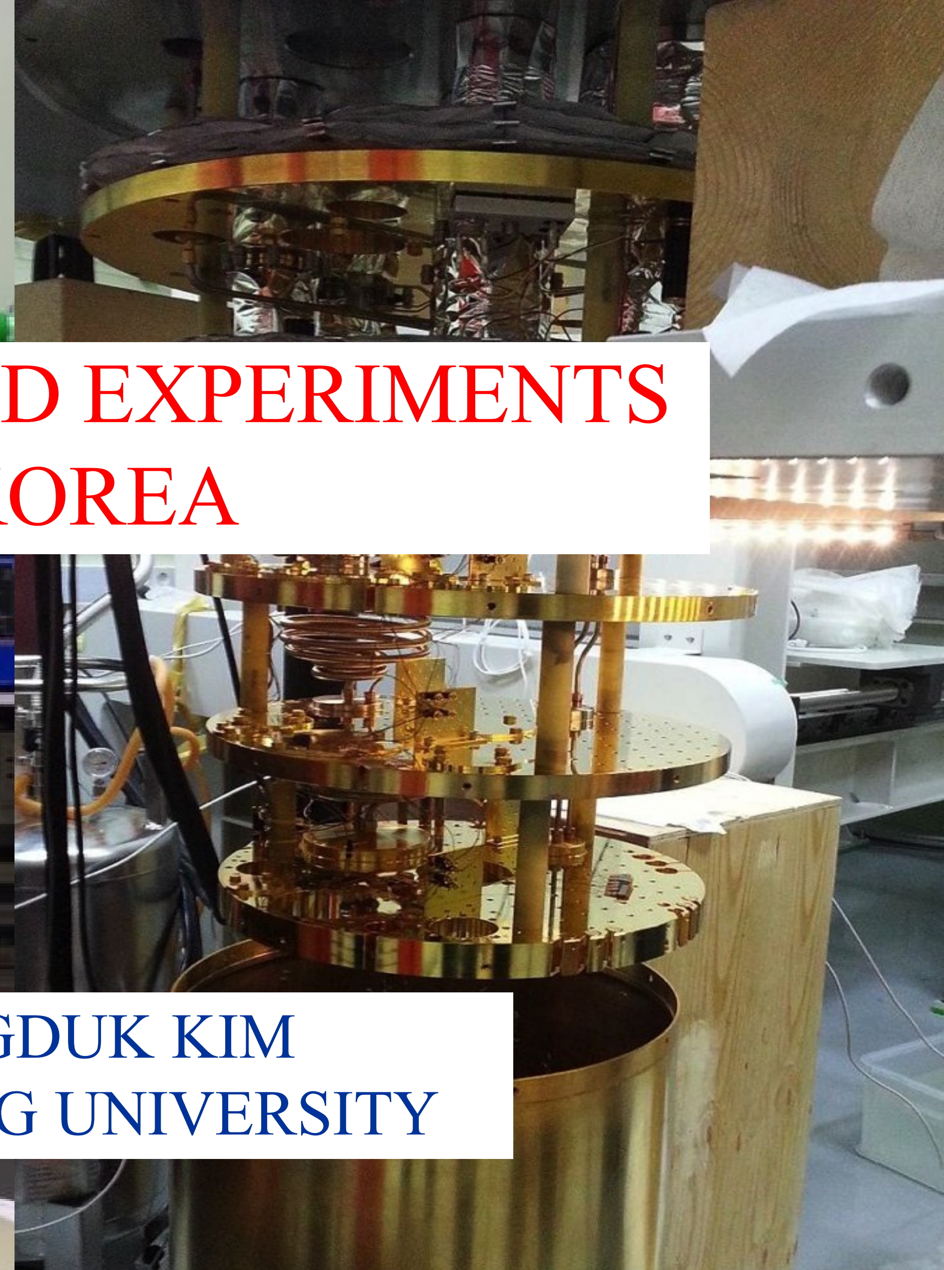


UNDERGROUND EXPERIMENTS IN KOREA

YEONGDUK KIM
IBS / SEJONG UNIVERSITY

2016. 5. 11.

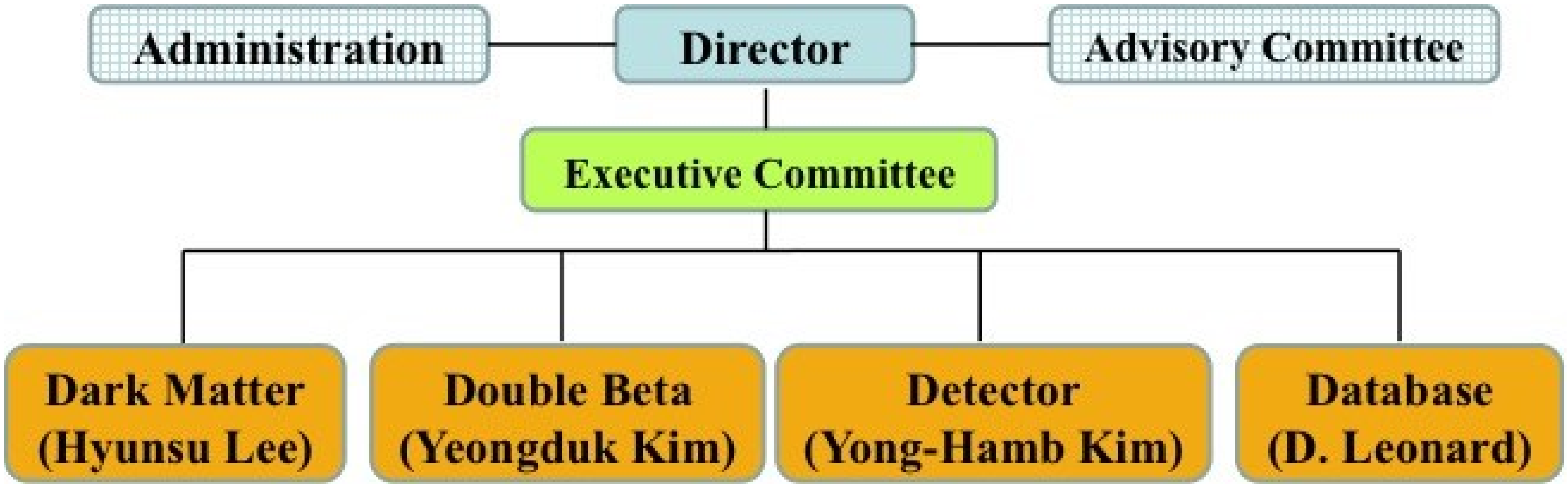
Revealing the history of the universe with underground particle and nuclear research 2016

Contents

- **Introduction to CUP & IBS**
- **Scientific Programs**
  1. **Neutrino-less Double beta decays - AMoRE**
  2. **Sterile neutrinos – NEOS**
  3. **Dark Matter – KIMS+**

CUP (Center for Underground Physics)

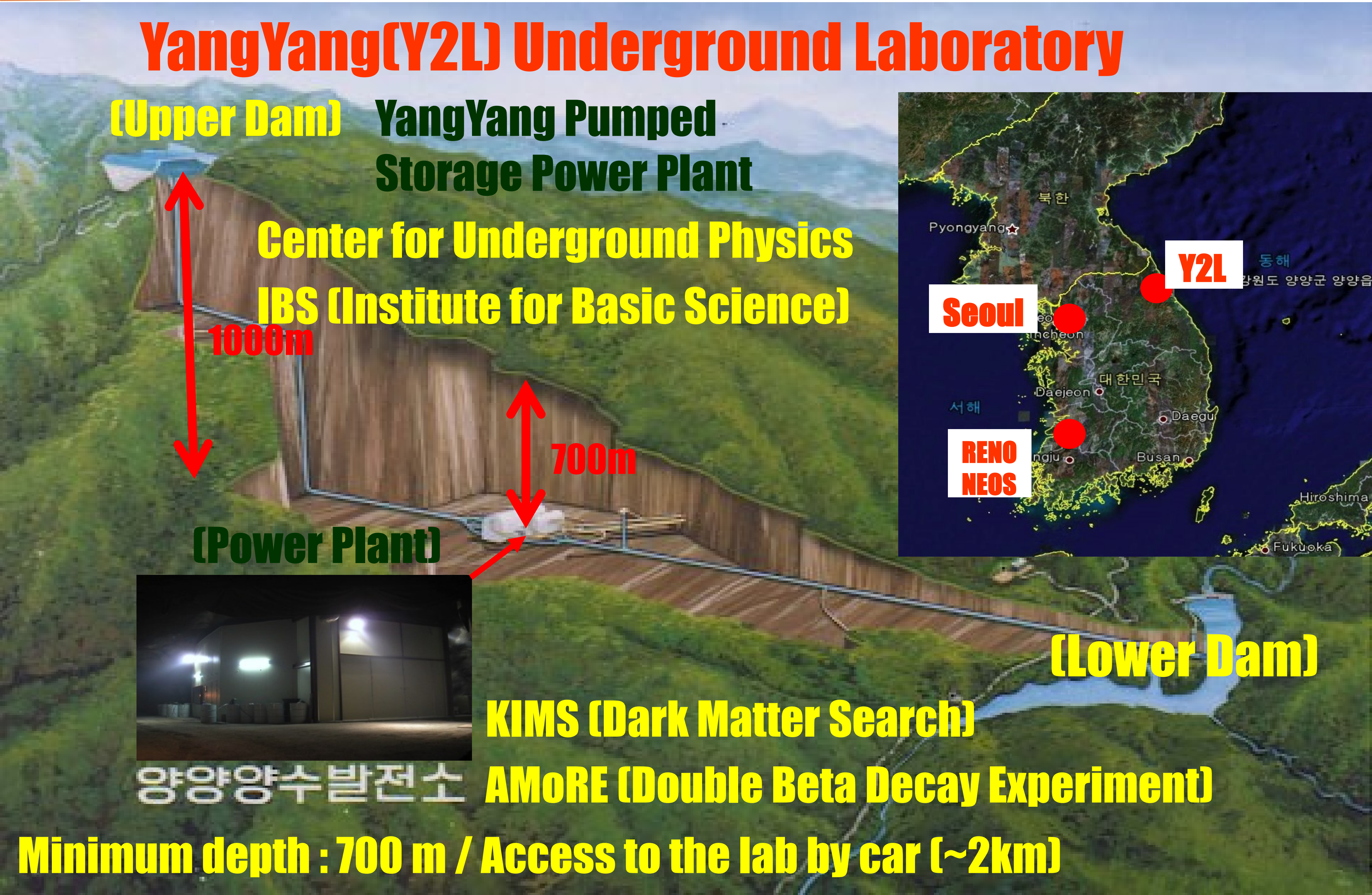
Organization of CUP



Members :

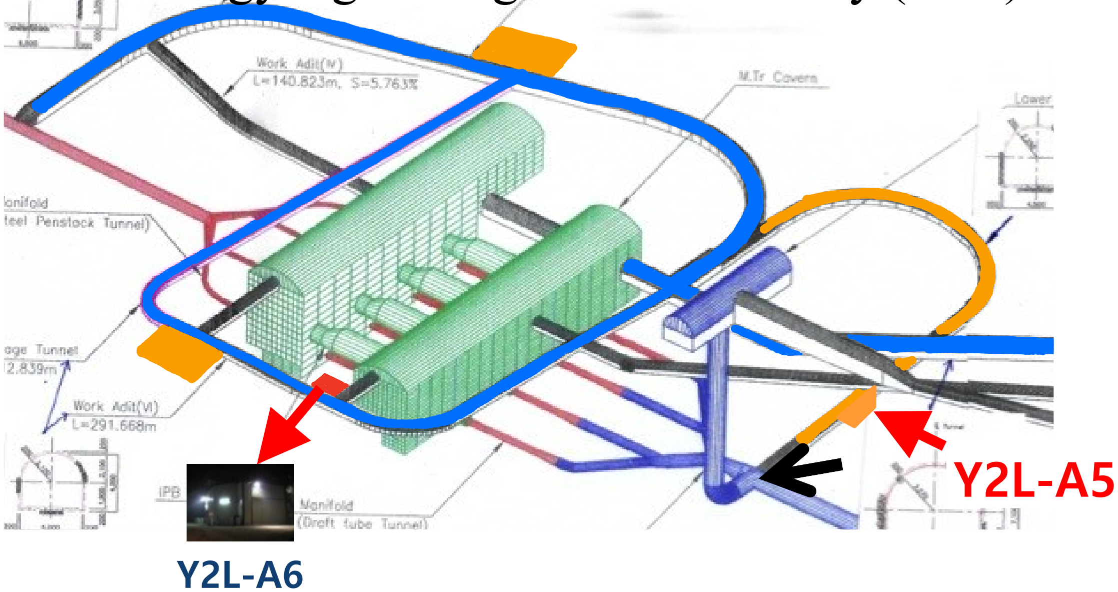
- 1 Director
- 2 Group Leaders
- ~25 Research Fellows
- 6 Technicians
- 3 Administrators
- ~25 Adjunct Students.

Laboratories



Laboratories

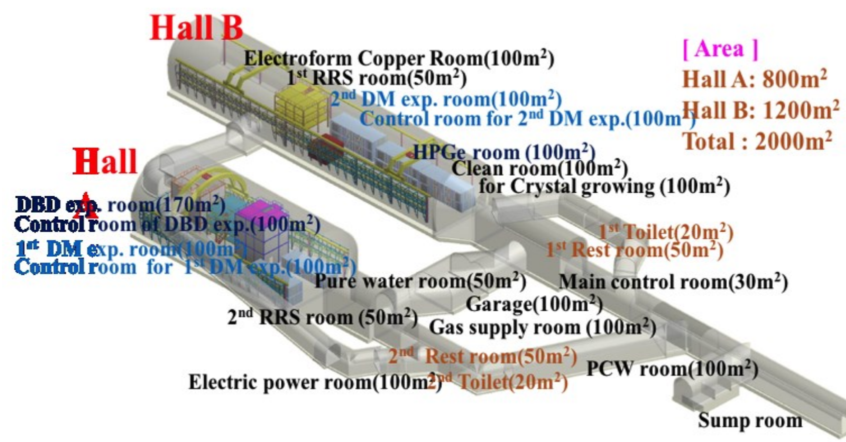
Yangyang underground laboratory (Y2L)



Current Daejeon Lab.

Headquarter (2018-)

New underground lab. (2019-)



AMoRE


8 Countries
18 Institutions
~90 Collaborators
AMoRE Collaboration Meeting

Which isotope for $0\nu\beta\beta$ experiment ?

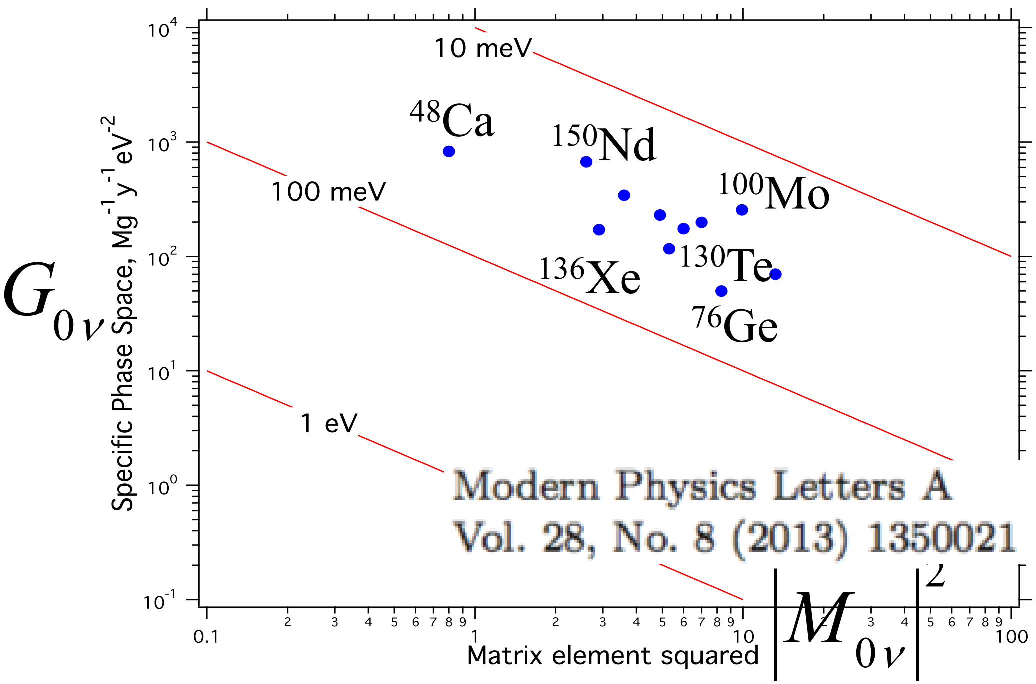
- Half-lifves depends on phase factor and matrix element.

$$\left[T_{1/2}^{0\nu}\right]^{-1} = G_{0\nu}\left|M_{0\nu}\right|^2\left(\frac{m_{\beta\beta}}{m_e}\right)^2$$

Half-life Measured **Phase factor** **Nuclear Matrix Element** **Neutrino Mass**

$$m_{\beta\beta} = U_{e1}^2 m_1 + U_{e2}^2 m_2 + U_{e3}^2 m_3$$

$$T_{1/2}^{0\nu} \rightarrow m_{\beta\beta}$$

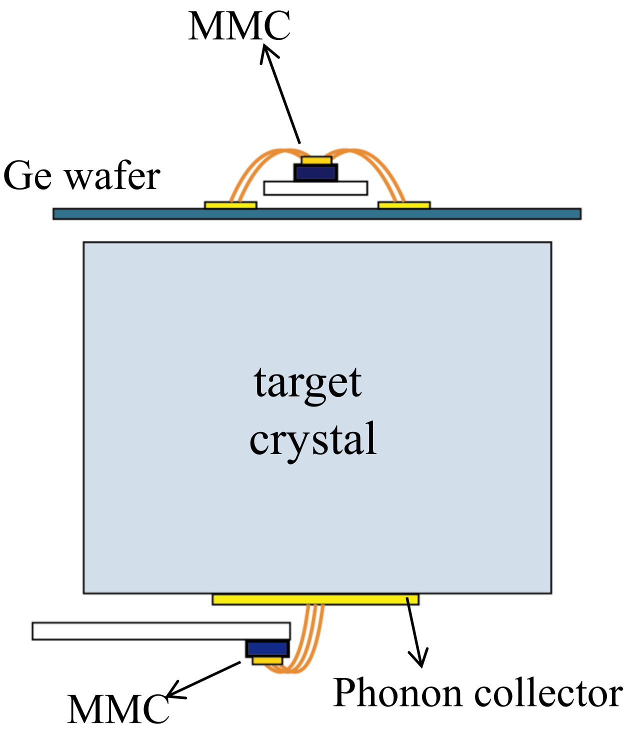


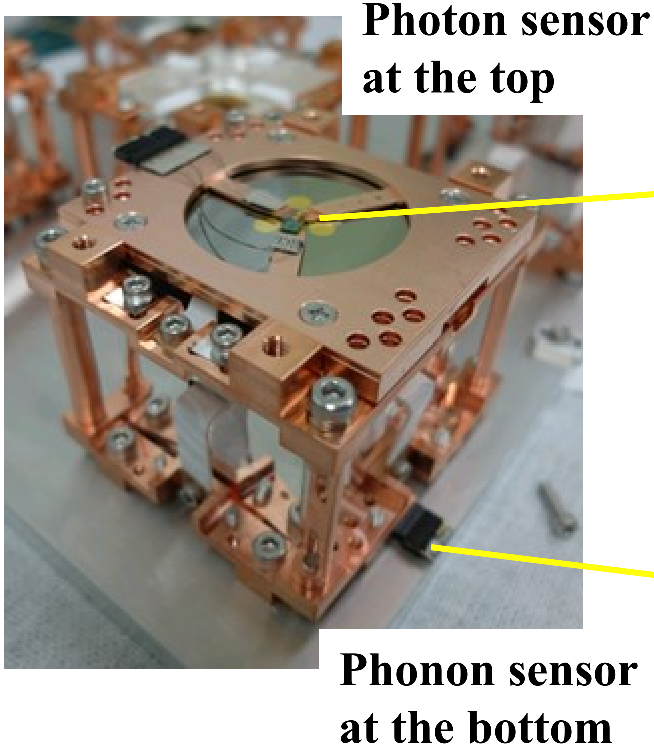
G and M has anti-correlation.
→ Generally no single isotope is preferred.

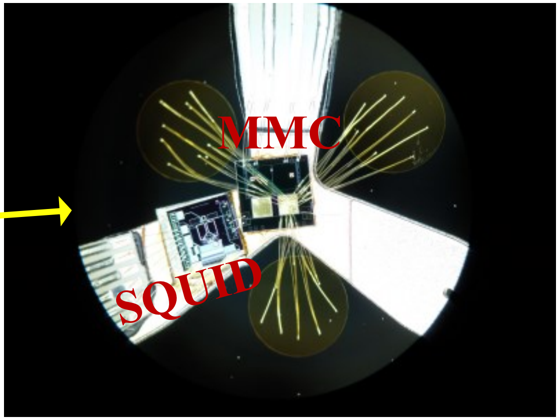
^{100}Mo is attractive, Q=3.04 MeV, Abundance ~ 10%

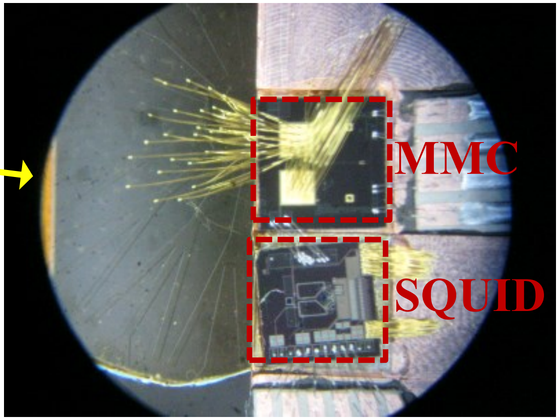
Detector schematics of AMoRE

Scintillating Bolometer : $(^{40}Ca,X)^{100}MoO_4$ + MMC





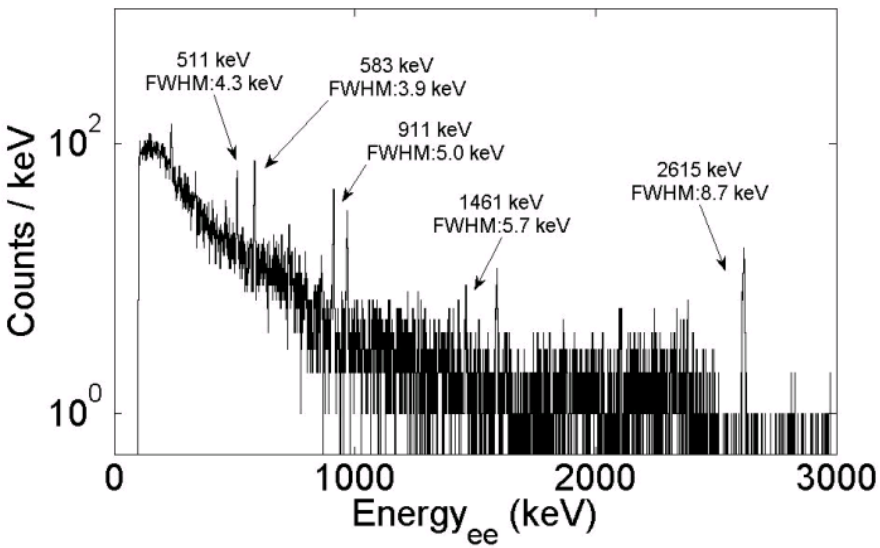


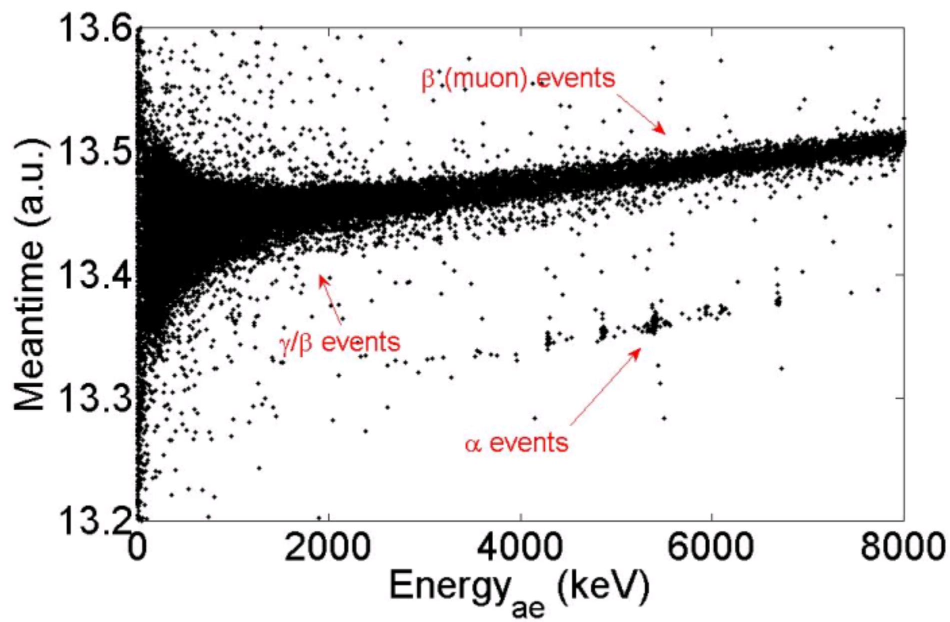


Each crystal requires
phonon collector films, MMCs, SQUIDs on heat & light channels.

Energy spectrum (above-ground)

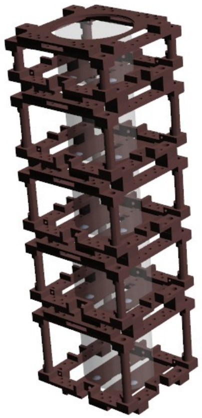
Electron and alpha events can be efficiently identified.





- **Better than 9 keV energy resolution was obtained at 10 mK temperature.**
- **Internal alpha background levels of each isotopes were calculated successfully.**

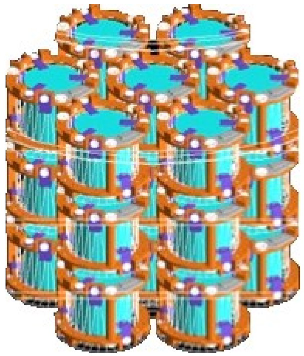
Phases of AMoRE Project



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

~ 1.5 kg

AMoRE Pilot



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

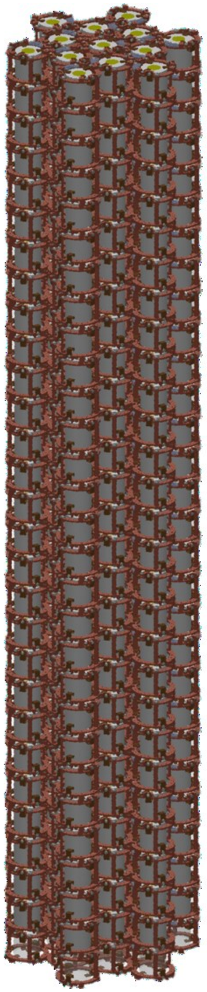
~ 5 kg

AMoRE-I

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

200 kg

AMoRE-II



ckky : counts/ (keV kg year)

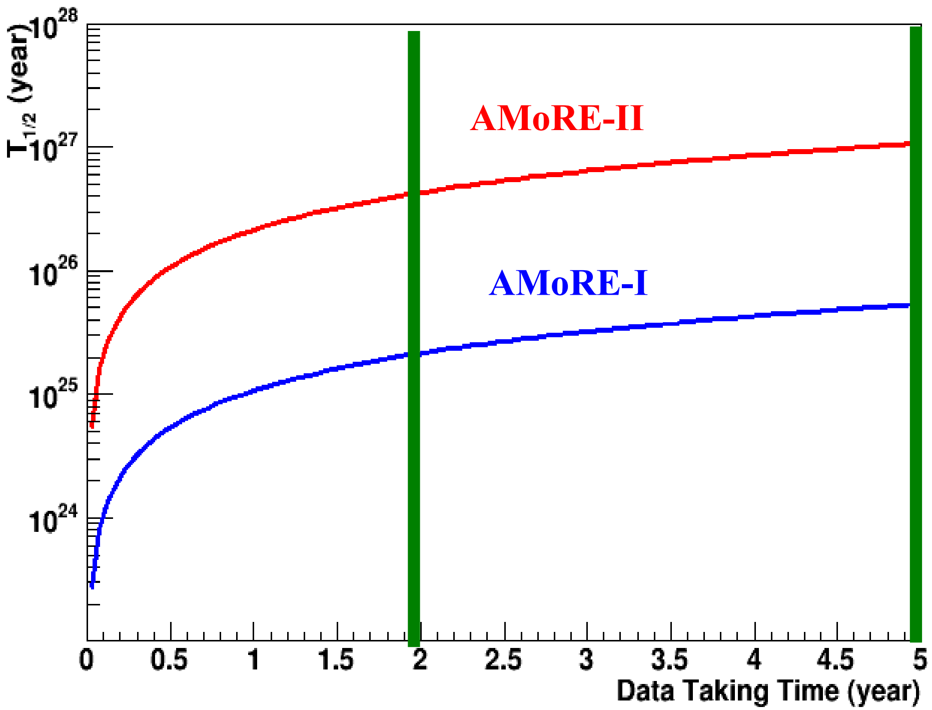
	AMoRE-Pilot	AMoRE-I	AMoRE-II
Crystal Mass (kg)	1.5	5	200
Backgrounds(ckky)	10^{-2}	10^{-3}	10^{-4}
$T_{1/2}$(year)	1.0×10^{24}	8.2×10^{24}	8.2×10^{26}
m_{bb} (meV)	380-719	130-250	13-25
Schedule	2015	2017-2018	2020-2023

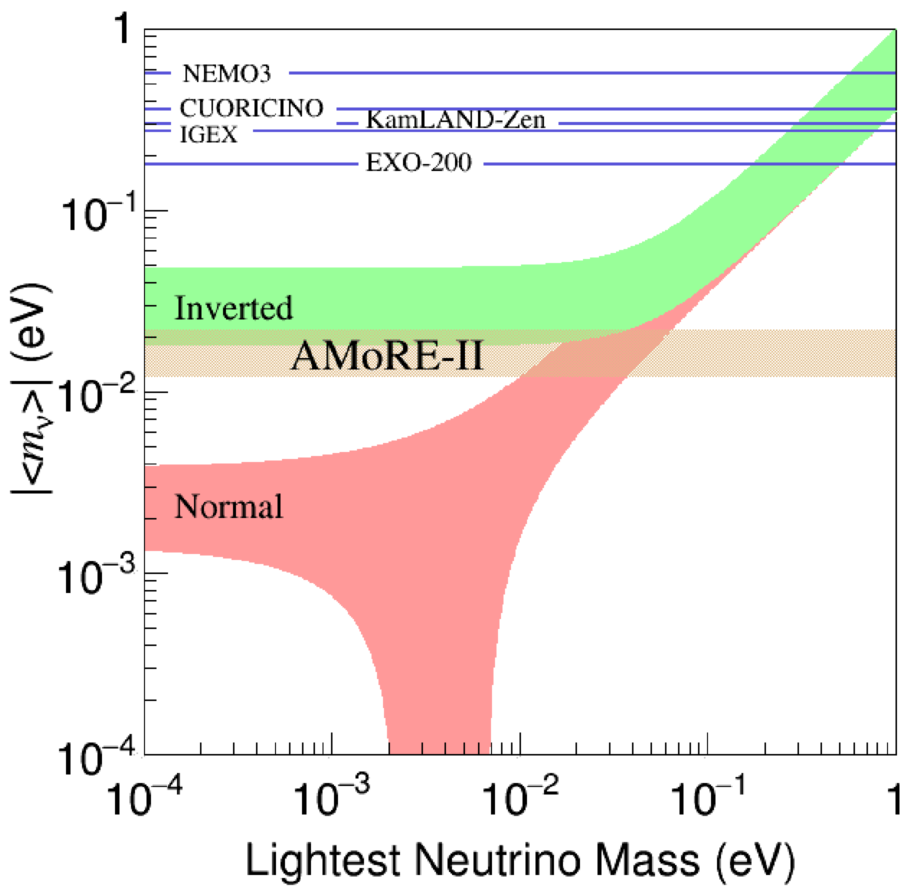
AMoRE Goal & Sensitivities

Aim at "Zero Background" experiment in the region of $0\nu\beta\beta$ signal. < 1 event

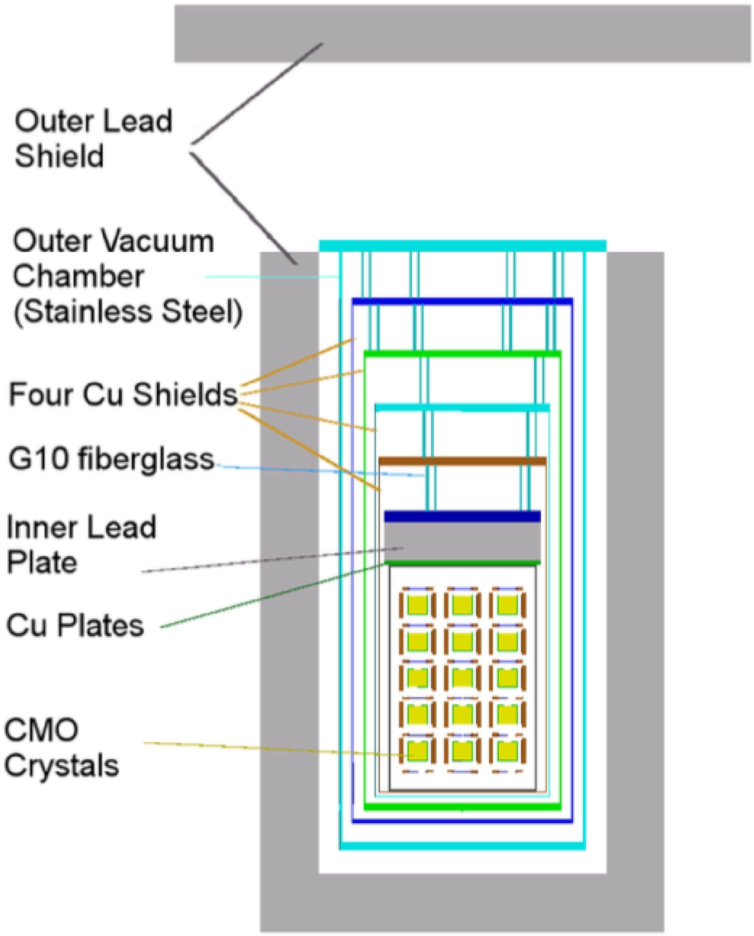
Good energy resolution & Ultra low background are MUST.

AMoRE will cover inverted mass hierarchy region.

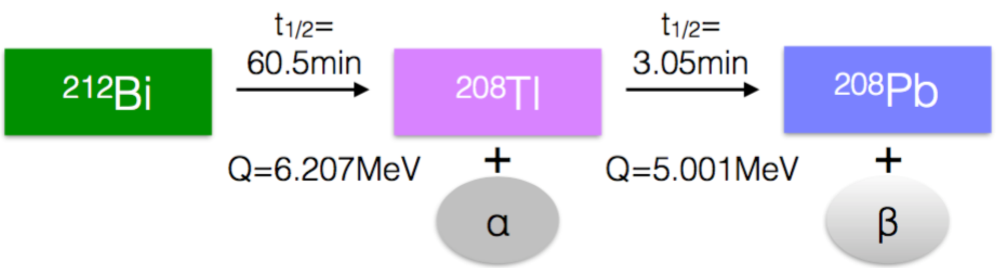




Simulation for AMoRE-I setup



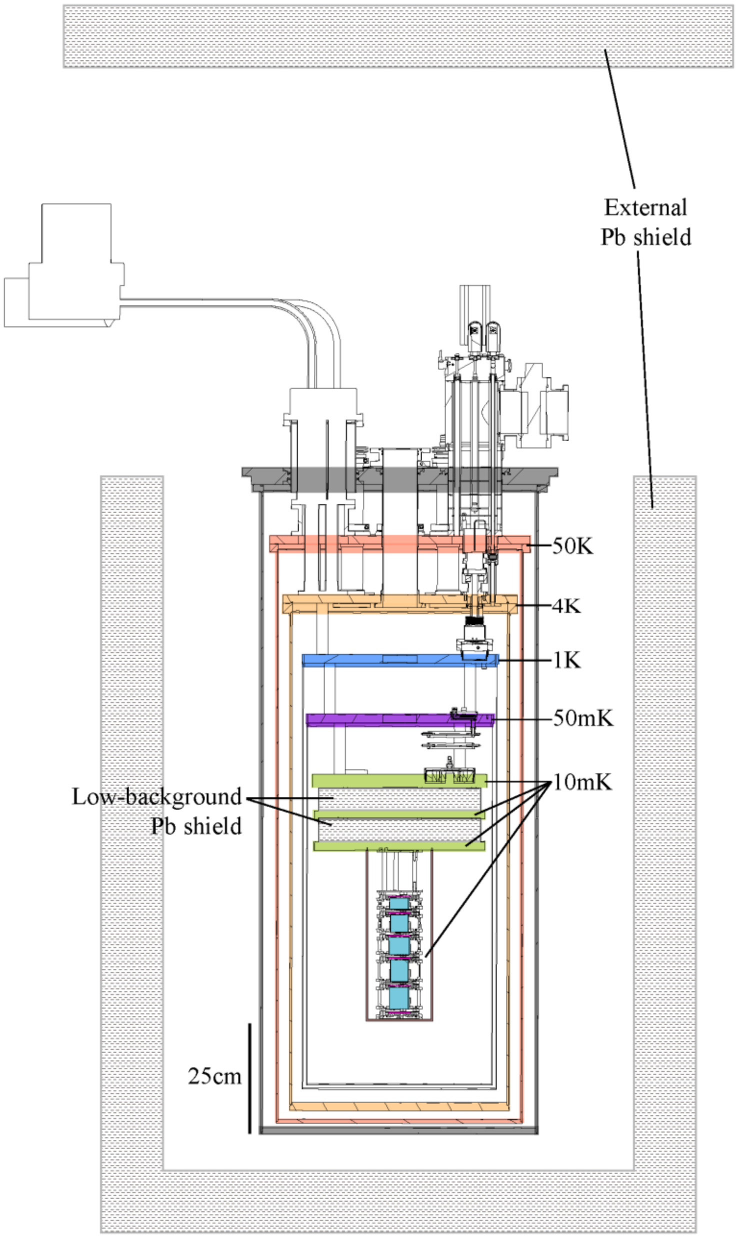
- ^{228}Th backgrounds



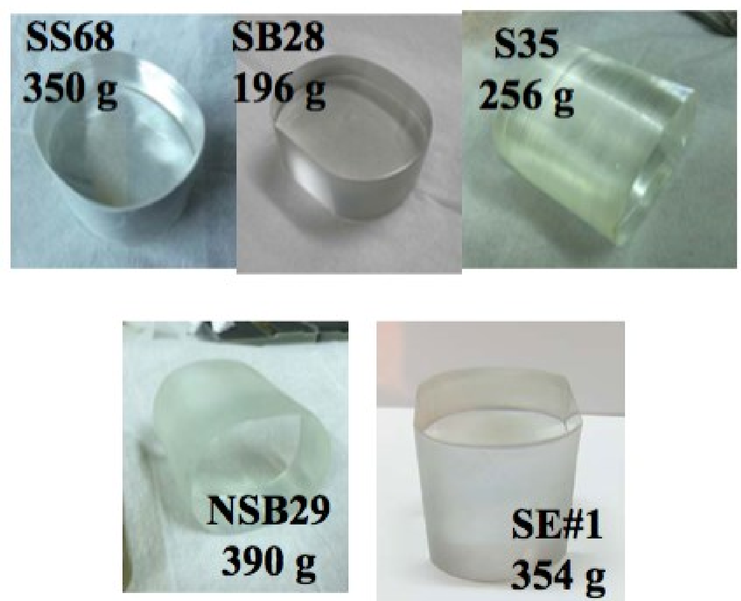
- Major Background Sources

Material	Source	Activity (mBq/kg)	Background (10^{-3}ckky)
CMO	^{226}Ra	65	0.015
	^{228}Th	50	0.72
Vikuiti	^{214}Bi	<0.91	<0.119
	^{208}Tl	<0.48	<0.177
Copper	^{228}Th	<0.25	<0.25
Accidentals	^{100}Mo		0.12
Total			<1.6

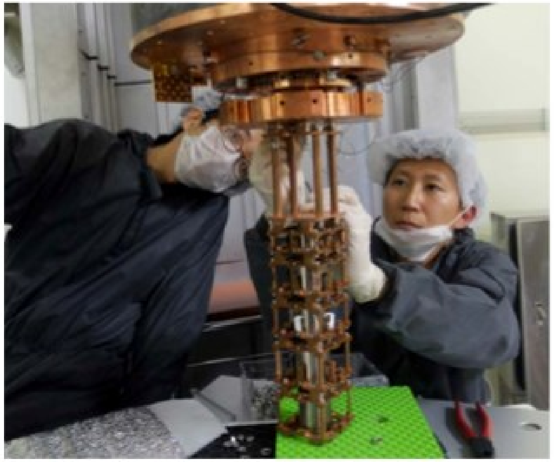
AMoRE-Pilot Setup (2015 ~)



- 5 $^{40}Ca^{100}MoO_4$ crystals
- total mass = 1546g
- Made by a Russian company (FOMOS) by double crystallization.

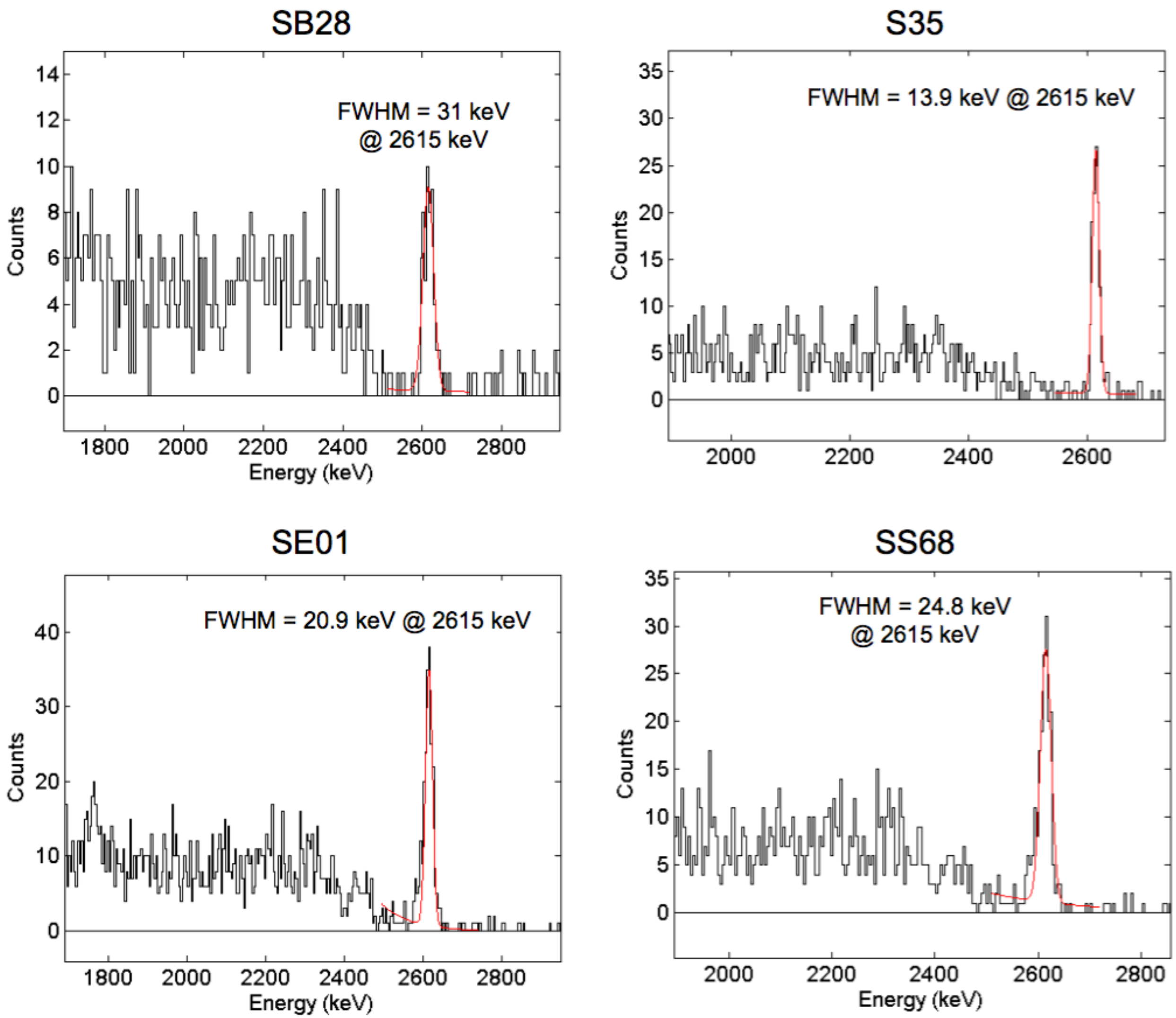


Mounting detectors



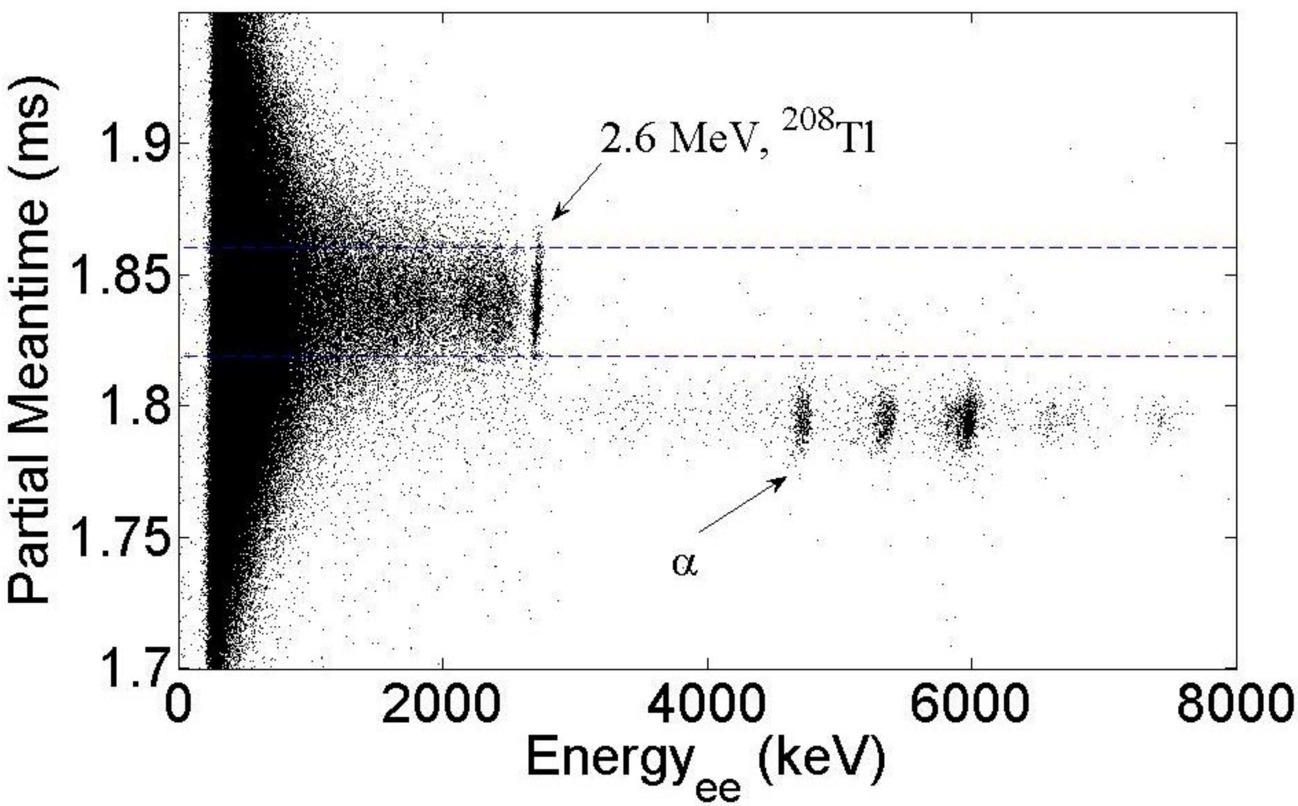
Energy resolution with outside source

- Pulsed Tube Cooler generates vibrational noise.
- Energy resolution 14 – 32 keV FWHM @ 2.6 MeV.

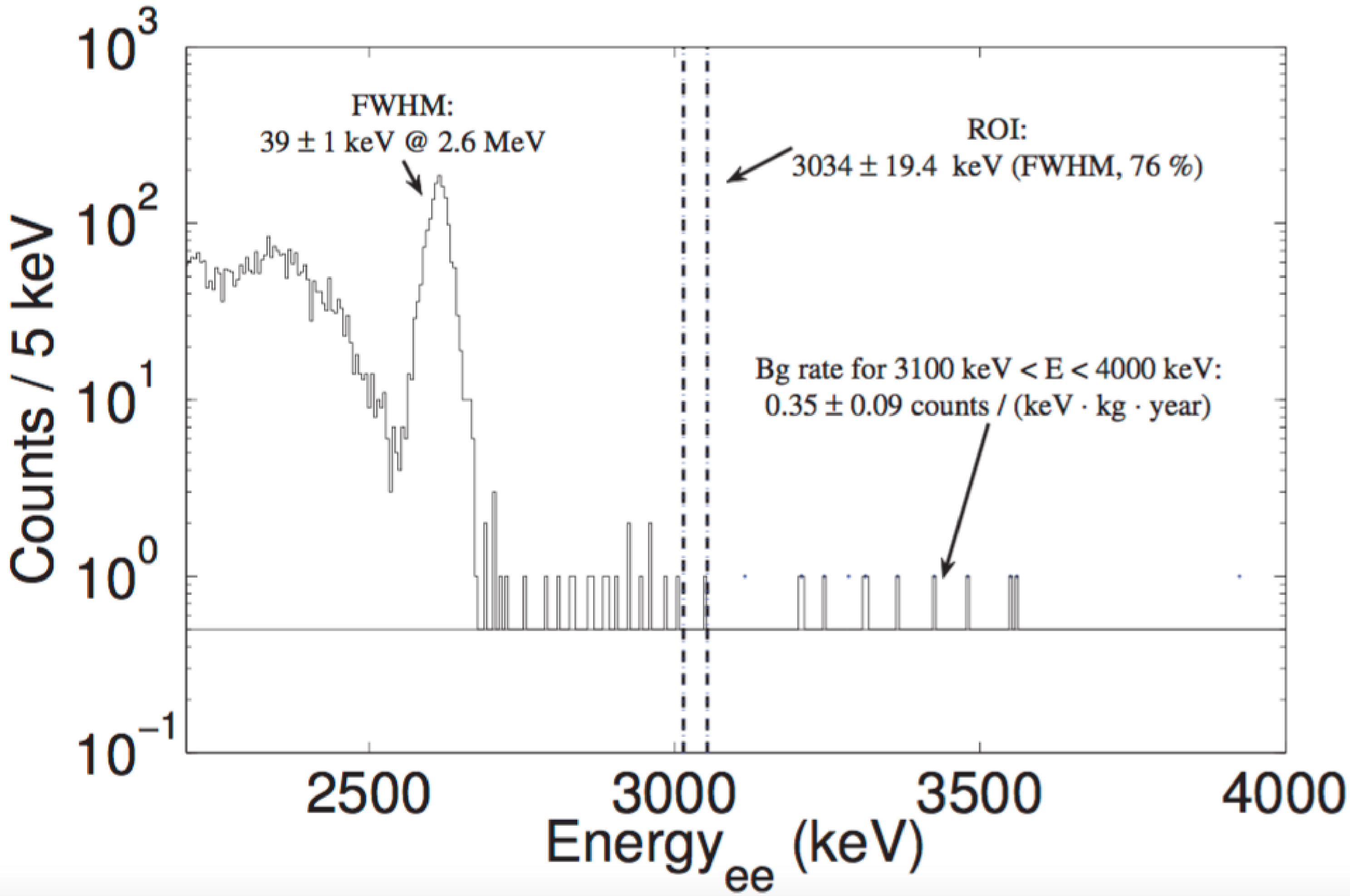


Running at Y2L now….

- The dilution fridge reaches 8 mK with 250kg lead attached.
- We are trying to reduce the vibrational noise.
  - High frequency noise : reasonably low.
  - Low frequency noise : should be improved. We are working on this !



Backgrounds Spectrum



- **Higher backgrounds due to poor PID from vibrational noise.**

AMoRE-I

- FOMOS will supply 3.5 kg of enriched crystals more in 2016
  → AMoRE-I
- Requirements :
  1. ^{228}Th < 50 micro Bq/kg
  2. ^{226}Ra < 100 micro Bq/kg
  3. Total Alphas < 1mBq/kg
- This will ensure to meet the goal of AMoRE-I
- All crystals will be delivered until Aug. 2016.

Crystals for AMoRE-II

- **For AMoRE-II, crystals will be selected.**
- **Crystal growth R&D is done at CUP & KNU in Korea.**

Crystal	Light Yield	density	Mo Fraction	Exp
$CaMoO4$	100	4.34	0.49	AMoRE-1, 2(?)
$ZnMoO4$	~15	4.37	0.436	LUMINEU
Li_2MoO4	~4	3.03	0.562	AMoRE-II(?)
$PbMoO4$	?	6.95	0.269	AMoRE-II(?)
$Na_2Mo_2O_7$	?	3.62	0.558	AMoRE-II(?)

Purification for $XMoO_4$ crystals.

- $^{100}MoO3$ powder by Russia :
  ^{232}Th, $^{238}U < 1$ ppb
- $^{100}MoO3$ powder will be delivered until 2019.
- We will purify $^{100}MoO_3$ powder by sublimation + co-precipitation, or recrystallization method.
- Develop the purification techniques with 99.95% $^{nat}MoO_3$ powder (0.2 ppb of ^{232}Th and 3.5 ppb of ^{238}U)
- Purified powder will be measured by ICP-MS (10 ppt sensitivity for ^{232}Th and ^{238}U now).
- Ra reduction will be confirmed by Ba measurement.
- $XMoO_4$ crystal growing techniques are being developed.

Example : Purification of $CaCO_3$ powders

Main goal: Reduction of ^{226}Ra (one of main background in AMoRE)

Starting process: $CaCO_3 + HNO_3 \rightarrow Ca(NO_3)_2 + CO_2 + H_2O$

ppb unit

Solution	Fe	Sr	Ba	Th	U
Initial Sol.	16,120	8,129	67	0.73	20.4
Purified Sol.	359	132	0.023	<0.001	0.039
D_f	44.9	61.6	2,913	> 730	523

Note: $D_f = C_i/C_f$, C_i & C_f are contamination of initial and final solutions

- **Use the column chromatography method.**
- **Sr and Ba are the same family of Ra in periodic table.**
  → Indicate large reduction of ^{226}Ra.
- **Significant reduction of Th and U.**

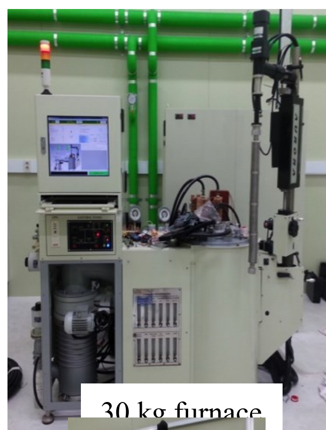
Crystal Growing Technique

- The center is based on crystal detector and forming a facility for crystal growing.
- Goal : develop the technology for ultra-low background crystals for experiments.
- With a new underground lab, underground crystal growing is possible.

Facility

Czochralski furnace
- $CaMoO_4$ crystals
- T<1500 ℃
- M< 3 kg

Kyropoulos furnace
- NaI crystals
- T<2200 ℃
- M<30 kg



30 kg furnace

5 kg furnace

30 kg of sapphire

Bridgmann furnace
- Scintillation crystals
- T<1500 ℃
- D= 5 cm

Future : ~ Ton scale enriched low-temperature experiment

CUPID : European proposal for ~ ton scale DBD experiment.

TABLE I: CUPID sensitivity goals

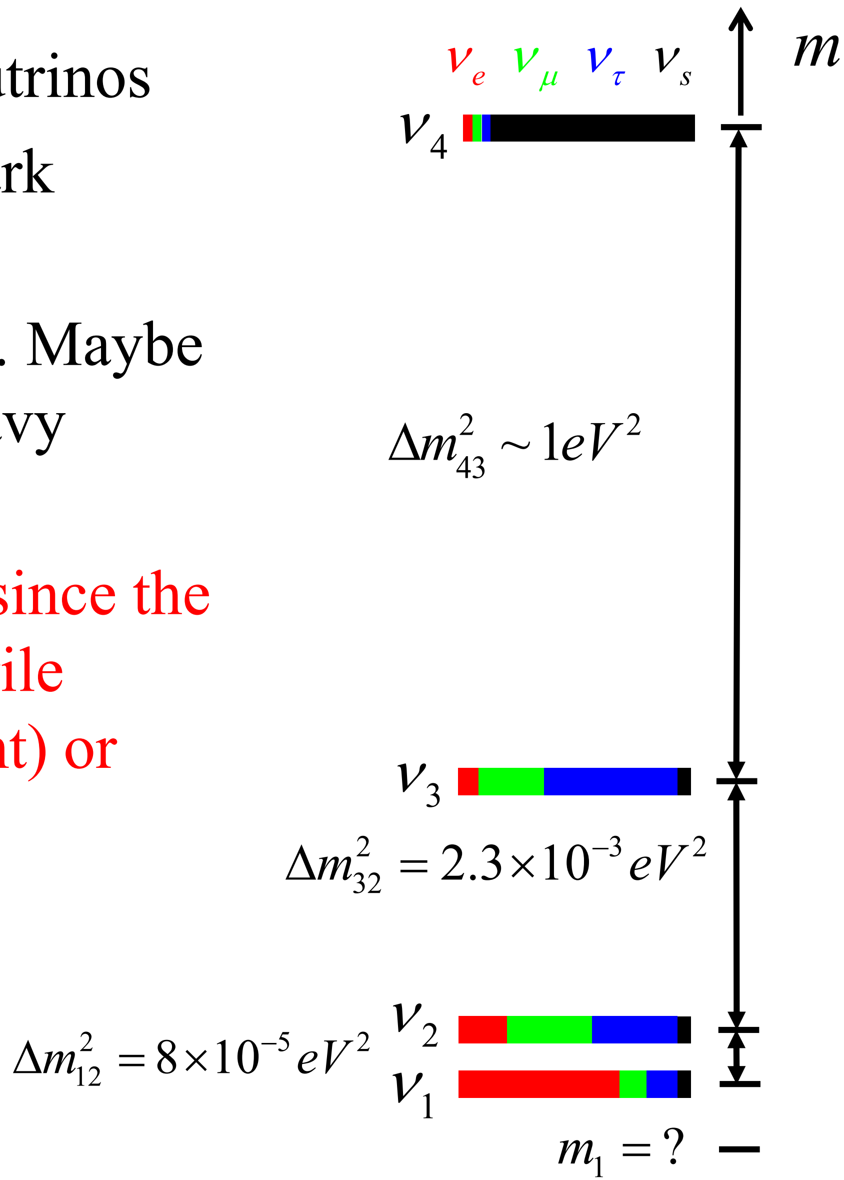
Parameter	Projected value and/or range	
Readiness for construction	2018 (technical limit)	
Construction time	5 years	
Total fiducial mass (kg)	TeO_2	750
	$ZnMoO_4$	540
	ZnSe	670
	$CdWO_4$	980
Isotope fiducial mass (kg)	^{130}Te	543
	^{100}Mo	212
	^{82}Se	335
	^{116}Cd	283

- If normal hierarchy, international collaboration is necessary for > ton scale exp.
- AMoRE will be one of the major exp to be compiled for ~ ton ^{100}Mo data.
- International collaboration (limited) began between LUMINEU and AMoRE

2. Sterile neutrinos – NEOS

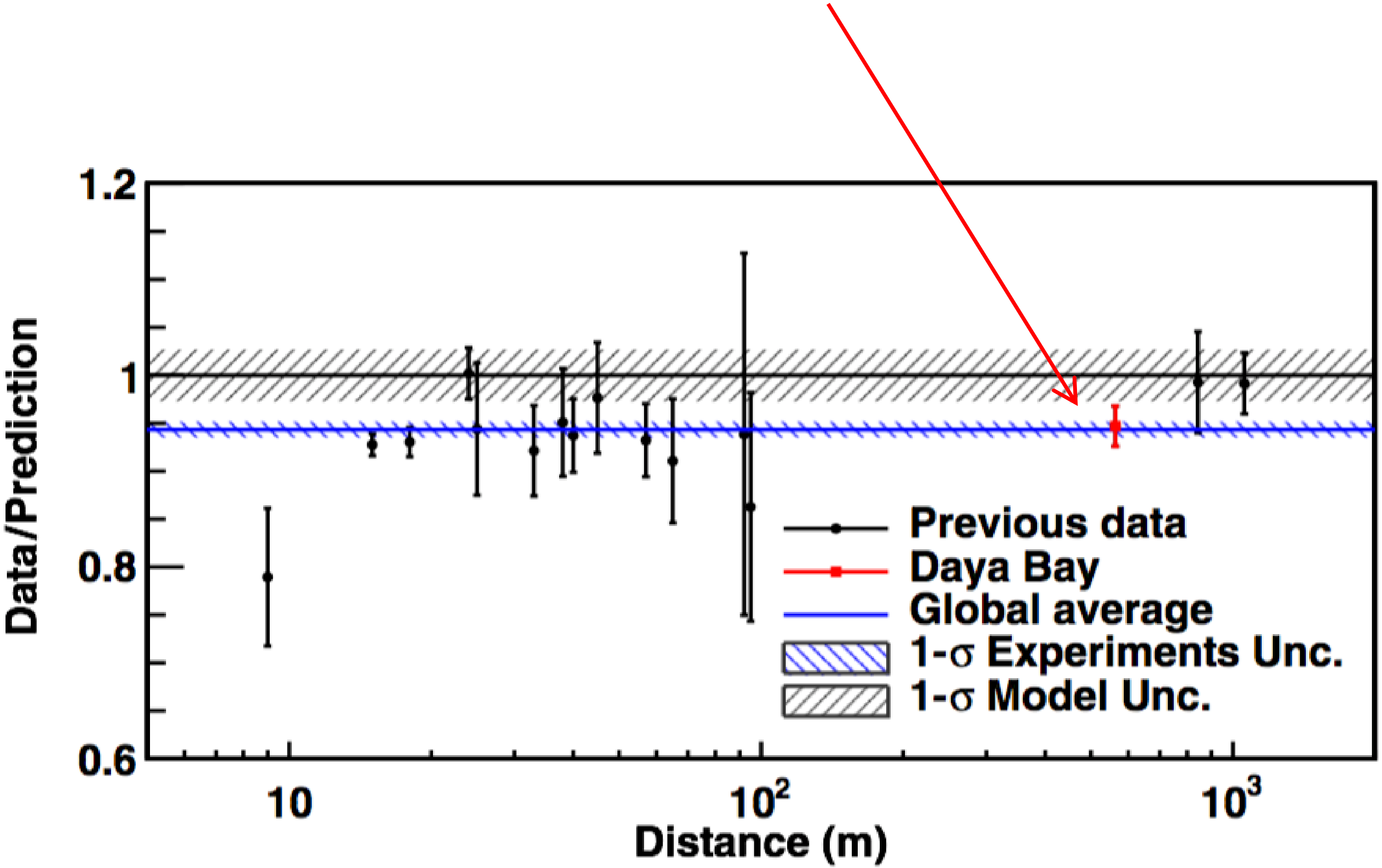
Sterile Neutrino Search – NEOS

- Sterile neutrinos – right-handed neutrinos
- Sterile neutrinos – maybe Warm Dark Matter
- Nothing is known about the masses. Maybe very light (m_n<<1MeV) or very heavy (m_n>>10^{10}GeV)
- Sterile neutrinos may be identified since the active neutrinos can oscillate to sterile neutrinos (disappearance experiment) or again oscillate to active neutrinos (appearance experiment).

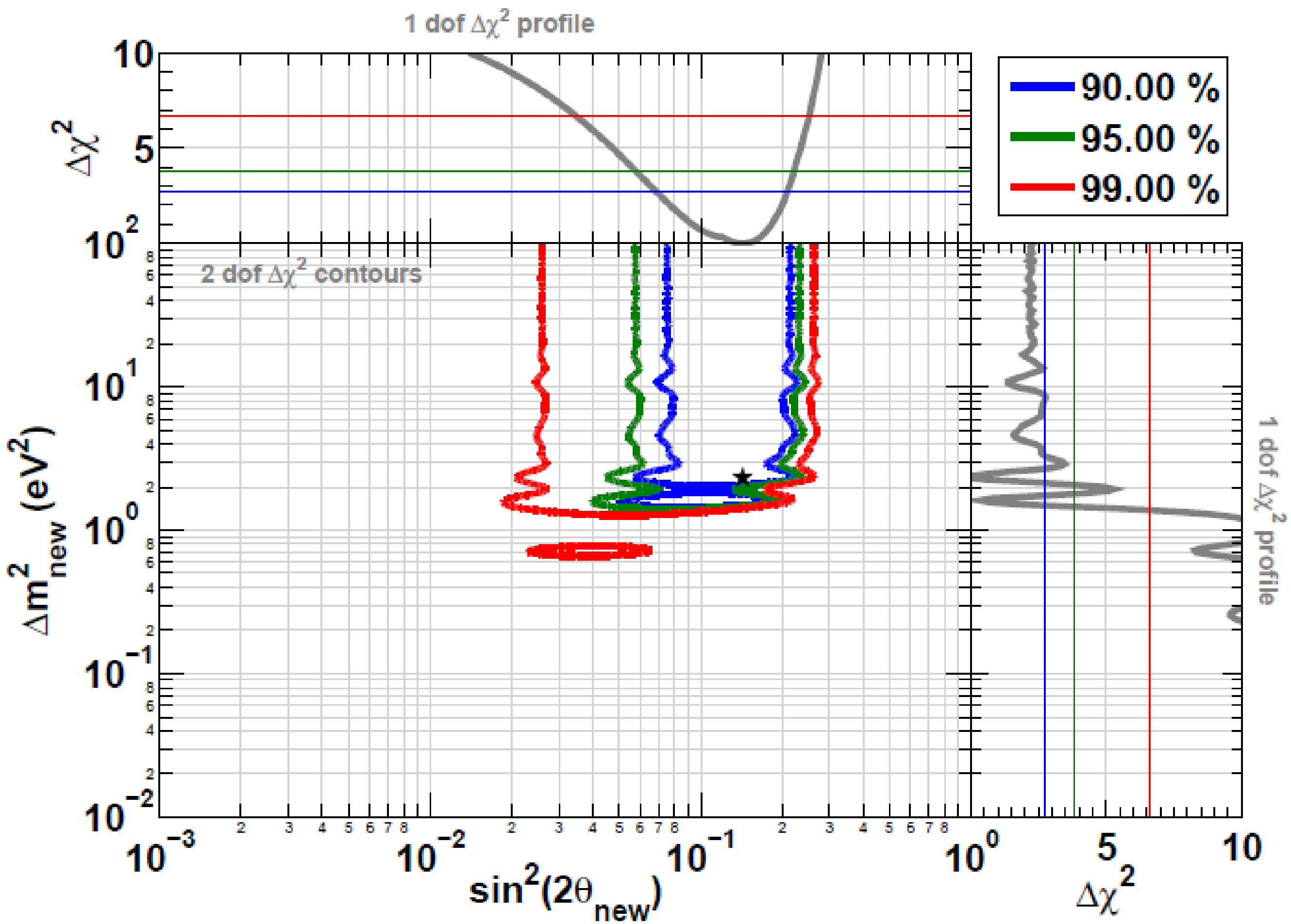


Reactor Anomaly & Sterile ν

- There are reports about the deficit of reactor neutrinos at baseline < 100m from the expected flux. ~ 6%
- This may be due to active to sterile neutrino oscillation, ~ 1eV.
- RENO, Double Chooz, DAYA BAY (PRL116, 061801) confirmed this effect.

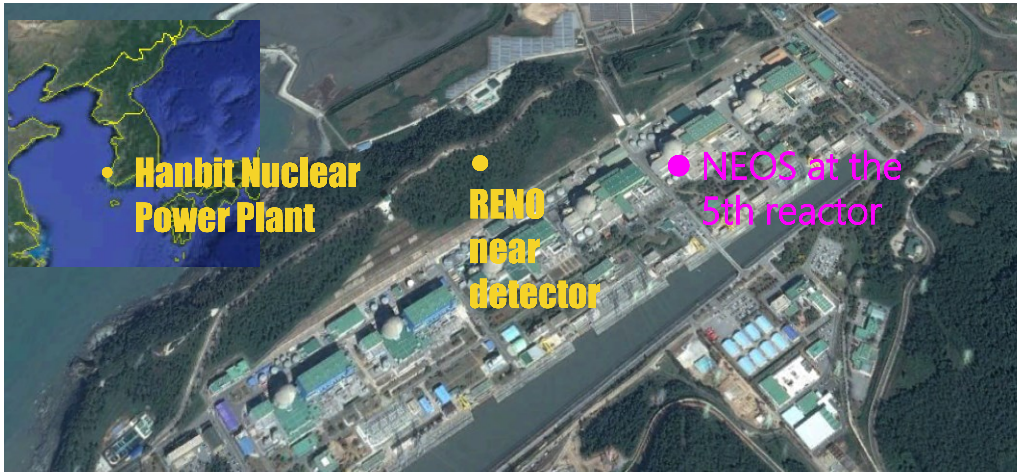


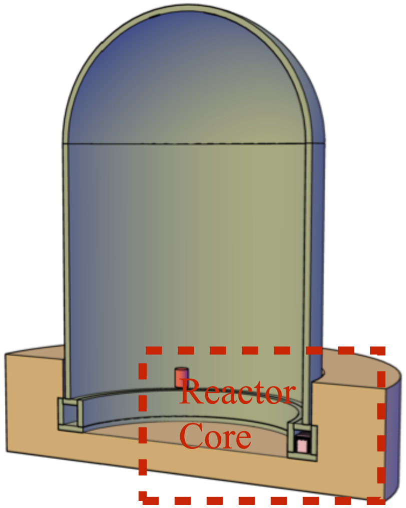
- Mention et al., PRD 83, 073006 (2011)



NEOS (Neutrino Experiment for Oscillation at Short baseline)

- Possibility to do sterile neutrino experiment at the commercial power plant.
- Unique experiment with 3 baseline at the same time,
  -- NEOS (25m), RENO-near(~250m) , RENO-far(1300m)

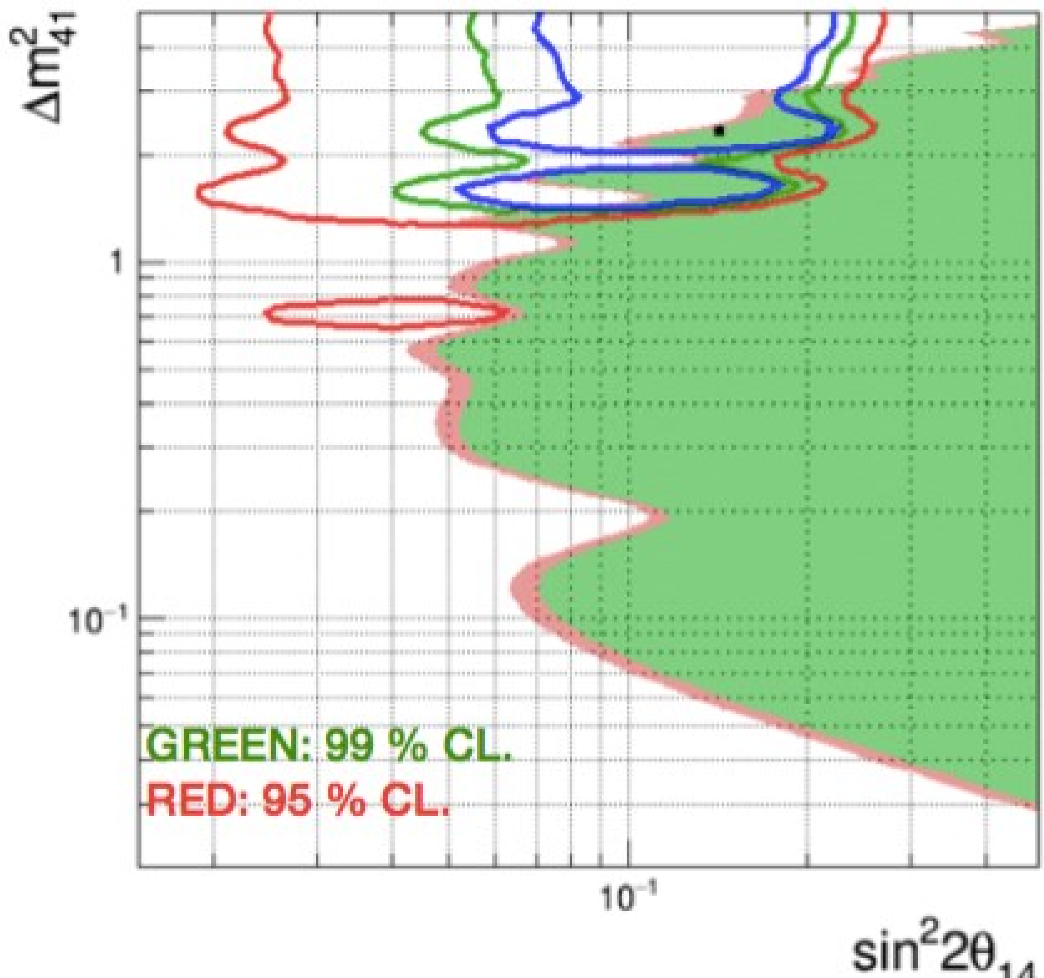




Experiments	Thermal Power	Baseline	Country
Nucifer	70 MW	~ 7 meters	France
PROSPECT	85 MW	7 - 12 (near), 15 - 19 (far) meters	US
Stereo	57 MW	8.9 - 11.1 meters	France
CHANDLER	60 MW	~ 6 meters	Belgium

Design and Sensitivity

"Identical two detectors at different baseline" was the key point for RENO, DAYABAY, and Double Chooz, NEOS can do a similar analysis, the ratio between NEOS and RENO (DayaBay)-NEAR, to improve the sensitivity for Θ_{14}.



NEOS Detector

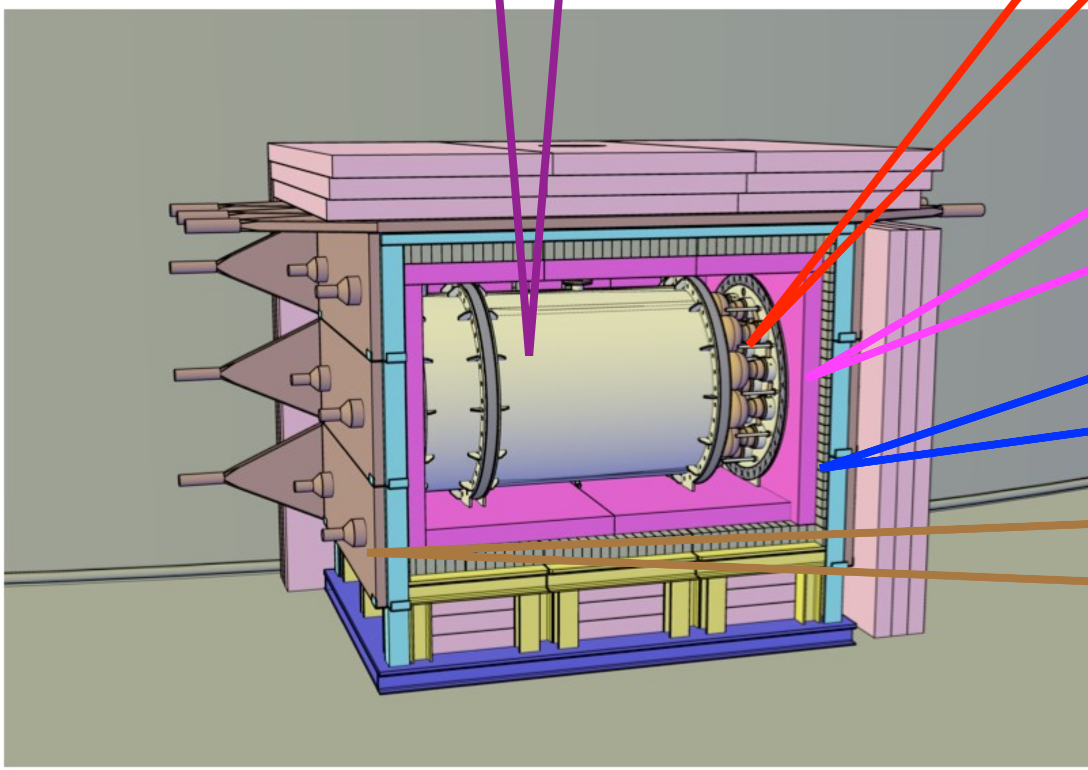
- Volume of Liquid Scintillator (LS) is ~ 1000 L
- Mixture LS: LAB based + DIN based (9:1)
- 0.5 % gadolinium is loaded.

- 8" photomultiplier (PMT)
- 38 PMTs in mineral oil

- Borated polyethylene (10 cm)
- B-PE shields neutrons produc ed at lead.

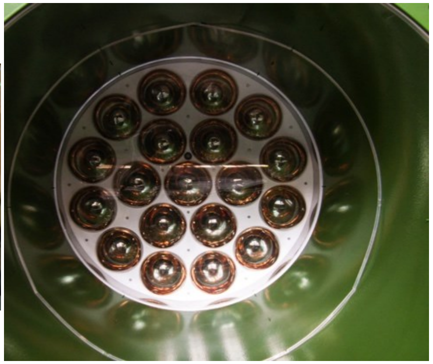
- 10 cm lead shield for gamma

- 4π muon detector for veto (except bottom)
- Plastic scintillator
- 2" or 5" PMTs

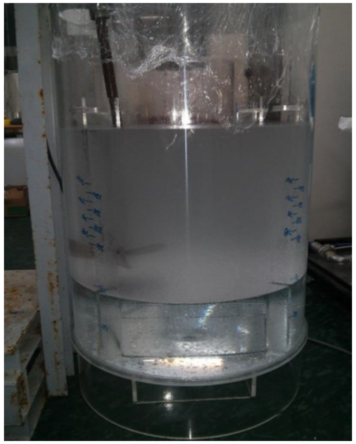


Main Detector Constucted & Installed.

@ Korea Atomic Energy Research Institute

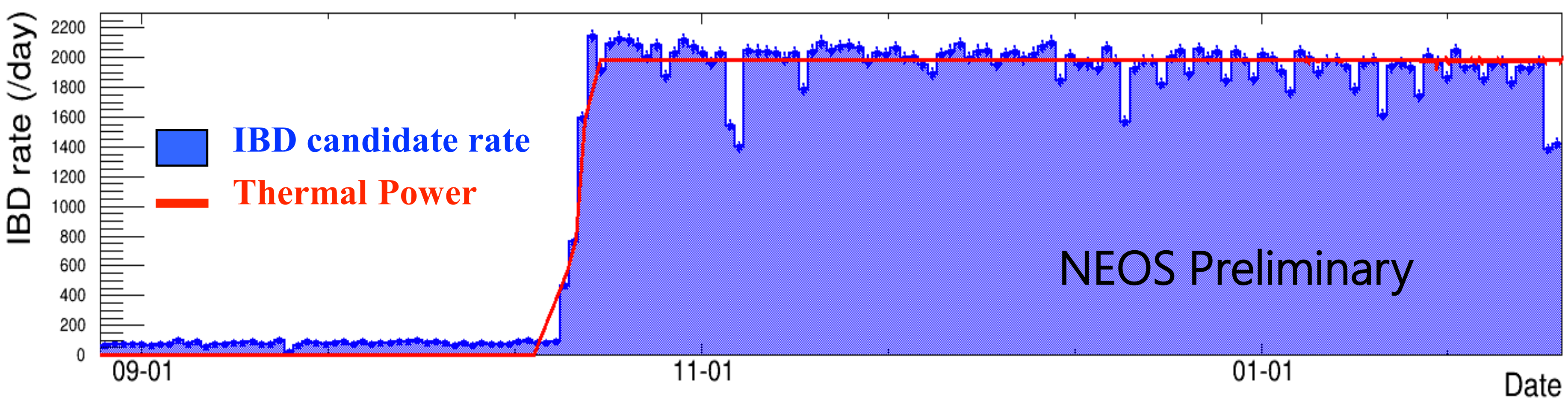


Construction and Installation at Tendon Gallery finished on Aug. 6th, 2015



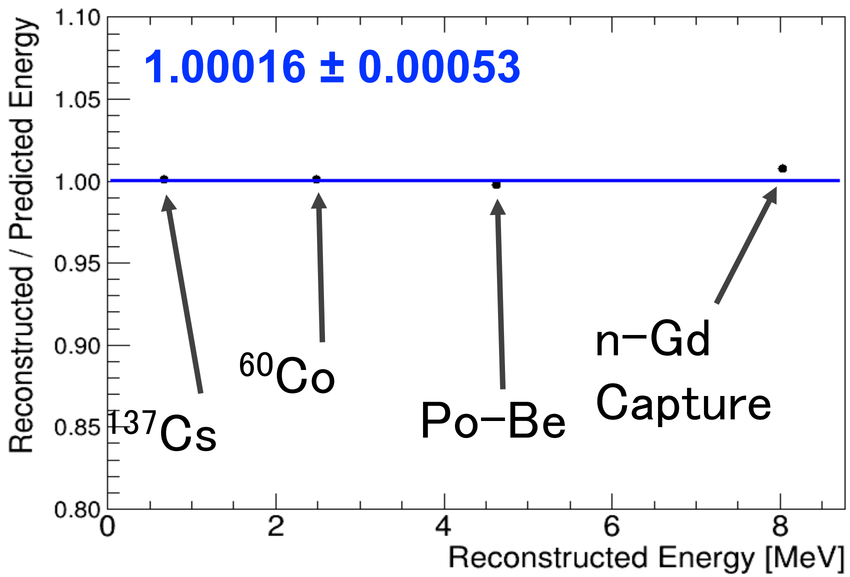
Milestones of NEOS Experiment

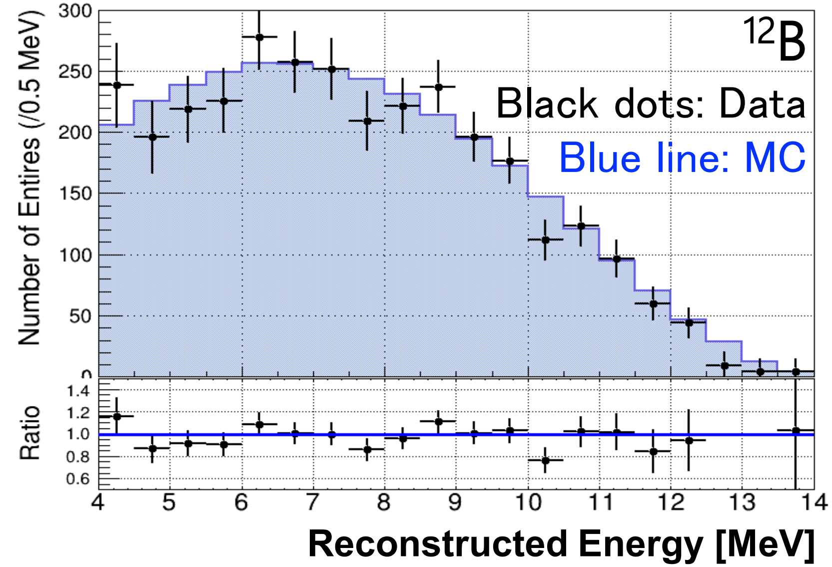
- August 2015: Start data taking, (Reactor off)
- October 2015: Reactor on
- May 2016: Detector will be uninstalled.

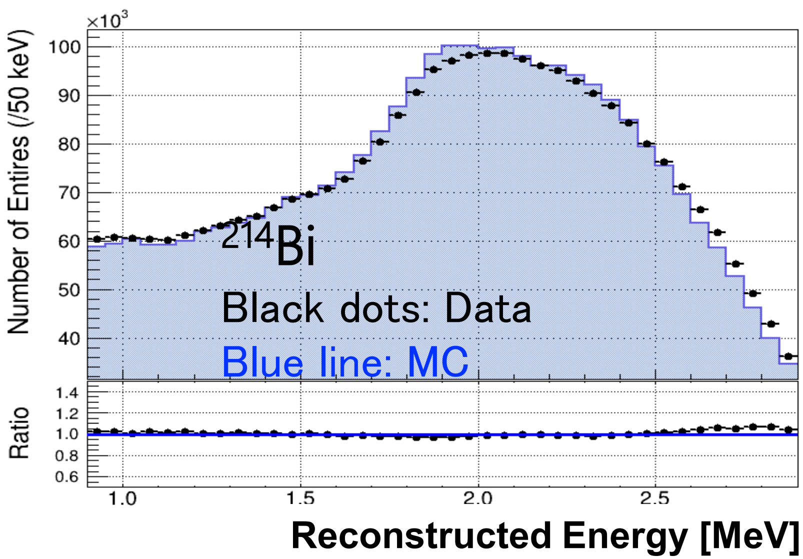


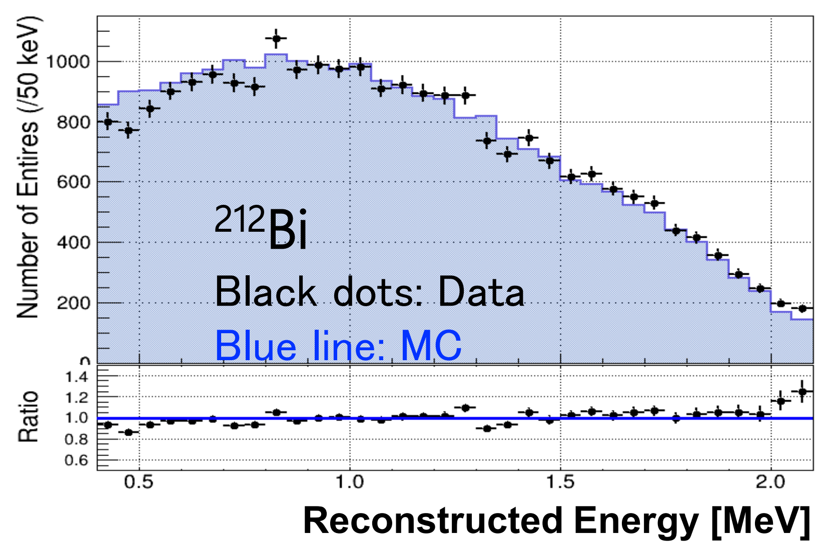
- Neutrino event rates ~2000/day.→ Highest rate among all n detectors in history !!
- Reactor ON/Off ratio is large, ~20, highest ratio among short baseline detectors.

MC Tuning - γ and β sources



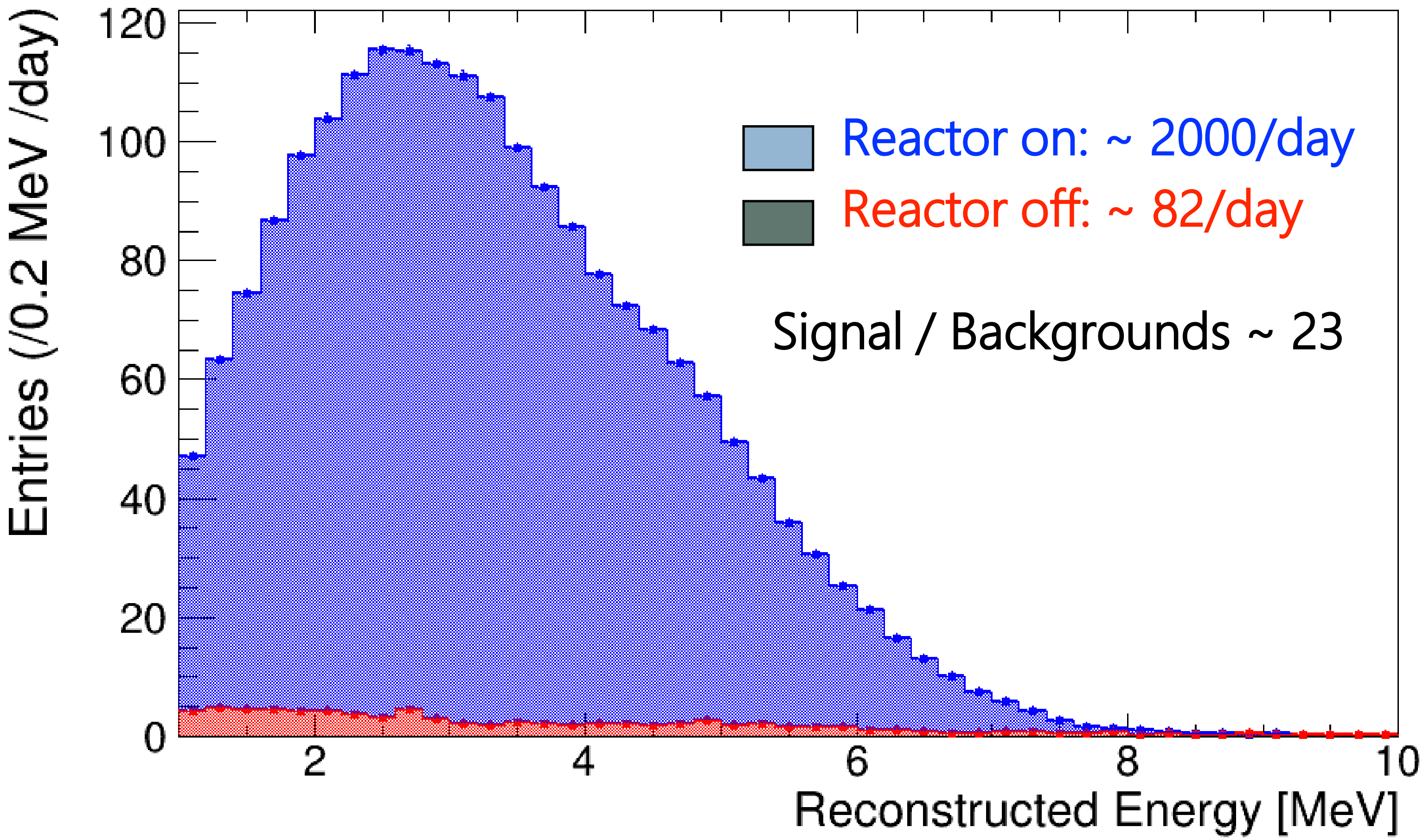






Energy Spectrum

- S/B ratio is high enough to investigate the energy spectrum in detail.
- We Do see the similar ~5MeV bump !
- Shape analysis for sterile neutrino is on going for 6months data and will be presented Neutrino 2016.



3. Dark Matter Search – COSINE

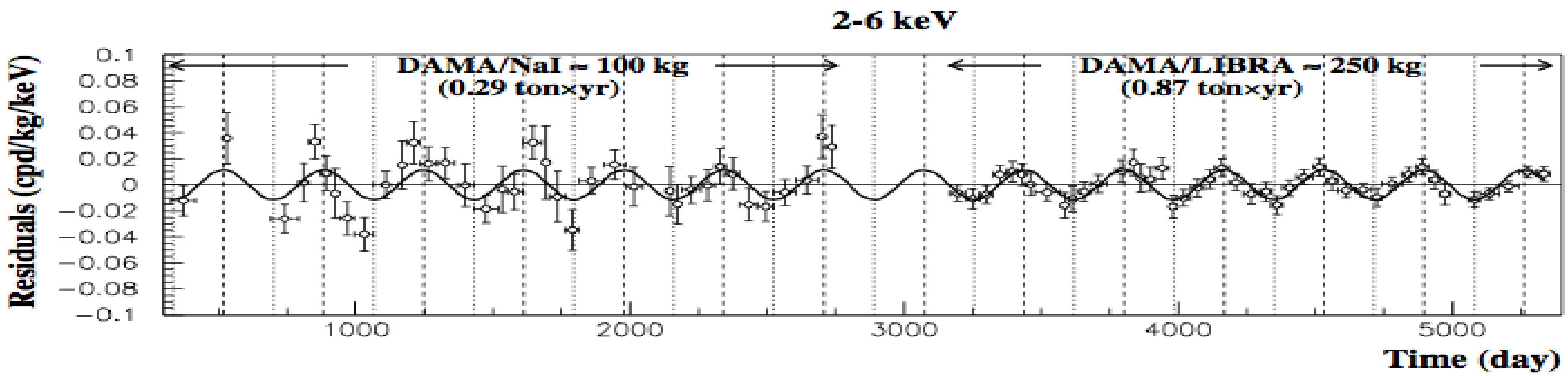
Yale Wright Laboratory

The University Of Sheffield.

Center for Underground Physics

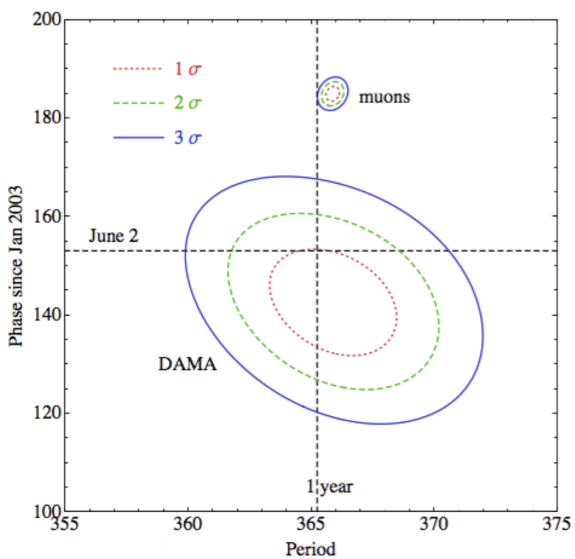
Why NaI(Tl) exp ?

- DAMA group reported modulation for 14 years consistently. → "DAMA anomaly"
- Direct check for DAMA is necessary even though other experiments rejected DAMA modulation signal based on standard WIMP-nucleon interaction.



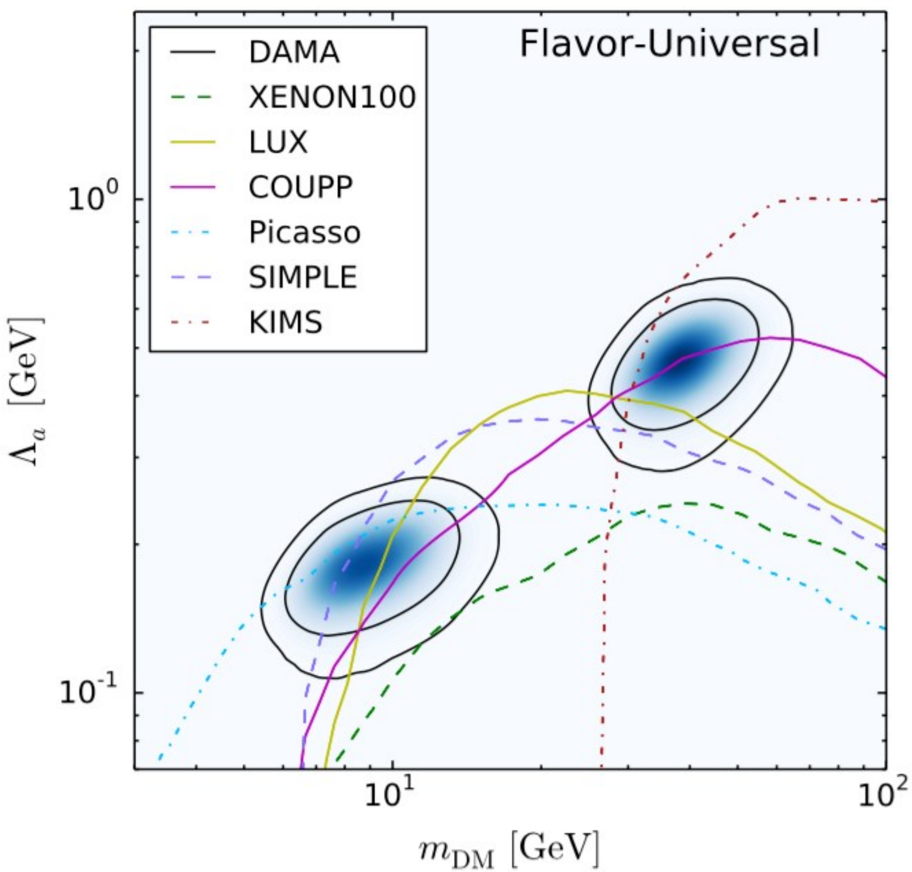
Difficulty

1. Muon (or solar neutrino) induced neutrons are not abundant to explain the modulation rate.
2. DAMA phase is 1 month earlier than muon phase.



DAMA vs LUX, SuperCDMS

- There are still plausible models for both DAMA and other data together.
  (ex) Arina et al., PRL 114, 011301 (2015)



- A DM particle interacting with ordinary matter via the exchange of a light pseudoscalar can accommodate the DAMA data while being compatible with all null direct DM searches.
- The best fit is obtained when the pseudoscalar mediator is much lighter than the DM mass and has universal coupling with heavy quarks, as in hadronic axion models.

KIMS-NaI/DM-ICE (COSINE-100) Experiment

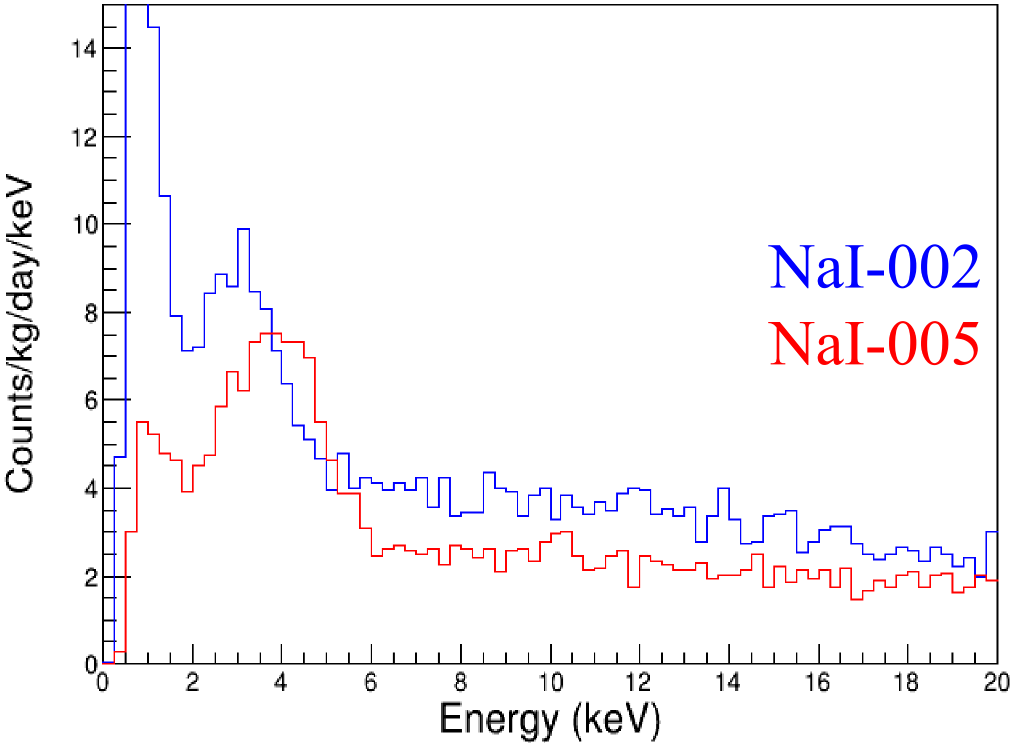
- Crysmatec company apparently can not supply ultra-low background NaI(Tl) crystals.
- 2014-2015 : ~10 R&D crystals will be tested.
- KIMS-NaI + DM-ICE → COSINE-100 exp.

DAMA ~ 1dru, 2 keV threshold.
Goal : unambiguous (de)confirmation of DAMA modulation
Purification → < 0.5 dru
Lower threshold ~ 1 keV

Detector Development

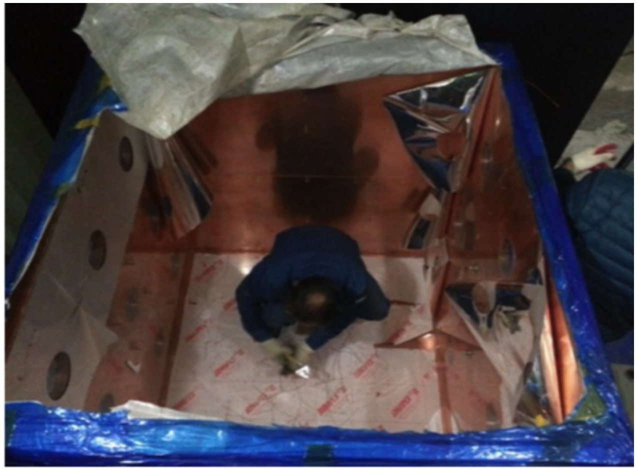
K.W.Kim et al., Astropart. Phys. 62, 249 (2015)

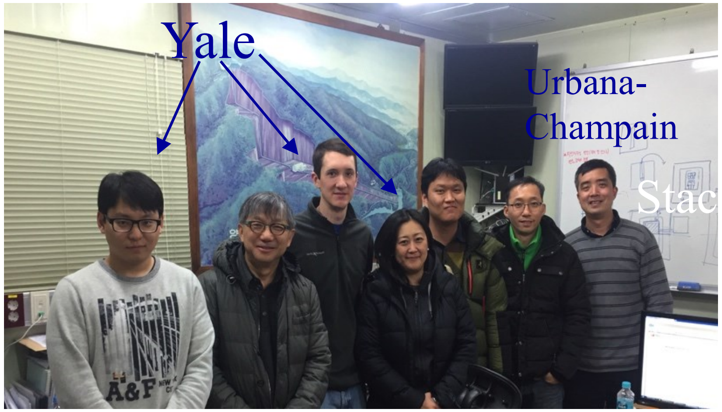
P. Adhikari et al., arXiv:1510.04519



Construction of shielding

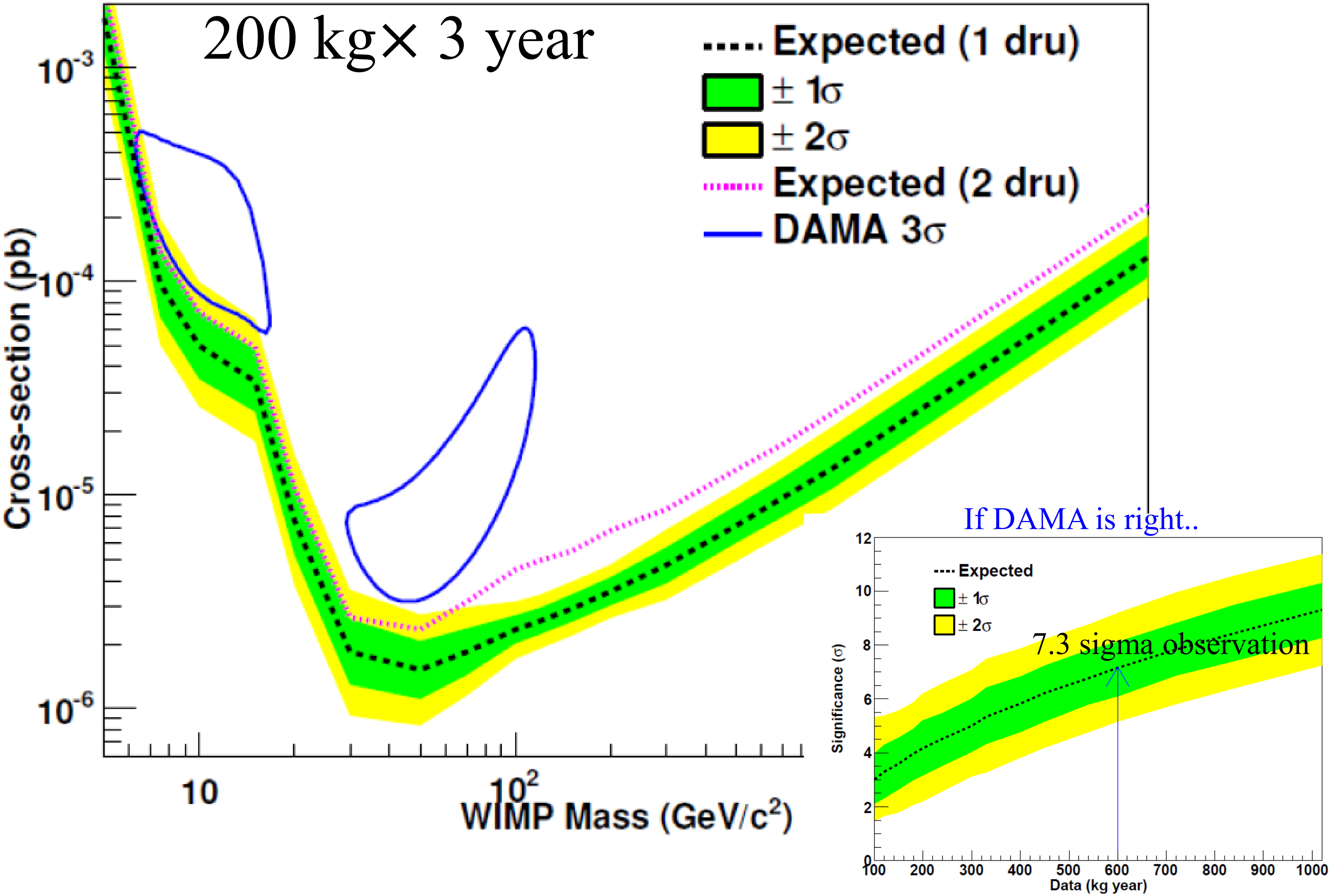
Acrylic + Copper box





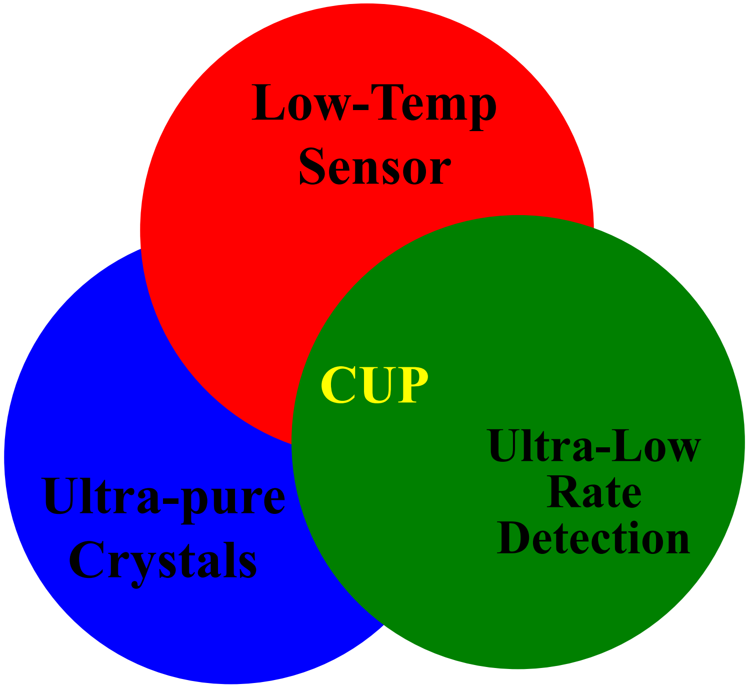
Muon veto with plastic scintillator is finished.
We will start phase-0 experiment jointly with DM-Ice collaboration using ~100 kg crystal from June/2016 at Y2L

Sensitivity of KIMS-NaI experiment



CUP Infrastructure

- For the next generation neutrino and dark matter programs, CUP is developing ultra-low background technology and infrastructure.
- Ultra-low background technology can be realized with a combination of low background measurement and purification with the ultra-sensitive sensor.
- CUP is unique to have all the technique in a center.



Summary

- **AMoRE project will cover inverted mass hierarchy for a discovery and will lead the ton-scale 0nbb with international collaboration.**
- **NEOS will test the sterile neutrino anomaly in near future.**
- **KIMS+ will conclude the DAMA anomaly, and will investigate most low mass WIMP parameter space, and also for high mass with LZ exp.**
- **CUP will be the Center for the Ultra-low Background Techniques. For the planned projects, we need a new underground laboratory, which will be the basic facility for the fundamental, great physics.**