AMORE

YEONGDUK KIM
DIRECTOR OF CUP

2019. 9. 20.

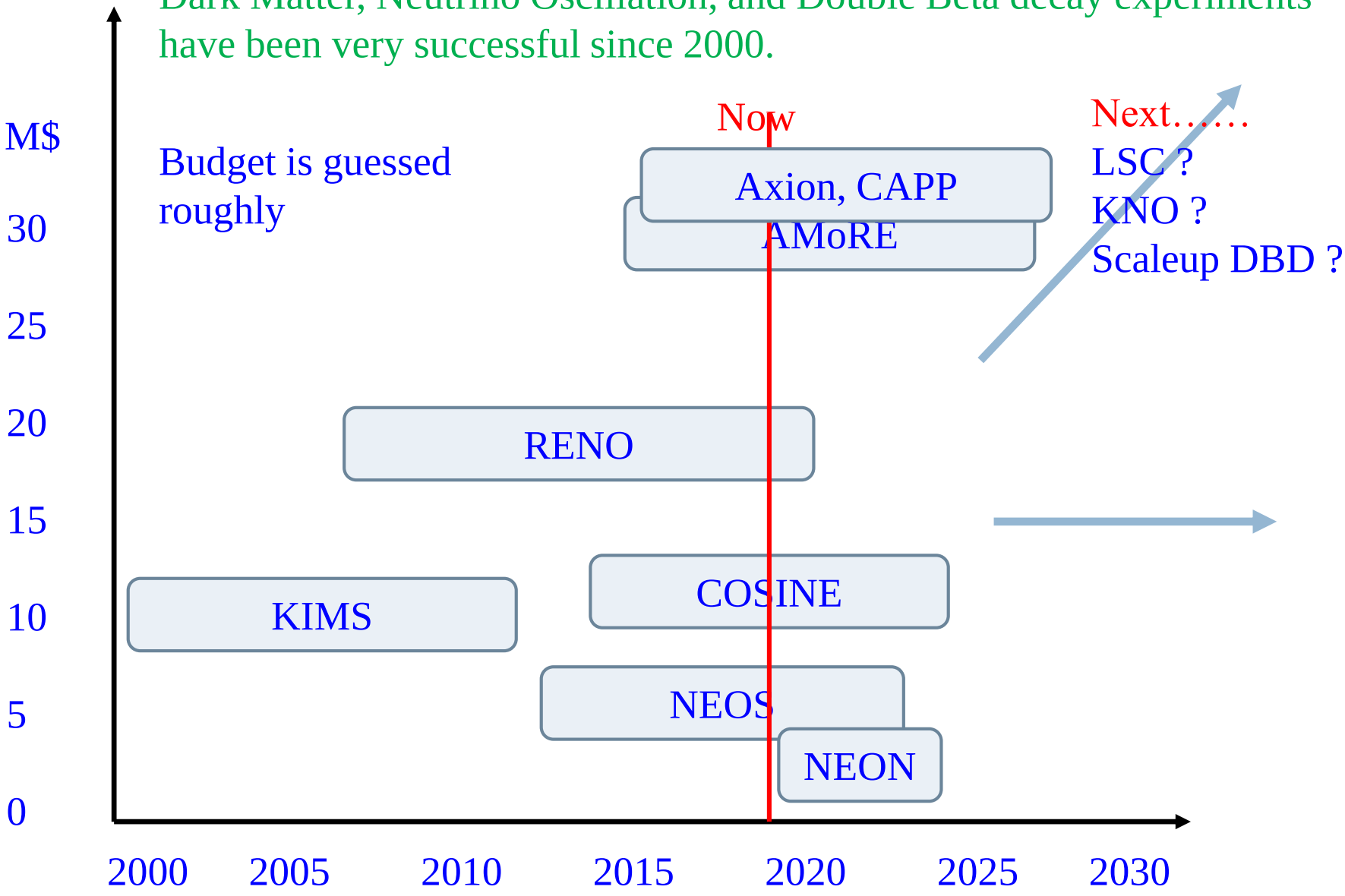
Long-term Strategy of High Energy Physics in Korea

I will talk about

1. Overview of AMoRE project
2. Achievements
3. Comparison
4. Budget
5. Yemilab construction
6. CUP Infra
7. Schedule
8. Rare-beta, SIMP (Preliminary Project)

Non-accelerator Projects in Korea

Dark Matter, Neutrino Oscillation, and Double Beta decay experiments have been very successful since 2000.



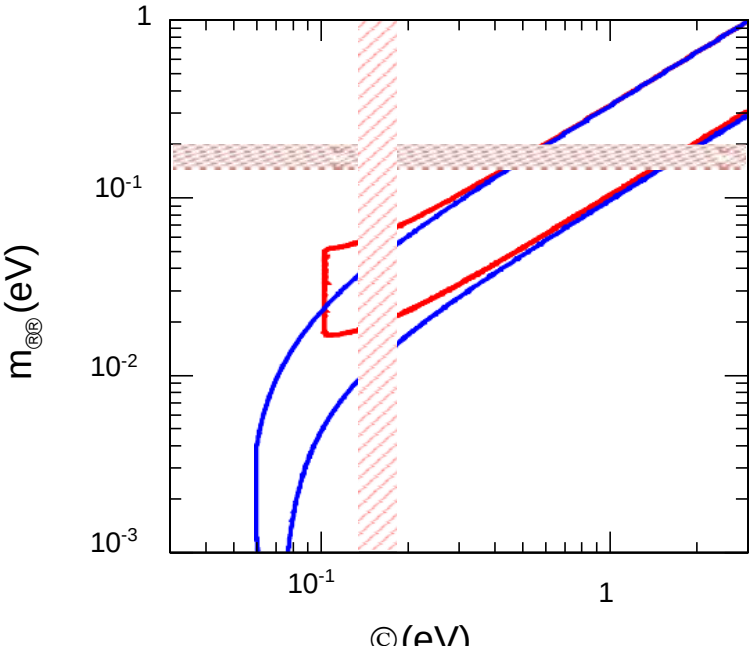
Observation of 0νββ

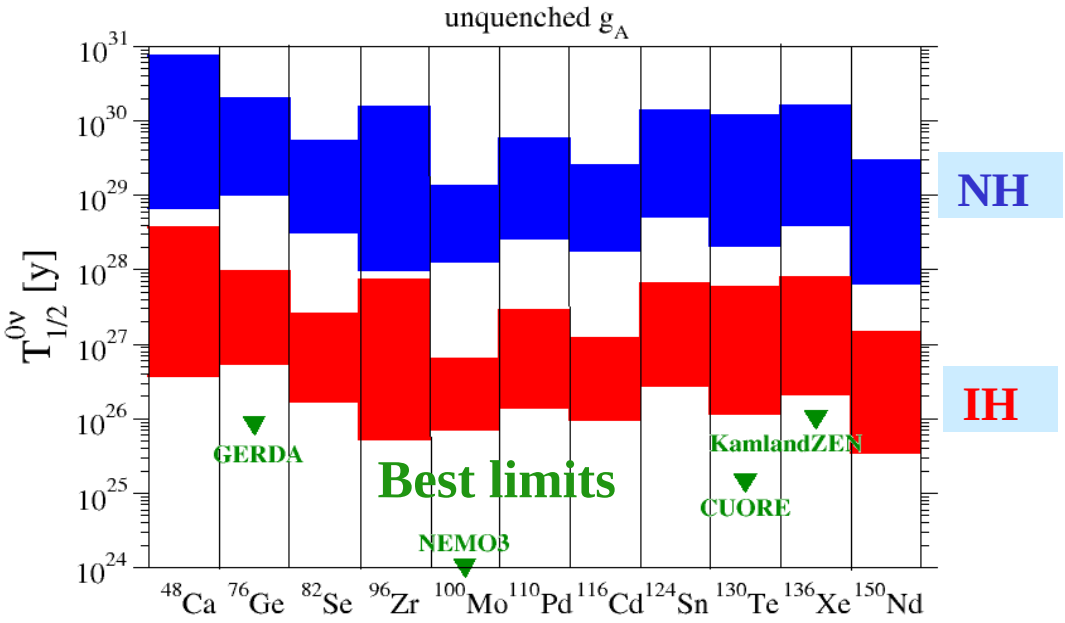
Most promising BSM Physics !

- **will confirm**
  - **Neutrinos are Majorana particles.**
  - **Lepton number violation.**
- **will support on**
  - **See-Saw model of the neutrino mass.**
  - **Leptogenesis to account for the baryon asymmetry of the universe.**

$$m_n \approx \frac{m_D^2}{m_N}$$

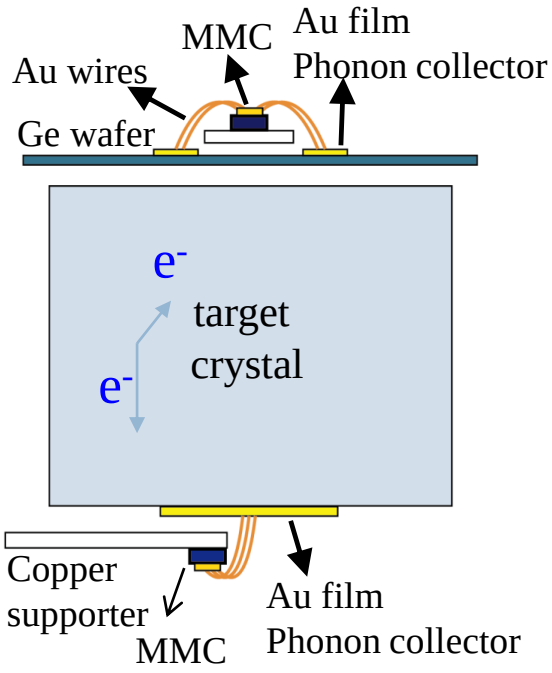
Current Limits

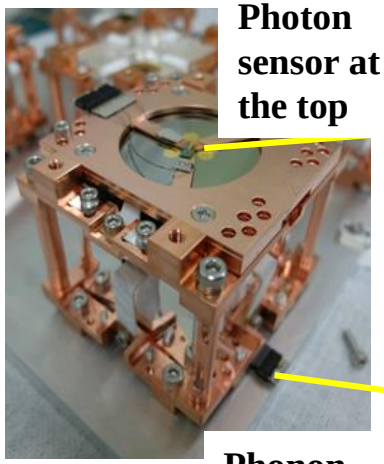




Principle of AMoRE Detector

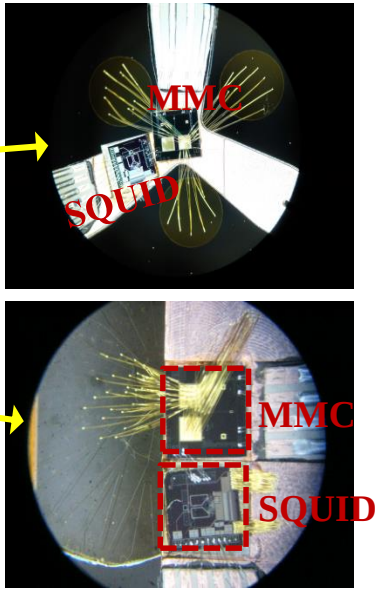
- **Use Mo containing Scintillating Bolometer : $(^{40}Ca,X)^{100}MoO_4$ + MMC**
- **For Each crystal, phonon and photon sensors made of MMCs+SQUIDs to separate alphas (background) and betas (signal). Highly Technical !**

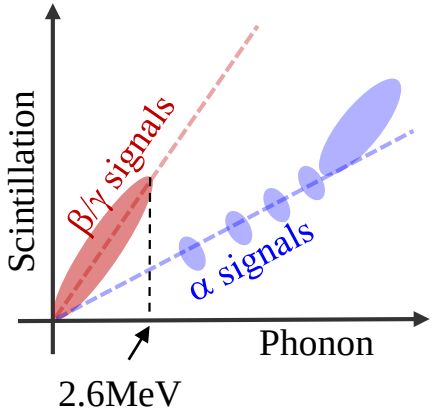


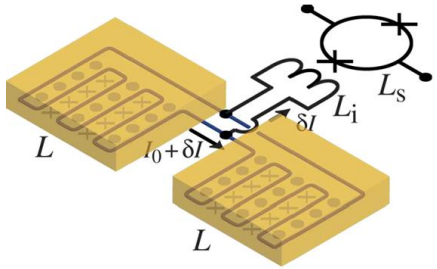


Photon sensor at the top

Phonon sensor at the bottom

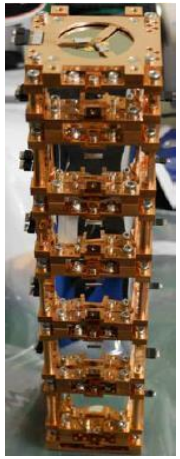






MMC: Metallic Magnetic Calorimeter

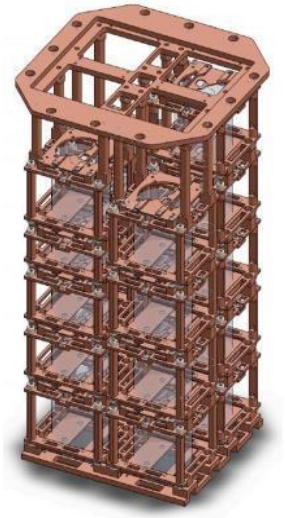
Planned Phases of AMoRE Project



$^{40}Ca^{100}MoO_4$

~ 1.9 kg

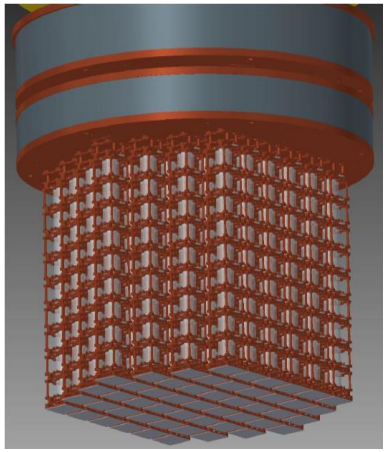
AMoRE Pilot



$^{40}Ca(Li)^{100}MoO_4$

~ 6 kg

AMoRE-I



$(^{40}Ca,Li)^{100}MoO_4$

200 kg

AMoRE-II

ckky : counts/ (keV kg year)

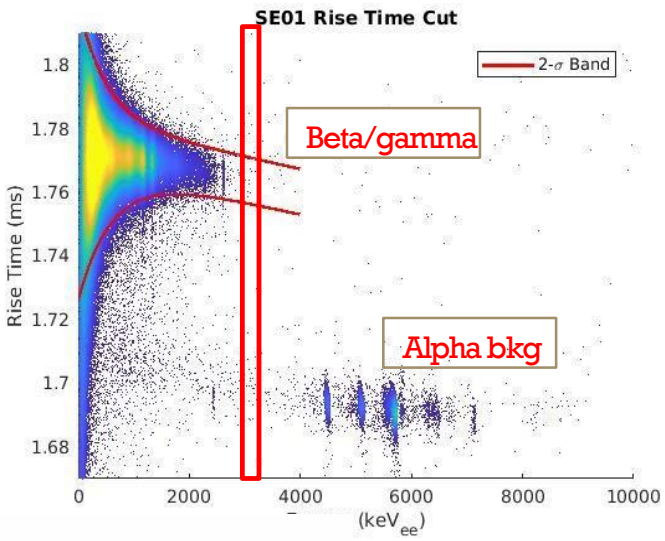
	AMoRE-Pilot	AMoRE-I	AMoRE-II
Crystal Mass (kg)	1.9	6	200
Backgrounds(ckky)	10^{-2}	10^{-3}	10^{-4}
$T_{1/2}$(year)	1.1×10^{24}	8.2×10^{24}	8.2×10^{26}
m_{bb} (meV)	380-719	130-250	13-25
Schedule	2015-2018	2019-2022	2022-2026

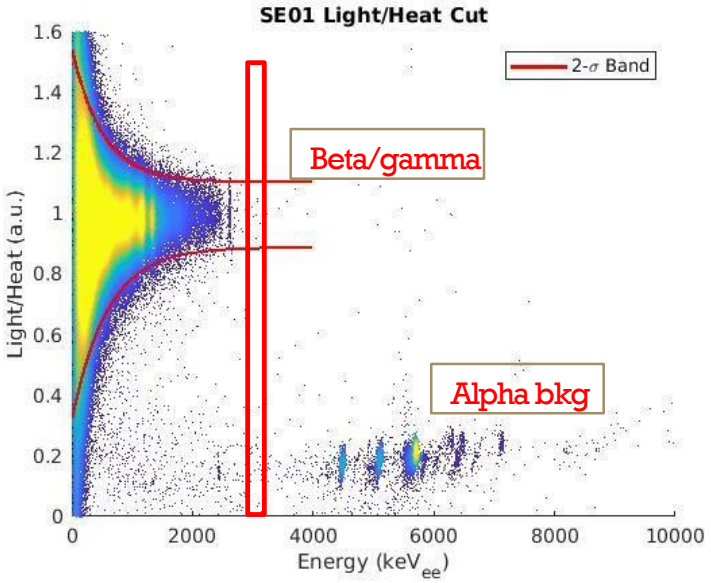
It took long time to get ready for AMoRE-II !

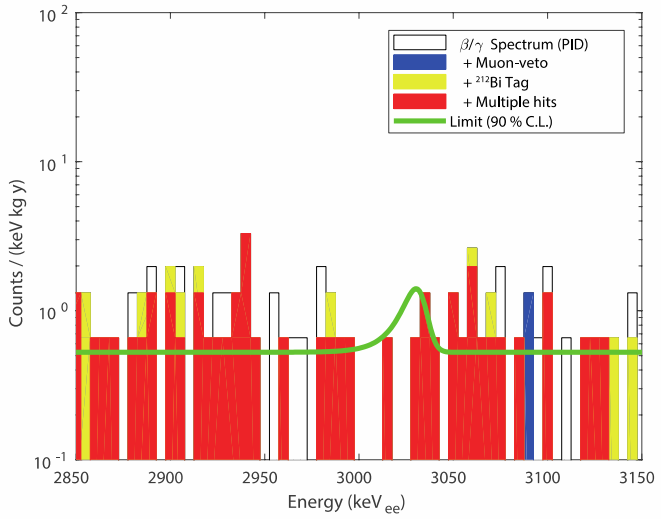
Achievements 1. – Demonstration of detectors

Alpha Backgrounds are effectively rejected with PSD & Light/Heat raio.

arXiv:1903.09483, Accepted to EPJC







- 111 (kg day) exposure.

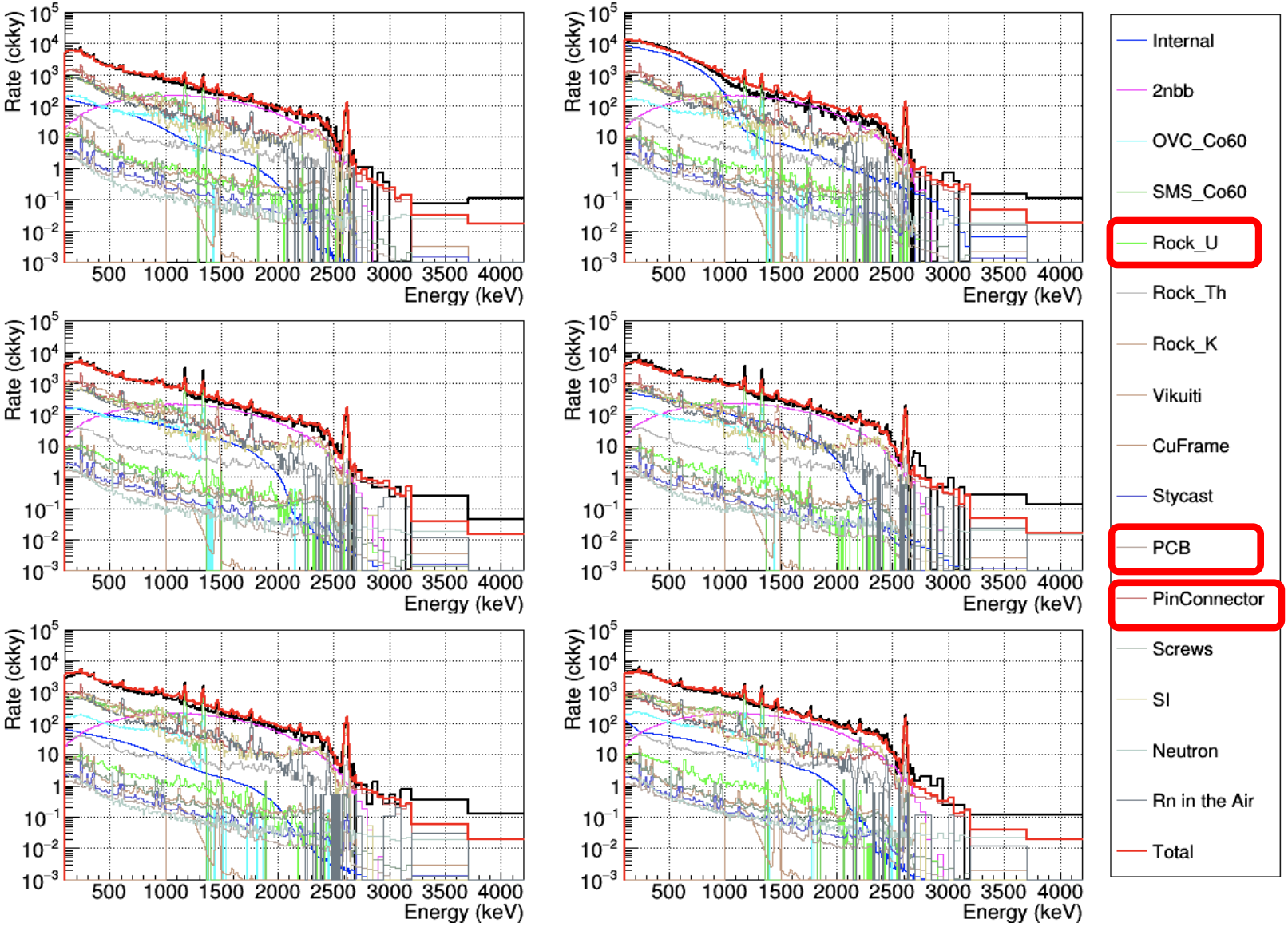
→ Final background level : 0.55 ckky

→ $T_{1/2}^{0\nu} > 9.5 \times 10^{22} years$

NEMO best limit $1.1 \times 10^{24} years$

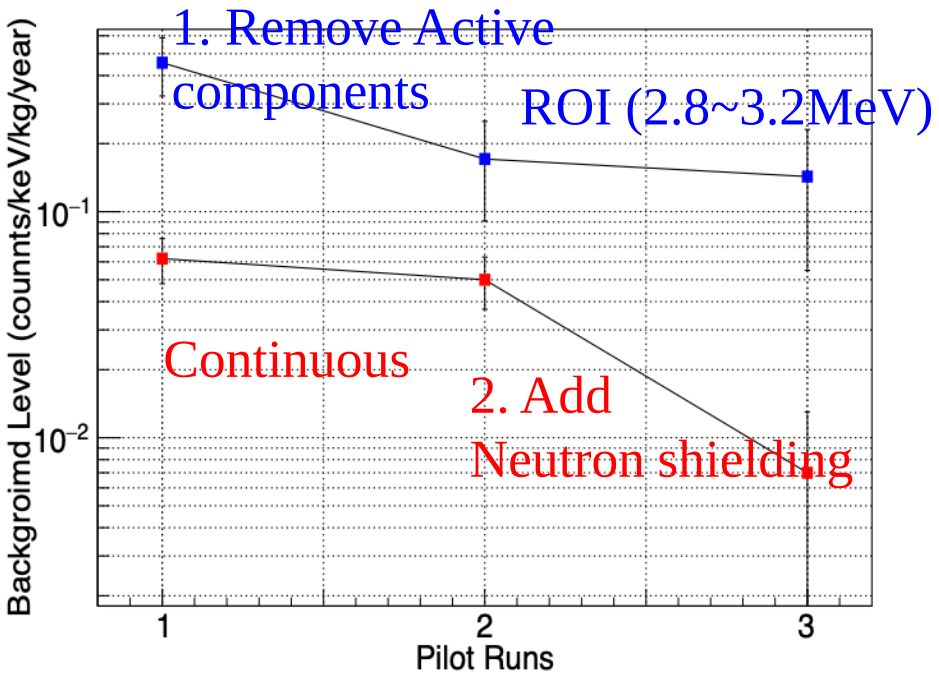
2. Background Modeling

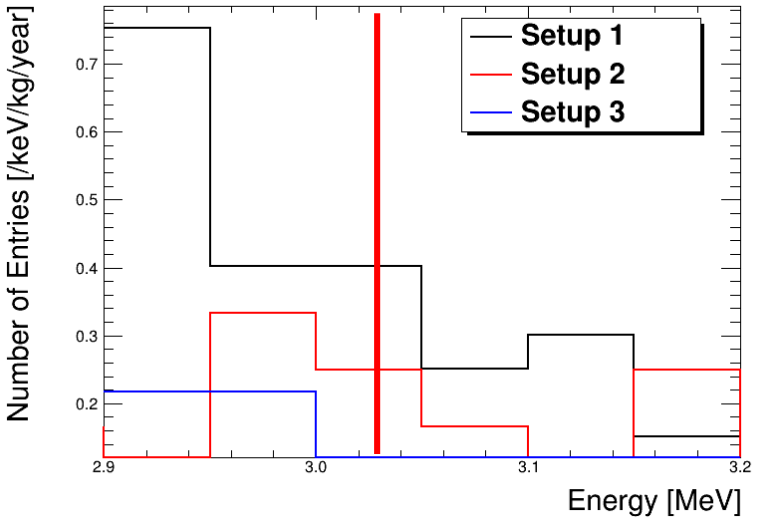
Active components harmful at ROI are identified.



3. Background reduction

Two major background sources are removed.



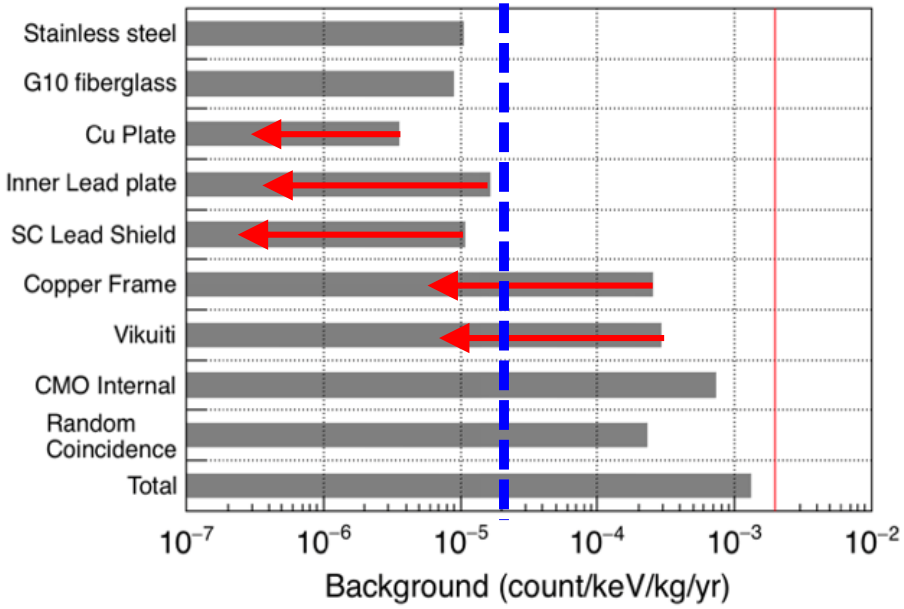


The goal for AMoRE-I starting this Oct. is to understand the background better. More shielding are added for this test.

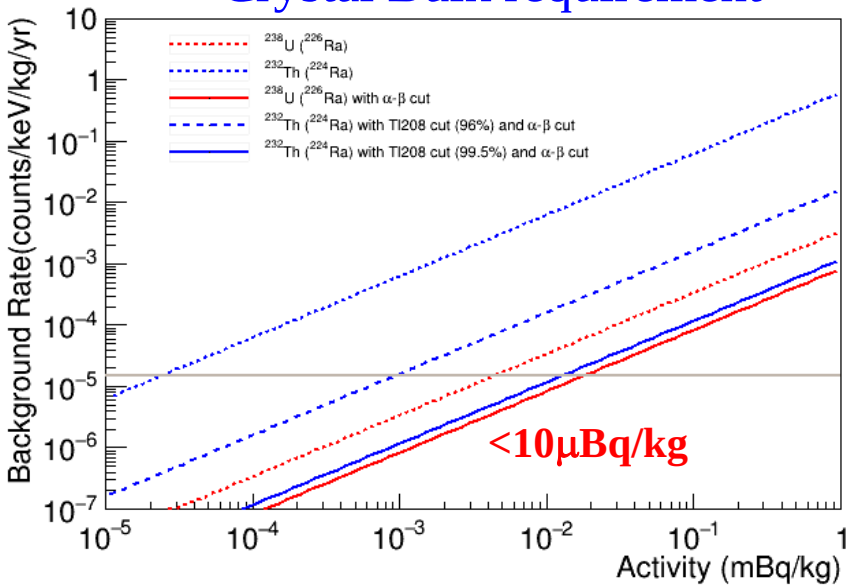
Estimation for AMoRE-II backgrounds

- **Tried to identify critical components in the setup for AMoRE-II experiment.**
- **For AMoRE-II, the Crystal Bulk activity for zero background has been set.**

AMoRE-II requirement



Crystal Bulk requirement



4. Ultra-pure Crystal R&D

Enriched $Li_2{}^{100}MoO_4$ crystal grown at CUP

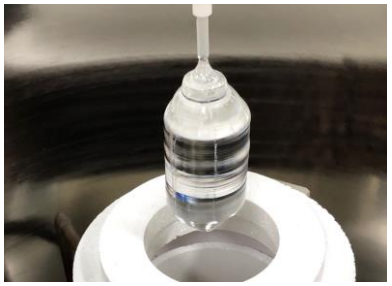
We have grown an enriched LMO crystal without any purification to check what level of contamination would be reached by only from crystal growing process.

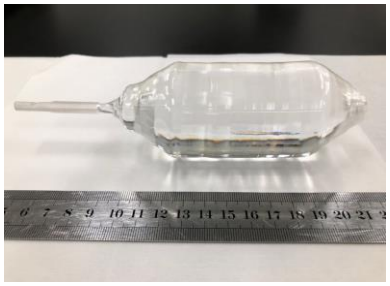
$Li_2CO_3+MoO_3 \rightarrow Li_2MoO_4+CO_2$

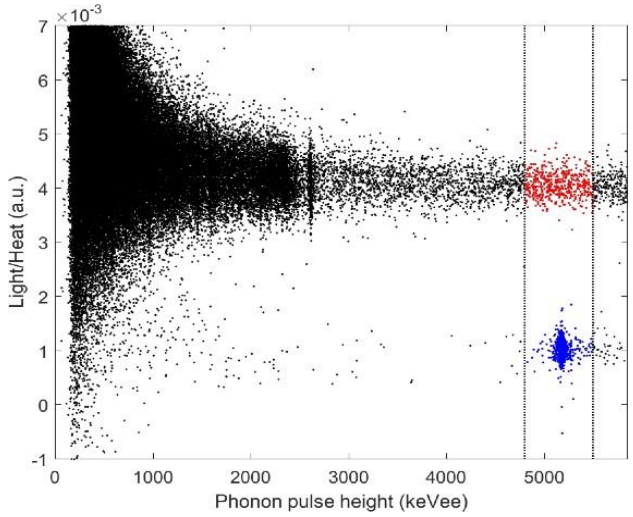
- Natural LMO tested at wet dilution refrigerator.
- 300 g crystal + MMC
- Light/Heat ratio gave DP~12.
- A problem of Au foil attachment. After a few months, the Au phonon collector seems unstable.

CZ02-L1803E

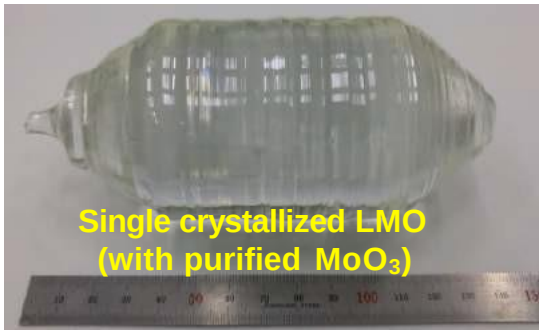
1. mass : 607.2 g (including seed)
2. diameter : 50.0 ~ 51.3 mm
3. Total length : 136.0 mm
4. Body length : 64.4 mm







Purities of CUP grown LMO crystals



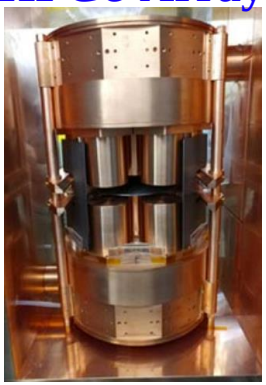
Element		Al	K	Ba	Sr	Pb	Th	U
No.	sample	(ppb)	(ppb)	(ppb)	(ppt)	(ppt)	(ppt)	(ppt)
Single crystallized natural LMO (w/o purification)								
CMD 113	L1701-1	48.1	347.3	5.445	<15	<300	<15	<16
CMD 113	L1701-2	21.7	449.2	5.401	75	<300	<15	<16
Single crystallized natural LMO (MoO_3 sublimed)								
CMD163.1	CZ02-L1706-T	<11	38	7.579	<50	<100	<8	<8
CMD163.2	CZ02-L1706-B	<11	83	9.617	<50	<100	<8	<8
Double crystallized natural LMO (MoO_3 sublimed)								
CMD191.1	CZ02-L1801-T	<11	<30	4.744	<50	<100	<8	<8
CMD191.2	CZ02-L1801-B	<11	<30	5.814	<50	<100	<8	<8
Enriched LMO (w/o purification)								
CMD00236.2	CZ02-L1803E-T	1437	<40	6.82	<31	<225	<6	<6
CMD00236.3	CZ02-L1803E-B	1484	<40	7.07	<31	<225	<6	<6
CMD00236.1	CZ02-L1803E-RM	3824	249	28.58	4110	12290	71	472

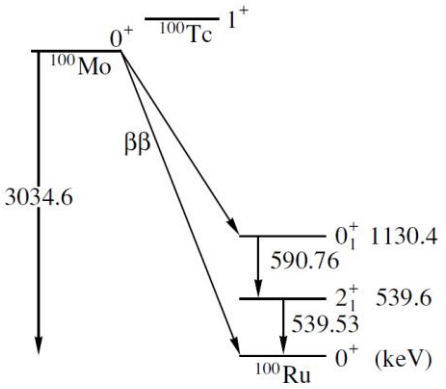
- Li2MoO4 crystal is pure enough for AMoRE-II.
- CUP can purify & Grow the crystals. Another provider for satisfactory crystal is AMoRE collaboration.

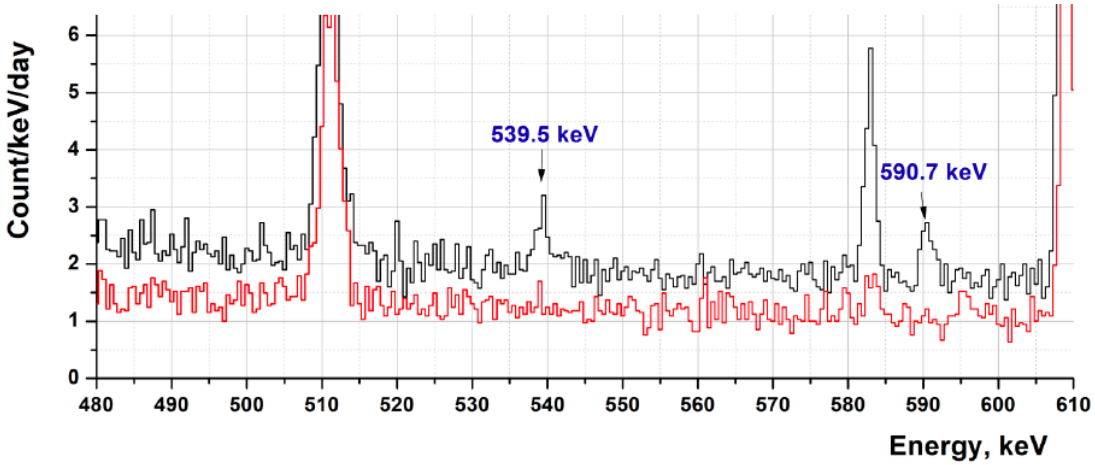
5. Purification & Measurements

- Purification by recrystallization, sublimation, etc..
- Measurements by ICP-MS, HPGe-Array, Alpha counters….All techniques are developed well.
  - ICP-MS : sub-ppt(10^{-9}) level for U, Th with solid extraction method.
  - HPGe-Array : 14 HPGe crystals, **2νββ** to an excited state is observed !!
  - Alpha counter : Surface contamination …

HPGe-Array



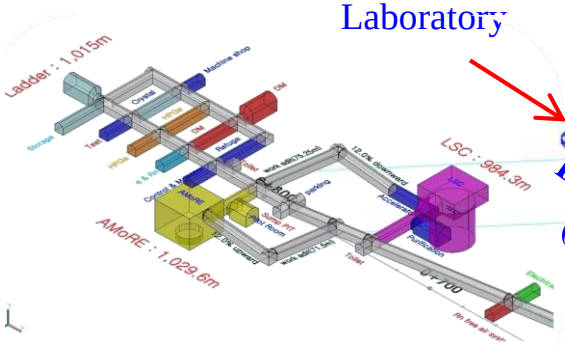


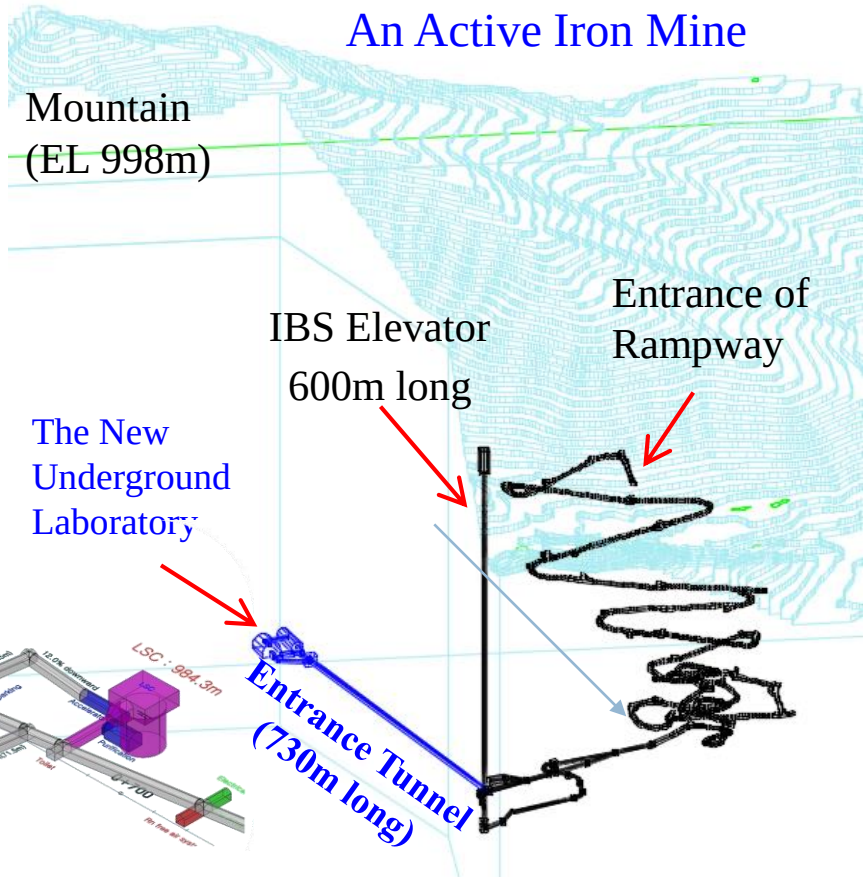


Yemilab for AMoRE-II

- **Important Concepts**
- **An independent entrance (vertical lift for human) from mine activity.**
- **The construction starts early of 2019 and be completed by end of 2020.**

Bird's eye view of Handuk Iron Mine

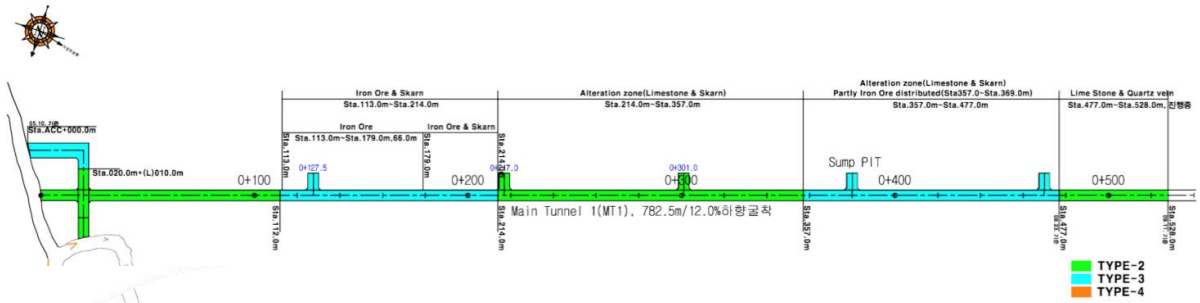


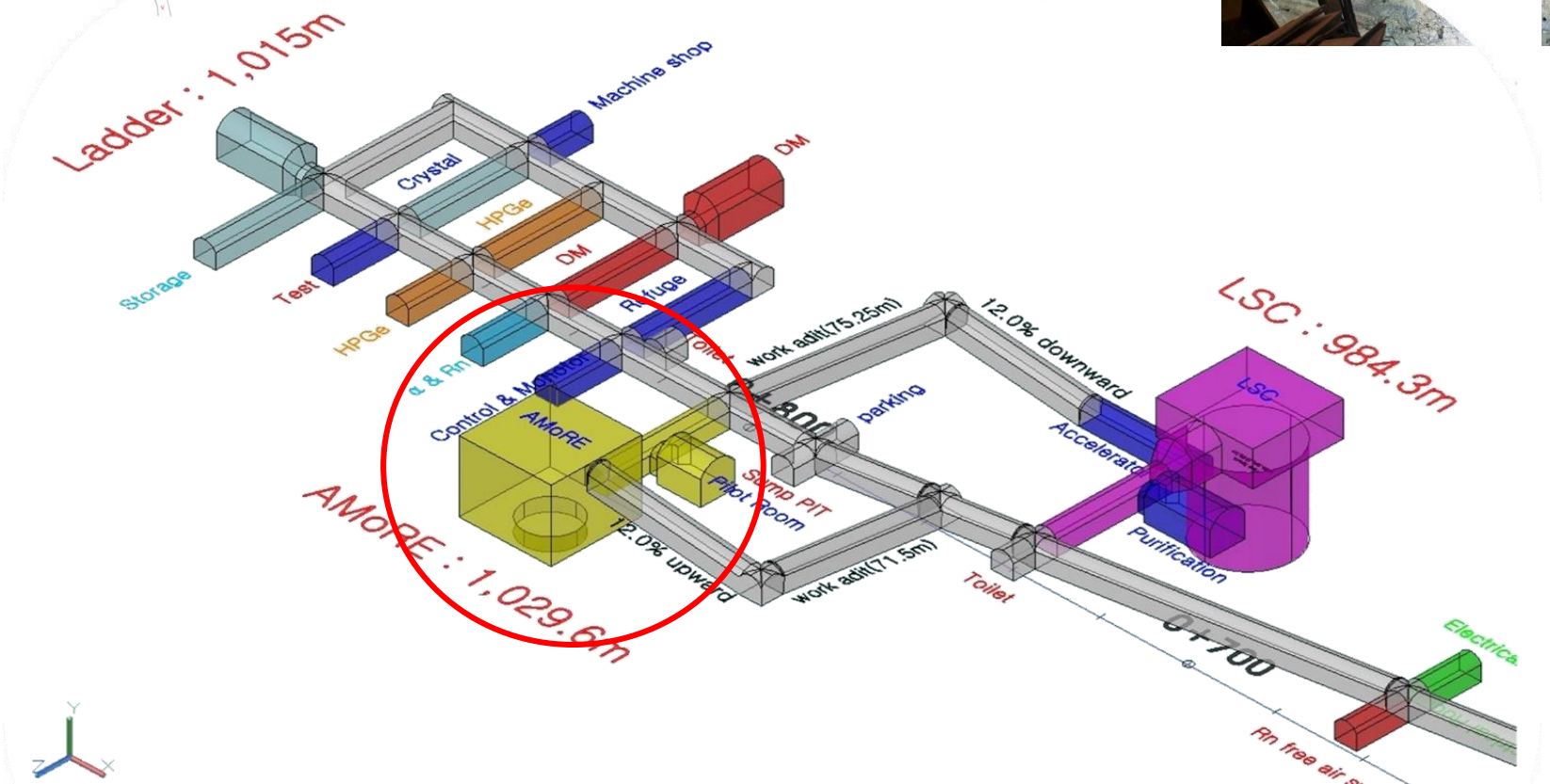


Large (>2000m^2), deeper (1100m depth)

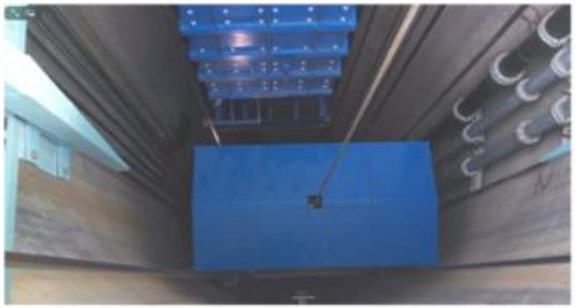
The floor plan

- ~ 500m tunnel is excavated at present.
- 8 experiments with 12 space, 10 utility rooms



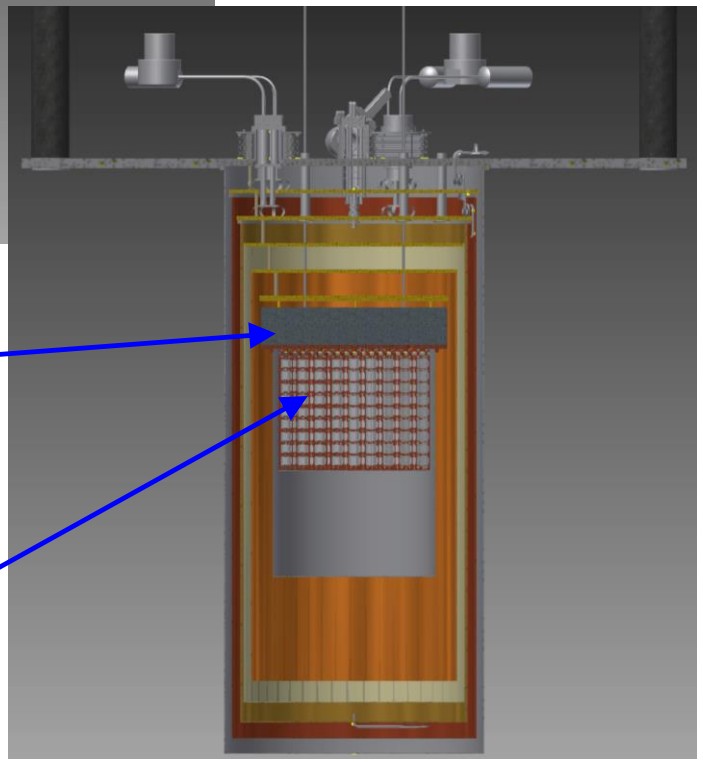


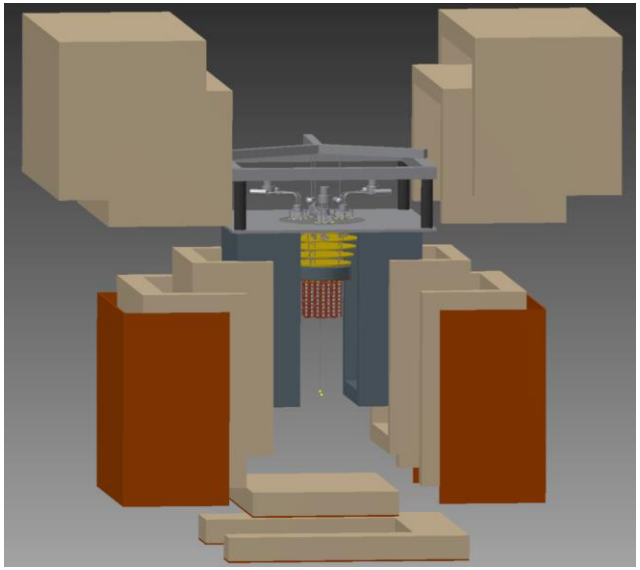
Construction



Design for AMoRE-II experiment

Tunnel
(20mx20mx16m(h))





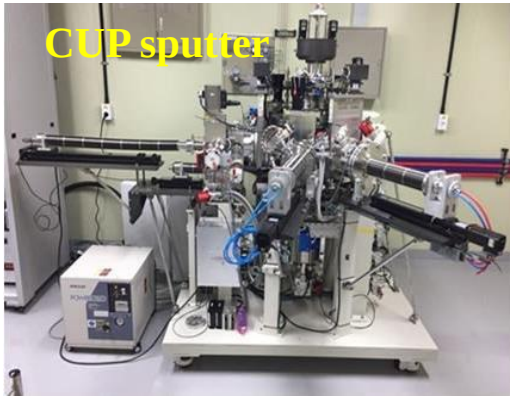
25 cm
Lead

200 kg
crystals

Fab facility for MMC @ CUP

CUP produces MMC sensors.
Squids are provided by our collaboragtors in Heidelberg group.

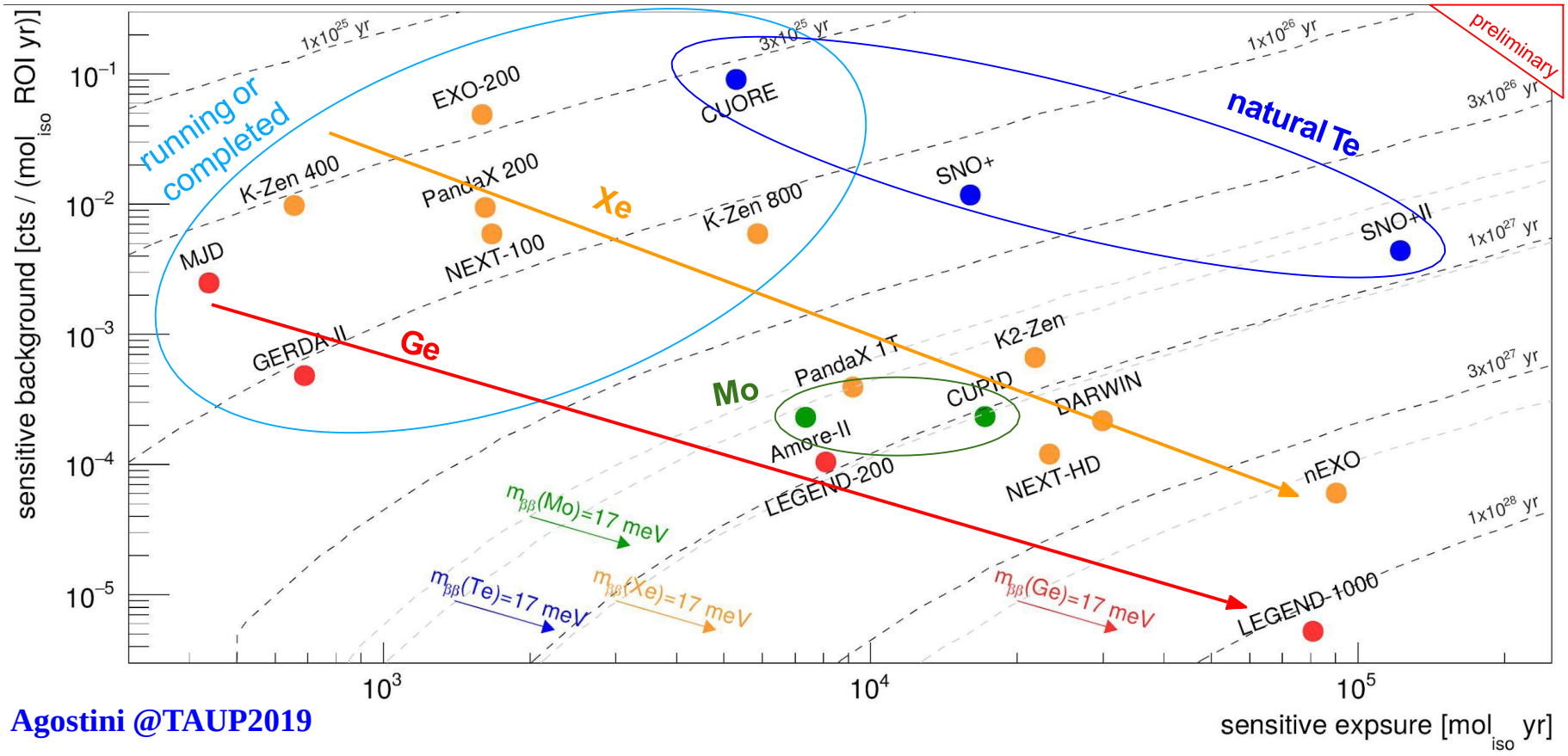
Fabrication facility	
Metal thin film system	Metallic magnetic calorimeter sputtering system
	Radon free environment e-beam evaporator system
Pattern lithography equipment	Maskless Micro Pattern Generator
	Dual Focus Micro-Pattern Mask Aligner
Metal film etching equipment	ICP-RIE (Inductively Coupled Plasma- Reactive Ion Etching) system
Insulation film growth equipment	LT-PECVD (Low-Temperature Plasma-enhanced chemical vapor deposition)
	Anodizing unit
Thick Au layer fabrication	Simple electroplating unit
Chip dicing	Dicing saw
Resist coating unit	Spin coating system Hot plate
Fabrication step verification	3D Measuring Laser Microscope
	Optic Microscope
Collector annealing system	Rapid thermal process system


CUP sputter


An adiabatic demagnetization refrigerator system


E-beam evaporator

Comparison with other experiments.



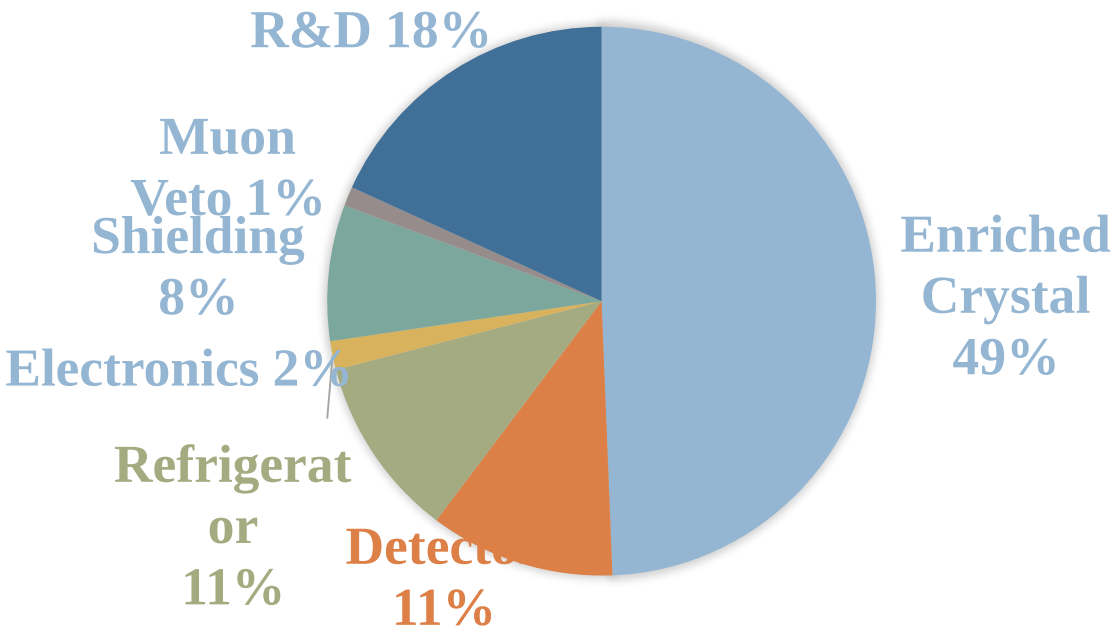
Agostini @TAUP2019

- AMoRE-II is comparable to CUPID, LEGEND-200, KamLAND2-ZEN.
- IBS(CUP) has a MOU with INFN(Gran Sasso) to collaborate between AMoRE and CUPID.

Budget

BUDGET OF AMORE-II FULL CONSTRUCTION (~23 M$)

Until 2023



Work force for AMoRE-II

- Overall Planning — Yeongduk Kim, Hongjoo Kim
- LT — Yong-Hamb Kim
  - Crystal Tests — Jungho So, Seungcheon Kim
  - DR & Cryostat Design — Chanseok Kang
  - MMC & SQUIDS — Hejin Lee, Sora Kim, Jinha Jeon, Sanggon Kim
- Crystal — Moohyun Lee
  - Crystal growing — Sejin Na, Daeyon Kim, Jukyung Son
  - Purification — Olga, GeonA Sin
  - NIIC crystals — Schlegel
- Infra
  - Cryostat, Shielding — Chanseok Kang
  - Clean Room — Kangsoon Park
  - DAQ, Muon Veto — Jaison Lee
- Simulation — Eunjoo Jeon
- Data Analysis — Yoomin Oh
  - Developers — Kazalov, Youngsoo Yoon

+ 13 students.

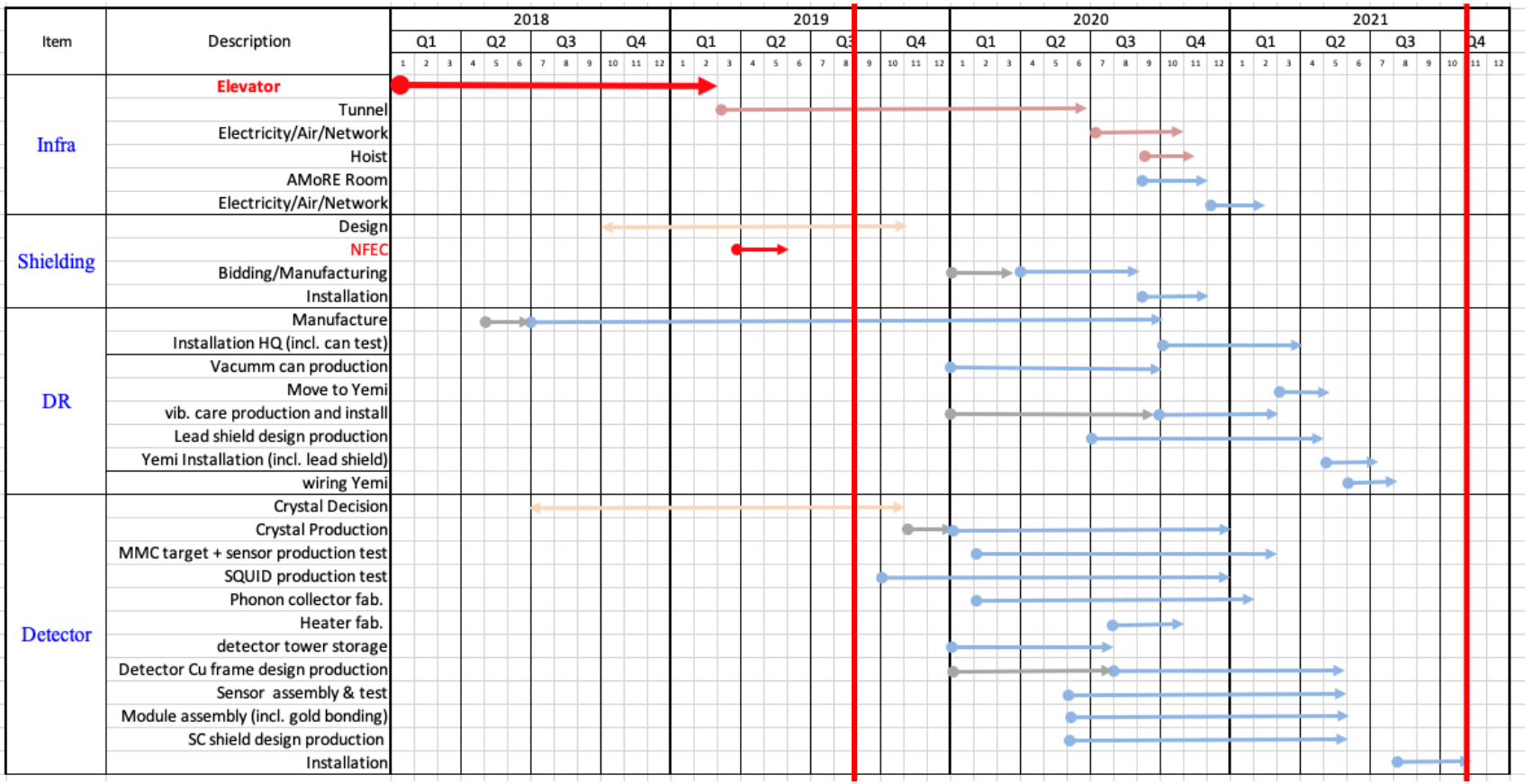
AMoRE Collaboration

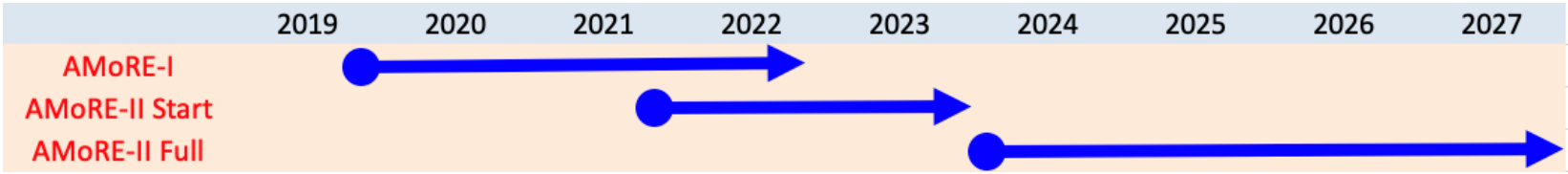
- **Total 105 members from 23 institutes at 8 countries.**
- **Two meetings per year.**

Korea	**CUP, Institute of Basic Science (CUP)**		
	Kyungpook National University (KNU)	**11**	**Simulation, Crystal Tests**
	Soongsil University (SSU)	**3**	**Theory**
	Seoul National University (SNU)	**4**	**Low Temp., Data Analysis**
	Ehwa Womans University (EWU)	**3**	**HPGe**
	Semyung University (SMU)	**1**	
	KRISS	**3**	**DR, Cryostat**
	Sejong University (SJU)	**3**	**Data Analysis, Muon**
	Chung-Ang University (CAU)	**3**	**Theory**
Russia	**JSC FOMOS-Materials (FOMOS)**	**2**	**CMO crystals**
	Baksan Neutrino Observatory of INR RAS (BNO)	**8**	**HPGe, Simulation**
	National Research Nuclear University (NRNU)	**1**	**Backgrounds, Crystals**
	Nikolaev Institute of Inorganic Chemistry (NIIC)	**3**	**Enriched Crystal**
Germany	**Physikalisch-Technische Bundesanstalt (PTB)**	**2**	**SQUID**
	Kirchhoff-Institute for Physics (KIP)	**3**	**MMC, Photon Detector**
Ukraine	**Institute for Nuclear Research (INR)**	**7**	**Simulation, Background**
China	**Tsinghua University (THU)**	**3**	
Thailand	**Nakhon Pathom Rajabhat University (NPRU)**	**6**	
Indonesia	**Institut Teknologi Bandung (ITB)**	**2**	**Muon Veto**
	University of Mataram (UM)	**1**	
Pakistan	**Abdul Wali Khan University (AWKUM)**	**1**	
	Kohat University of Science and Technology (KUST)	**2**	

Schedule

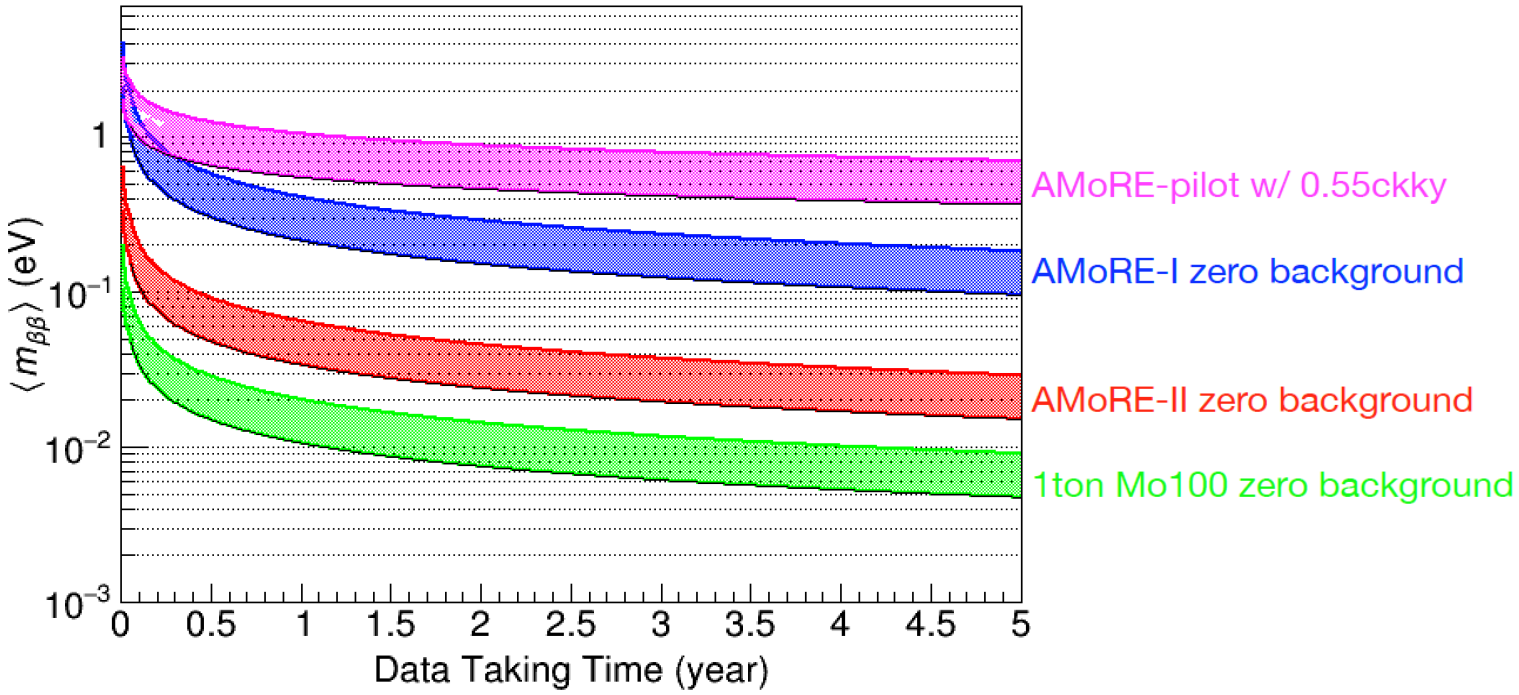
Construct AMoRE-II until Oct. 2021, and Upgrade to 100 kg of ^{100}Mo by 2023.





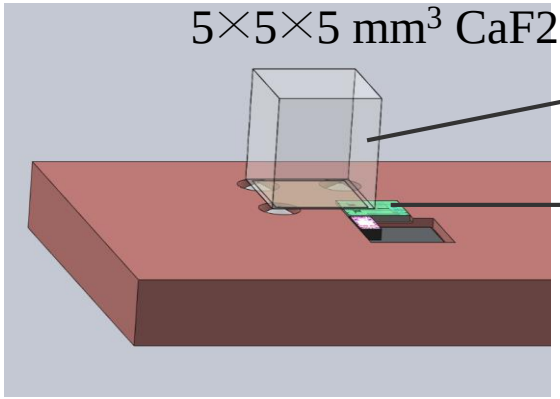
Further

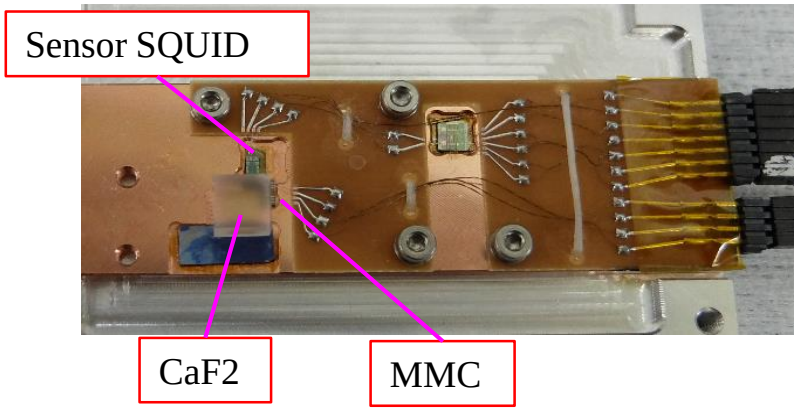
Modular expansion is possible.
After AMoRE-II, ton scale experiment can be done. ~ CUPID 1ton.

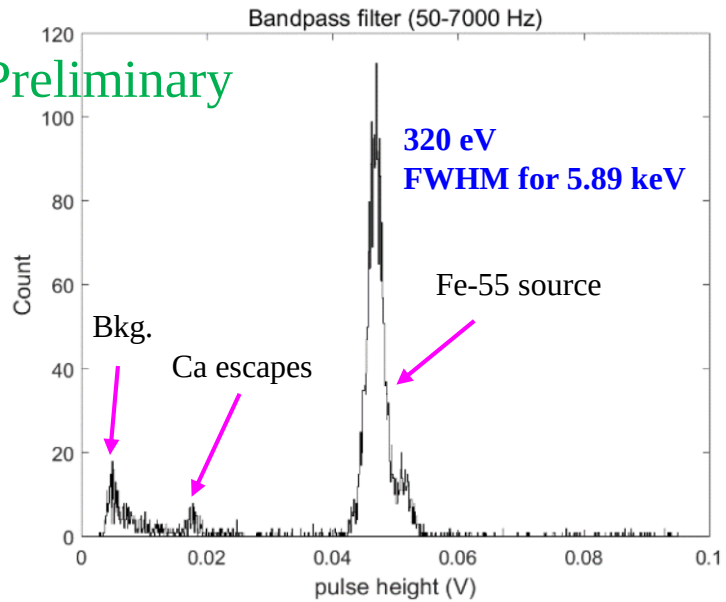


Low threshold detectors for DM exp - by LT group

To use low temperature sensor for dark matter detector, we need to reduce the threshold energy.



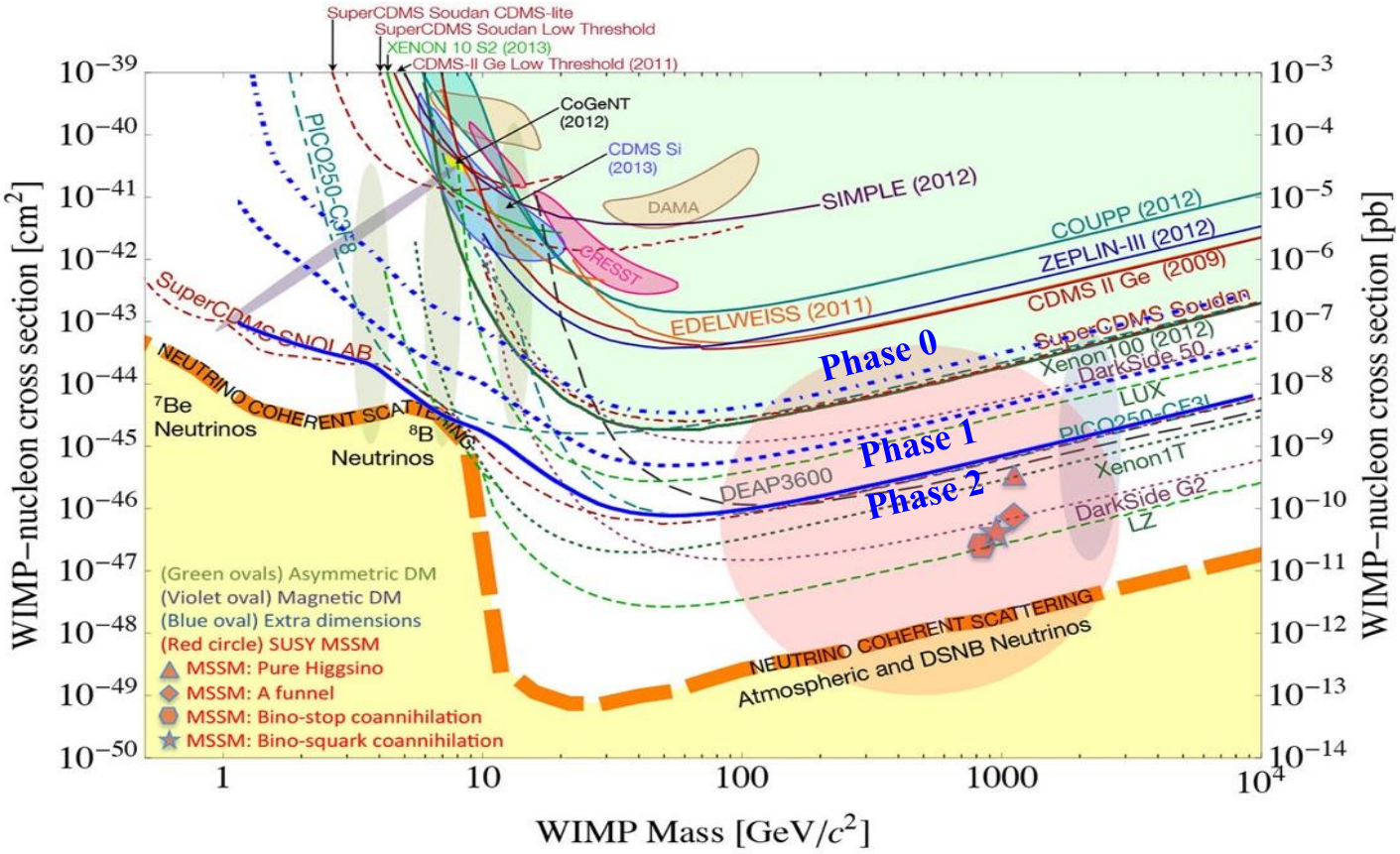




Baseline resolution indicates ~ 140 eV threshold @ 30 mK.
It is just beginning, and need to optimize the crystal size etc.

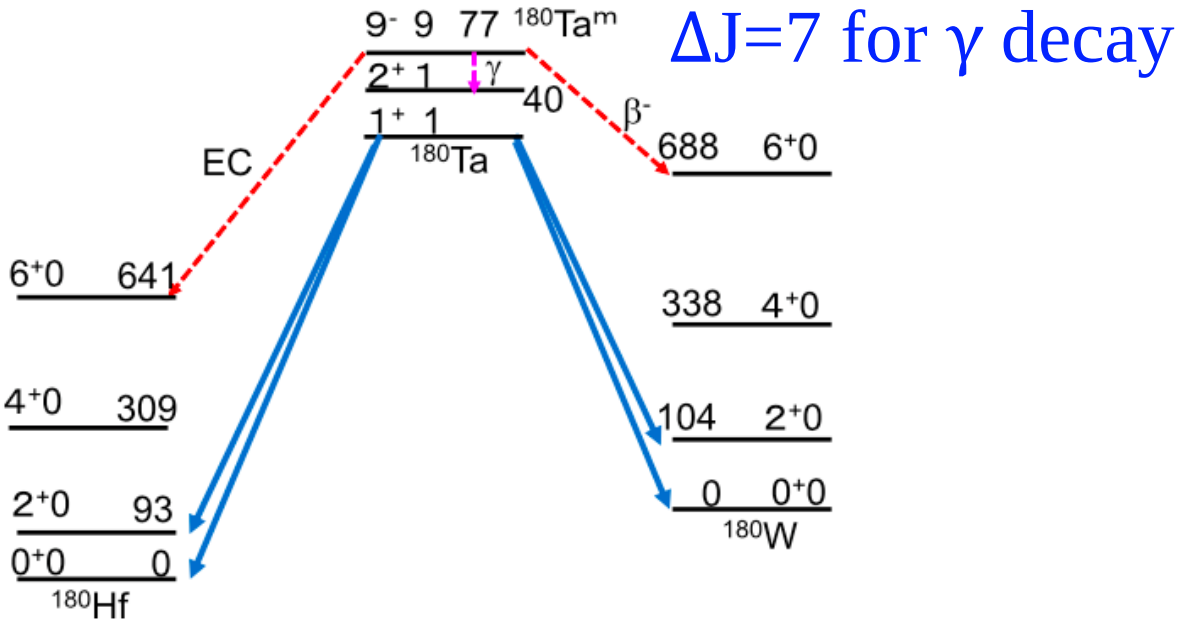
Low mass WIMP search

	Threshold	Background	Mass
Phase0	1 keV	1.0 dru	10 kg
Phase1	0.5 keV	0.1 dru	50 kg
Phase2	0.1 keV	0.01 dru	200 kg



^{180m}Ta decay as a SIMP dark matter signal

1. ^{180m}Ta is the rarest isotope (0.012%), the only isomer abundant naturally.
2. Its decay has never observed yet. ($t_{1/2}>10^{16}$ years)
3. The abundance of ^{180m}Ta is not explained well, and it's decay mode and lifetime will help to understand the astrophysical origin of ^{180m}Ta.



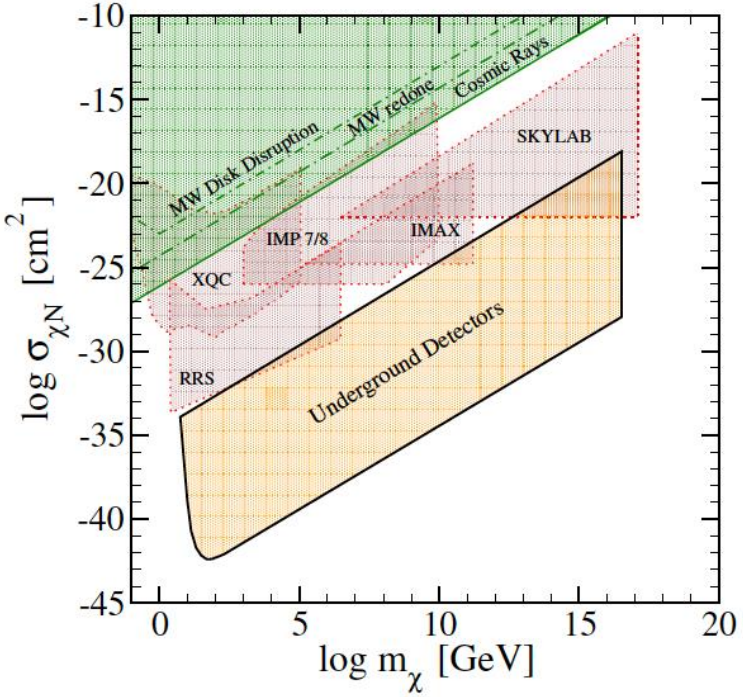
ΔJ=7 for γ decay

Motivation – Dark Matter Detector

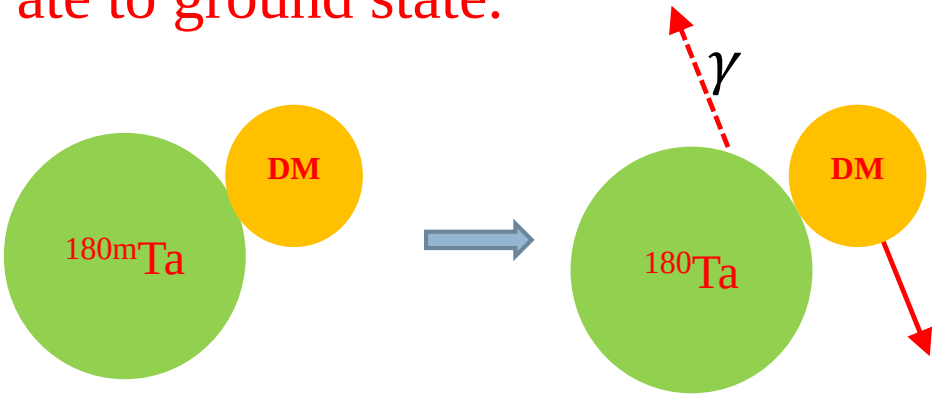
Maxim Pospelov et al., arXiv:1907.00011

"Metastable Nuclear Isomers as Dark Matter Accelerators"

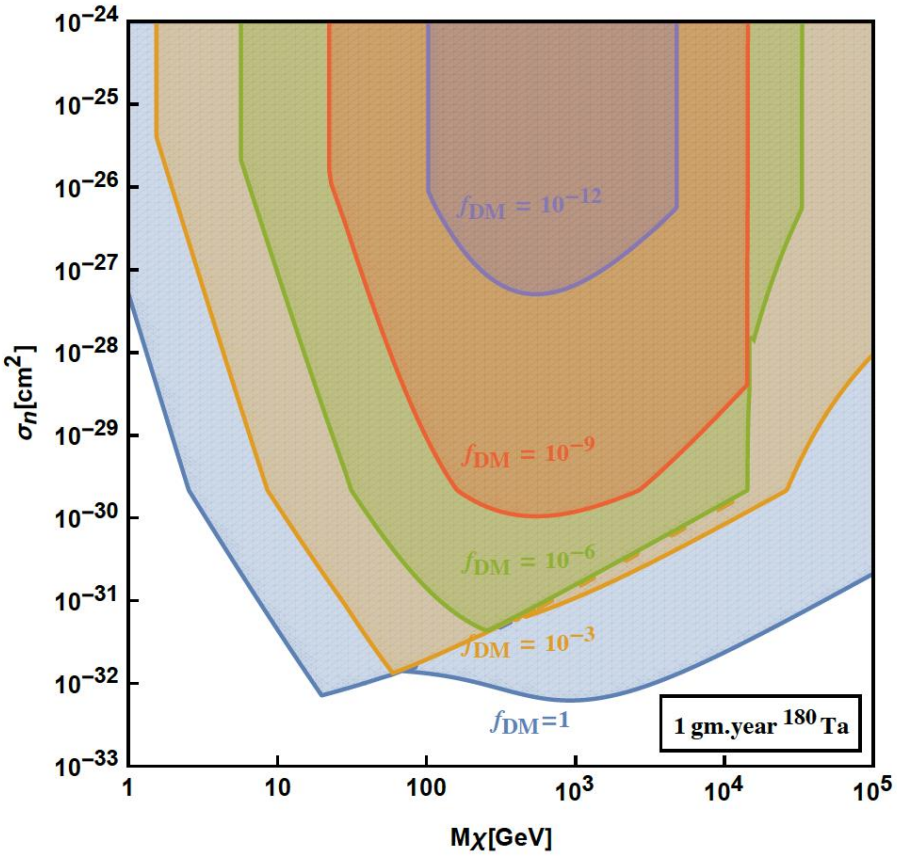
- Parameter space not explored yet for the Strongly Interactive Massive Particles (SIMP).
- SIMPs interacts strongly, so can't reach the underground detectors.
- Ground experiments limits the SIMP-nucleon cross sections.



Heavy, thermalized dark matter particle can deplete ^{180}Ta isomeric state to ground state.



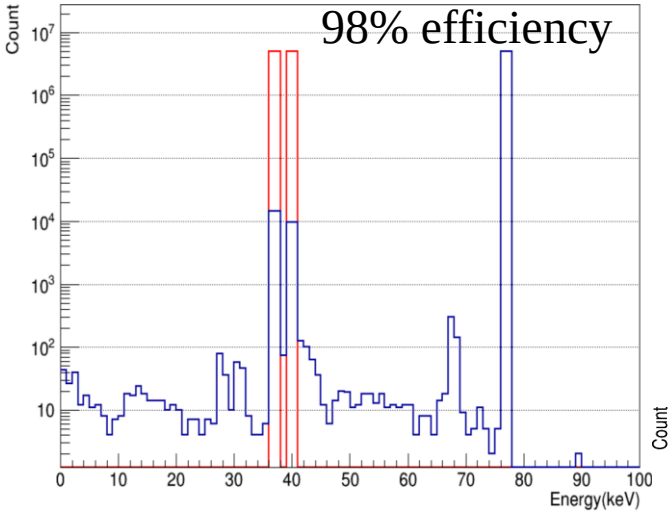
Sensitivity for SIMP-nucleon interaction

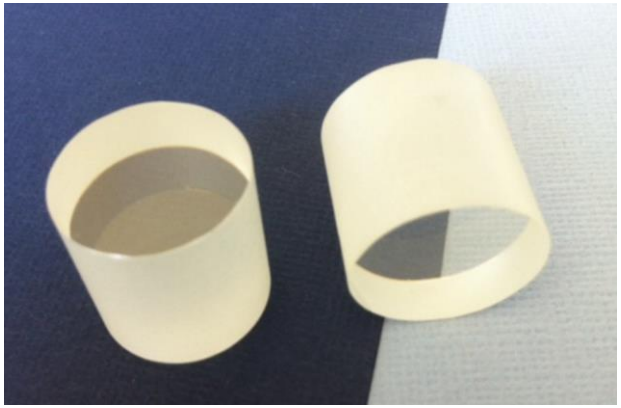


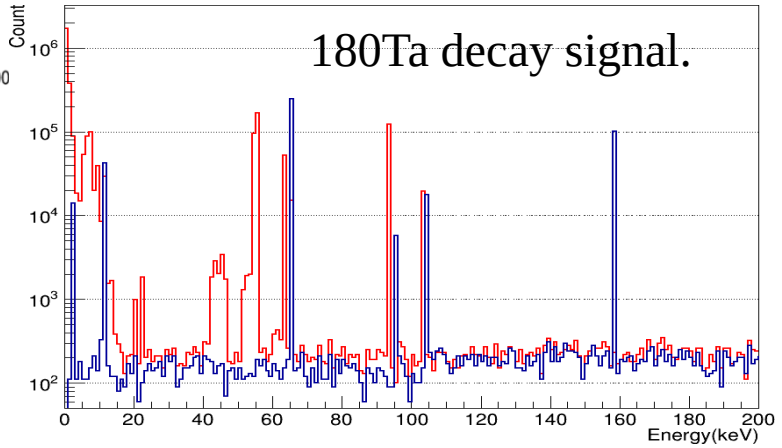
If experimental lifetime limit > 10^{21} years, then DM-nucleon scattering cross section is set smaller than 10^{-32} cm^2 for 10GeV-10TeV.

A proposal - Low temperature tantalate crystal

1. A $LiTaO_3$ crystal is available commercially.
2. $Li^{180m}TaO_3$ + MMC sensor with energy resolution ~ keV.
3. Depletion Signals are simulated.







Ta-180 enrichment necessary

- Ta-180 (0.012% natural abundance) should be enriched to have lower background.
- In Russia, 0.0123% → 0.5 % can be done with thermal diffusion column.
- For ~ 1g, expect 1M$.

Fig. 1. Isotopic production facility, lower level of the column equipment.

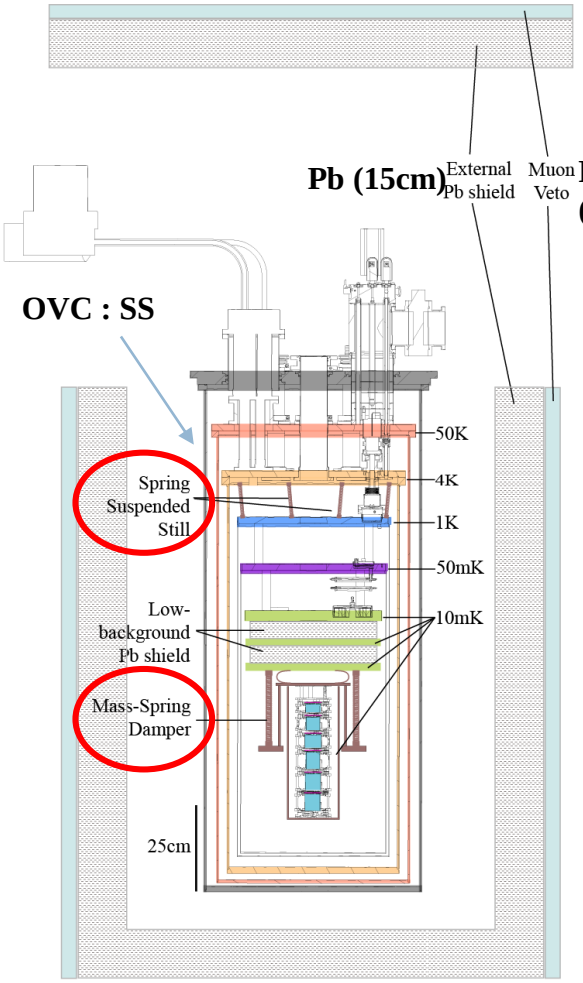
- With ~ 1g of ^{180m}Ta, it is almost guaranteed to discover the decay of ^{180m}Ta, which has been pursued for last 50 years.

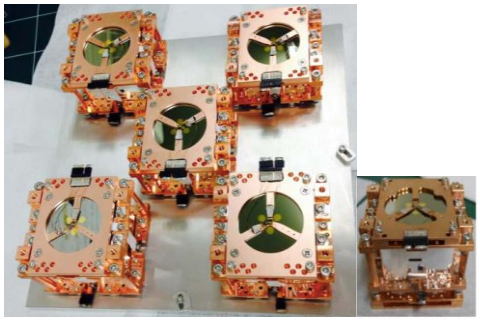
Summary

- AMoRE-II aim to be sensitive to 10^{27} year range for ^{100}Mo isotope. AMoRE-Pilot demonstrated detector performance and identified the background sources. Collaborative work with CUPID-Mo group is anticipated.
- AMoRE-II construction began and will be installed by end of 2021.
- AMoRE-II is the largest scale bolometer DBD experiment with concrete plan.
- Construction of Yemilab for AMoRE-II is going well. Need full budget for completion of the lab.
- The LT technology for underground physics are developed and can be applied to other experiments, such as Low mass DM or SIMP search.

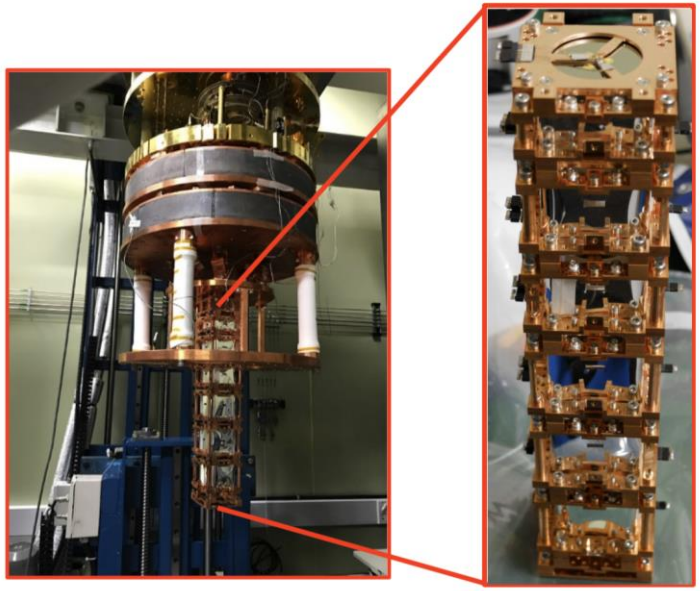
AMoRE-Pilot Setup

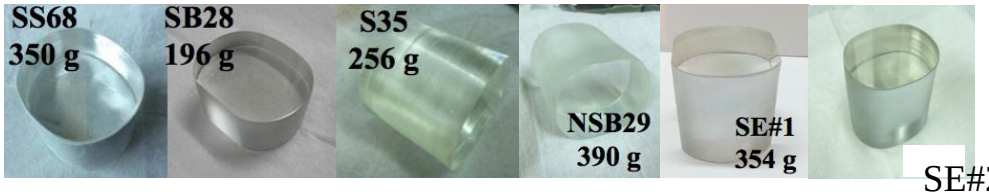
- **To demonstrate the detection principle and low backgrounds.**
- **6 crystals making total mass 1.89 kg.**
- **Two vibration reduction systems are installed.**





12 detector channels
(6 heat detectors + 6 light detectors)



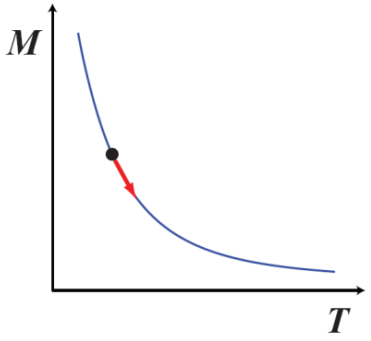


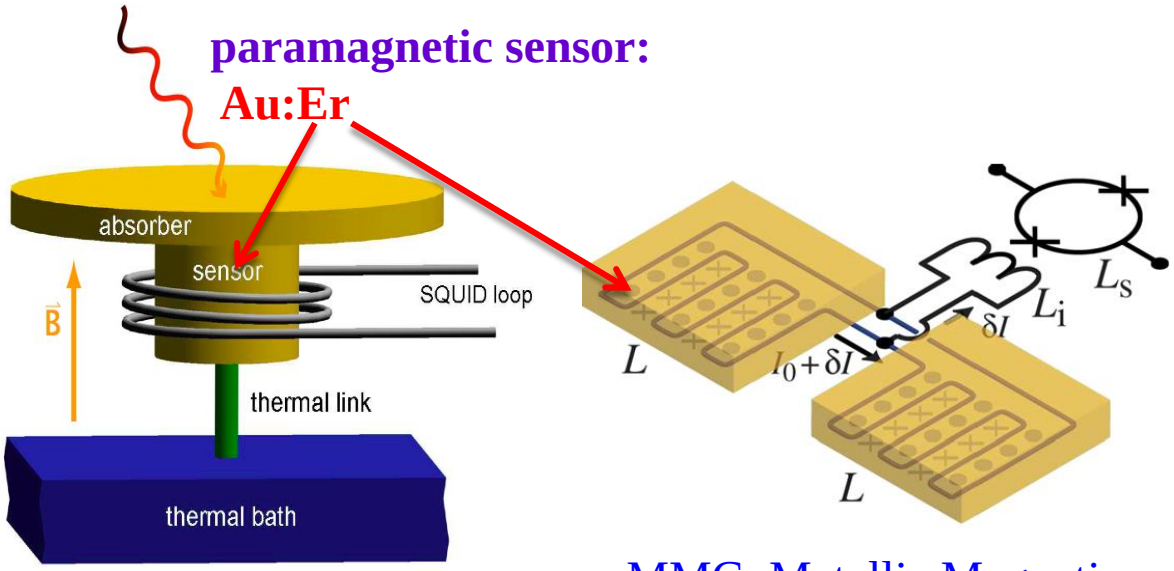
$^{40}Ca^{100}MoO_4$ crystals from Russian company, FOMOS.

Thermal detectors at low Temp. for AMoRE

- Particle interaction is detected through a temperature change at mK temperature.

Energy (Heat) absorption
→ Change in Temperature in an absorber
→ Change in Magnetization in a paramagnetic alloy(Au,Ag:Er) in a constant magnetic field
→ Induced current measured with a SQUID.





MMC: Metallic Magnetic Calorimeter