DETECTOR STATUS
OF AMORE-PILOT EXPERIMENT

Inwook Kim

On behalf of AMoRE-Collaboration

AMoRE

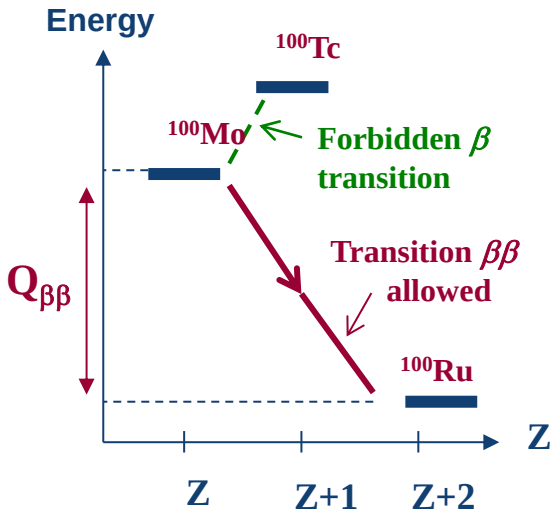
Advanced
Mo-based
Rare process
Experiment

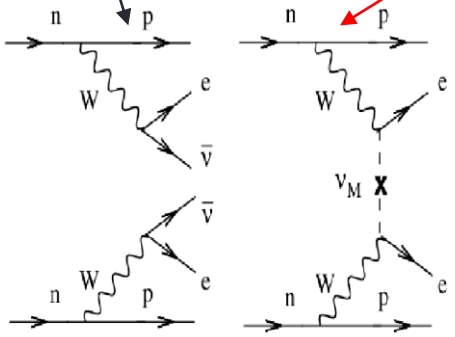
An experiment to investigate the Majorana nature of neutrino and hence measure the effective Majorana neutrino mass by searching for the NEUTRINOLESS DOUBLE-BETA DECAY of Molybdenum-100 using scintillating low temperature bolometers

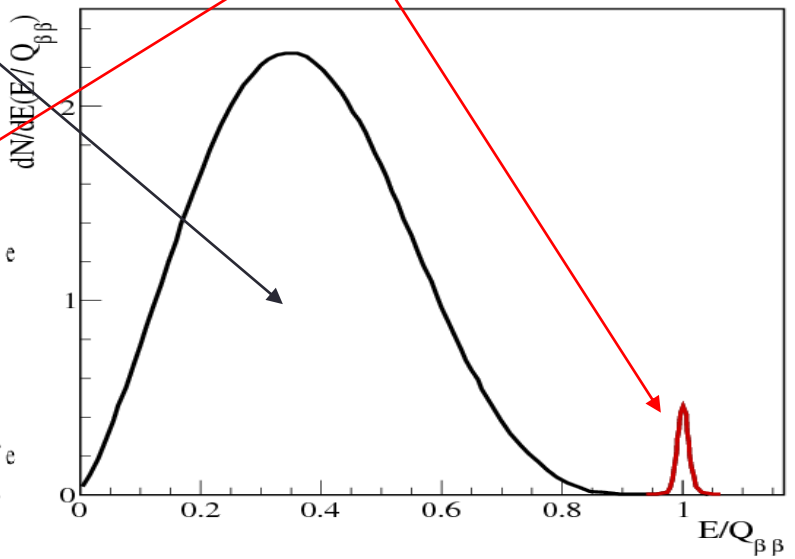
Neutrinoless Double Beta Decay (0nbb)

Double Beta Decay with two neutrinos
$(Z, A) \rightarrow (Z+2, A) + 2e^- + 2\text{anti-}\nu_e$ ($\Delta L = 0$, conserved)

Double Beta Decay with no neutrino
$(Z, A) \rightarrow (Z+2, A) + 2e^-$ ($\Delta L = 2$, violated)







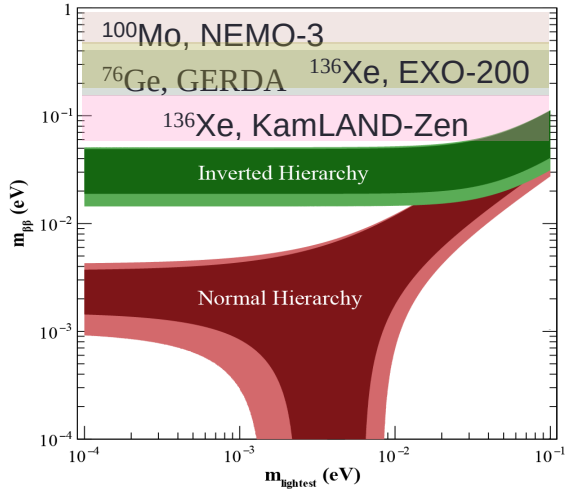
0nbb search enables to…

- Probe Majorana nature of neutrinos
- Measure the absolute effective Majorana mass of neutrinos
- Check the Lepton number conservation

…Possibility of physics beyond the SM!

Searching for 0nbb

Very rare Process ($T_{1/2}$>10^{25} yr)



For sizeable background case:

$$\lim T_{1/2}^{0\nu}(\exp) = (\ln 2)\, N_a \frac{a}{A}\varepsilon\sqrt{\frac{MT}{b\,\Delta E}}$$

Isotopic Abundance; Detection Efficiency; Detector Mass; Time; Atomic mass; Background level (count/keV kg year); Energy Resolution

Detection strategies:

- Large exposure
  - ✓ Large mass scale possible
  - ✓ High-abundance isotope
  - ✓ High detection efficiency
- Low background
  - ✓ Material selection
  - ✓ Shieldings from muons and external
  - ✓ High Q-value (to lower background)
  - ✓ Good energy resolution

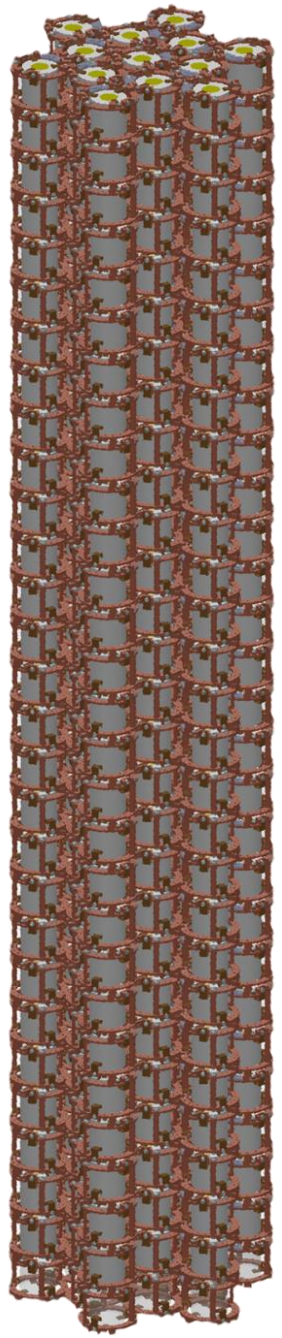
For "zero background" case:
(Expected background rate in ROI < 1 for given ***M T***)

$$\lim T_{1/2}^{0\nu}(\exp) = (\ln 2)\, N_a \frac{a}{A}\varepsilon\frac{MT}{n_{CL}}$$

AMoRE-Experiment

Advanced **Mo**-based **R**are process **E**xperiment

AMoRE-Phase II Concept design



- **0nbb source:** ^{100}Mo
- **Absorber**: Scintillating Mo-based crystal
- **Detection technique:** Low temperature detectors (MMCs @ ~10 mK)
- **Laboratory type:** Underground experiment

AMoRE-Experiment

Advanced Mo-based Rare process Experiment

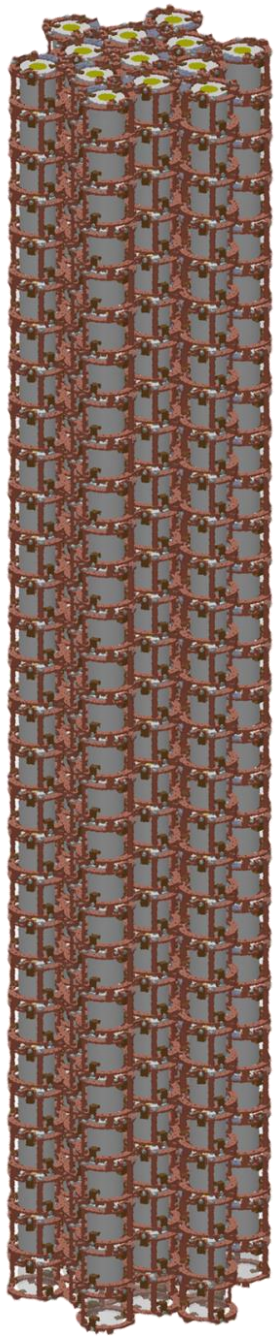
AMoRE-Phase II Concept design

Large exposure

- ✓ Large mass scale possible
- ❖ High-abundance isotope
- ❖ High detection efficiency

• Low background

- ❖ Material selection
- ❖ Shieldings from muons and external
- ❖ High Q-value (to lower background)
- ❖ Good energy resolution



AMoRE-Experiment

Advanced **Mo**-based **R**are process **E**xperiment

Large exposure

- ✓ Large mass scale possible
- ✓ High-abundance isotope
- ❖ High detection efficiency

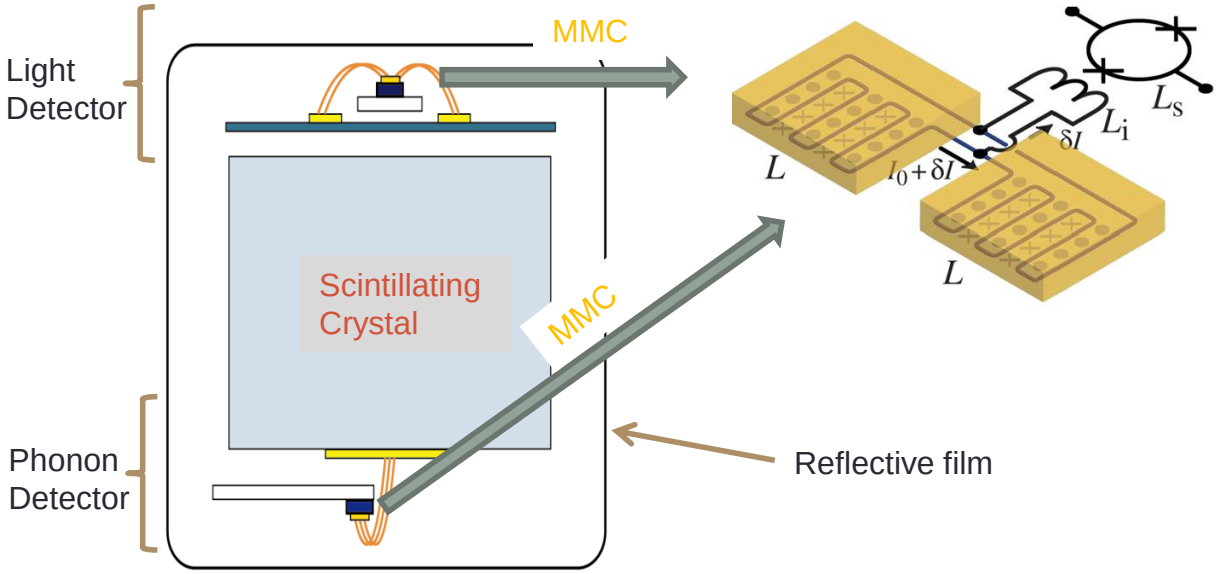
- ### Low background

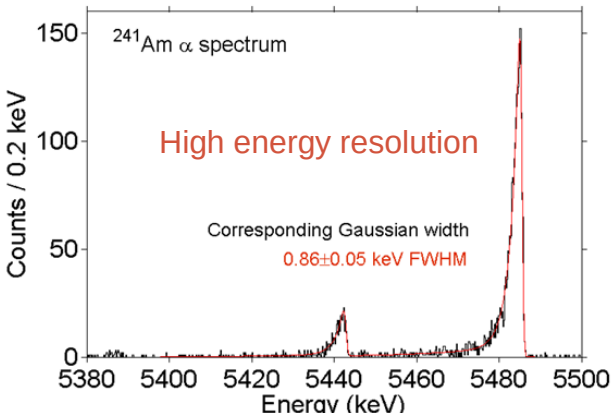
  - ❖ Material selection
  - ❖ Shieldings from muons and external
  - ✓ High Q-value (to lower background)
  - ❖ Good energy resolution

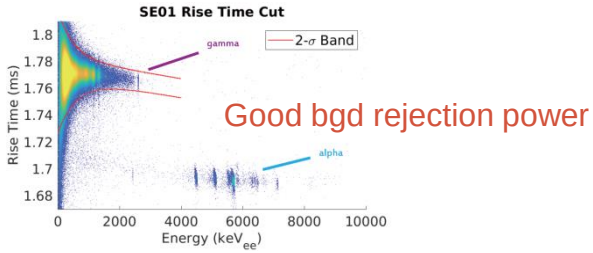
Candidates	$Q_{\beta\beta}$(MeV)	N.A. (%)
$^{48}Ca \rightarrow ^{48}Ti$	4.271	0.187
$^{76}Ge \rightarrow ^{76}Se$	2.040	7.8
$^{82}Se \rightarrow ^{82}Kr$	2.995	9.2
$^{96}Zr \rightarrow ^{96}Mo$	3.350	2.8
$^{100}Mo \rightarrow ^{100}Ru$	3.034	9.6
$^{110}Pd \rightarrow ^{110}Cd$	2.013	11.8
$^{116}Cd \rightarrow ^{116}Sn$	2.802	7.5
$^{124}Sn \rightarrow ^{124}Te$	2.228	5.64
$^{130}Te \rightarrow ^{130}Xe$	2.533	34.5
$^{136}Xe \rightarrow ^{136}Ba$	2.479	8.9
$^{150}Nd \rightarrow ^{150}Sm$	3.367	5.6

Phys. Rev. C 53, 695 (1996)

AMoRE Detector Concepts







AMoRE utilizes…

- ✓ Cryogenic detection method ~10mK temperature → Good energy resolution (~few keV)
- ✓ Metallic Magnetic Calorimeter (MMC) as temperature sensor → Fast response, good energy resolution (~ few keV)
- ✓ XMoOx(XMO) crystals as both the source and the absorber → High detection efficiency (~80%)
- ✓ Phonon-photon simultaneous detection technique → Good bgd rejection power

AMoRE-Experiment

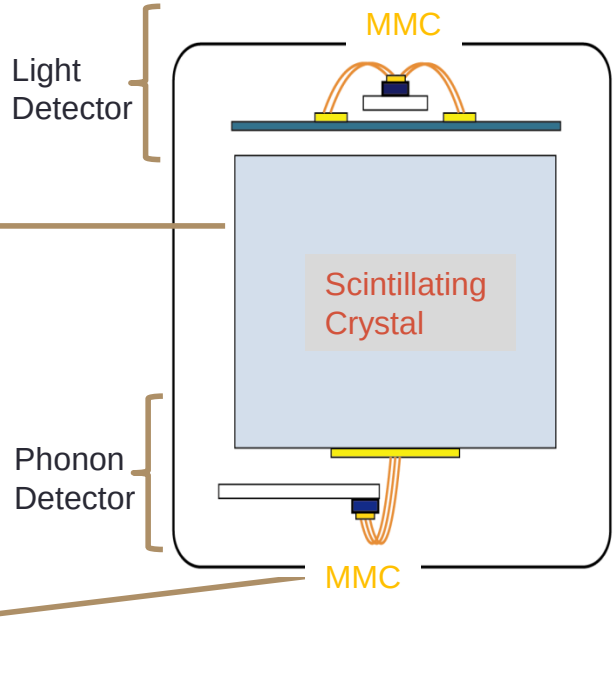
Advanced Mo-based Rare process Experiment

Large exposure

- ✓ Large mass scale possible
- ✓ High-abundance isotope
- ✓ High detection efficiency

• Low background

- ❖ Material selection
- ❖ Shieldings from muons and external
- ✓ High Q-value (to lower background)
- ✓ Good energy resolution



AMoRE-PILOT Experiment

The commissioning phase of AMoRE experiment at the Y2L underground laboratory

Purposes:

1. To check overall status of detector performances, cryostat, shielding, DAQ system and all other conditions.
2. To identify and to remove possible sources of backgrounds

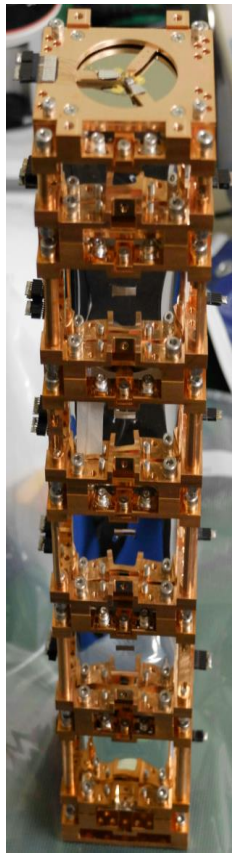
Period:

2015.08 ~ 2018.08 (Expected)

Conditions:

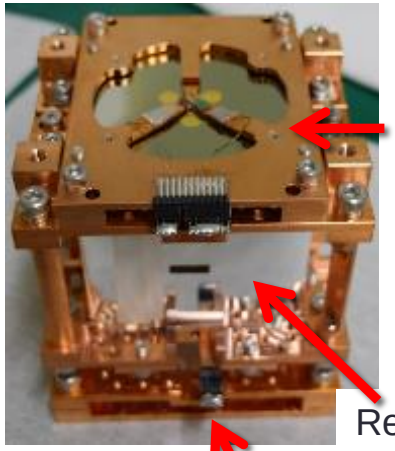
1. Base temperature @ 10-30 mK
2. 700-meter-deep Yangyang underground laboratory (Y2L)
3. Six $^{40}Ca^{100}MoO_4$ crystals, ~1.9 kg (grown at JSC “Fomos-Materials”)

6 Crystals



AMoRE-Pilot Setup

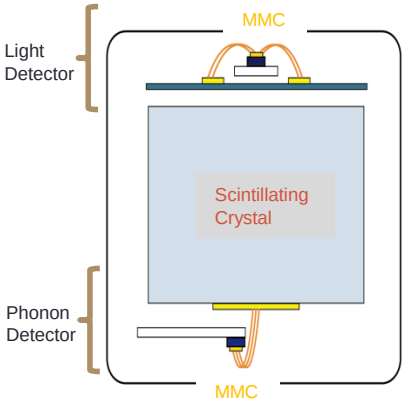
Detector module



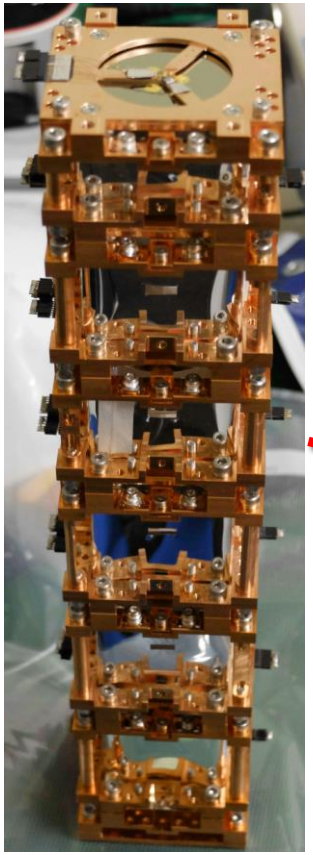
Detachable light detector

Reflective film (Crystal inside)

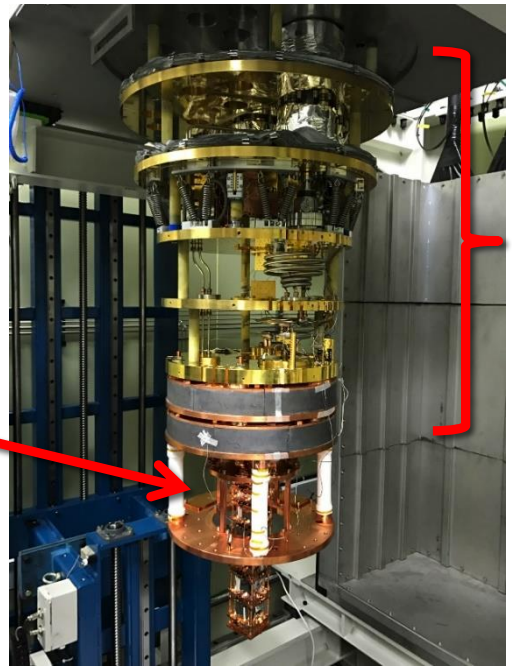
Heat detector at the bottom



Detector tower



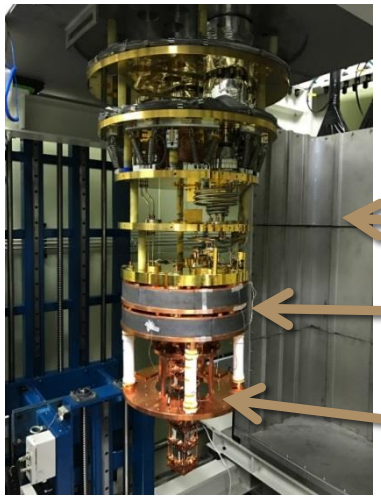
Installed in the cryostat



CF-DR

Background Reduction

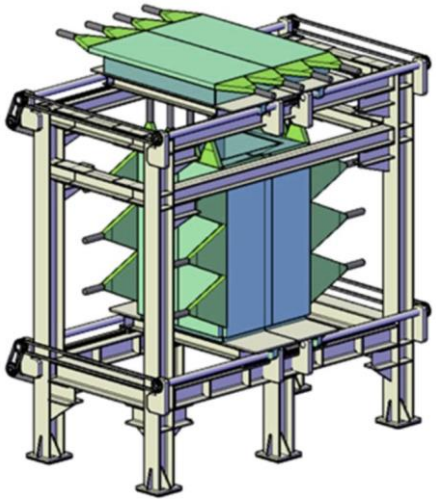
700-meter-deep Yangyang underground laboratory (Y2L)



15cm thick lead shield

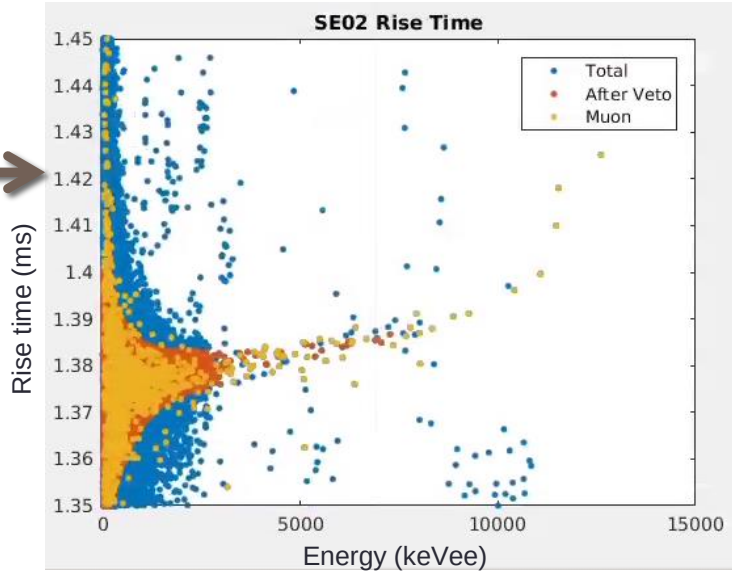
Low-background lead
(Ancient lead)

High radiopurity copper



Muon veto system

Muon-coincidence tagging



AMoRE-Pilot runs

- Run1: Pilot installation of 10 mK measurement for 5 crystals ($^{40}Ca^{100}MoO_4$)
- Run2: Noise improvement (low & high freq.) (Detector module design)
- Run3: New IVC installation (For background reduction)
- Run4: Noise improvement (low freq.) (Mass-spring damper)
- Run5: Muon veto, Noise improvement (low freq.) (Spring-suspended still)

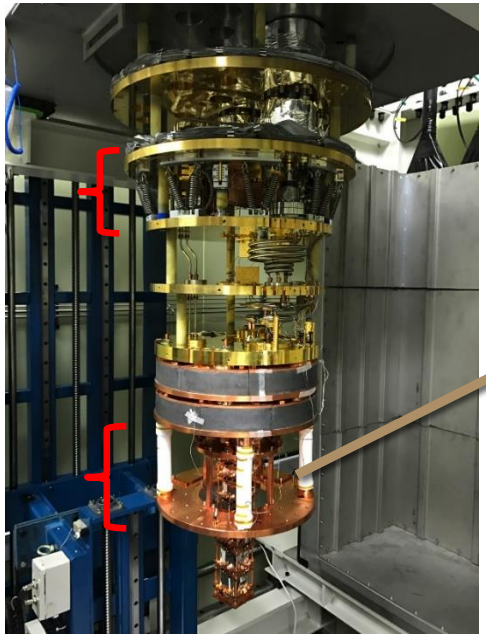
  (6 crystals, 4 month run.)

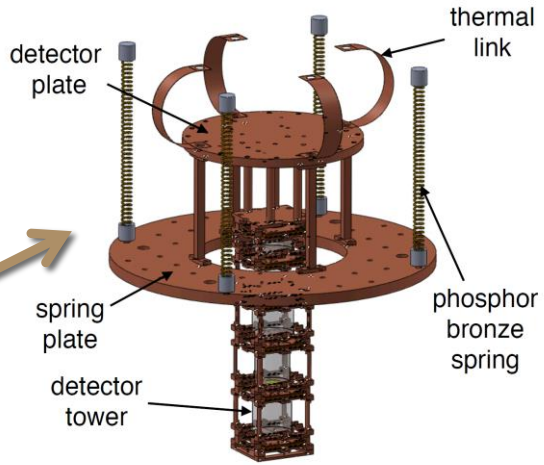
- **Run6: Main background source removal, Noise improvement (low freq.) (Now!)**

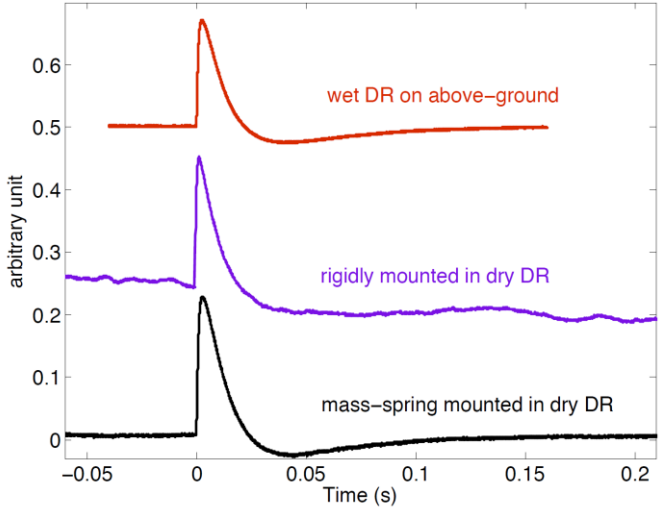
Two-Stage Vibration Isolation

Leiden Spin Imaging's Spring Suspended Still (SSS) damper [with Eddy currents]

Mass Spring damper (MSD)





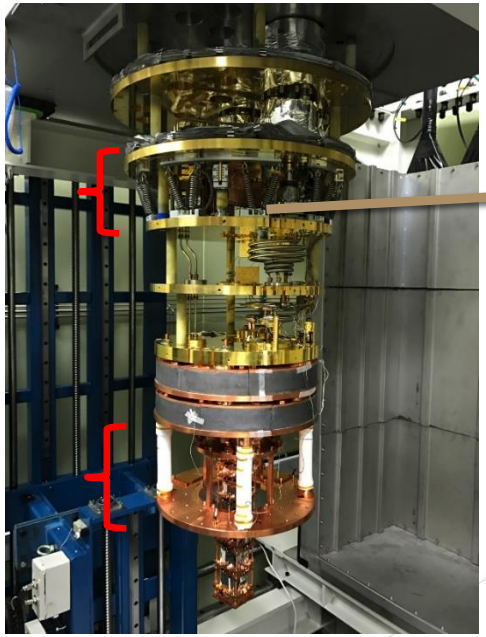


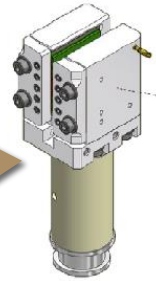
Run-4

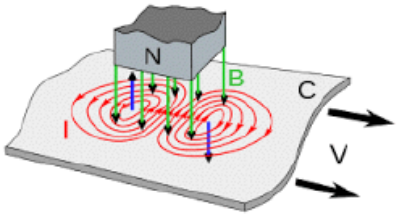
Two-Stage Vibration Isolation

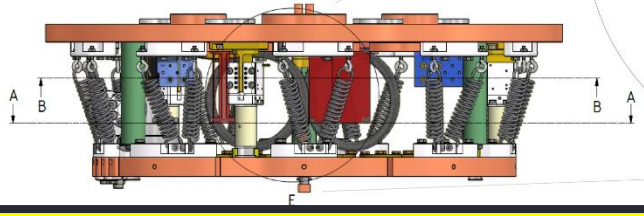
Leiden Spin Imaging's Spring Suspended Still (SSS) damper [with Eddy currents]

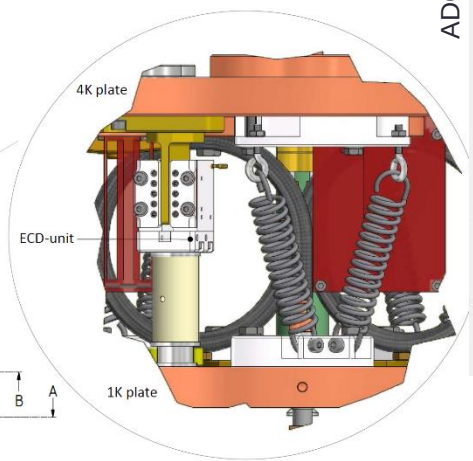
Mass Spring damper (MSD)

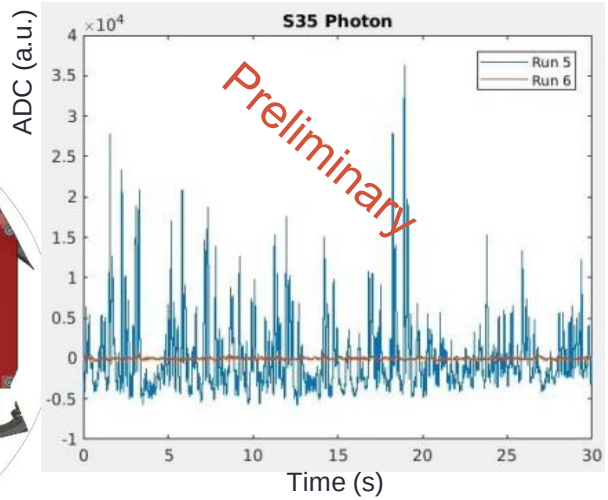












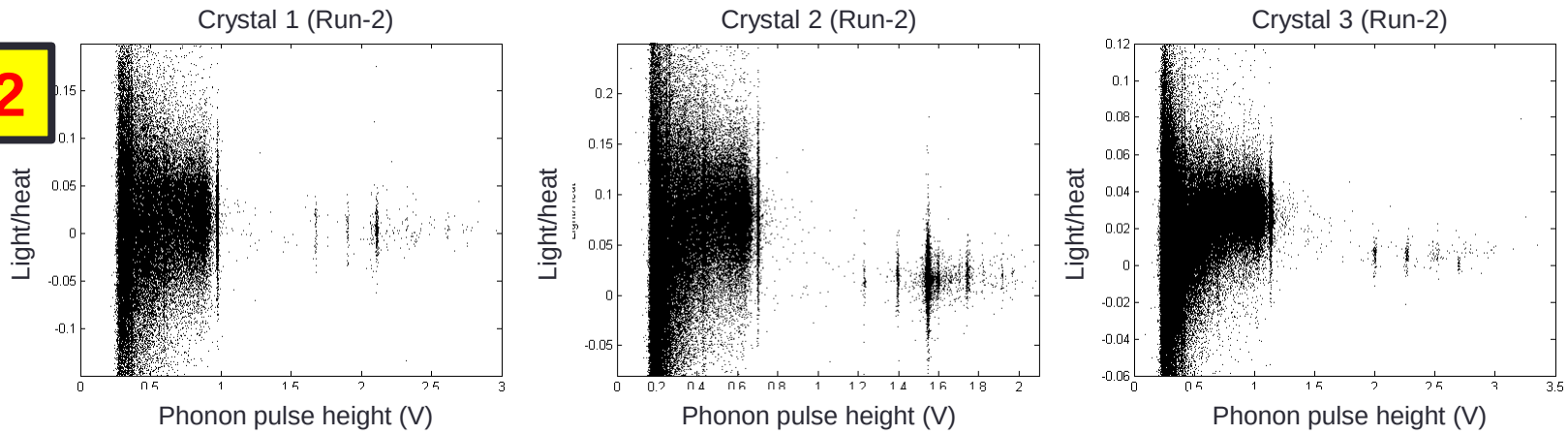
Orders of magnitude improvement

Run-5: Installed, not properly operated

Run-6: In full operation

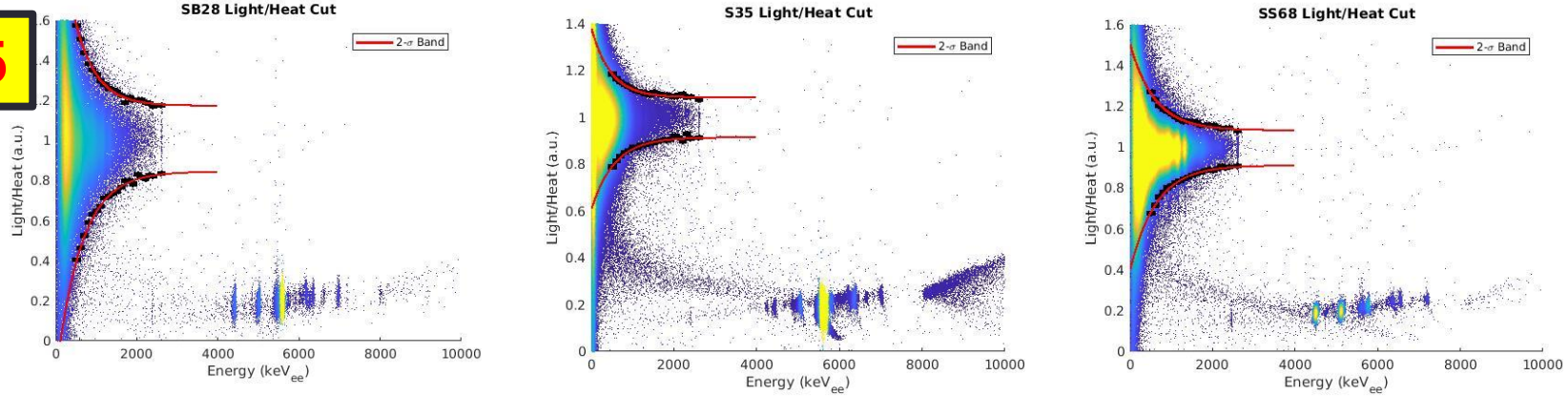
Improvements

Run-2



Improved background discrimination power

Run-5



Improvements

Run Number	FWHM energy resolution @ 2.615 MeV averaged over the detector modules (keV)	Remarks
1	43	First installation
2	22	Detector design improved
3	N/A	New IVC (to reduce bgd)
4	13	Mass-spring damper
5	11	Spring-suspended still (improper)
6	To be calculated	Spring-suspended still (Full) Stabilization heater

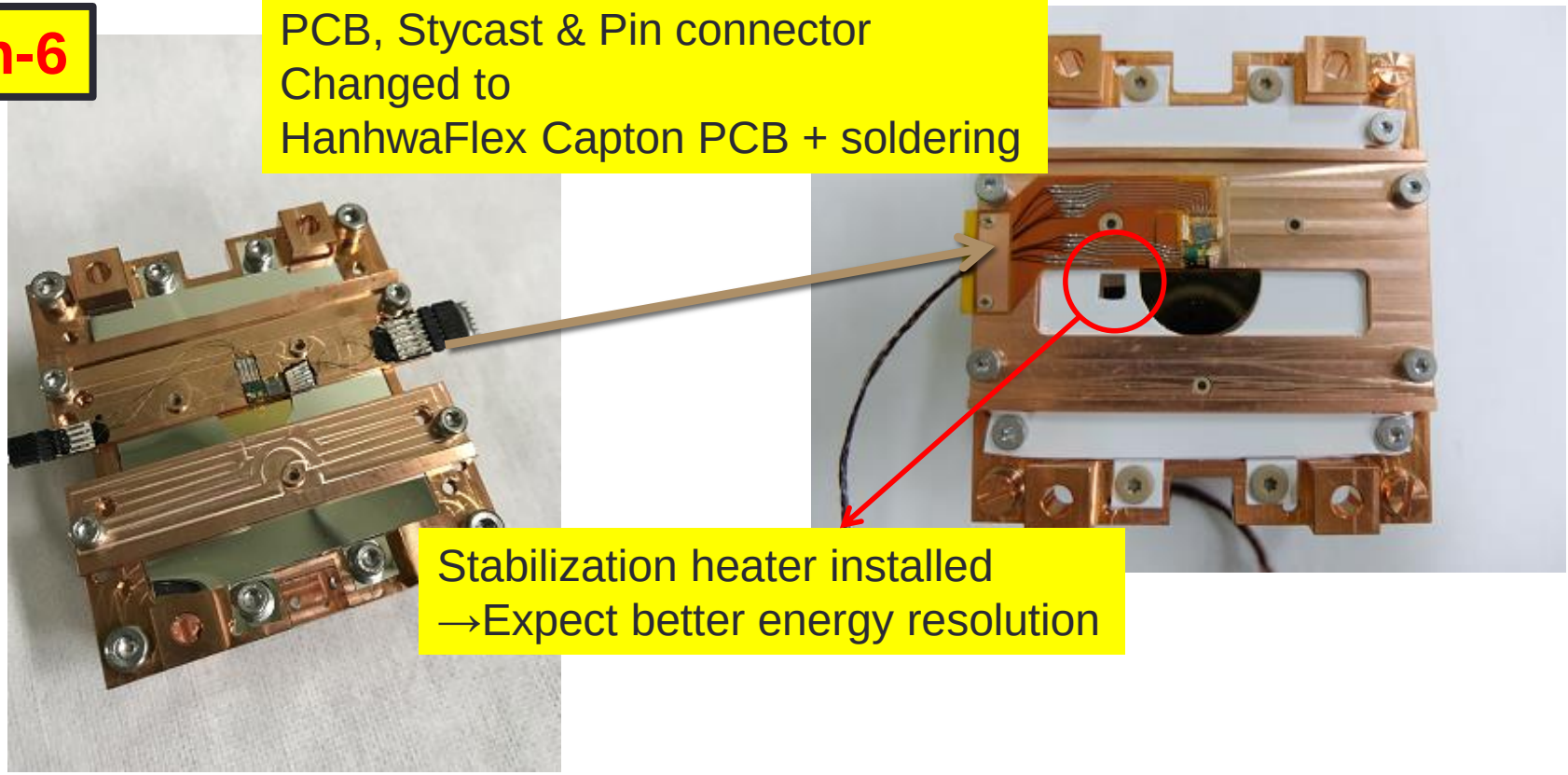
Improved Energy Resolution

Further Improvements (Run-6)

Background sources removed

Run-6

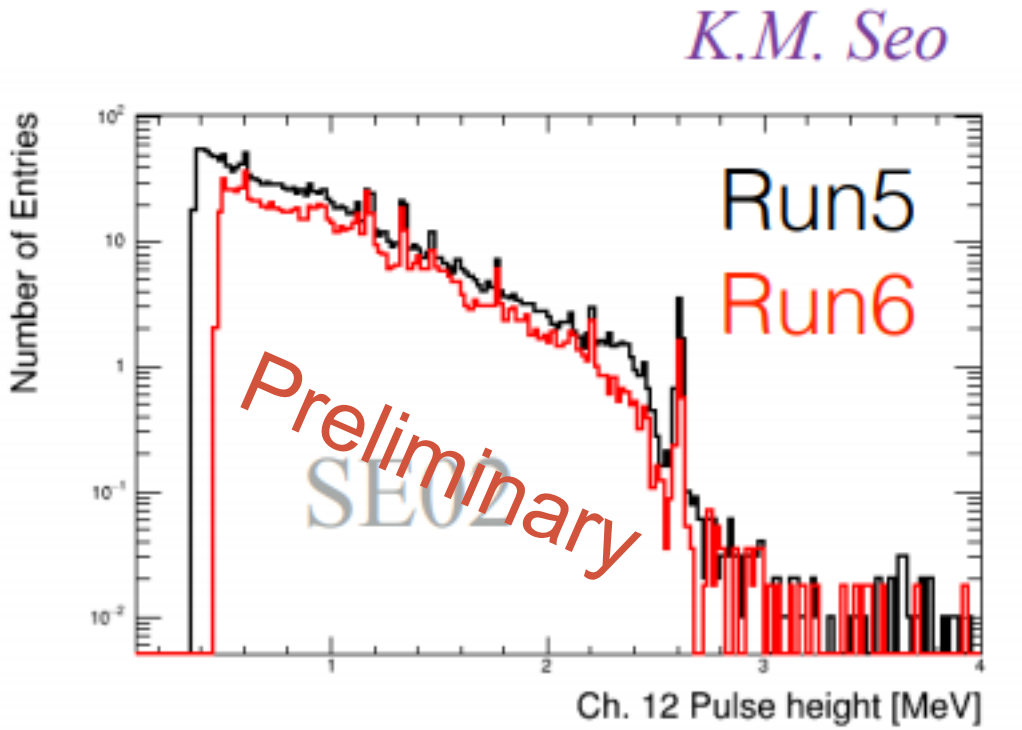
PCB, Stycast & Pin connector
Changed to
HanhwaFlex Capton PCB + soldering



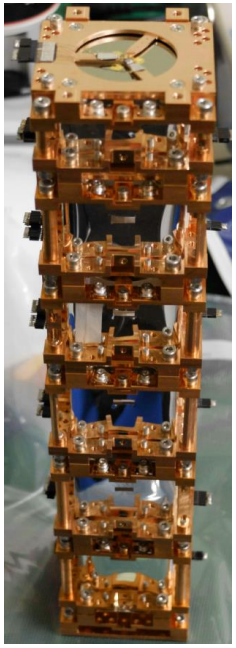
Stabilization heater installed
→Expect better energy resolution

Further Improvements (Run-6)

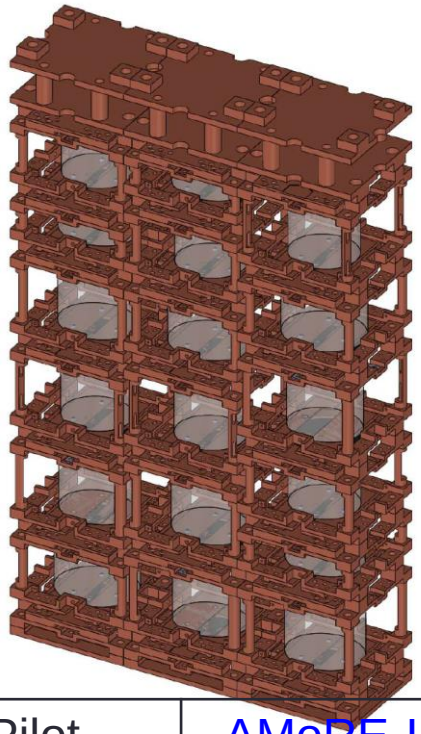
- Dr. Y. S. Yoon (7th. Jul. (Sat). 10:00 a.m, Neutrino session)



Future Plan for AMoRE

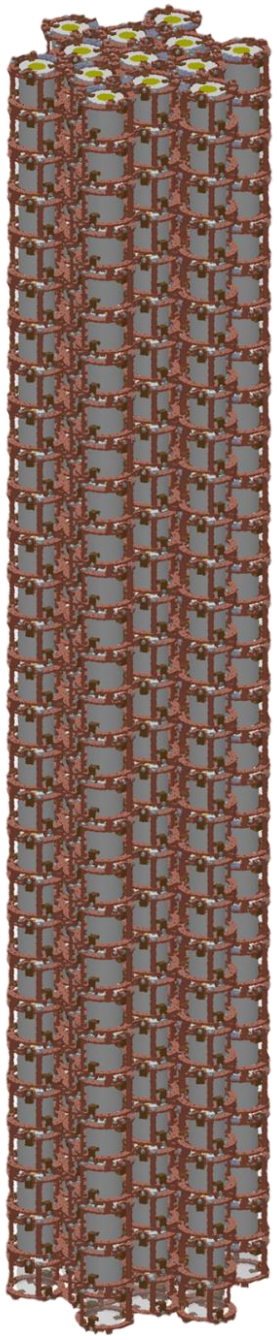


AMoRE-Pilot
1.9 kg
now~



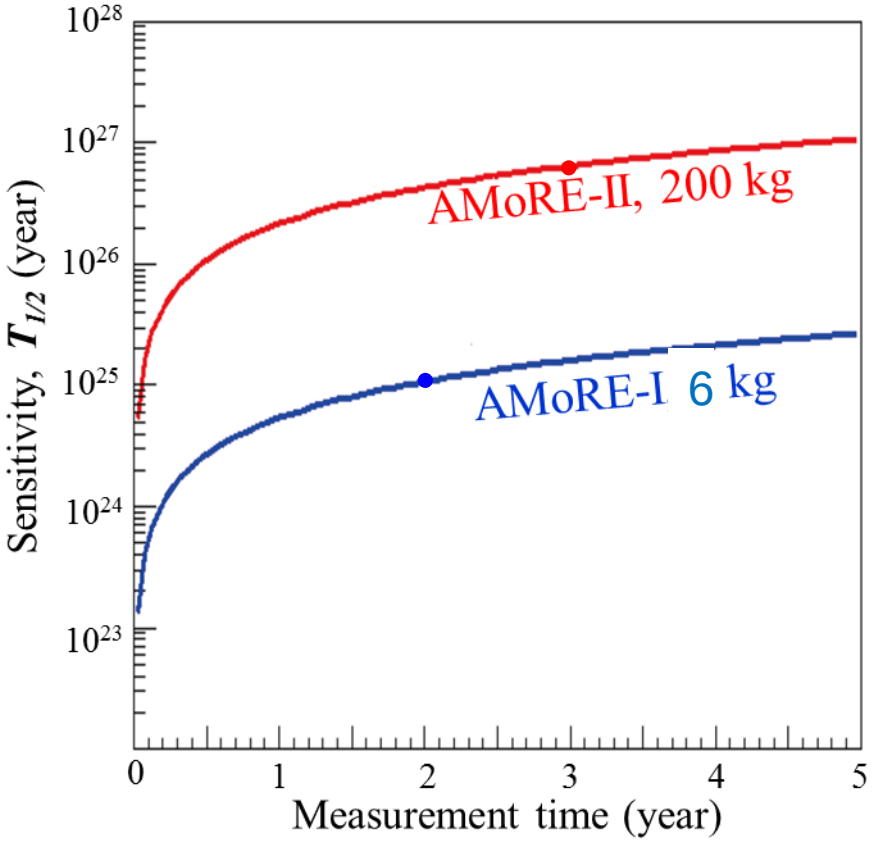
AMoRE-1
6 kg
2018~

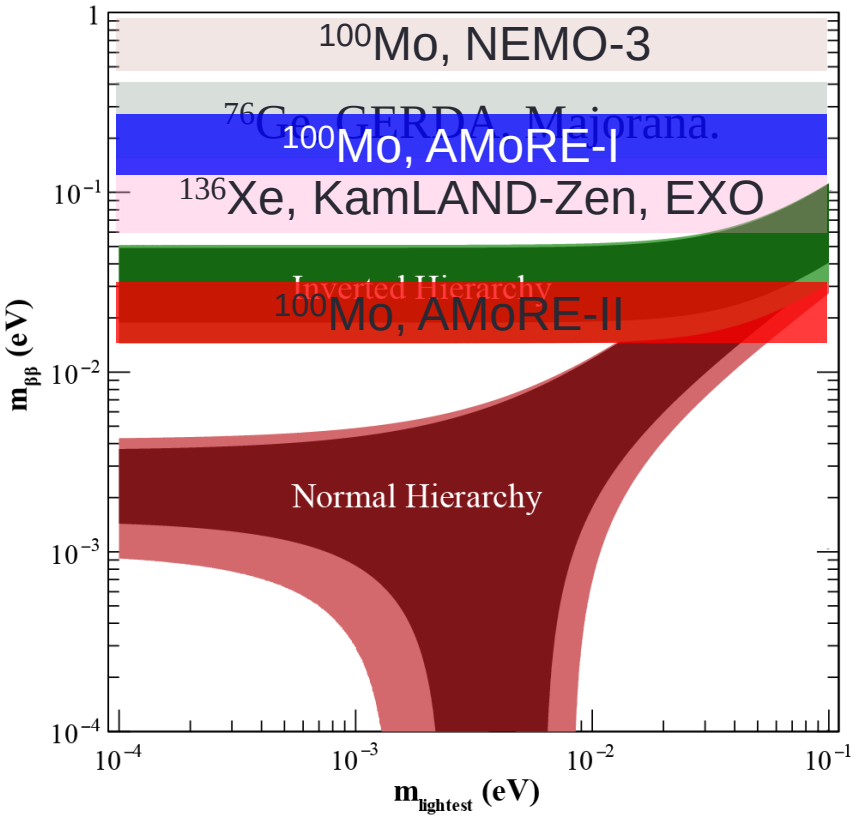
AMoRE-II
200 kg
2021~



	Pilot	AMoRE-I	AMoRE-II
Mass	1.9 kg	~6 kg	~200 kg
Channels	12	36	1000
Required Bkg. (ckky)	0.01	0.001	0.0001
Sensitivity($T_{1/2}$) (year)	~10^{24}	~10^{25}	~10^{27}
Sensitivity(m_{ee}) (meV)	380-720	120-230	17-32
Location	Y2L	Y2L	New Lab
Schedule	2018~	2018~	2021~

Future Plan for AMoRE





Summary

- AMoRE searches for neutrinoless double beta decay (0nbb) of 100Mo using Mo-based scintillating crystals and MMC sensors at milli-kelvin temperatures
- Throughout the AMoRE-Pilot runs, several upgrades (detector design upgrades, vibration reduction system, muon veto system) were made to improve noise and background conditions
- Energy resolution, background rejection power and the background level have been improved dramatically from the first run
- Run-6 is currently running with 6 crystals (total mass ~1.9 kg), two vibration damping systems and a muon veto system
- The main background sources were identified in Run-5, and have been removed from the detectors in Run-6
- Scaling-up for AMoRE-I to ~ 6 kg is in preparation: 13 $^{40}Ca^{100}MoO_4$ crystals and 5 others types of crystals (LMO, PMO, NMO etc)