NEUTRINO PROGRAMS AT CUP

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IBS / SEJONG UNIVERSITY

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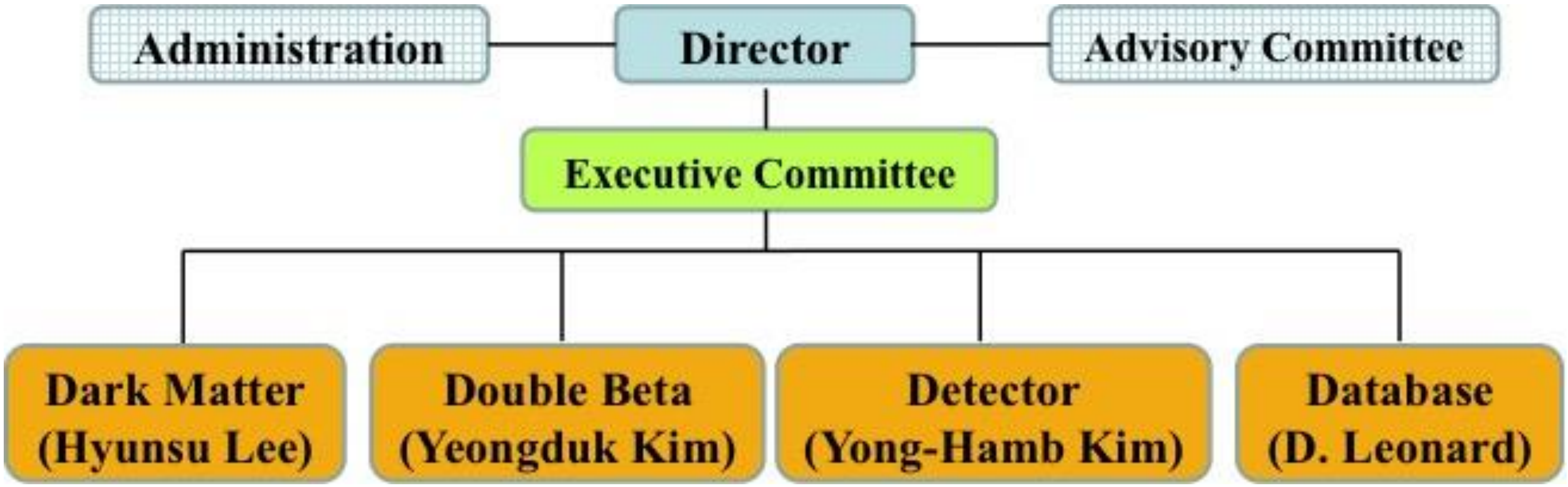
ICHEP 2016, Chicago

Theme for Center for Underground Physics (CUP)

1. What is dark matter ?
2. Are neutrinos Majorana particles ?
3. What created the asymmetry in the Universe ?
4. Extreme rare phenomena in energy region 10 eV – 100 MeV

Organization of CUP

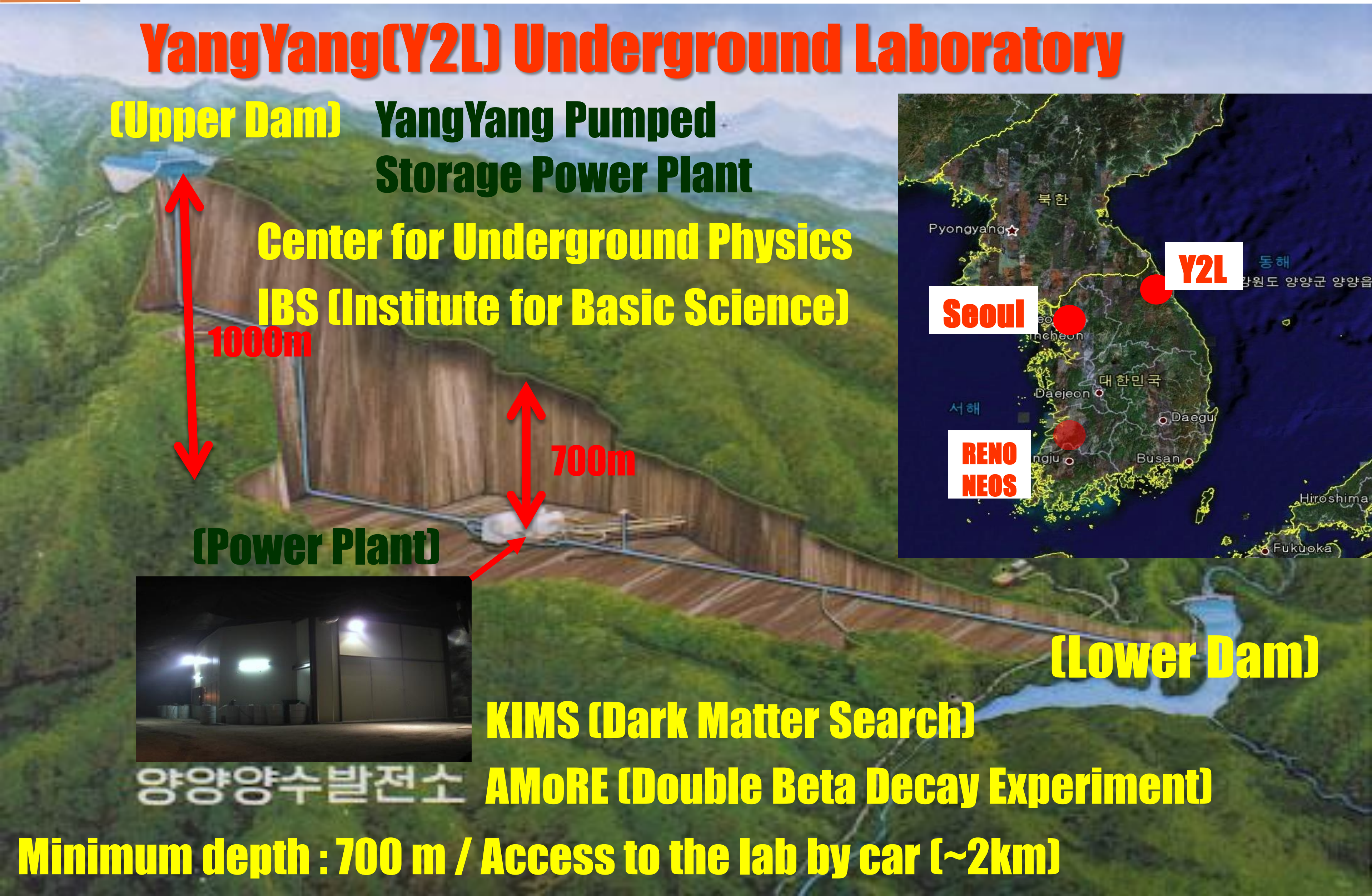


Members :

- 1 Director
- 2 Group Leaders
- ~25 Research Fellows
- 6 Technicians
- 3 Administrators
- ~ 10 Adjunct Professors
- ~25 Adjunct Students.

Laboratories

YangYang(Y2L) Underground Laboratory



YangYang Pumped Storage Power Plant

Center for Underground Physics

IBS (Institute for Basic Science)

KIMS (Dark Matter Search)

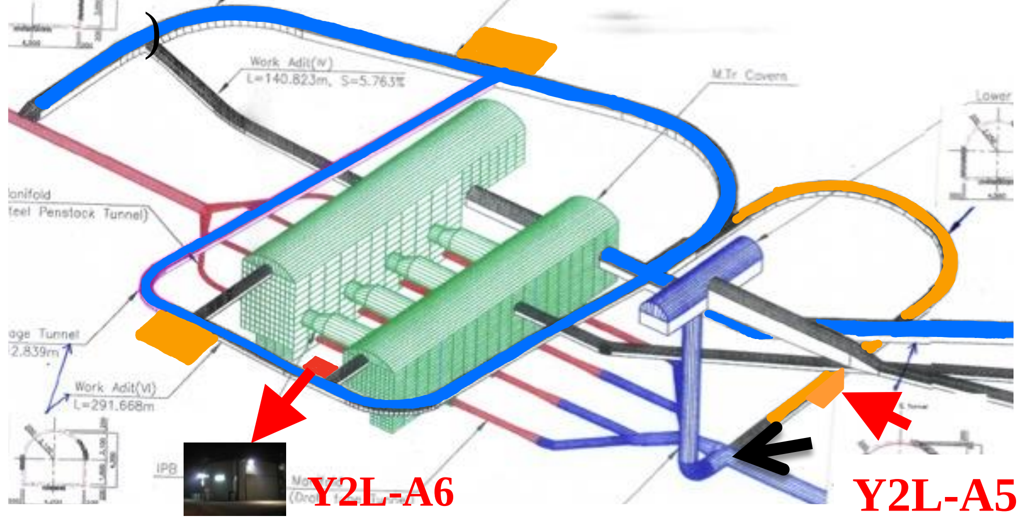
AMoRE (Double Beta Decay Experiment)

Minimum depth : 700 m / Access to the lab by car (~2km)

Laboratories

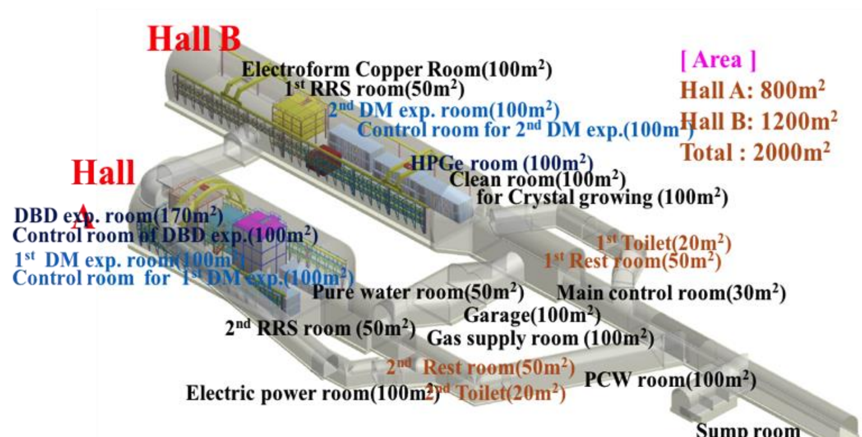
Current Ground Lab.

Yangyang underground laboratory (Y2L)



Headquarter (2018-)

New underground lab. (2019-)

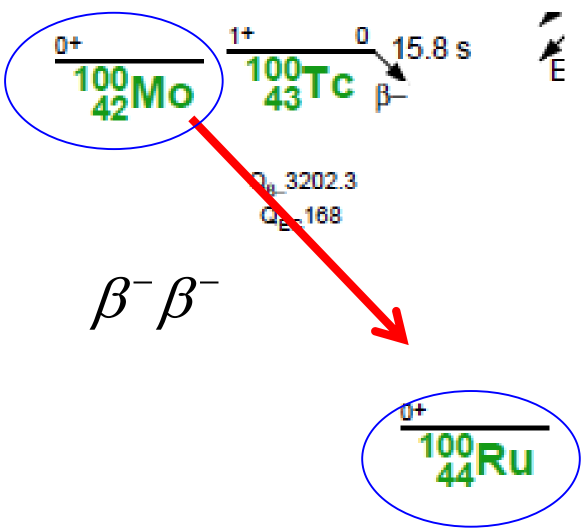


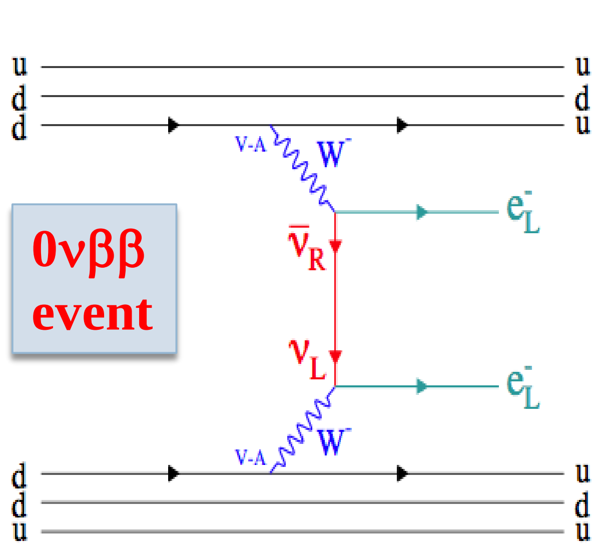
1. Double Beta Decay - AMoRE

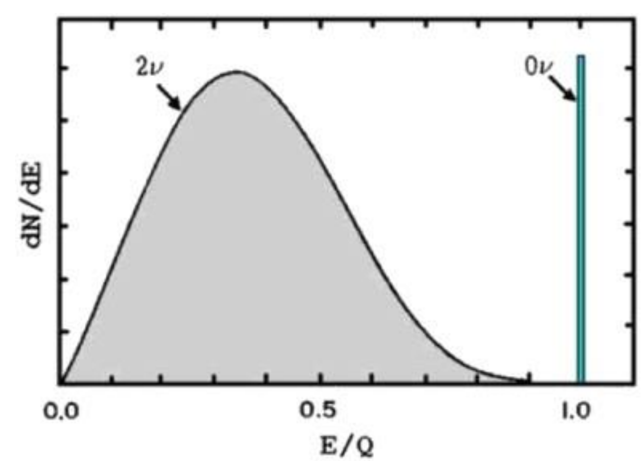
Search for Neutrinoless double beta decay (0νββ)

- **Observation of 0νββ will confirm**
  - **- Neutrinos are Majorana particles and have Majorana masses.**
  - **- Lepton number non-conservation.**
- **Observation of 0νββ will support more on**
  - **- See-Saw model of the neutrino mass.**
  - **- Leptogenesis to account for the baryon asymmetry of the universe.**

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



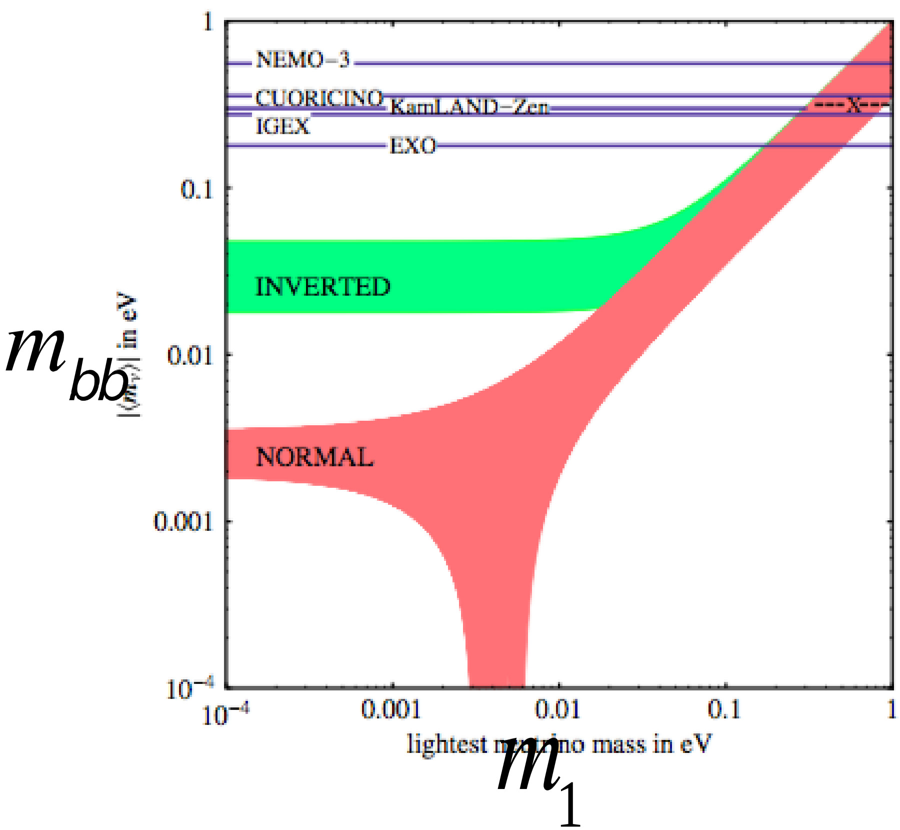




How to confine neutrino mass with $0nbb$

- If discovered with a measurement of half-life, then

$$T_{1/2}^{0n} \to m_{bb} \quad \text{by} \quad \left[T_{1/2}^{0n}\right]^{-1} \propto m_{bb}{}^{2}$$



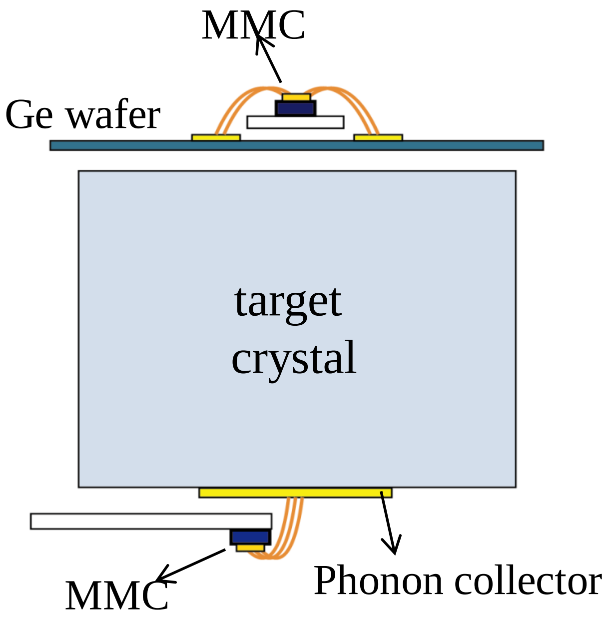
Current limit is 10^{26} years.

→ 100 kg ^{136}Xe has less than 3 events per year.

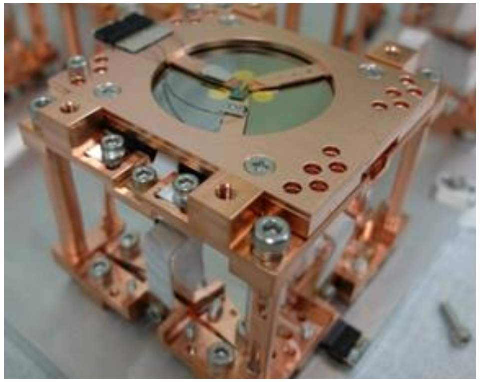
→ Need extremely low backgrounds with good energy resolution.

AMoRE (Advanced Molybdnum Rare-decay Experiment)

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



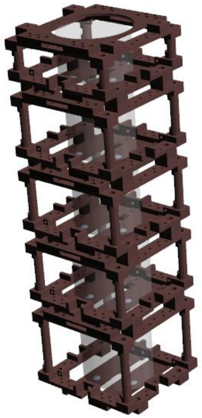
Photon sensor @ top



Phonon sensor @ bottom

- Phonon detector → High Energy Resolution
- Q = 3.04 MeV & Heat vs Photon → Low Background.
- 10% natural abundance → Reasonable Cost

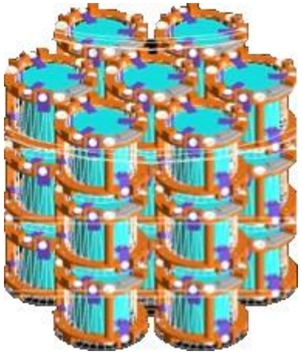
Phases of AMoRE Project



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

~ 1.5 kg

AMoRE Pilot



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

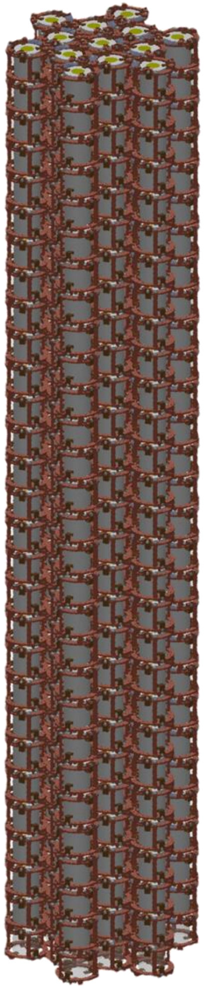
~ 5 kg

AMoRE-I

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

200 kg

AMoRE-II



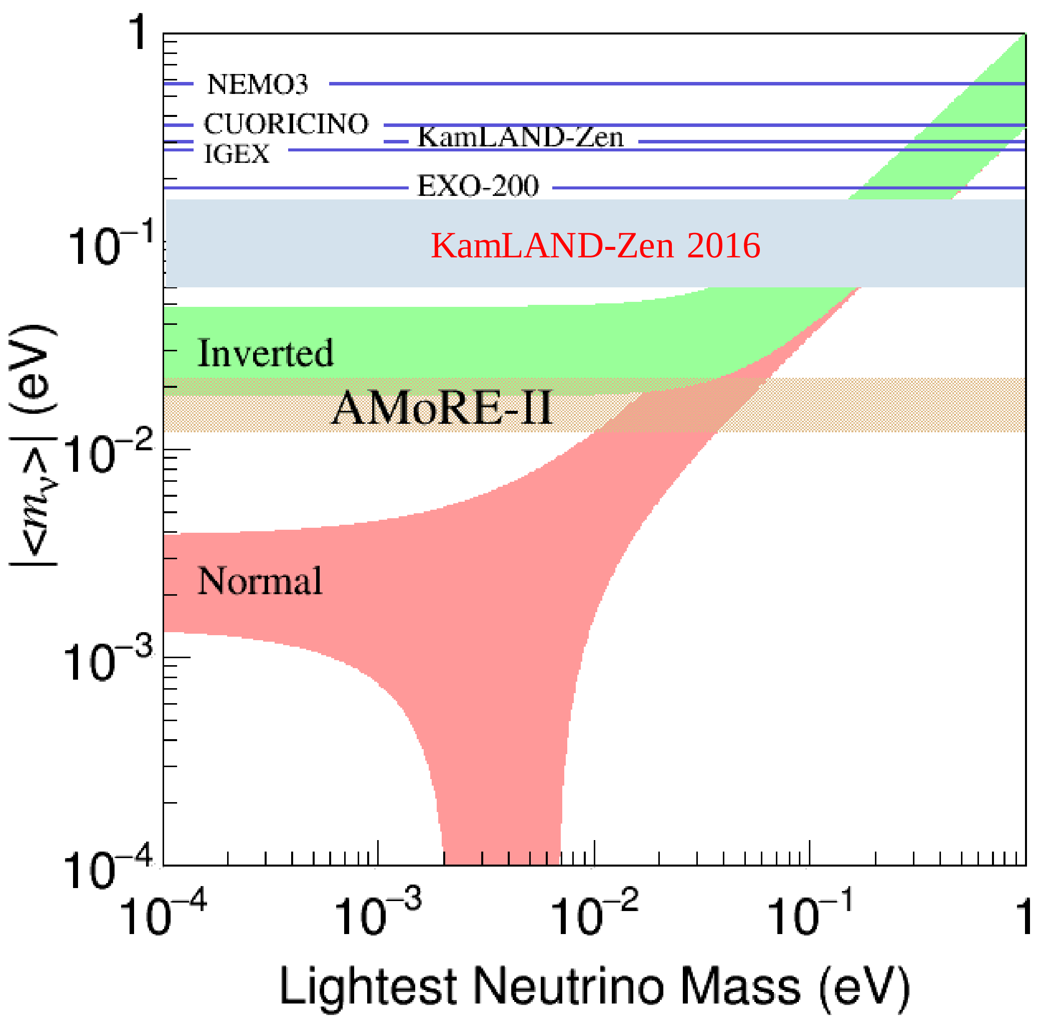
ckky : counts/ (keV kg year)

	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	2015-2016	2017-2018	2020-2022

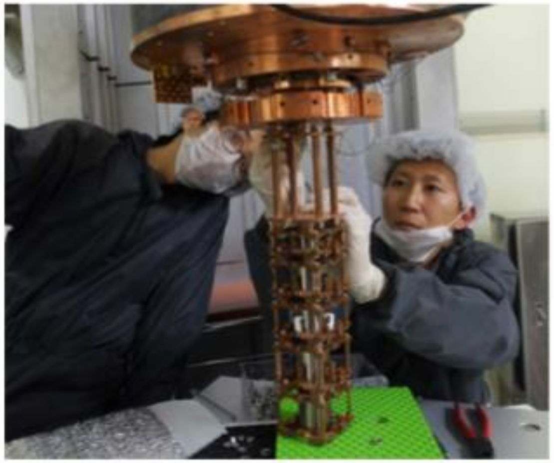
AMoRE Sensitivities

Aim at "Zero Background" experiment in the region of 0νββ signal.

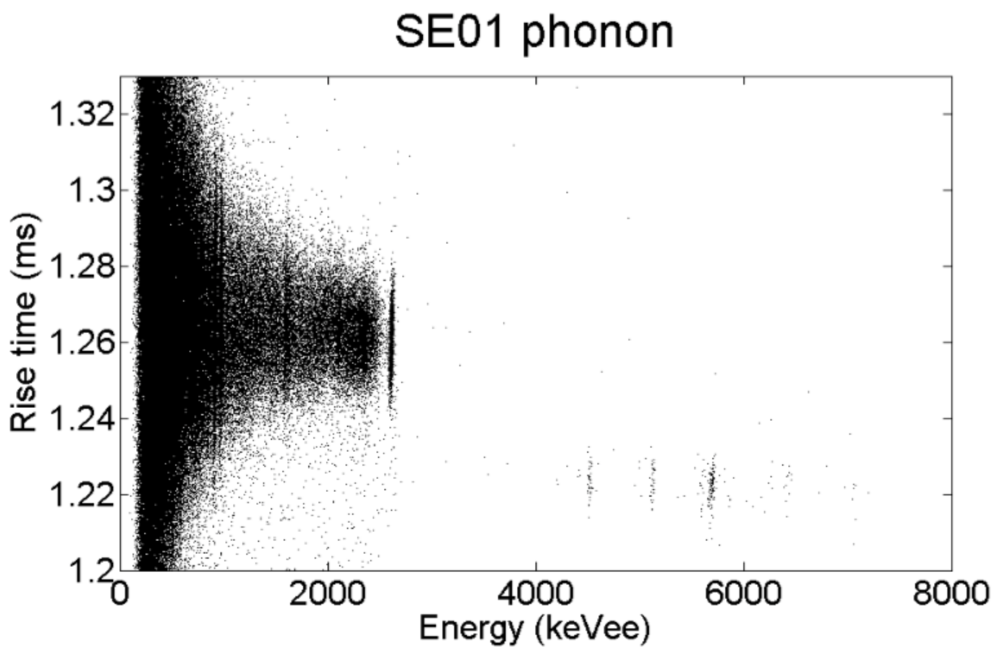
AMoRE will cover inverted mass hierarchy region.



Mounting detectors in pilot exp. at Y2L

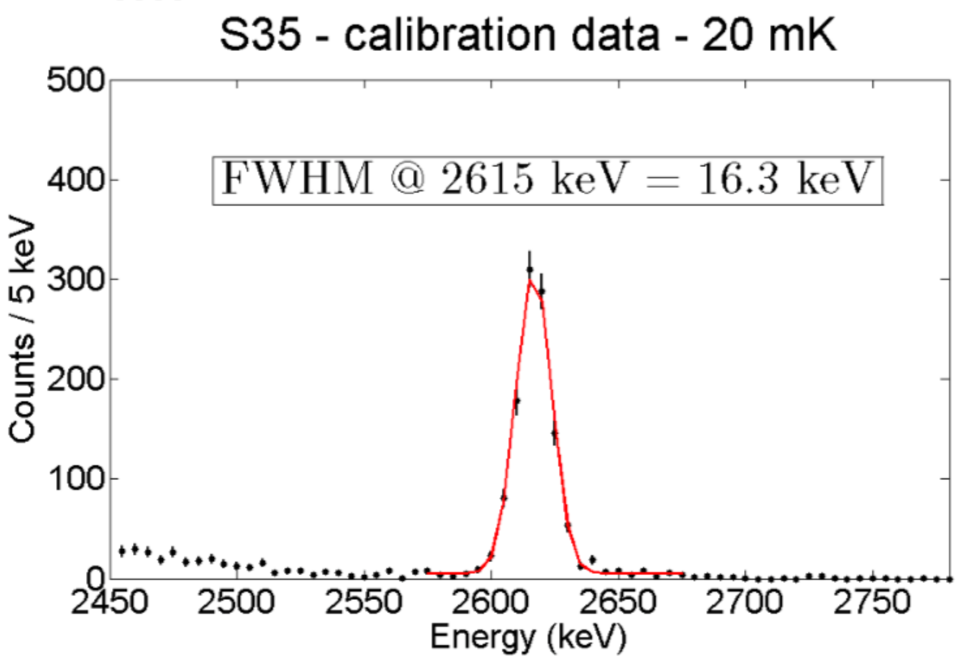


Preliminary results on AMoRE-pilot run

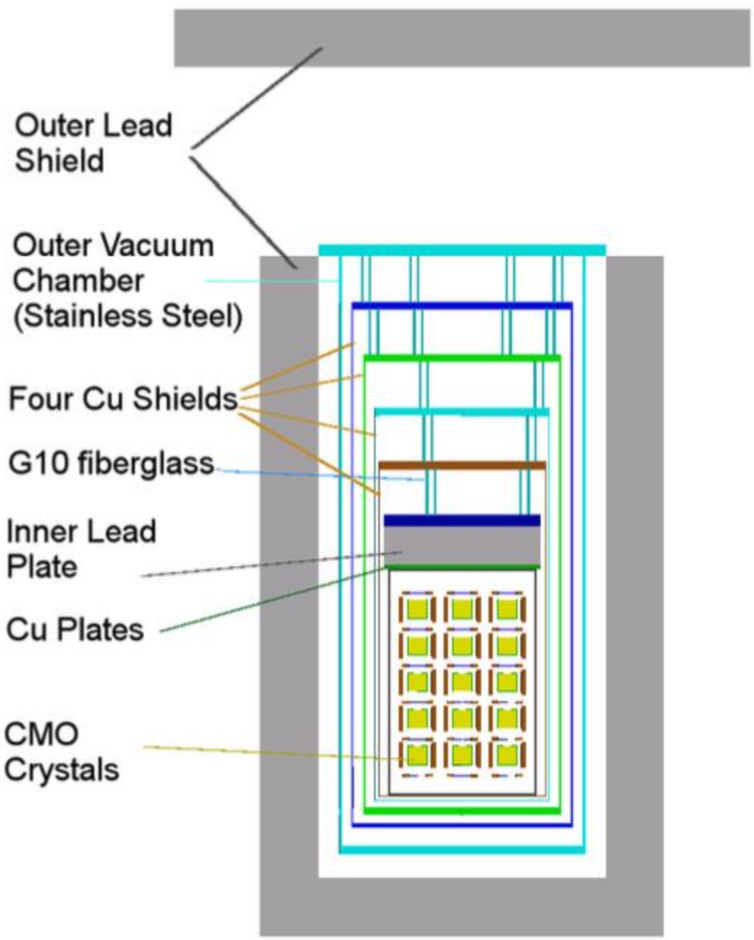


Vibration noise from Pulse Tube limits Pulse shape discrimination power & energy resolution.

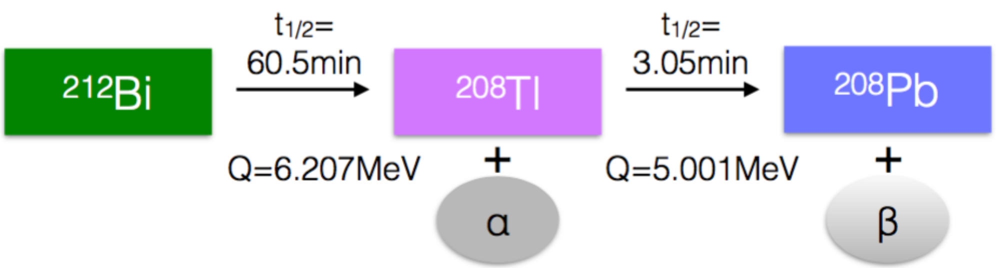
→ Try to detach Pulse Tube and install damping system.



Simulation for AMoRE-I setup



- ^{228}Th backgrounds

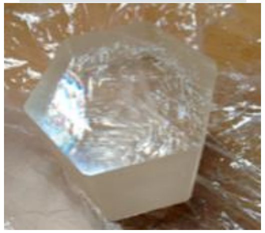


- Major Background Sources

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

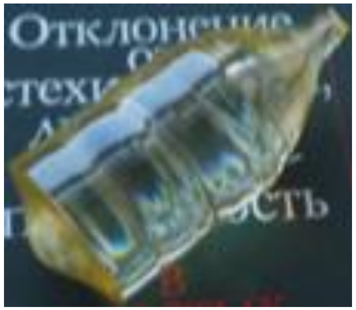
Crystals for AMoRE-II – studied by KNU

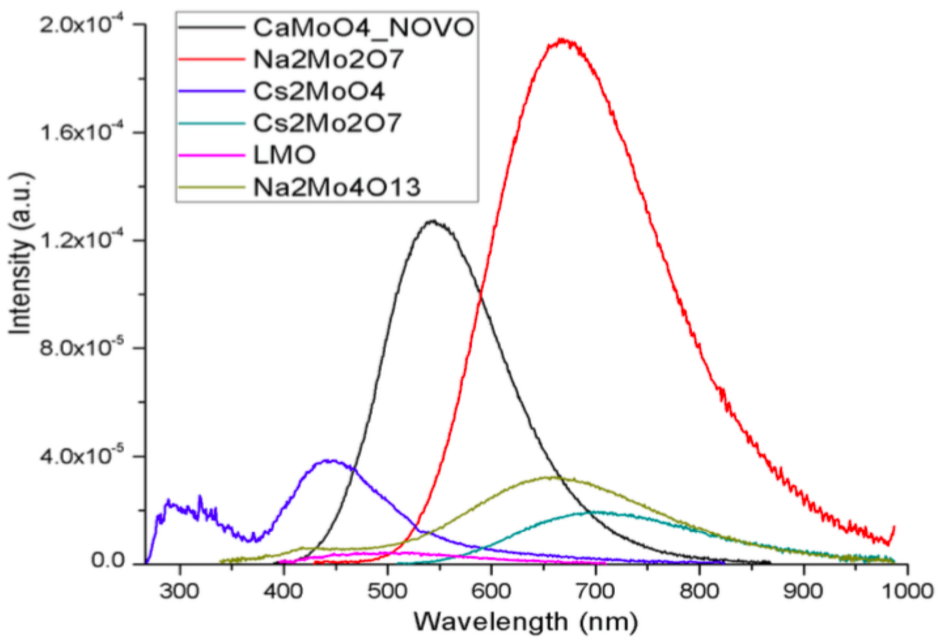
There are Mo crystals excellent for AMoRE-II experiment in addition to CaMoO4.



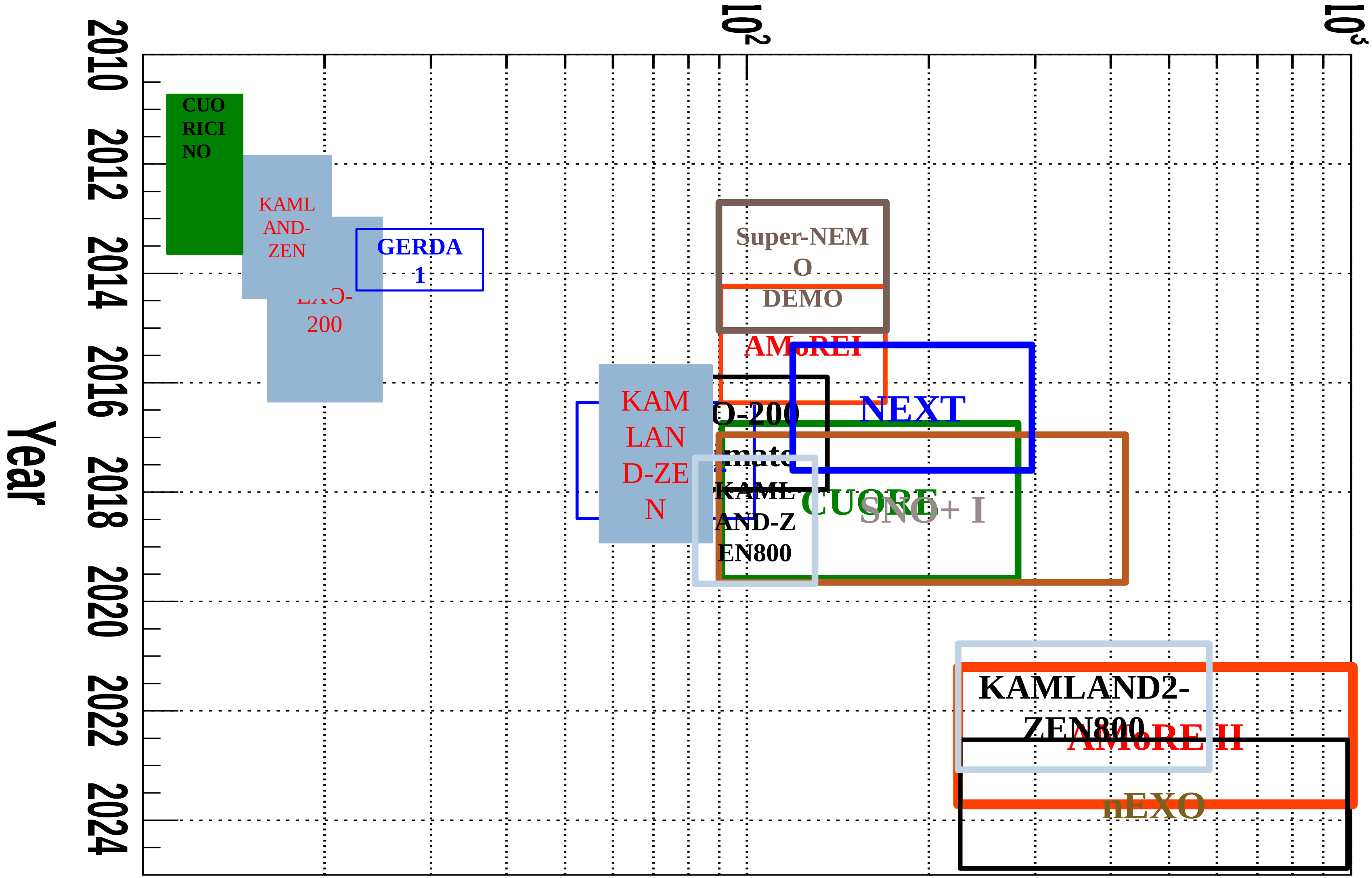
Crystal	Energy Yield @ 10K	density	Mo Fraction	Exp
CaMoO4	100	4.34	0.49	AMoRE-1, 2(?)
ZnMoO4	20	4.37	0.436	LUMINEU
Li_2MoO4	5	3.03	0.562	LUMINEU, AMoRE-II(?)
PbMoO4	10	6.95	0.269	AMoRE-II(?)
$Na_2Mo_2O_7$	140	3.62	0.558	AMoRE-II(?)

We will decide the crystal by end of 2017.



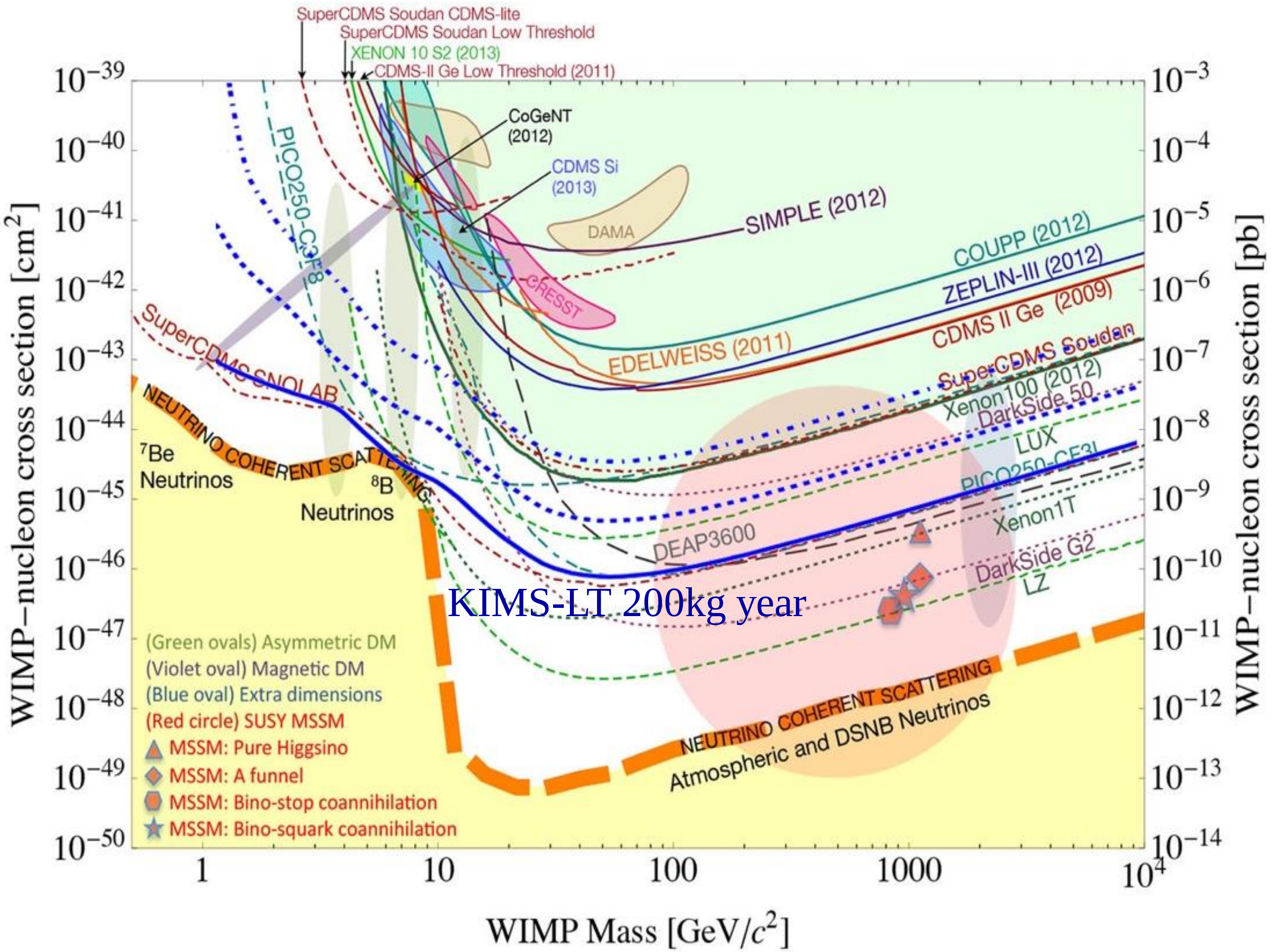


International Races for 0νββ



AMoRE-II is the most massive experiment with enriched isotope having Q value > 3MeV.

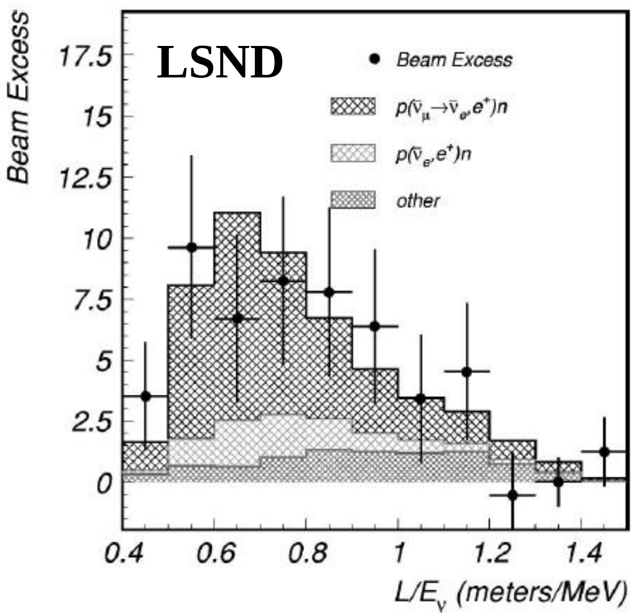
Sensitivity of KIMS-LT experiment – Hyunsu Lee



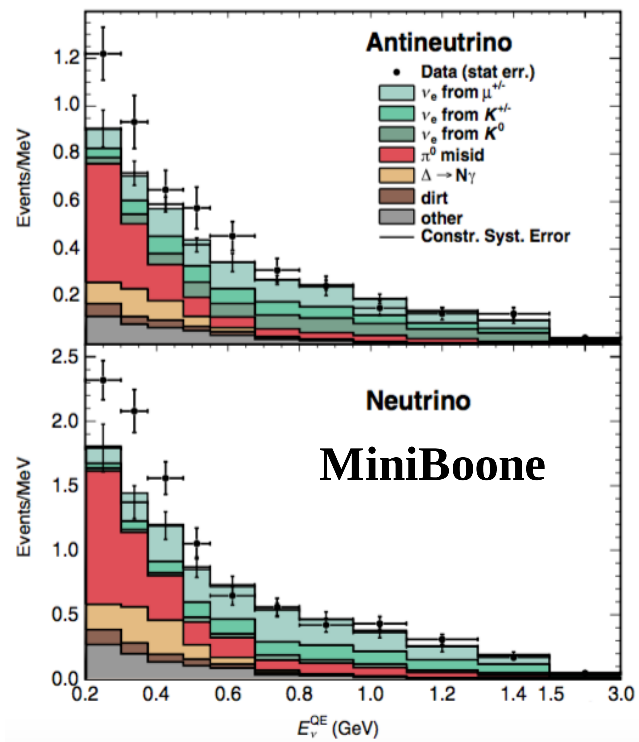
Goal to have the most sensitive detector for the low-mass dark matter

2. Sterile neutrinos search – NEOS

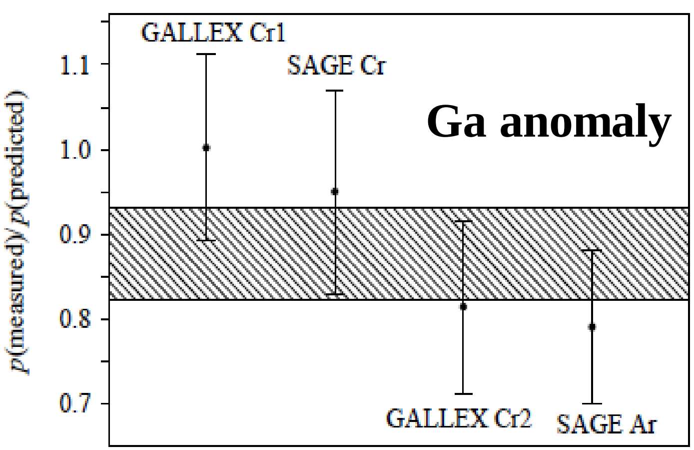
Hints for light sterile neutrinos

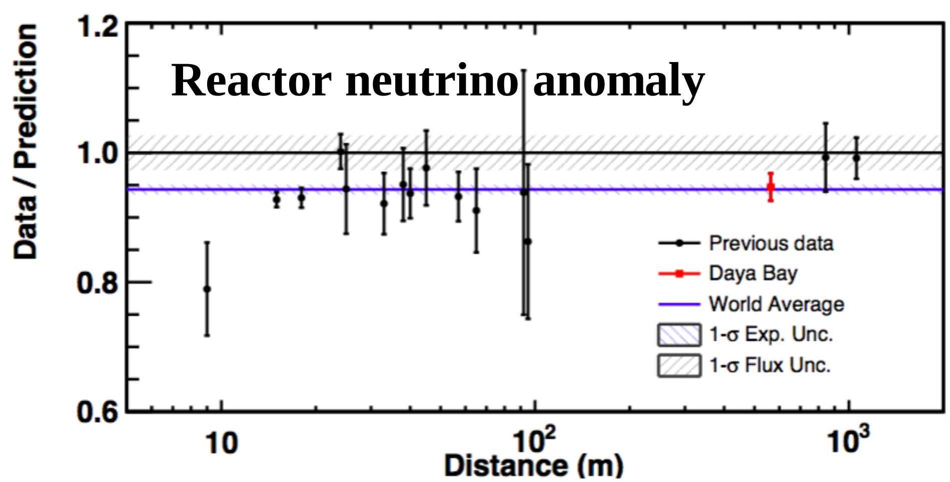


$\bar{\nu}_\mu \to \bar{\nu}_e$ oscillations



All these anomalies indicate ~ eV mass right-handed sterile neutrinos.

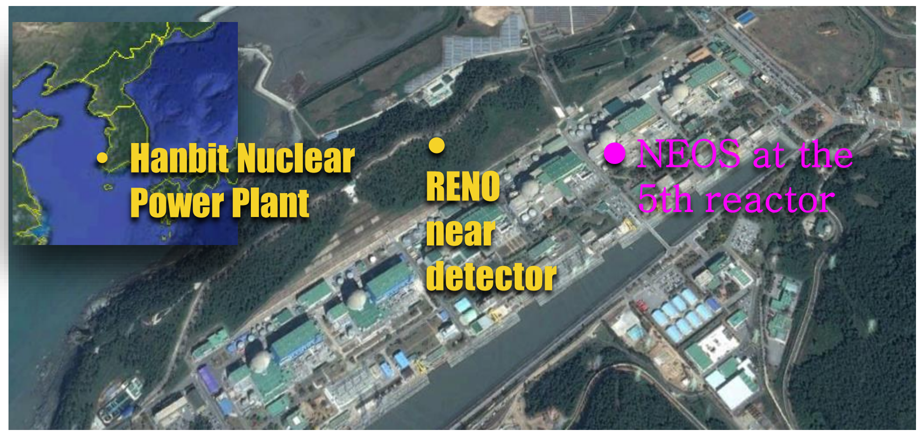


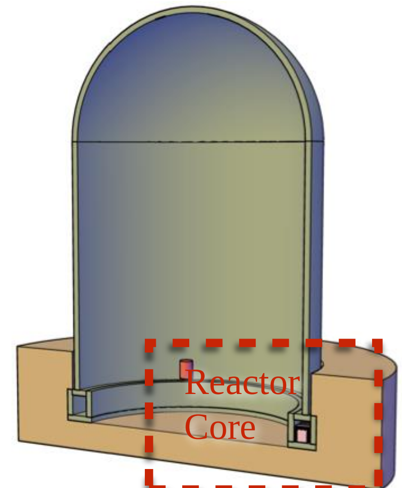


[SAGE, PRC 73 (2006) 045805, nucl-ex/0512041]

NEOS (Neutrino Experiment for Oscillation at Short baseline)

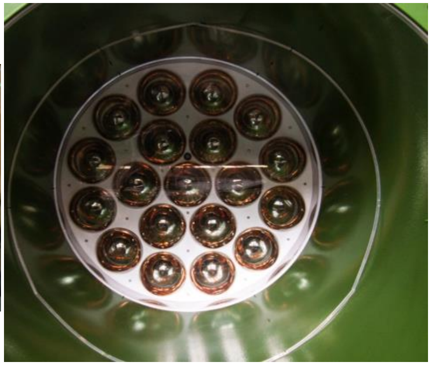
- Possibility to search sterile neutrinos at the commercial power plant.
- Unique experiment with 3 baseline at the same time,
  -- NEOS (25m), RENO-near(~250m) , RENO-far(1300m)





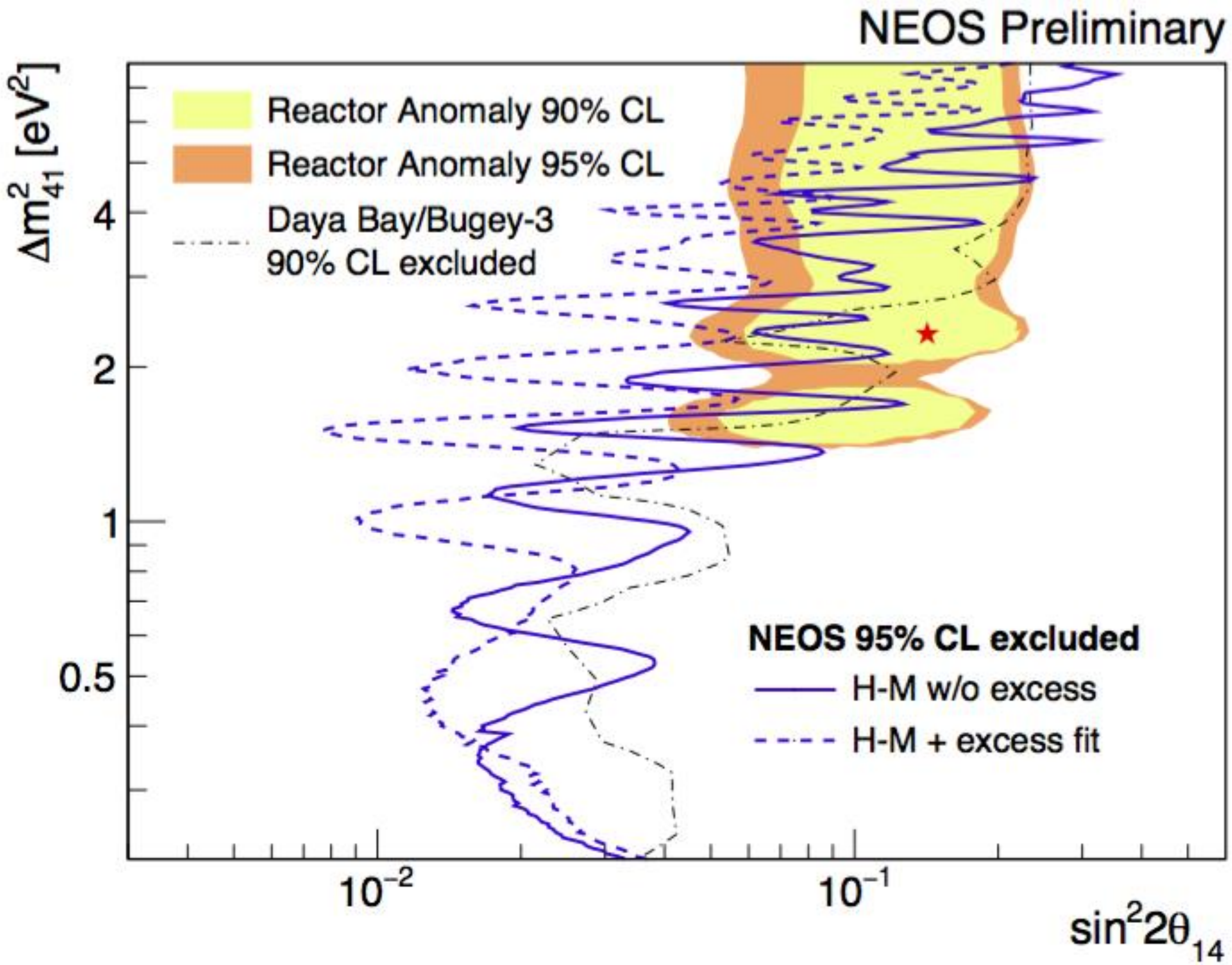
Experiments	Thermal Power	Baseline	Country
PROSPECT	85 MW	7 - 12 (near), 15 - 19 (far) meters	US
Stereo	57 MW	8.9 - 11.1 meters	France
CHANDLER	60 MW	~ 6 meters	Belgium

Detector Constucted & Installed.



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

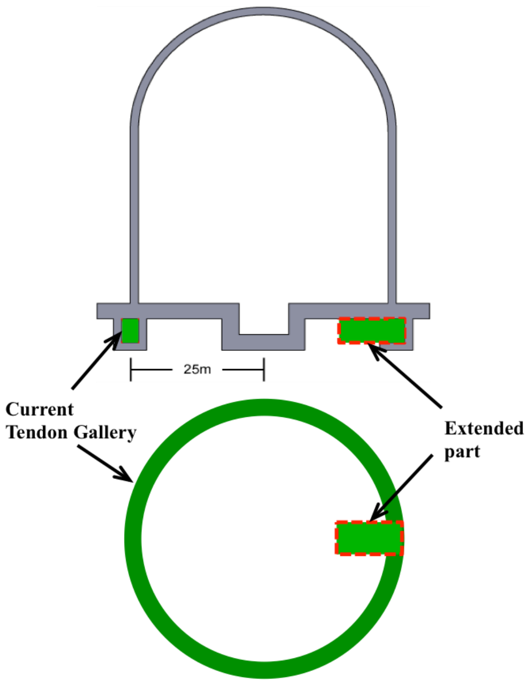
Preliminary results

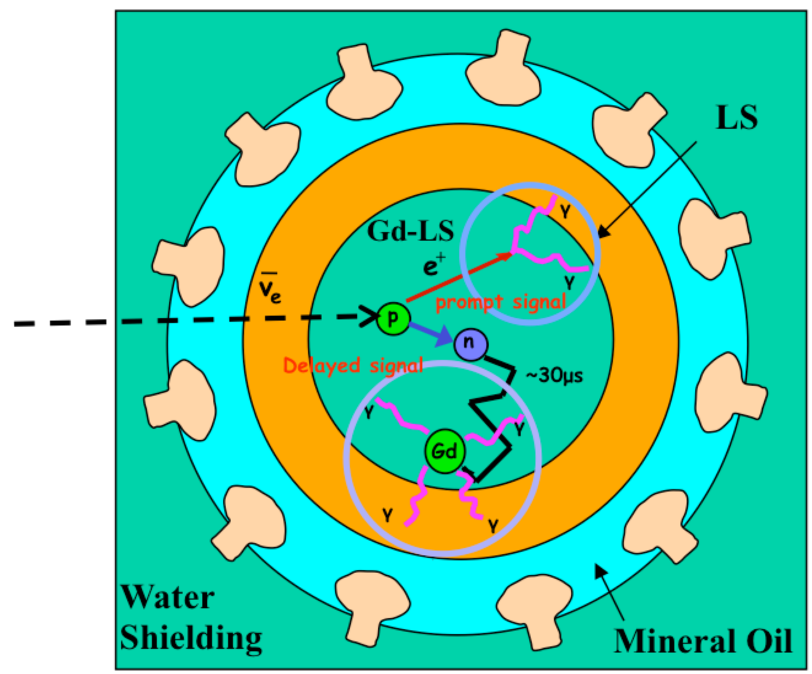


- First result after reactor neutrino anomaly.
- Rejected the best-fit parameter for the anomaly
- Further analysis with Daya Bay and RENO antineutrino spectra.

Ultimate reactor neutrino spectra ?

- A new ~ 2ton size detector with photocathode coverage > 70% at shorter baseline (~15m) can have an energy resolution better than 3% and high statistics (>10000 events/day)
- Tendon Gallery may be extended in a new reactor under consideration in Korea or China for complete burn-up measurements.

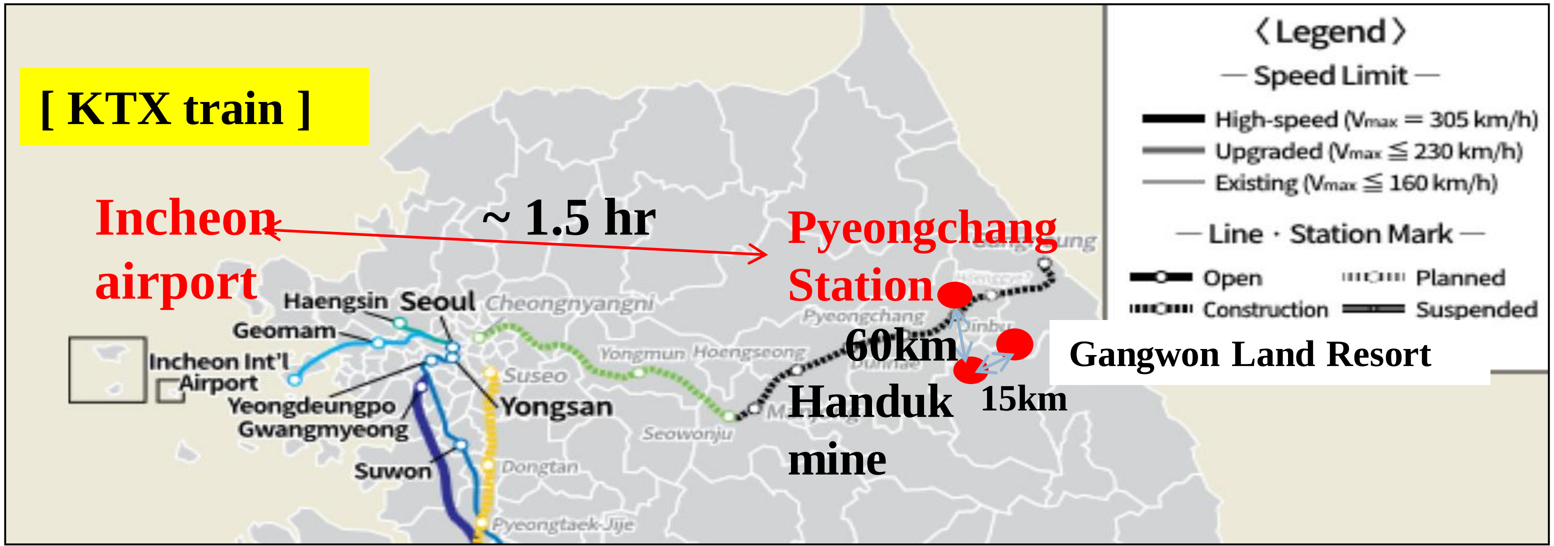




A new underground laboratory at Handuk mine

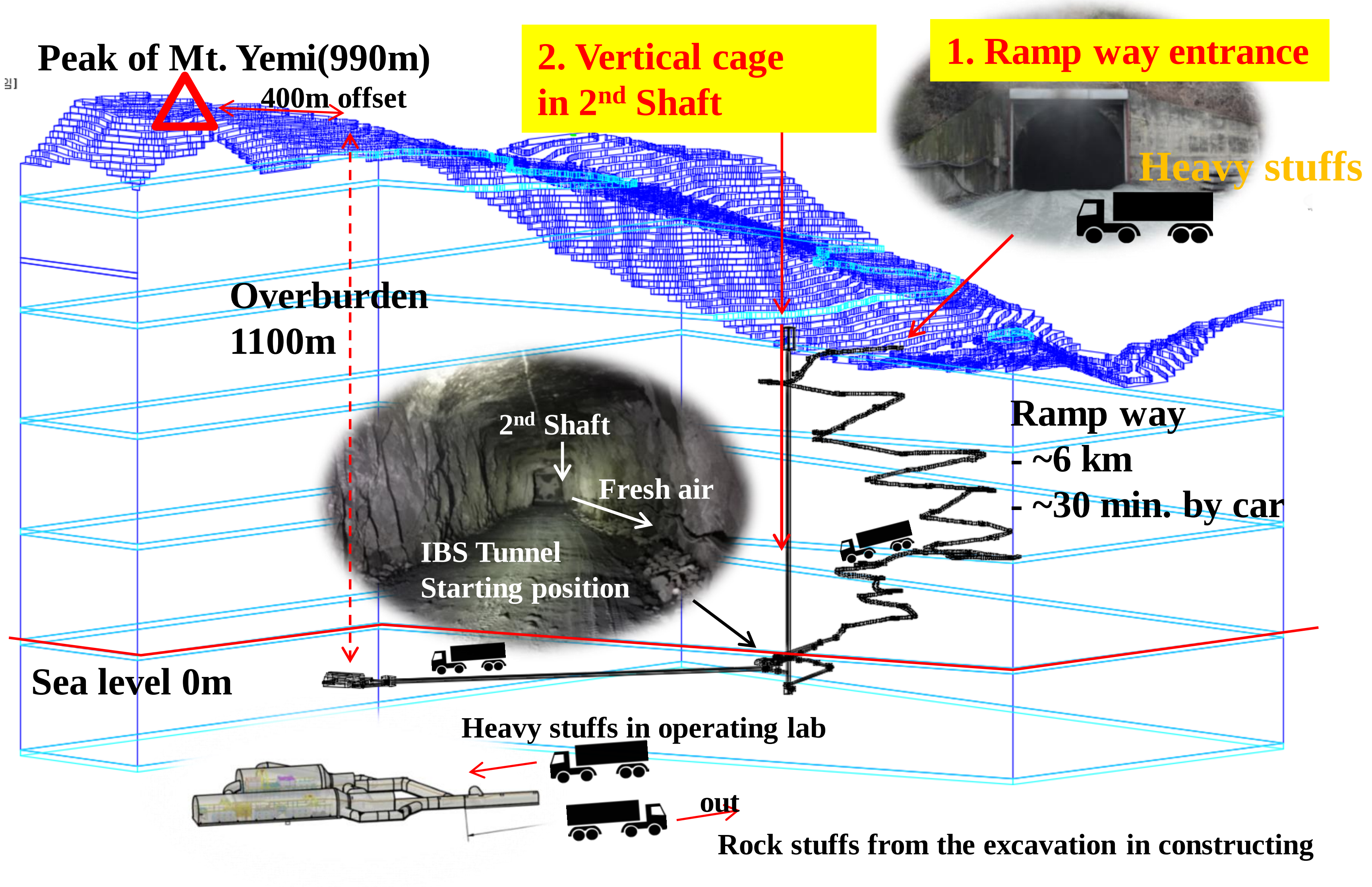
After extensive study, we finally decided to build a new underground lab at an active iron mine, Handuk.

- For 2018 Winter Olympic, construction of a high-speed train between airport to east has started.
- ~ 3 hour from Incheon airport to Handuk mine.

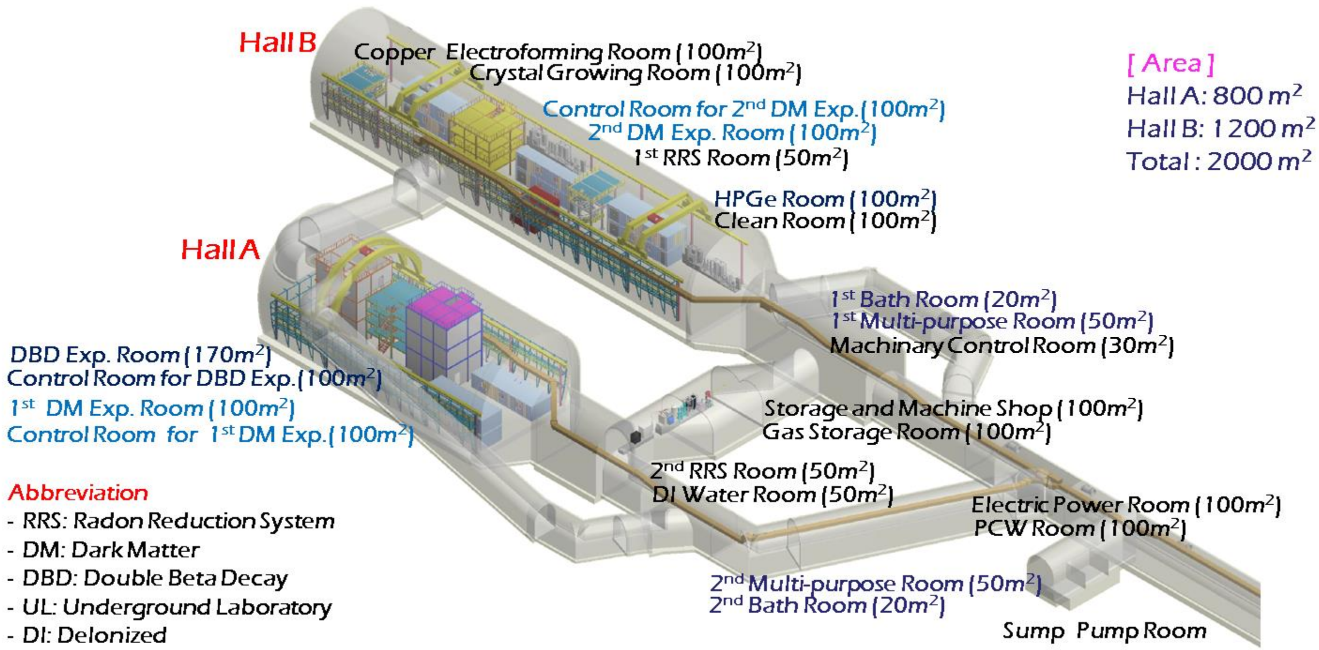


Overview of the laboratory

- Two ways to access to the entrance of IBS tunnel, ramp way and vertical shaft.
- 730 meter long tunnel will be constructed and lab at the end.



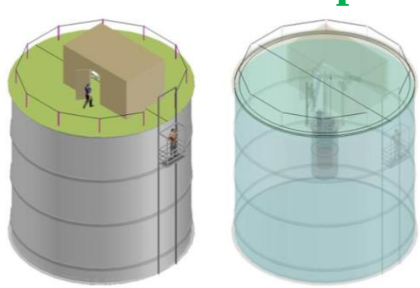
Concept of space in the Underground Lab



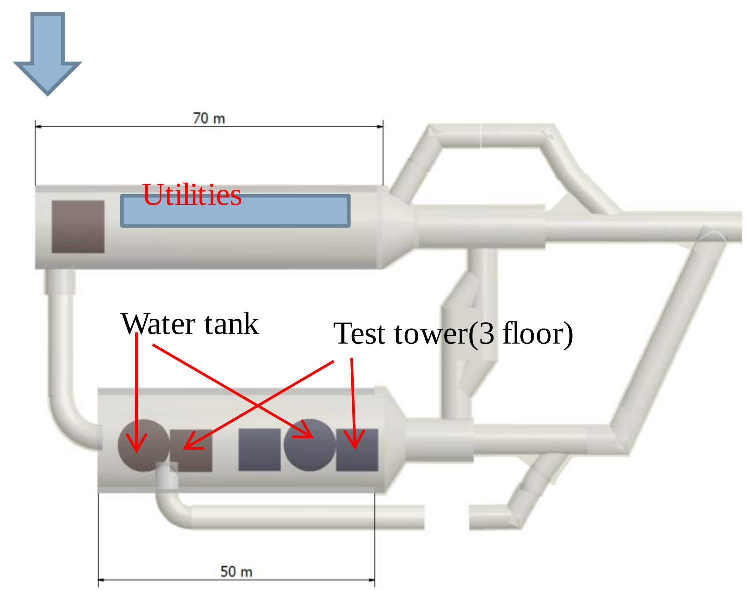
Abbreviation
- RRS: Radon Reduction System
- DM: Dark Matter
- DBD: Double Beta Decay
- UL: Underground Laboratory
- DI: DeIonized
- PCW: Process Cooling Water

	Room Name	Area	Location
1	DBD Exp. Room	170 m²	Hall A
2	Control Room for DBD Exp.	100 m²	Hall A
3	1st DM Exp. Room	100 m²	Hall A
4	Control Room for 1st DM Exp.	100 m²	Hall A
5	2nd DM Exp. Room	100 m²	Hall B
6	Control Room for 2nd DM Exp.	50 m²	Hall B
7	HPGe Room	100 m²	Hall B
8	Clean room (50m2 x 2)	100 m²	Hall B
9	Crystal Growing Room	100 m²	Hall B
10	DI Water Room	50 m²	Hall B
11	Copper Electroforming Room	100 m²	Hall B
12	1st and 2nd RRS Room	100 m²	Aux. space
13	PCW Room	100 m²	Aux. space
14	Gas Storage Room	100 m²	Aux. space
15	Storage and Machine Shop	100 m²	Aux. space
16	Electric Power Room	100 m²	Aux. space
17	Multipurpose RoomX2	100 m²	Aux. space
18	Bath Room (20m2 x 2)	40 m²	Aux. space
19	Machinary Control Room	30 m²	Aux. space
	Total	1740 m²	

[Relocation scheme of lab space]

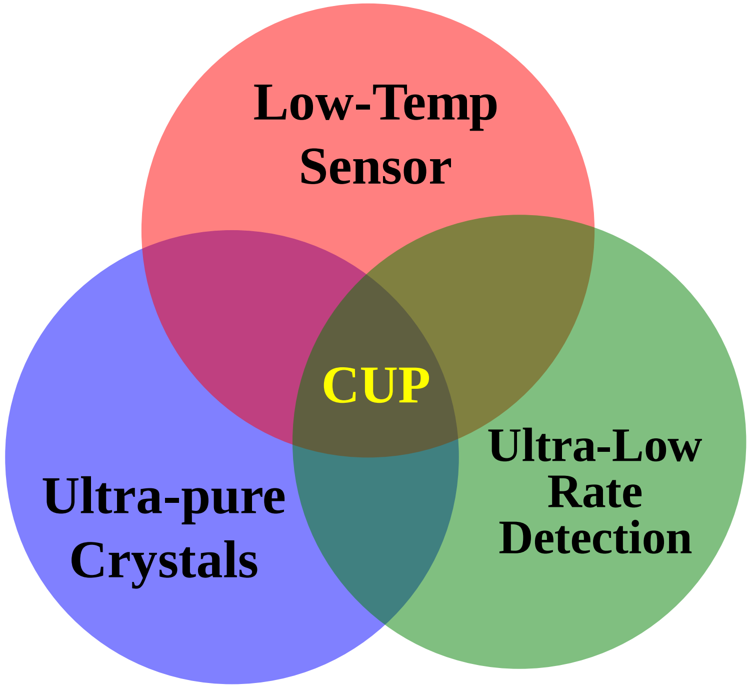


We consider the concept of water-tank(D: 10m, H: 10m) for LT detectors



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.

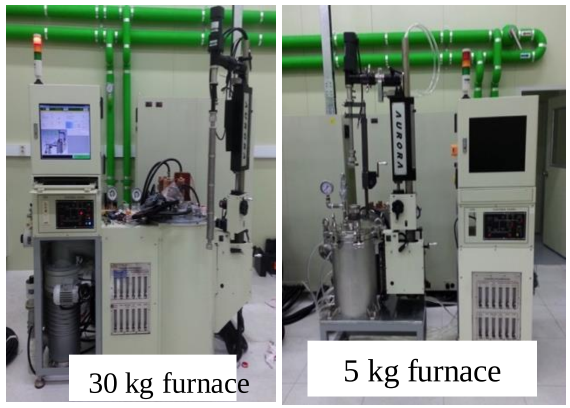


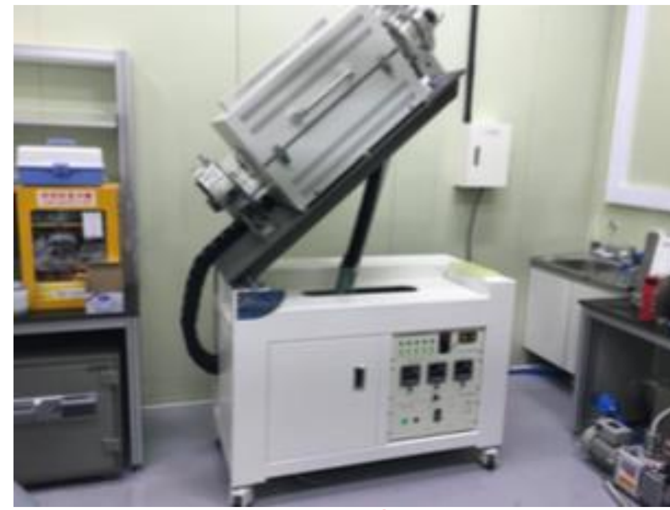
Ultrapure crystals – Purification & growing crystal

- 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.

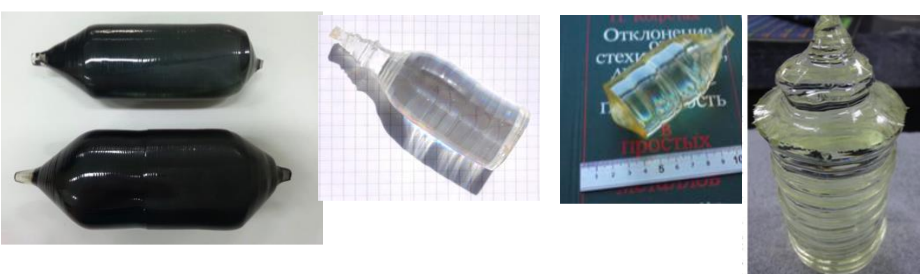
Czochralski furnace

Kyropoulos furnace





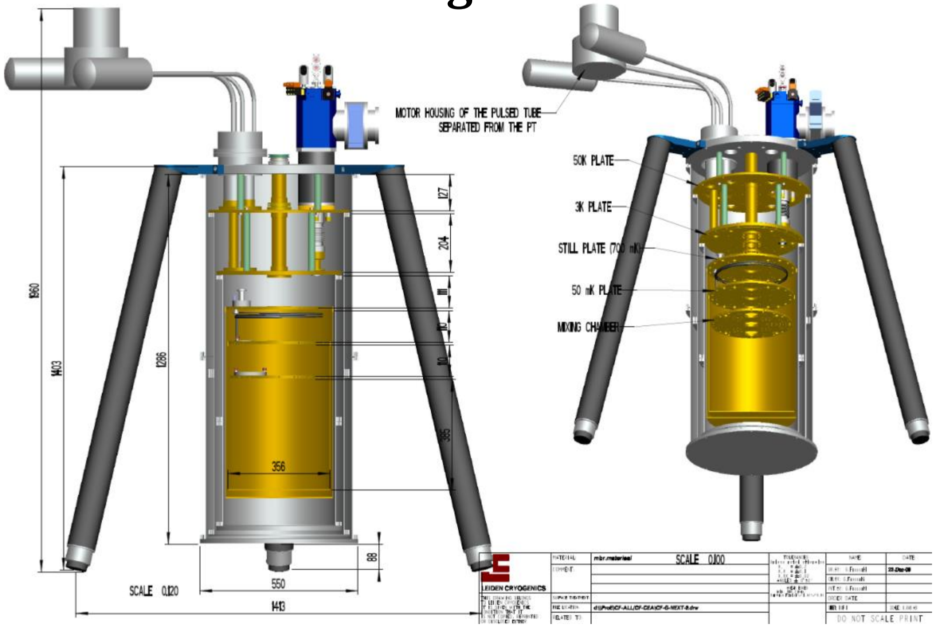
Sublimation facility



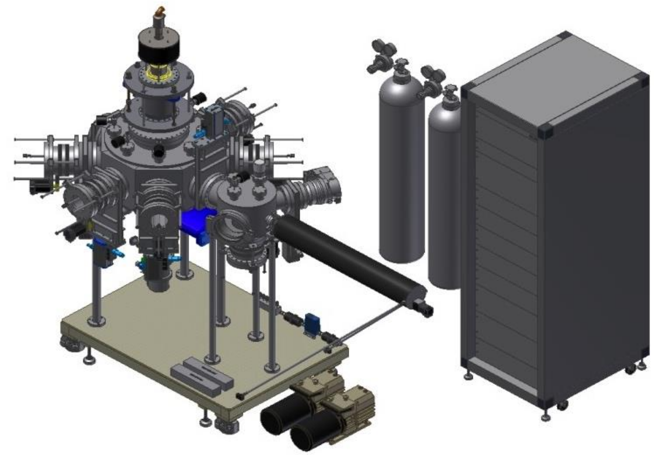
Chemistry Lab.

Low temp sensors and detectors

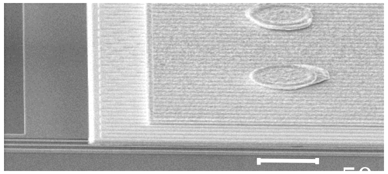
Dilution refrigerators

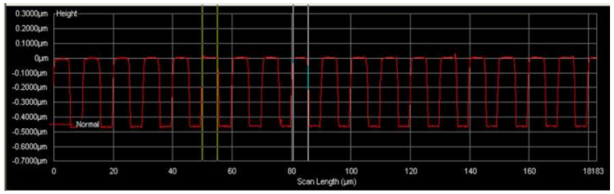


Sputtering system: Au:Er, Au, Nb, MoGe,



ICP RIE: Dry etching Nb superconducting coil



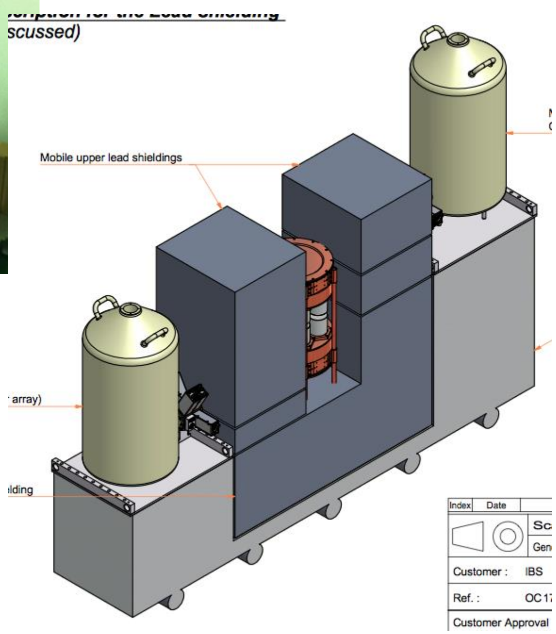


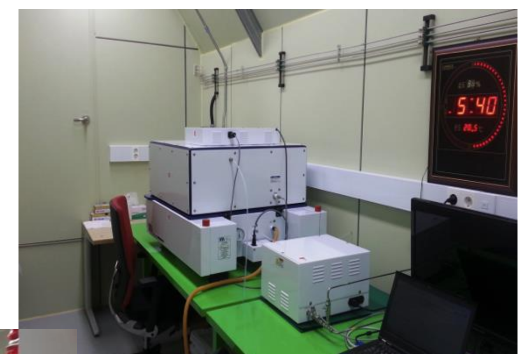
Magnetic property measurement system: Au:Er characterization

Ultra-low radioactivity measurements

- To reach the required low radioactivity in the detectors, we need to develop techniques to measure such low radioactivity in materials.

- Developed Techniques
  1. HPGe gamma-ray detectors. — Ra : 0.01mBq/kg level
  2. ICP-MS analyzer — U, Th down to ppt level
  3. Alpha counter — R>0.0001 alphas/cm^2/hour
  4. Radon detector — Radon level down to 5mBq/m^3





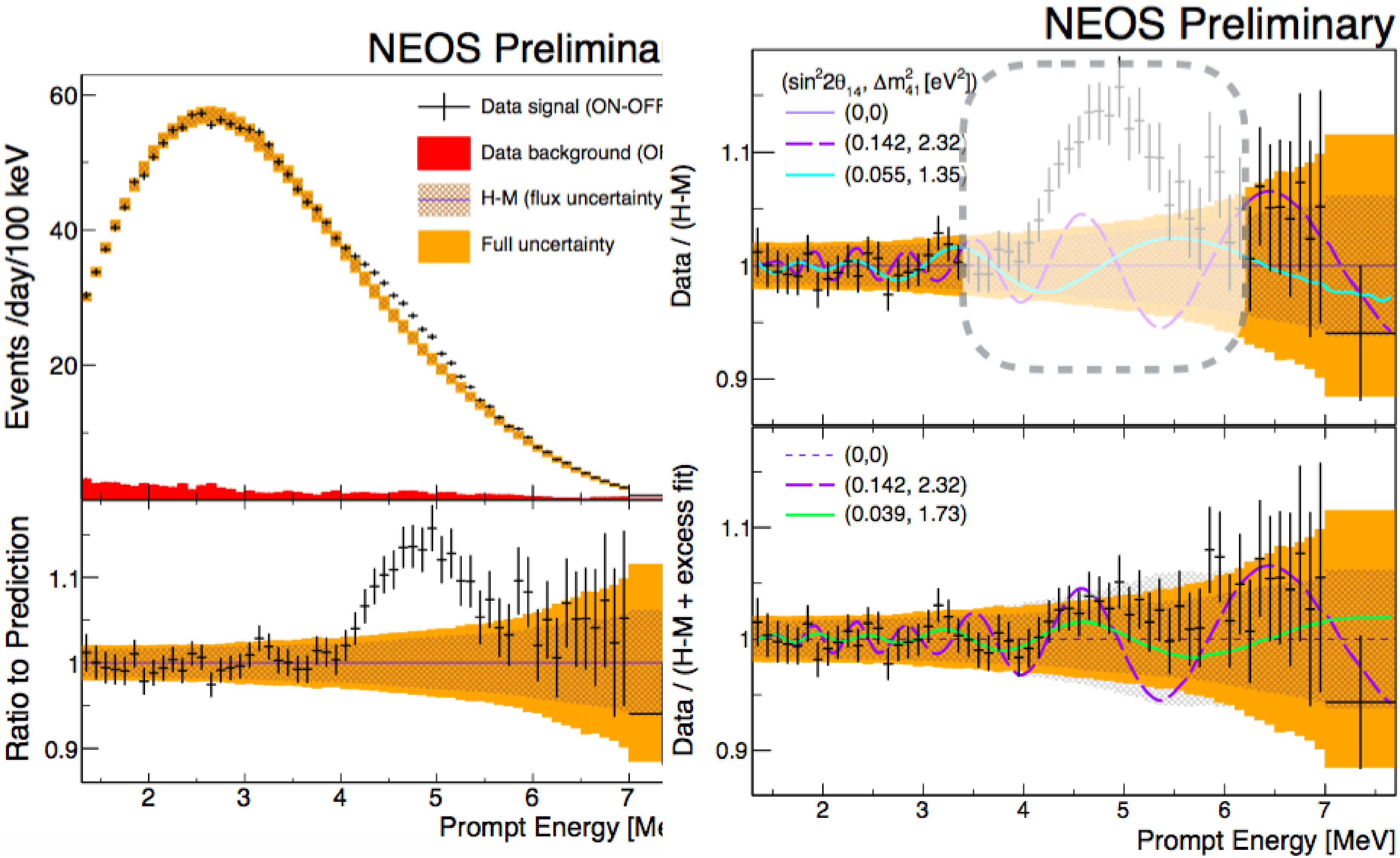
Summary

- In addition to Dark Matter Search program, neutrino physics programs are actively pursued at CUP.
- AMoRE project will cover inverted mass hierarchy region for a discovery and will lead the ton-scale 0nbb with international collaboration.
- NEOS gives more stringent limits to the reactor neutrino anomaly, and rejects the best-fit parameters.
- 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.

If you are interested in CUP researches,
join to CUP !!

Job announcement in Aug. – Sep. this year !!

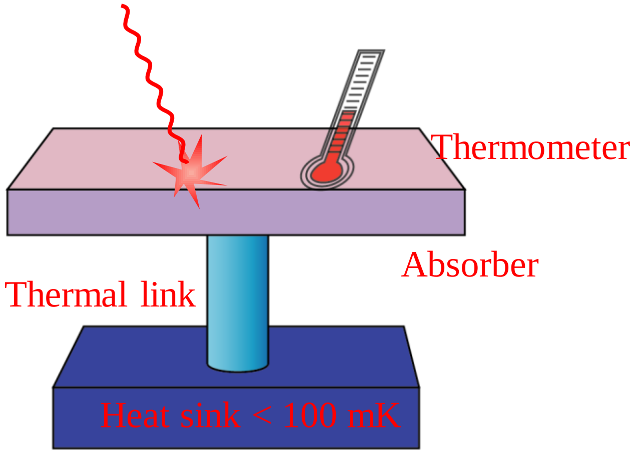
http://www.ibs.re.kr
http://cupweb.ibs.re.kr

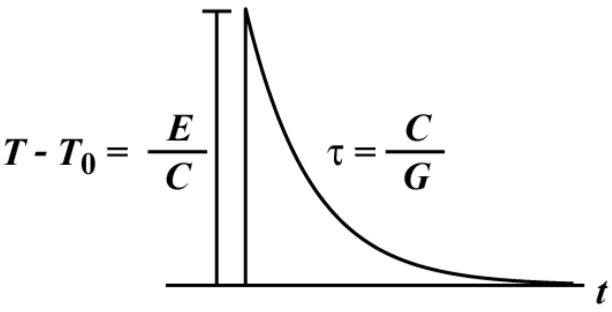

NEOS Prelimina
Data signal (ON-OFF
Data background (OF
H-M (flux uncertainty
Full uncertainty
Events /day/100 keV
Ratio to Prediction
Prompt Energy [Me
NEOS Preliminary
($\sin^2 2\theta_{14}$, Δm^2_{41} [eV^2])
(0,0)
(0.142, 2.32)
(0.055, 1.35)
Data / (H-M)
(0,0)
(0.142, 2.32)
(0.039, 1.73)
Data / (H-M + excess fit)
Prompt Energy [MeV]

Low temperature detector technique

"Calorimetric measurement of heat signals at mK temperatures"

Energy absorption → Temperature

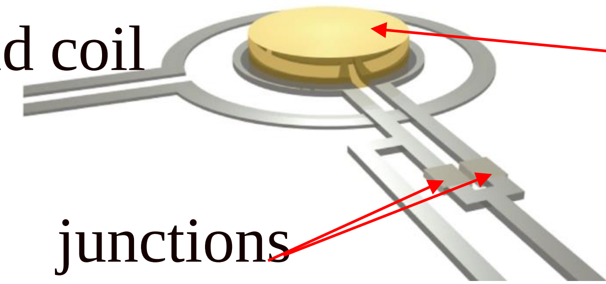




Choice of thermometers

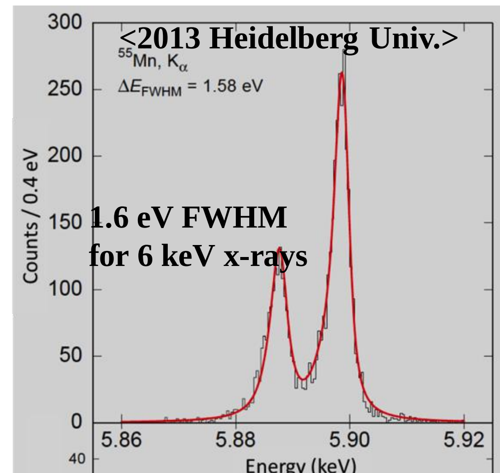
- Thermistors (NTD Ge, doped Si)
- TES (Transition Edge Sensor)
- **MMC (Metallic Magnetic Calorimeter)**
- etc.

Metallic magnetic calorimeter (MMC)

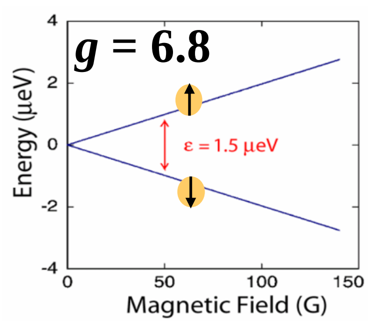


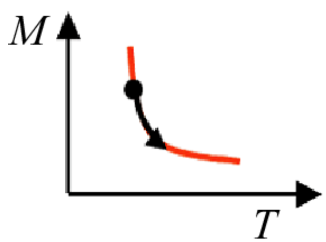
Magnetic material Au:Er(10~1000ppm)

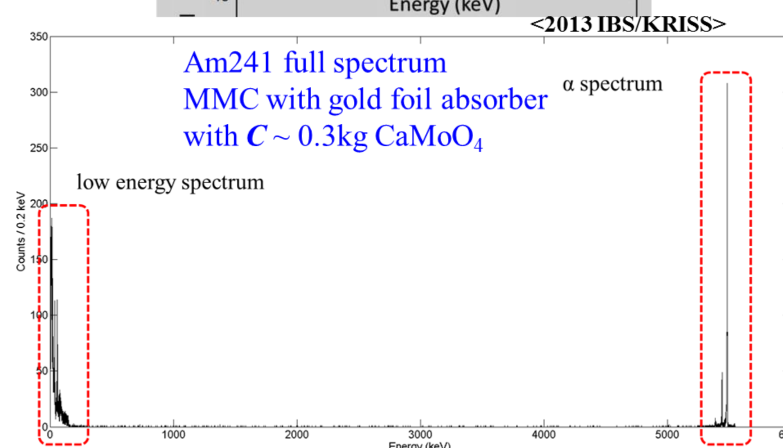
- weakly-interacting paramagnetic system
- metallic host: fast thermalization (~ 1μs)



$$\delta E \rightarrow \delta T \rightarrow \delta M \rightarrow \delta \phi$$







0.3 keV FWHM
for 60keV γ

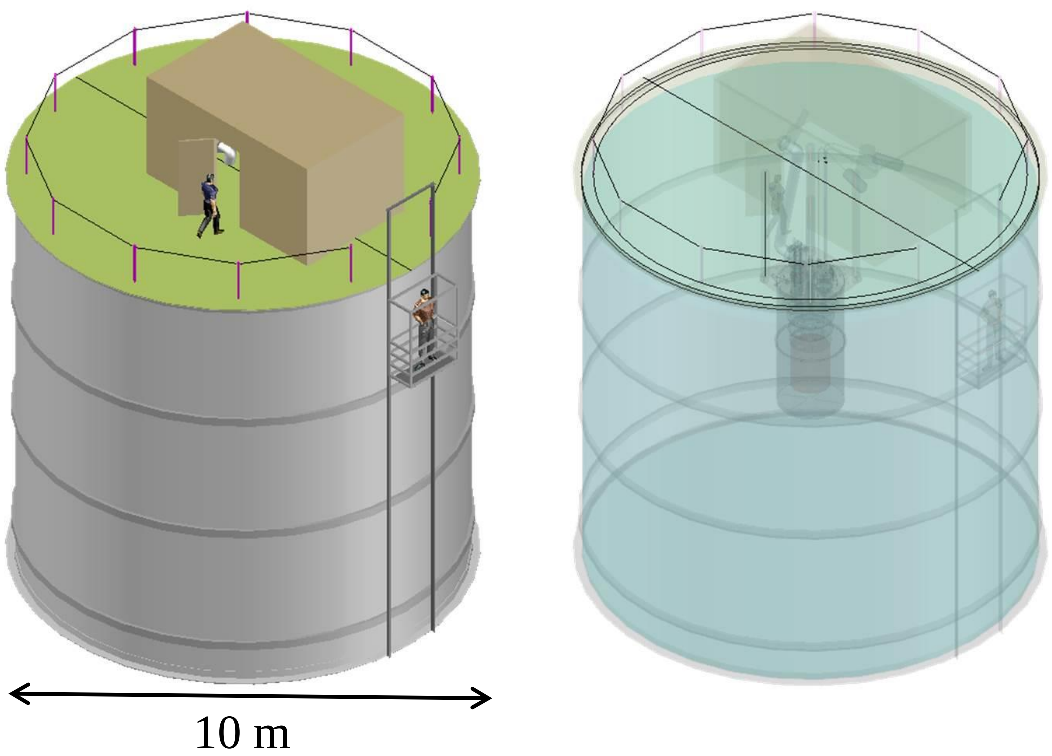
1.2 keV FWHM
for 5.5MeV α

5 mT → $\Delta\varepsilon$ = 1.5 μeV

1 keV → 10^9 spin flips

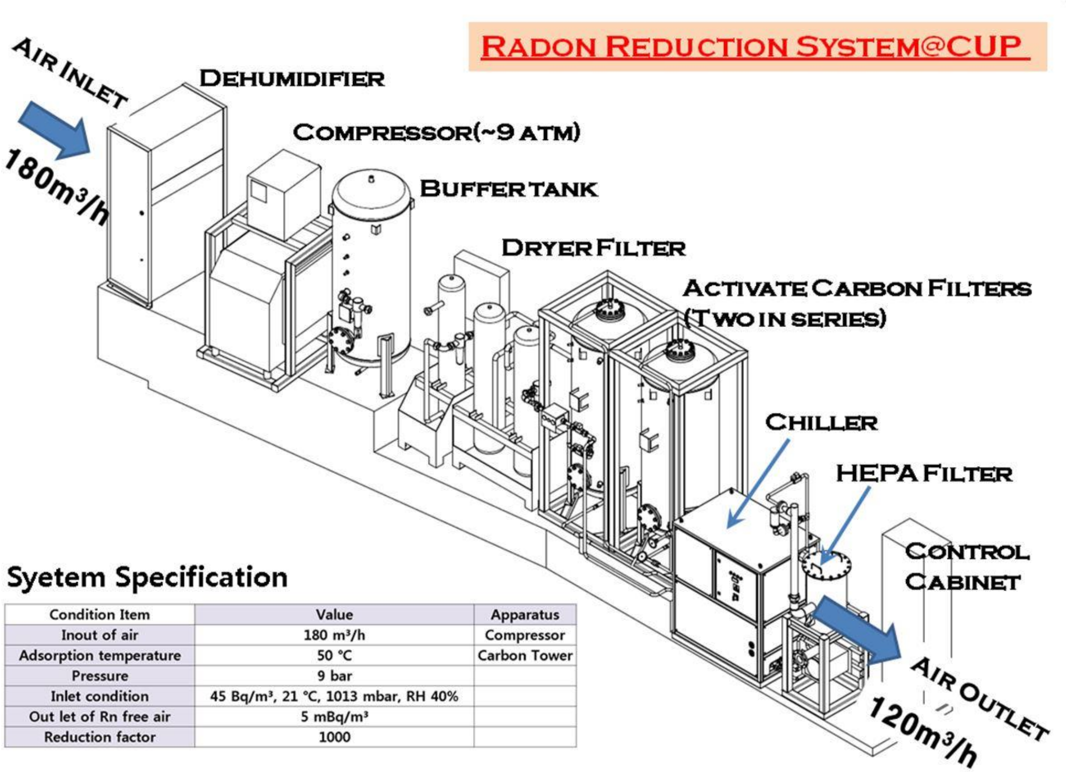
AMoRE-II(200kg) Shield and Cryostat

- One of conceptual plans
- Water tank for active shield (similar design and size of LUX and XMASS)
- Cryostat submerged in the pure water.
- This setup requires lots of R&Ds,
- and desperately requires wider, higher, and hopefully deeper lab space.



Radon reduction system

- Imported from Czech and installed in Aug. 2015.
- 120 m^3/hour of Rn free air (50 Bq/m^3 → 5mBq/m^3) will be supplied.
- Important to prohibit Radon contamination during detector assembly
- Korean company will try to develop the technique.
- Rn-free air will be supplied to the most sensitive clean room.

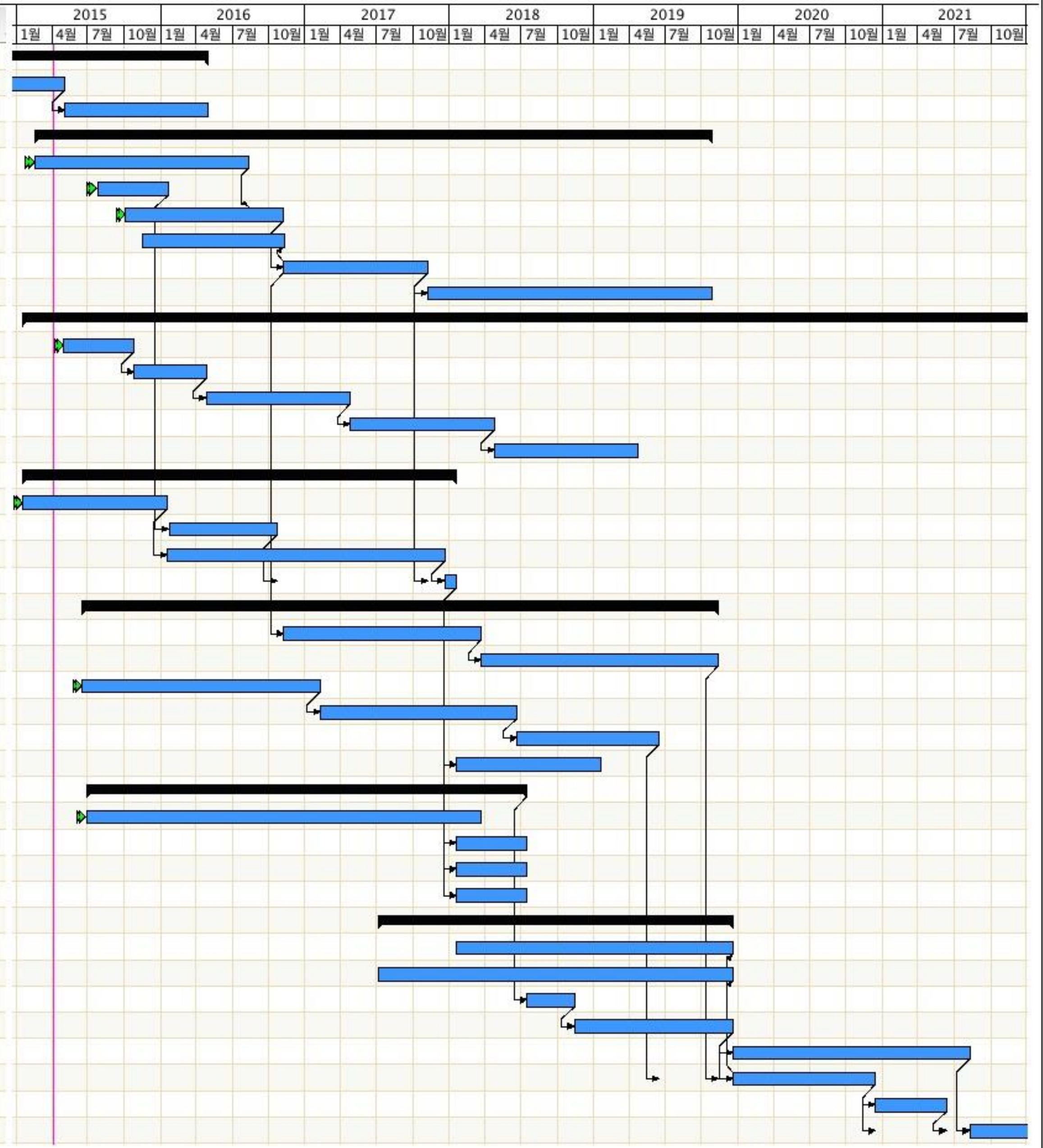


Syetem Specification

Condition Item	Value	Apparatus
Inout of air	180 m^3/h	Compressor
Adsorption temperature	50 °C	Carbon Tower
Pressure	9 bar	
Inlet condition	45 Bq/m^3, 21 °C, 1013 mbar, RH 40%	
Out let of Rn free air	5 mBq/m^3	
Reduction factor	1000	

AMoRE schedule

Key	Task Name	Duration (Days)
79	AMoRE-Pilot	540.0
78	Setup Y2L	180.0
77	Run	360.0
10	AMoRE-10	1,715.0
220	Get Crystals	540.0
246	Setup test cryostat Y2L	180.0
221	Tests on Crystals	400.0
269	Electronics	360.0
219	Run 1	365.0
257	Run 2	720.0
12	AMoRE-200	3,125.0
229	Mo100 contract	180.0
228	Get Mo100 10kg	180.0
227	Get Mo100 30kg	365.0
226	Get Mo100 40kg	365.0
225	Get Mo100 40kg	365.0
224	Decision on Crystal	1,095.0
244	Get crystals	365.0
243	Cryostat tests	270.0
242	Grow & test Crystals	700.0
247	Decide crystal	30.0
255	Cryostat for AMoRE200	1,608.7
256	Cryo Design	500.0
258	Cryo Manuf & Install	600.0
263	Shielding Decisior	600.0
262	Shielding Design	500.0
264	Make shielding	360.0
222	Get 40Ca (option)	365.0
265	Establish ULB crystals	1,114.3
230	Research Low Bkg.	1,000.0
260	Recovery R&D	180.0
266	Confirm ULB	180.0
267	Confirm growing	180.0
270	Electronics	900.0
271	MMCs	700.0
272	SQUID Manuf.	900.0
259	Growing contract	120.0
231	Grow Crystals 70kg	400.0
249	Grow Crystals 130kg	600.0
232	Run Phase 70kg	360.0
268	Upgrade	180.0
233	Run Phase 200kg	730.0



Current best results for 0νββ

Isotope	**Exp**	**$T_{1/2}(10^{24}Y)$**
^{48}Ca	ELEGANT VI	>0.058
^{76}Ge	GERDA-I	>21
^{82}Se	NEMO-3	>0.32
^{96}Zr	NEMO-3	>0.0092
^{100}Mo	NEMO-3	>1.0
^{116}Cd	Solotvina	>0.17
^{130}Te	CUORE	>2.8
^{136}Xe	EXO-200,KamLAND-Zen	>19
^{150}Nd	NEMO-3	>0.018

Background Simulations for AMoRE-I

Internal

Near CMO

		Concentration (mBq/kg)	Time	Rate (10^{-3} counts/keV/kg/yr)		
				α	β events	β with cut
Internal CMO	Pb210	7.3	42.66	17		
	U238	0.98	34.25	5.5		
	Ra226	0.065	516.38	1.16	0.15	**0.015**
	Th228	0.050	698.91	0.546	27.3	**0.72**
	Bi211	0.470	68.20	5.53		
Vikuiti	Bi214	<0.91	2.34E+04	9.41	0.846	**0.119**
	Tl108	<0.48	4.68E+04	3.68	0.396	**0.177**
CMO supporting copper frame	Ra226	<0.16	8484	0.0146	0.0022	**0.0022**
	Th228	<0.25	5684	0.0170	0.2556	**0.2542**
SC lead shield	Ra226	1 ppt	9253		0.0029	0.0029
	Th228	1 ppt	30354		0.0079	0.0079
Inner lead plate	Ra226	1 ppt	1465.8		0.007	0.007
	Th228	1 ppt	1182.8		0.009	0.009
Cu Plate	Ra226	<0.16	8746.0		0.0013	0.0013
	Th228	<0.25	6077.6		0.0023	0.0023
G10 fiberglass	Ra226	2.16×10^4	2.43E+04		0.0026	0.0026
	Th228	5.03×10^4	2.50E+04		0.0064	0.0064
Stainless Steel	Ra226	<0.2	5.26E+06		0.0049	0.0049
	Th228	<0.1	2.55E+07		0.0057	0.0057
Total				42.86	29.00	**1.34**

Total backgrounds $< 1.34\times10^{-3}$ ckky.

Expect zero backgounds for AMoRE-I.

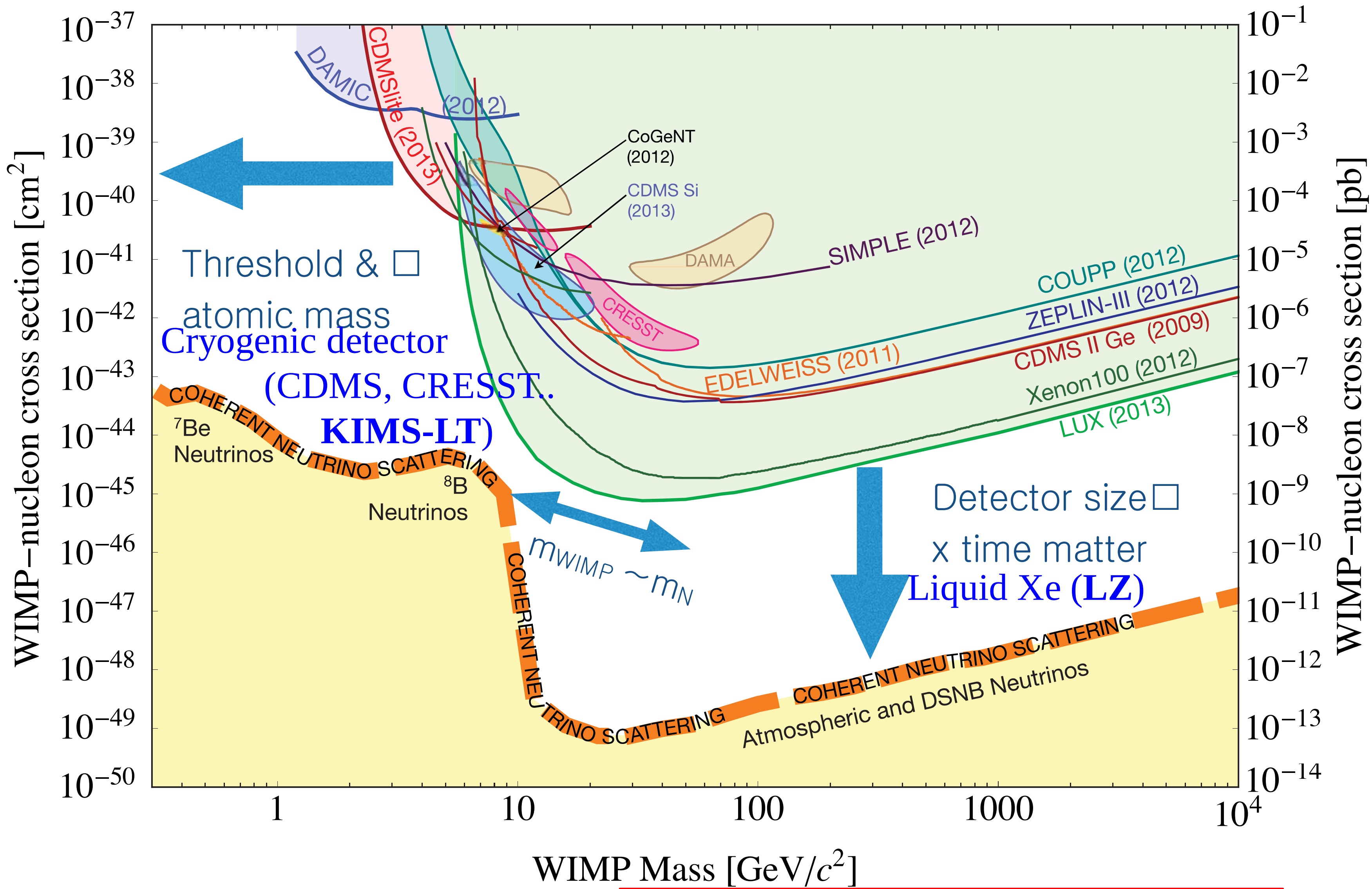
Strategy for AMoRE-II

- **Crystallization is very delicate technique.**
- **CUP is purchasing 120 kg of ^{100}Mo powder from ECP company directly and will have all the material until 2018.**
- **CUP will develop purification and crystal growing techniques with a collaboration with Russian researchers and institutes.**
- **AMoRE-II is the largest DBD experiment fully approved, and will reach inverted mass region first !!**
- **If not detected at that region, then go further with ~ ton scale exp.**

Crystal Experts related with AMoRE projects

- Dr. Shlagel, Institute for Inorganic Chemistry, Novosibirsk, Russia
- Dr. Galashov, Novosibirsk State University, Russia → will set up new tech in CUP
- Dr. Kornoukhov, IHEP, Moscow, Russia
- Dr. Ren, SICCAS, China
- Dr. Danevich, INR, Ukraine
- Prof. Hongjoo Kim, Kyungpook National University
- TPS company in Korea.

World-wide dark matter search status



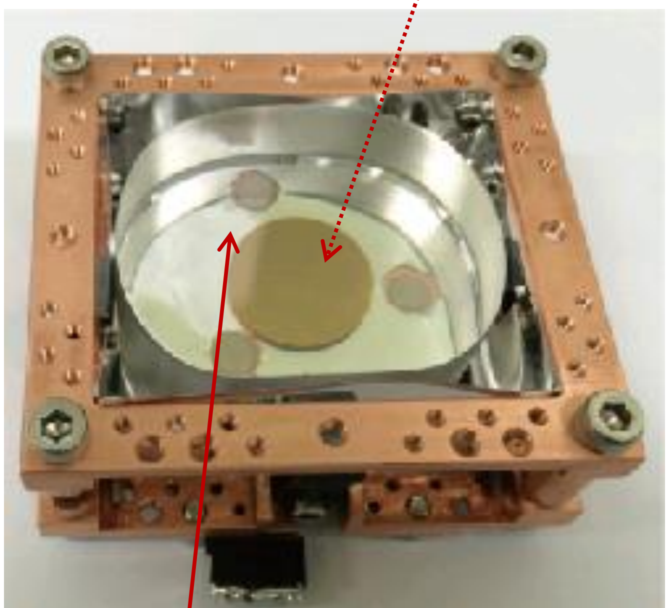
From Lepton Photon 2015, L. Baudis

3. KIMS-LT Project

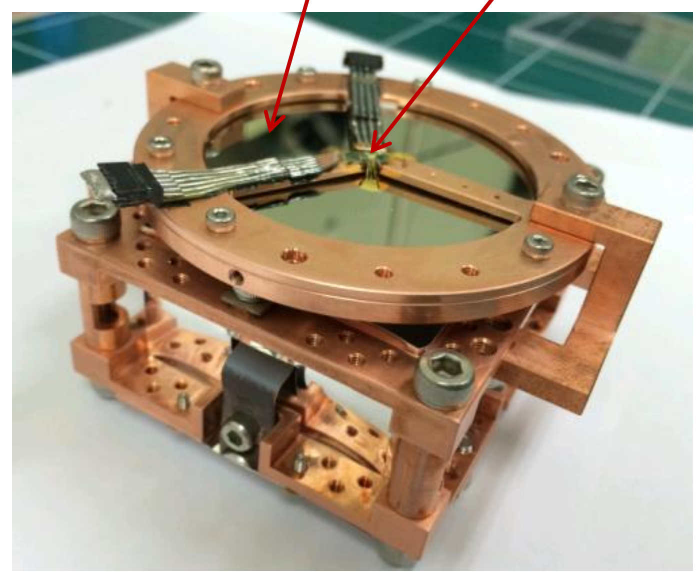
- Scintillating Crystal @ 10-20 mK
- Phonon vs Light will separate nuclear recoil signal.
- Technology developed for AMoRE experiment

Phonon collector film
on bottom surface

Light detector
2 inch Ge wafer + MMC



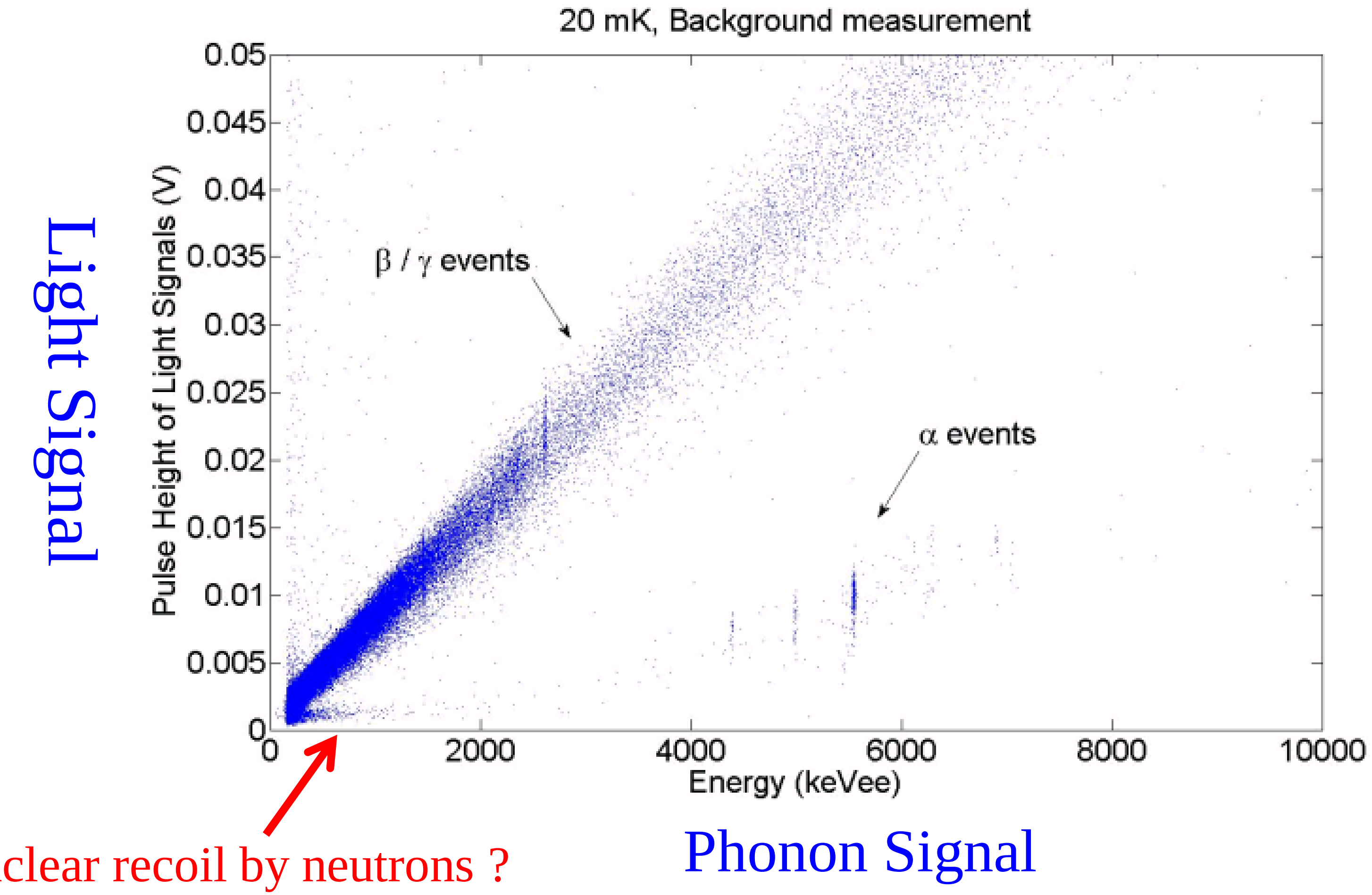
$200g\ CaMoO_4$



MMC : Metallic Magnetic Calorimeter

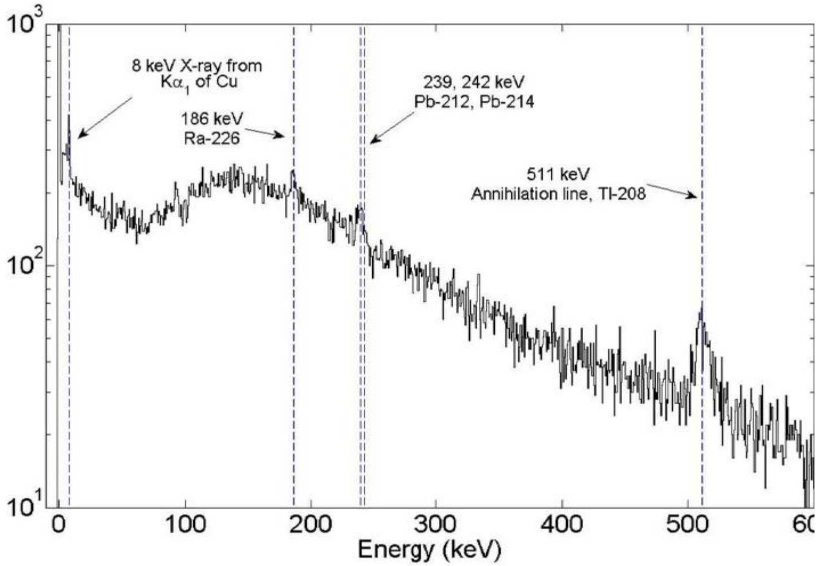
Phonon and Photon signals

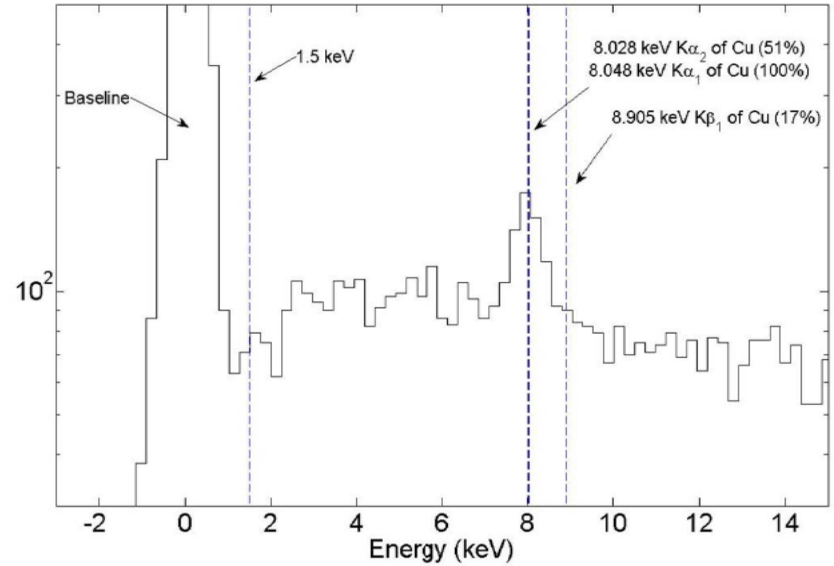
at KRISS (over-ground) lab

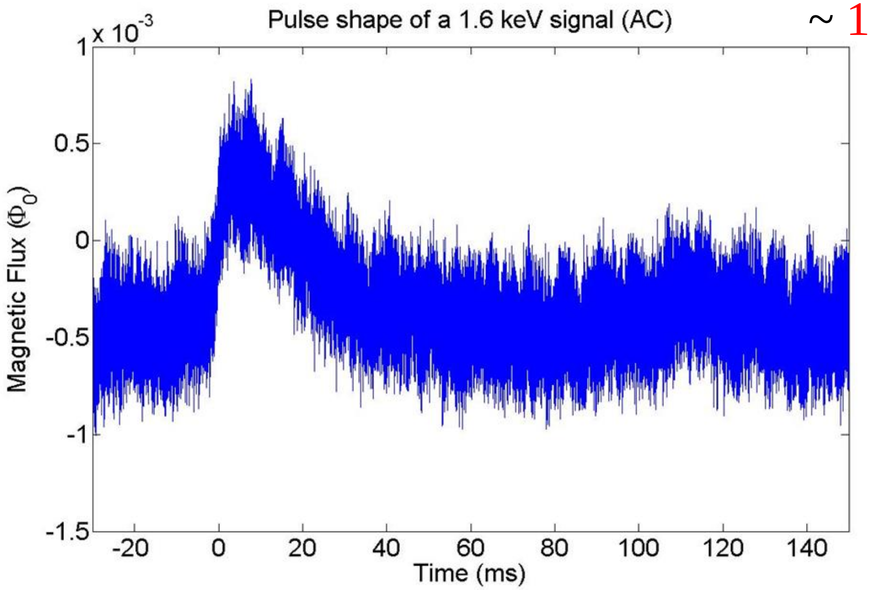


Need to optimize the separation at low energy.

Low energy spectrum

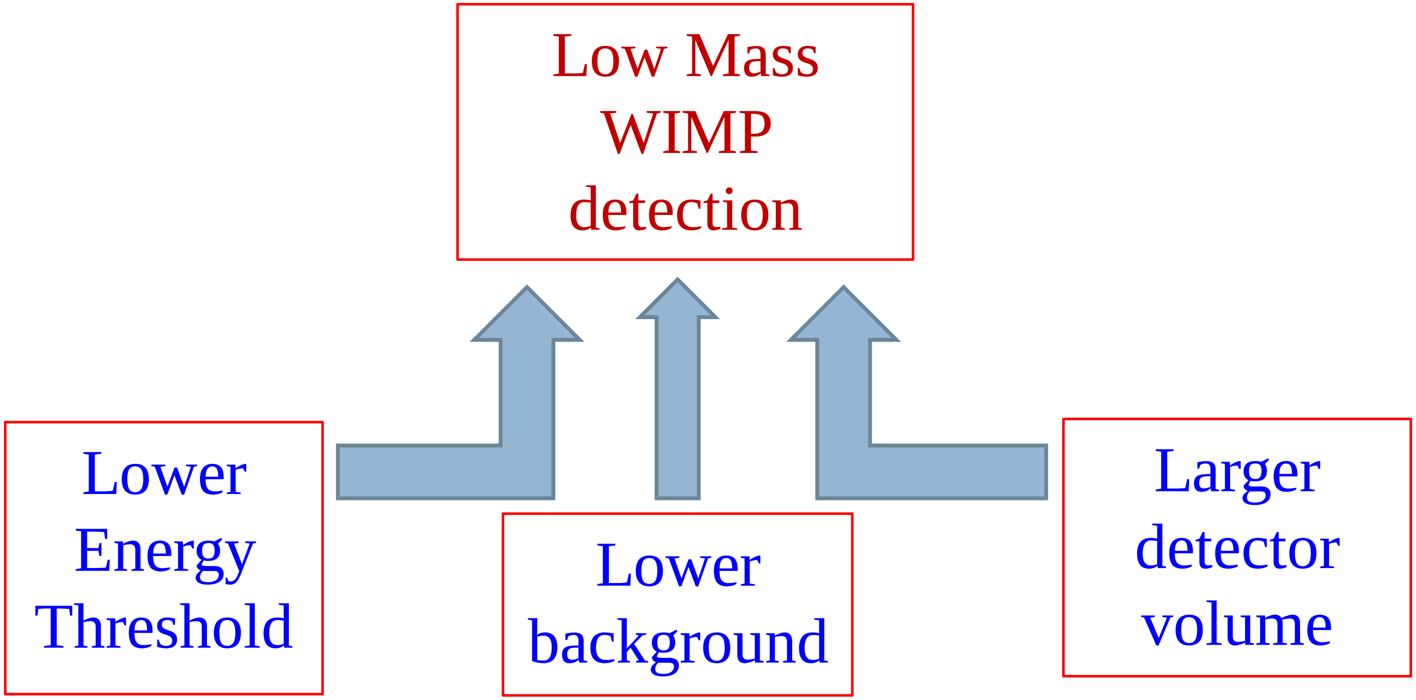




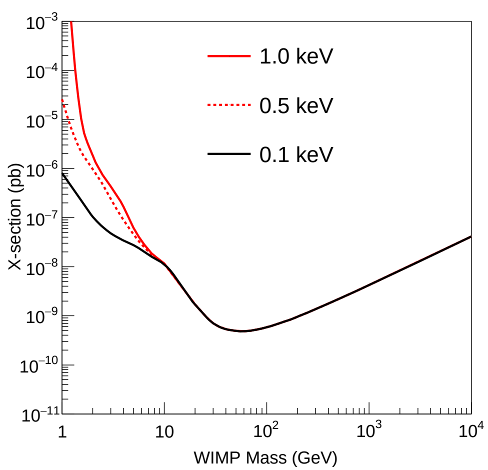


~ 1keV energy threshold

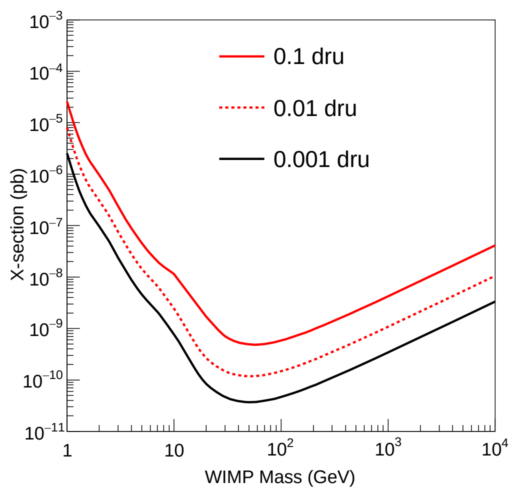
Strategy for low-mass dark matter search



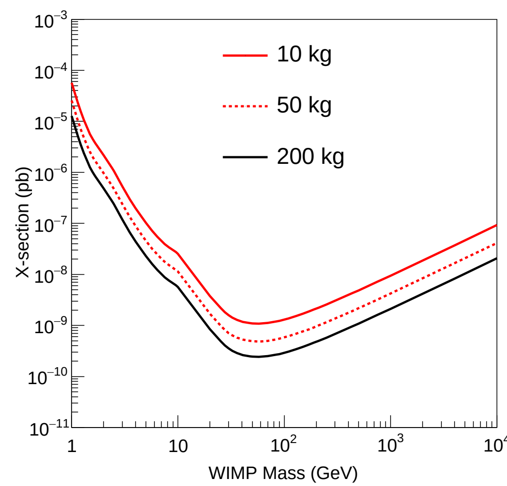
50 kg, 0.1 dru



50 kg, 0.5 keV threshold



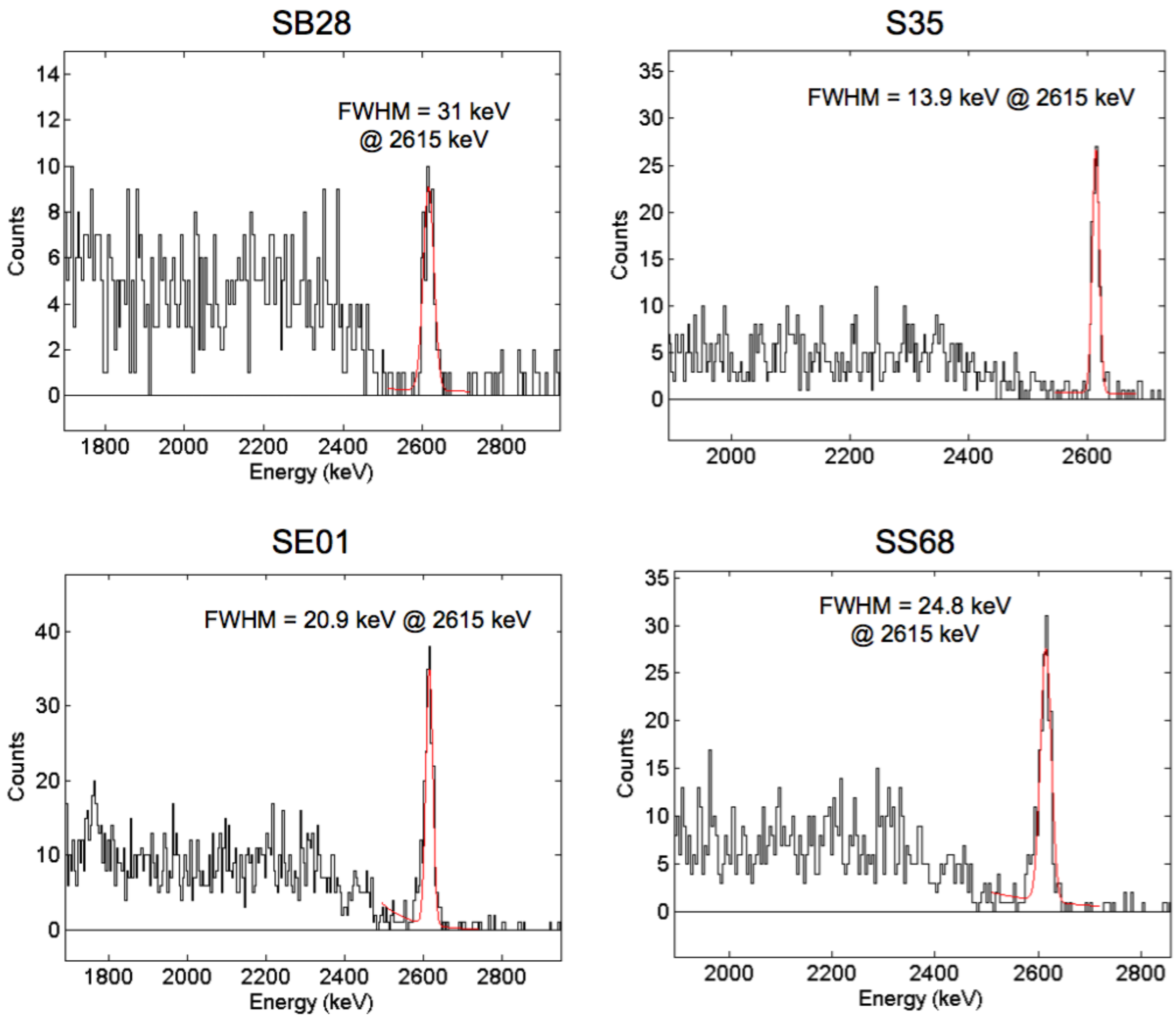
0.1 dru, 0.5 keV threshold



CUP (Center for Underground Physics)

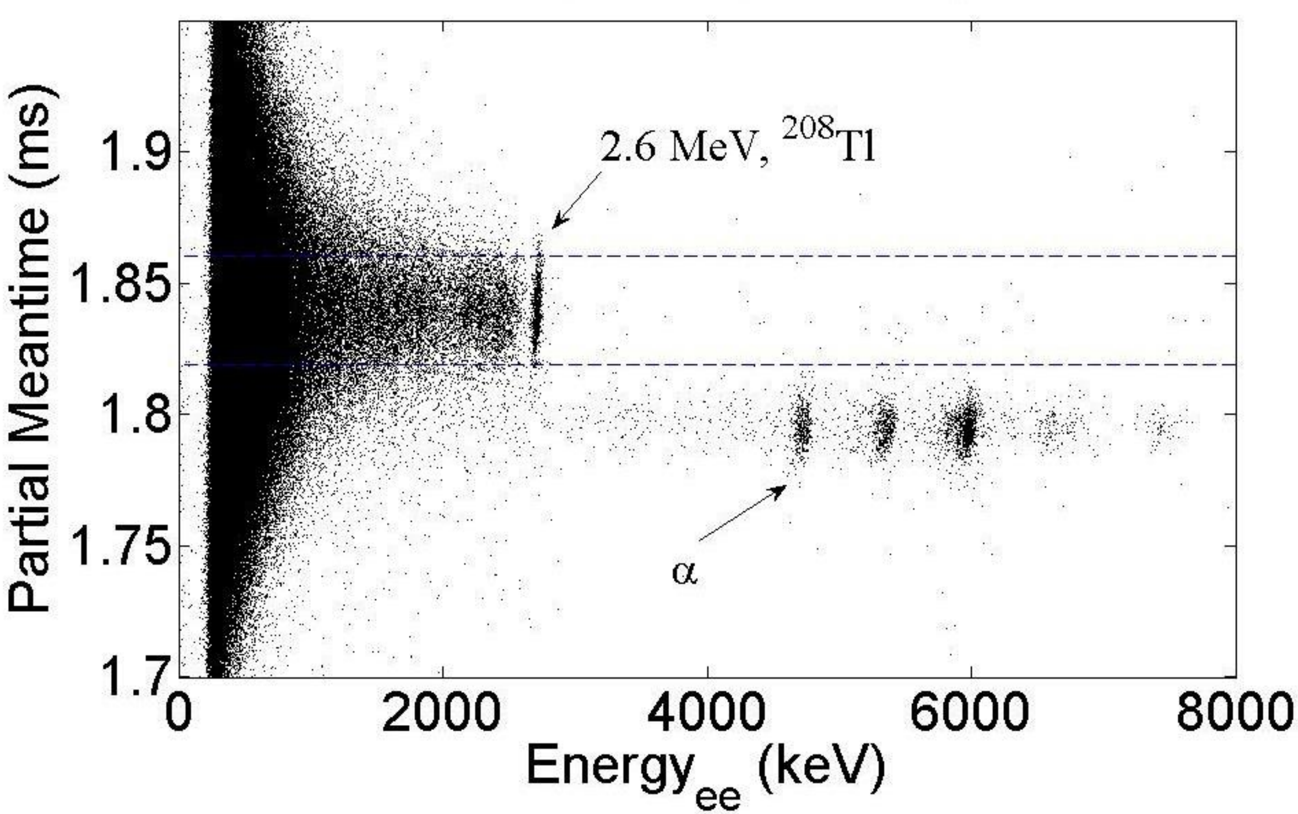
Energy resolution with outside source

- 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 !

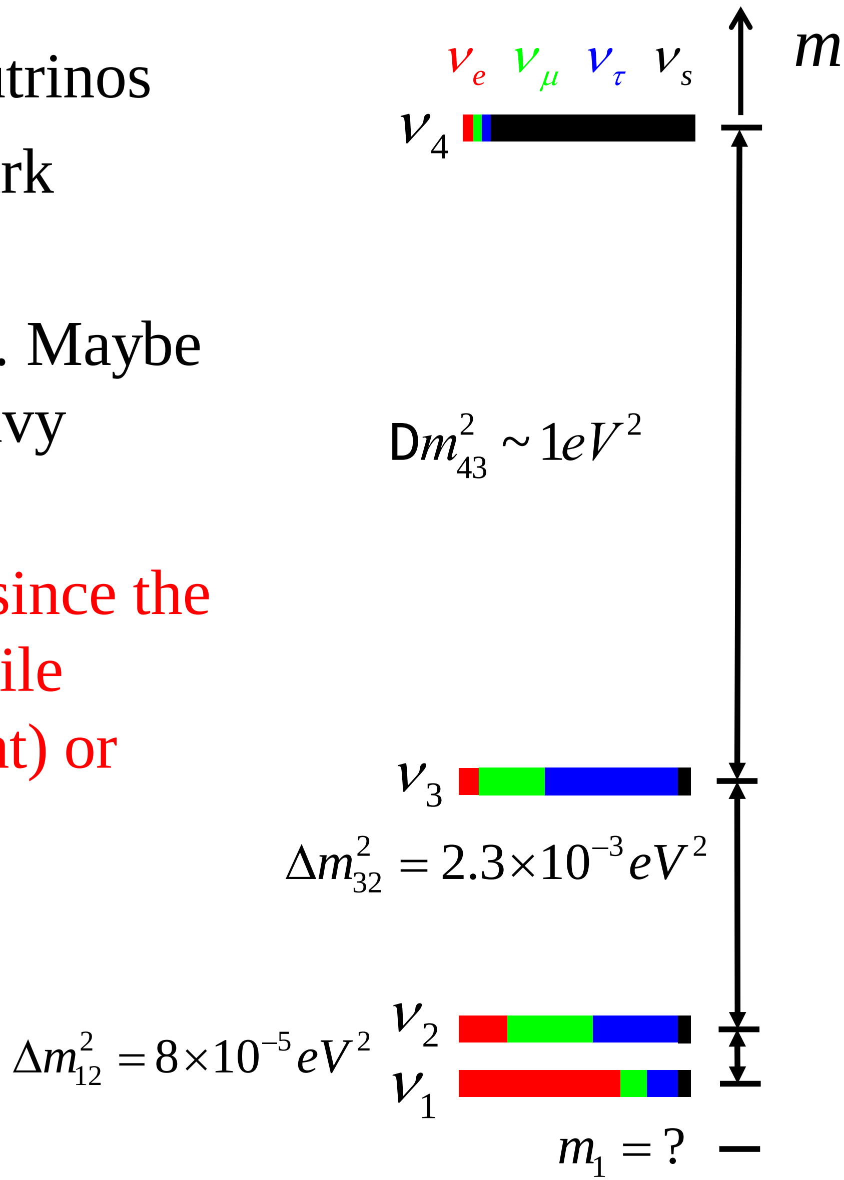


Purification for $XMoO_4$ crystals.

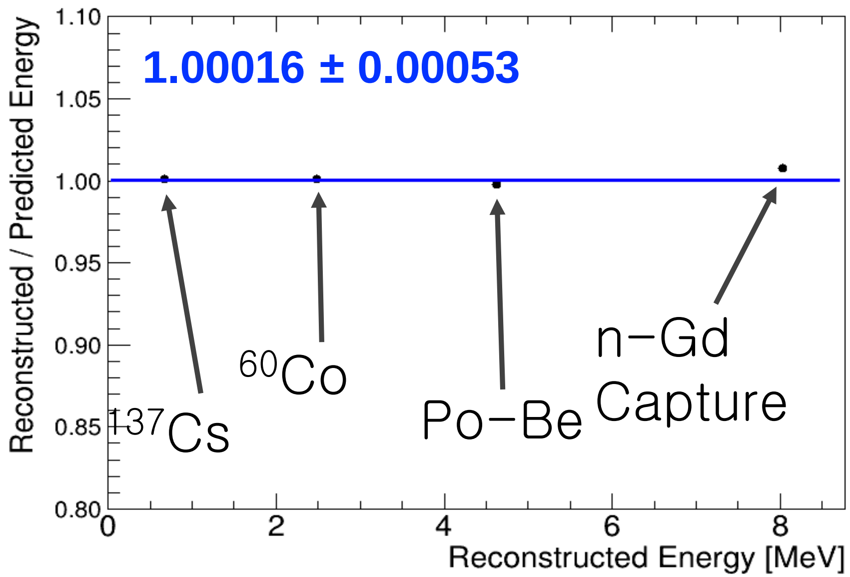
- $^{100}MoO3$ powder by Russia :
  ^{232}Th, $^{238}U < 1$ ppb
- $^{100}MoO3$ powder will be delivered until 2019.
- We will purify $^{100}MoO_3$ powder by sublimation + co-precipitation, or recrystallization method.
- Develop the purification techniques with 99.95% $^{nat}MoO_3$ powder (0.2 ppb of ^{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.

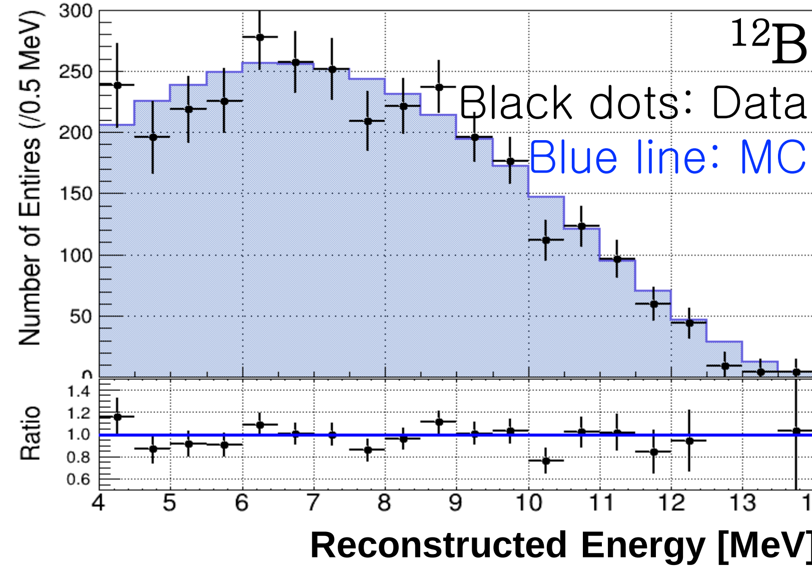
Sterile Neutrino Search – NEOS

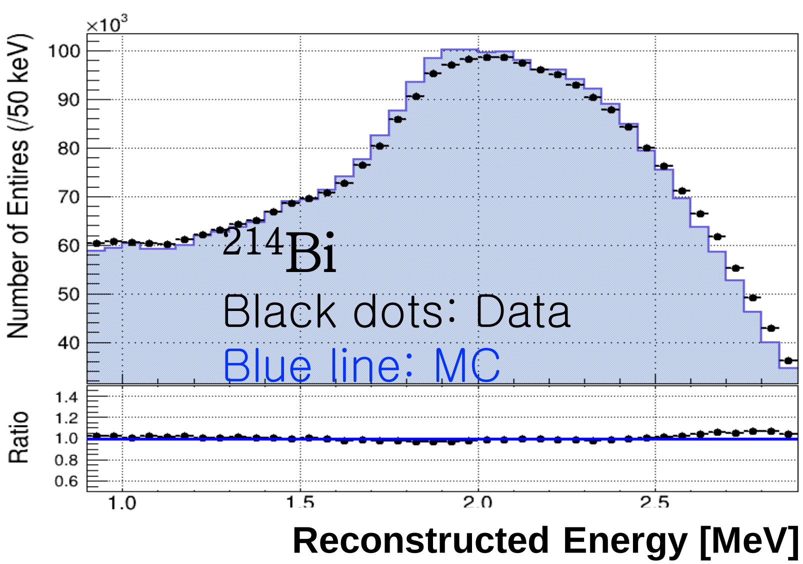
- Sterile neutrinos – right-handed neutrinos
- Sterile neutrinos – maybe Warm Dark Matter
- Nothing is known about the masses. Maybe very light (m_n<<1MeV) or very heavy (m_n>>10^{10}GeV)
- Sterile neutrinos may be identified since the active neutrinos can oscillate to sterile neutrinos (disappearance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

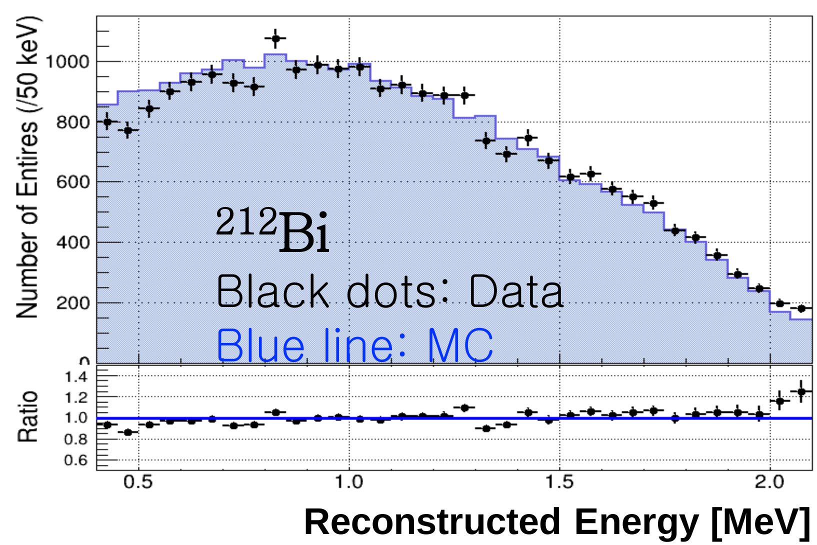


MC Tuning - γ and β sources









NEOS Detector

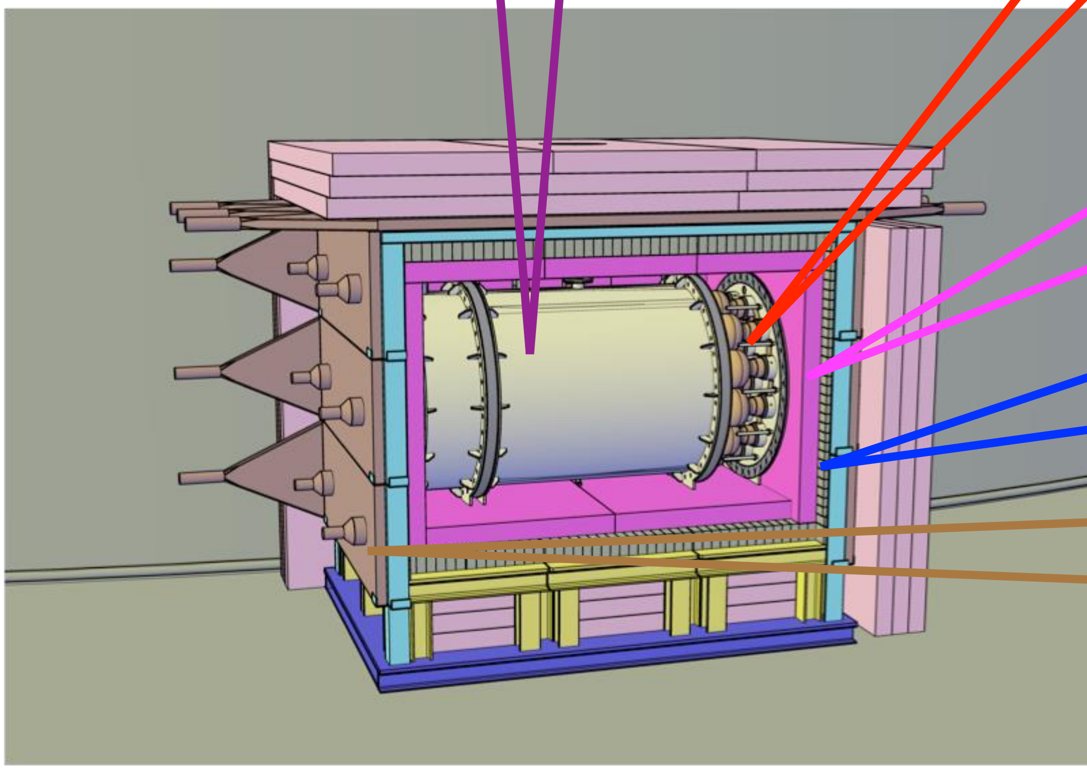
- Volume of Liquid Scintillator (LS) is ~ 1000 L
- Mixture LS: LAB based + DIN based (9:1)
- 0.5 % gadolinium is loaded.

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

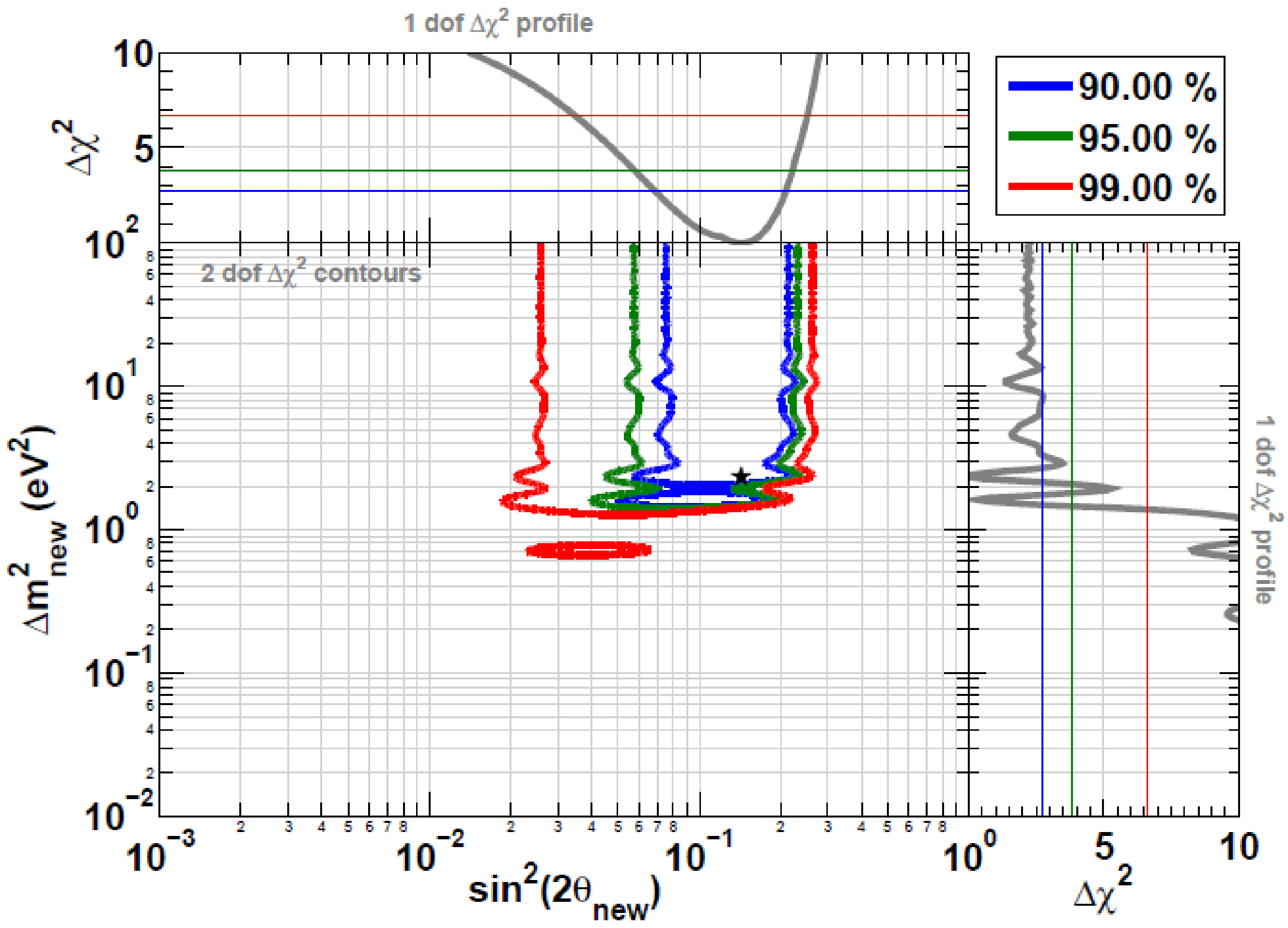
- Borated polyethylene (10 cm)
- B-PE shields neutrons produced at lead.

- 10 cm lead shield for gamma

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



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



Schedule of IBS-ARF

		2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Infra	Y2L-A5		Oper.	Oper.	Oper.	Oper.						
	IBS-ARF			Design	Constrution		Operation					
	Low Bkg. Facility			Test Experiment			Operation					
DM Exp.	KIMS-NaI		Data taking									
	KIMS-LT			Test Experiment				Data taking				
DBD Exp.	AMoRE-10			Data taking								
	AMoRE-200							Data taking				

Which isotope for 0nbb experiment ?

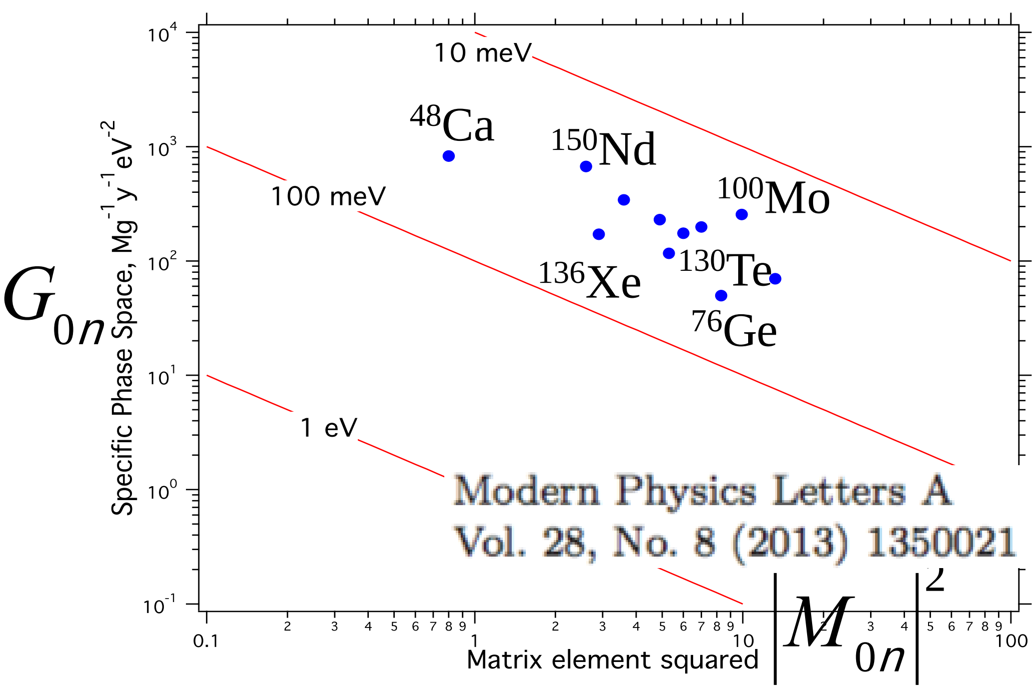
- Half-lifves depends on phase factor and matrix element.

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

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

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

$$T_{1/2}^{0n} \rightarrow m_{bb}$$

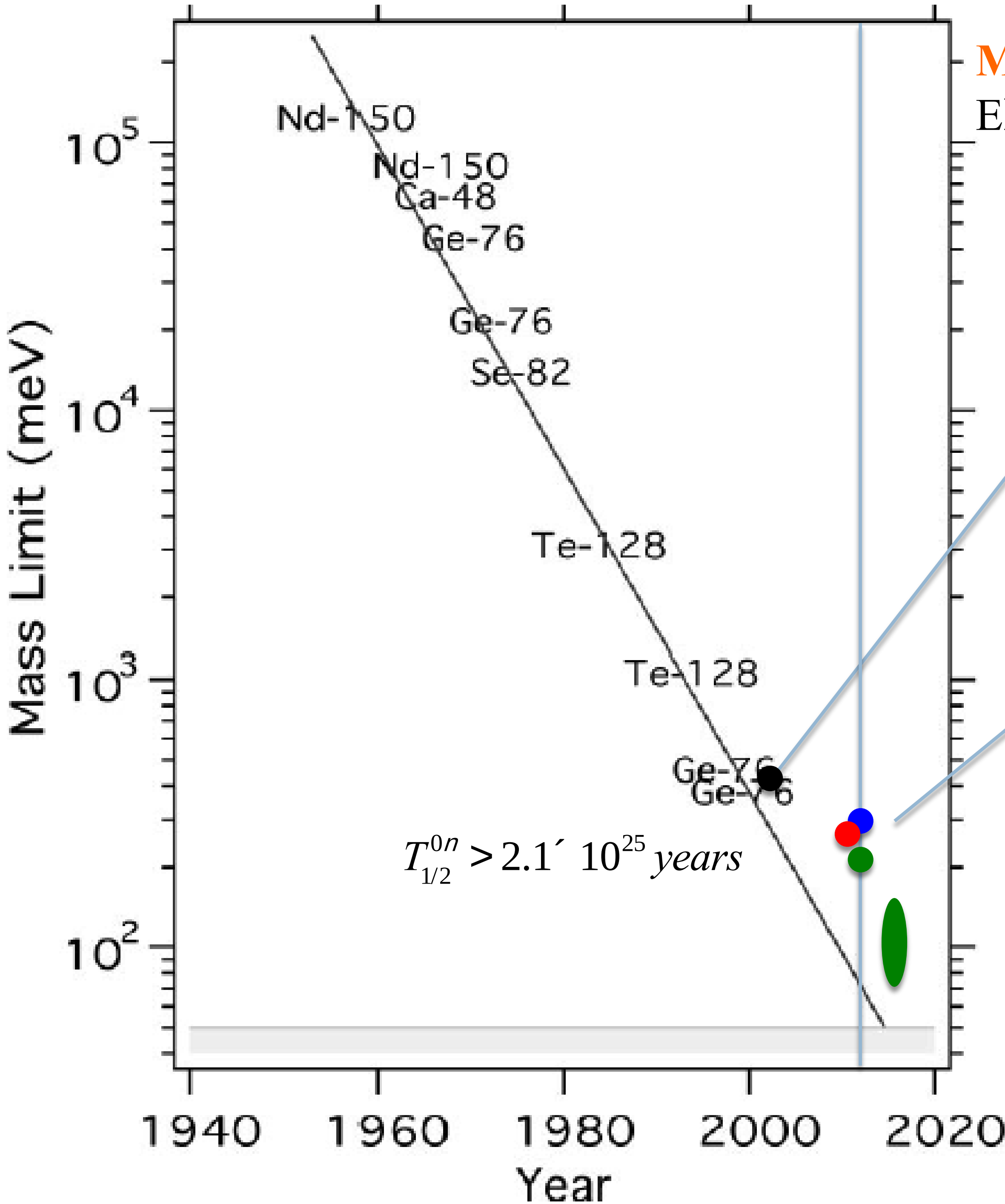


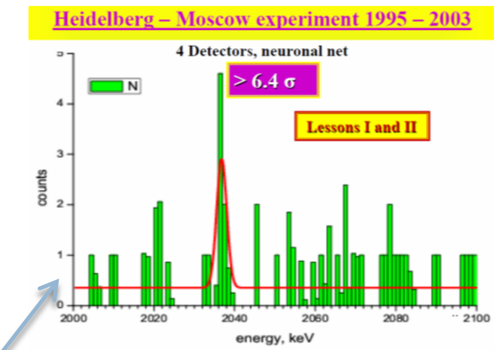
G and M has anti-correlation.

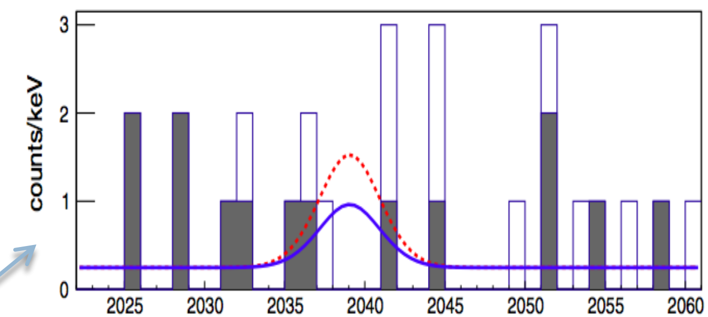
→ Generally no single isotope is preferred.

Moore's law for 0νββ ?

Elliott & Vogel, Ann, Phys. (2002)







^{76}Ge, Gerda (0.3) 2013.9

^{136}Xe, EXO (0.26) 2012.7

^{136}Xe, KAMLAND-ZEN, 2013.2

^{136}Xe, KAMLAND-ZEN, 2016.5 !!!