A New Results of AMoRE-I Experiment

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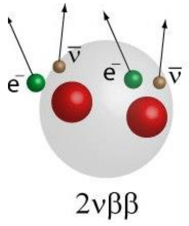
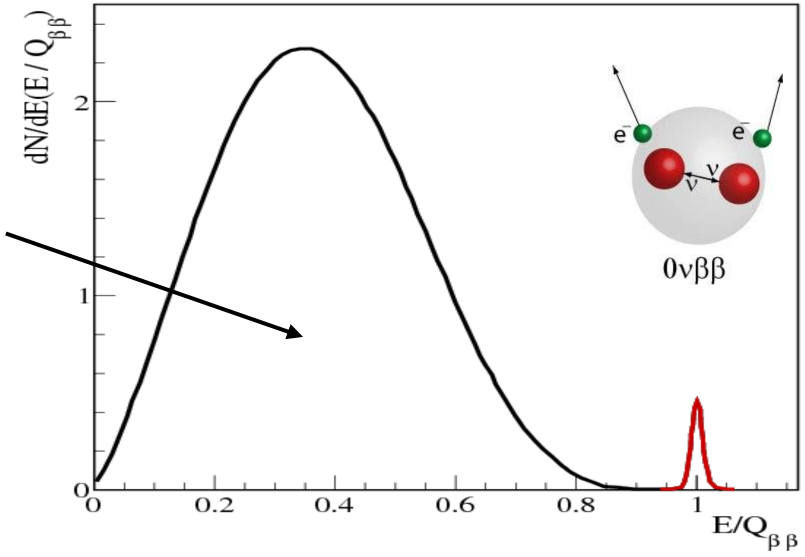
$0\nu\beta\beta$ search using ^{100}Mo

AMoRE:

A search for neutrinoless double beta ($0\nu\beta\beta$) decay of ^{100}Mo using Mo-based scintillating crystals and low-temperature sensors.

$2\nu\beta\beta$ decay
- 2^{nd} order beta decay
- Rare nuclear decay
- ($>10^{18}$ years of half life)





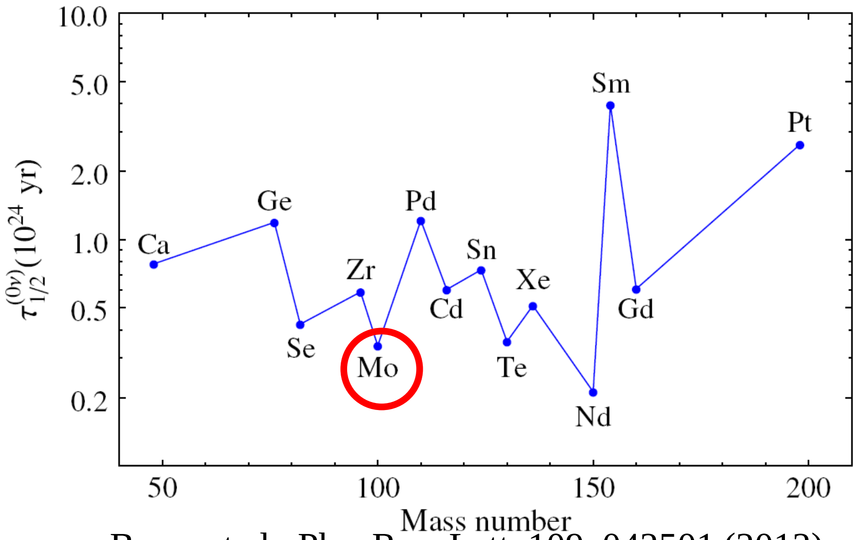
$0\nu\beta\beta$ decay
- Massive neutrino
- Majorana particle
- Beyond the SM model
- $>10^{25}$ years of half-life

$$(Z, A) \rightarrow (Z+2, A) + 2e^- + 2\bar{\nu}_e$$
$$(Z, A) \rightarrow (Z+2, A) + 2e^-$$

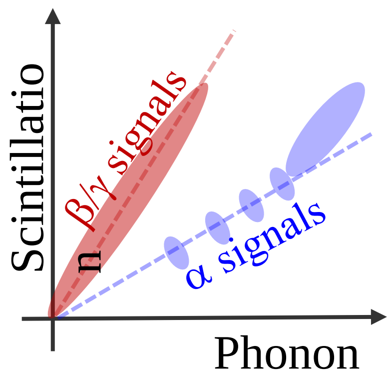
- Neutrinoless double beta decay:
  - Direct measure of Majorana nature of neutrino.
  - Lepton number violation process.
  - Effective neutrino mass.

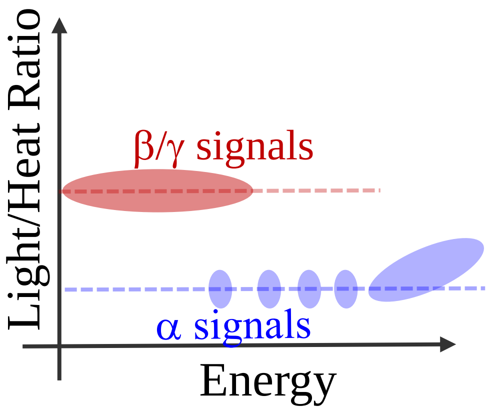
0νββ search using ^{100}Mo

^{100}Mo:
- High $Q_{\beta\beta}$ = 3034 keV
- High natural abundance: 9.7 %
- 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.
- Relatively short half life (0νββ) in theoretical expectation



Barea et al., Phy. Rev. Lett. 109, 042501 (2012)

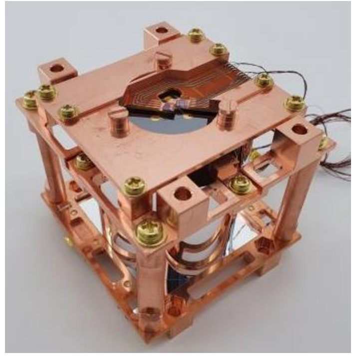


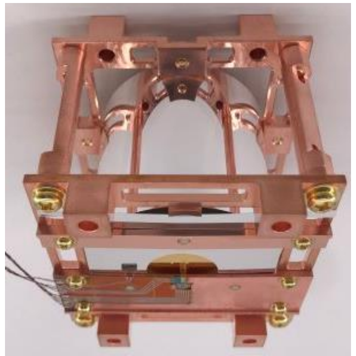


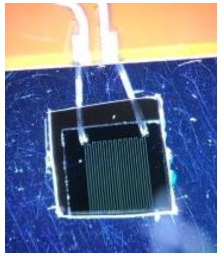
ββ-decay nuclei with Q > 2 MeV	Q (MeV)	Abund. (%)
^{48}Ca → ^{48}Ti	4.271	0.187
^{76}Ge → ^{76}Se	2.040	7.8
^{82}Se → ^{82}Kr	2.995	9.2
^{96}Zr → ^{96}Ru	3.350	2.8
^{100}Mo → ^{100}Ru	3.034	9.7
^{110}Pd → ^{110}Cd	2.013	11.8
^{116}Cd → ^{116}Sn	2.802	7.5
^{124}Sn → ^{124}Ge	2.228	5.8
^{130}Te → ^{130}Xe	2.528	34.2
^{136}Xe → ^{136}Ba	2.479	8.9
^{150}Nd → ^{150}Sm	3.367	5.6

Detector Module

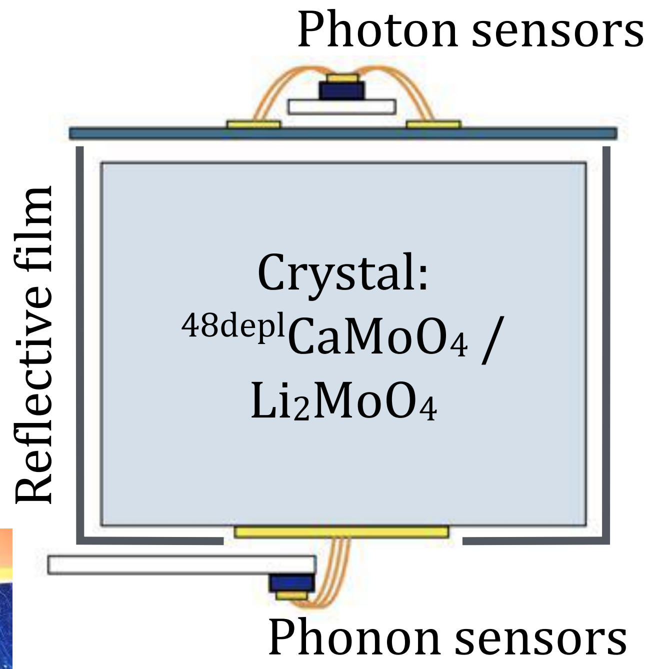
- Cylindrical CMO and LMO crystals, sizes vary $\Phi \geq 4$ cm / H $\lesssim 5$ cm.
  - CMO: ^{48}Ca depleted, $Q_{\beta\beta}$ (^{48}Ca) = 4271 keV.
- Metallic magnetic calorimeter (MMC) + SQUID:
  - Fast signal timing: a few millisecond rise-time for phonon signals at mK.
  - Low random coincidence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



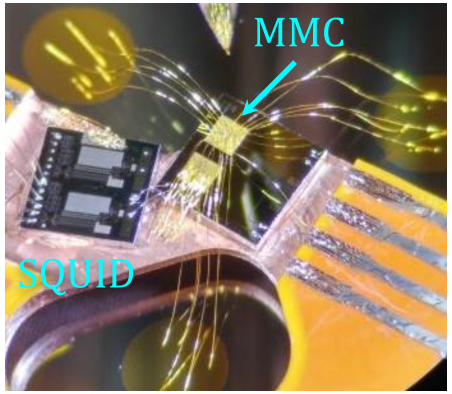




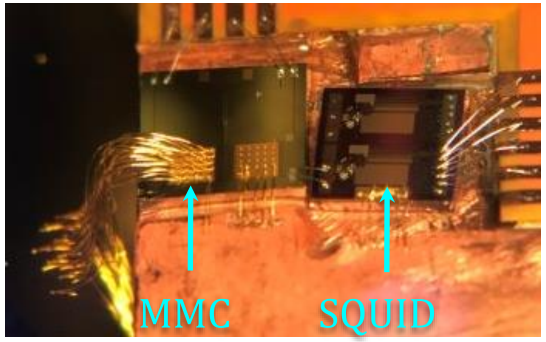
Stabilization heater



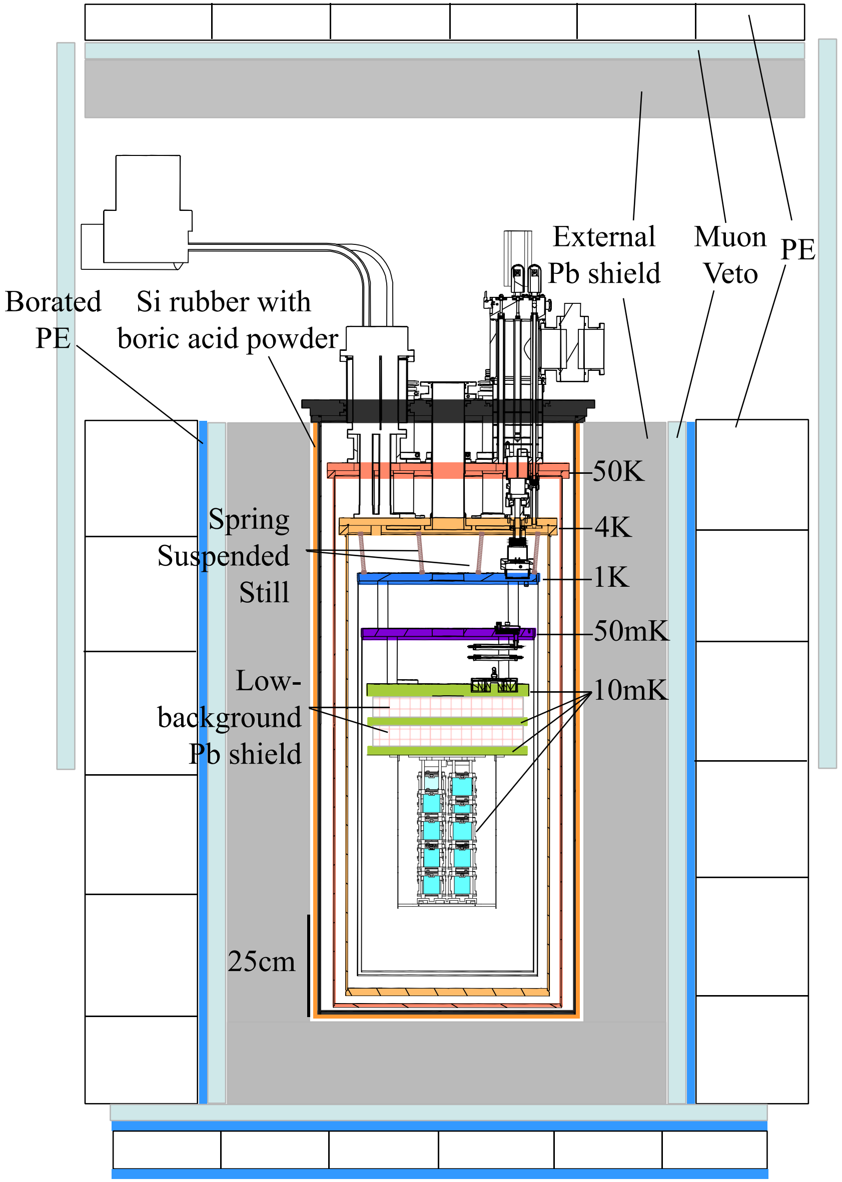
Light absorber (Ge/Si wafer)



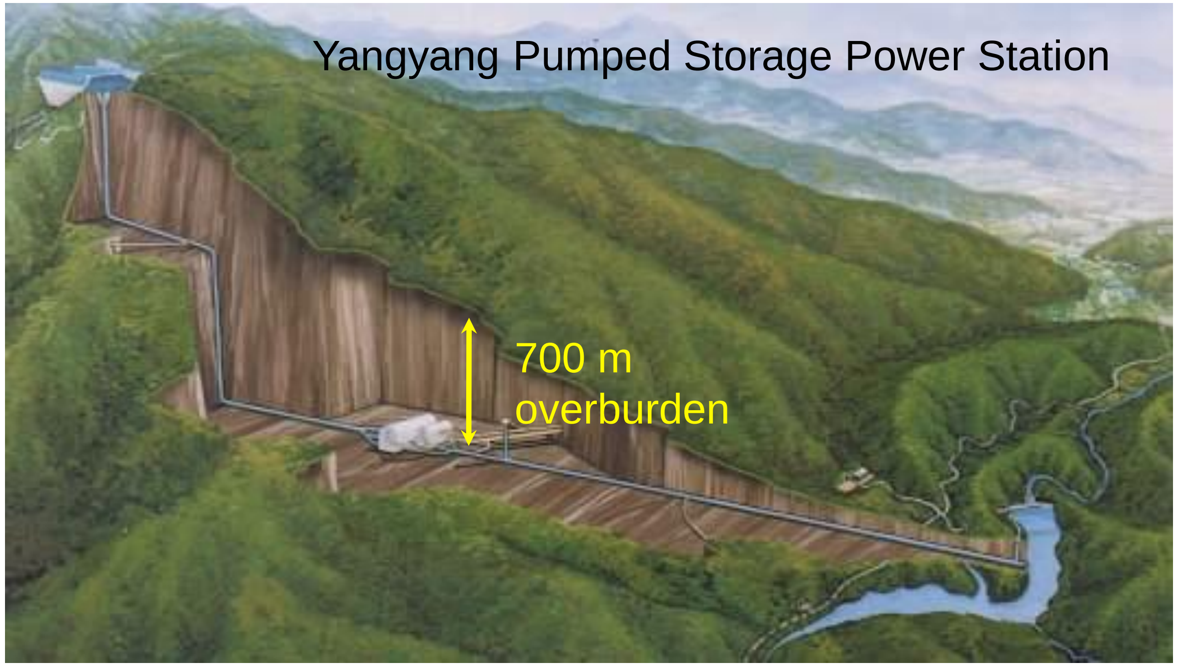
Phonon collector (Au film)



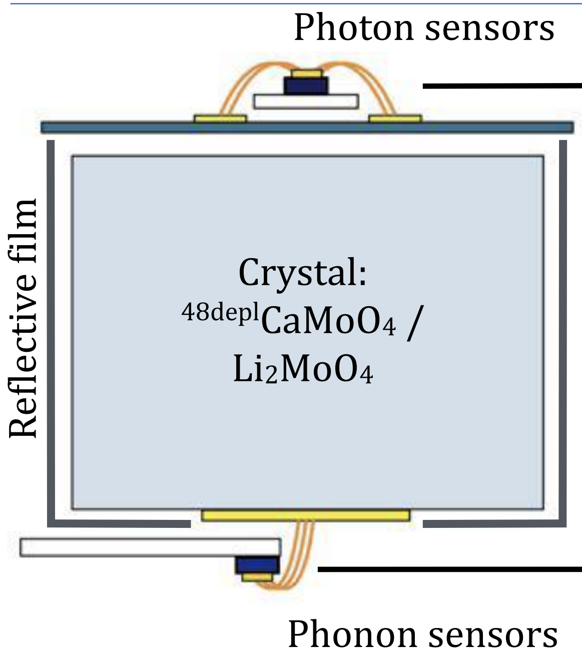
Cryostat & Shielding



- Cryogen-free dilution refrigerator.
- For AMoRE-pilot and AMoRE-I.
- Now operating at 12 mK with ~1 μW cooling power.
- Pb (γ), boron, and polyethylene (n).
- Plastic scintillator muon counter.
- Yangyang Underground Laboratory (Y2L) at 700 m depth.

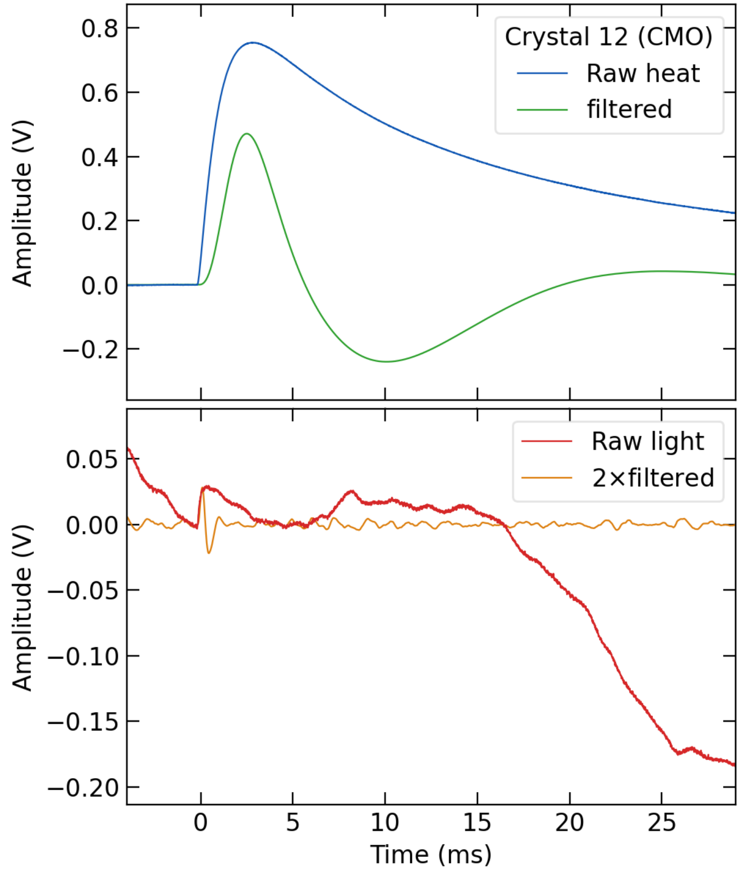


Signal Processing & Analysis



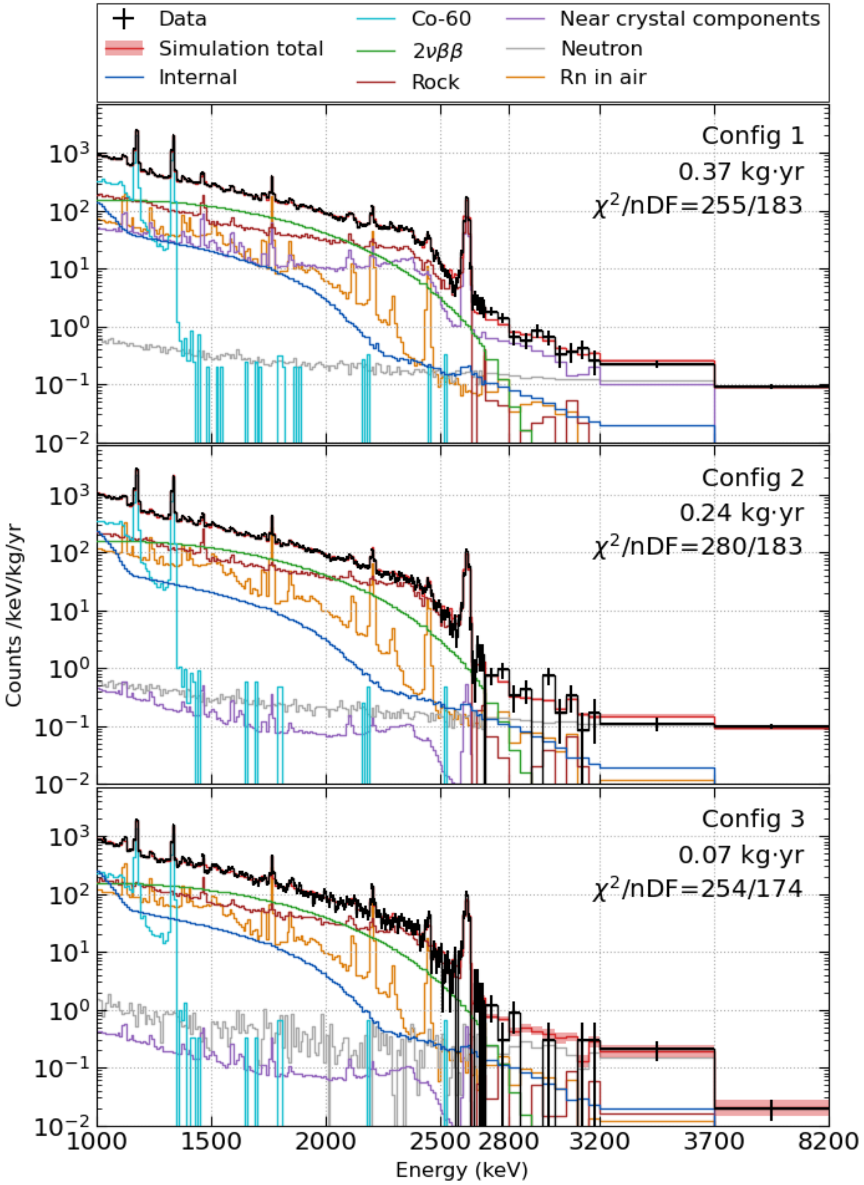
ADCs:
18-bit resolution,
100 kHz sampling

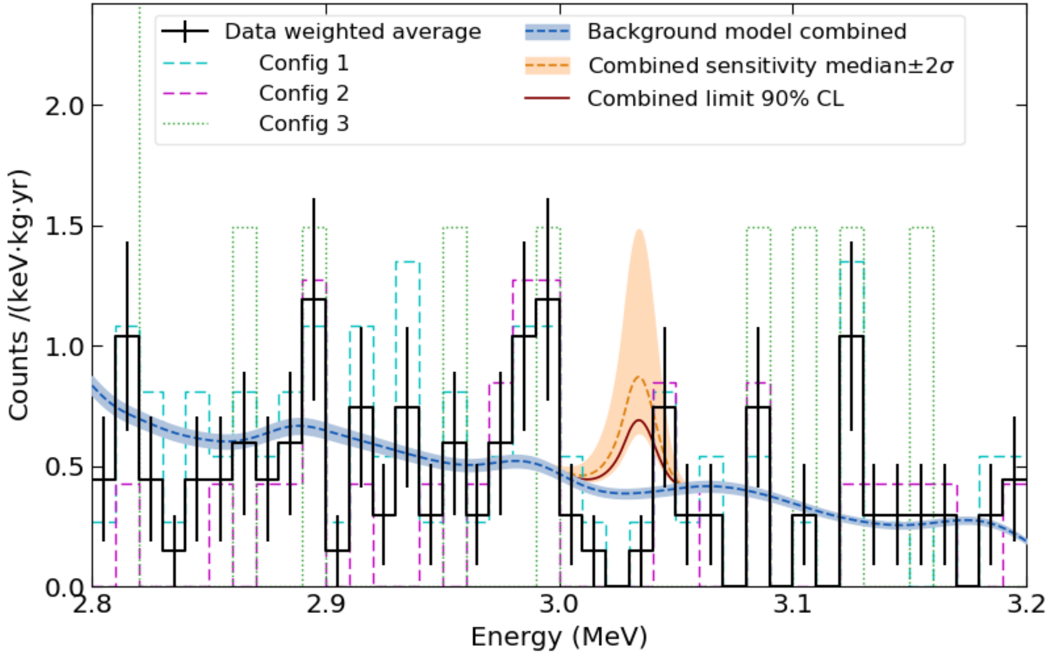
- Software trigger for phonon signal, using Butterworth bandpass filter.
- Trigger threshold: 30-200 keV.



- 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 to gain drift corrections.

AMoRE-pilot final result

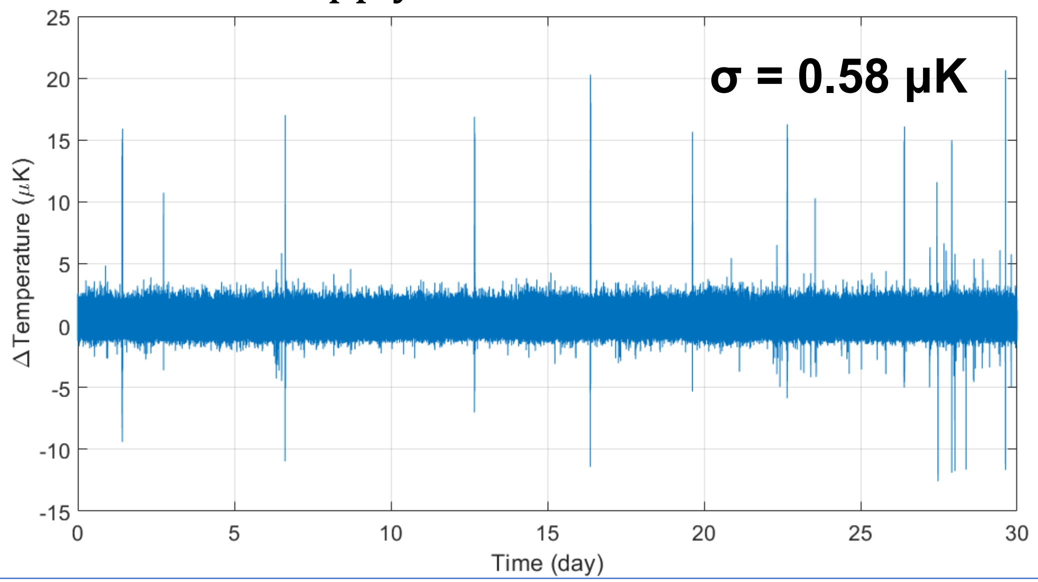


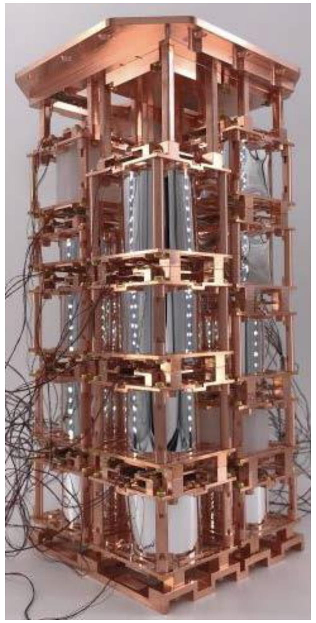


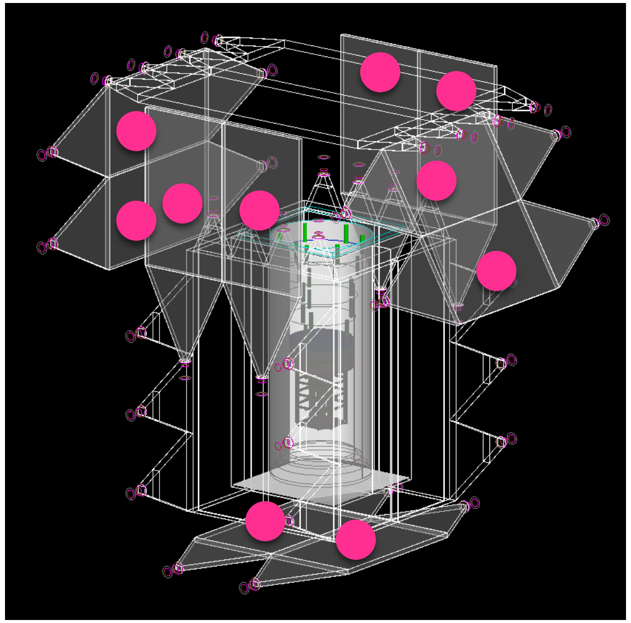
- Experiment between 2016-2018
- Understanding of the background components and reduction of them.
- Background level of ~0.5 counts/keV/kg/yr at 2.8-3.2 MeV.
- neutron-induced γ, crystals' internal contamination, rock/air-radon γ.
- Internal background— arXiv:2107.07704
- $T_{1/2}^{0\nu} > 3.2 \times 10^{23}$ years at 90% CL.

AMoRE-pilot → AMoRE-I

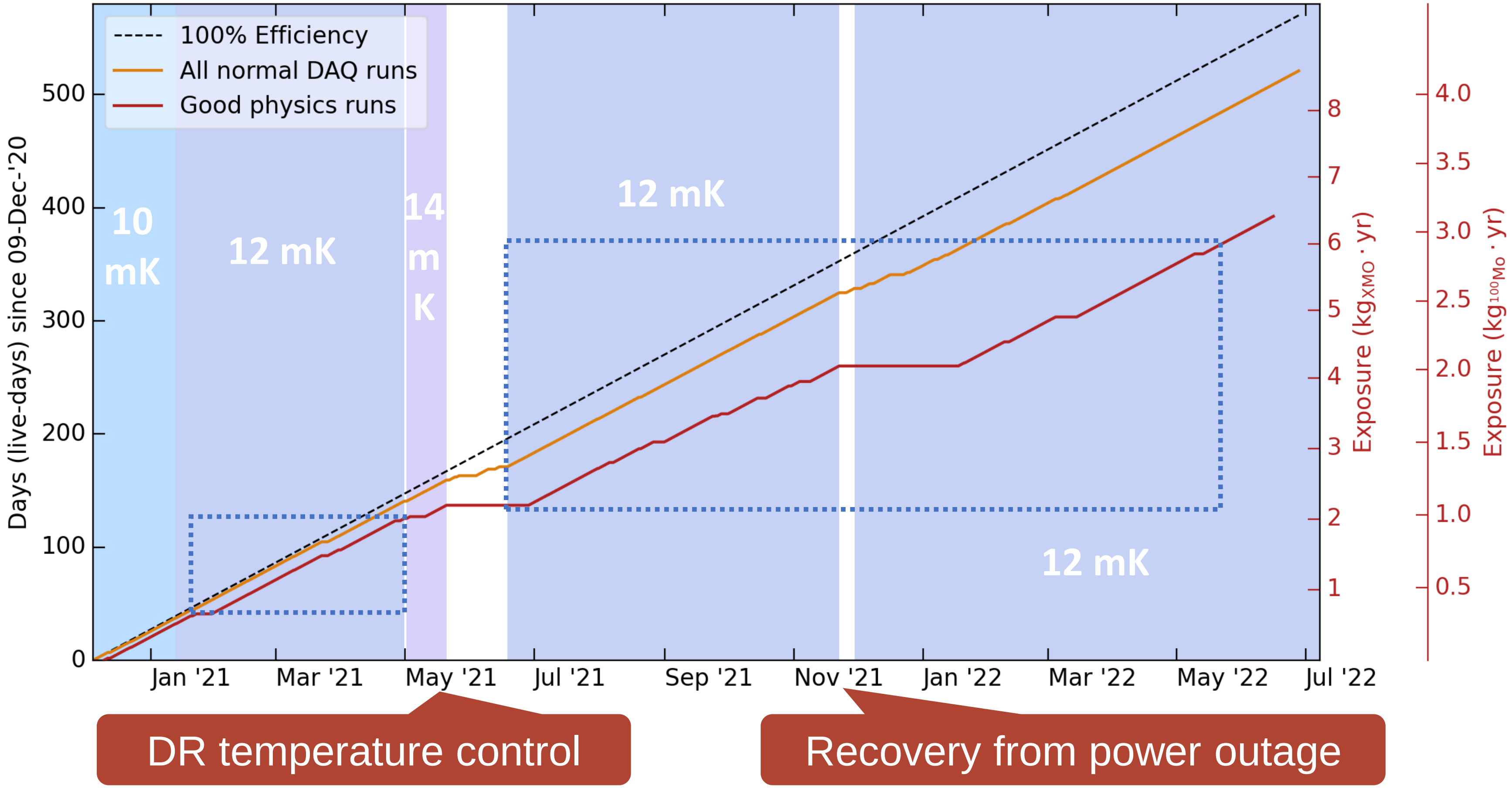
- 6 CMO (1.89 kg) ➔ 13 CMO (4.58 kg) + 5 LMO (1.61 kg)
  - Total crystal mass = 6.19 kg, ^{100}Mo mass = 3.0 kg
- Stabilization heater for all crystals.
- MMC sensor: Au:Er ➔ Ag:Er.
- Using same cryostat + two stage temperature control: ⟨ΔT⟩ < 1 μK.
- Shielding enhancements:
  - Outer Pb: 15 ➔ 20 cm;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

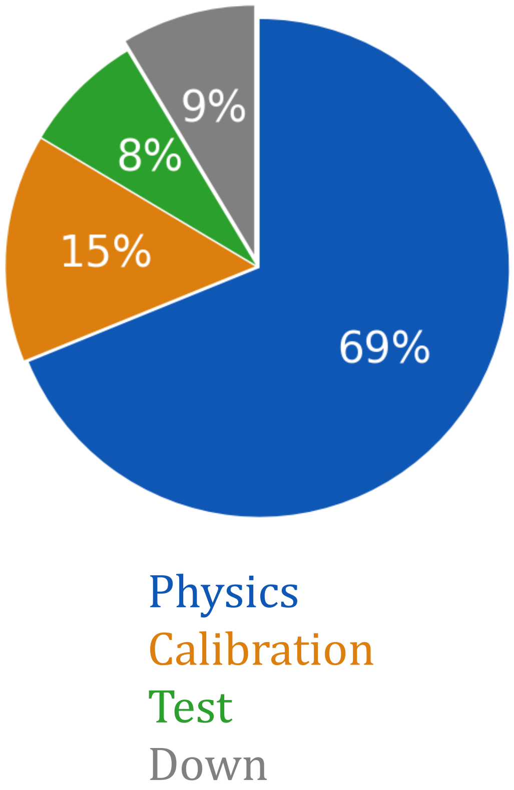






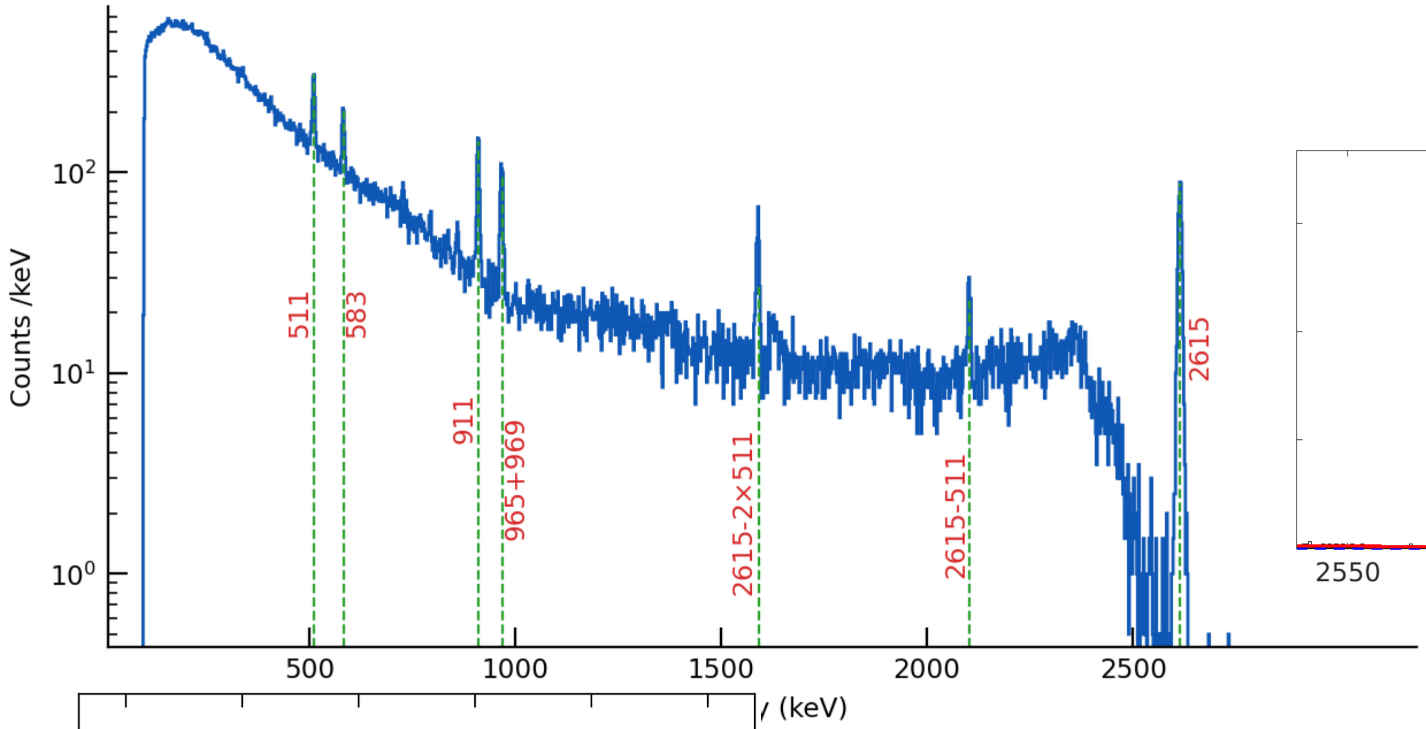
AMoRE-I data taking

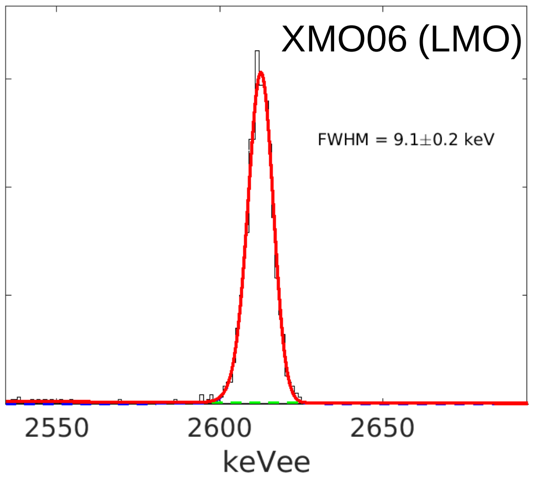


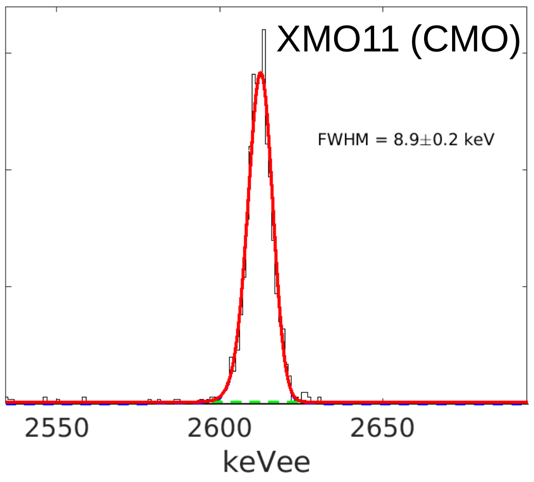


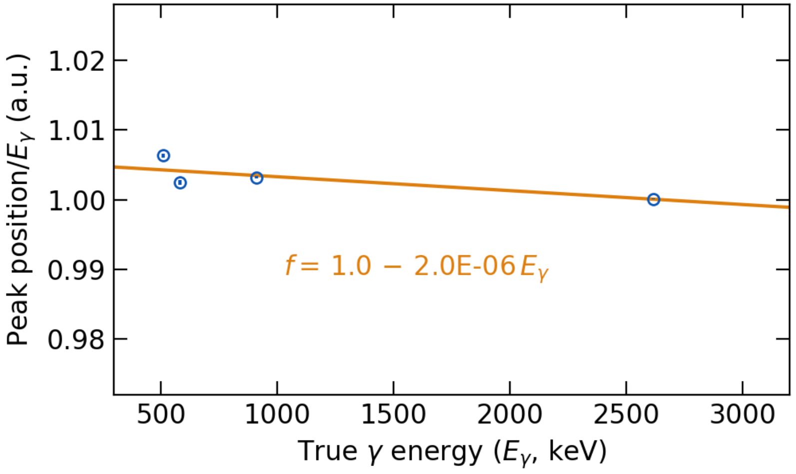
- Data taking until the end of 2022 (at least)
- 4.68 kg · year crystal (2.24 kg · year ^{100}Mo) exposure is presented here (selected data in blue dotted boxes).

Energy Calibration



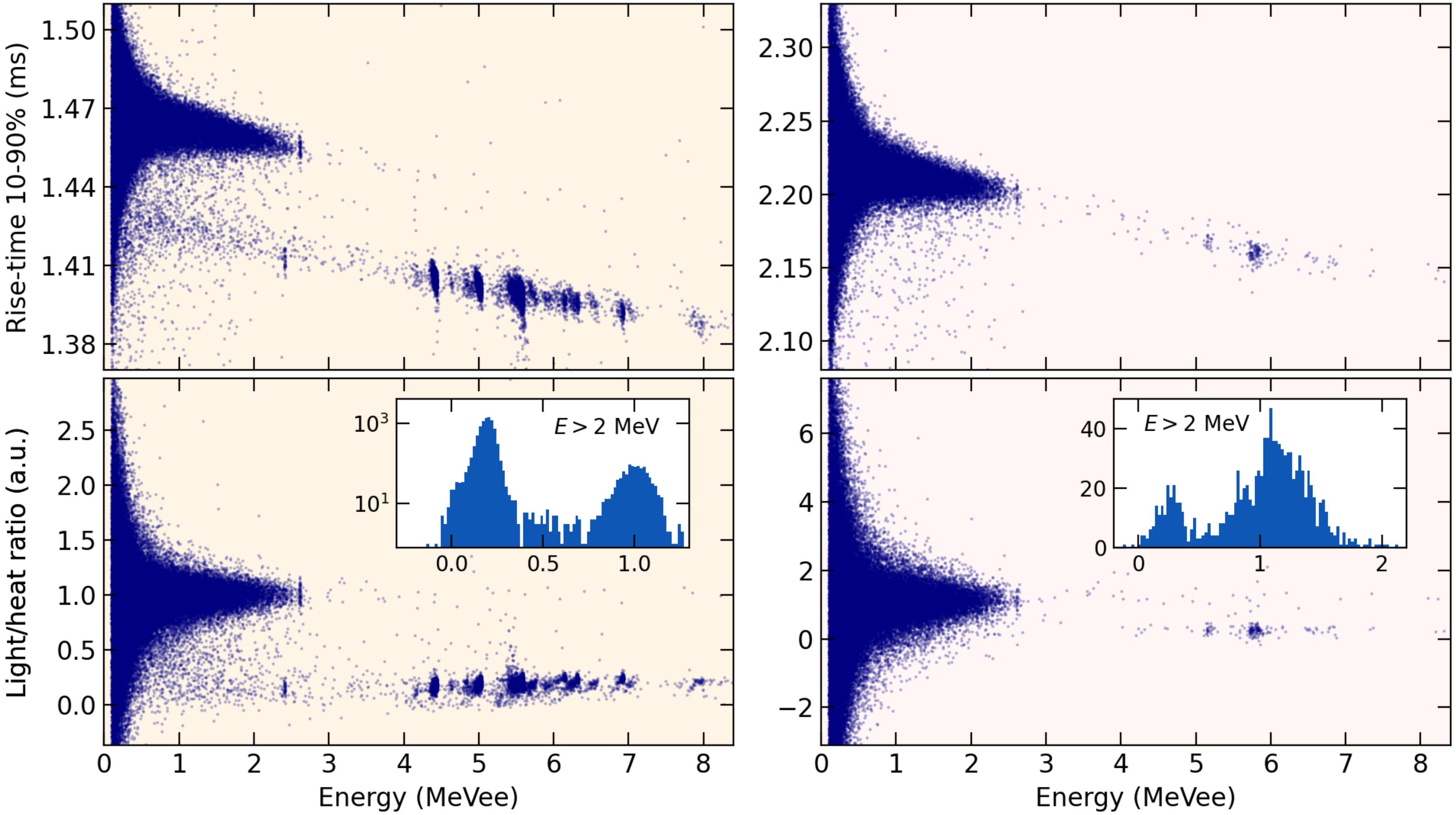






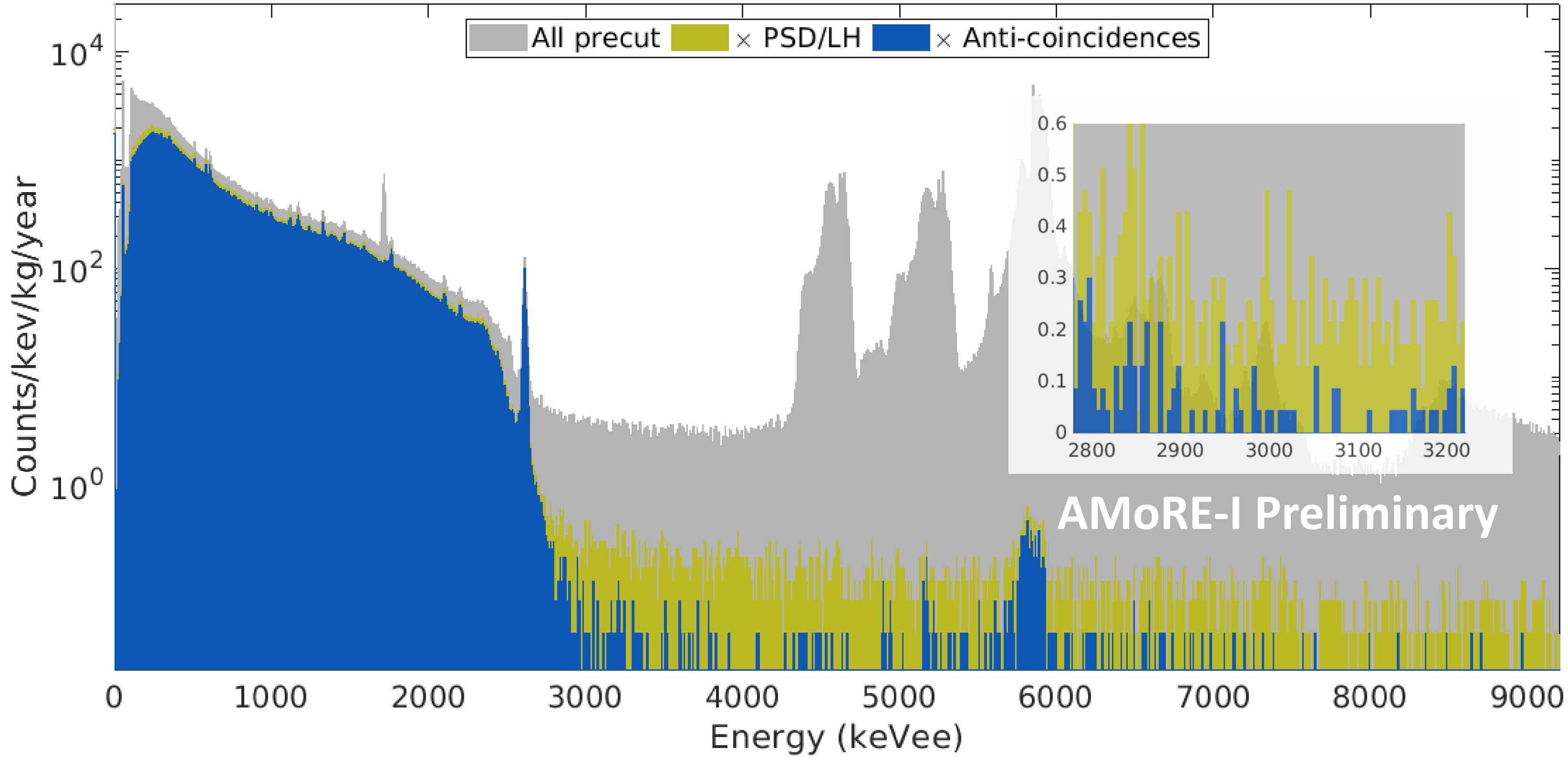
- Calibration source: ^{232}Th-rich welding rods just outside of OVC
- Slight non-linearity between signal amplitude and energy.
- Energy resolution: [8.9-32.7] keV FWHM at 2615 keV, ~15 keV in average.

Particle Identifications, CMO and LMO



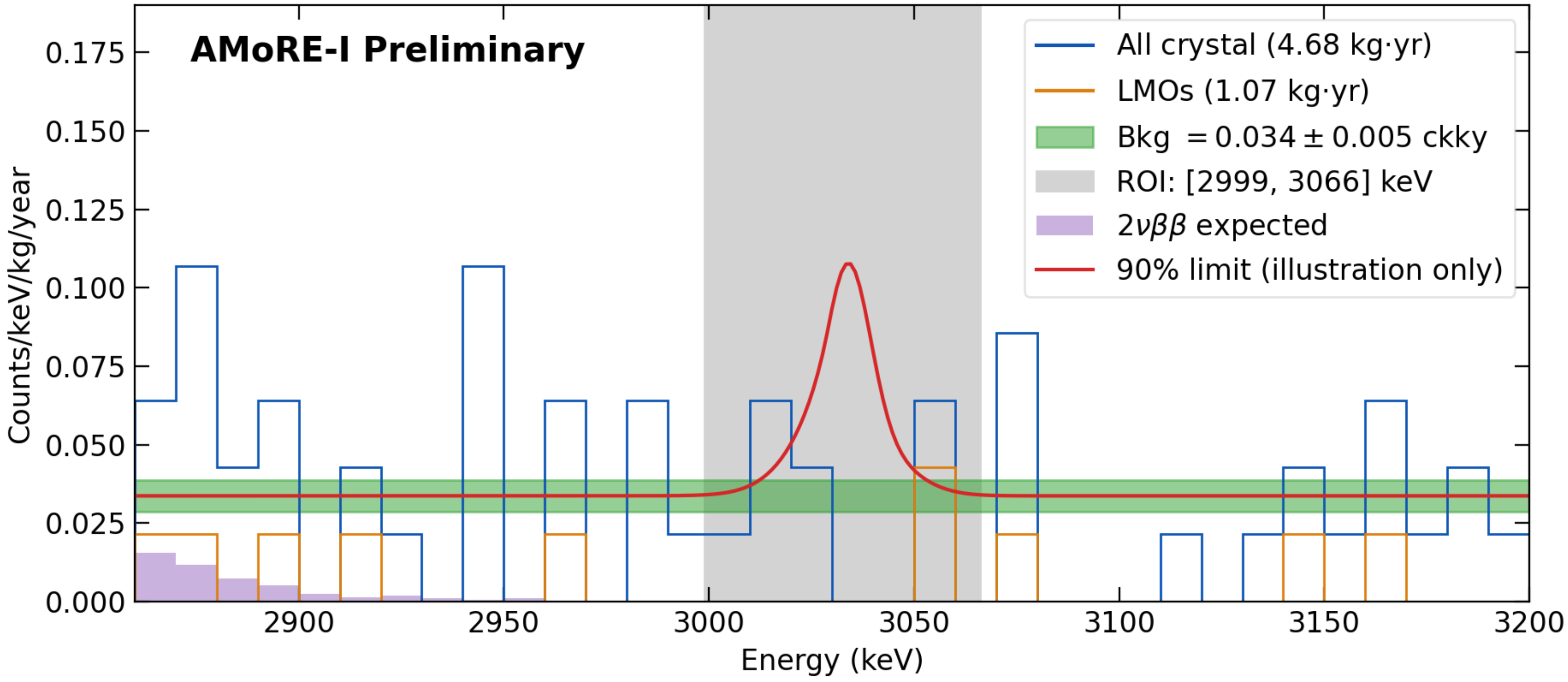
- CMO shows better discrimination power — light yield: CMO > LMO.
- LMO has much less α contamination.

Background Spectrum



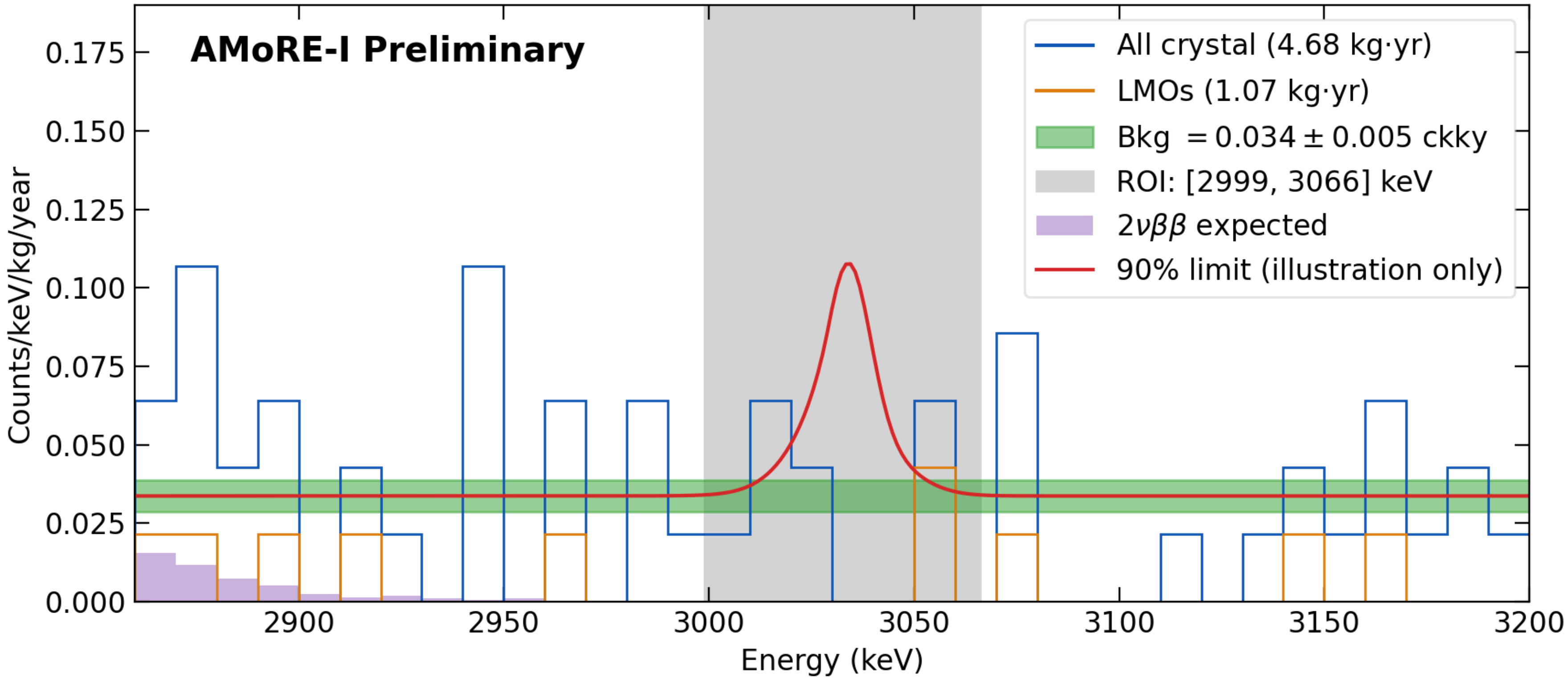
- All crystal excluding 1 LMO for very poor β/α discrimination power:
  - 13 CMO + 4 LMO: exposure = 4.68 kg_{XMO} · yr = 2.24 kg_{ISO} · yr.
- Anti-coincidence cuts reject events:
  - coincident at multiple crystals within 2 ms (ε ~ 99%),
  - within 10 ms after a muon counter event (ε ~ 99.7%),
  - within 20 minutes after a ^{212}Bi α-decay event candidate (ε ~ 98%).

Preliminary 0νββ limit from AMoRE-I



- Key parameters for the experimental sensitivity:
  - Signal ~ efficiency × [isotope mass × time] exposure.
  - Background ~ radioactivity level at around $Q_{\beta\beta}$ and energy resolution.

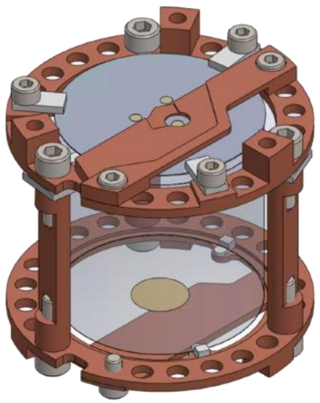
Preliminary 0νββ limit from AMoRE-I



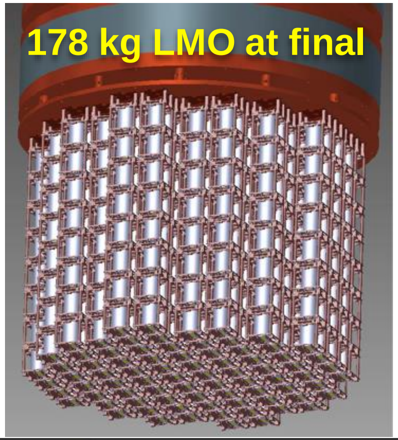
- ROI to contain most (> 99%) of the 0$\nu\beta\beta$ signal peak, $\varepsilon_{\text{containment}}$ ~ 81%.
- Background = 0.034 ± 0.005 counts/keV/kg/year, from ROI side-band.
- Combining the result of counting analysis at ROI, with a flat background constraint from the side-band events for each crystal.
- $T_{1/2}^{0\nu} > 1.05 \times 10^{24}$ years at 90% C.L.

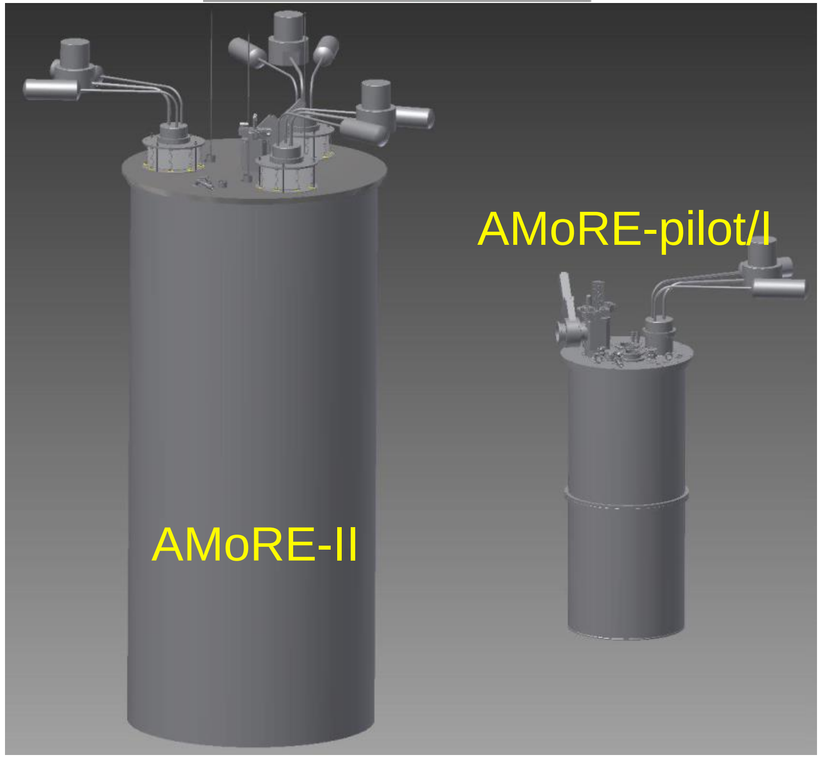
AMoRE-II in preparation

AMoRE-II
Detector module

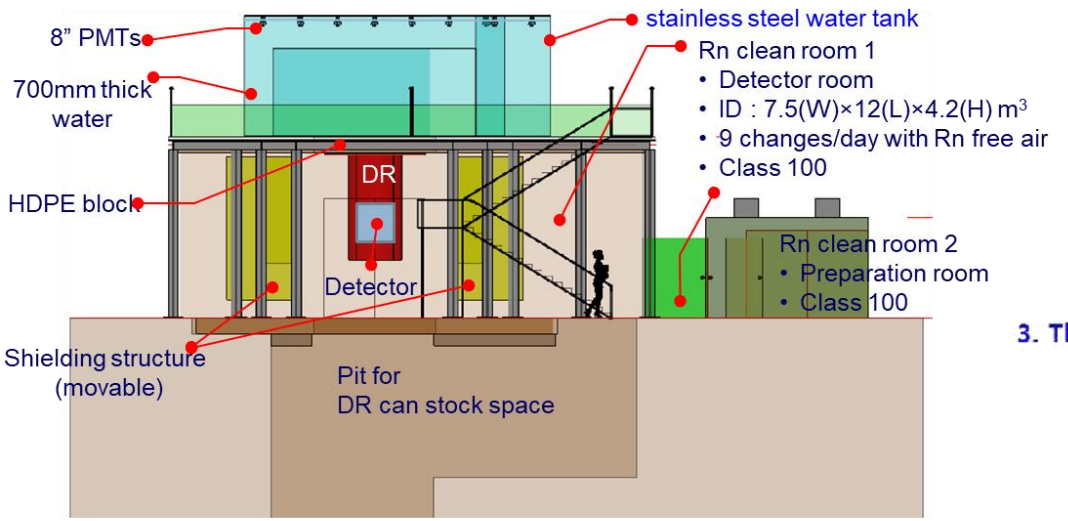


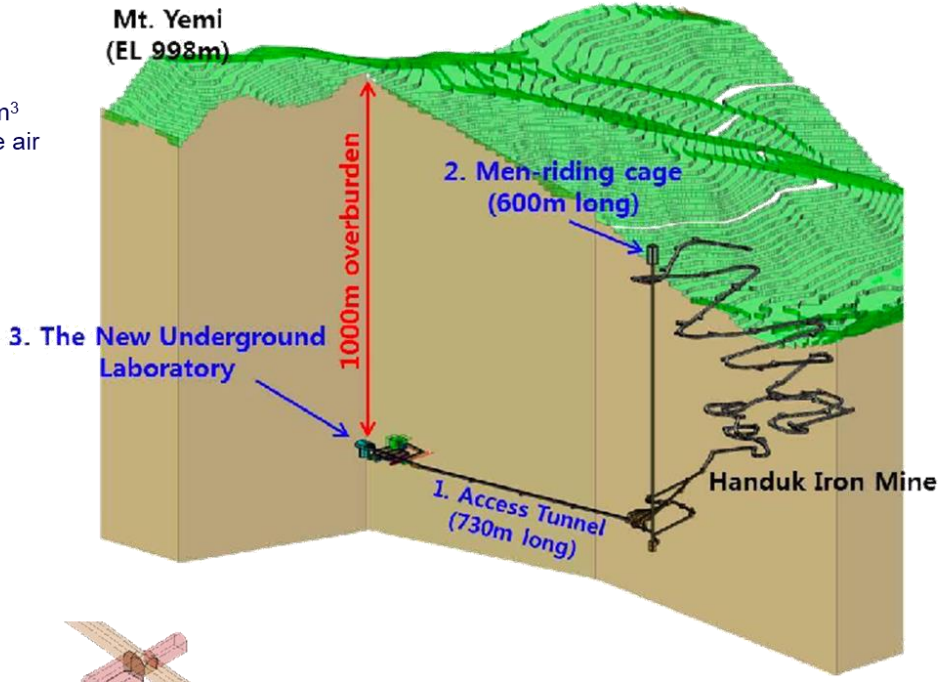
90 modules (~27 kg LMO)
for the first stage

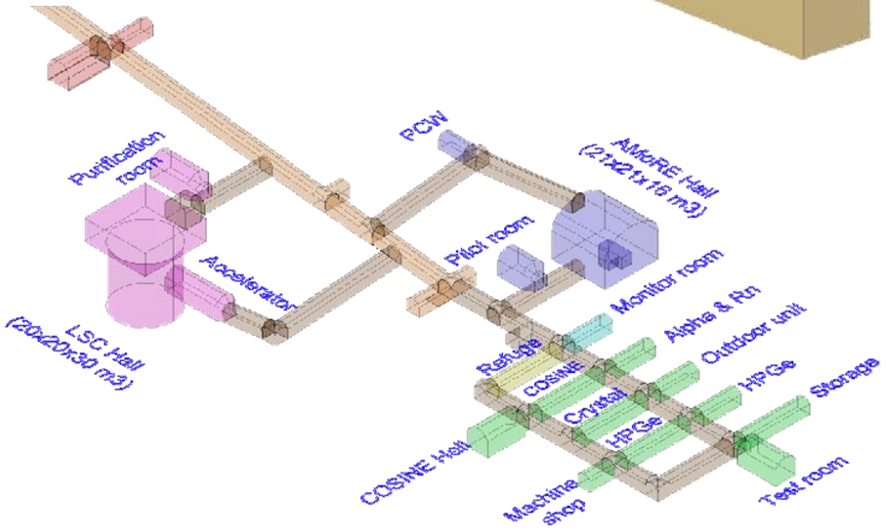




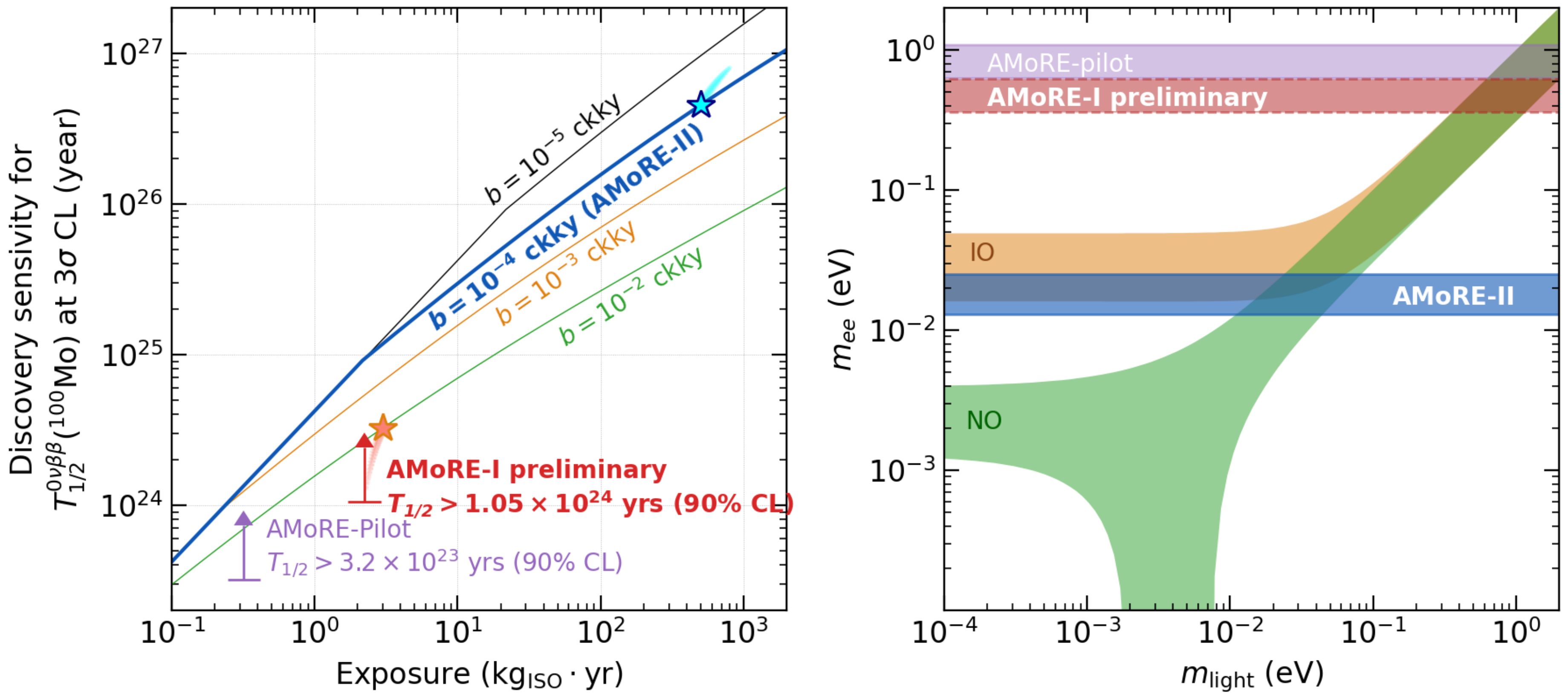
AMoRE-II in YemiLab







Limits & Sensitivities



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

Summary

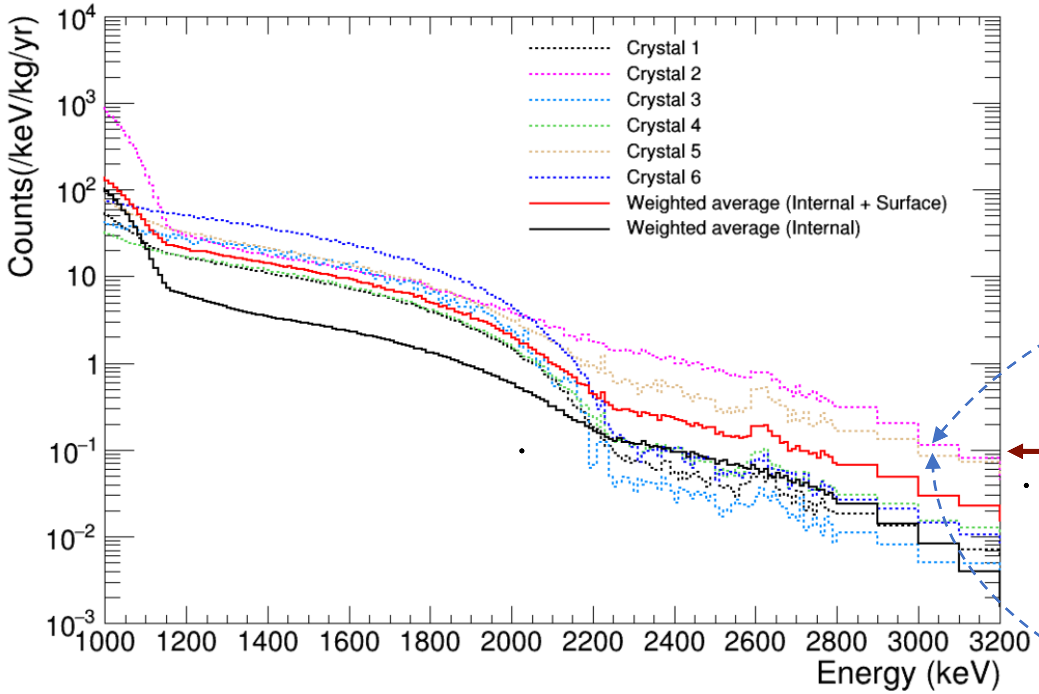
- AMoRE searches for 0νββ using ^{100}Mo based scintillation crystals at the low temperature detector system.
- Preliminary result of AMoRE-I at its mid-point:
  - Mass×time exposure: 4.68 (2.24) kg・yr XMO (^{100}Mo).
  - Background level ~ 0.03 counts/keV/kg/year at 2860-3200 keV.
  - $T_{1/2}^{0\nu} > 1.05 \times 10^{24}$ years.
  - AMoRE-I data taking will continue at least until end of 2022.
- AMoRE-II starts its data taking soon to head for $T_{1/2}^{0\nu} > 5 \times 10^{26}$ years.

Thank you!

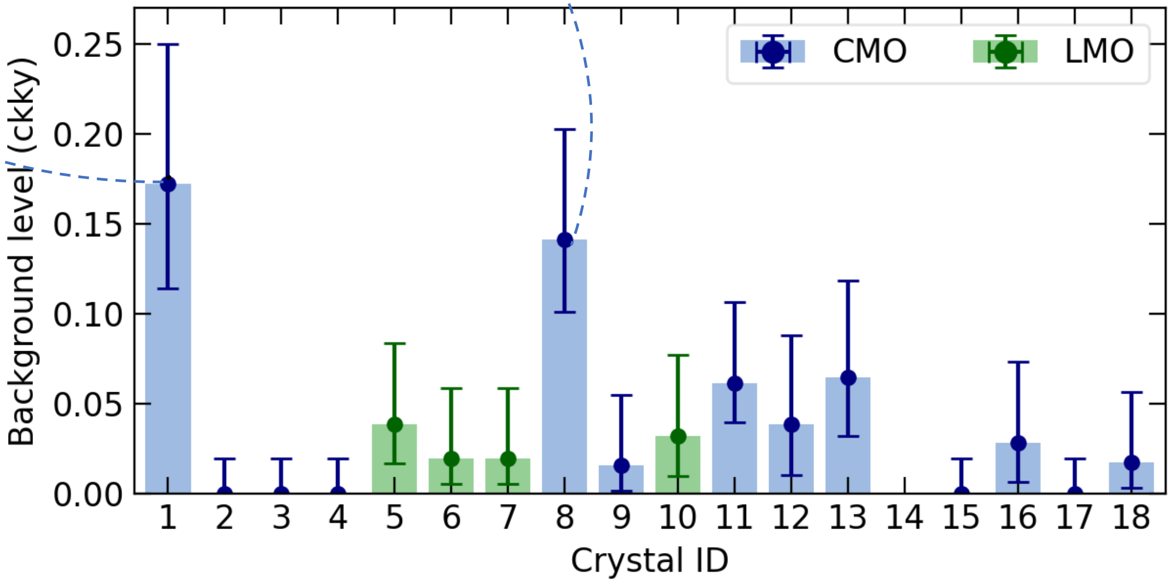
backup

CMO internal background

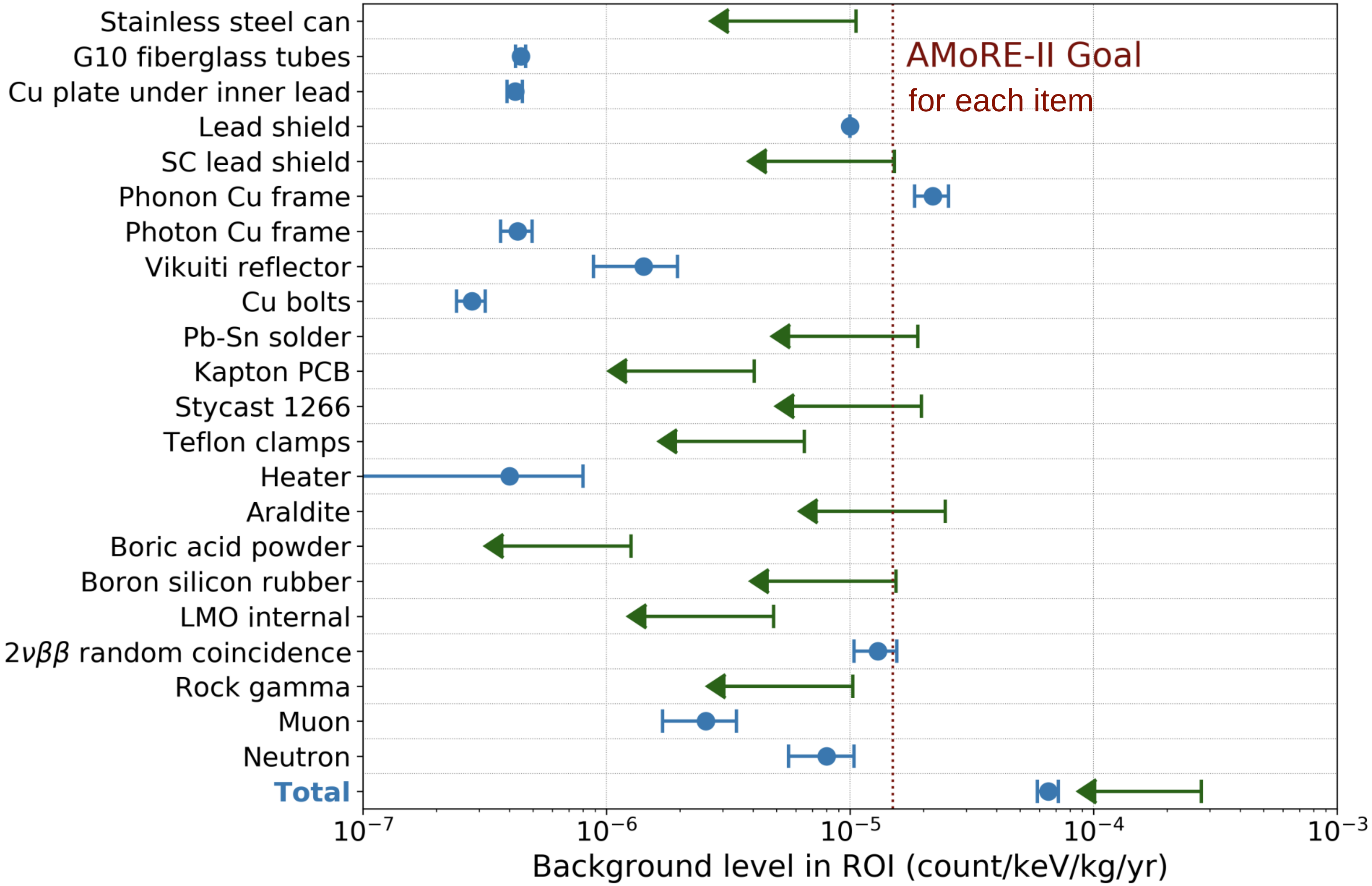
arXiv:2107.07704



0.1 ckky!



Background budget for AMoRE-II



Two stage temperature control