Future project in Yemilab: AMoRE-II (+COSINE1T)

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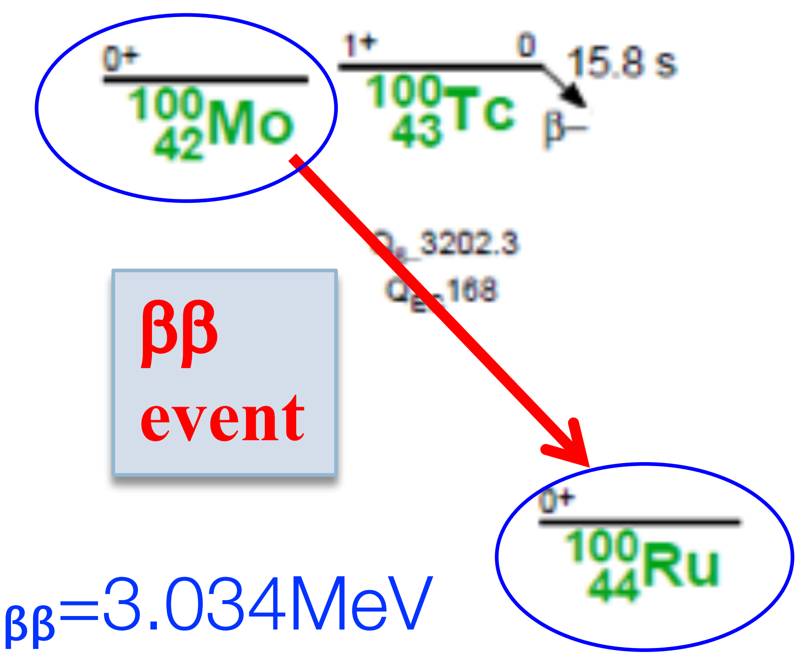
The 3rd TAU collaboration meeting
March 28, 2019

AMoRE project

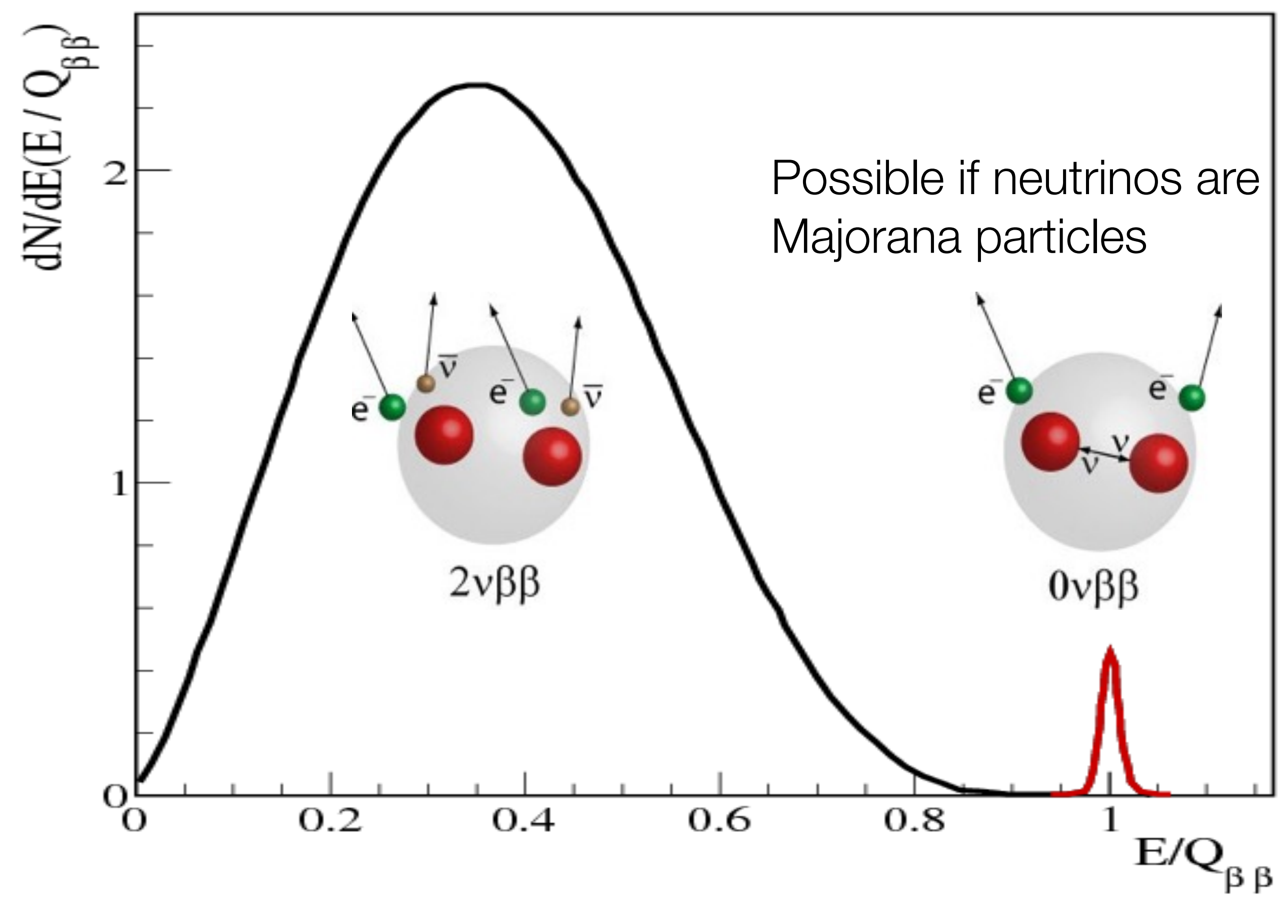
AMoRE
: Advanced Mo-based Rare Process Experiment

- Goal

It is to search for neutrinoless double-beta decay ($0\nu\beta\beta$) of ^{100}Mo in molybdate crystals



$Q_{\beta\beta}$=3.034MeV

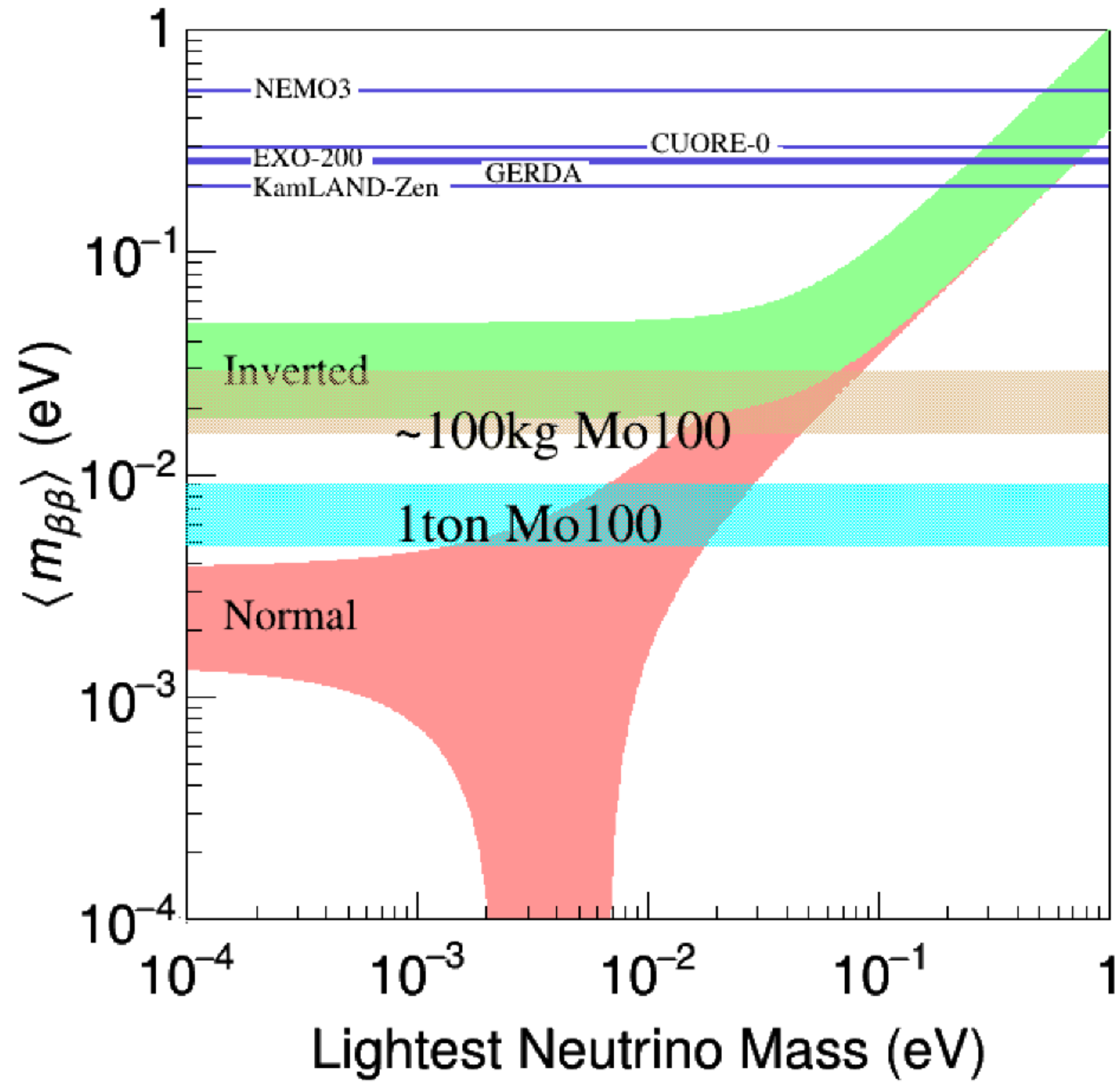


What are we measuring?

$$[T^{0\nu}_{1/2}]^{-1} = G_{0\nu}|M_{0\nu}|^2\langle m_{\beta\beta}\rangle^2$$

$$\langle m_{\beta\beta}\rangle = \left|\sum_{i=1}^{3} U_{ei}^2 m_i\right|$$

- If the decay rate of the 0νββ is precisely measured, the absolute neutrino masses can be calculated

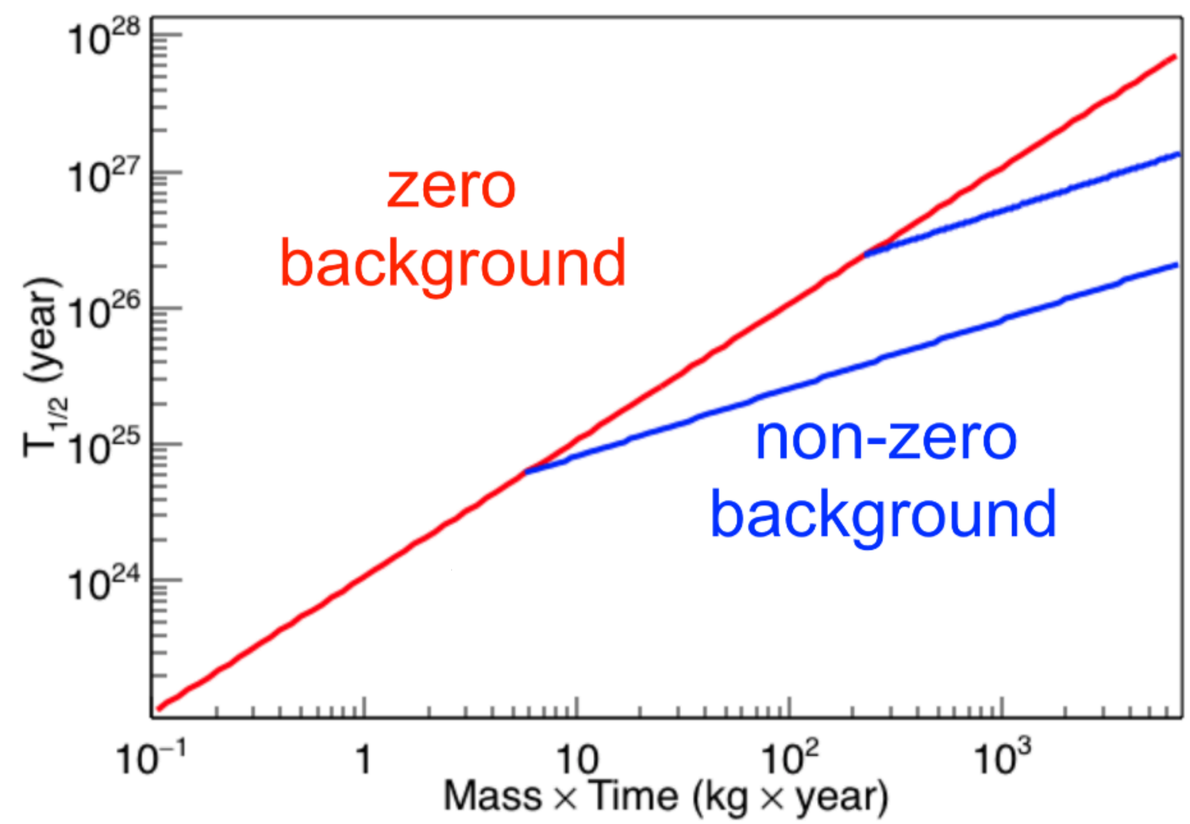


AMoRE experimental approach

$$T^{0\nu}_{1/2} \propto M \cdot T$$ (for zero background)

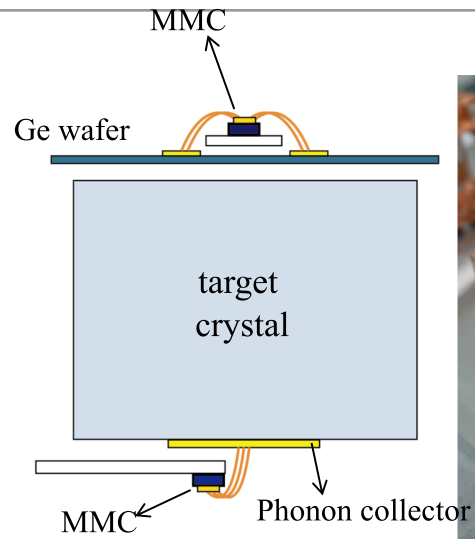
$$T^{0\nu}_{1/2} \propto \sqrt{\frac{M \cdot T}{B \cdot \Delta E}}$$

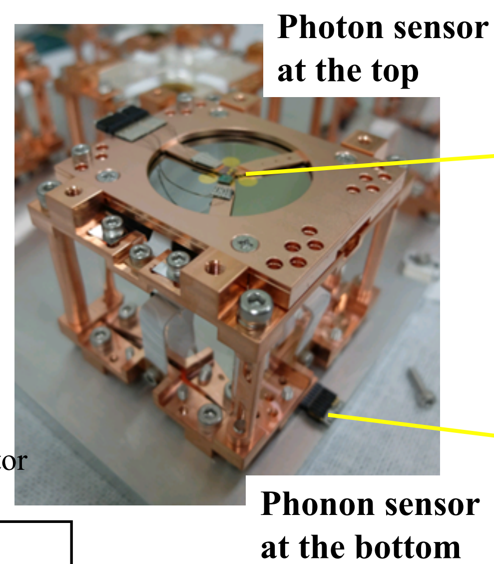
(for finite background)

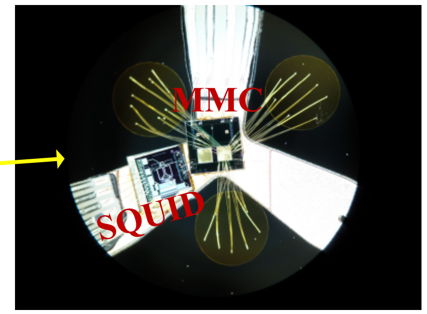


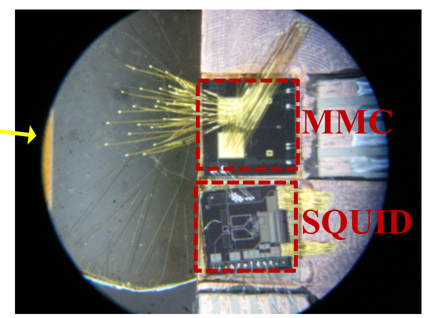
- Half-life limits are proportional to the detector mass M and DAQ time T, If finite background, sqrt(MT)
- To discover a sharp peak @ Q-value we need a good energy resolution and etremely low background at the energy → ***AMoRE is aming for zero background***

AMoRE detector

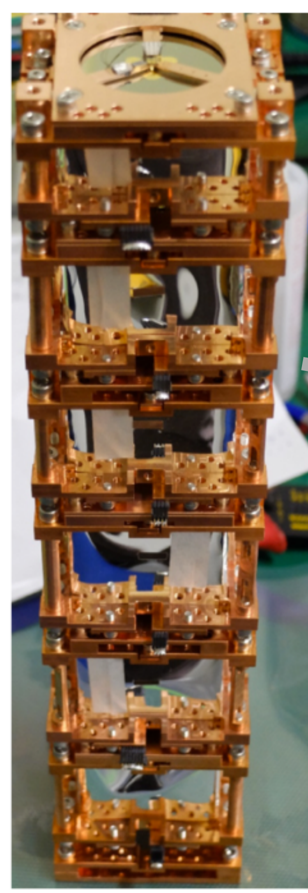


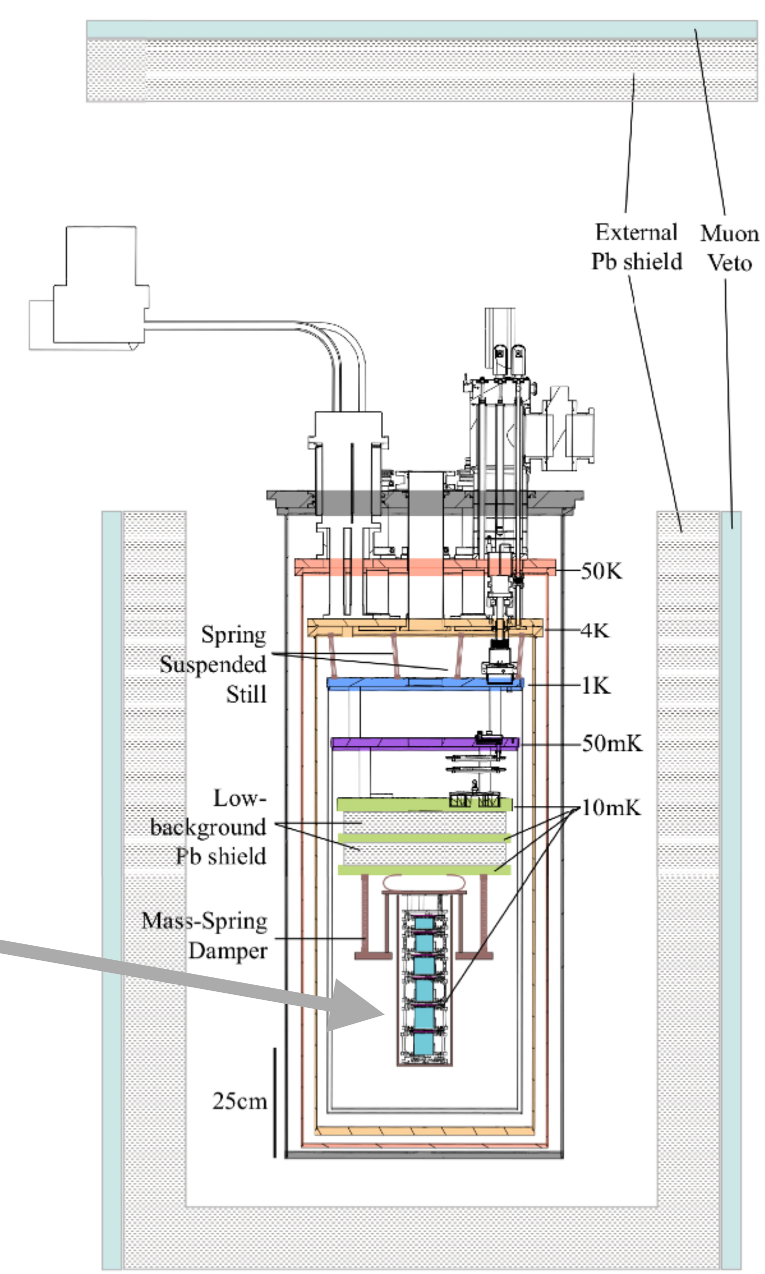






- ^{100}Mo is expected to have a smallest half-life except ^{150}Nd
- Natural abundance ~10%
  ➔ enrichment cost in moderate
- Baackground will be low for Q>3MeV (Q=3.034MeV for ^{100}Mo)





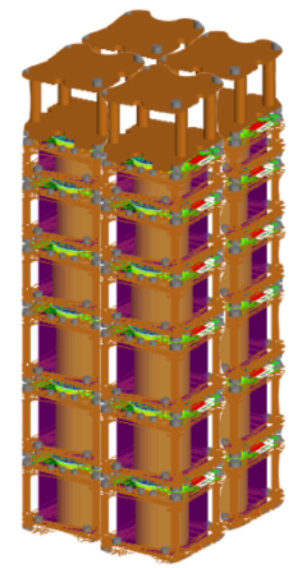
- Use Mo containing scintillating bolometer: $(^{40}Ca,X)^{100}MoO_4$+MMC
- For each crystal phonon and photon sensors made of MMCs, SQUIDs to separate alpha backgrounds and betas

Plan of AMoRE project
(Total 105 members from 23 institutes at 8 countries)

AMoRE-Pilot

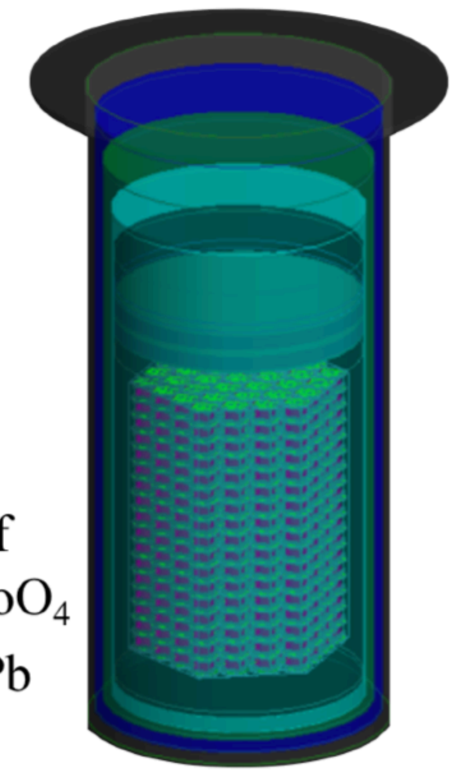
1.5~1.9 kg of $^{40}Ca^{100}MoO_4$

AMoRE-I



~6 kg of $(^{40}Ca,X)^{100}MoO_4$
X=Li, Na, Pb

AMoRE-II

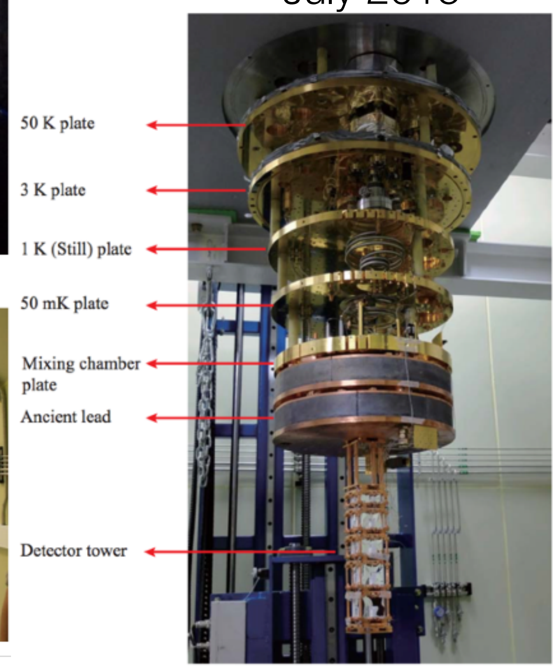


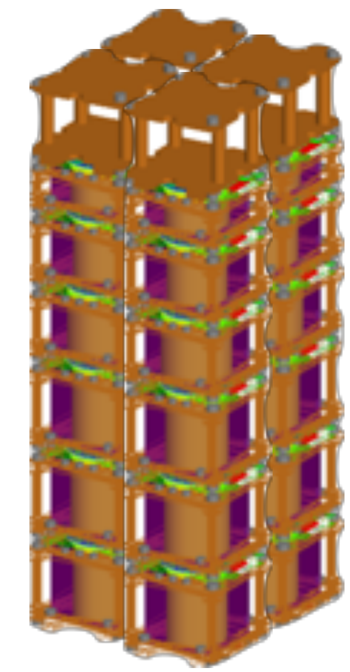
~200 kg of $(^{40}Ca,X)^{100}MoO_4$
X=Li, Na, Pb

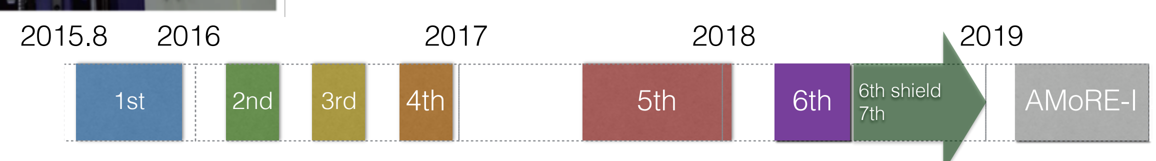
	AMoRE-pilot	AMoRE-I	AMoRE-II
Mass	1.9 kg	6 kg	200 kg
Background goal (keV kg year)$^{-1}$	~10^{-2}	~10^{-3}	~10^{-4}
Expected $T_{1/2}$ sensitivity (years)	~1×10^{24}	8.2×10^{24}	8.2×10^{26}
Expected $\langle m_{\beta\beta}\rangle$ (meV)	380-719	130-250	13-25
Laboratory	Y2L	Y2L	New Lab.
Schedule	2015-2018	2019-2021	2021-

What have we been doing?

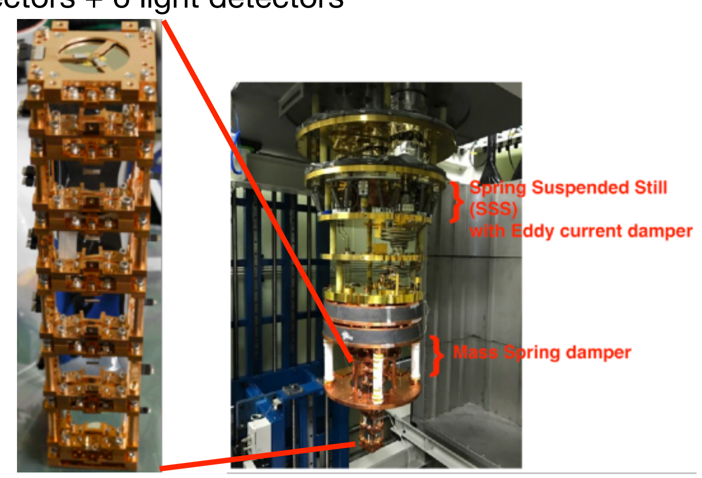
July 2015



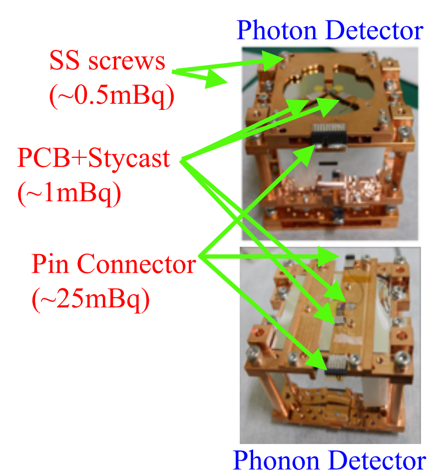




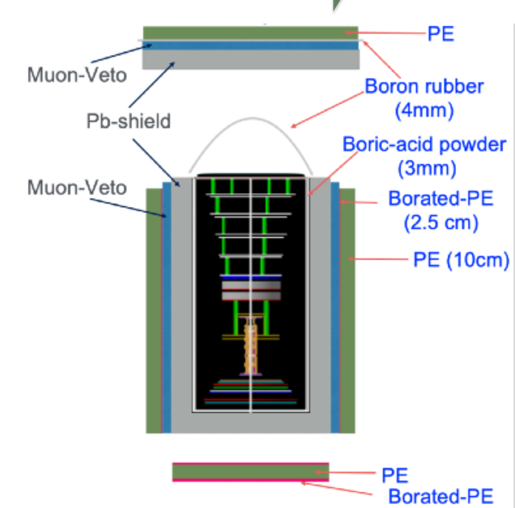
6 heat detectors + 6 light detectors



- 6 crystals making total mass 1.89kg
- Two vibration reduction systems are installed: Mass spring damper+spring-suspended still



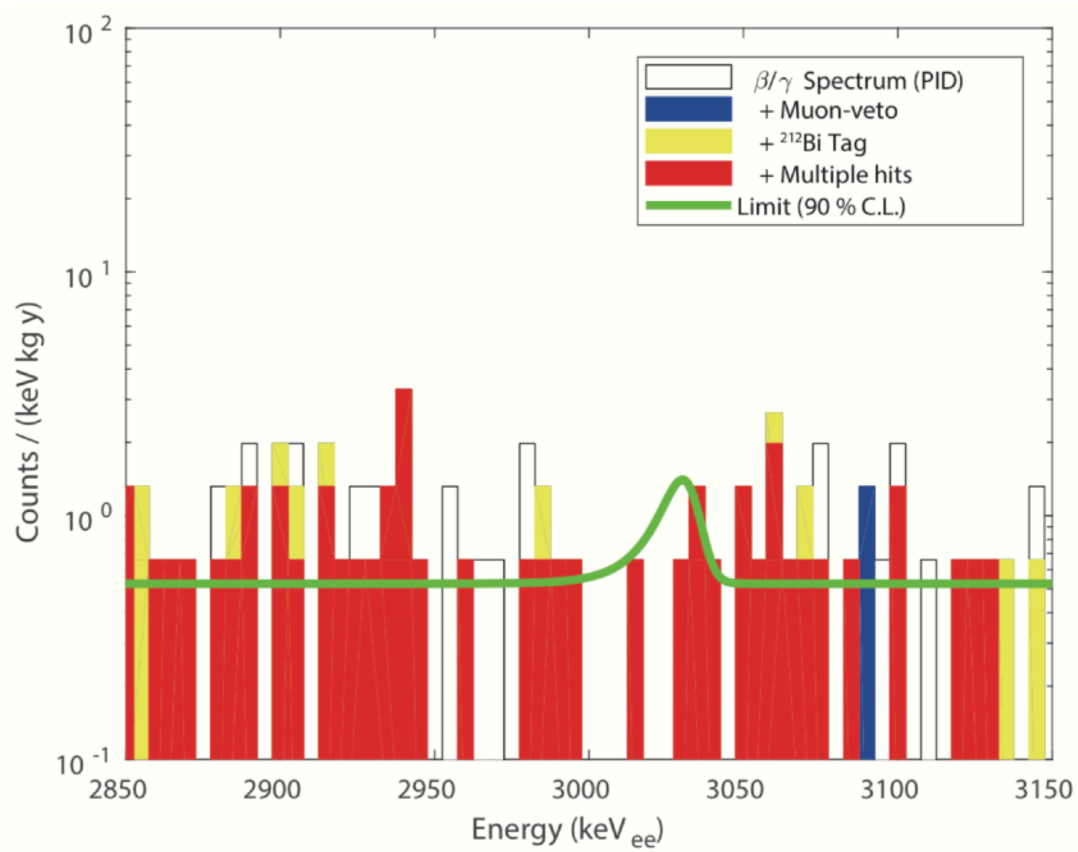
- Connectors, glue, and PCB boards were highly radioactive from HPGe measurements
- Removed these parts for Run 6 in Pilot setup

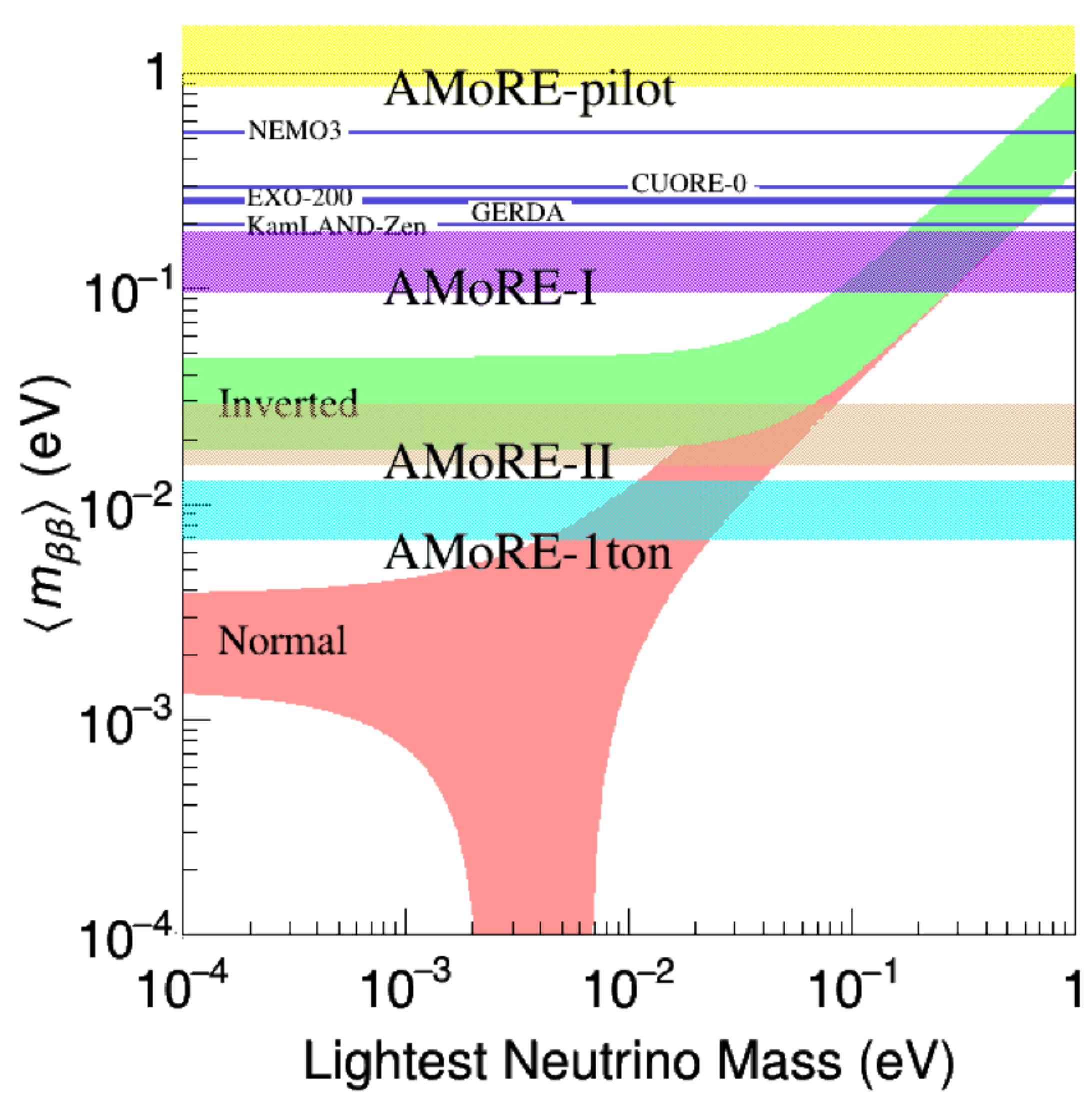


- Neutron shield layers were installed to block neutrons induced by muon and come from rock as an environment neutrons underground (Run 7)

AMoRE-pilot result & Majorana mass sensitivity of the AMoRE project

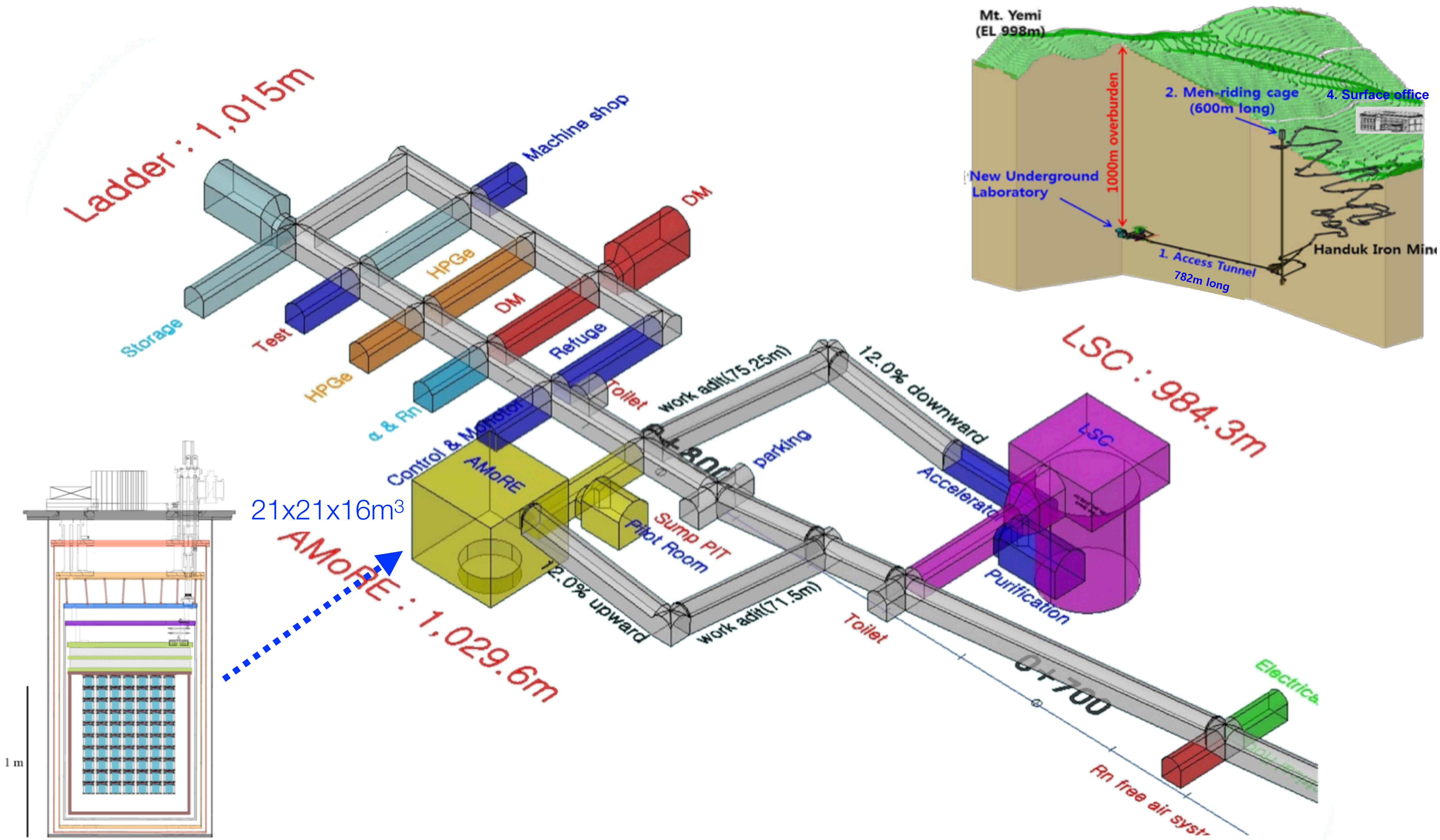
arXiv:1903.09483





- No evidence for $0\nu\beta\beta$ of ^{100}Mo is found with a detection sensitivity of $T^{0\nu} > 1.1 \times 10^{23}$y at 90% C.L.

Location for AMoRE-II
: Yemi underground laboratory (Yemilab)



Background estimation for AMoRE

1. Inside SC shield

- Crystals
- Radioactive components nearyby crystal
- Cu frame and Vikuiti reflector
- Surface contamination

2. Materials above inner lead

3. Cans

4. Shields

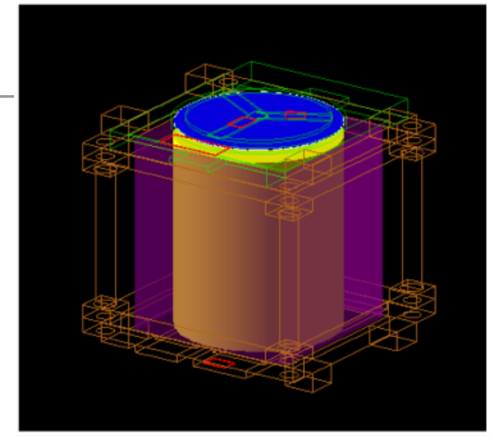
- SC shield
- Inner lead shield
- Outer lead shield

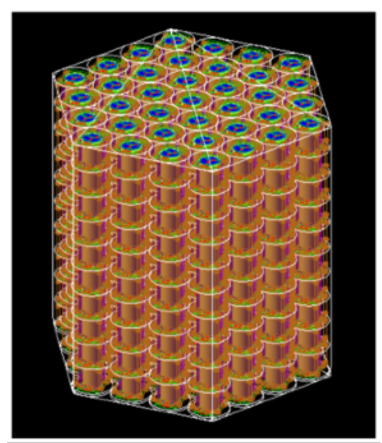
5. Rock internal: can be blocked by lead shield

6. Muons and Neutrons

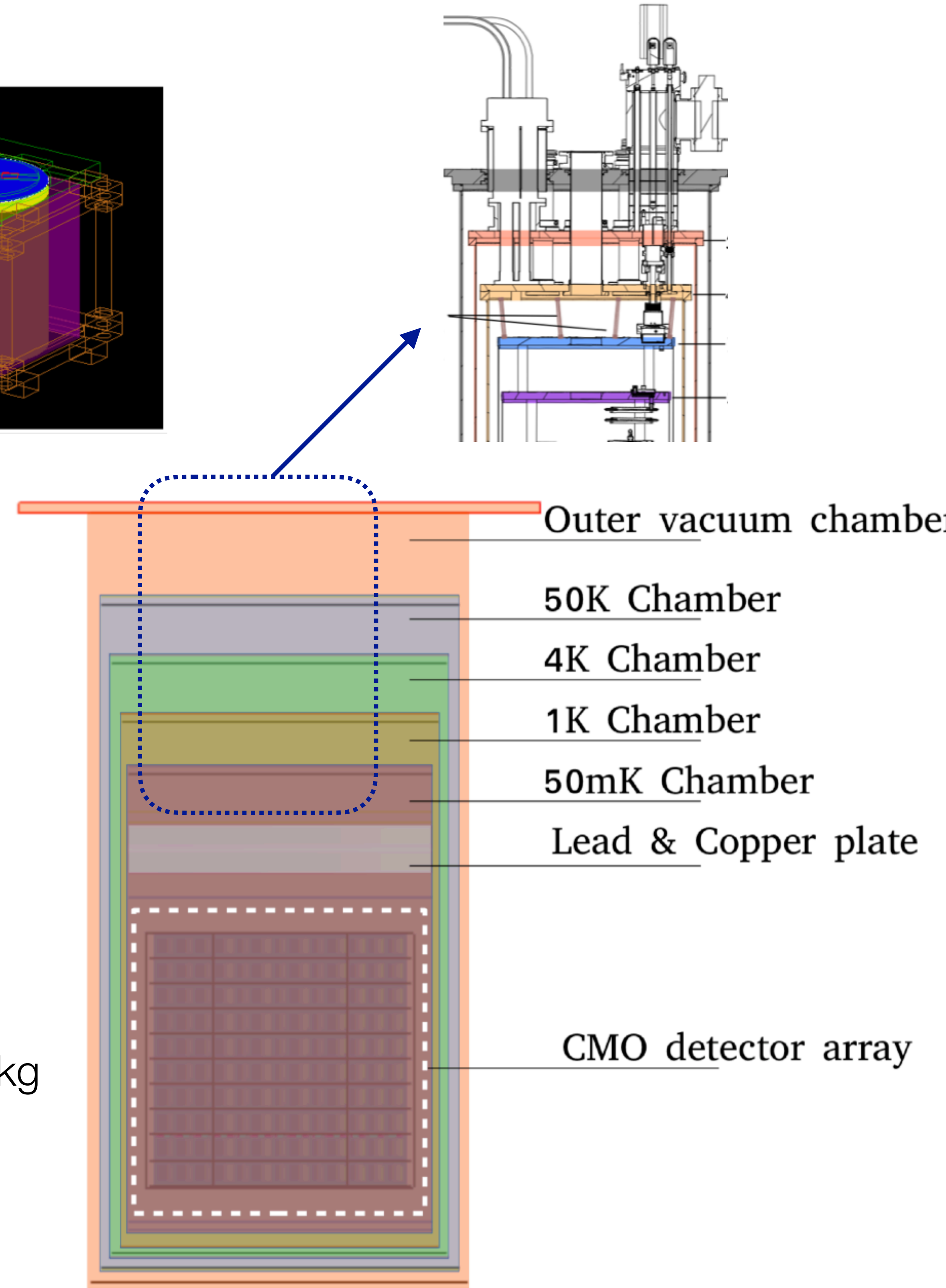
7. Cosmogenic isotopes: will be negligible after 1 year at underground

8. Accidental pile-up due to two neutrino DBD





37x10x0.538=199kg

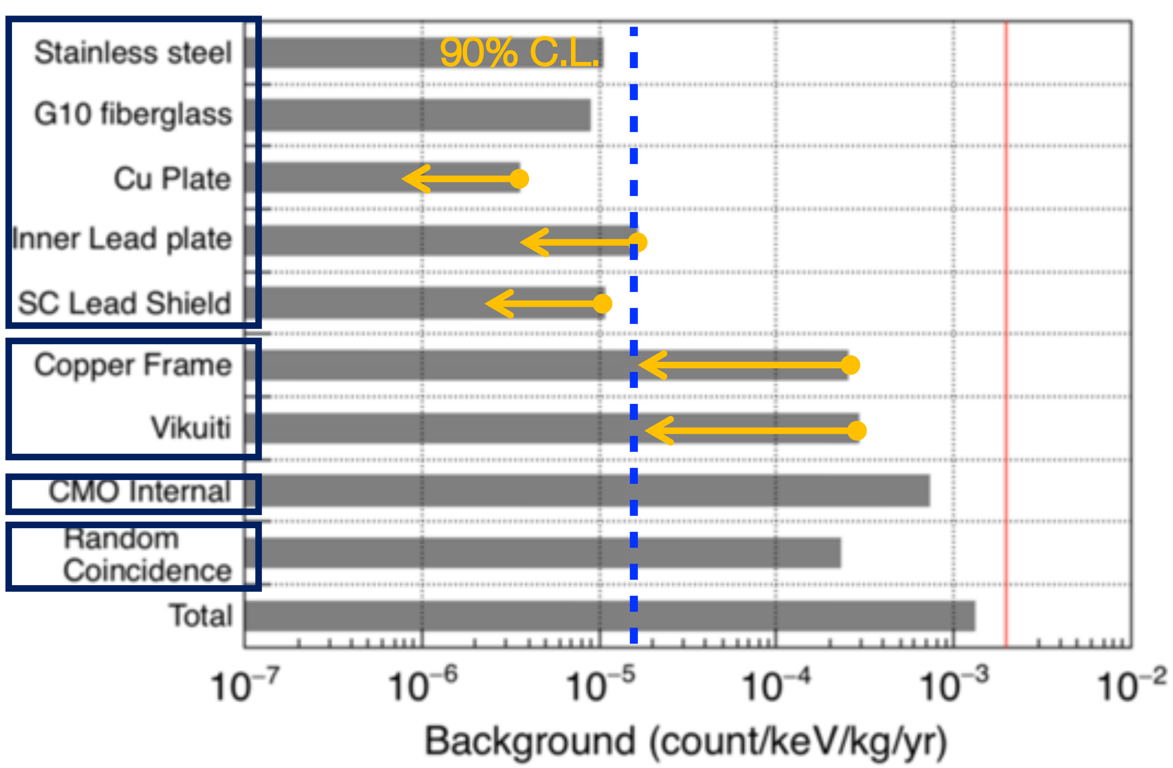


Estimated background level of AMoRE-I

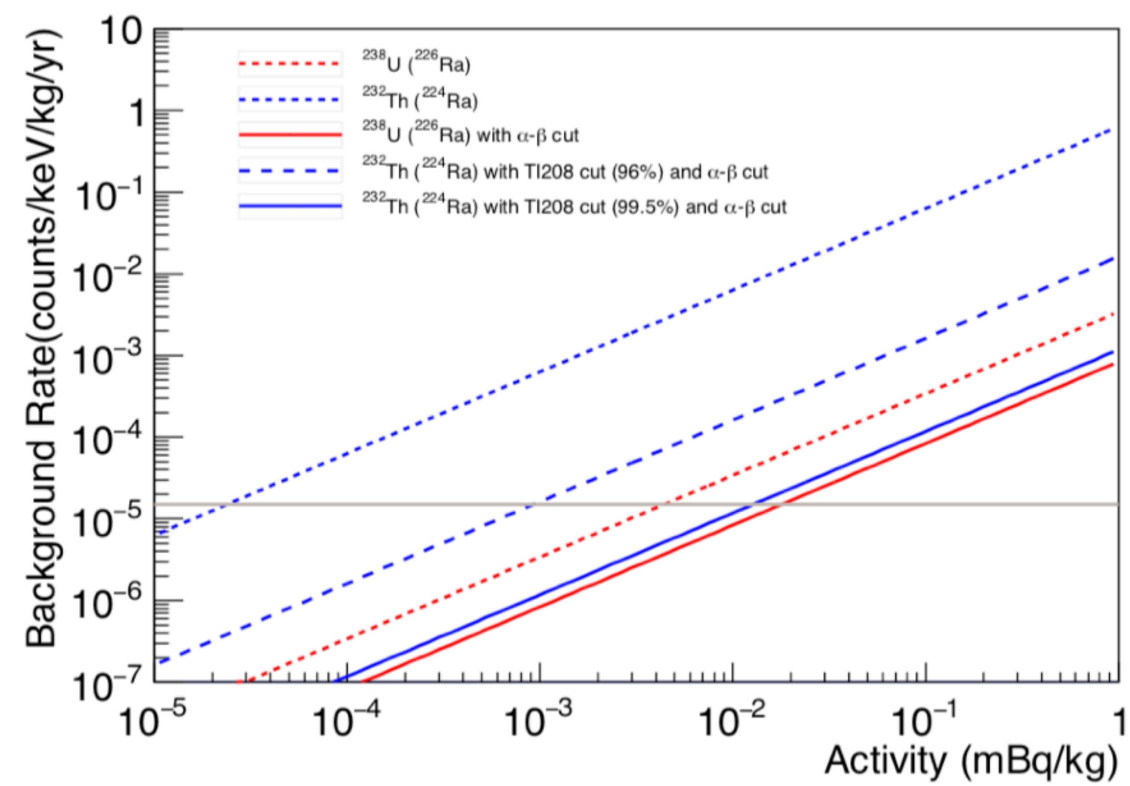
- Only Thorium and Uranium natural radioactivity are critical for Q > 3.02MeV.
- We tried to identify crital components in the setup for AMoRE-II
- Crystal bulk has largest contribution in CaMoO4 crystal case
- For AMoRE-II the crystal bulk acitivity for zero background has been set.

$<10^{-5}$ ckky for AMoRE-II

$<10^{-3}$ ckky for AMoRE-I

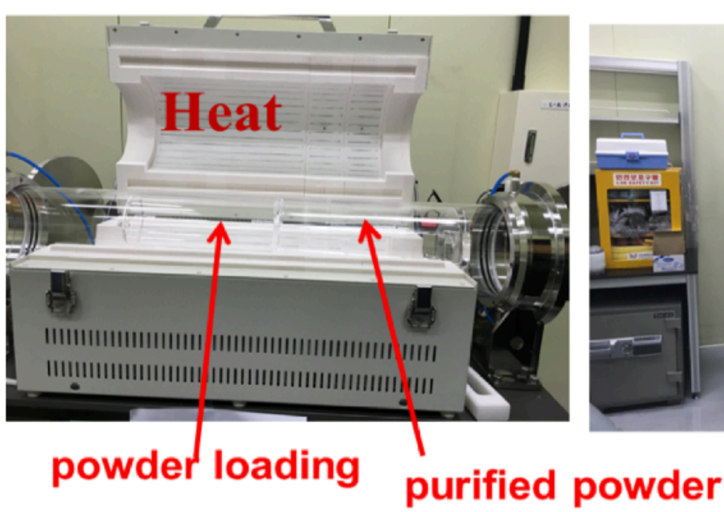


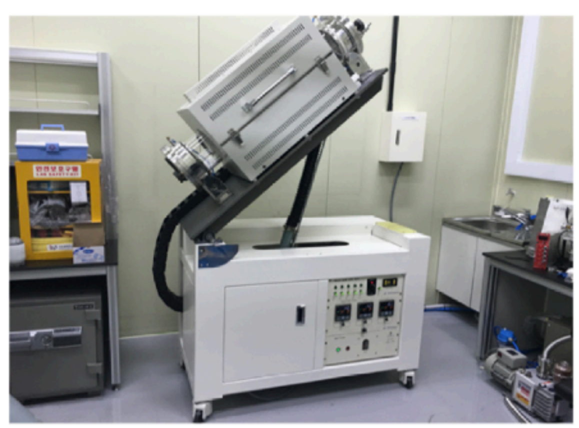
(Nucl. Instr. Meth. A 855 (2017) 140)



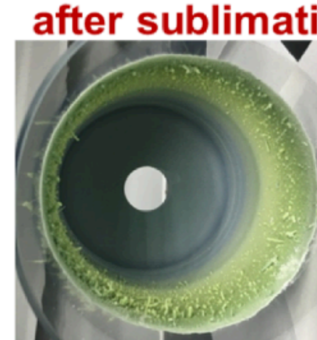
Crystal growing and purification at CUP

- We grow molybdate crystals at CUP
- R&Ds on purification are ongoing

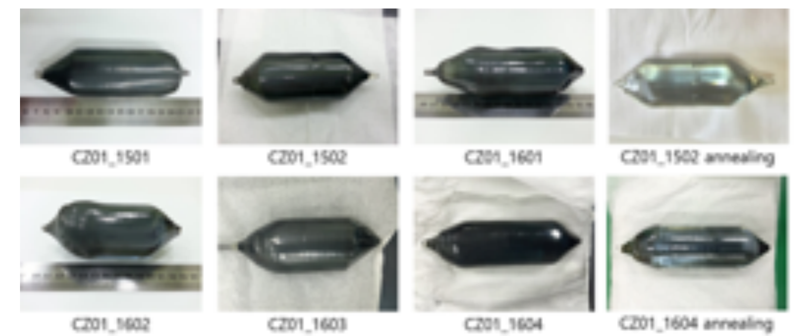




Purified powder after sublimation

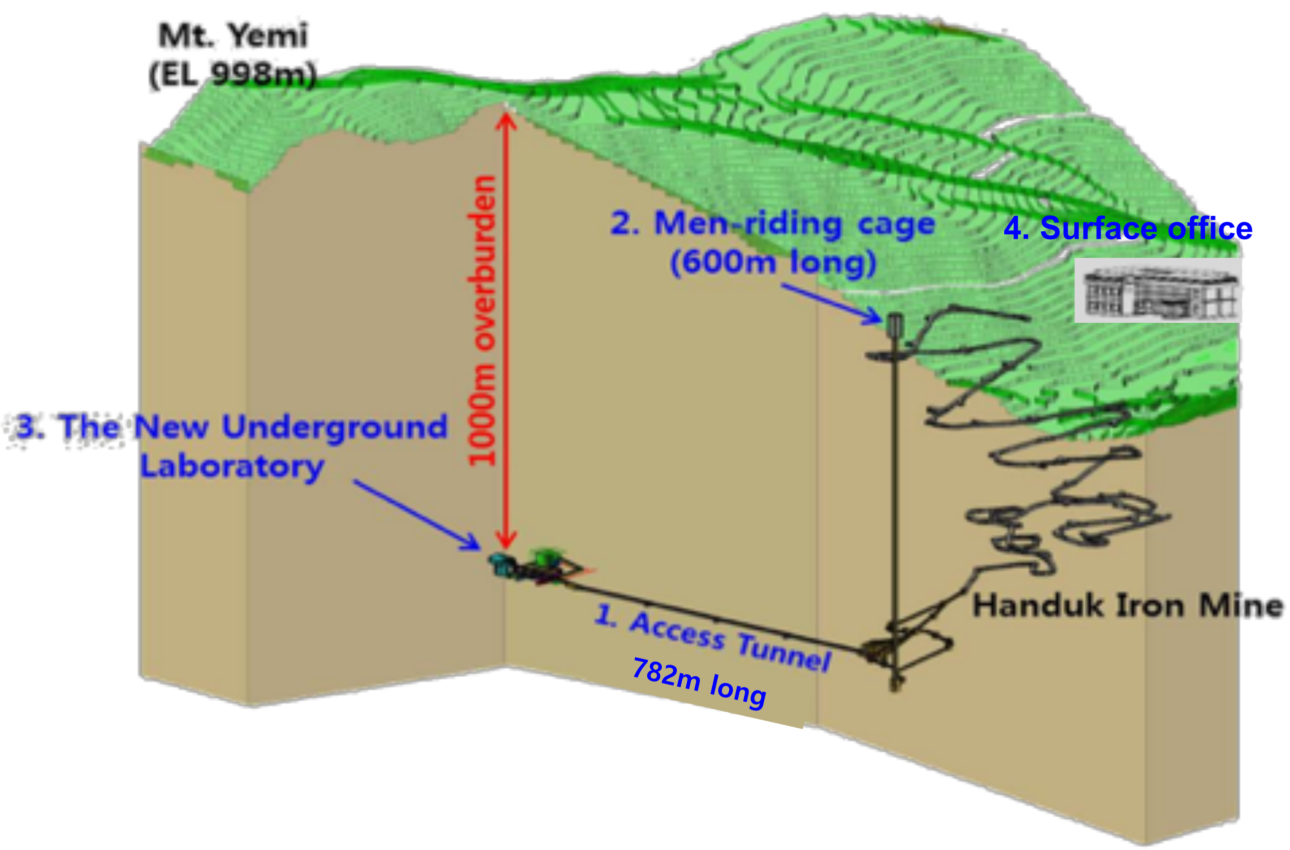


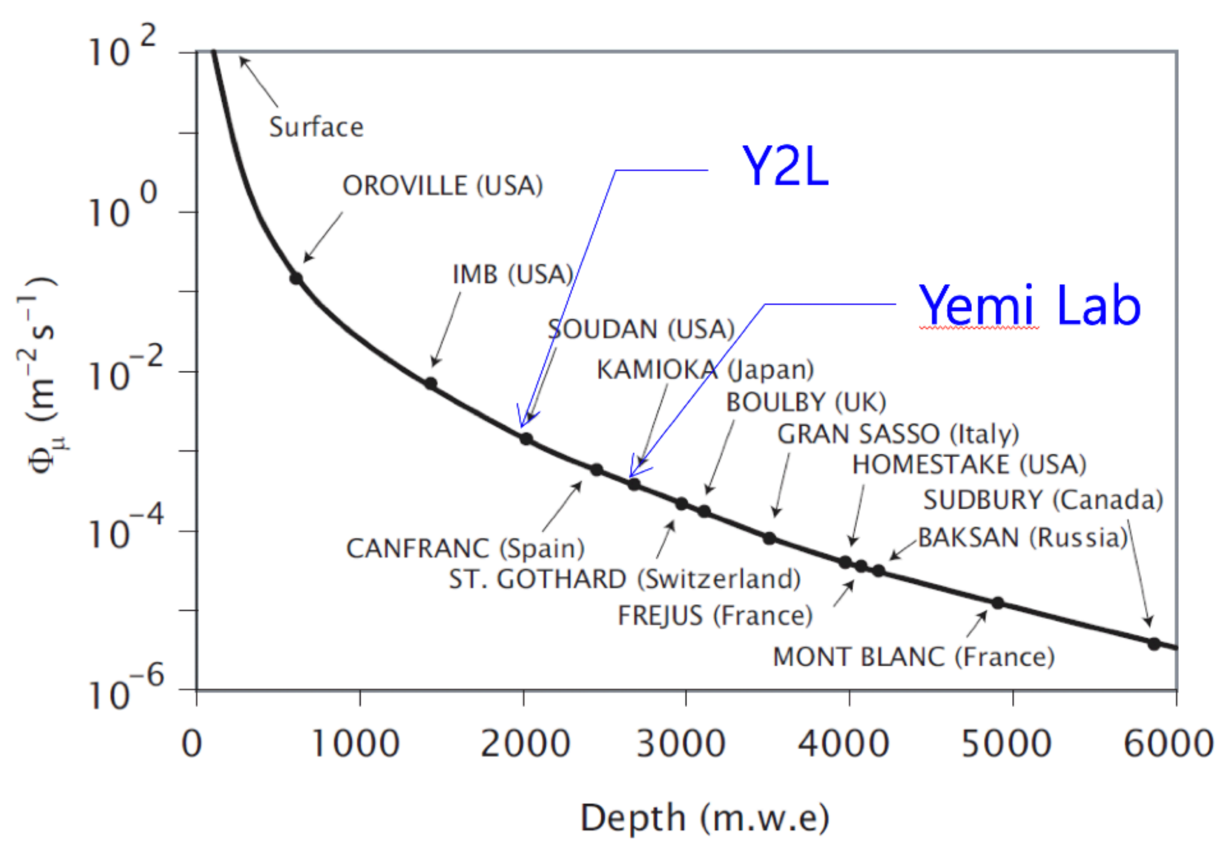
Unpurified Mo and Ca powders



Purified Mo and Li powders

Muon flux at Yemilab





Muon and muon-induced background

- With 100% muon tagging efficiency (It is ~10^{-6} ckky with 30cm lead when muon tagging eff. is 99.9%)

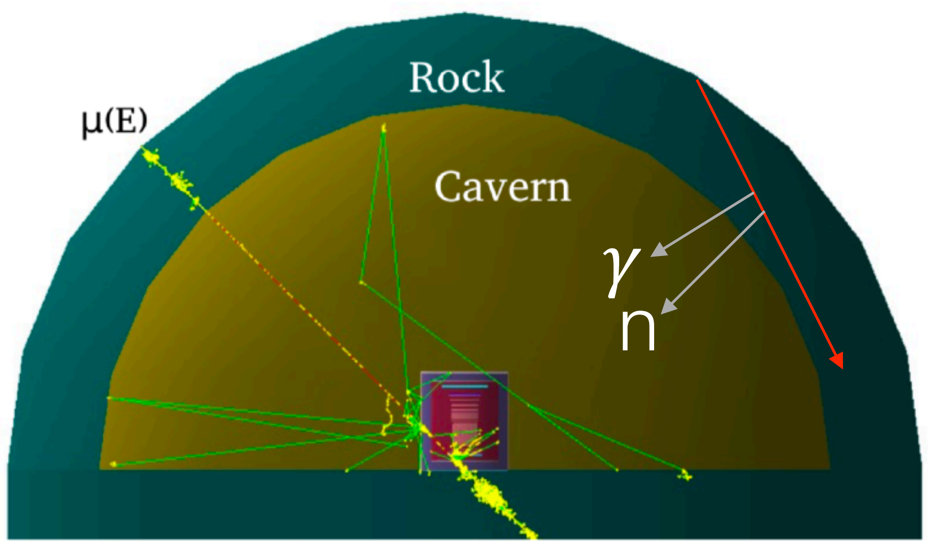
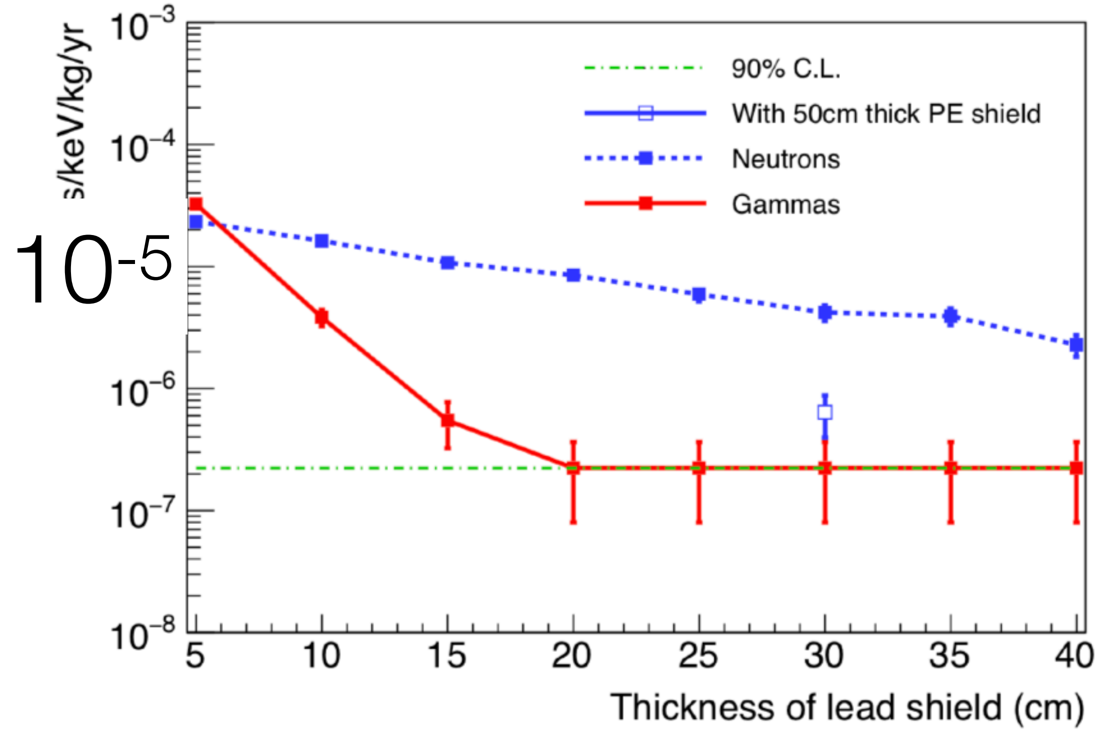
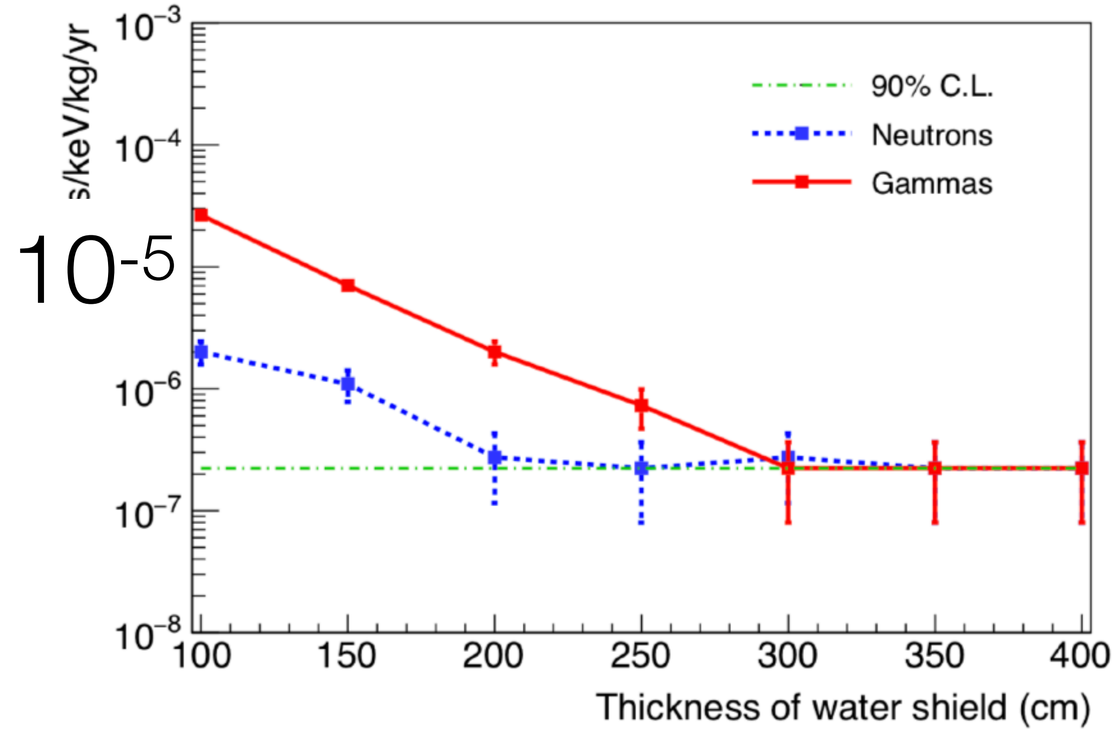


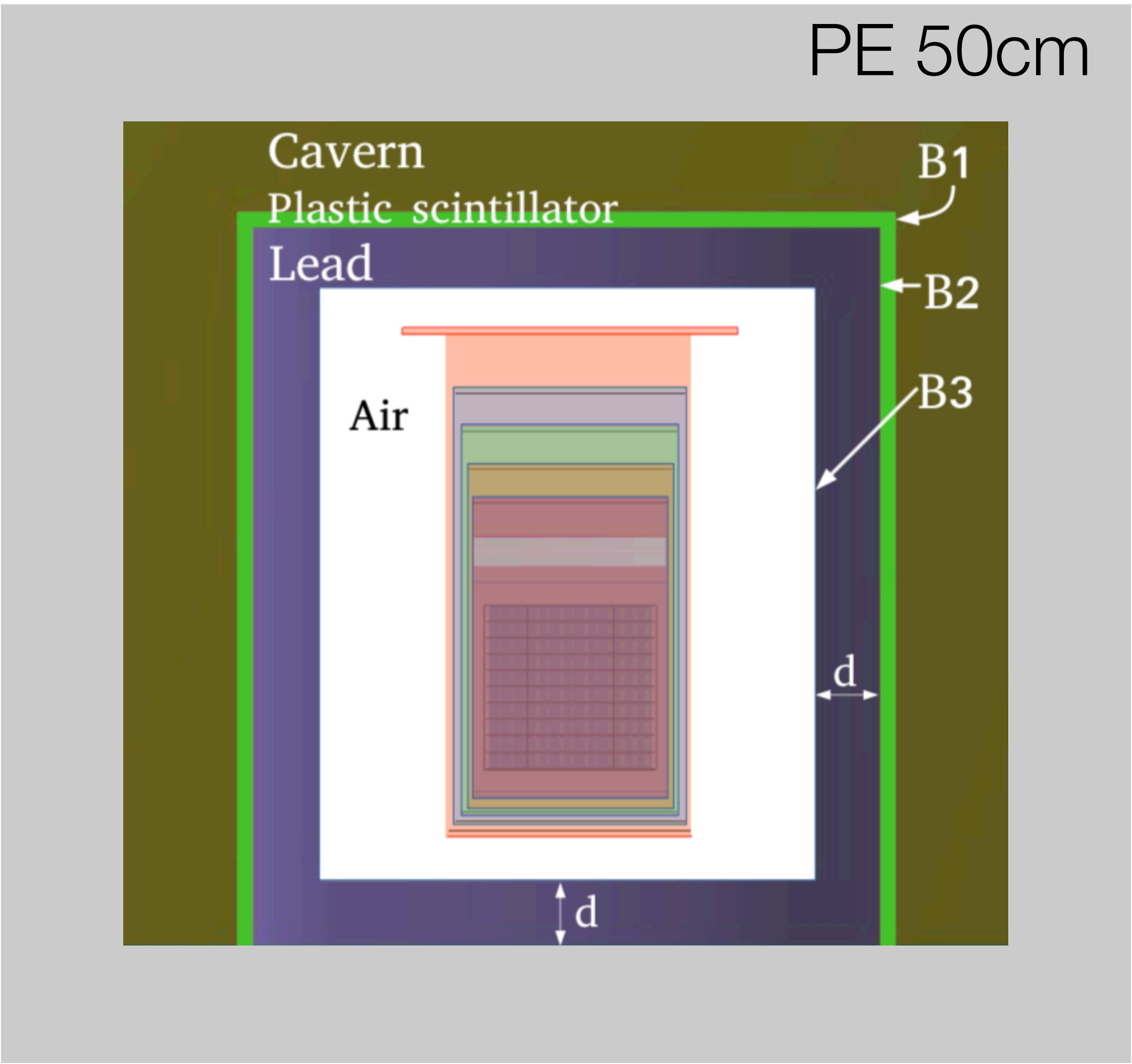
Figure 3: Schematic view of the muon generated by brute-force simulations.

arXiv:1812.07476

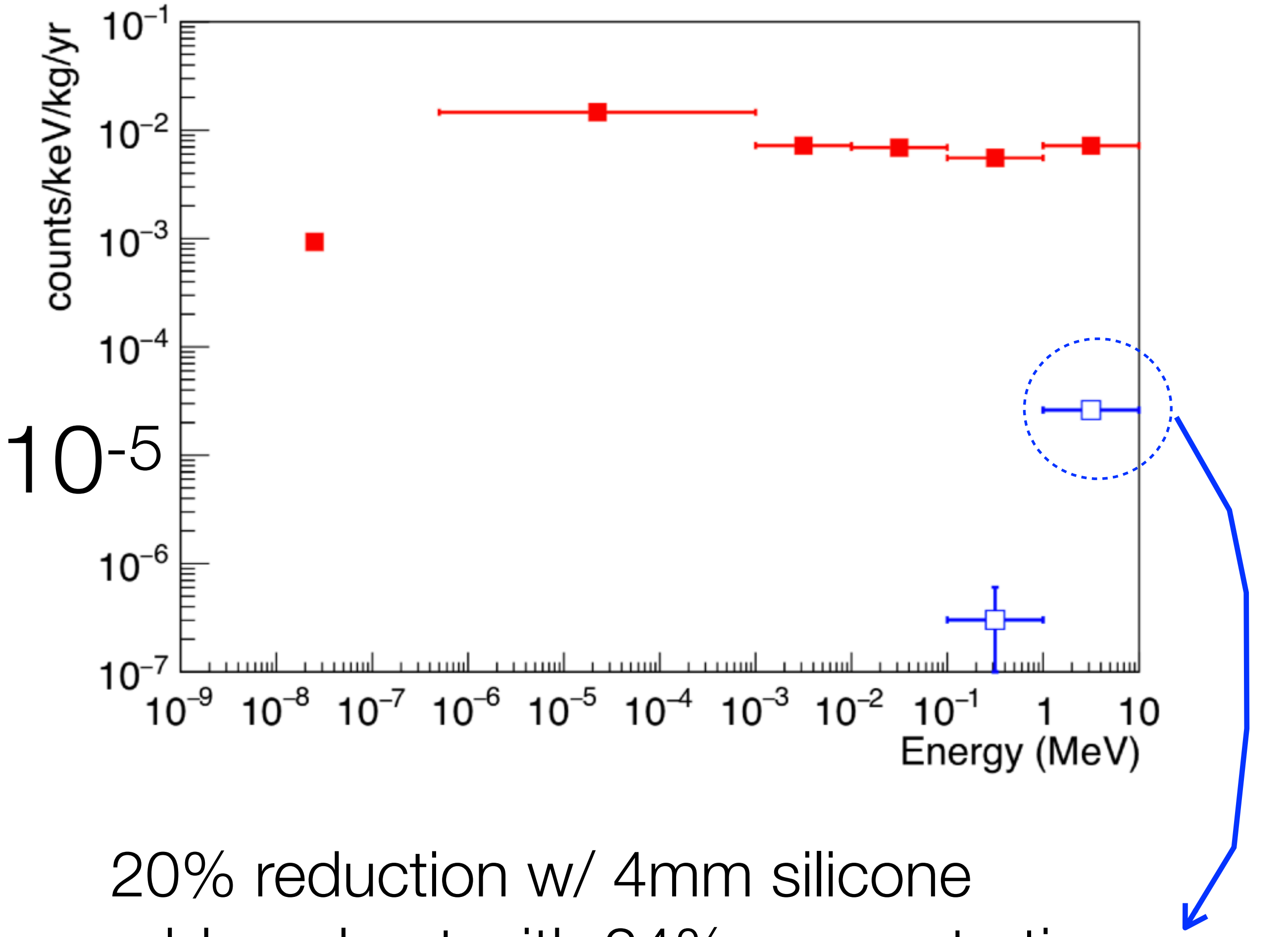




Neutrons from undergeround environment (using measurements at Y2L)



arXiv:1812.07476



20% reduction w/ 4mm silicone rubber sheet with 24% concentrations of boron carbide

Summary

- We evaluated background level for AMoRE-II based on AMoRE-I simulation
  → CMO crystal bulk has a largest contribution
  - We grow molybdate crystals at CUP
  - R&Ds on purification and ultra clean crystals are ongoing
  - Decision on crystals for AMoRE-II
- Rock-γ, neutron, and muon-induced backgrounds can be reduced to the aimed background level by the optimized shielding design and veto system
- Extreme radioassay for AMoRE-II
  - R&D on improving measurement with ICP-MS is ongoing

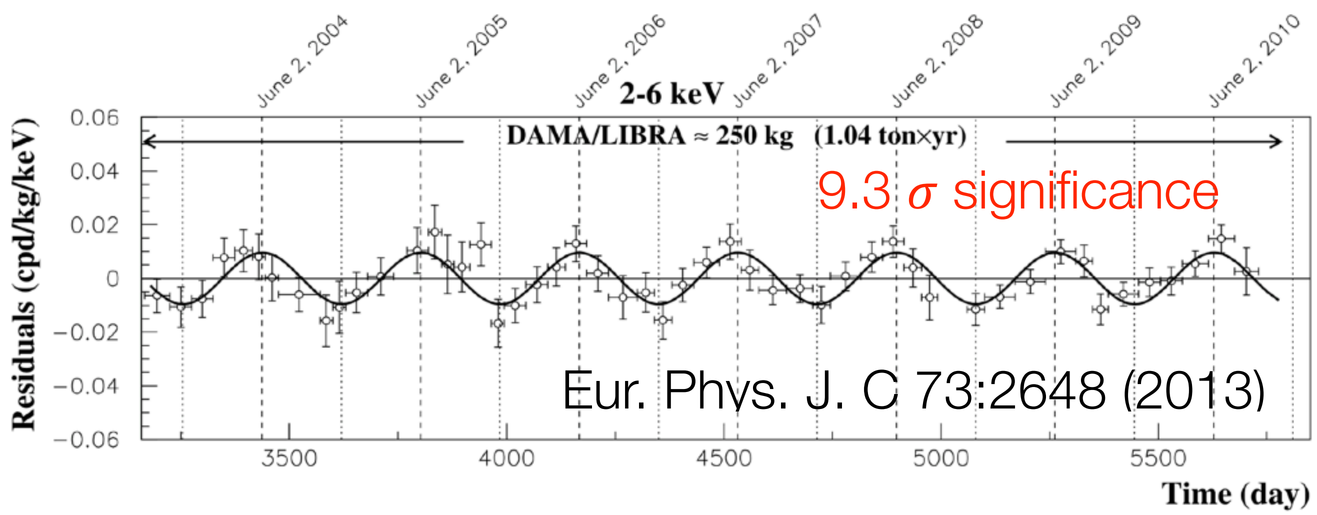
COSINE project

COSINE project (since 2015)
(~50 members from 14 institutes at 5 countries)

Joint collaboration between KIMS and DM-Ice to search for dark matter interactions in NaI(Tl) scintillating crystals.

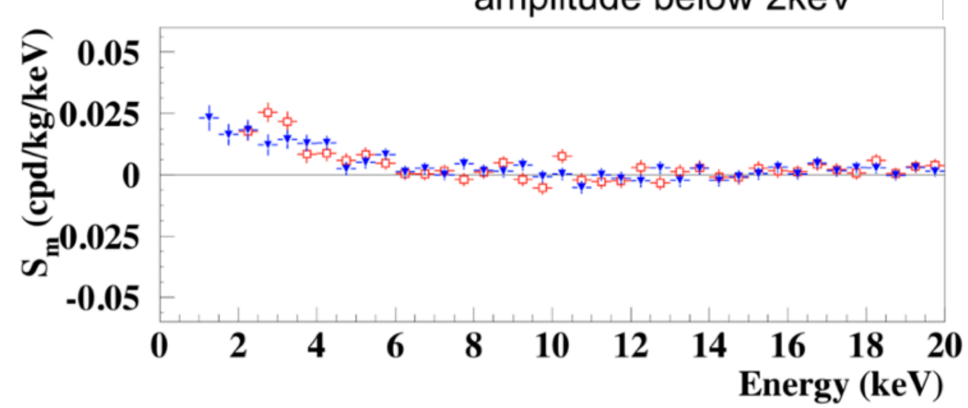
Motivation:

- DAMA/LIBRA experiment is to search for the DM annual modulation signature with an array of NaI(Tl) crystals
  → ***They claimed an observation of the dark matter***



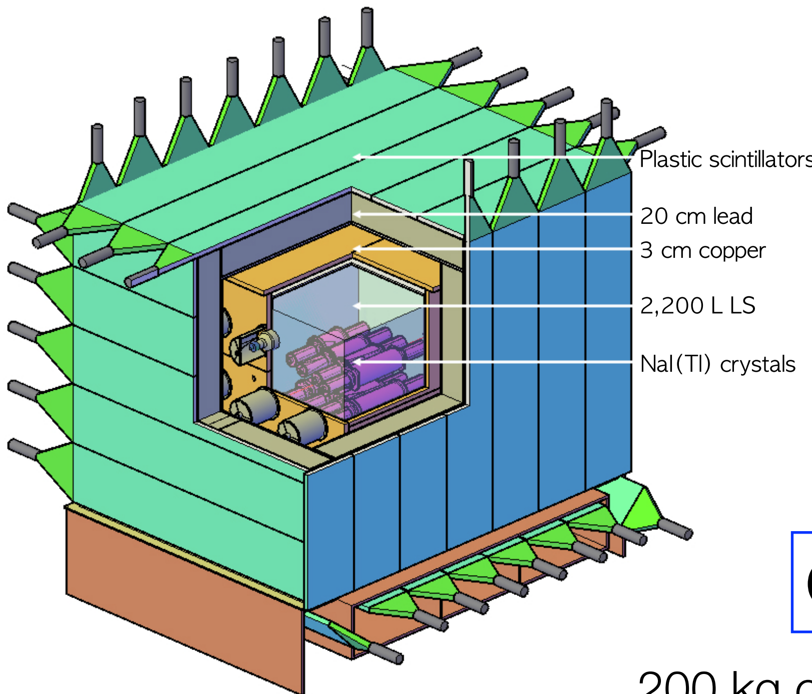
DAMA/LIBRA-phase 2

- Energy threshold reached 1keV with better PMTs
- Still there is modulation
- Significance
  - ❖ 1-6 keV : **9.5** σ (phase 2)
  - ❖ 2-6 keV : **12.9** σ (phase 1+2)
- Increased modulation amplitude below 2keV



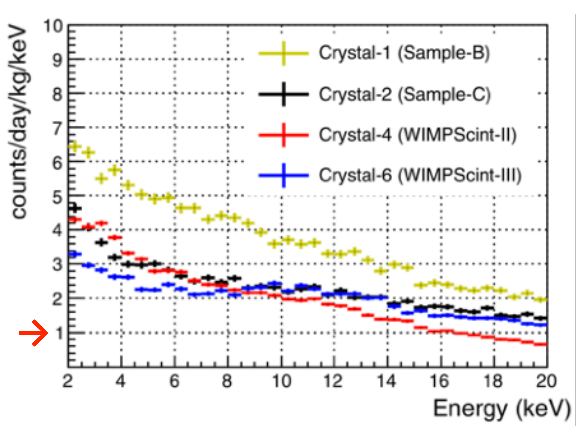
- However, other experiments with different targets or techniques exclude the region of parameters singled out by DAMA/LIBRA
- To be checked with independent measurements using the same NaI(Tl) crystals

Plan of COSINE project



COSINE-100

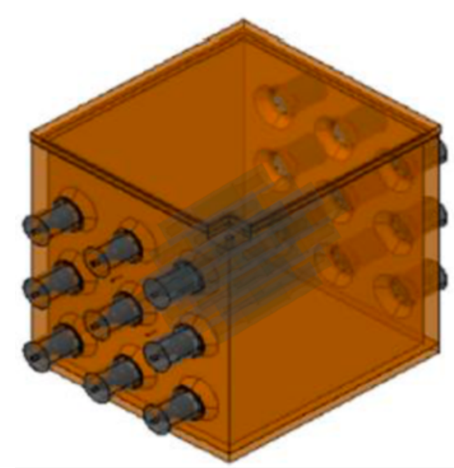
106 kg of NaI(Tl) crystals



- Background level is 2-3 times higher than DAMA/LIBRA
- Extremly pure crystal development → ***we decided to do our own development for the entire process***
- Lower energy threshold from 2 keV to 1 keV

COSINE-200

200 kg of NaI(Tl) crystals: current shield design is capable of seating 16x12.5kg



- Background level < 1 dru
- Energy threshlod < 1 keV

COSINE-1T at Yemilab

- Lower background level < 0.1 dru
- Lower energy threshold < 0.5 keV
  - Should grow clean crystals
    - Lower ^{40}K and ^{210}Pb
  - Crystal handling is very important
    - No surface contamination
  - Should minimize cosmogenic activation
    - Better to go underground as soon as possible
  - Should use clean materials for encapsulation
    - need to devlop cleaning recipe for all materials

Our facility

Powder purification performance

K.A. Shin et al., J. Rad. Nucl. Chem. 317, 1329 (2018)

	K (ppb)	Pb (ppb)	U (ppb)	Th (ppb)
Initial NaI	248	19.0	<0.01	<0.01
Purified NaI	<16	0.4	<0.01	<0.01

(Goal: K less than 20 ppb)

- We will soon make low-background NaI(Tl) crystal!

COSINE-100 results

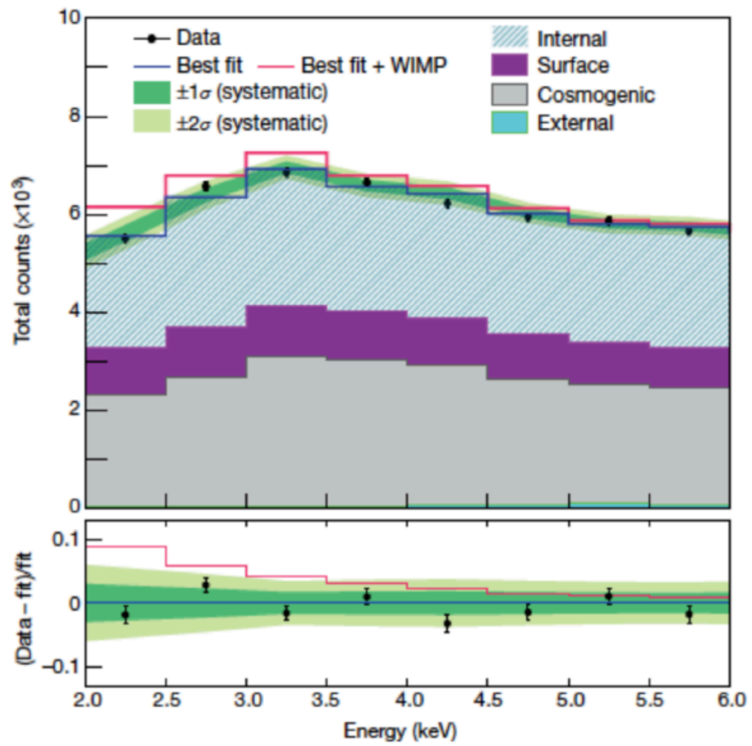
COSINE-100 excludes DAMA/LIBRA-phase1's interpretation with the spin-independent WIMP interaction in Standard Halo Model

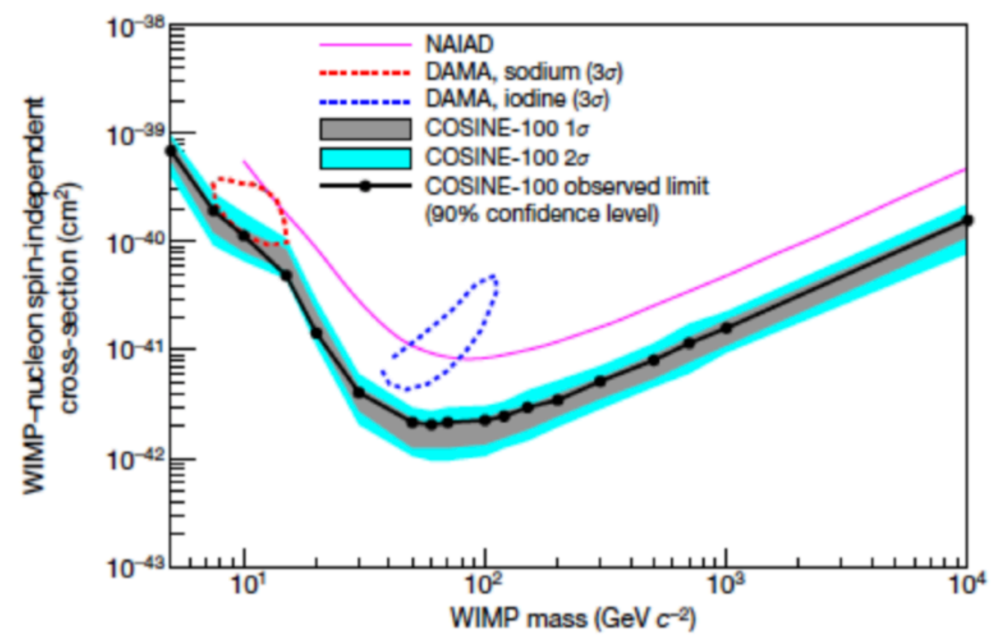
First time with same NaI(Tl) target

Consistent with other null experiments

Nature 564, 83 (2018)

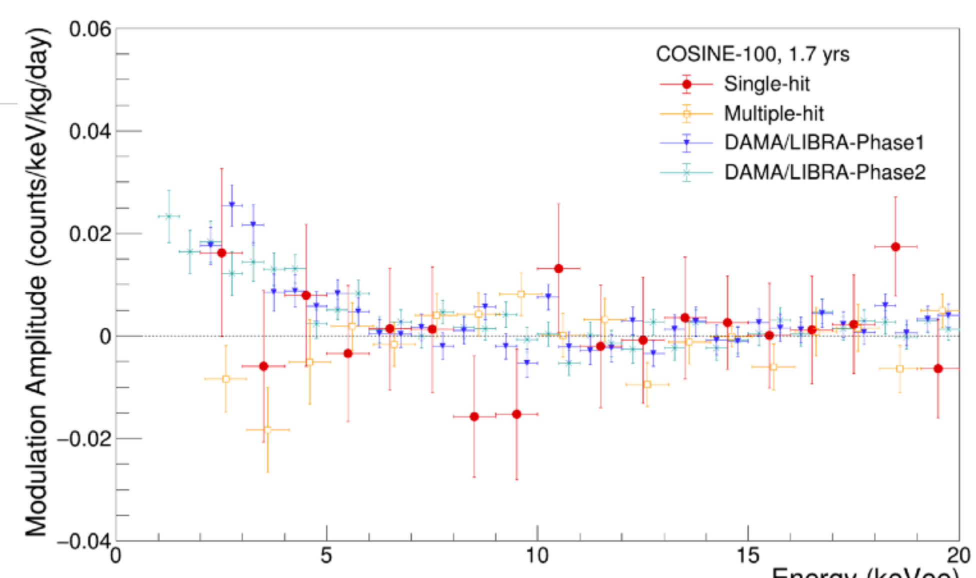
No sign of signal excess





arXiv:1903.10098

At 68.3% C.L., this result is consistent with both a null hypothesis and DAMA/LIBRA's 2–6 keV best fit value. We expect approximately 3 σ coverage of DAMA region using the same target within five years of data exposure.

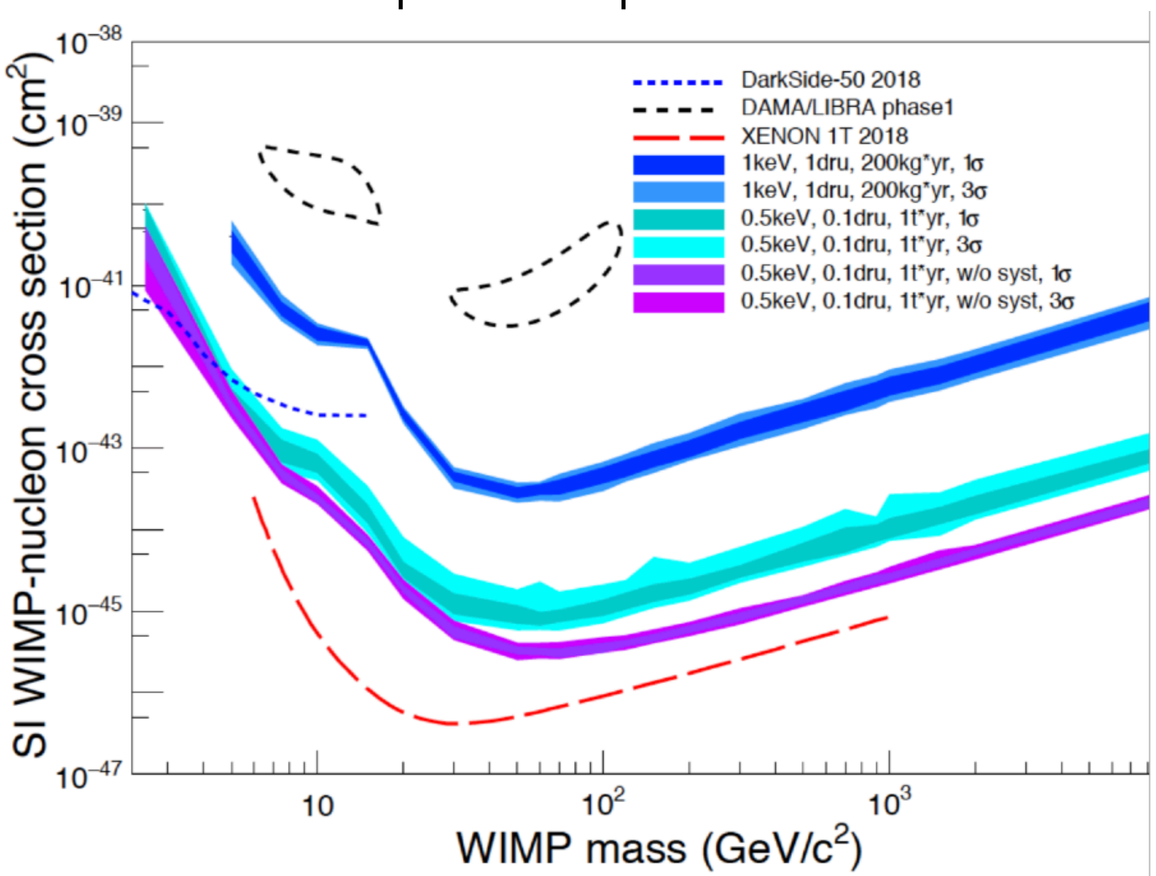


COSINE-1T sensitivity

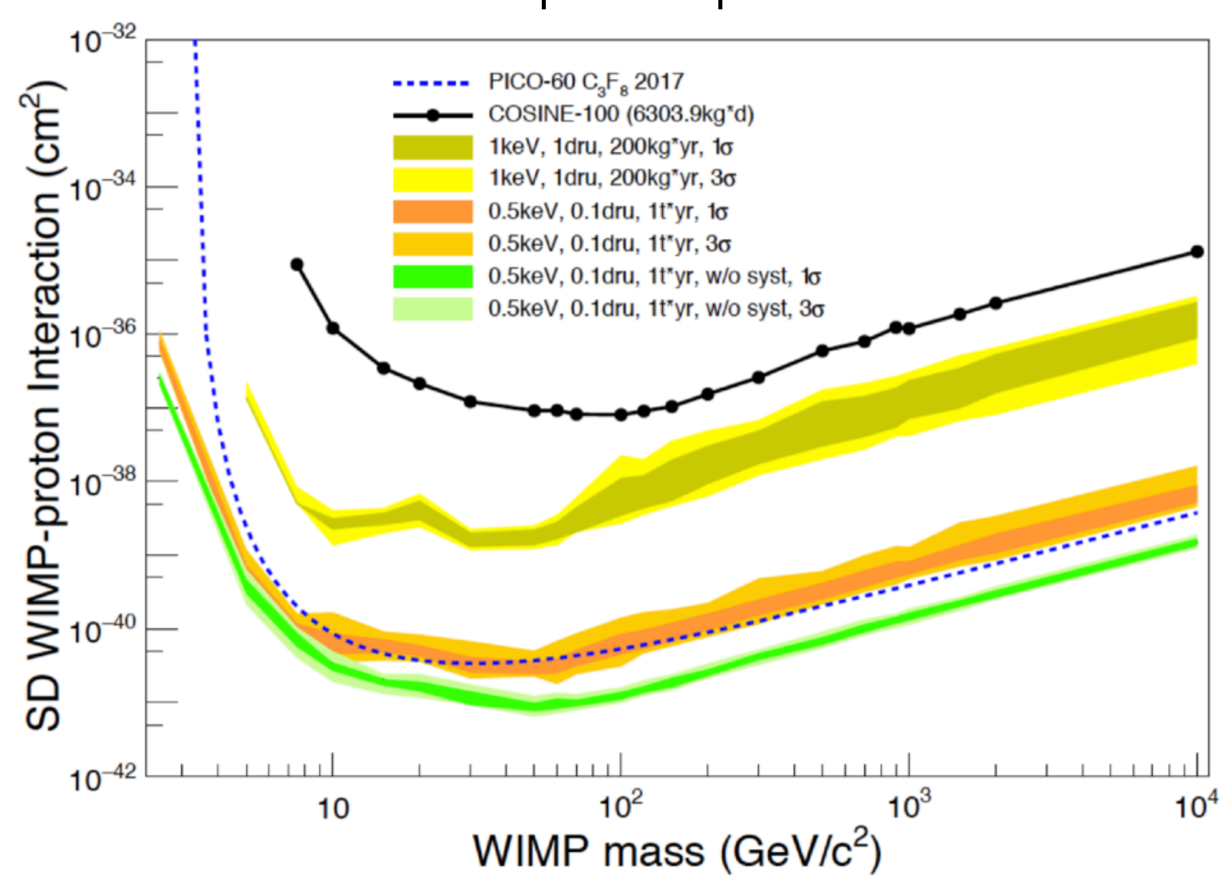
Assumption:

- 200 kg, 1 keV threshold, 1 years
- 1 T, 0.5 keV threshold, 1 years
- SI & SD
- Quenching factor measured by ourselves
- SET1 analysis (spectral shape, efficiency systematic)

- spin-independent



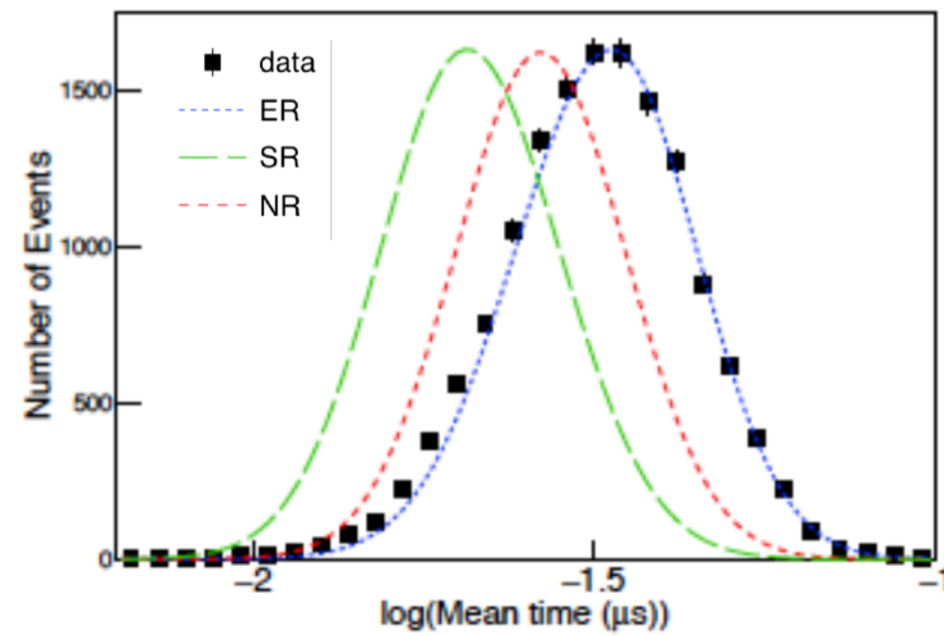
- spin-dependent



- **Low-mass SD can be the world best sensitivity!!**

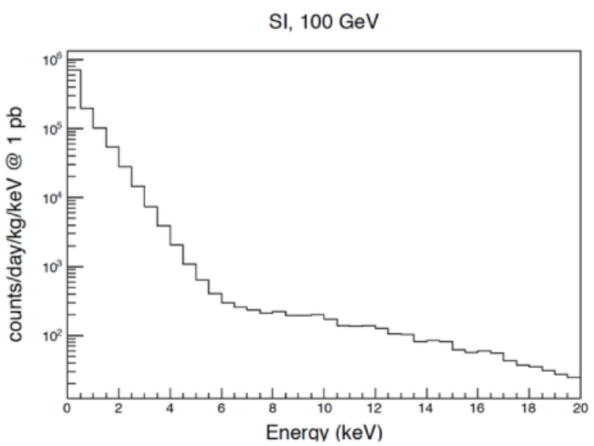
- We can do combined analysis of spectral shape and pulse shape
  - ~ a few factor improvement in low mass?
  - ~ an order improvement in high mass?

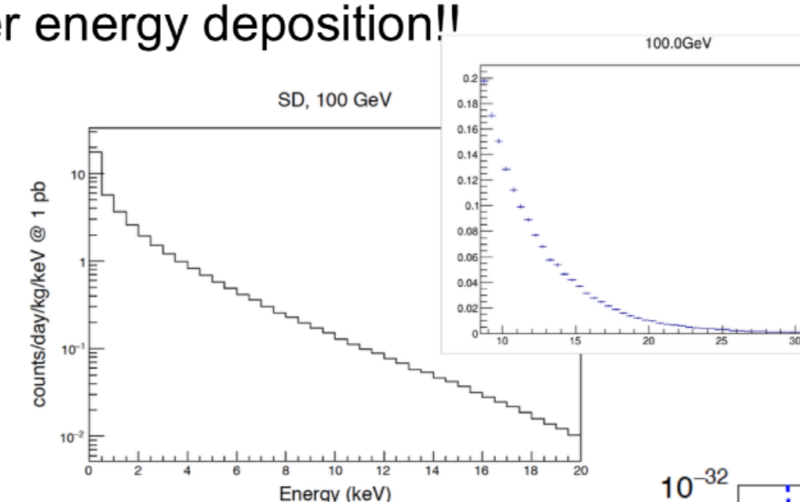
arXiv:1806.06499



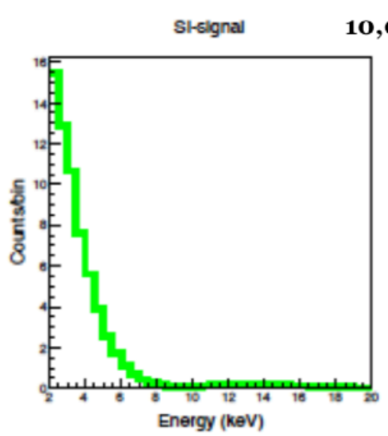
(b) 3–4 keV

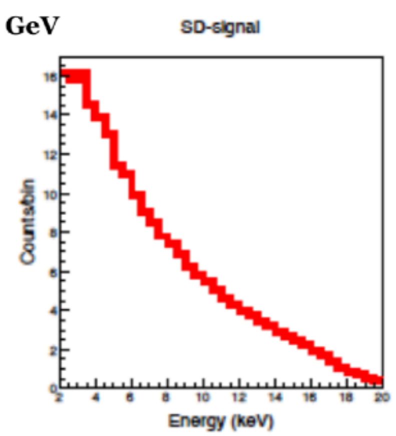
- SD case predict much higher energy deposition!!

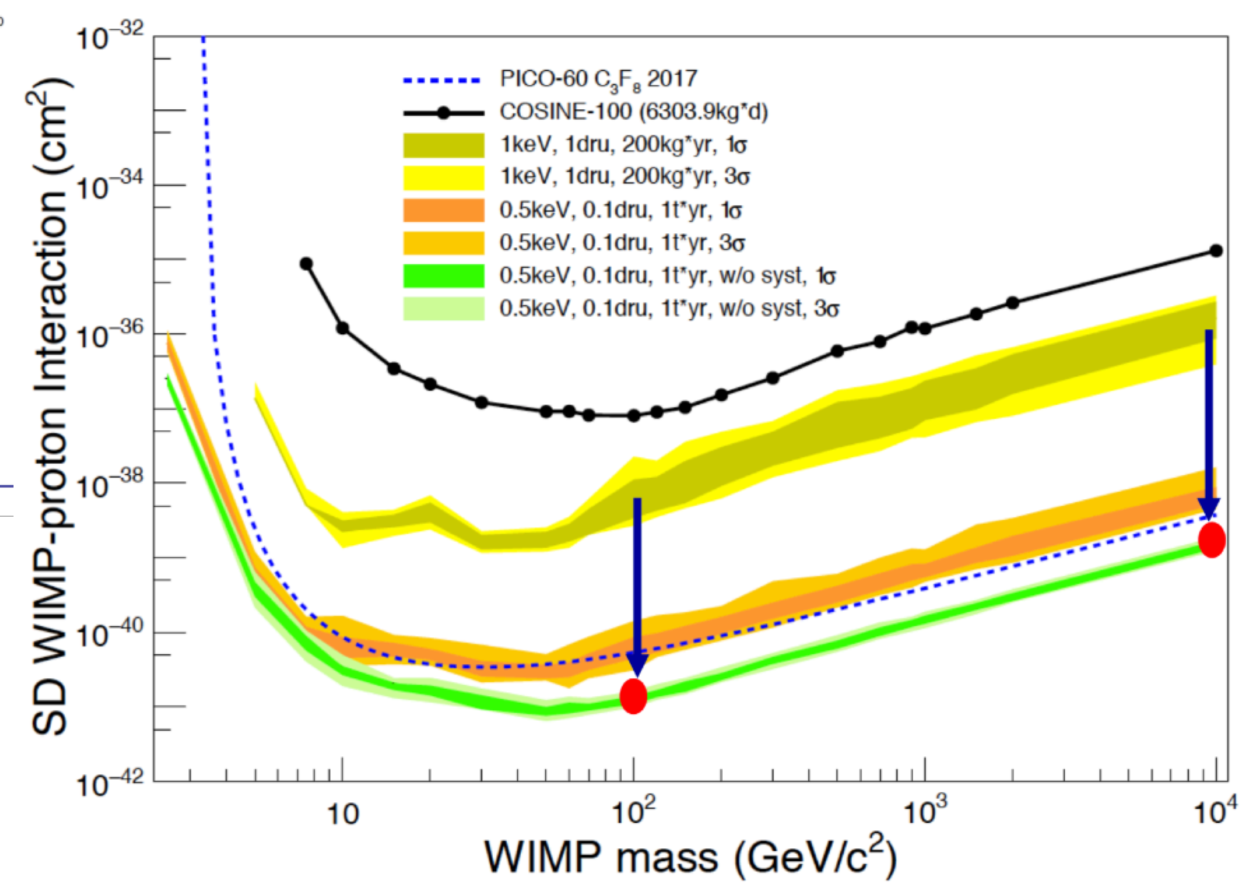




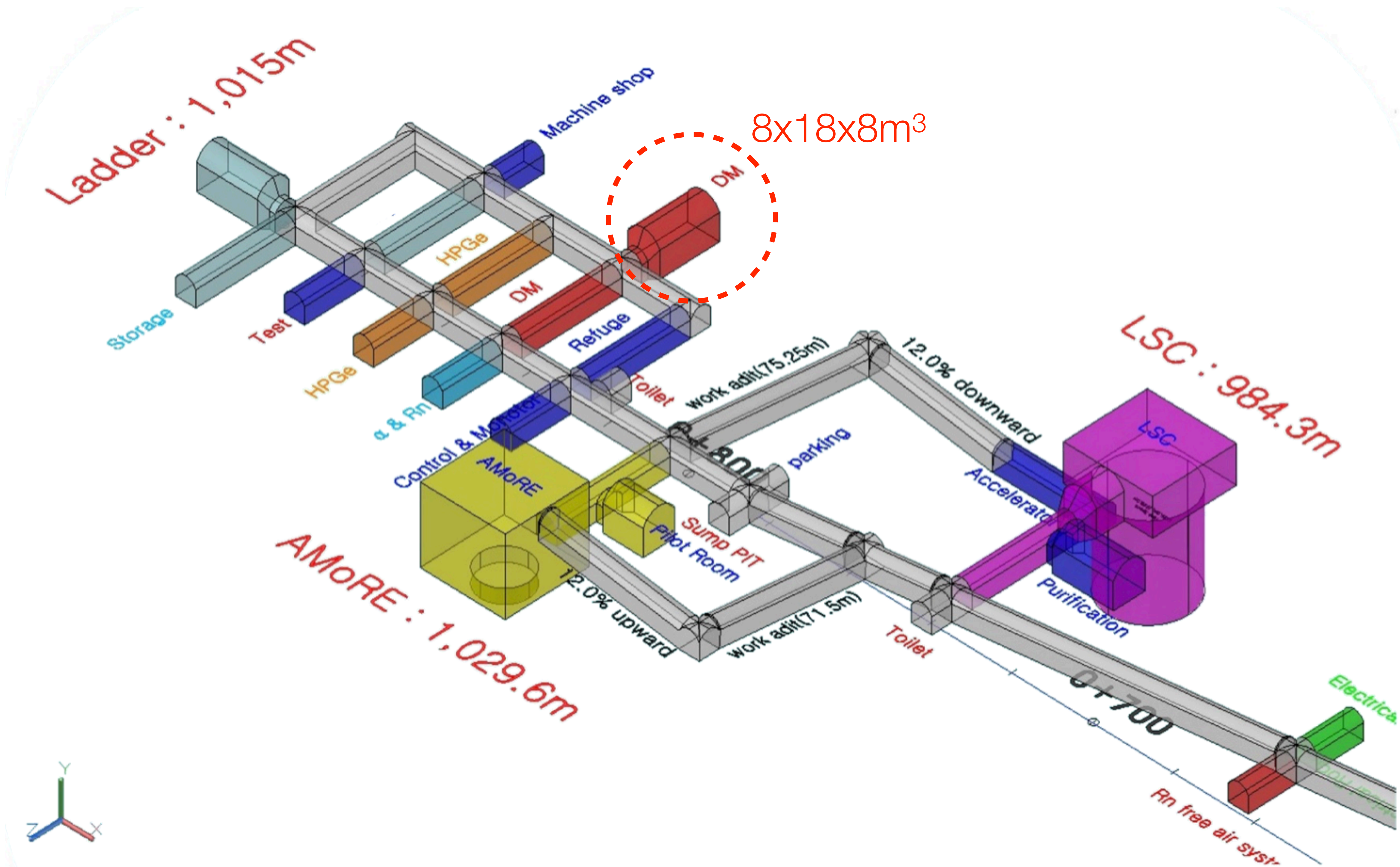
10,000 GeV







Location for COSINE-1T



Summary

- COSINE-1T can be the most sensitive detector in the world for spin-dependent WIMP interaction in both low-mass region and high-mass region
- COSINE-200 can be a demonstrator for the COSINE-1T
- A couple of R&D are ongoing and may get certain improvements
  - It can result much better sensitivity in both SI and SD interactions

Thank you.