AMoRE

31 May @ *ν*-2022

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on behalf the AMoRE Collaboration

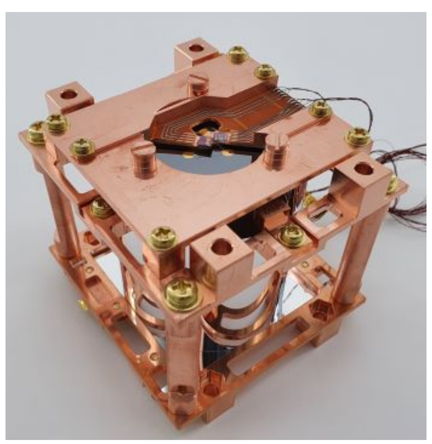
CENTER FOR UNDERGROUND PHYSICS
ibs

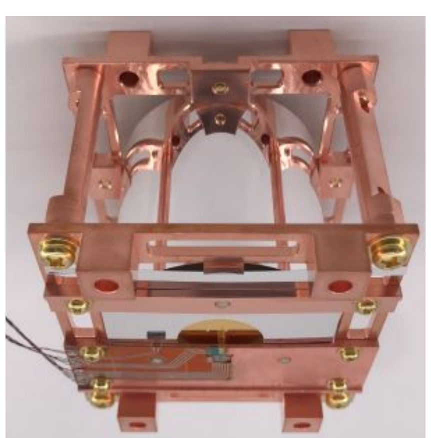
$0\nu\beta\beta$ search using Mo-100

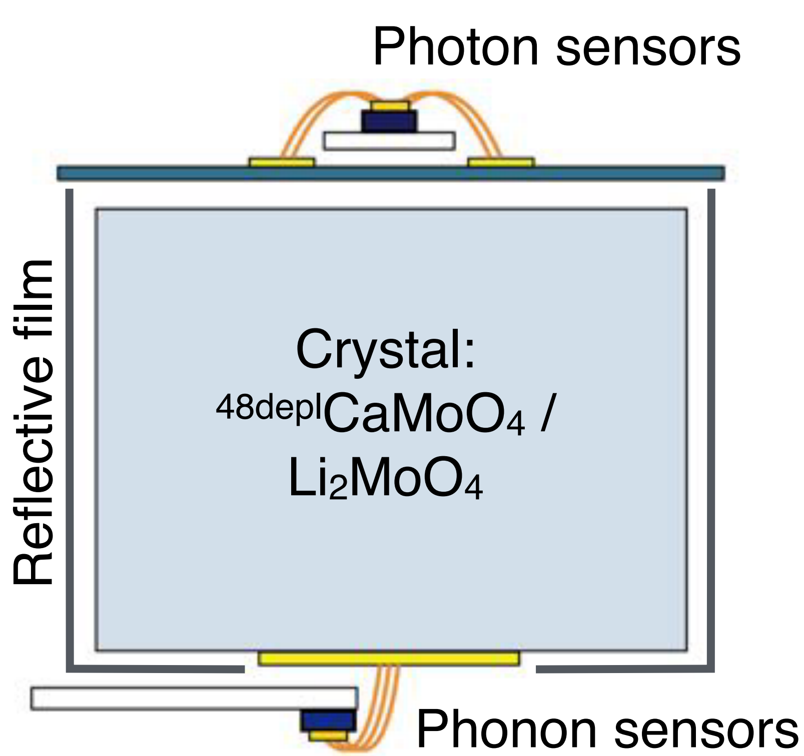
- Neutrinoless double beta decay:
  - Direct measure of Majorana nature of neutrino.
  - Lepton number violation process.
  - Effective neutrino mass.
- Molybdenum-100:
  - $Q_{\beta\beta}$ = 3034 keV.
  - Natural abundance = 9.74%.
  - Scintillation crystals with ^{100}Mo enrichment > 95% — XMo_aO_b (XMO):
    - X=Ca, Li_2, Na_2, Zn, Sr, Pb, …
    - Detection of light/heat signal ➔ rejection of surface-α background.
- Key parameters for the experimental sensitivity:
  - Signal ~ efficiency × [isotope mass × time] exposure.
  - Background ~ radioactivity level at around $Q_{\beta\beta}$ and energy resolution.

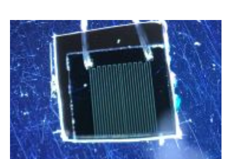
Detector module

- Cylindrical CMO and LMO crystals, sizes vary $\Phi \geq 4$ cm / $H \lesssim 5$ cm.
  - CMO: ^{48}Ca depleted, $Q_{\beta\beta}$ (^{48}Ca) = 4271 keV.
- Metallic magnetic calorimeter (MMC) + SQUID:
  - Fast signal timing: a few millisecond rise-time for phonon signals at mK.
  - Low random coincidence background.
  - Energy resolution ~ 10 keV FWHM at 2.6 MeV.

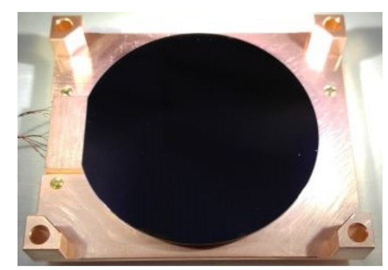




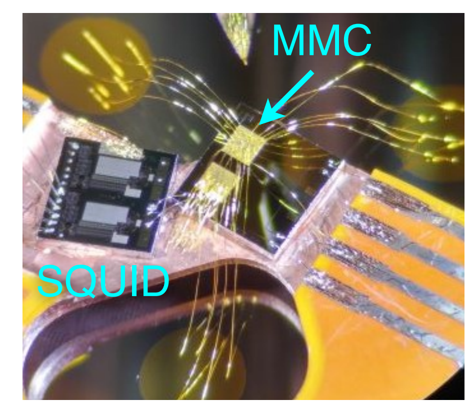




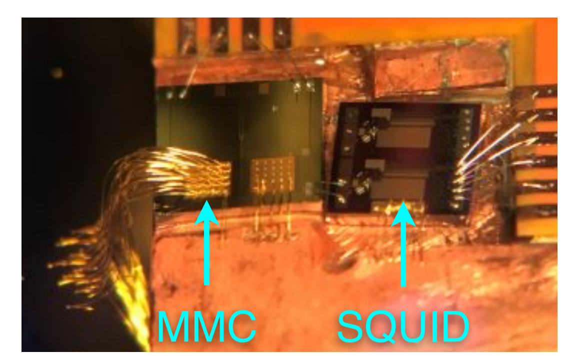
Stabilization heater



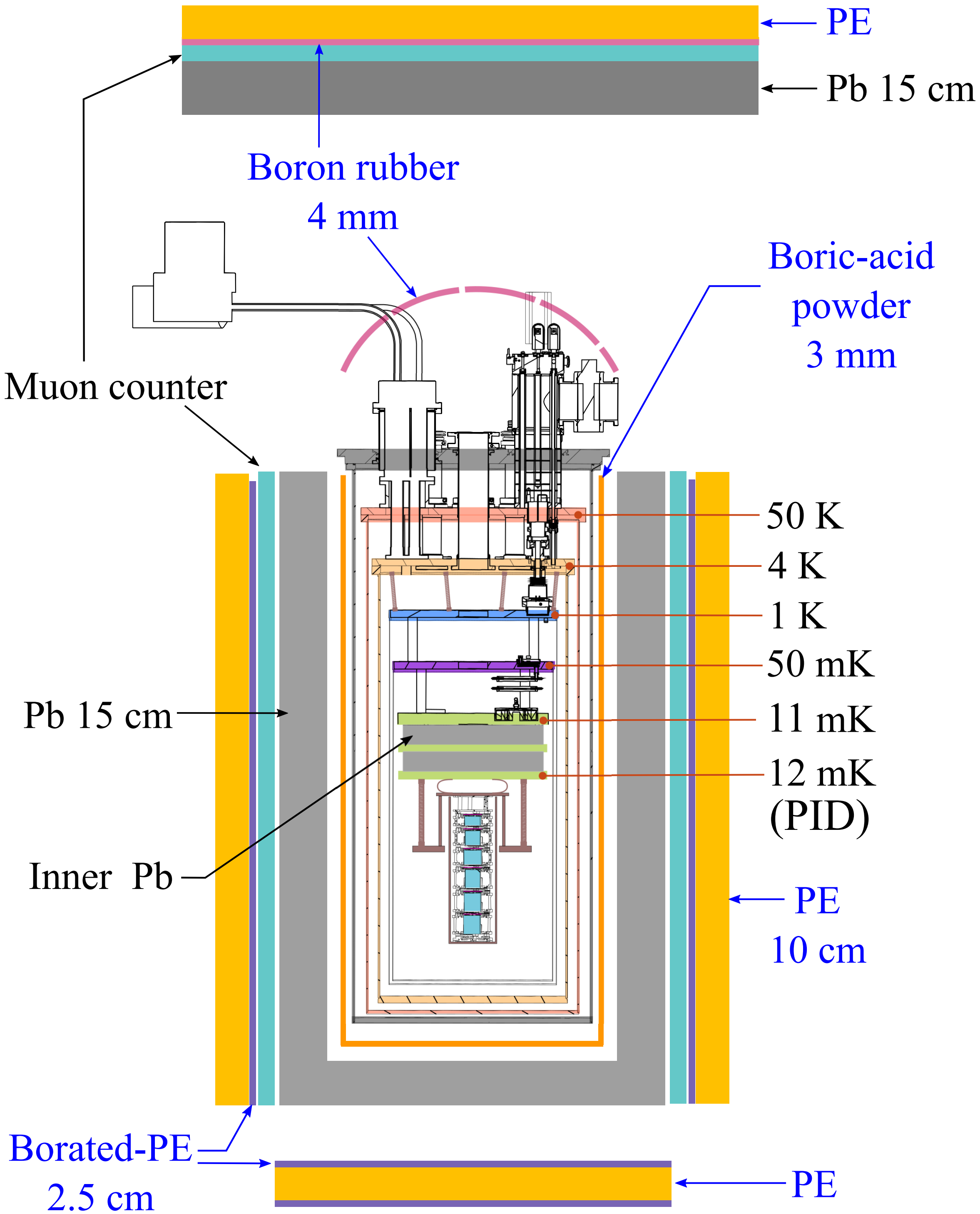
Light absorber
(Ge/Si wafer)



Phonon collector
(Au film)

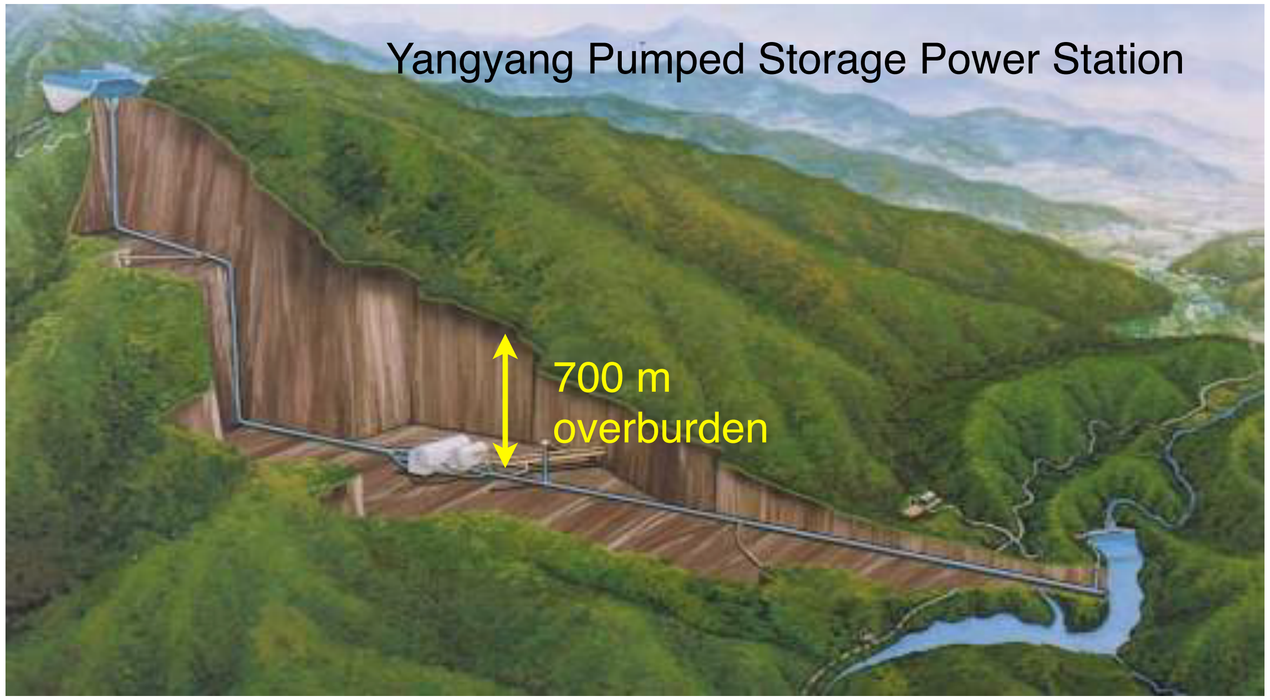


Cryostat / shielding

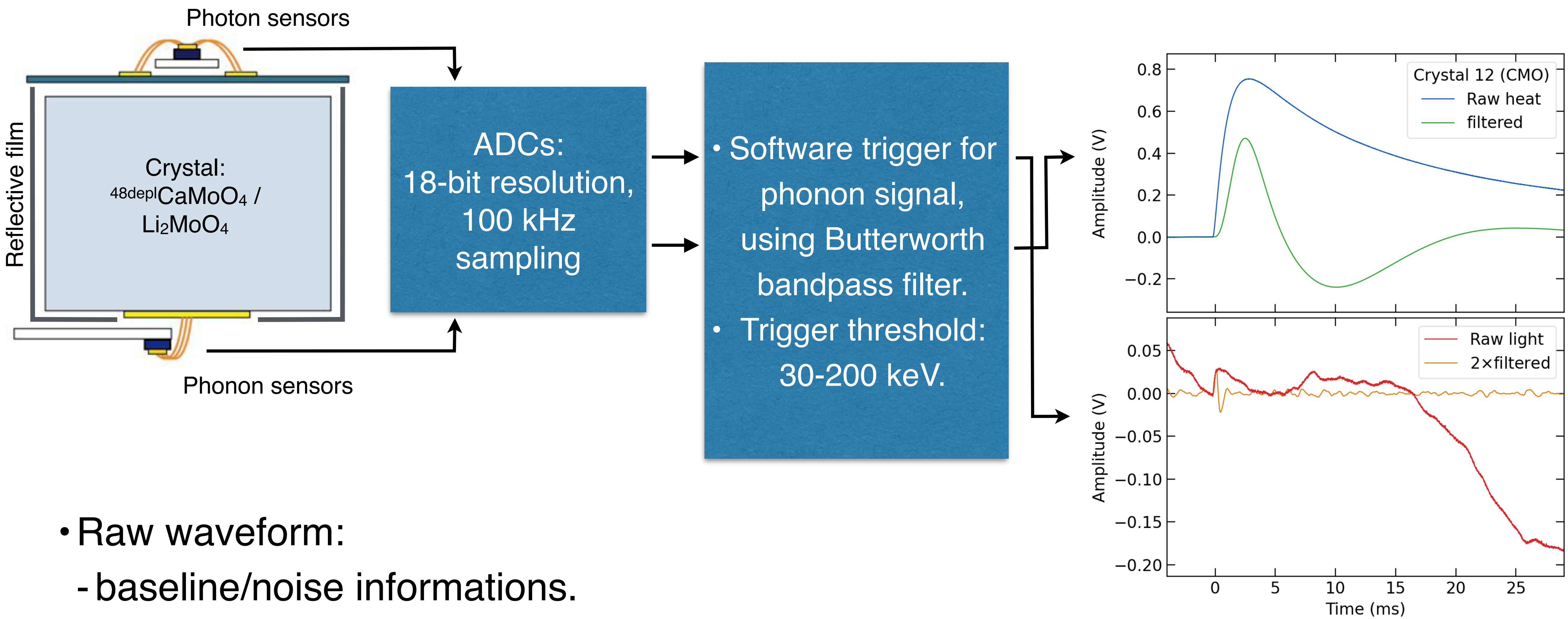


+ More enhanced shielding for AMoRE-I

- Cryogen-free dilution refrigerator.
- For AMoRE-pilot and AMoRE-I.
- Now operating at 10 mK with 1.2 μW cooling power.
- Pb (γ), boron, and polyethylene (n).
- Plastic scintillator muon counter.
- Yangyang Underground Laboratory (Y2L) at 700 m depth.

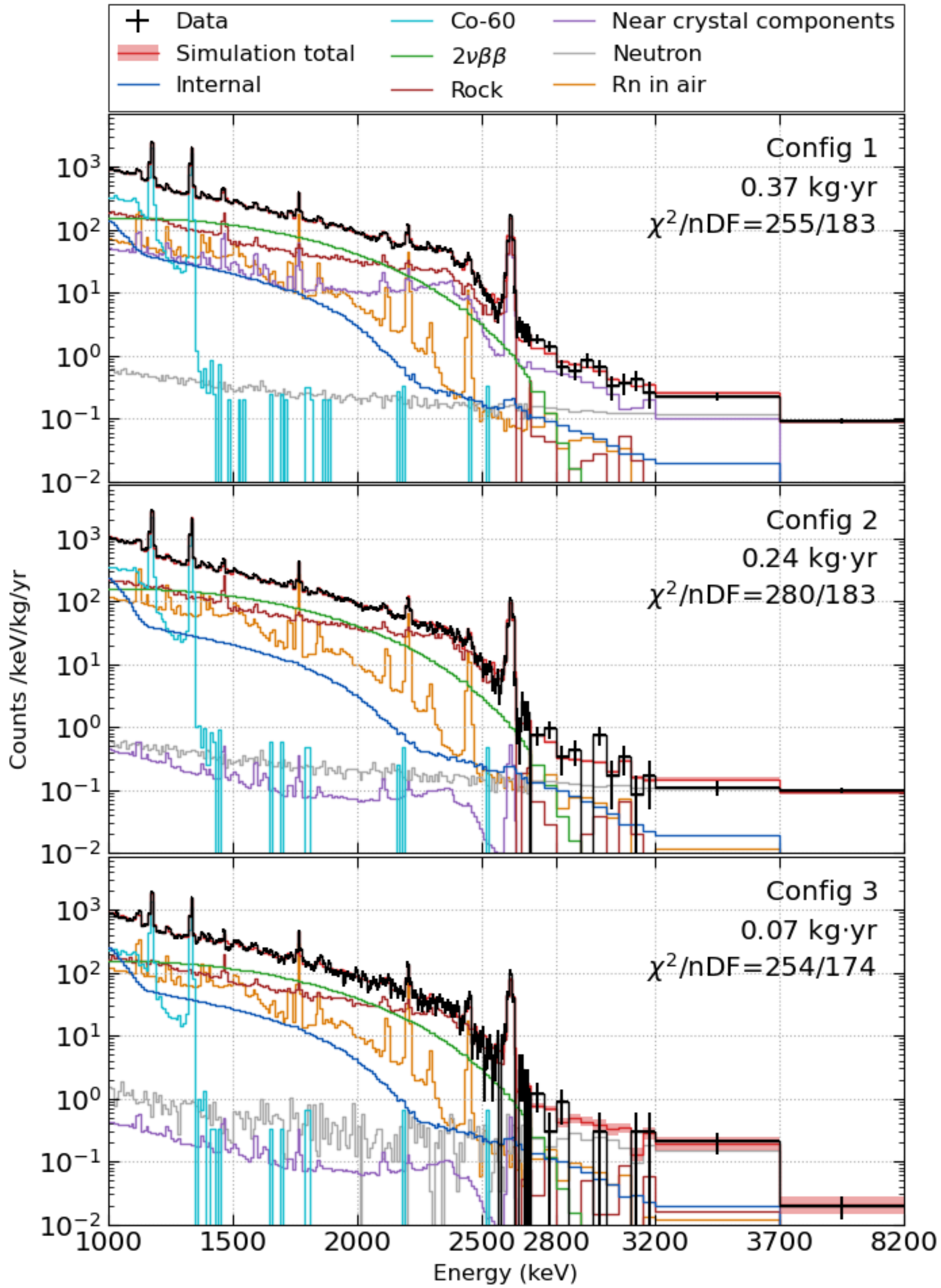


Signal processing and analysis

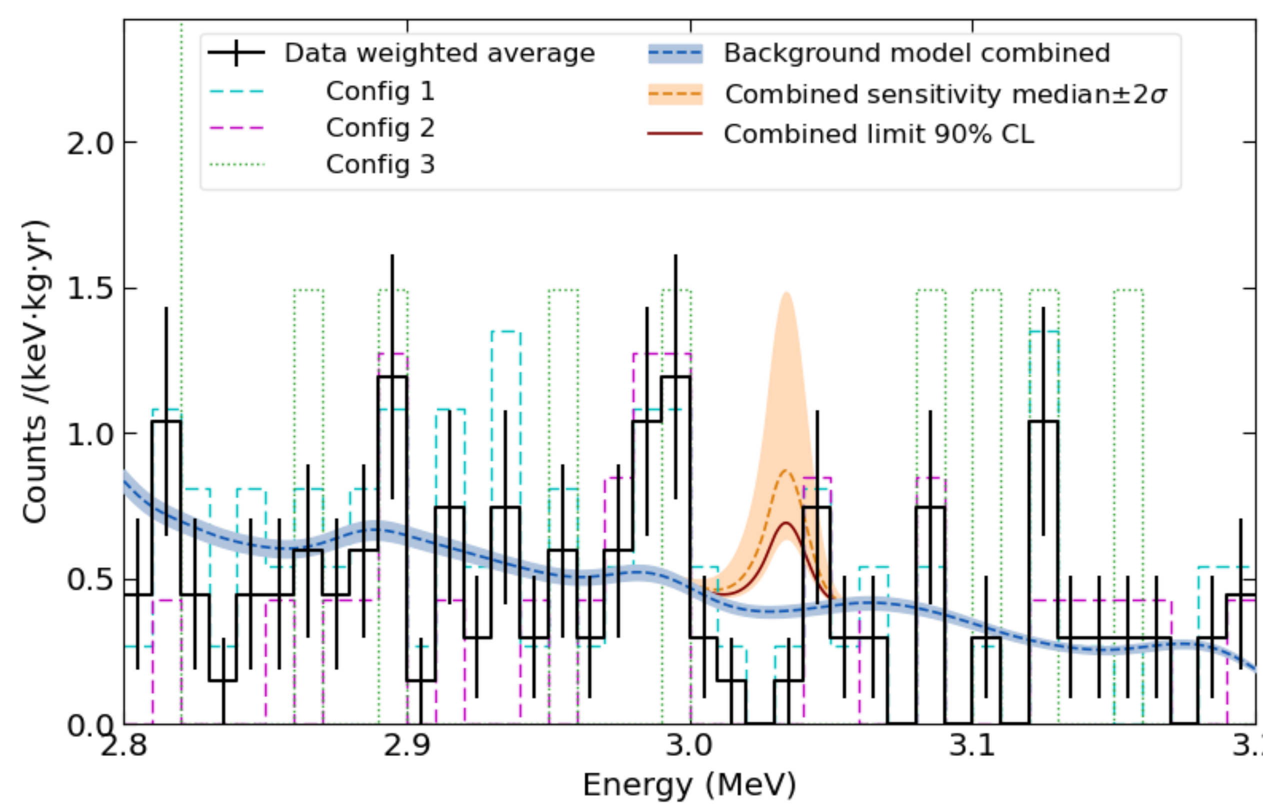


- Raw waveform:
  - baseline/noise informations.
  - timings (rise/fall): pulse shape discrimination (PSD).
- Reconstruction for improving energy resolution and β/α discrimination power (DP):
  - Butterworth bandpass filter— mainly for noise suppression:
    - pulse amplitude: pulse height or a least square fit to the template signal.
  - Stabilization heater signal every 10 seconds for gain drift corrections.

AMoRE-pilot final result

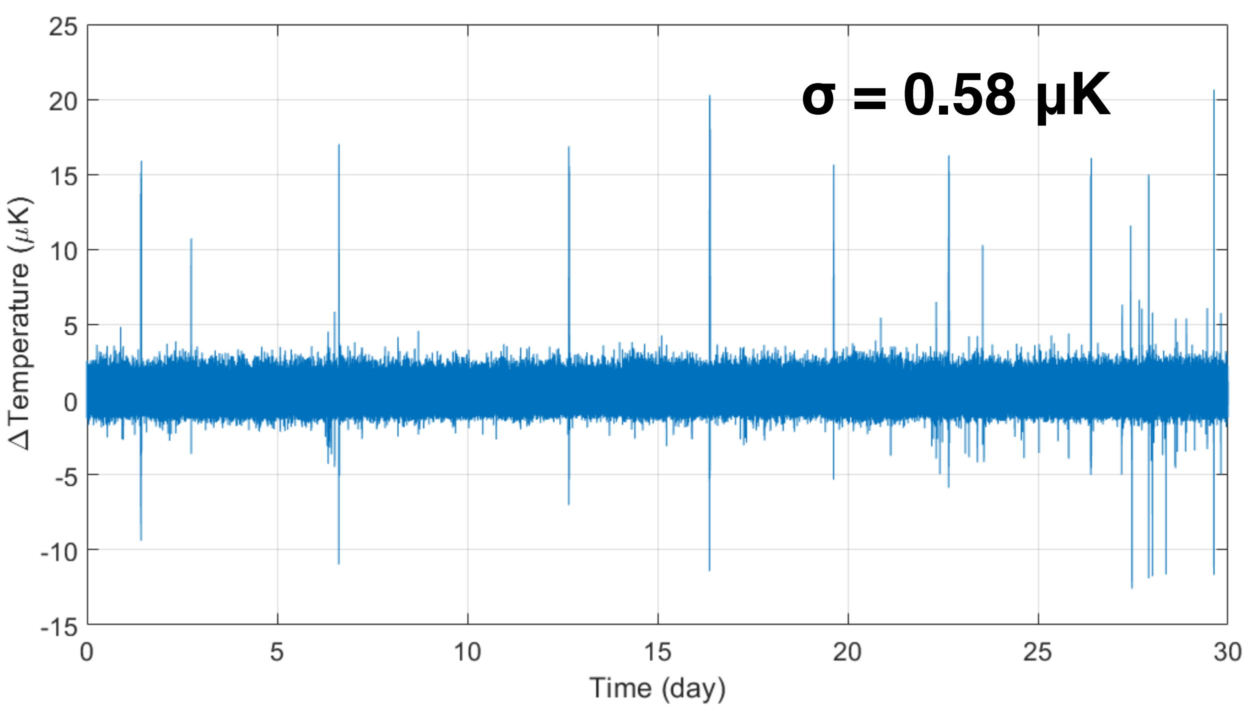


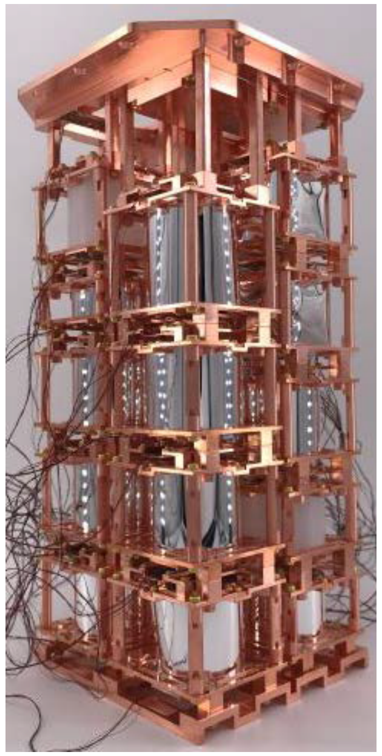
- Understanding of the background components and reduction of them.
- Background level of ~0.5 counts/keV/kg/yr at 2.8-3.2 MeV.
  - neutron-induced γ, crystals' internal contamination, rock/air-radon γ.
  - Internal background— arXiv:2107.07704
- $T^{0\nu}_{1/2} > 3.2 \times 10^{23}$ years at 90% CL.

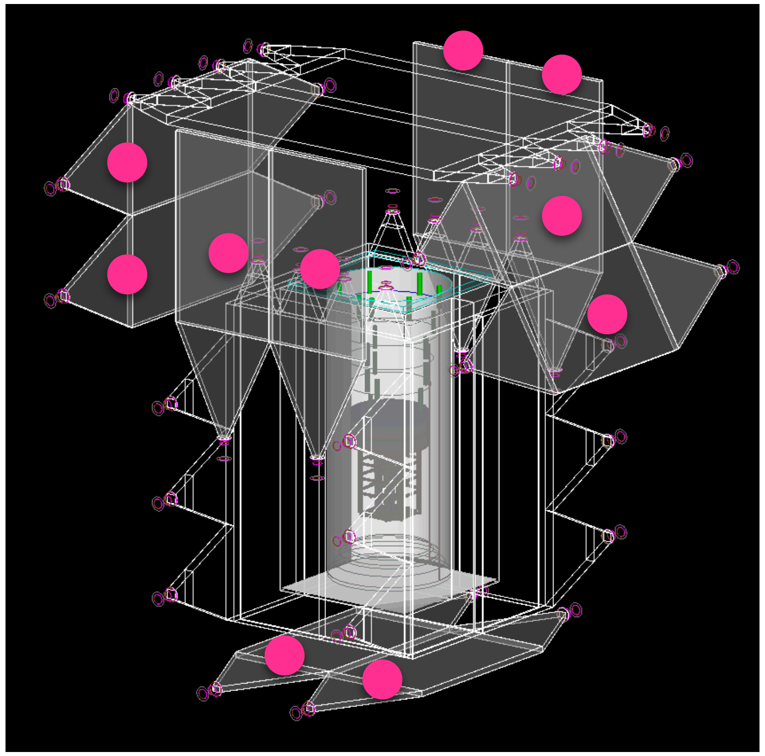


AMoRE-pilot ➔ AMoRE-I

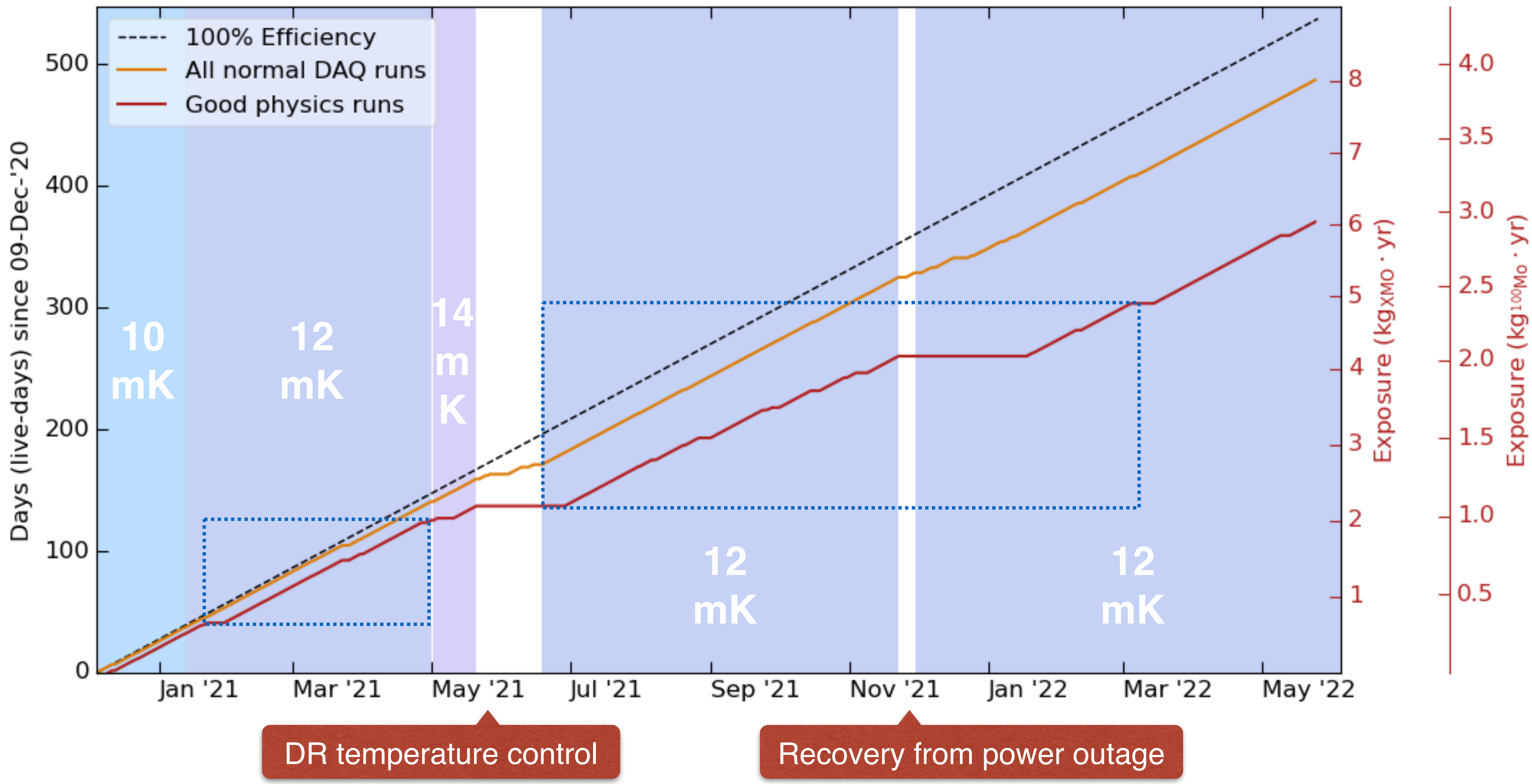
- 6 CMO (1.89 kg) ➔ 13 CMO (4.58 kg) + 5 LMO (1.61 kg)
  - Total crystal mass = 6.19 kg, ^{100}Mo mass = 3.0 kg
- Stabilization heater for all crystals.
- MMC sensor: Au:Er ➔ Ag:Er.
- Using same cryostat + two stage temperature control: $\langle \Delta T \rangle < 1$ μK.
- Shielding enhancements:
  - Outer Pb: 15 ➔ 20 cm; neutron shields: boric acid silicon + more PE / B-PE.
  - More muon counter coverage.
  - More supply of Rn-free air.





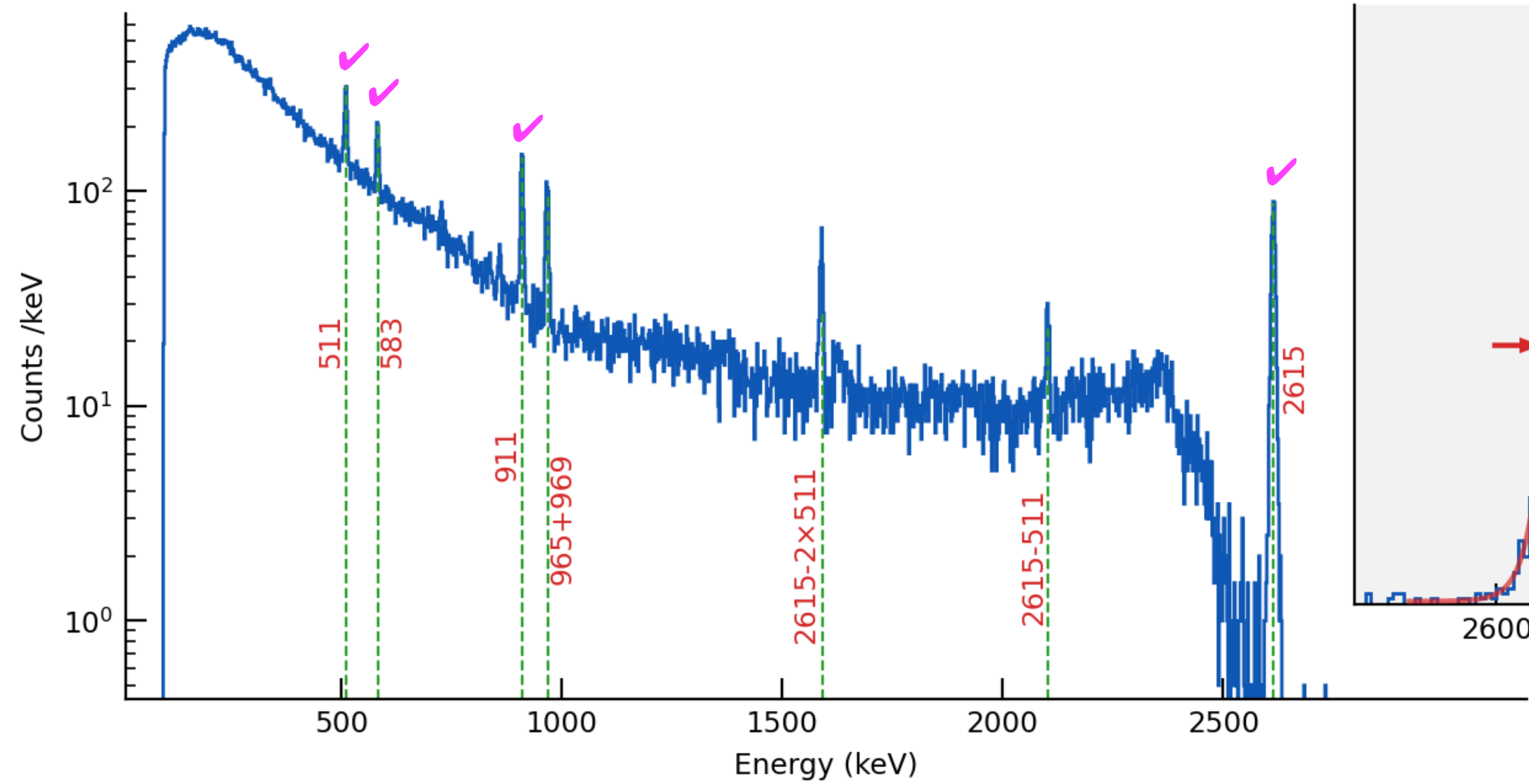


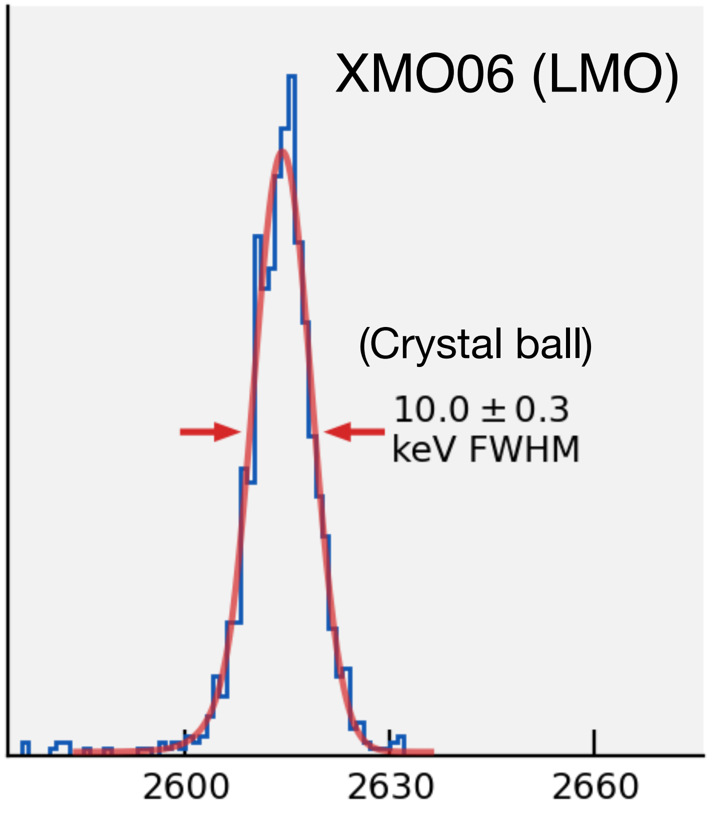
AMoRE-I data taking

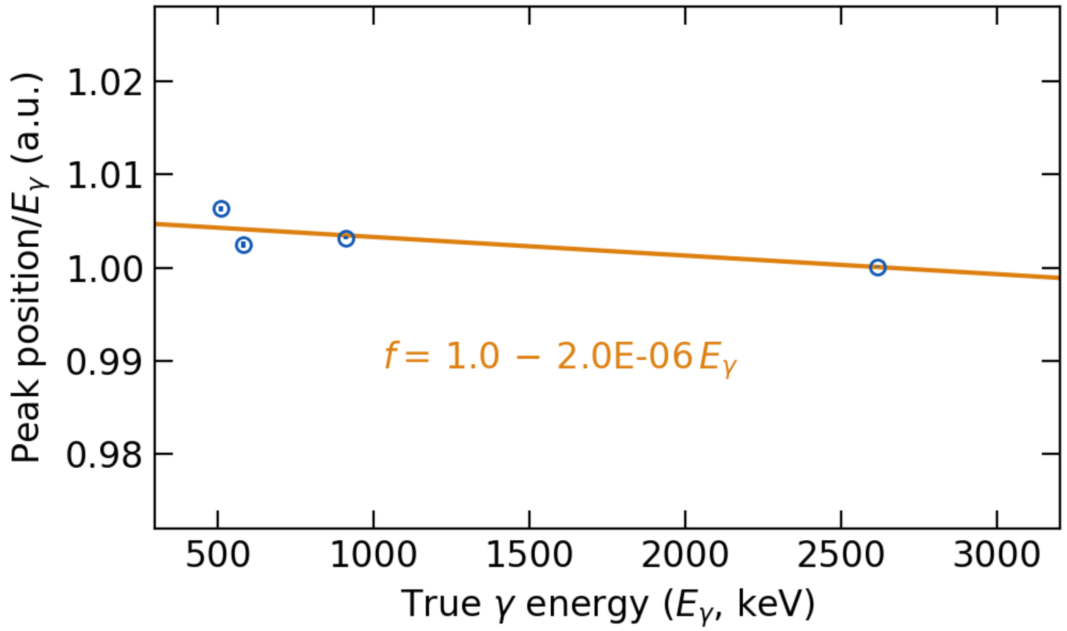


- DAQ duty factor ~ 90%, good physics data ~ 75%.
- Data taking until end of 2022 (at least).
- 3.44 kg·yr crystal (1.67 kg·yr ^{100}Mo) exposure is presented here (selected data in blue dotted boxes).

Energy calibration

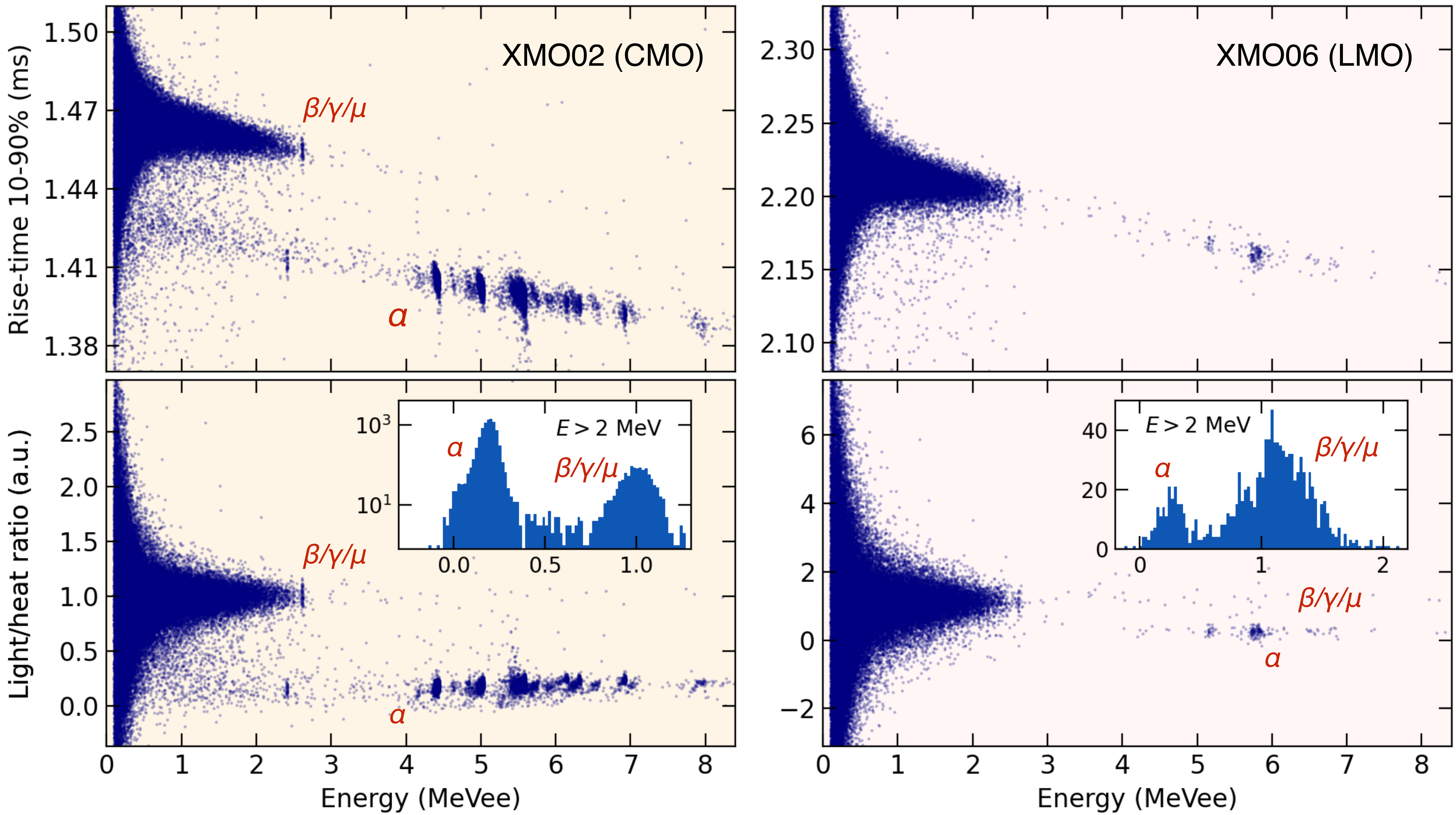






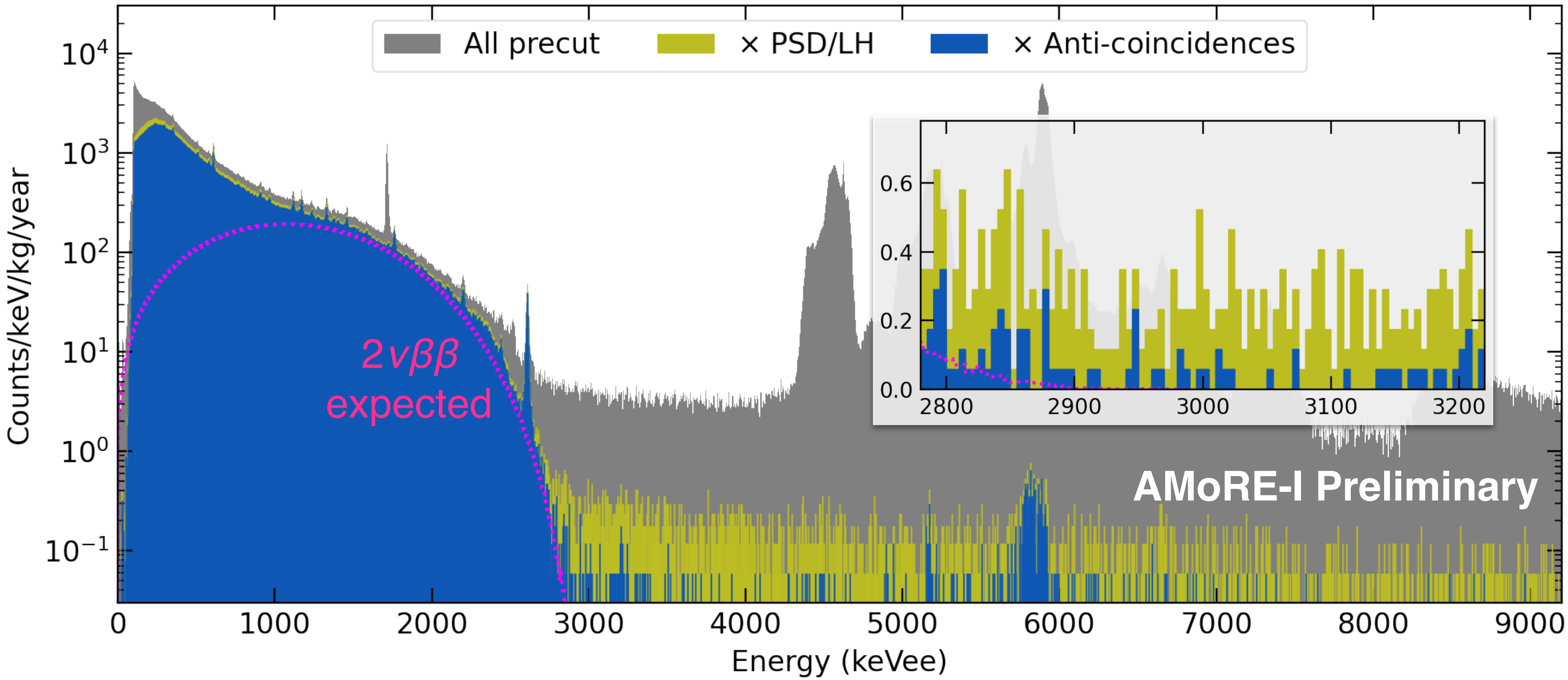
- Calibration source: ^{232}Th-rich welding rods just outside of OVC.
- Slight non-linearity between signal amplitude and energy.
- Energy resolution: [10-30] keV FWHM at 2615 keV, ~15 keV in average.

Particle IDentifications, CMO and LMO



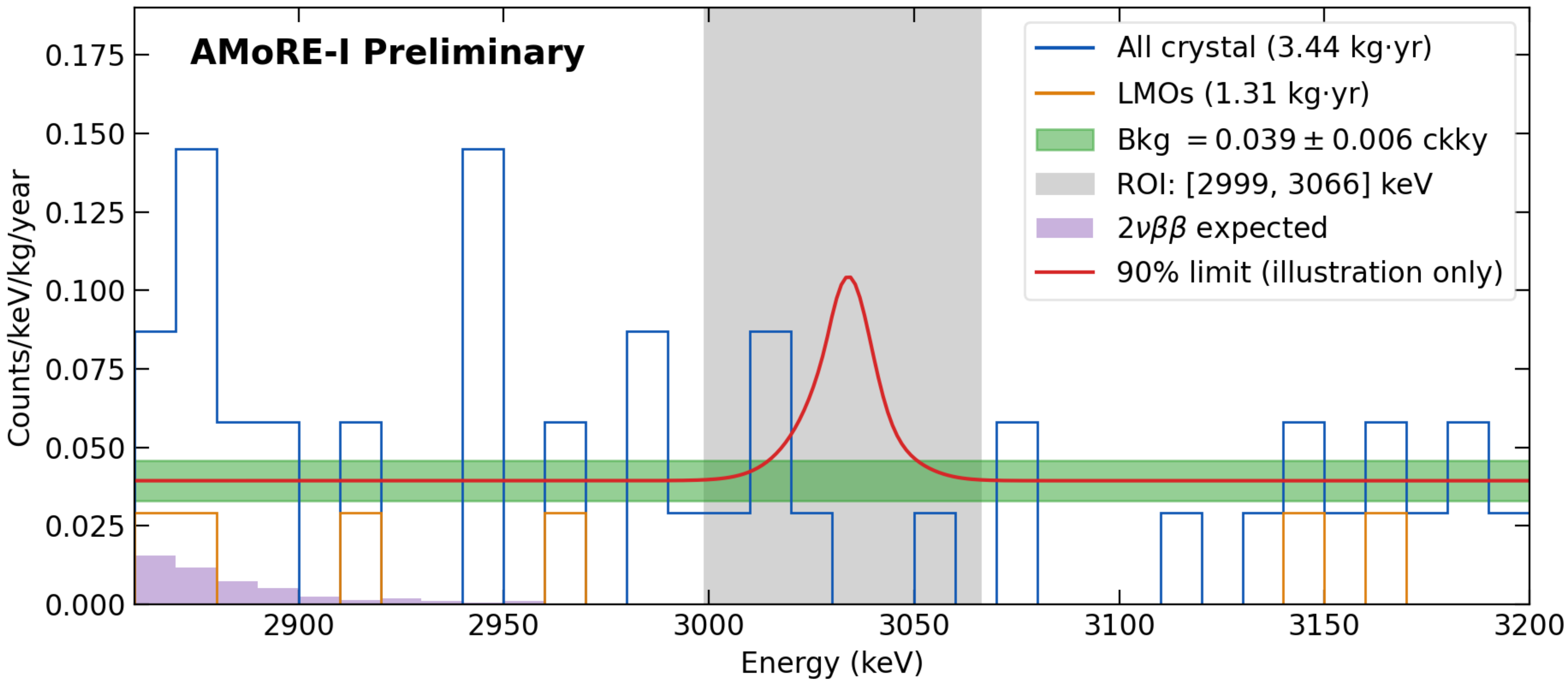
- CMO shows better discrimination power — light yield: CMO > LMO.
- LMO has much less *α* contamination.

Background spectrum



- All crystal excluding 1 LMO for very poor β/α discrimination power:
  - 13 CMO + 4 LMO: exposure = 3.44 kg_{XMO}·yr = 1.67 kg_{ISO}·yr.
- Anti-coincidence cuts reject events:
  - coincident at multiple crystals within 2 ms ($\varepsilon \sim 99\%$),
  - within 10 ms after a muon counter event ($\varepsilon \sim 99.7\%$),
  - within 20 minutes after a ^{212}Bi α-decay event candidate ($\varepsilon \sim 98\%$).

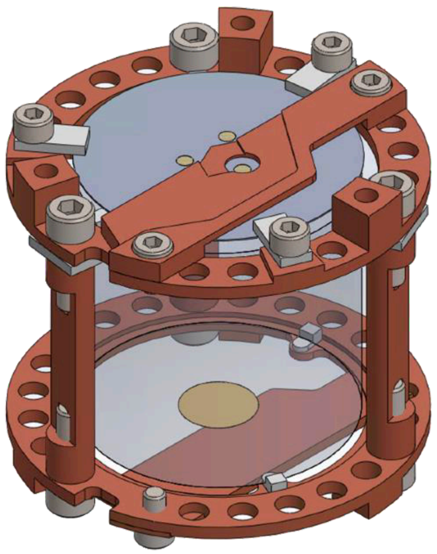
Preliminary 0νββ limit from AMoRE-I

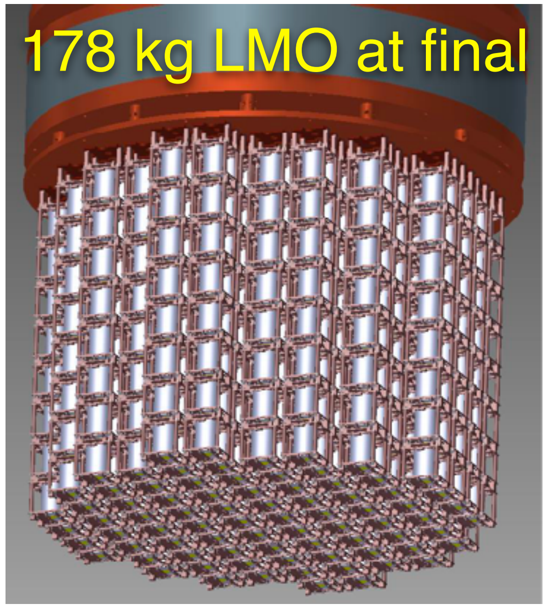


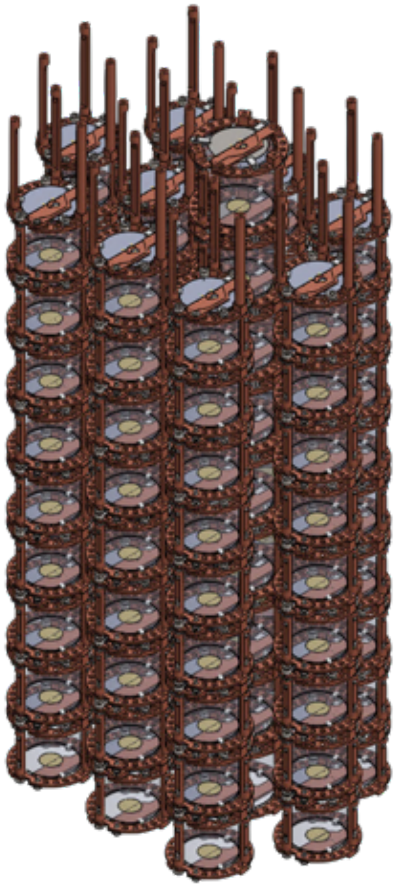
- ROI to contain most (> 99%) of the $0\nu\beta\beta$ signal peak, $\varepsilon_{\text{containment}} \sim 81\%$.
- Background = 0.039 ± 0.006 counts/keV/kg/year, from ROI side-band.
- Combining the result of counting analysis at ROI, with a flat background constraint from the side-band events for each crystal.
- $T^{0\nu}_{1/2} > 1.2\times10^{24}$ years at 90% CL.

AMoRE-II in preparation

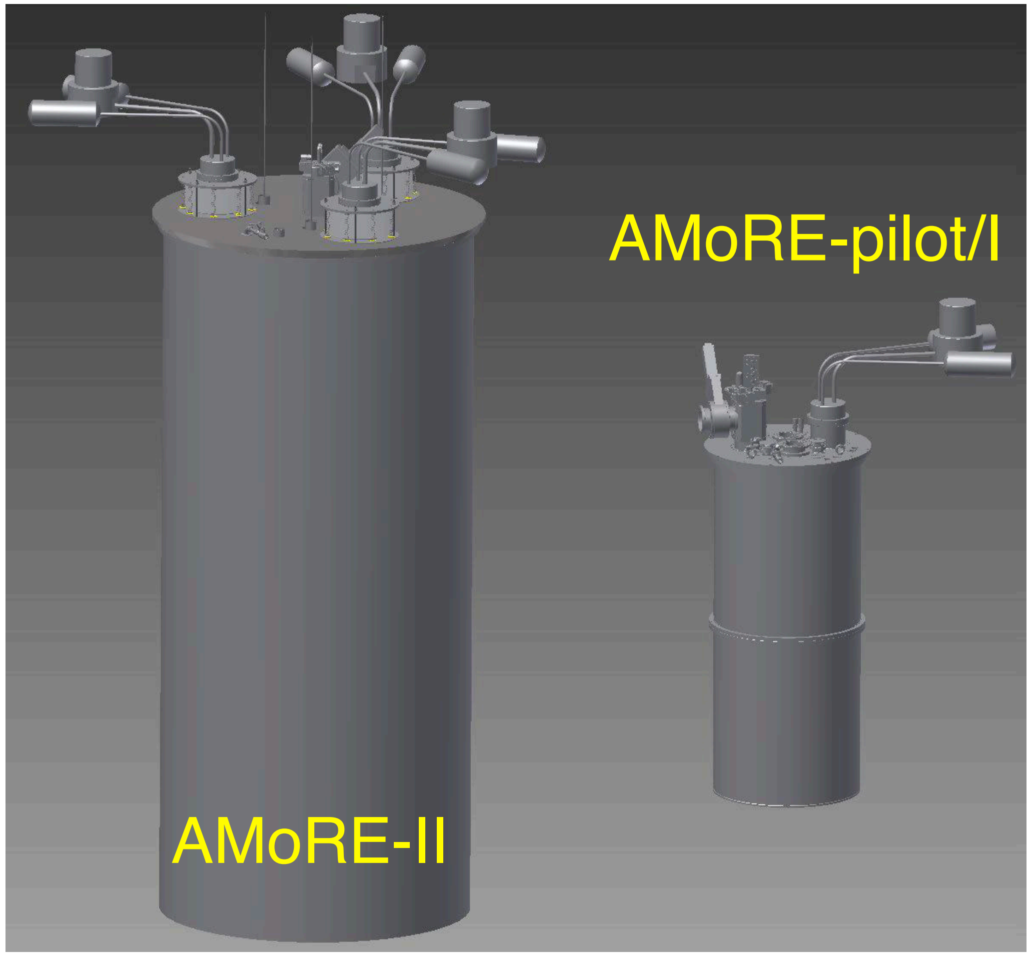
AMoRE-II
Detector module



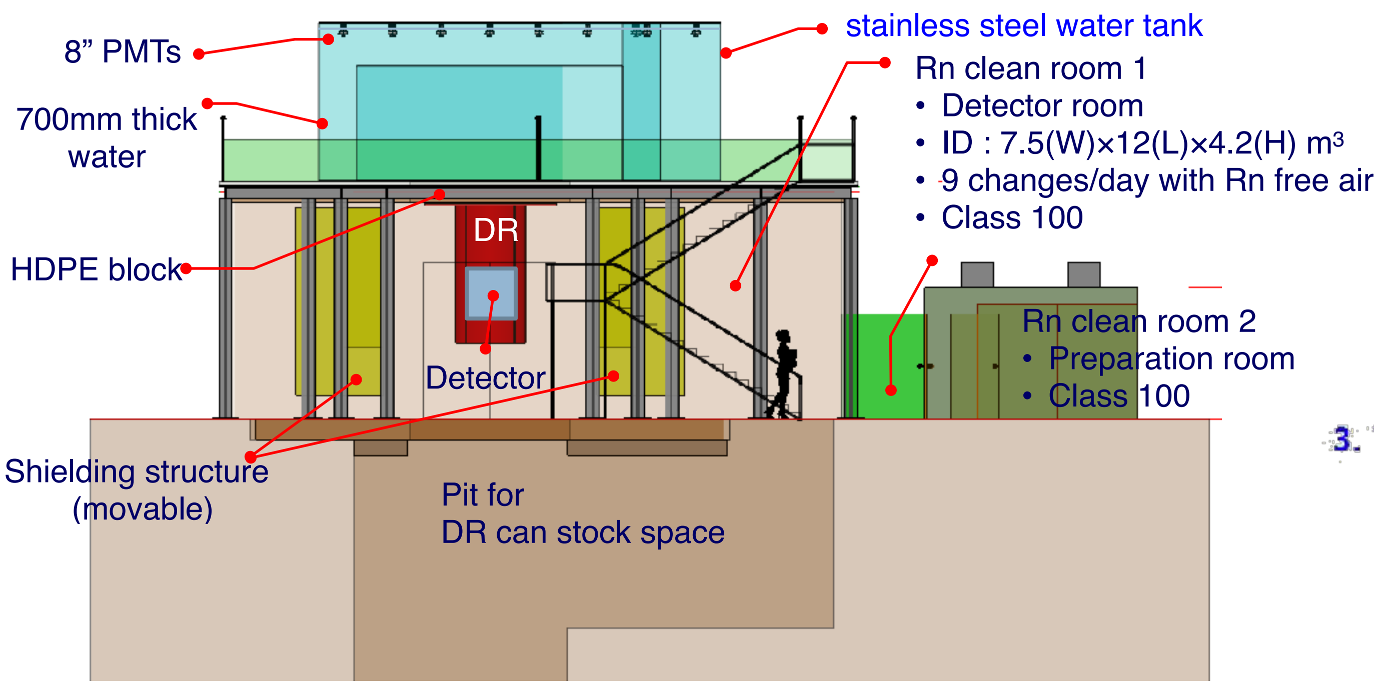


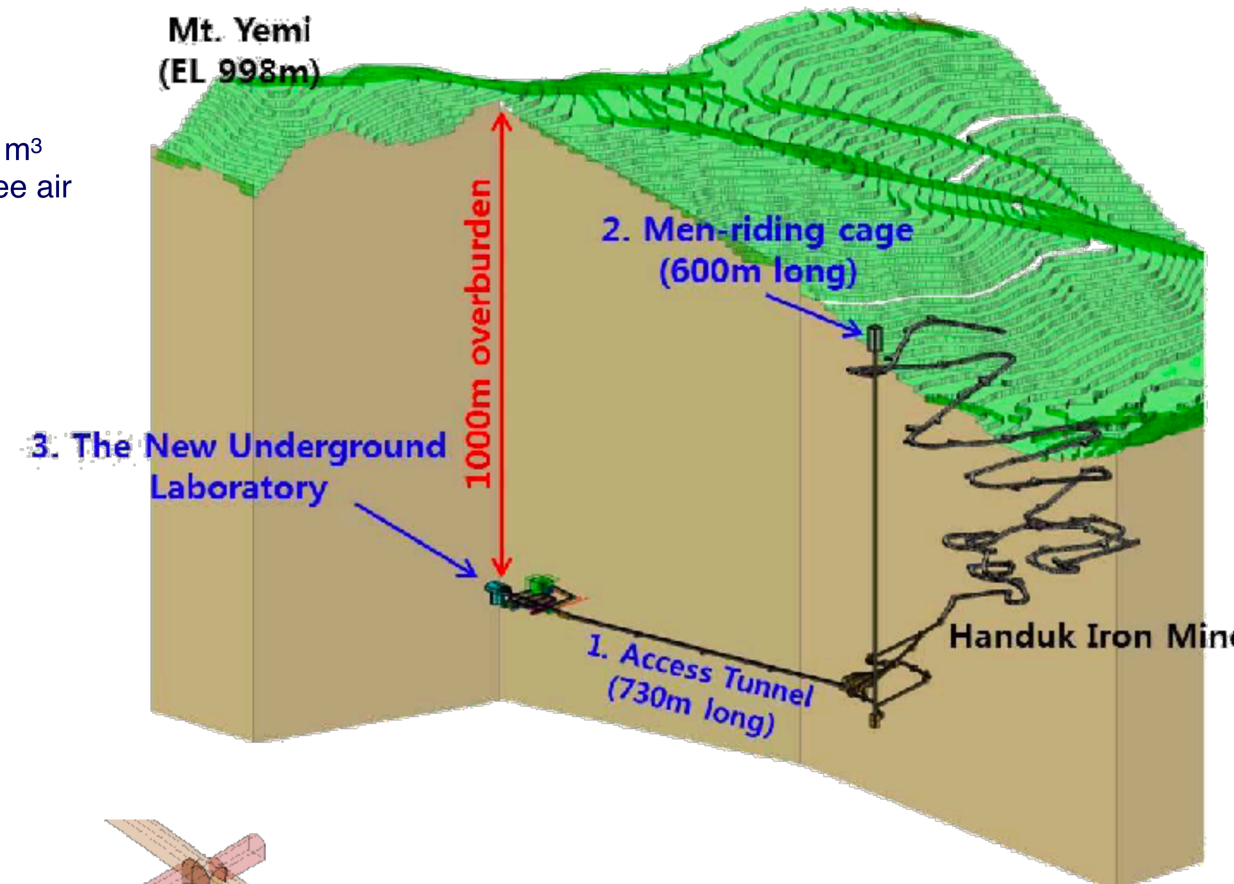


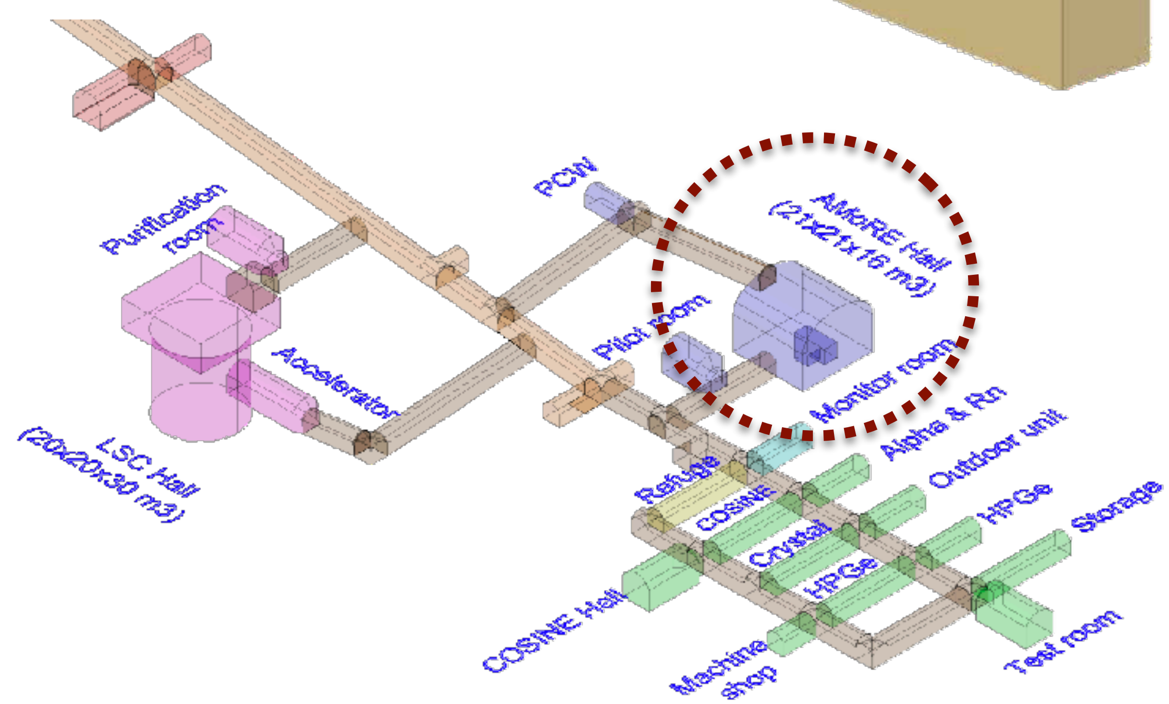
90 modules (~27 kg LMO)
for the first stage



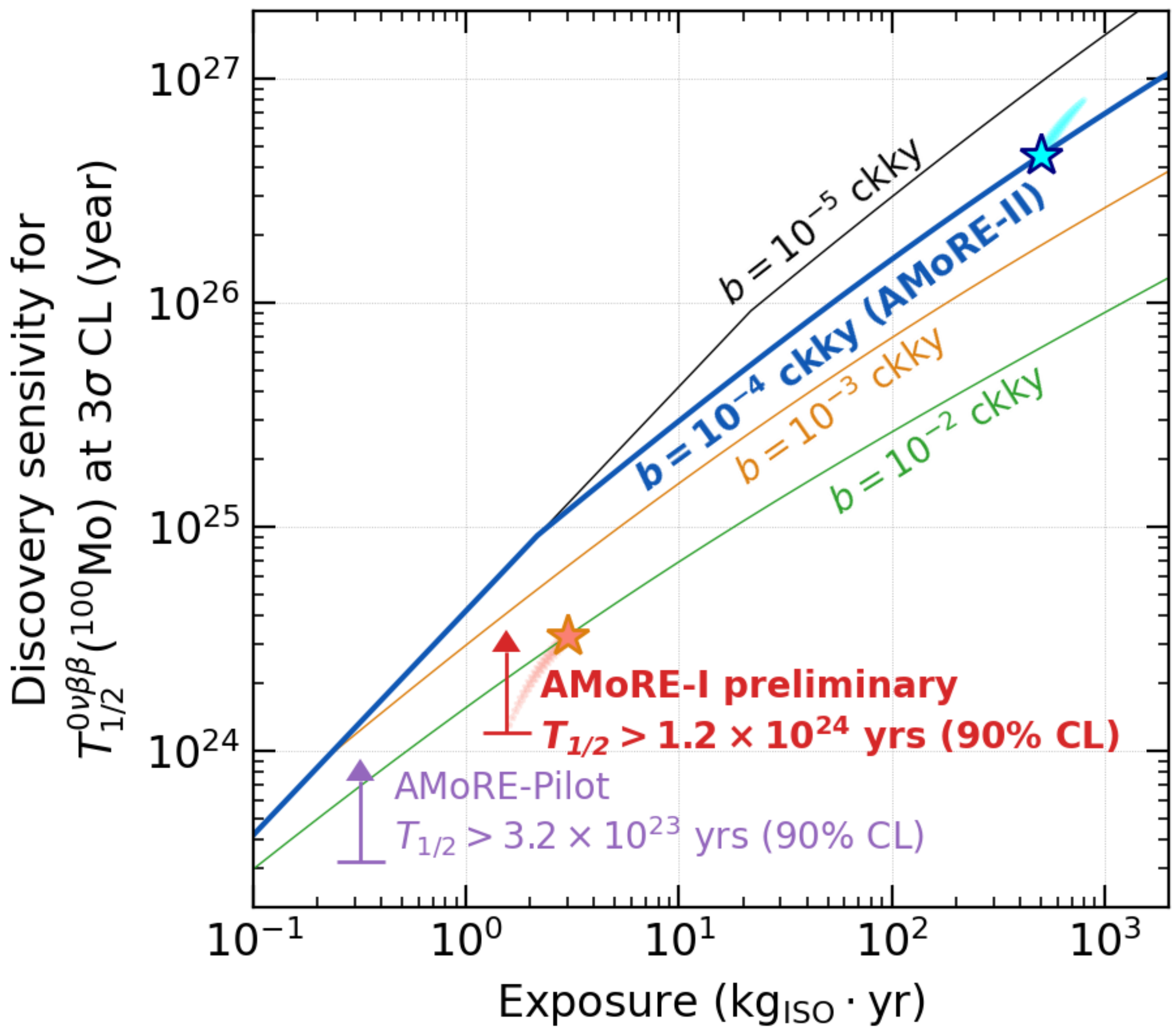
AMoRE-II in Yemilab

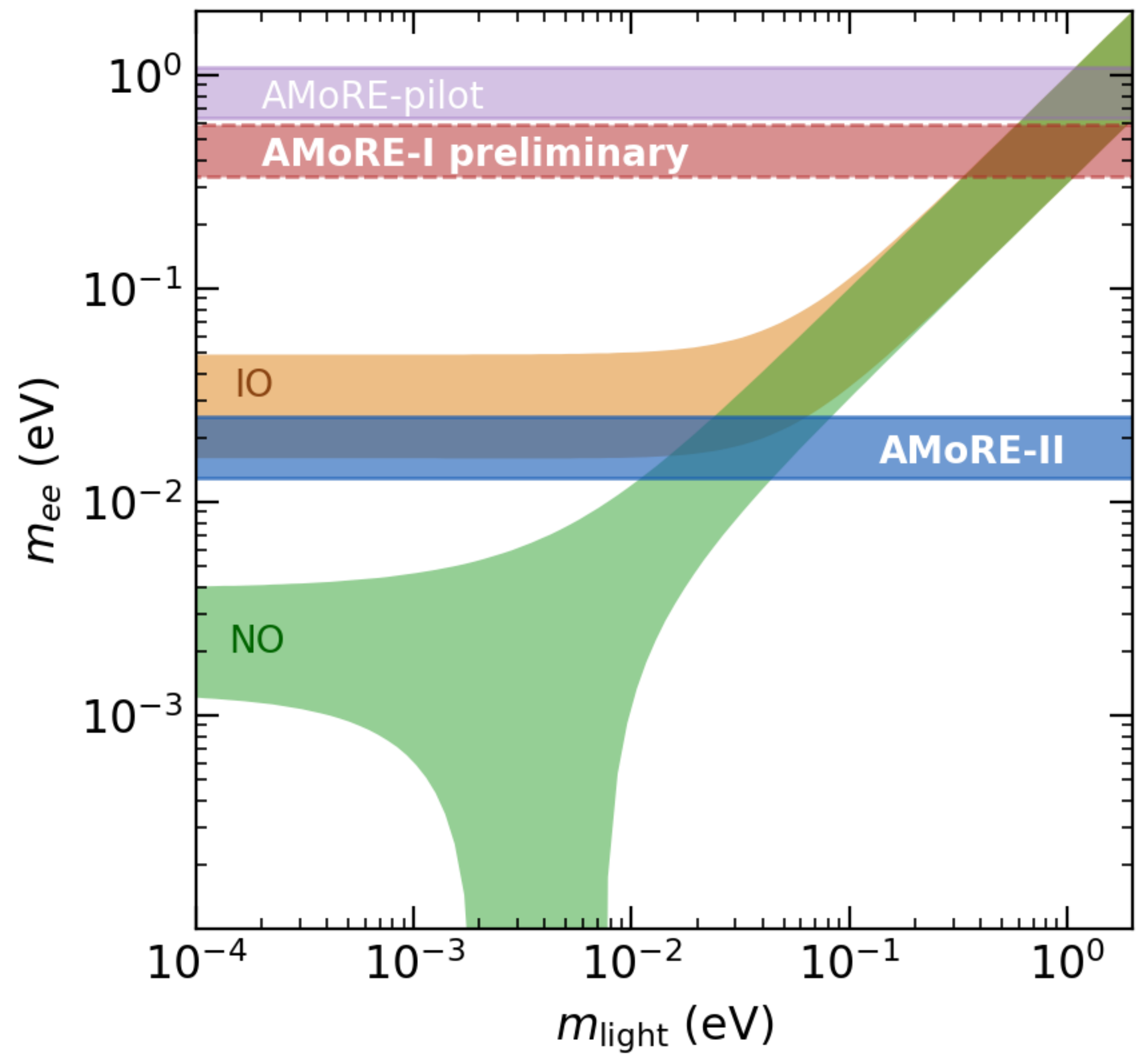






Limits and sensitivities





- Final results of AMoRE-I with doubled data and further improved analysis.
- AMoRE-II for $T^{0\nu}_{1/2}$ > ~5×10^26 years by 100 kg of Mo-100 × 5 years running.
- Reduction of background level down below 10^{-4} ckky.

Summary

- AMoRE searches for 0vbb using Mo-100 based scintillation crystals at the low temperature detector system.
- Preliminary result of AMoRE-I at its mid-point:
  - Mass×time exposure: 3.44 (1.67) kg·yr XMO (^{100}Mo).
  - Background level ~ 0.04 counts/keV/kg/year at 2860-3200 keV.
  - $T^{0\nu}_{1/2} > 1.2\times10^{24}$ years.
  - AMoRE-I data taking will continue at least until end of 2022.
- AMoRE-II starts its data taking soon to head for $T^{0\nu}_{1/2} > 5\times10^{26}$ years.

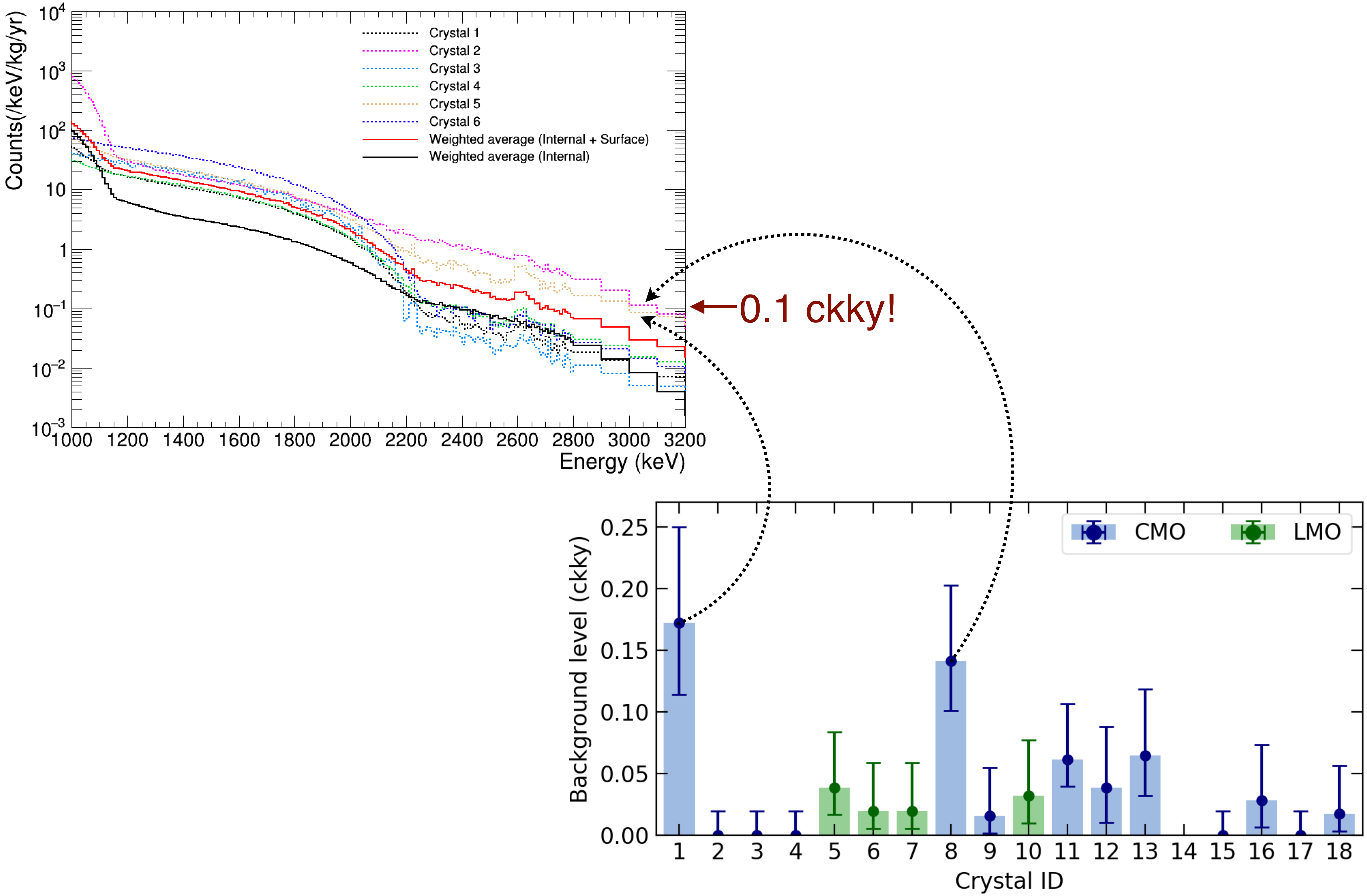
Posters on 4F. Dirac (Session 1-b)

- [DT04-774] Hanbum Kim, "AMoRE-I data analysis"
- [DT04-398] Hyejin Lee, "Detector sensors and modules for AMoRE-II"
- [DT04-377] Wootae Kim, "Detector R&D for AMoRE-II"
- [DT04-385] Jeewon Seo, "Radioassay and simulation for AMoRE-II"
- [DT04-560] Jaison Lee, "AMoRE-II construction"

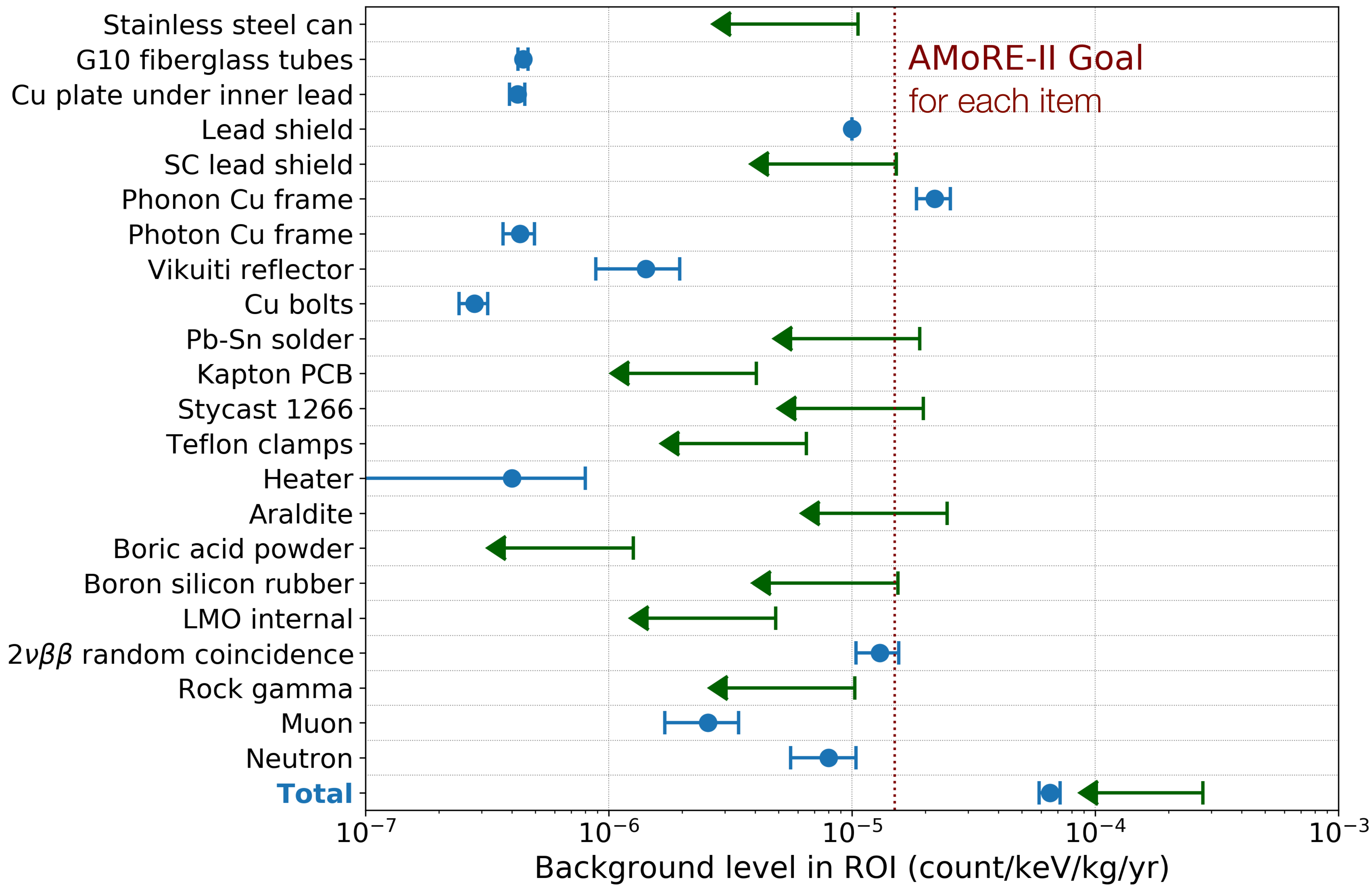

Good afternoon,
good evening
and
good night.
back up slides >>

CMO internal background

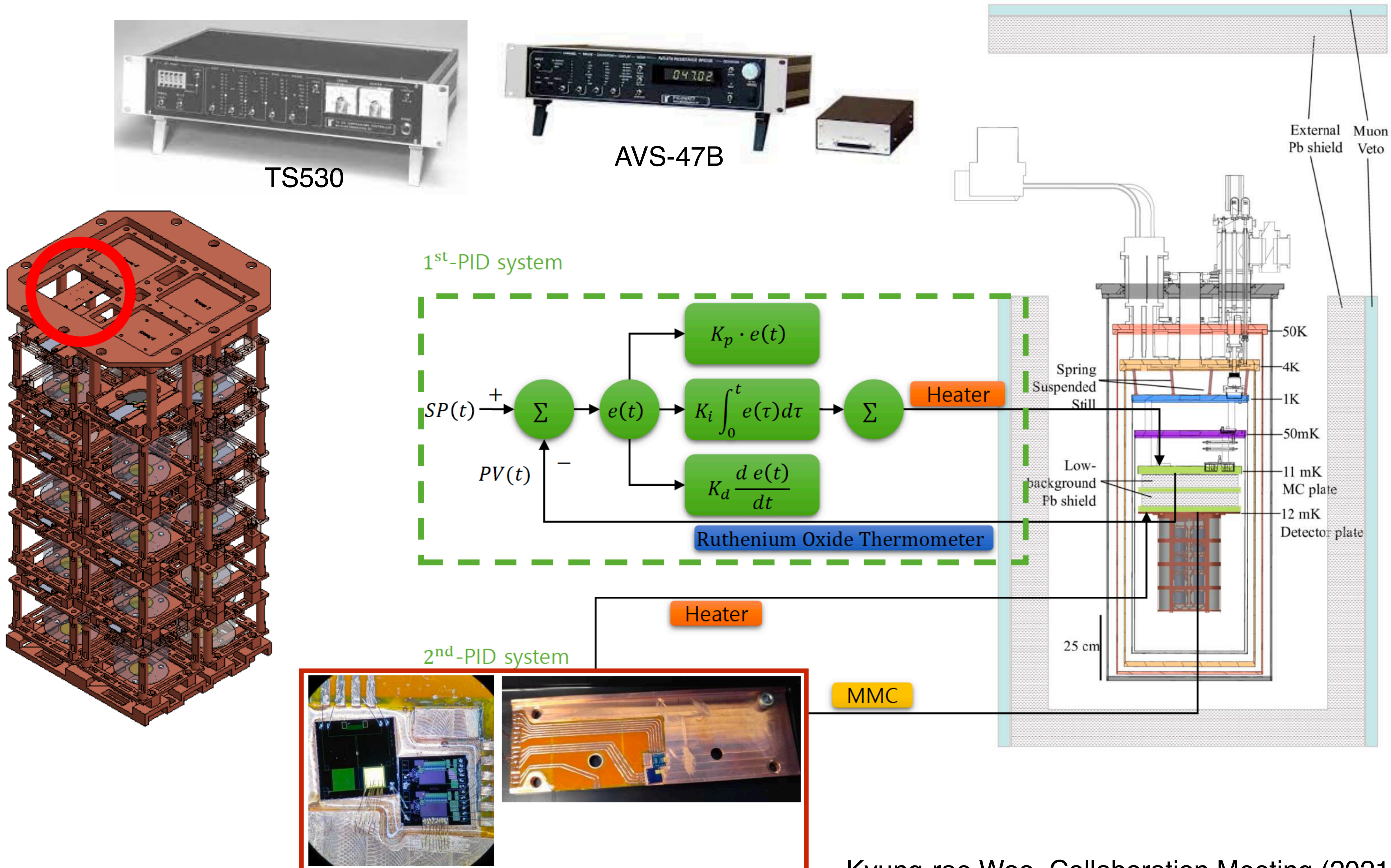
arXiv:2107.07704



Background budget for AMoRE-II



Two stage temperature control



Kyung-rae Woo, Collaboration Meeting (2021)