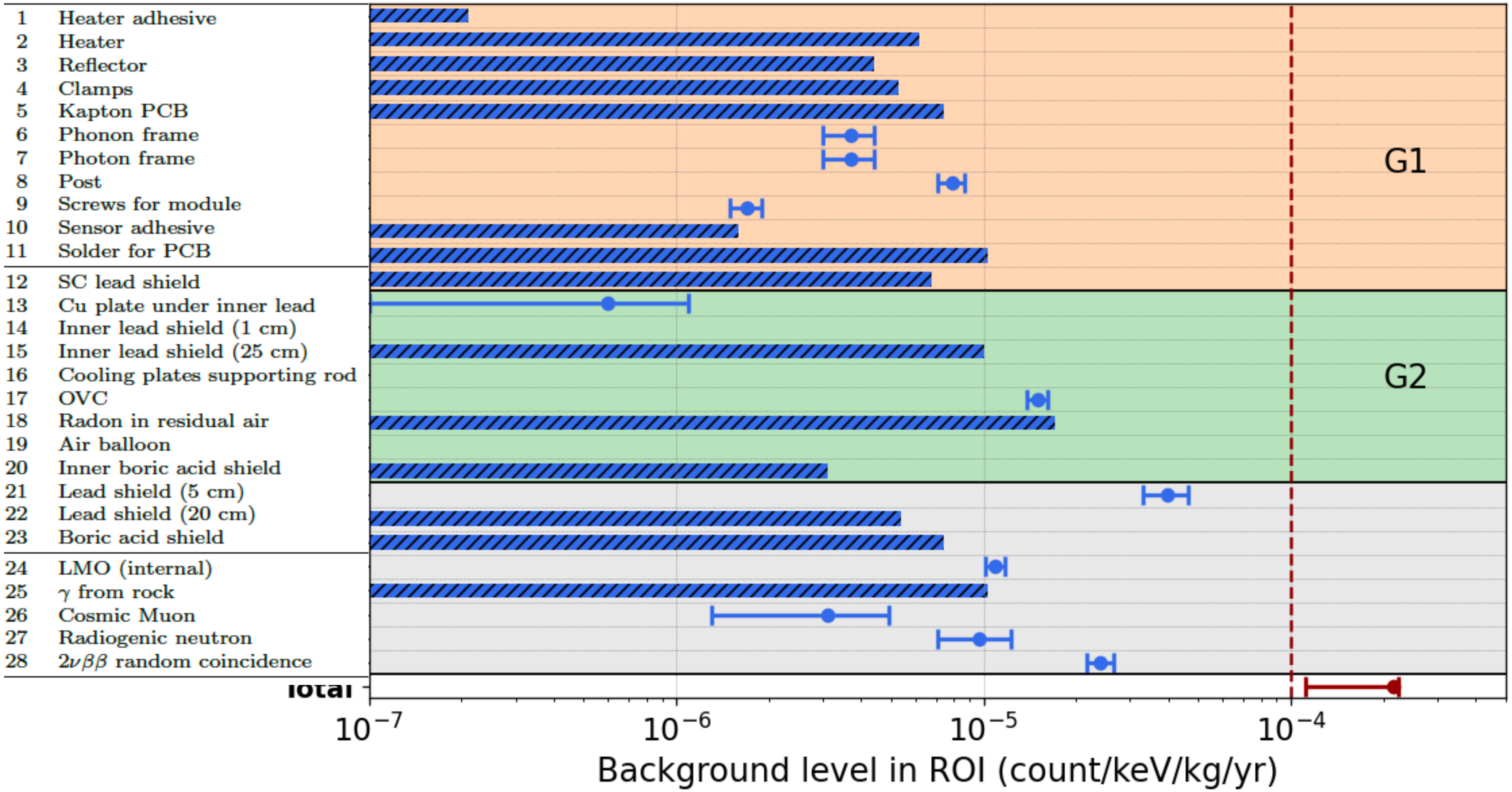
Expect to reduce the pileup backgrounds with light signal rise time analysis.





Background of AMoRE-II

- A few items will be improved by replacing the materials.
- Expect to reach 10^{-4} counts/(keV kg year) (ckky) level.



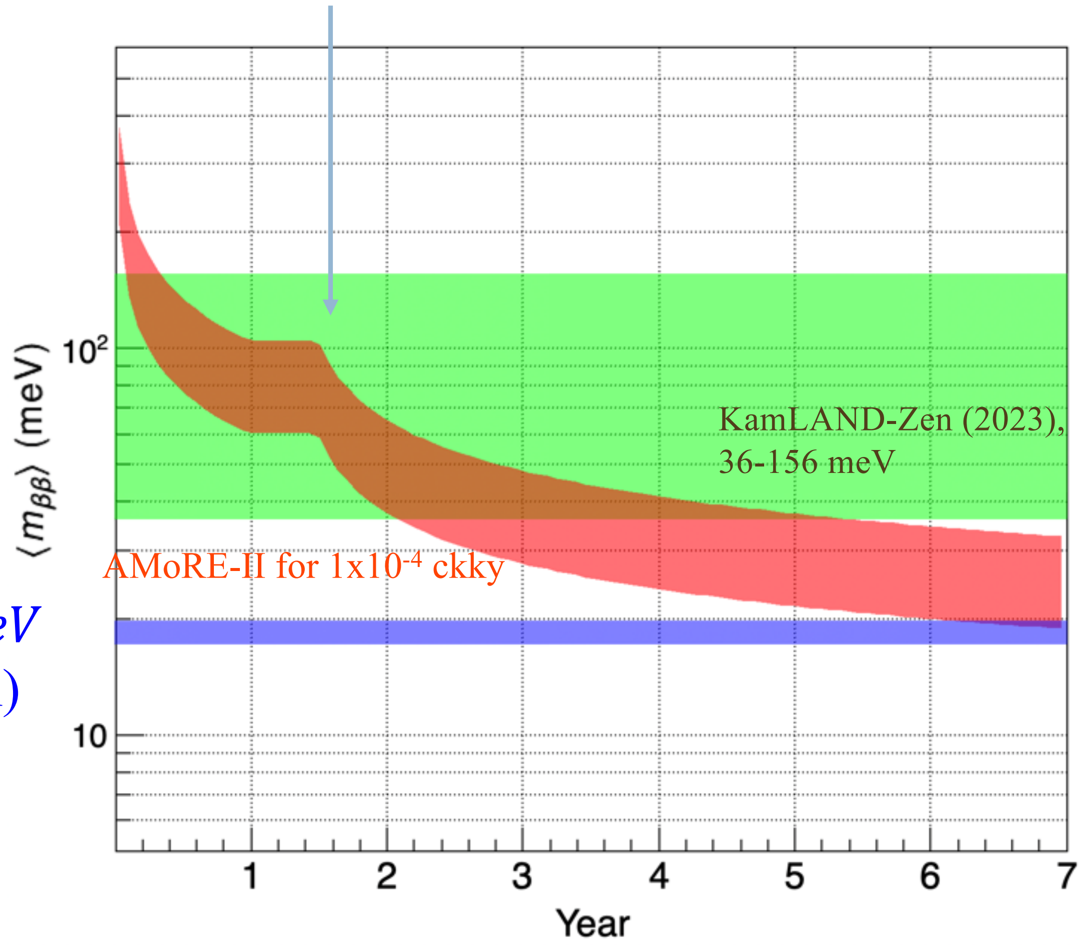
Sensitivity of AMoRE-II

Discovery sensitivity :

The half-life for which an experiment has a 50% chance to measure a signal above background with a significance of at least 3 sigma (99.7%).

90 crystals

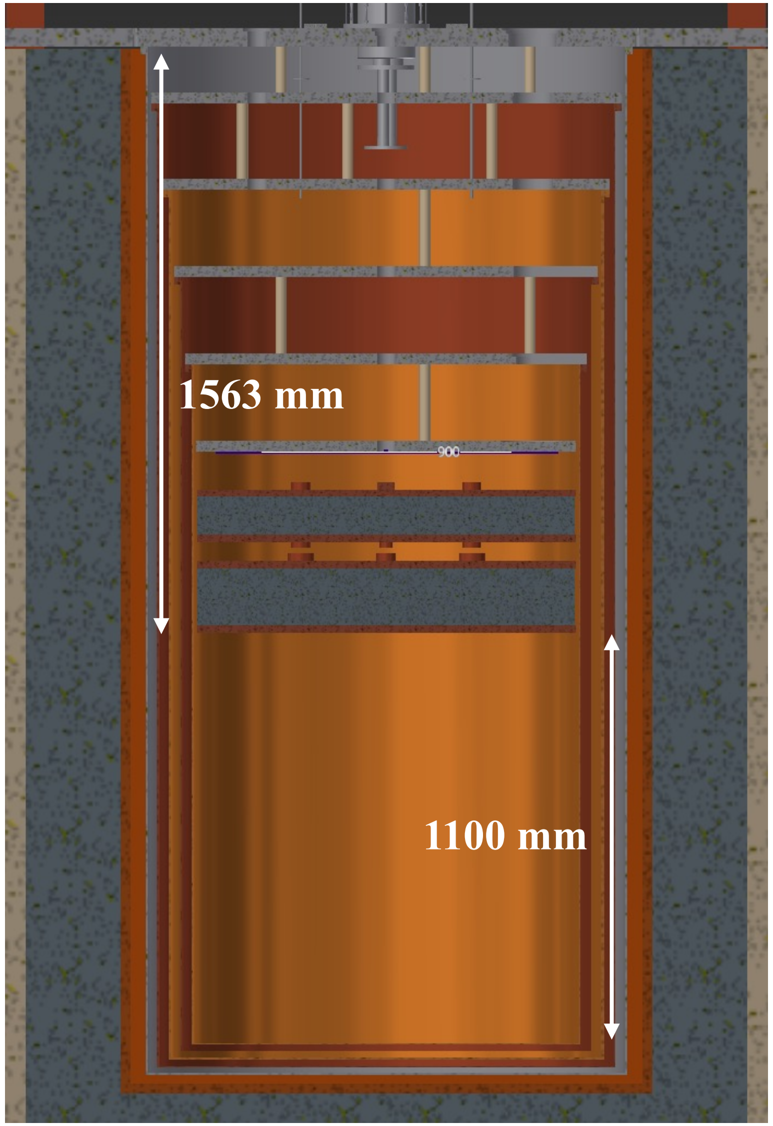
400 crystals

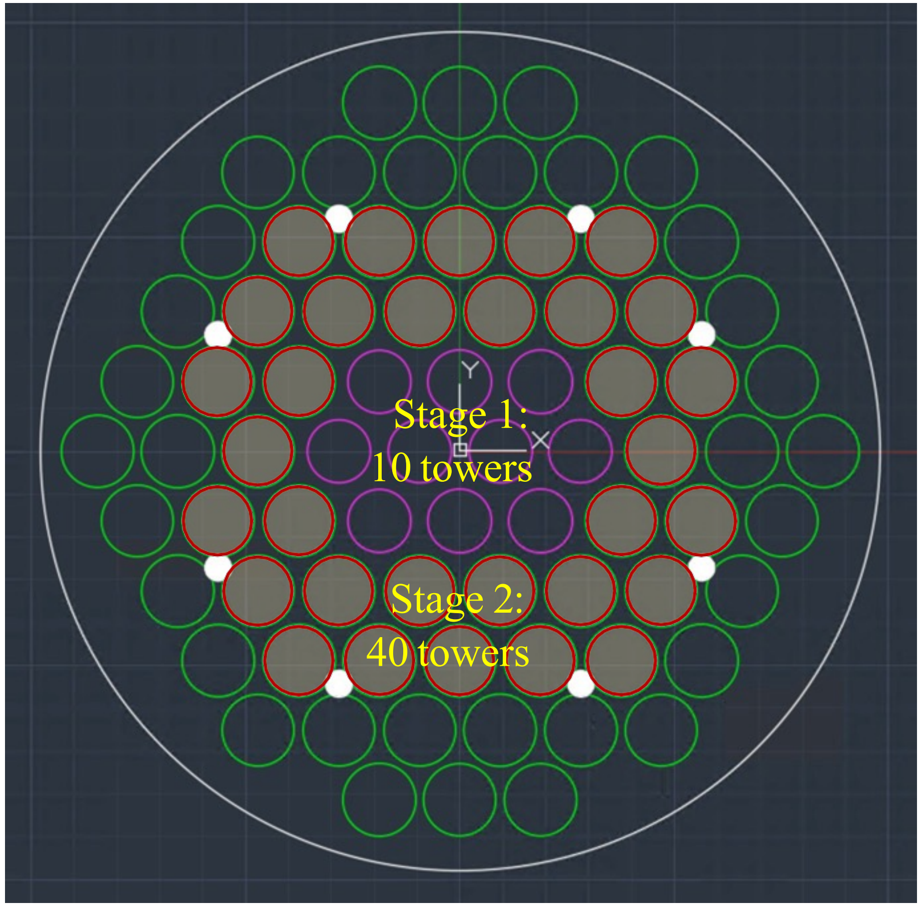


$18.4 \pm 1.3\ meV$

(IO band min)

Beyond AMoRE-II





Maximum capacity of current Cryostat:
~ 900 crystals. (~200 kg ^{100}Mo isotopes)

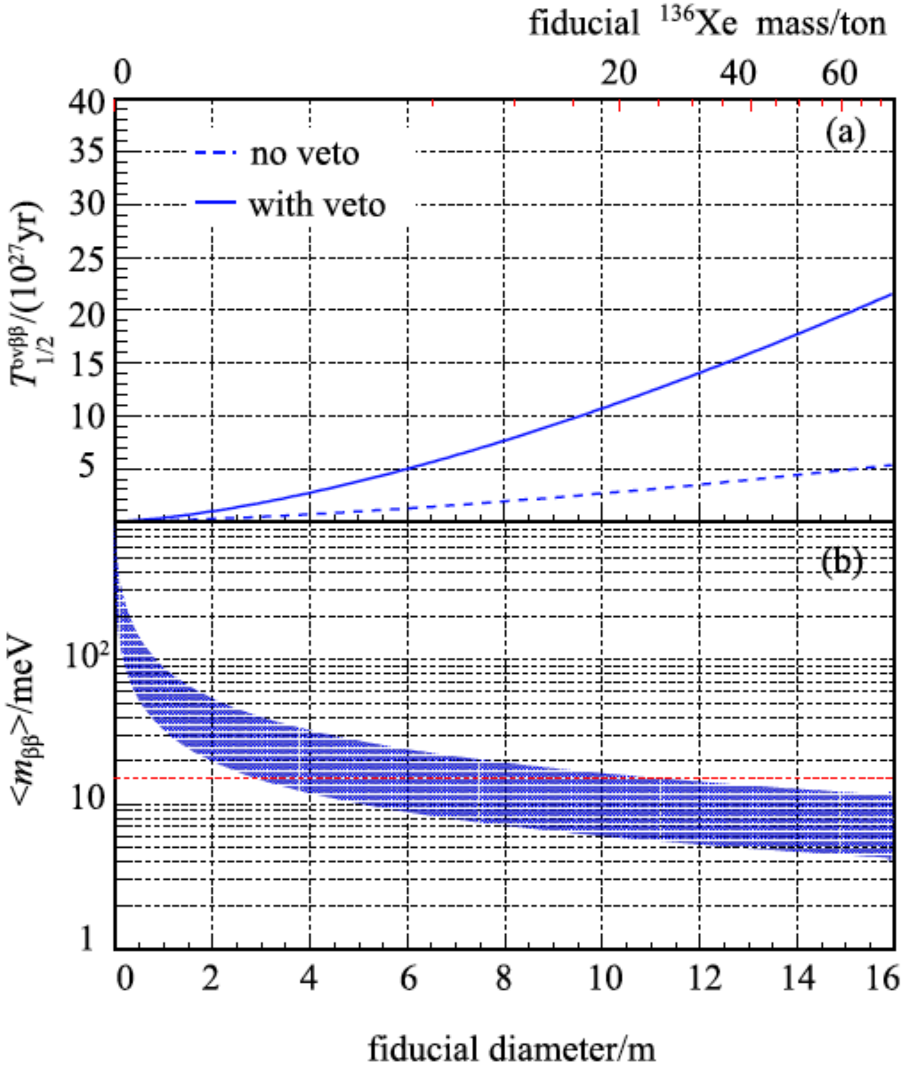
Summary

- AMoRE-II experiment aims to be sensitive ~ 5×10^{26} years range for ^{100}Mo isotope and could expand to 200 kg scale.
- The background reduction of a few active materials is expected and further studies of pileup reduction with light detector is going on.
- Further developments to background level of 10^{-5} ckky and multi-tons of ^{100}Mo, ^{76}Ge, and multi-tens of ^{136}Xe are doable though takes time.

Jump to reach ~ 8 meV

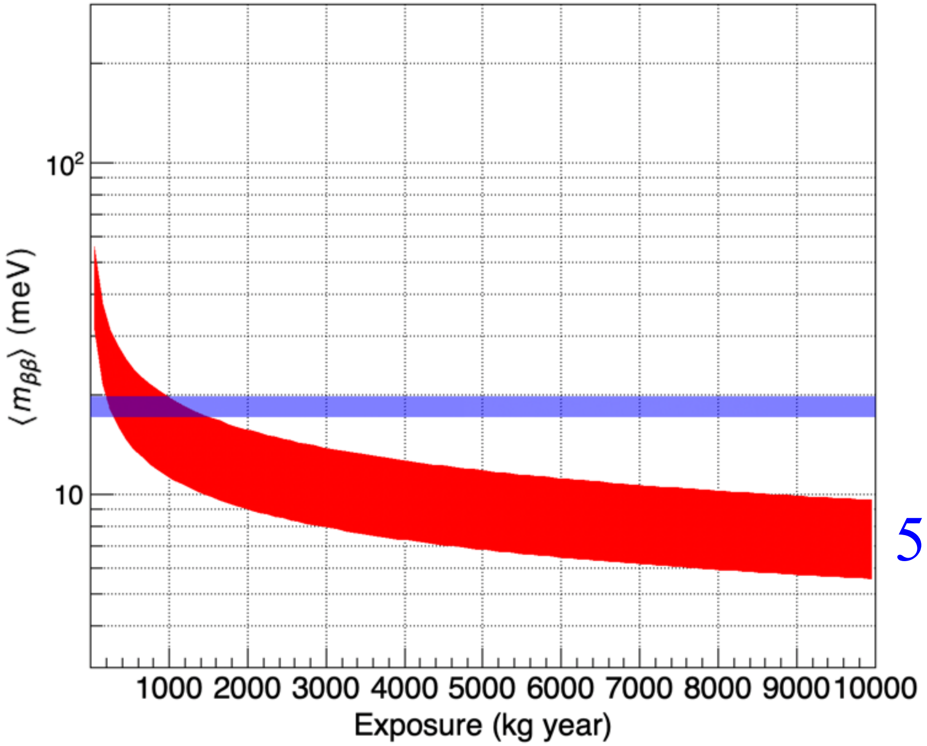
JUNO-Xe, Similar to THEIA-Xe, Theia-Te

5 years run → 300 ton year exposure



5-12 meV

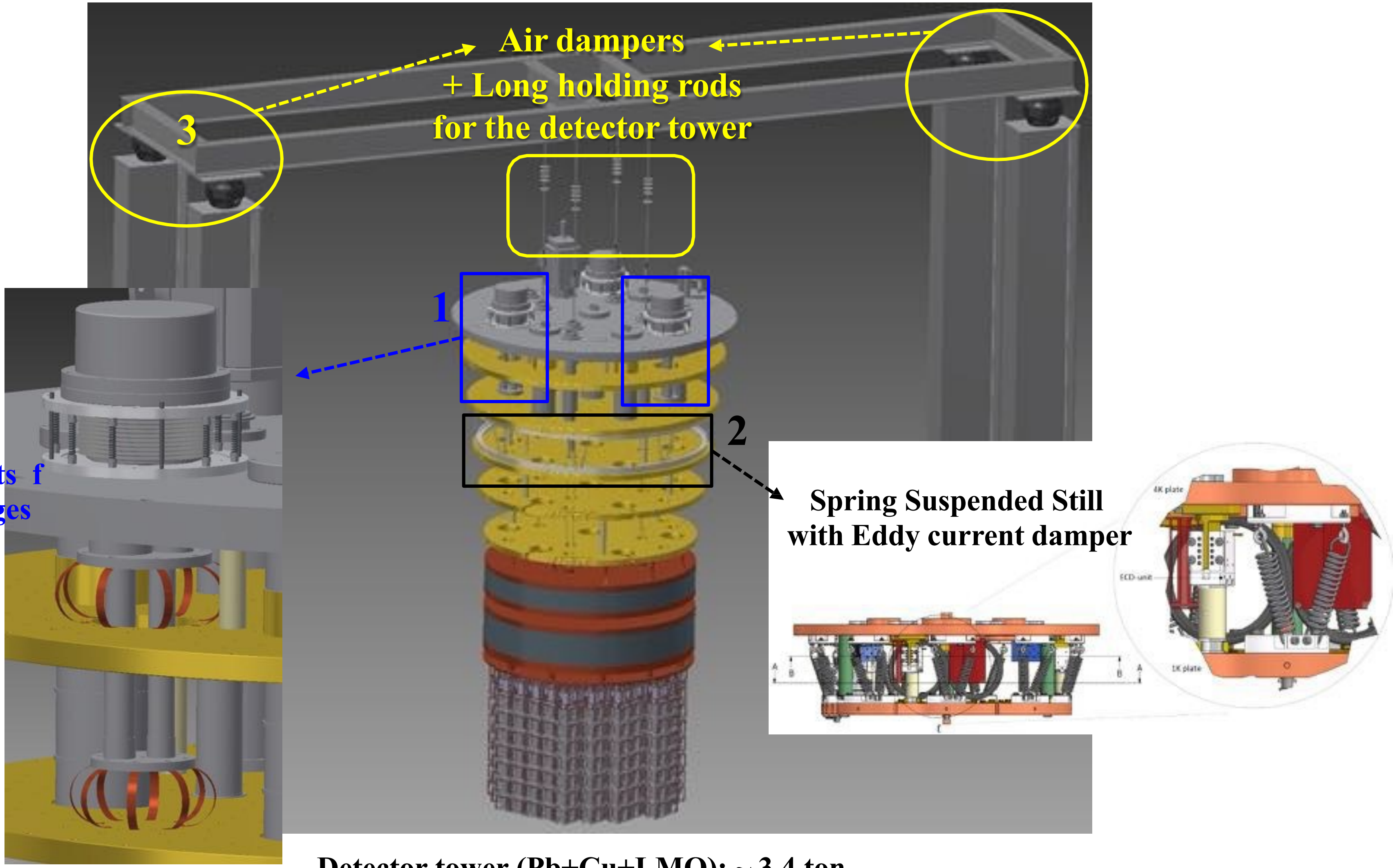
^{100}Mo, Bkg =2x10^{-5} ckky



5.5-10 meV

Need international collaborative work to achieve the backgrounds and energy resolution etc.

Vibration damping systems



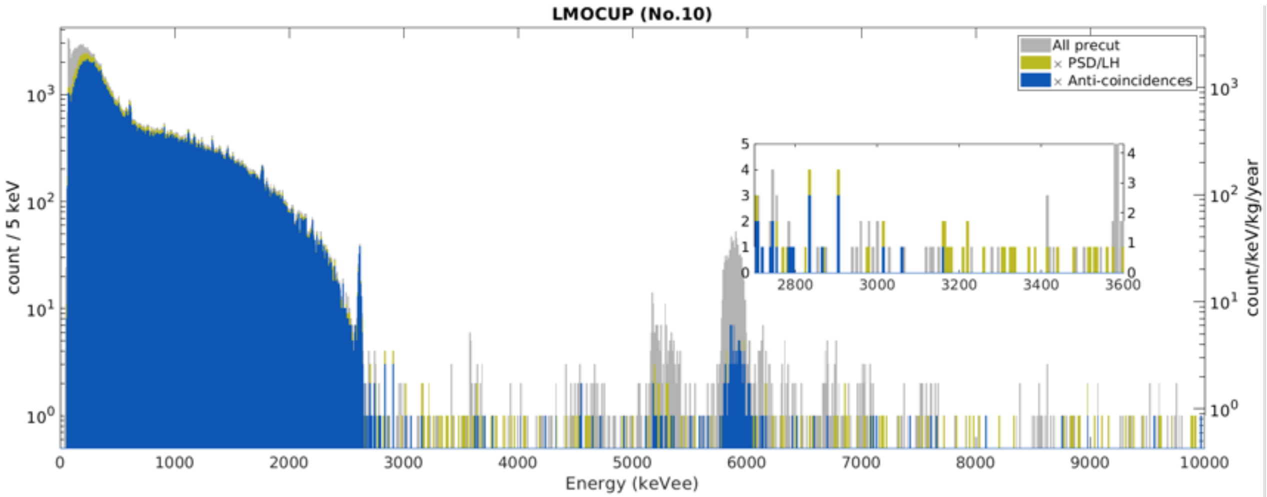
Detector tower (Pb+Cu+LMO): ~ 3.4 ton
Independent support of Kevlar strings + STS rods from room temp.
Cooling method: IVC exchange gas + soft copper foils

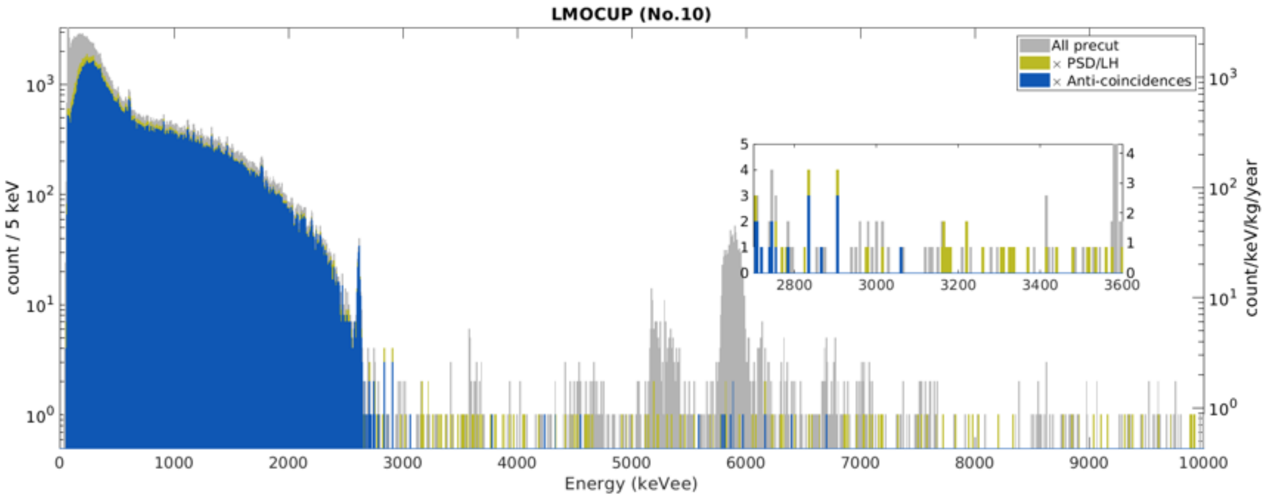
CUP LMO in AMoRE-I
Tighter cut removed most alpha backgrounds.

3 MAD

2 MAD

Run 643-695





LMO backgrounds

- Alpha-alpha coincidence analysis