The AMoRE project

(Advanced Mo-based Rare process Experiment)

Neutrinoless double beta decay search
using low temperature $^{40}Ca^{100}MoO_4$ calorimeters

Yong-Hamb Kim for AMoRE collaboration

Center for Underground Physics (CUP), Institute for Basic Science (IBS)

The AMoRE Project

AMORE: ‘Love’ in Italian

The AMoRE Project

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AMORE: Bar near my hotel

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AMORE: “A cosmetic company in Korea”

The AMoRE Project

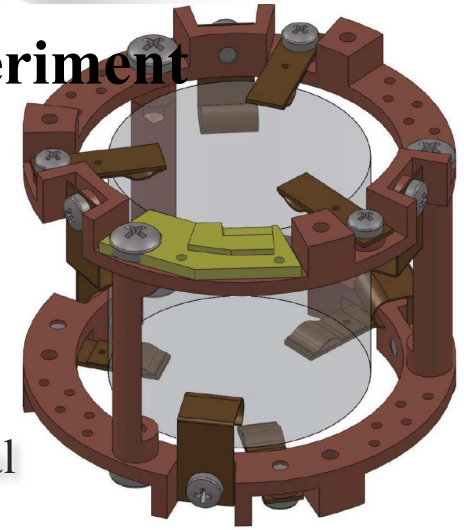
AMORE: 'Love' in Italian

AMORE: Bar near my hotel

AMORE: "A cosmetic company in Korea"

AMoRE: **A**dvanced **Mo**-based **R**are process **E**xperiment
to search for neutrinoless double decay of ^{100}Mo
using **cryogenic $^{40}Ca^{100}MoO_4$ detectors**

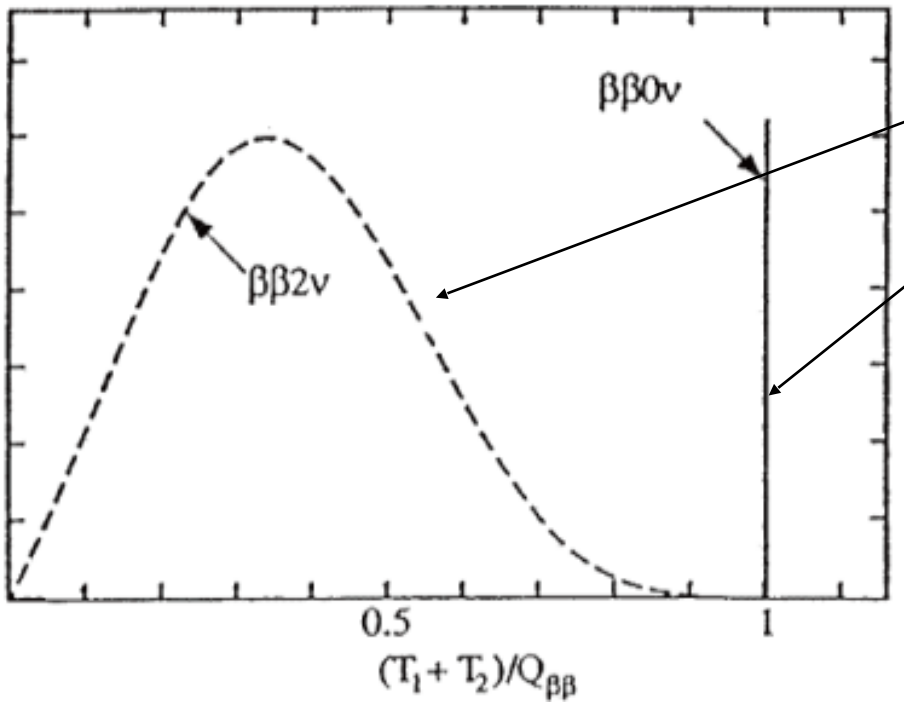
That's AMoRE for us!



Ø4cmx4cm
$CaMoO_4$ crystal

AMoRE collaboration (since 2009)

Neutrinoless double beta decay (0νββ)



Double Beta Decay with two neutrinos

$$(A, Z) \rightarrow (A, Z+2) + 2e^- + 2\bar{\nu}_e$$

Double Beta Decay with no neutrino

$$(A, Z) \rightarrow (A, Z+2) + 2e^-$$

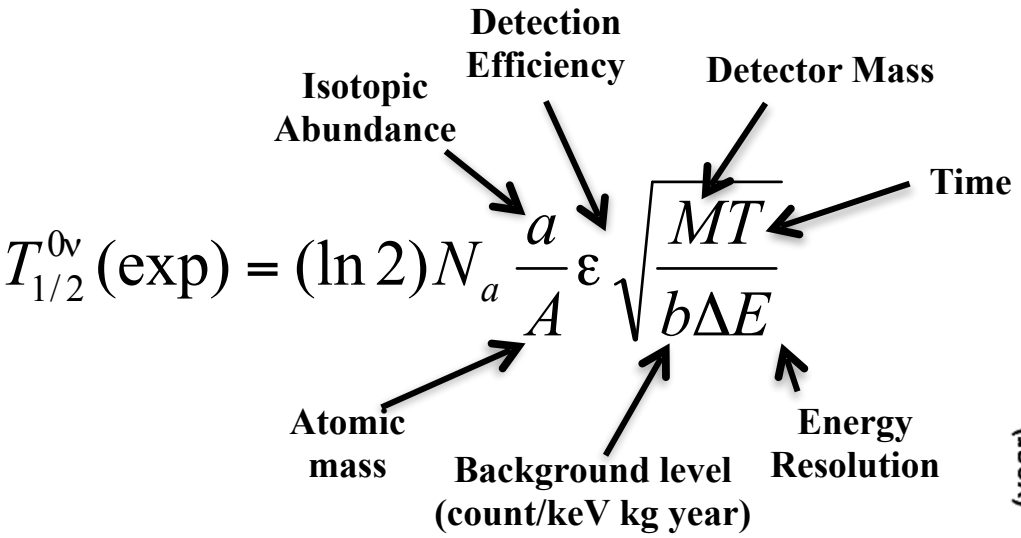
requires massive Majorana ν !

It may answer

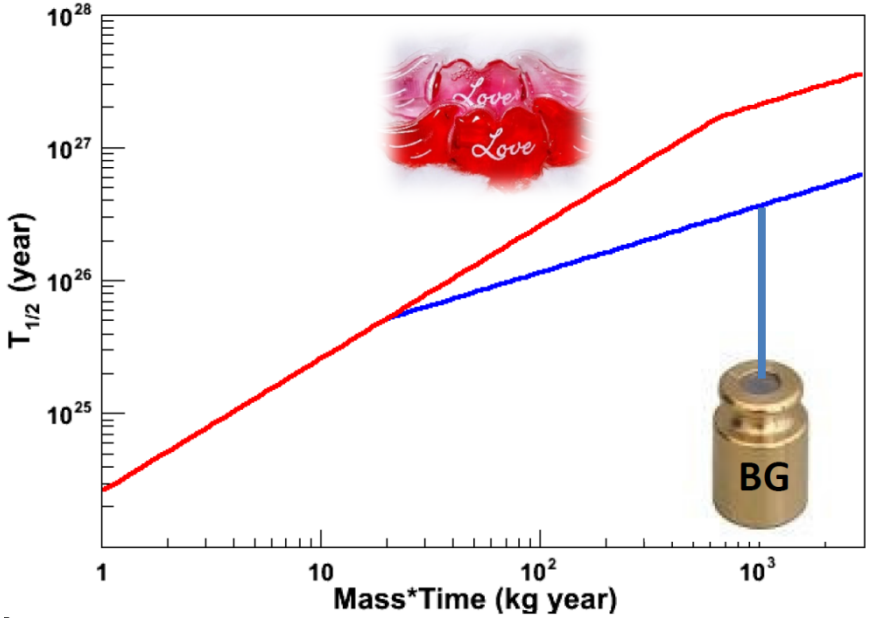
- Mass of neutrinos ($1/T_{1/2}^{0\nu} \propto m_\nu^2$)
- Majorana ($\nu = \bar{\nu}$), or Dirac particles ($\nu \neq \bar{\nu}$)
- Lepton number conservation?

Experimental Sensitivity of $T_{1/2}$ ($0\nu\beta\beta$)

For sizeable background case:



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



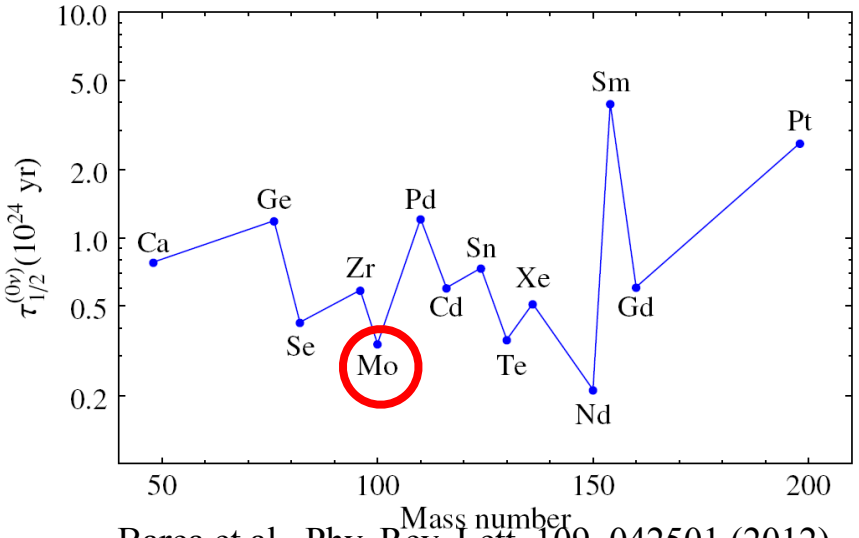
For "zero" background case:

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

^{100}Mo is chosen for 0νββ experiment

- ^{100}Mo
  - ✓ High Q-value (ββ) of 3034.40 (12) keV.
  - ✓ High natural abundance of 9.6%
  - ✓ Relatively short half life (0νββ) expected from theoretical calculation

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

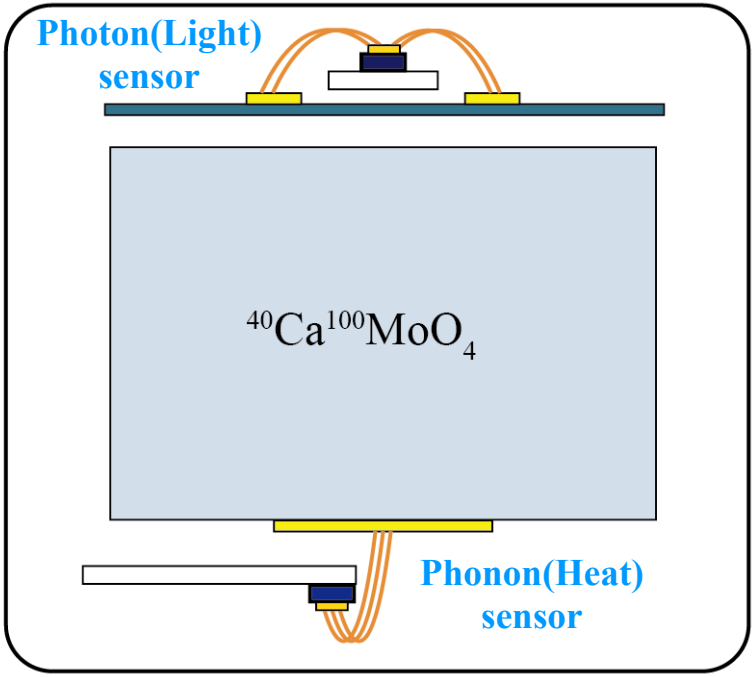


Barea et al., Phy. Rev. Lett. 109, 042501 (2012)

Candidate	Q (MeV)	Abund. (%)
^{48}Ca	***4.271***	***0.19***
^{76}Ge	2.040	7.8
^{82}Se	***2.995***	***8.7***
^{100}Mo	3.034	9.6
^{116}Cd	***2.802***	***7.5***
^{124}Sn	2.228	5.8
^{130}Te	***2.533***	***34.1***
^{136}Xe	2.479	8.9
^{150}Nd	***3.367***	***5.6***

AMoRE detector technology

$^{40}Ca^{100}MoO_4$ + MMC : Source = Detector



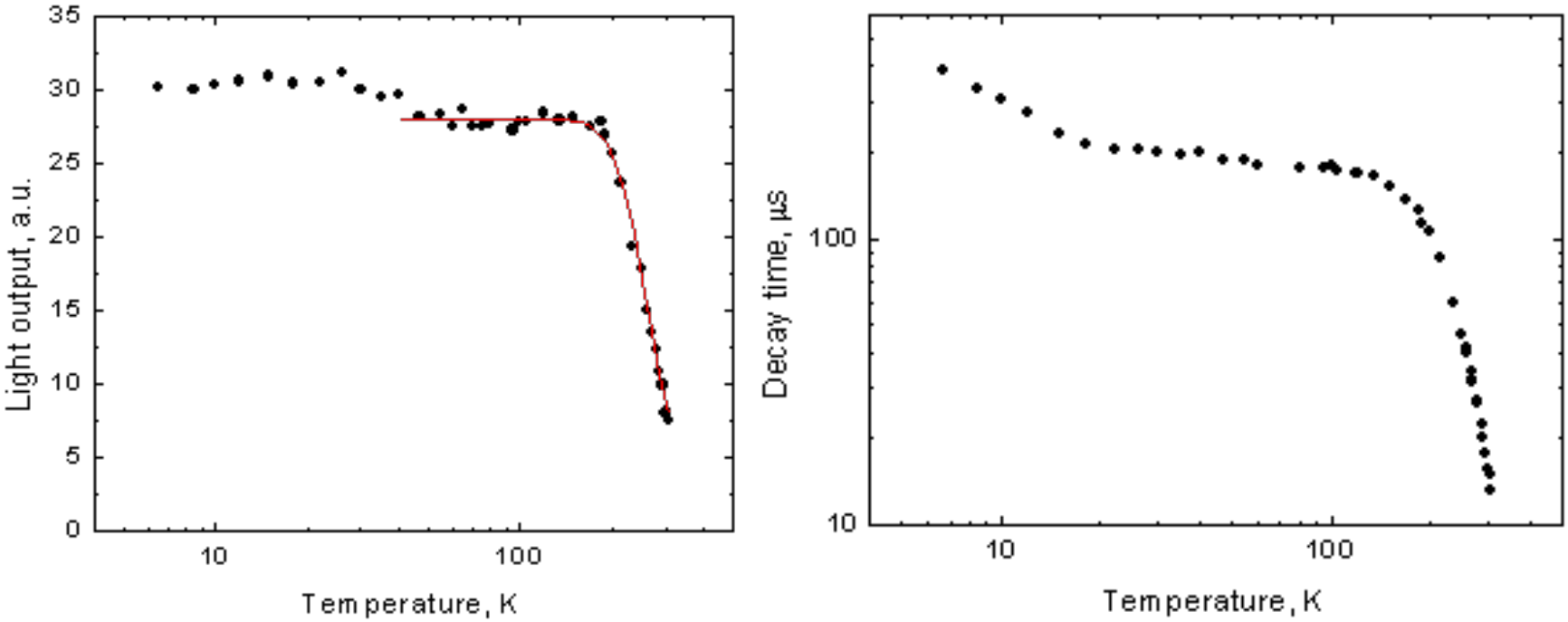
$CaMoO_4$
- Scintillating crystal
- High Debye temperature: T_D = 438 K, $C \sim (T/T_D)^3$
- ^{48}Ca, ^{100}Mo $0\nu\beta\beta$ candidates
- AMoRE uses $^{40}Ca^{100}MoO_4$ w. enriched ^{100}Mo and depleted ^{48}Ca

MMC (Metallic Magnetic Calorimeter)
- Magnetic temperature sensor (Au:Er) + SQUID
- Sensitive low temperature detector with highest resolution
- Wide operating temperatures
- Relatively fast signals
- Adjustable parameters in design and operation stages

Temperature dependent $CaMoO_4$ scintillation

From RT to 7 K, the light yield increases 6 times

(V.B. Mikhailik et al., NIMA 583 (2007) 350)



CaMoO4 absolute light yield @RT: 4900±590 ph/MeV

(H.J. Kim et al., IEEE TNS 57 (2010) 1475)

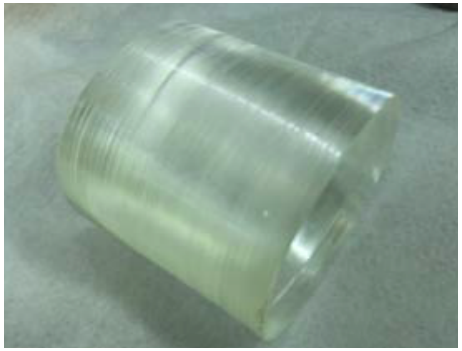
→ Light yield at low temp. : ~ 30,000 ph/MeV

→ **Largest light yield among Mo contained crystals.**

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

- Enrichment of ^{100}Mo (natural abundance : 9.6%)
  - Gas-centrifuge method
  - Enrichment of ^{100}Mo is higher than 96%.

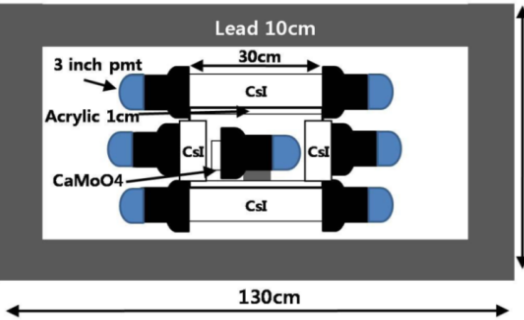
- Depletion of ^{48}Ca (natural abundance : 0.187%)
  - Electromagnetic separation
  - Composition of ^{48}Ca is less than 0.001 %.



Internal backgrounds of $^{40}Ca^{100}MoO_4$ crystals

4π CsI(Tl) active setup with Pb shielding at Y2L

4π gamma veto system



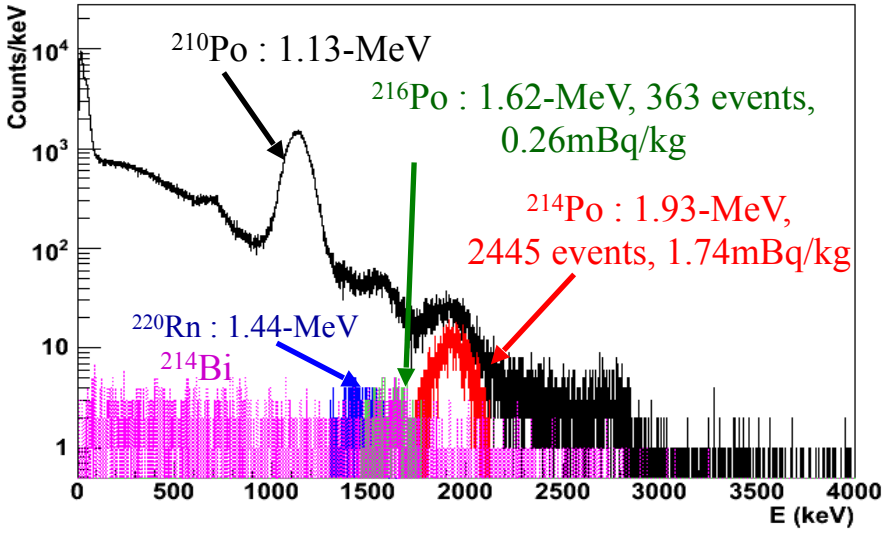
β–α decay in ^{238}U

^{214}Bi (Q-value : 3.27-MeV) → ^{214}Po (Q-value : 7.83-MeV)→ ^{210}Pb

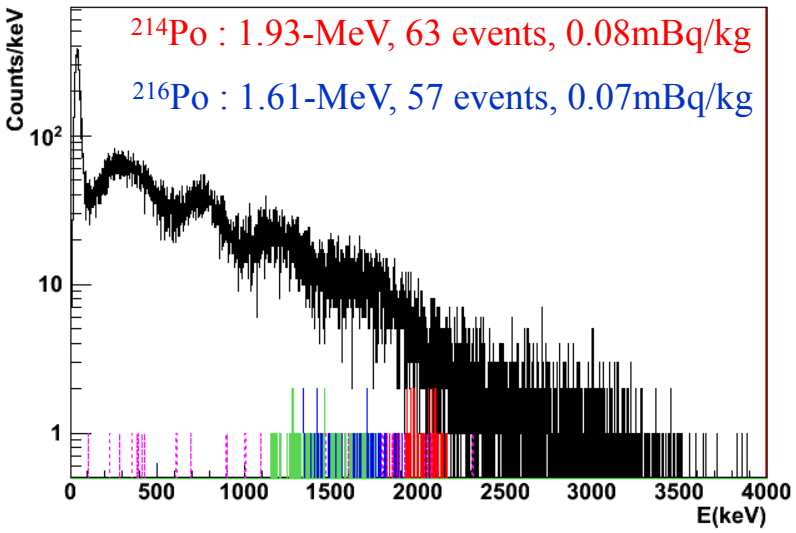
α–α decay in ^{232}Th

^{220}Rn (Q-value : 6.41-MeV) → ^{216}Po (Q-value : 6.91-MeV)→ ^{212}Pb

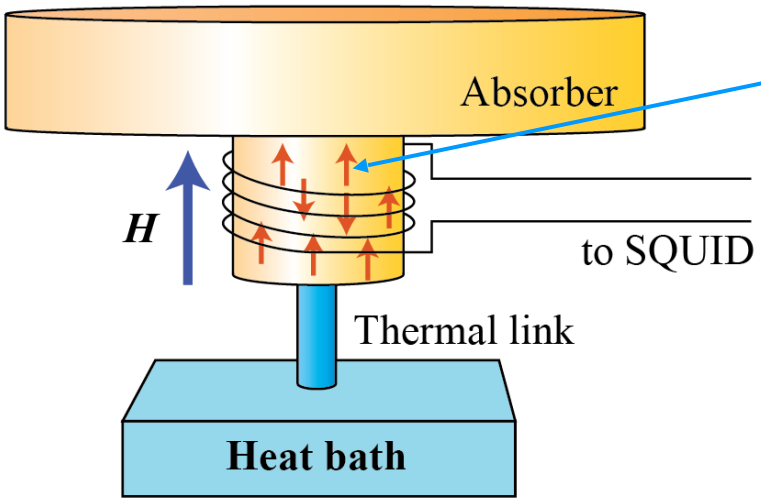
Crystal S35



Crystal SB28

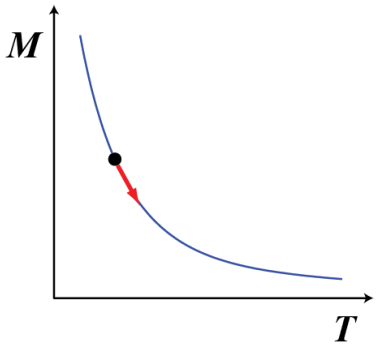


Metallic Magnetic Calorimeter (MMC)



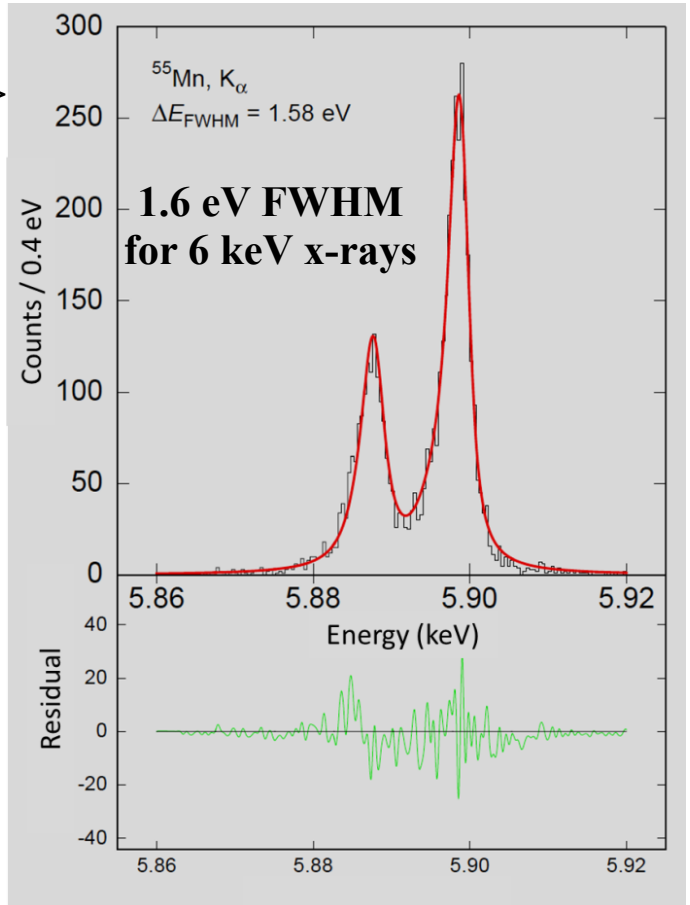
Magnetic material Au:Er(100~1000ppm)

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



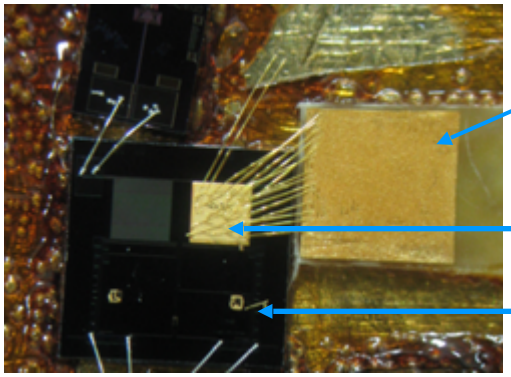
$$\delta E \rightarrow \delta T \rightarrow \delta M \rightarrow \delta \phi$$

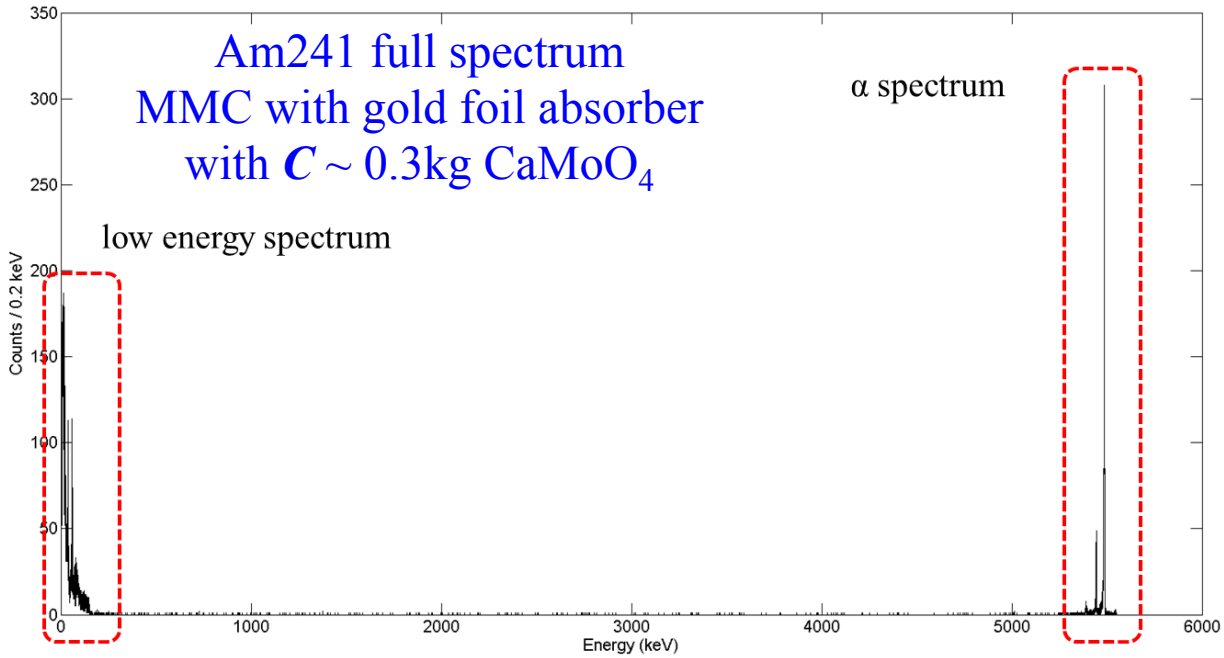
<2013 Heidelberg Univ.>



MMC provides high resolution detection

- 1x1 mm^2 Au:Er layer designed for MeV signals
- Fabricated at KRISS





0.4keV FWHM
for 60keV γ

1.2keV FWHM Gaussian width
for 5.5MeV α

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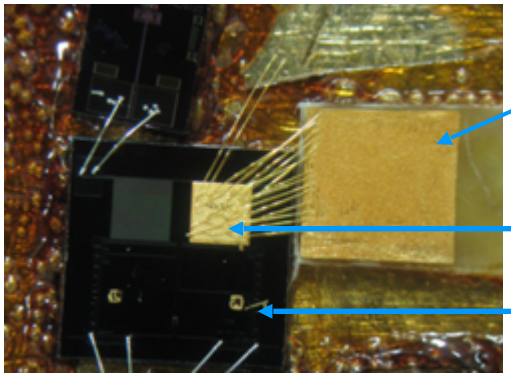
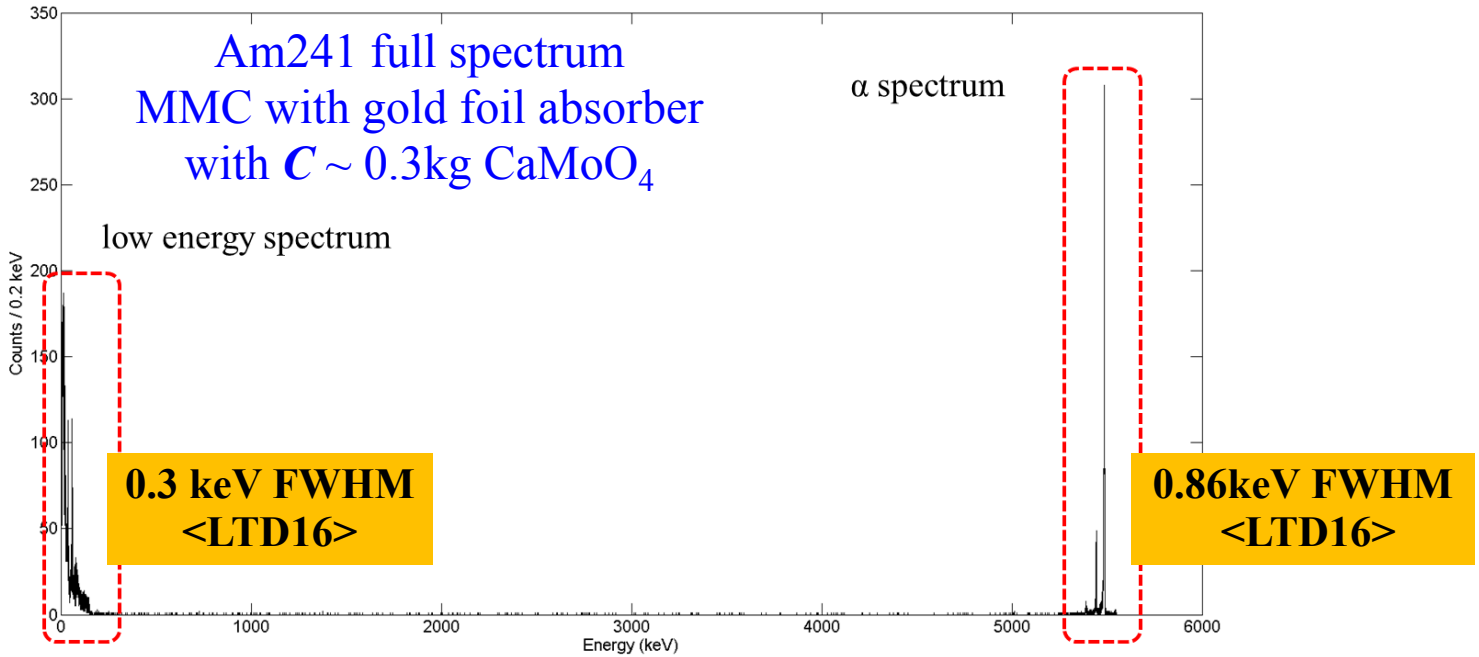
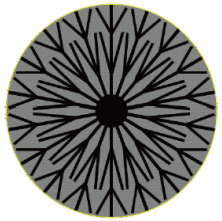




0.4keV FWHM
for 60keV γ

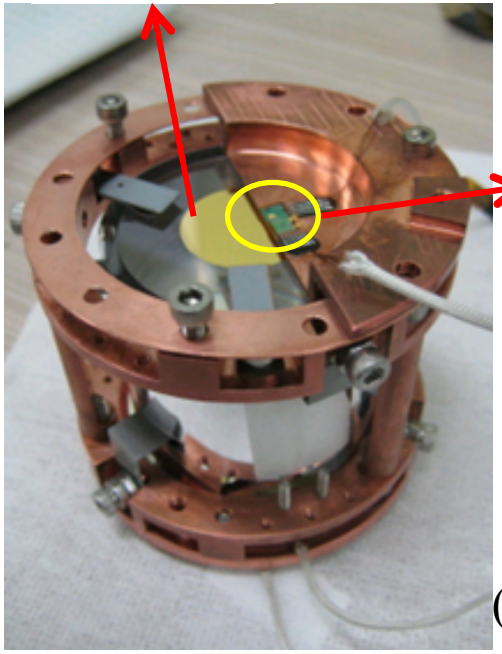
1.2keV FWHM Gaussian width
for 5.5MeV α

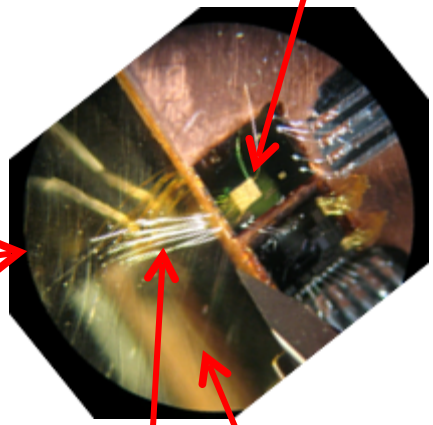
Phonon sensor for AMoRE



Phonon collector
Patterned gold film

MMC



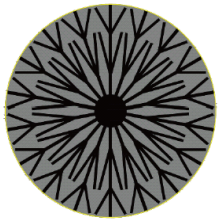


Gold film

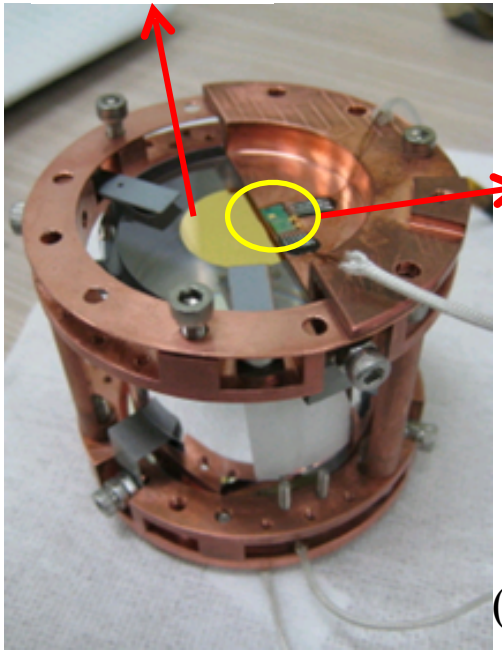
Gold wires
(thermal connection)

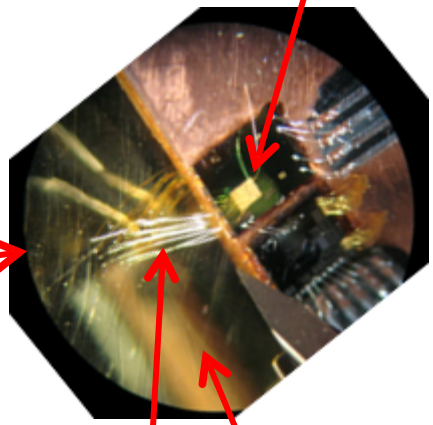
We measure both thermal and athermal phonons.

Phonon sensor for AMoRE



Phonon collector
Patterned gold film





MMC

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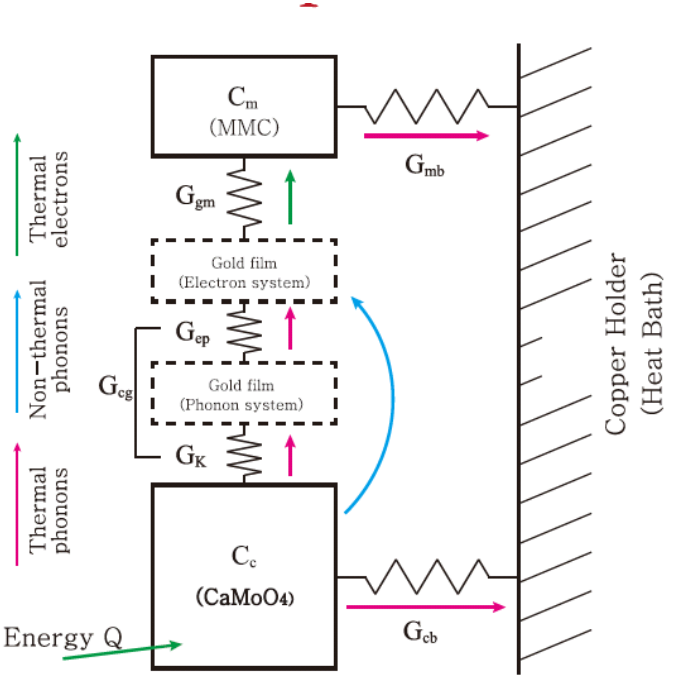
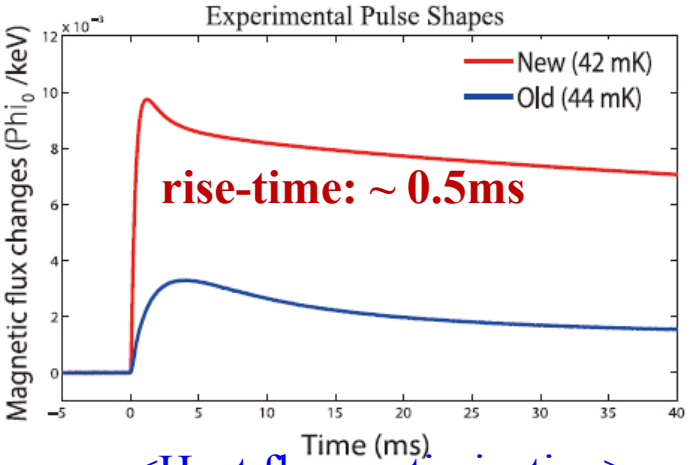
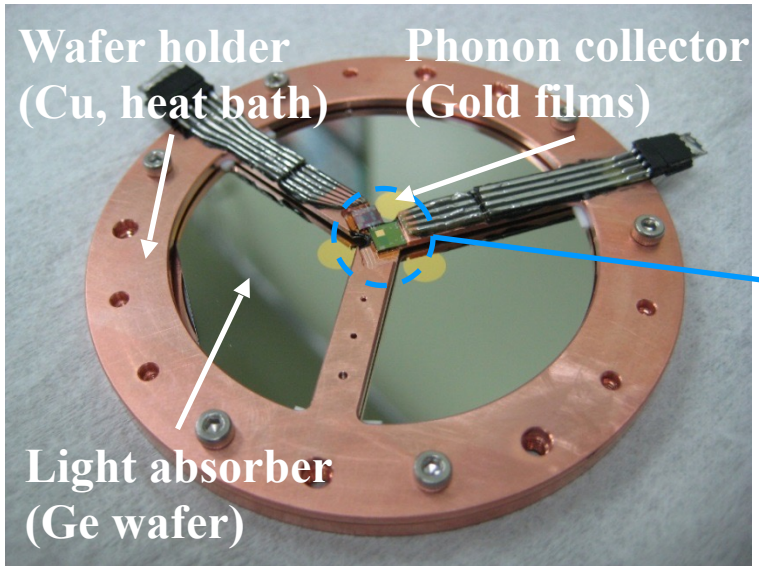
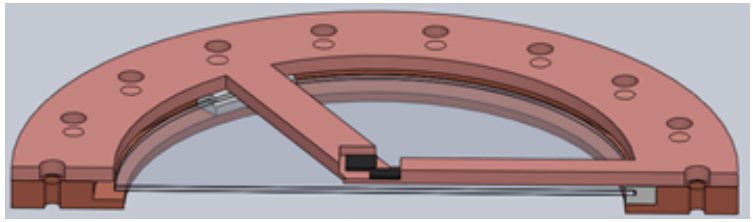


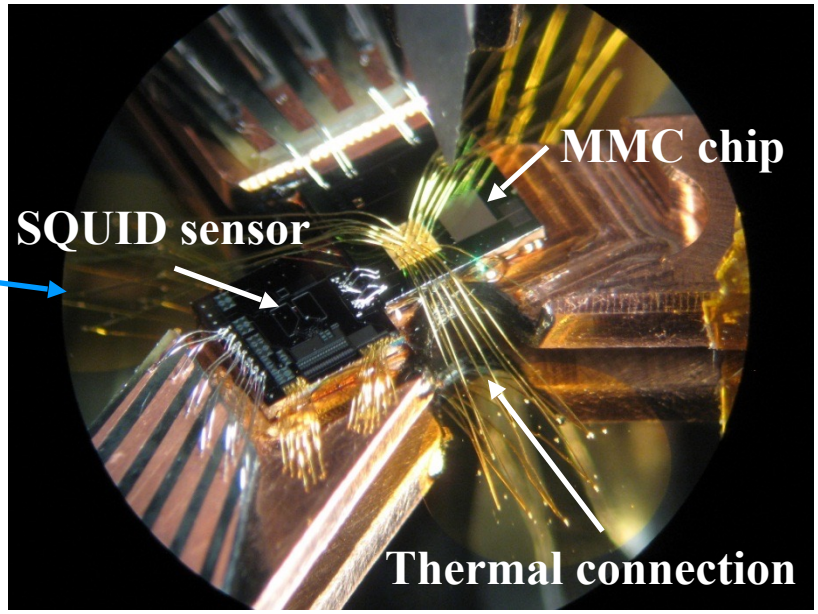


<Heat flow optimization>

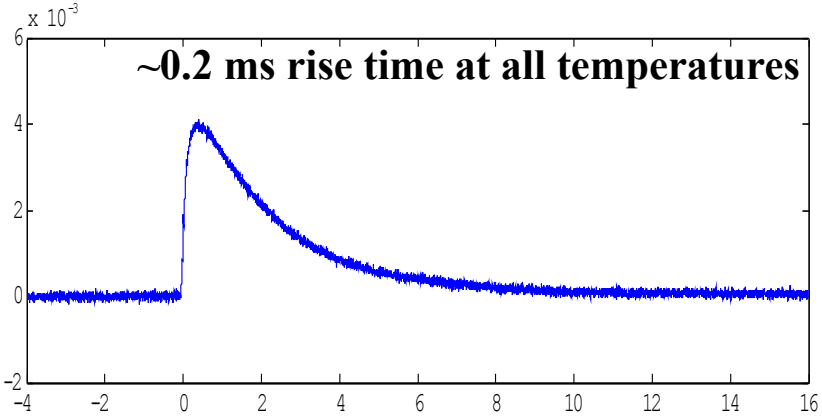
Light (patchable) sensor with MMC

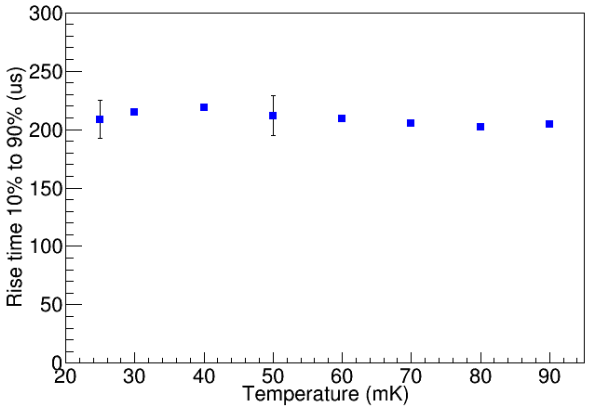






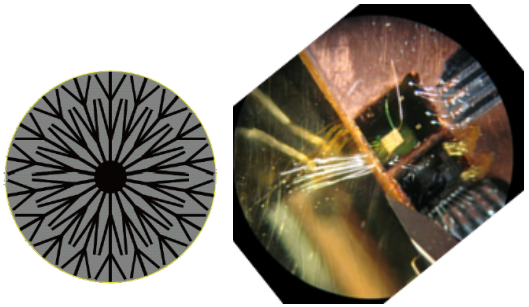
Temperature independent rise-time !





Phonon + Photon Assembly

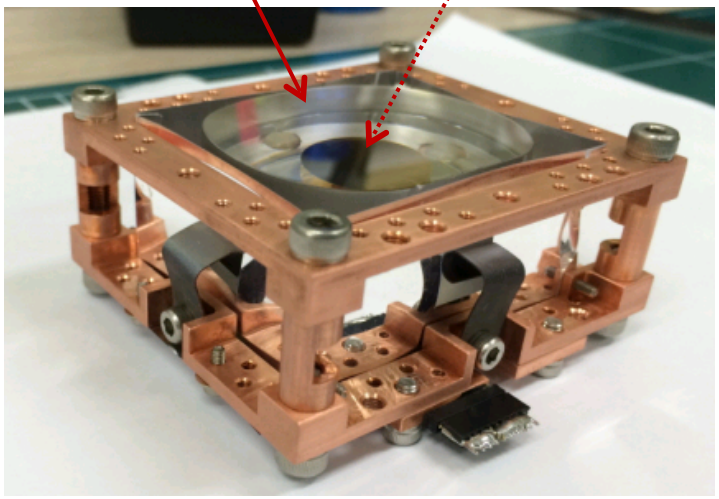
Phonon collector film
on bottom surface

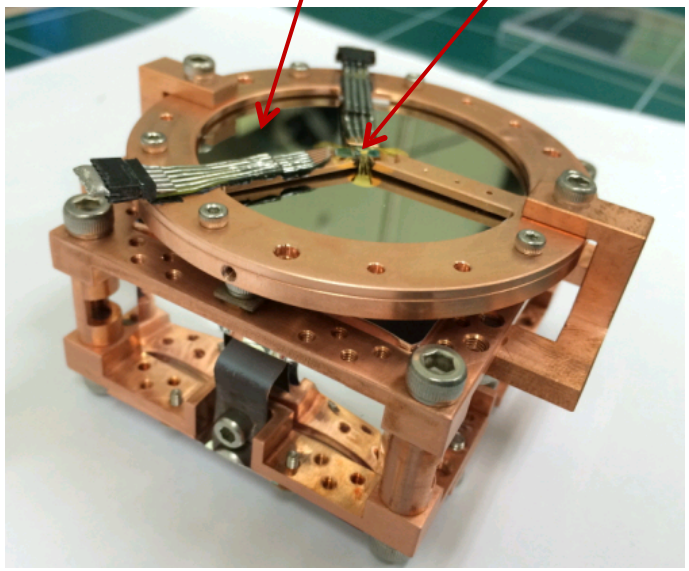


196 g $^{40}Ca^{100}MoO_4$
(doubly enriched crystal)

Phonon collector film
on bottom surface

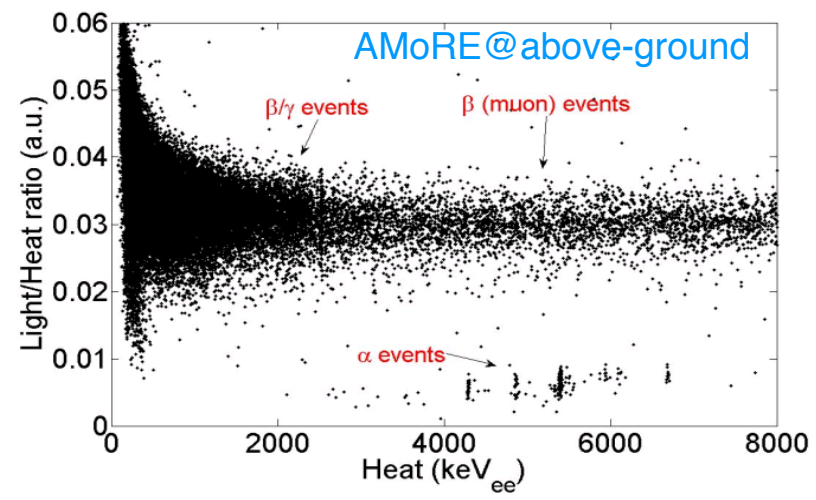
Light detector
2 inch Ge wafer + MMC



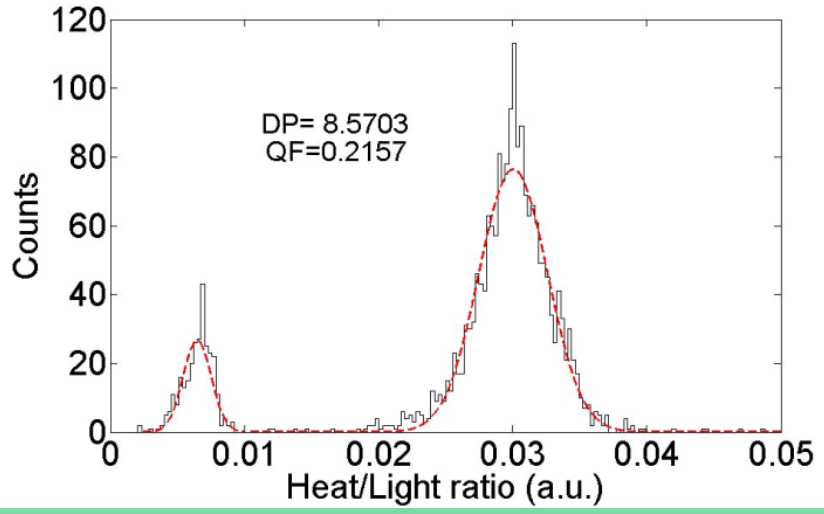


Particle discrimination

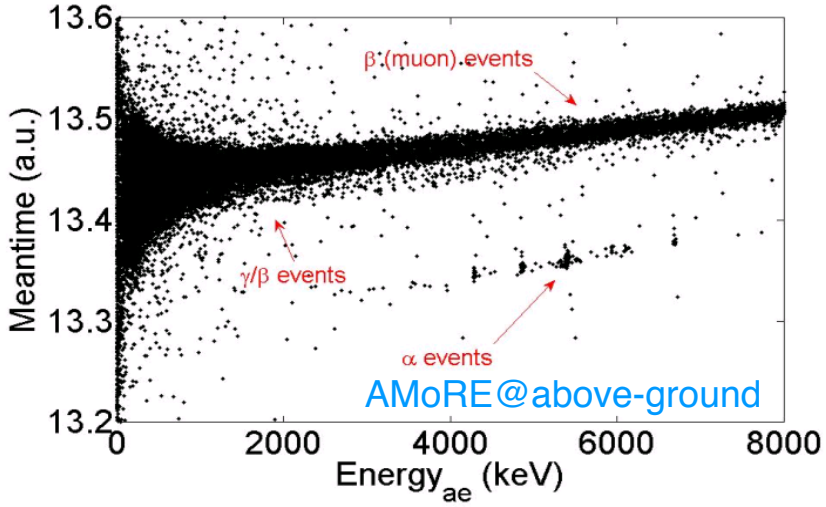
Particle discrimination by light heat ratio



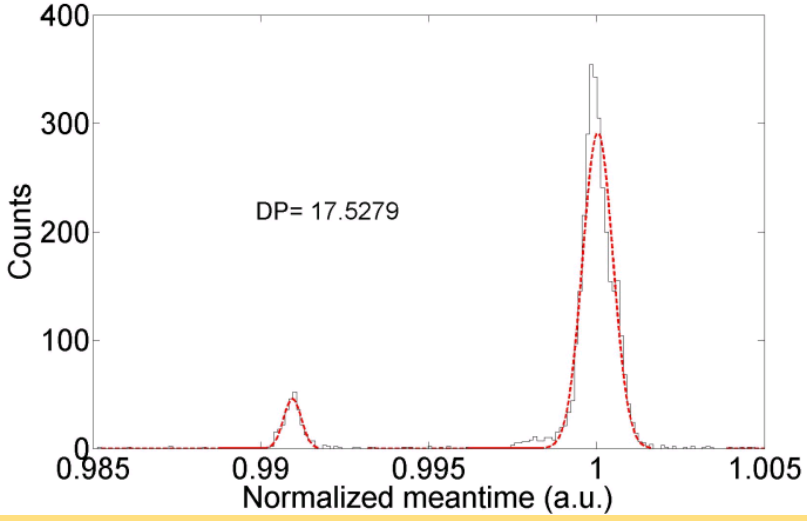
4 MeV < E_{ae} < 7 MeV



Phonon pulse shape discrimination (PSD)

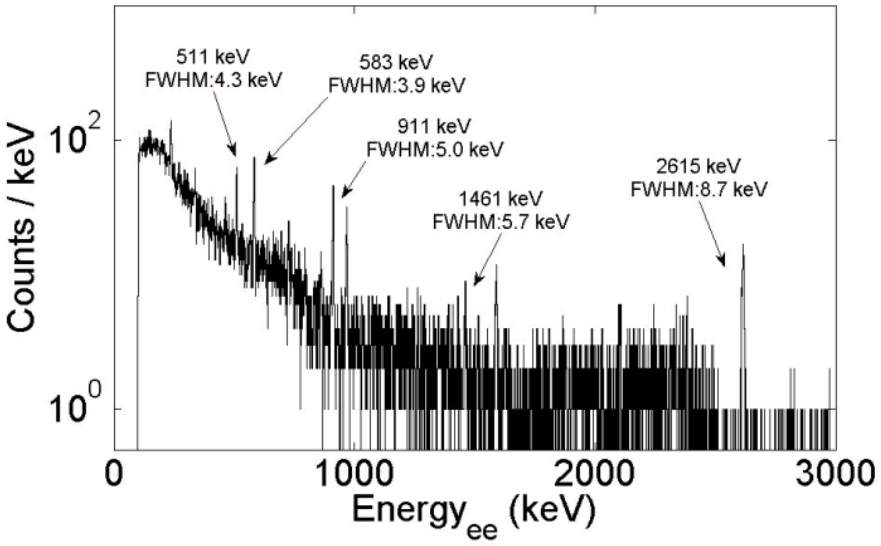


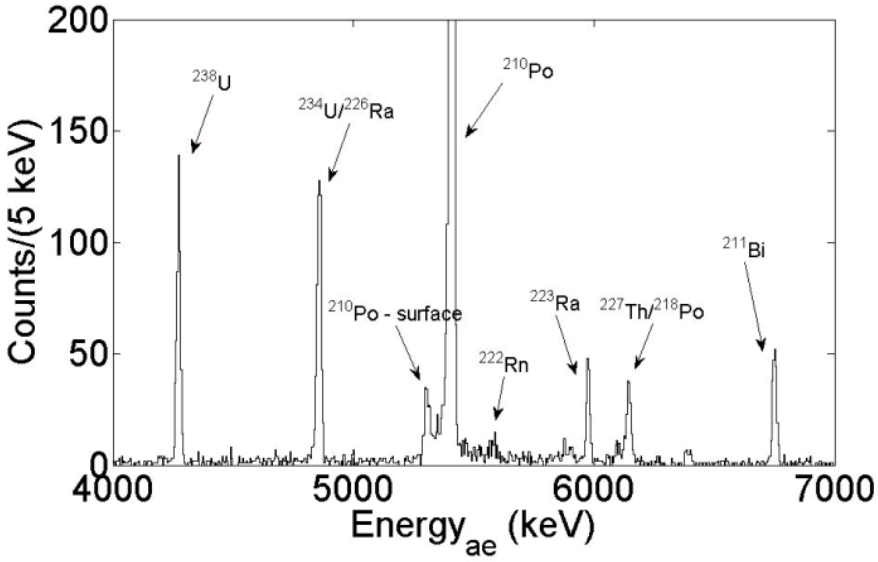
4 MeV < E_{ae} < 7 MeV



Energy spectrum (above-ground)

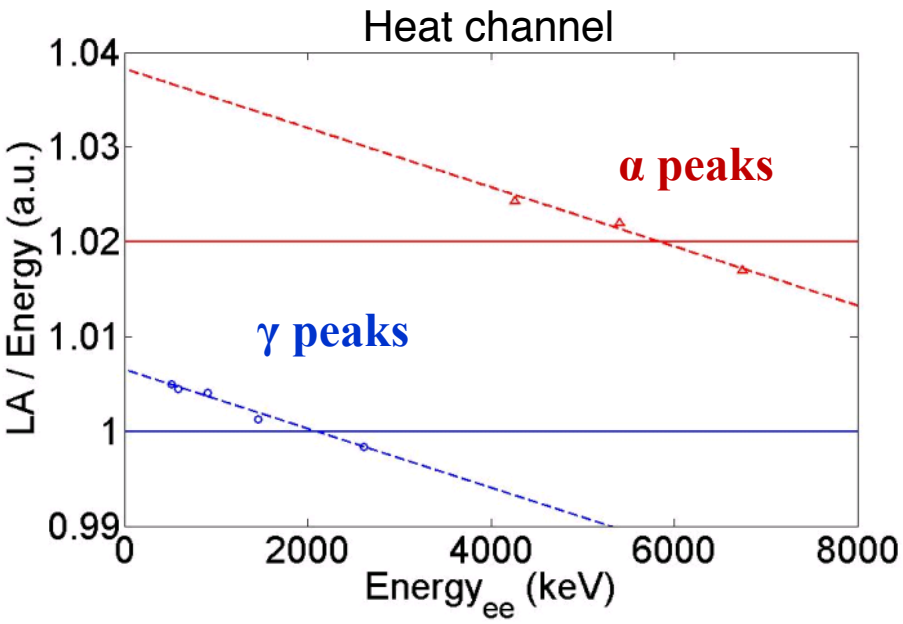
Electron and alpha events can be efficiently identified.

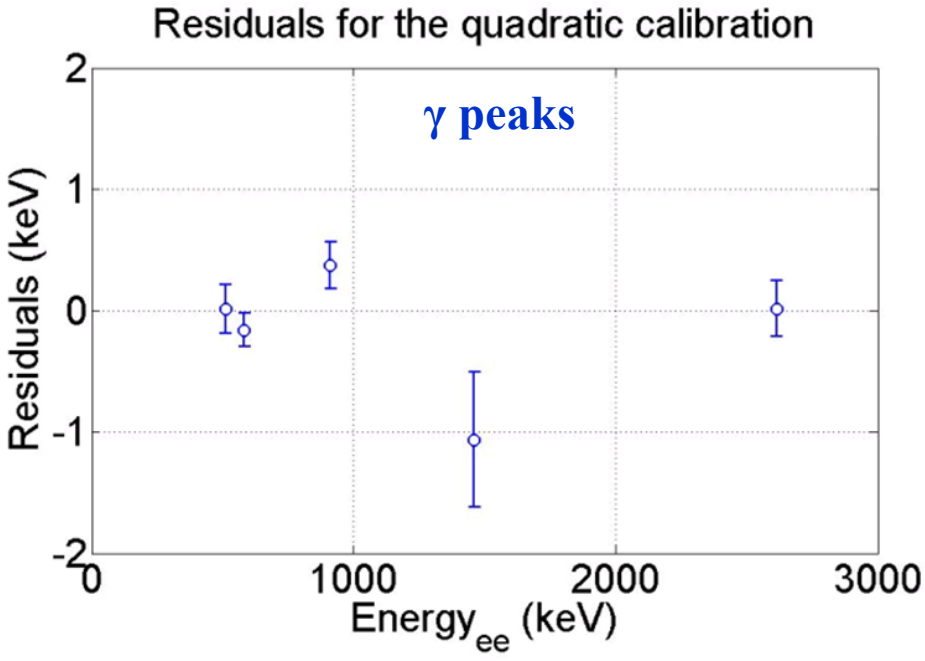




- Better than 9 keV energy resolution was obtained at 10 mK temperature.
- Internal alpha background levels of each isotopes were calculated successfully.

Energy calibration



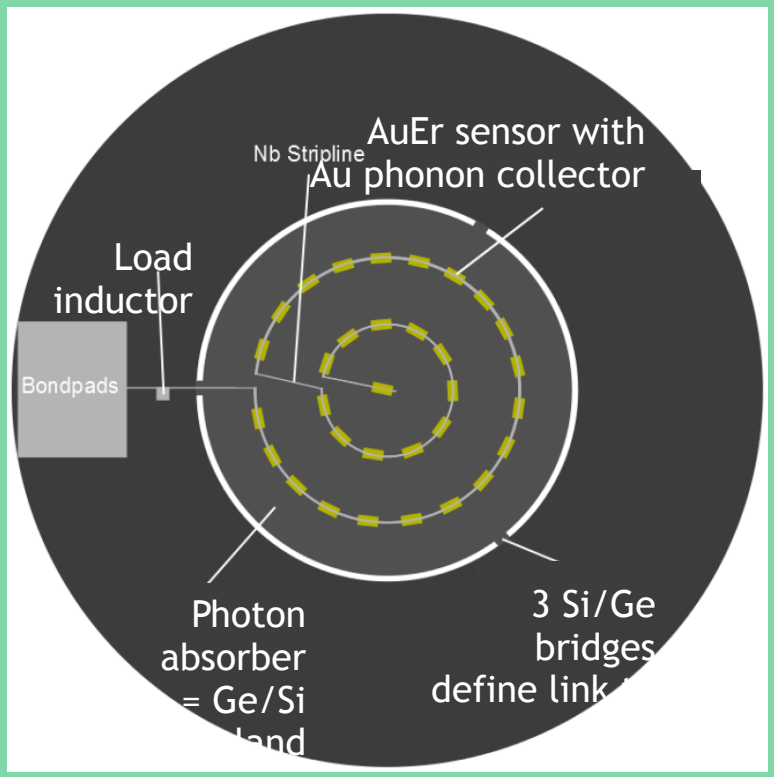


- Alpha peaks are slightly larger than gamma peaks
- A few % non-linearity was found for α and γ peaks
- Better than 1 keV calibration is expected at 3MeV with a quadratic function

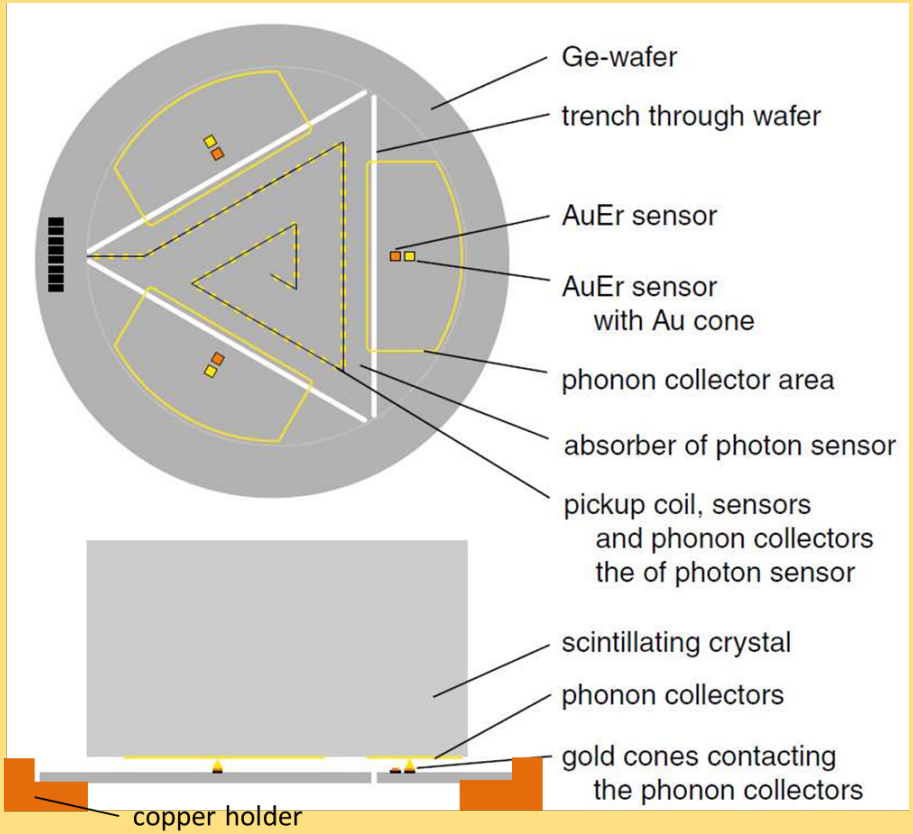
Other detector R&Ds in AMoRE

with Heidelberg University

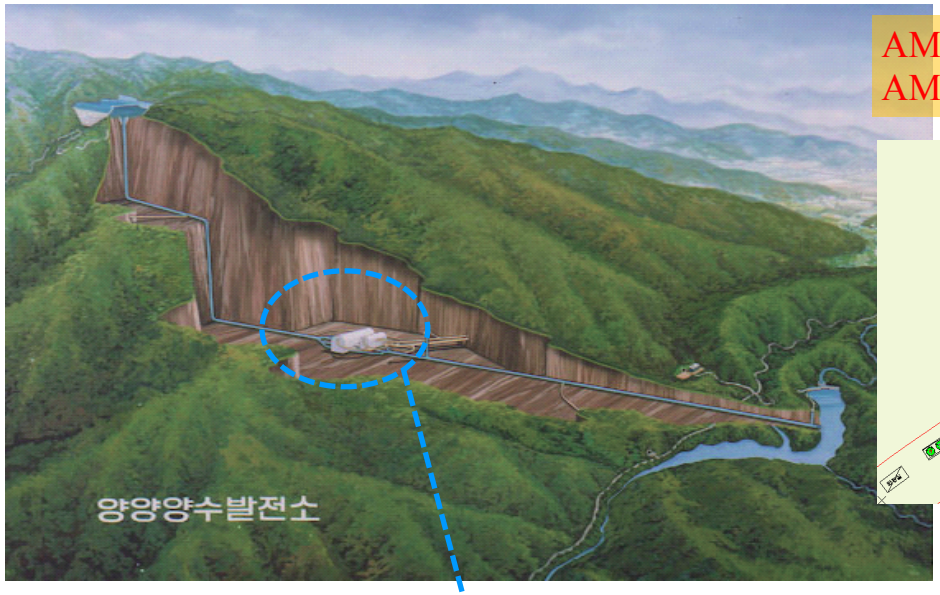
Integrated light sensors



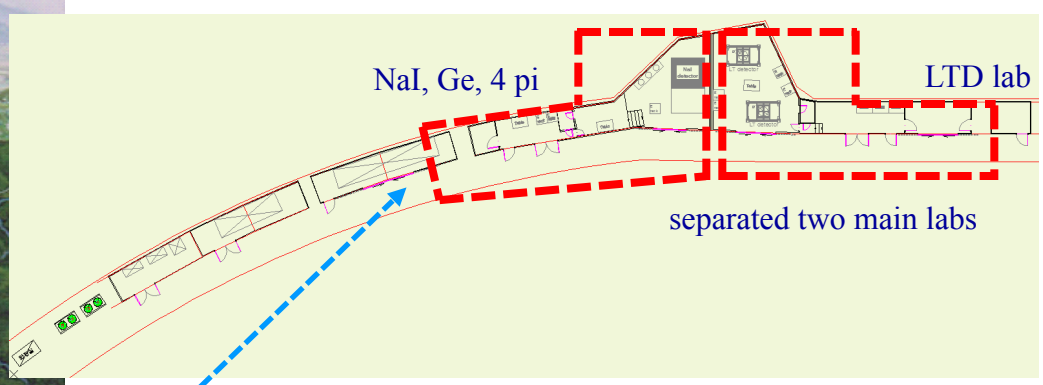
Combined phonon and photon detector

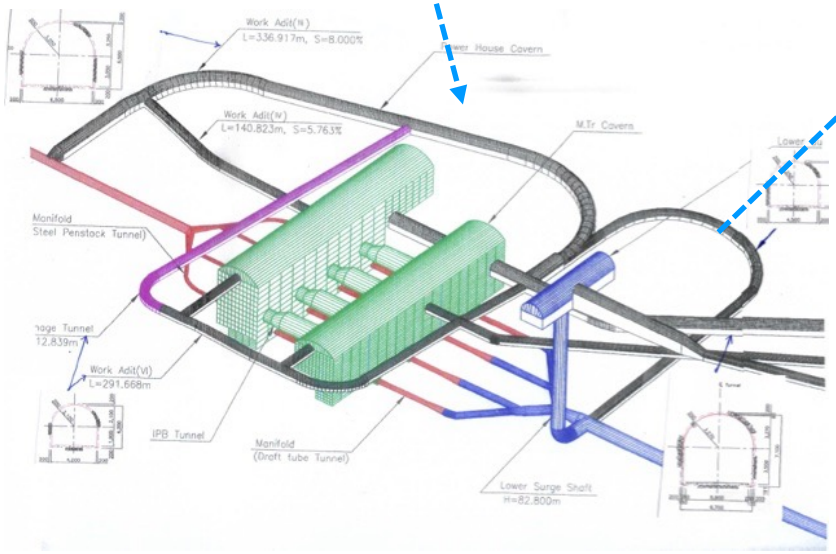


YangYang Underground Laboratory (Y2L)



AMoRE-pilot and AMoRE-phase1 will be run at Y2L.
AMoRE-phase2 will be run at other place. (New underground lab.)





Yangyang pumped storage Power Plant

Minimum vertical depth : 700 m

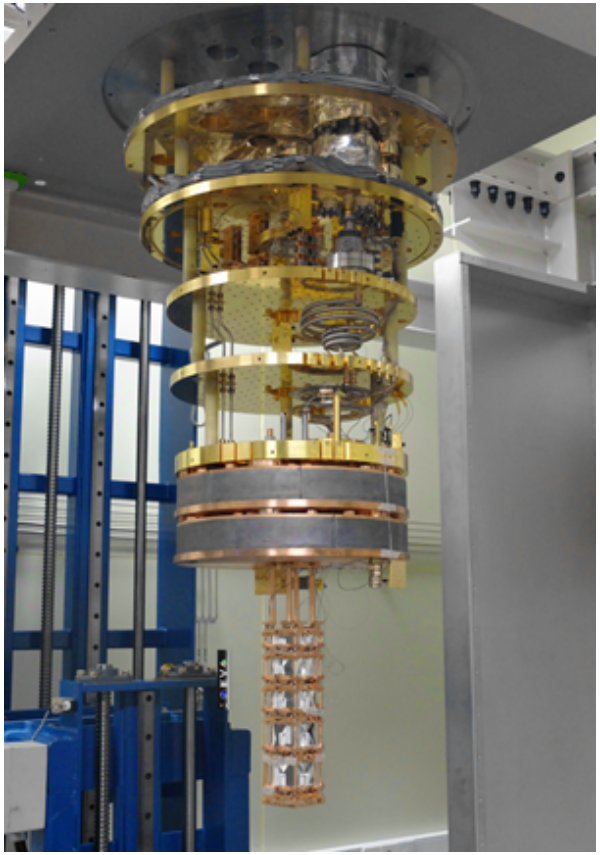
Access to the lab by car : around 2 km

Experiments

- KIMS : dark matter search experiment
- AMoRE : 0νββ decay search experiment

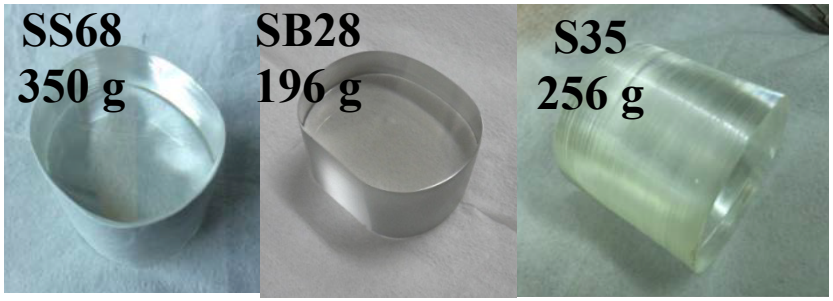
We've been busy at construction

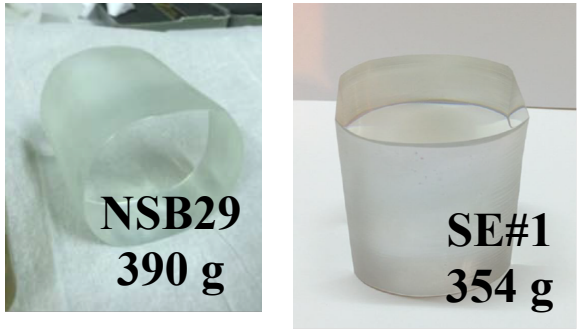
July 2015

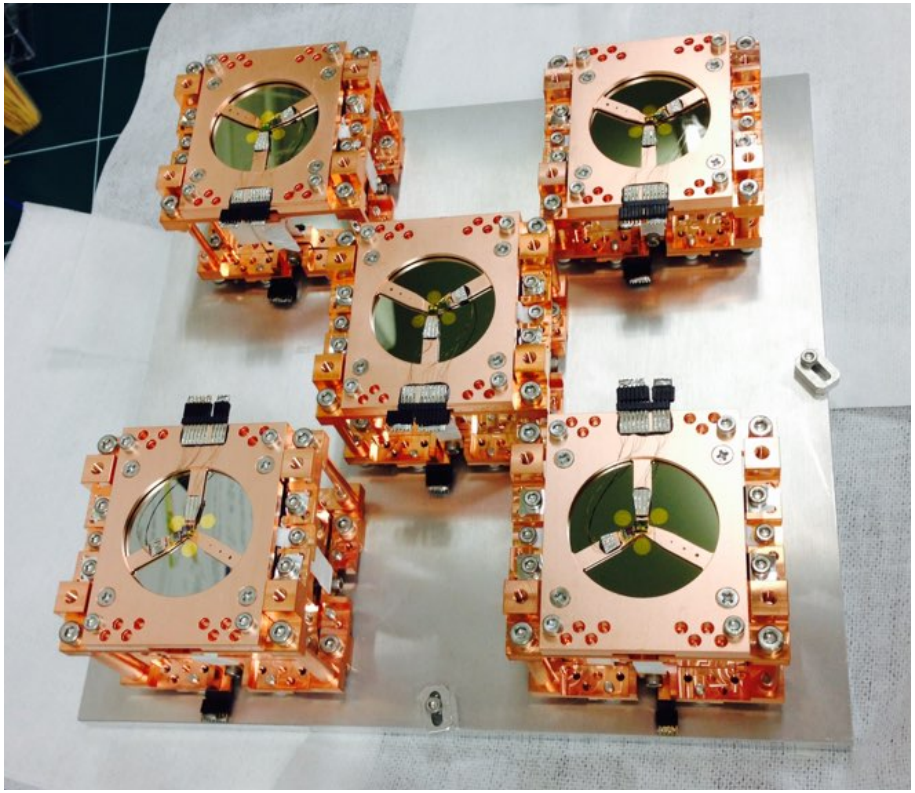


AMoRE pilot: 1.5 kg $^{40}Ca^{100}MoO_4$

5 Crystals ($^{40}Ca^{100}MoO_4$) with total mass ~1.5 kg

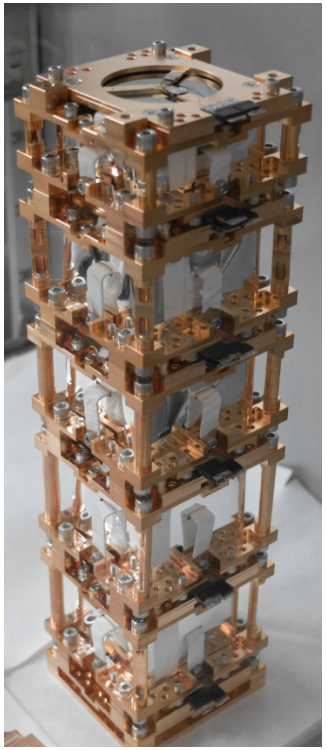


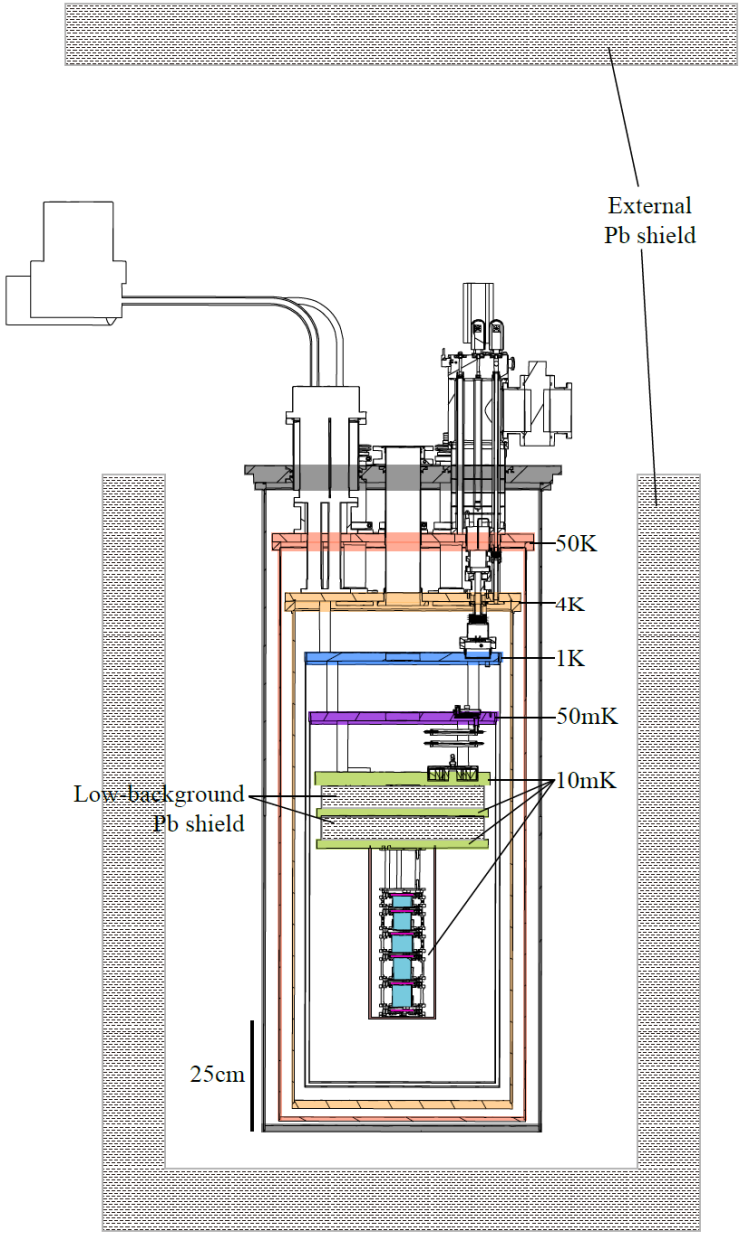




AMoRE pilot : 5 phonon + 6 photons

All are installed in a dilution refrigerator.

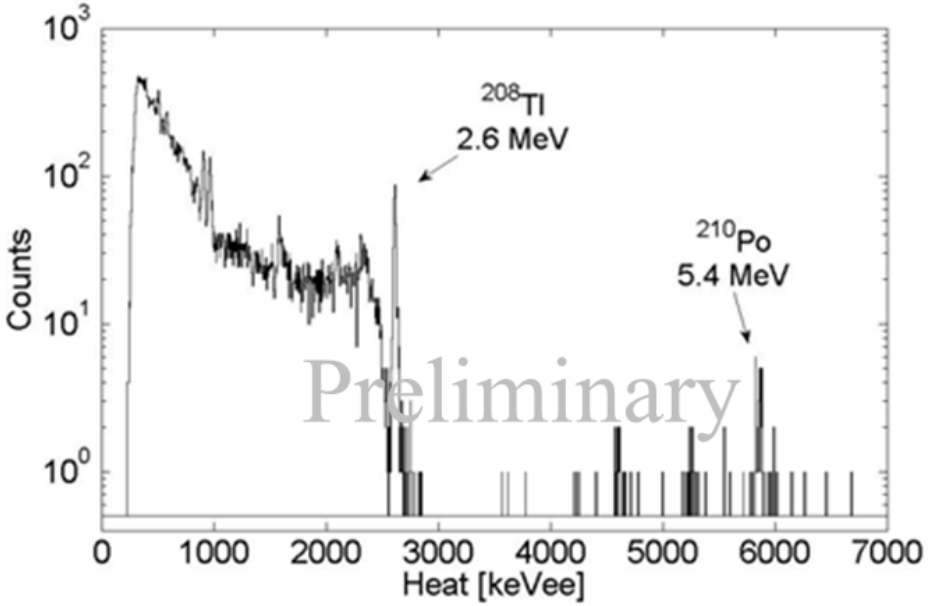




Now it is cold.

- All of the shields are mounted.
- The dil. fridge reaches 8 mK with 250kg lead & copper attached to M.C.
- We are improving noise figures now.
  - High friq.: reasonably low.
  - Low friq.: should be improved, and getting better.

with an external source at 20 mK



Schedule of the AMoRE project

- Crystal: $^{40}Ca^{100}MoO_4$, doubly enriched scintillating crystals
- MMC technology for heat and light measurement
- Temperature: 10-30 mK
- Zero background measurement in ROI
- Location: Y2L (till Phase I) and a new deeper place (after)

	Pilot	Phase I	Phase II
Mass	1.5 kg	~5 kg	~200 kg
Background (keV kg year)$^{-1}$	0.01	0.001	0.0001
Sensitivity($T_{1/2}$) (year)	~10^{24}	~10^{25}	~5×10^{25}
Sensitivity(m_{ee}) (meV)	< 300-900	60-180	15-40
Location	Y2L	Y2L	New Lab
Schedule	2015	2016-2018	2018-2022

TAUP2013, Now, TAUP2015

<2013 Asilomar>

13th International Conference on Topics in Astroparticle and Underground Physics
Asilomar, California USA
Sep. 8-13, 2013

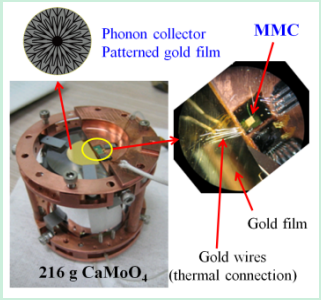
The AMoRE project

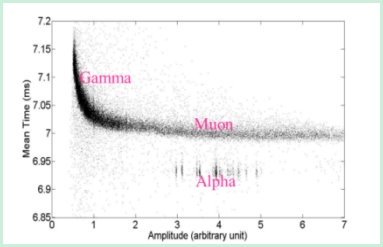
(Advanced Mo-based Rare process Experiment)

to search for neutrinoless double decay of ^{100}Mo
using cryogenic $CaMoO_4$ detectors

Yong-Hamb Kim (IBS & KRISS)
for AMoRE collaboration

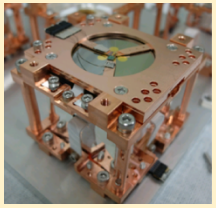
KRISS 한국표준과학연구원 ibs 기초과학연구원



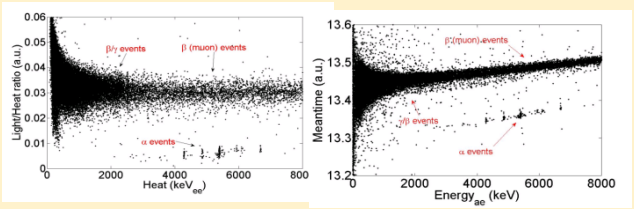


Clear PSD
9 keV FWHM for 2.6 MeV

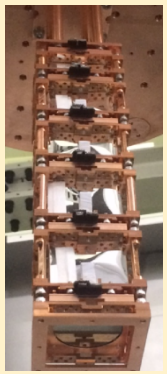
<2015 Torino>

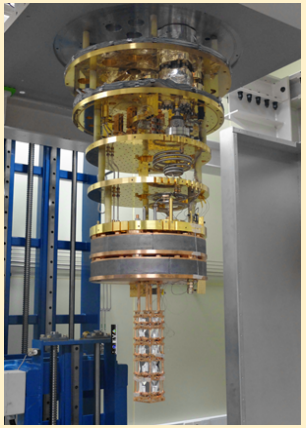


Heat+Light PSD



Underground lab at 2YL
Pilot started





<2017 ??>

Hopefully, we can discuss

Pilot physics result,

and on …