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 Korea Research Institute of Standards and Science

ibs 기초과학연구원 Institute for Basic Science

AMoRE Collaboration

- Korea (56)

  Seoul National University : H.Bhang, S.Choi, M.J.Kim, S.K.Kim, M.J.Lee, S.S.Myung, S.Olsen, Y. Sato, K.Tanida, S.C.Kim, J.Choi, H.S.Lee, J.H.Lee, J.K.Lee, X.Li, J.Li, H.Kang, H.K.Kang, Y.Oh, S.J.Kim, E.H.Kim, K.Tshoo, D.K.Kim(23)

  Kyungpook national University : H.J.Kim, Y.S.Hwang, S.J. Ra, J.Y.Lee, S.Khan, L. Ali, R. Bibi, J.H. So (8)

  Sejong University : Y.D.Kim, E.-J.Jeon, K. Ma, J.I.Lee, W.Kang, J.Hwa (6)

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  Ehwa Woman's University: I.S.Hahn, H.S.Lee (2)

  Sungsil University: M.-K. Cheoun, E.J. Ha, K.S. Choi (3)

  Semyung University: S.J. Kang (1)

  Chung-Ang University: S.Y. Kim (1)

- Russia (18)

  ITEP(Institute for Theoretical and Experimental Physics) : V.Kornoukhov, P. Polozov, N.Khanbekov (3)

  JSC-FORMOS Materials : V.V. Alenkov, O.A. Buzanov (2)

  Baksan National Observatory : A.Ganggapshev, A.Gezhaev, V.Gurentsov, V.Kuzminov, V.Kazalov, O.Mineev, S.Panasenko, S.Ratkevich, A.Verensnikova, S.Yakimenko, N.Yershov, K.Efendiev, Y.Gabriljuk (13)

- Ukraine(9)

  INR(Institute for Nuclear Research) : R.S. Boiko, D.M. Chernyak, F.A. Danevich, V.V. Kobychev, V.M. Mokina, D.V. Poda, R.B. Podviyanuk, O.G. Polischuk, V.I. Tretyak (9)

- China(3)

  Tsinghua University : J.Li, Y. Li, Q.Yue(3)

- Germany(3)

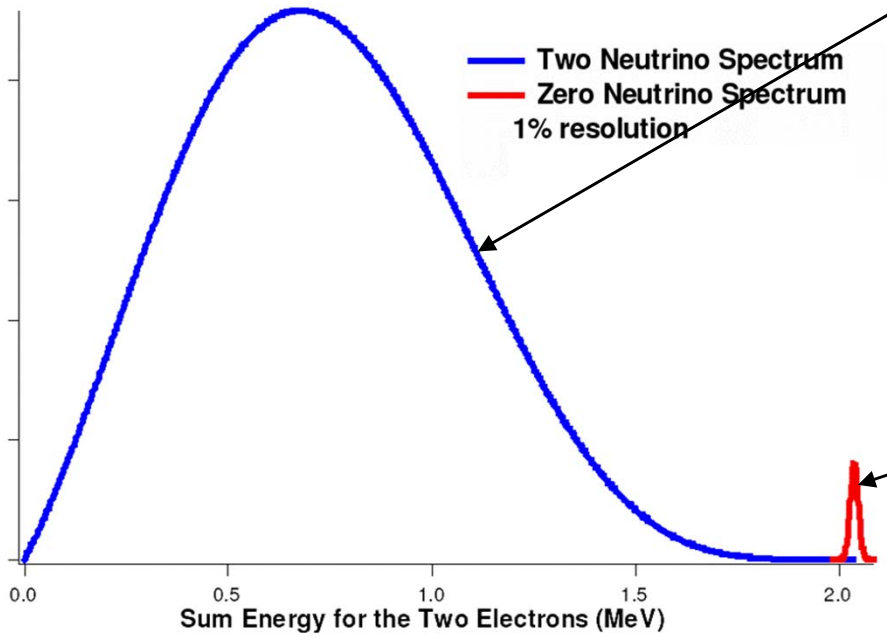
  University of Heidelberg : C.Enss, A. Fleischmann, L. Gastaldo (3)

- Parkistan(1)

  Abdul Wali Khan Univ : G. Rooh (1)

6 countries, 15 institutions, 90 collaborators

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 !

Key test proposed by Racah in 1937

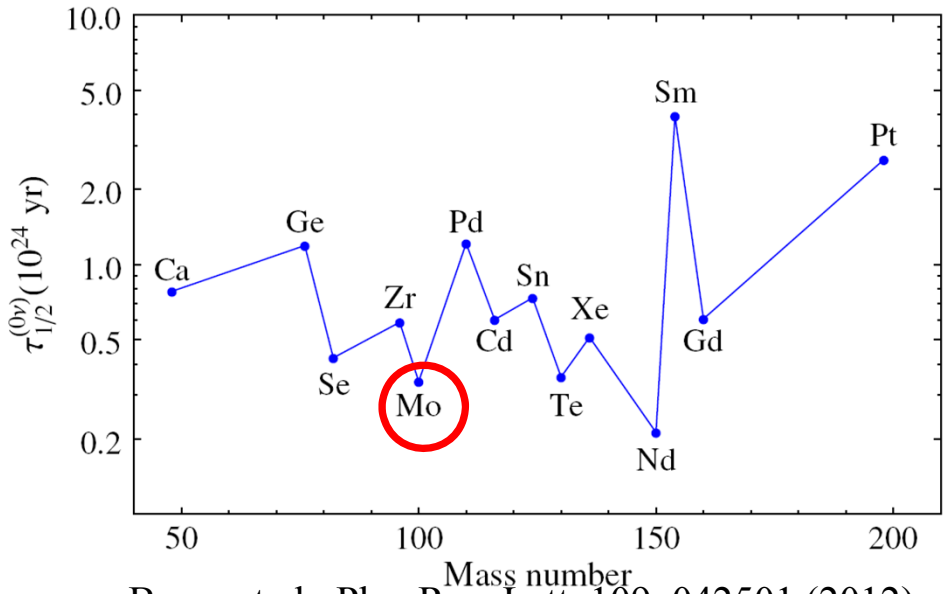
It may answer

- 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

^{100}Mo is chosen for 0νββ experiment

- ^{100}Mo
  - ✓ High Q-value (ββ) of 3034.40 (12) keV.
  - ✓ High natural abundance of 9.7%
  - ✓ 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)

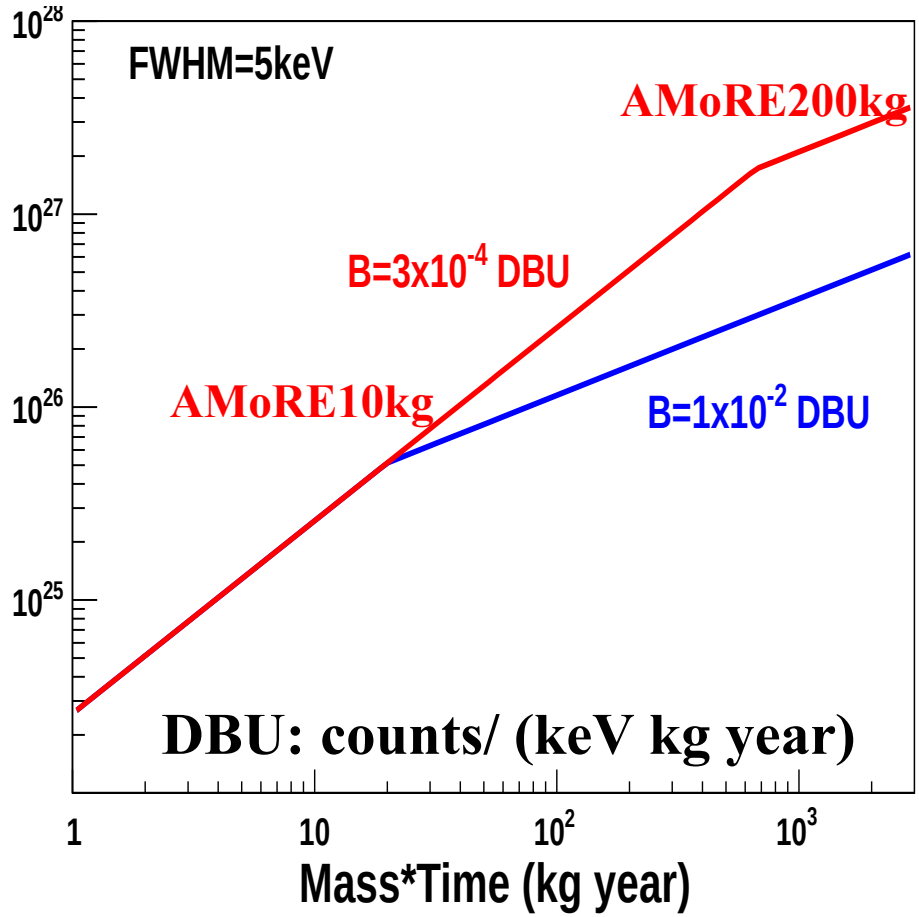
Candidate	Q (MeV)	Abund. (%)
^{48}Ca	4.271	0.19
^{76}Ge	2.040	7.8
^{82}Se	2.995	8.7
^{100}Mo	3.034	9.7
^{116}Cd	2.802	7.5
^{124}Sn	2.228	5.8
^{130}Te	2.533	34.1
^{136}Xe	2.479	8.9
^{150}Nd	3.367	5.6

Experimental Sensitivity on 0νββ search

For sizeable background case;

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

Isotopic Abundance; Detection Efficiency; Detector Mass; Time; Atomic mass; Background level (count/keV kg year); Energy Resolution



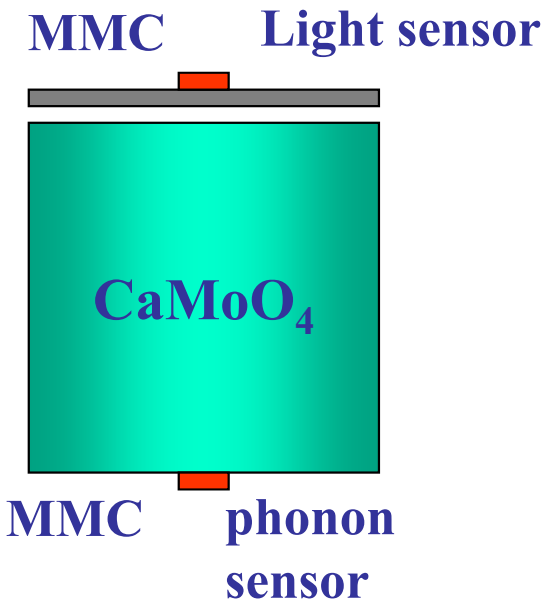
For "zero" background case; # of background events ~ 0 (1)

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

AMoRE detector technology

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

Low Temp. Detector
Source = Detector



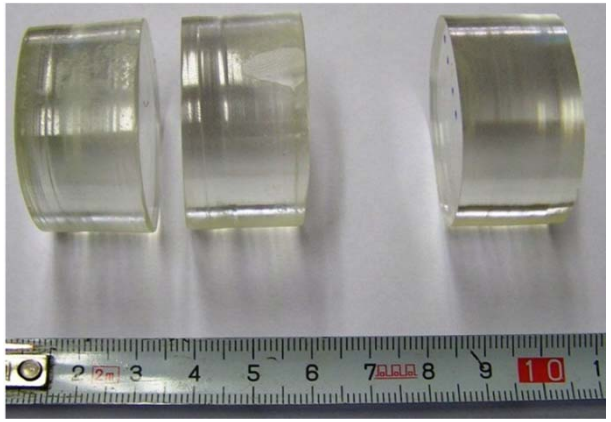
<10-50 mK>

$CaMoO_4$
- 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

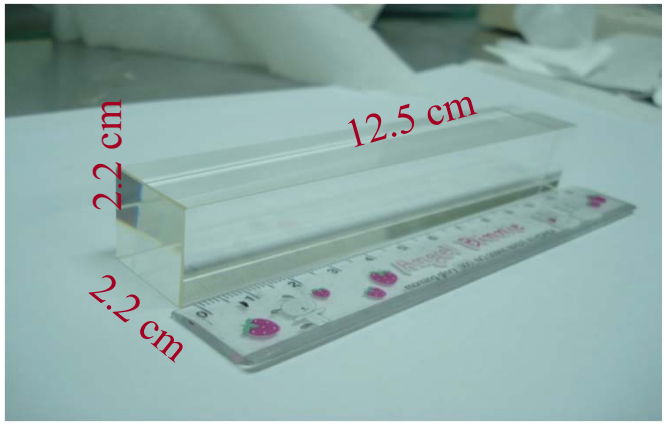
MMC (Metallic Magnetic Calorimeter)
- Magnetic temperature sensor (Au:Er) + SQUID
- Sensitive low temperature detector with highest resolution
- Wide operating temperature
- Relatively fast signals
- Adjustable parameters in design and operation stages

$CaMoO_4$ crystal development

Korea(2003)

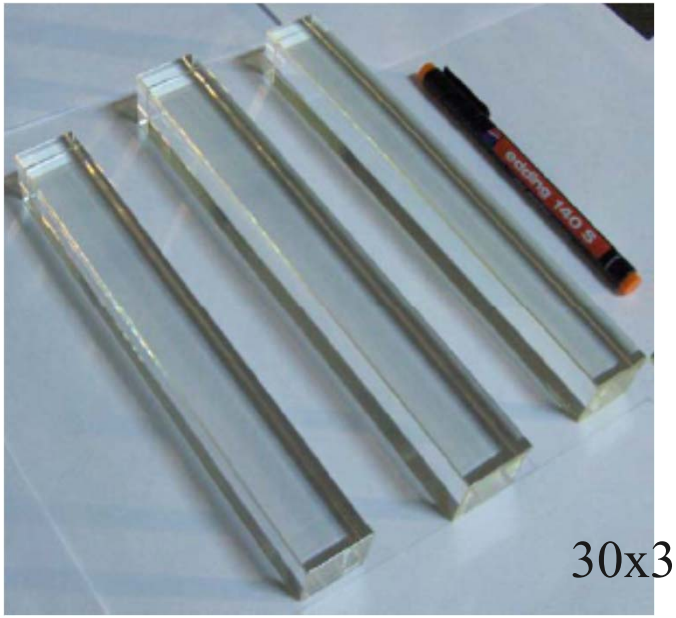


Ukraine-CARAT(2006)



Russia(2006)

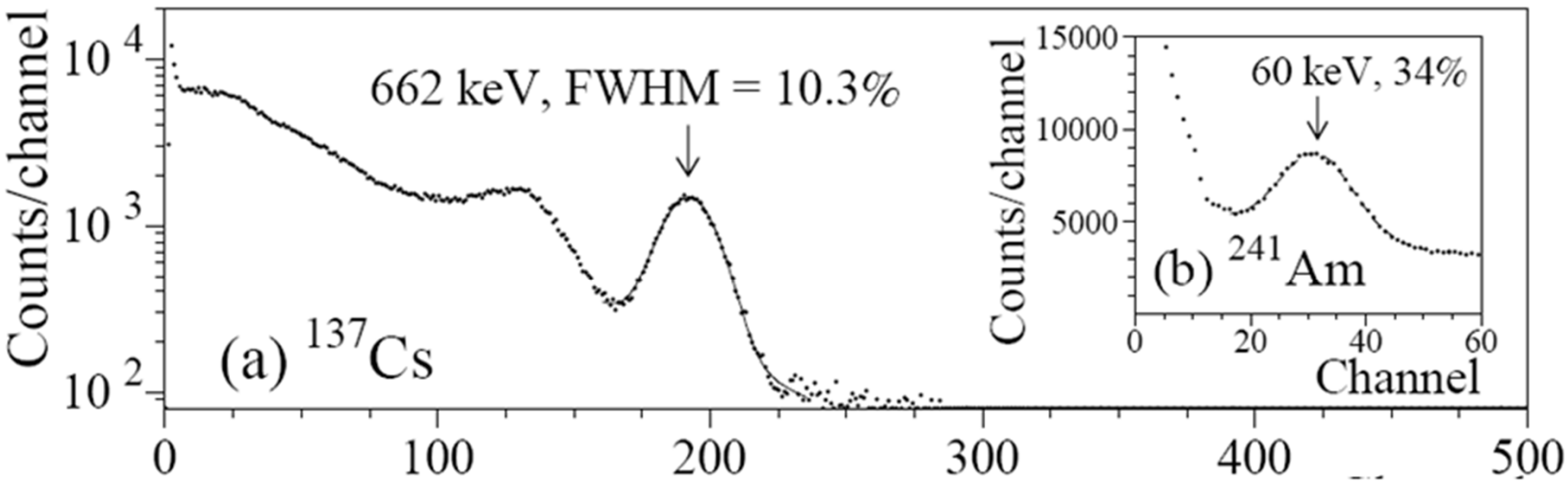
IEEE/TNS 2008

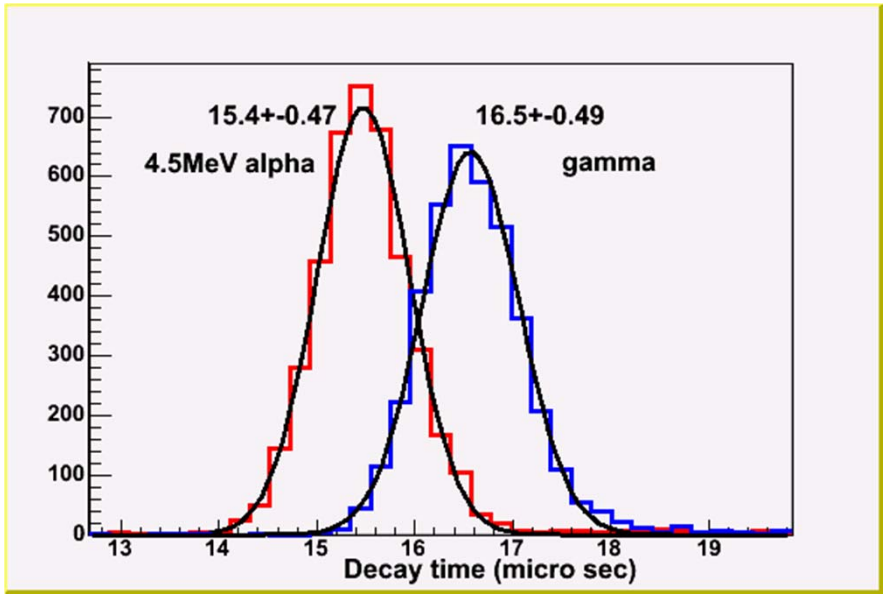


30x30x200mm

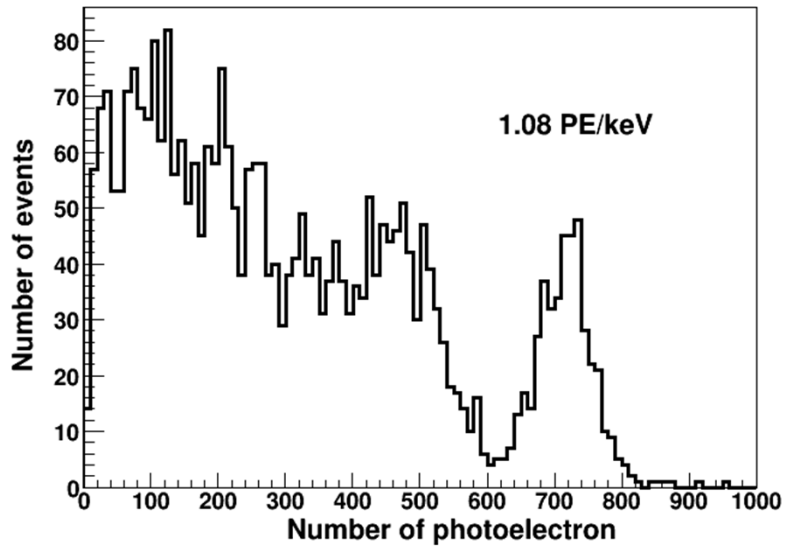
$CaMoO_4$ characterization

NIMA 584, 334 (2008)





IEEE TNS 57 (2010) 1475



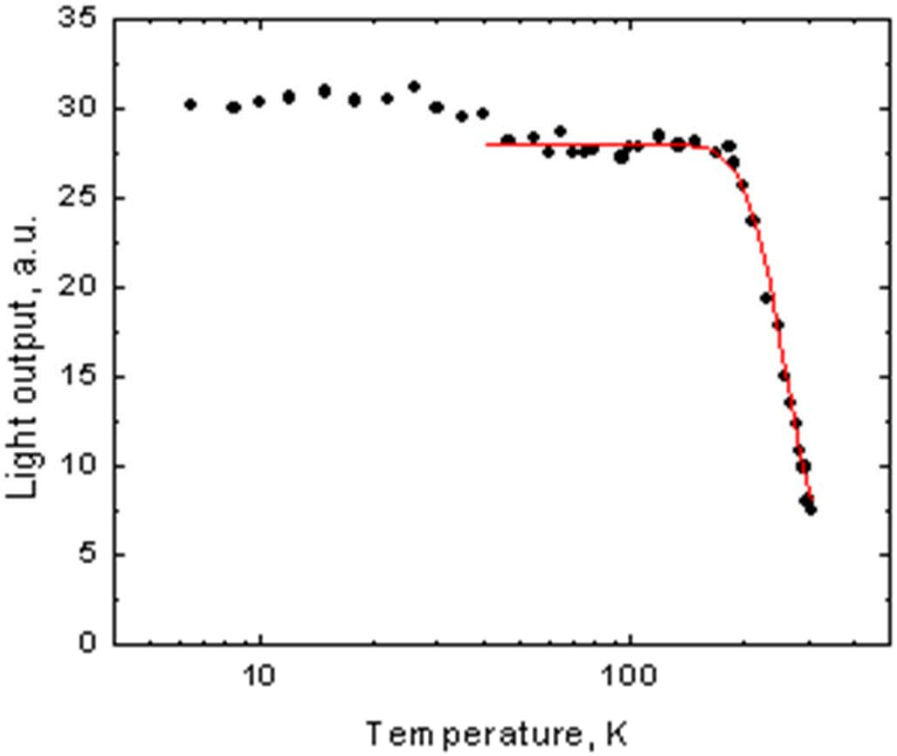
4% FWHM at 3 MeV

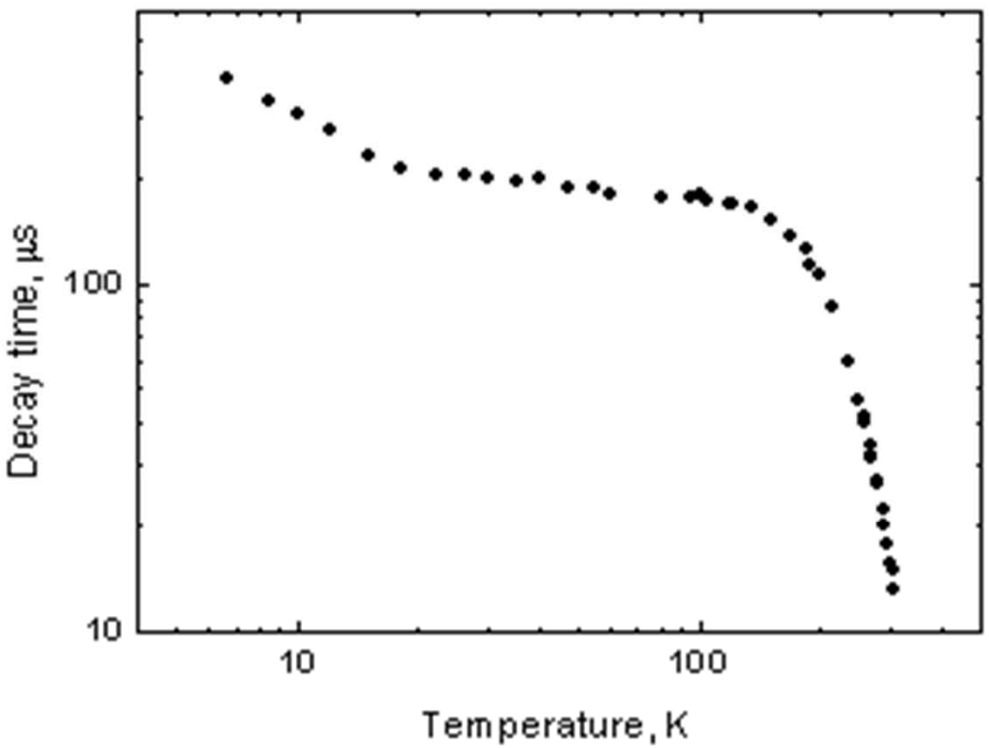
Only with photoelectron statistics

Temperature dependent 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.**

^{100}Mo, ^{40}Ca enriched materials

- Mo-100 isotope production:
  ECP (Electrochemical plant) Zelenogorsk, Krasnoyarsky kray, Siberia

  $^{100}MoO_3$
  - Enrichment: ^{100}Mo = 97%
  - Impurities
    ICP-MS measurement: U ≤ 0.2 ppb, Th ≤ 0.1 ppb
    HPGe At Baksan: ^{226}Ra < 2.3 mBq/kg, ^{228}Ac < 3.8 mBq/kg

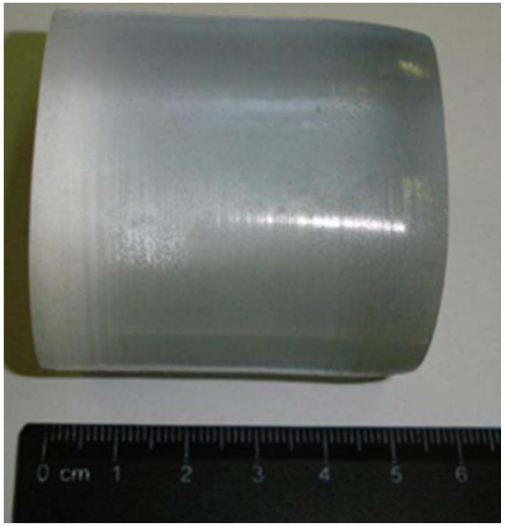
- Ca-40 isotope production:
  ELEKTROCHIMPRIBOR, Lesnoy, Sverdlovky region

  $^{40}CaCO_3$
  - ^{48}Ca < 0.001%
  - Impurities: U ≤ 0.1 ppb, Th ≤ 0.1 ppb, Sr = 1 ppm, Ba = 1 ppm
    ^{226}Ra = 51 mBq/kg ^{228}Ac(^{228}Th) = 1 mBq/kg

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

- SB28
  weight 196 g

- SB29
  weight 390 g

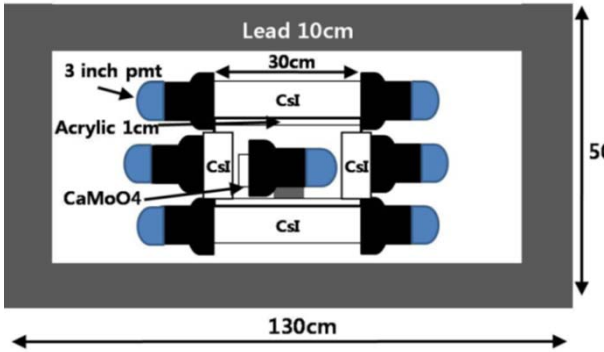


- S35
  weight ~300 g

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

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

4π gamma veto system



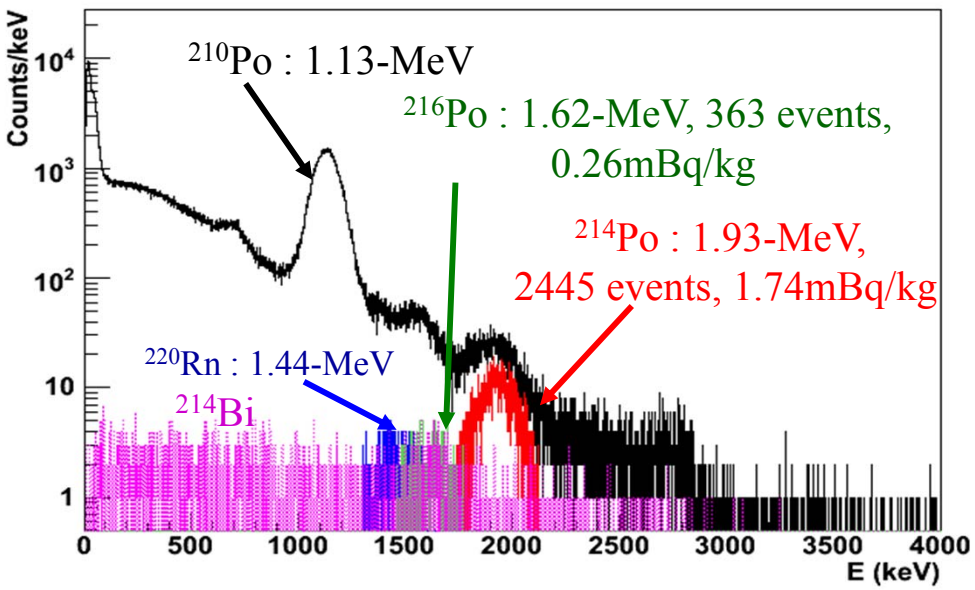
β–α decay in ^{238}U

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

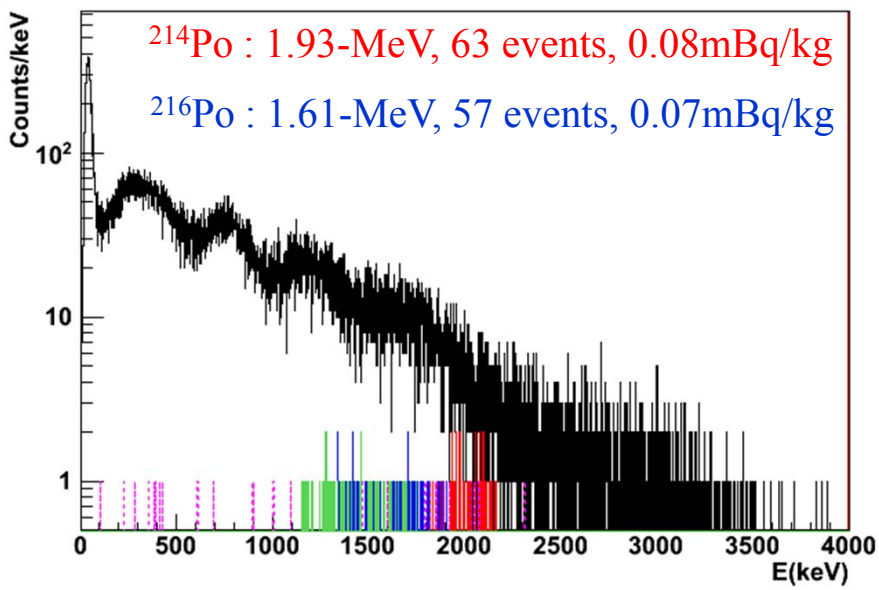
α–α decay in ^{232}Th

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

Crystal S35



Crystal SB28



YangYang(Y2L) Underground Laboratory

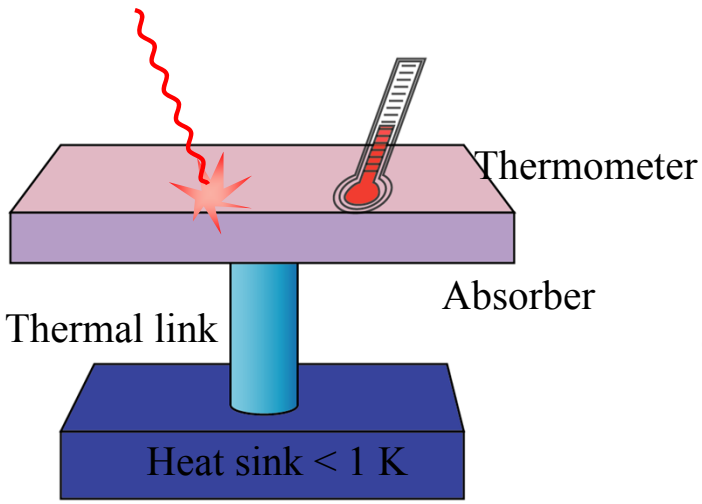
KIMS (Dark Matter Search)

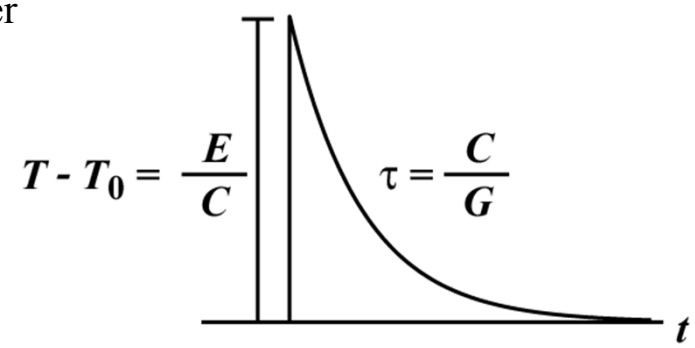
AMoRE (Double Beta Decay Experiment)

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

Low temperature detectors (Calorimeters)

Energy absorption ➔ Temperature

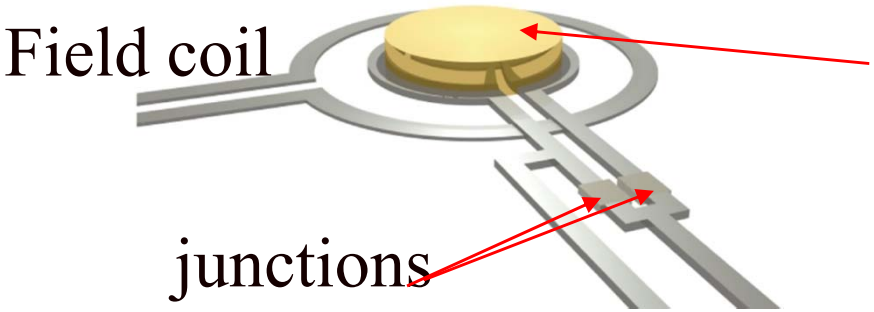




Choice of thermometers

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

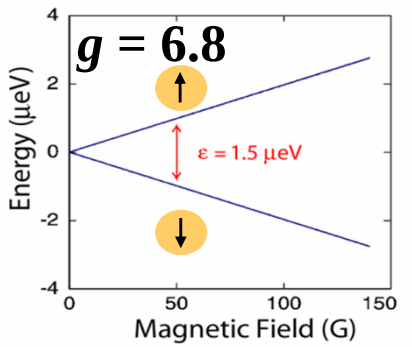
Metallic Magnetic Calorimeter (MMC)

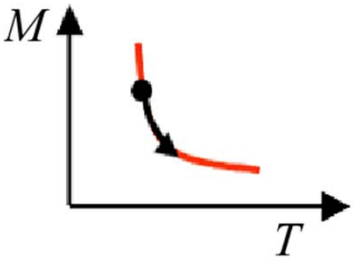


Magnetic material Au:Er(10~1000ppm)

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

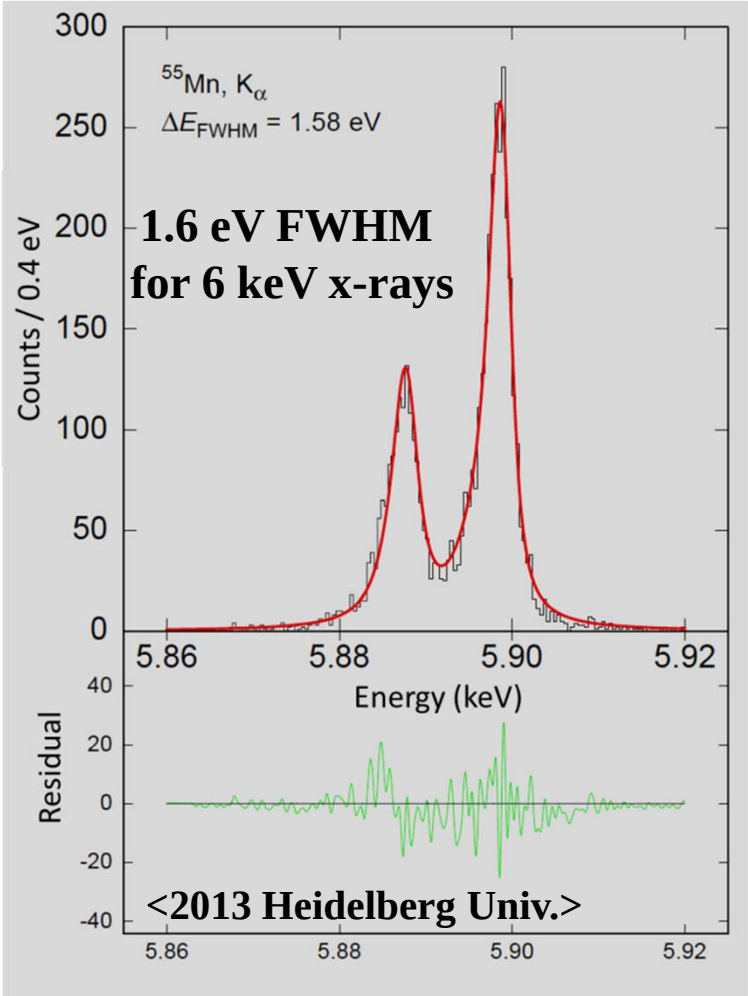
$$\delta E \rightarrow \delta T \rightarrow \delta M \rightarrow \delta \phi$$



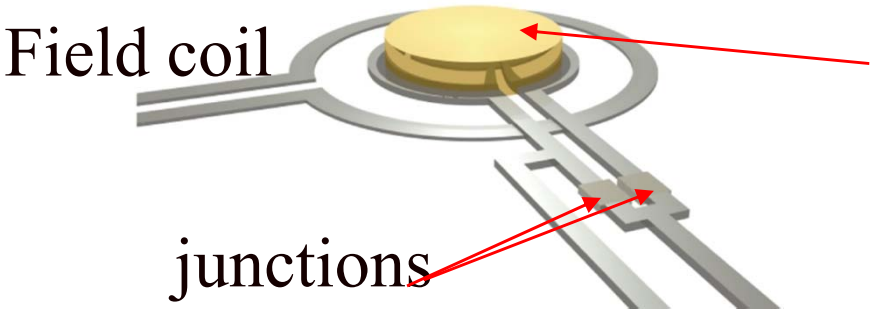


5 mT → $\Delta\varepsilon$ = 1.5 μeV

1 keV → 10^9 spin flips



Metallic Magnetic Calorimeter (MMC)



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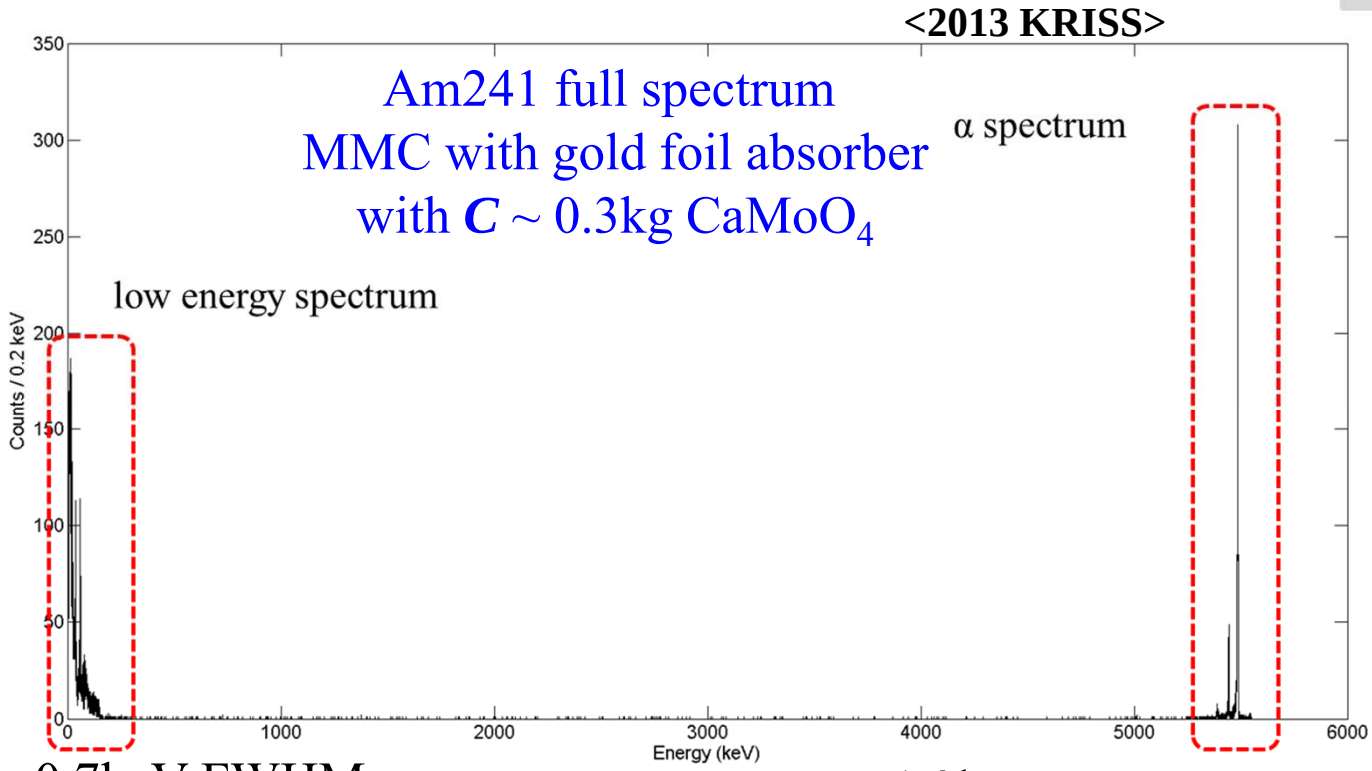
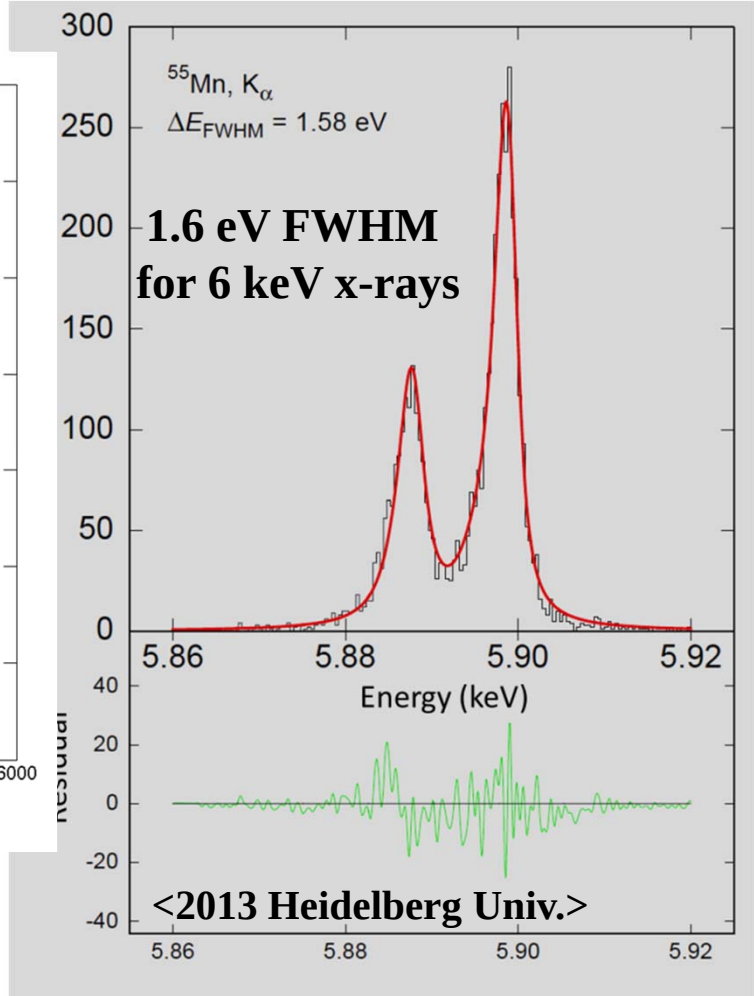
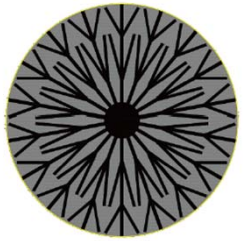
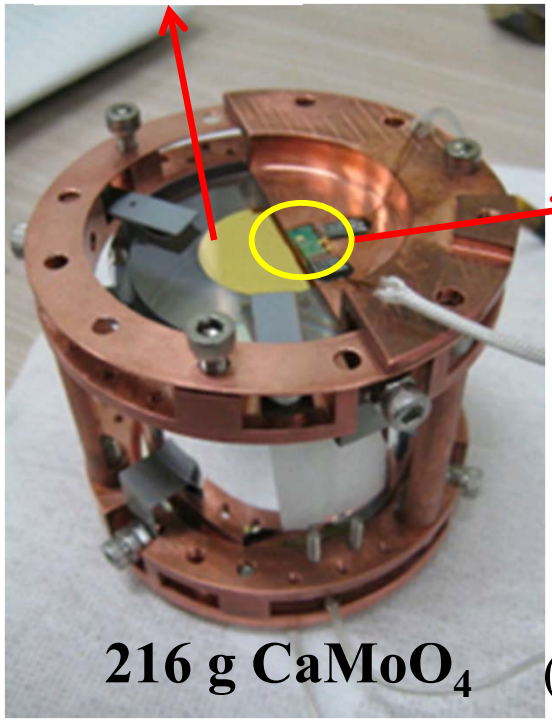




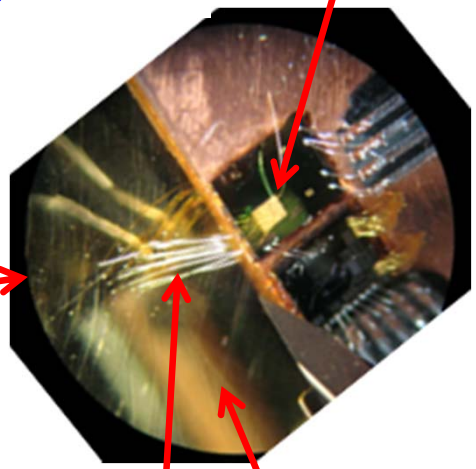
Phonon sensor for AMoRE



Phonon collector
Patterned gold film



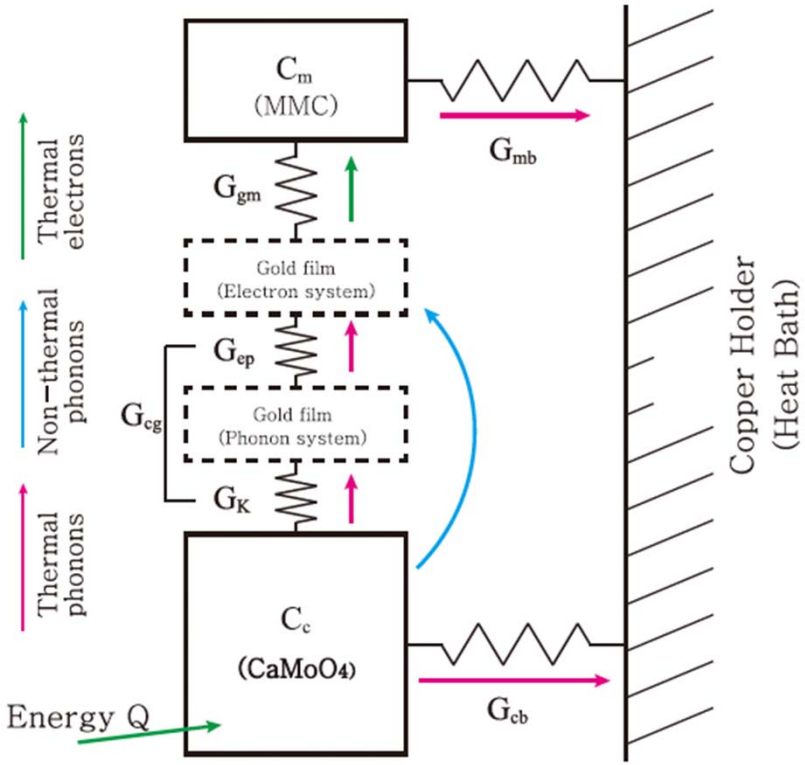
216 g $CaMoO_4$

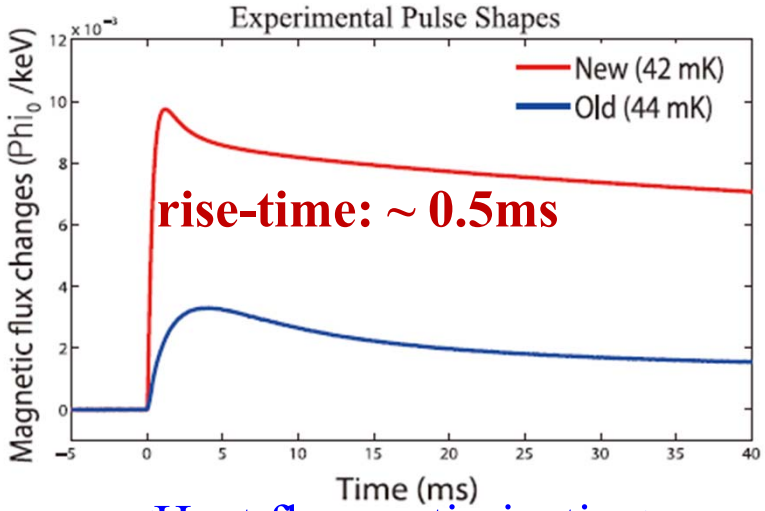


MMC

Gold film

Gold wires
(thermal connection)



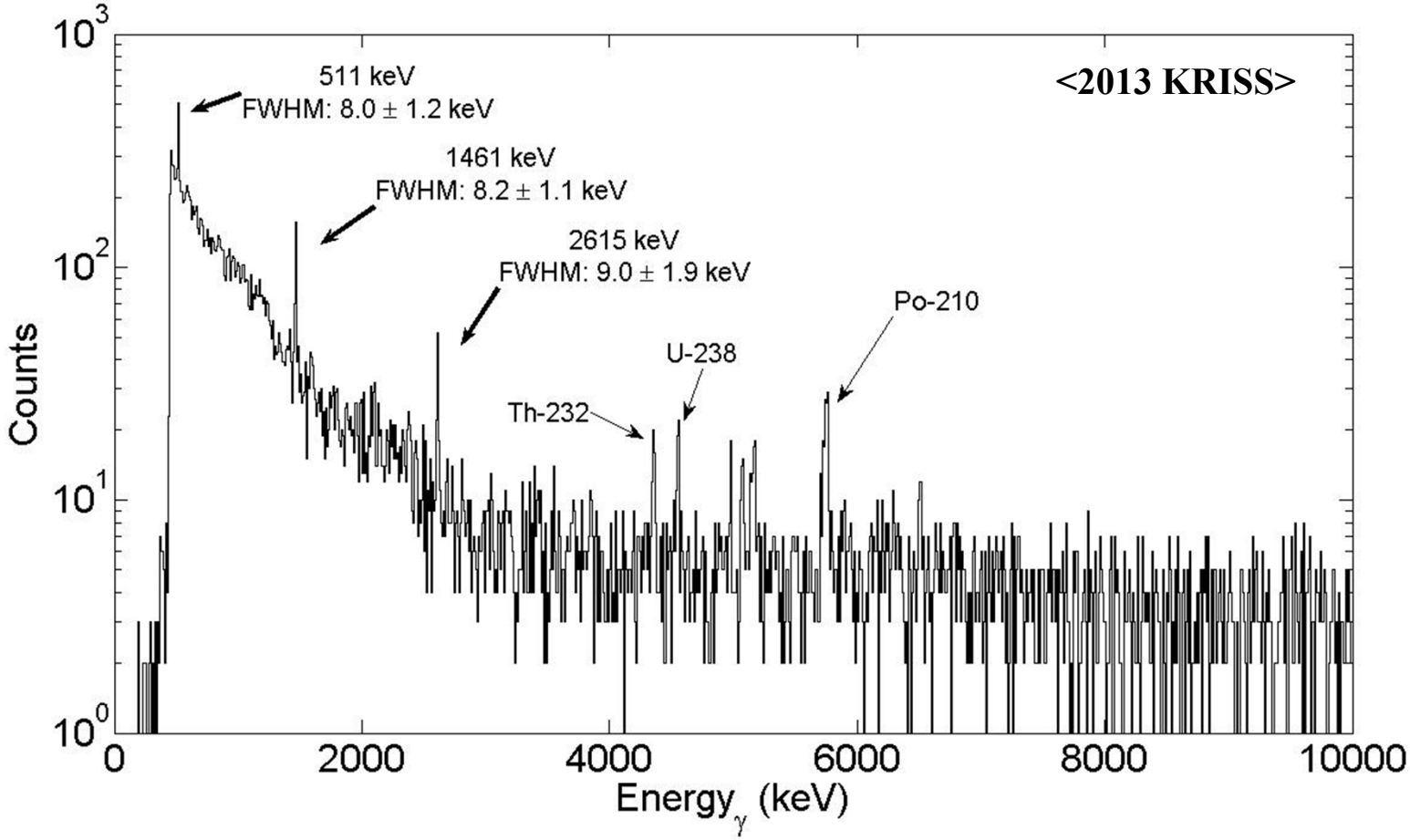


<Heat flow optimization>

We measure both thermal and athermal phonons.

Detector R&D in an over-ground lab

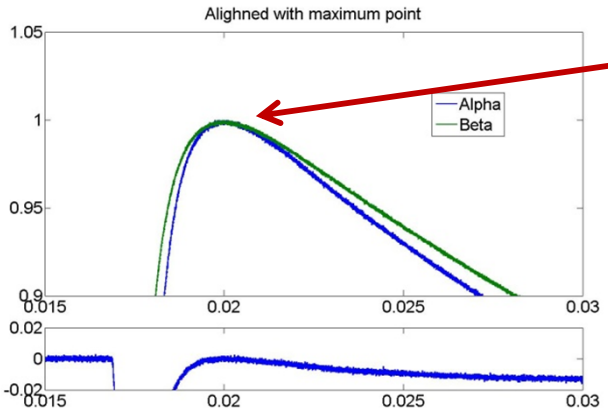
216 g $CaMoO_4$(natural) with a phonon sensor only.

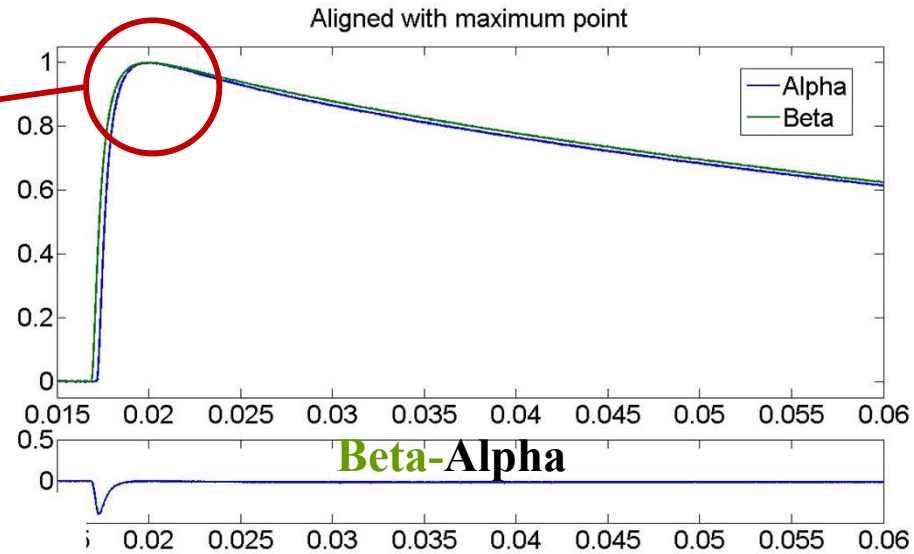


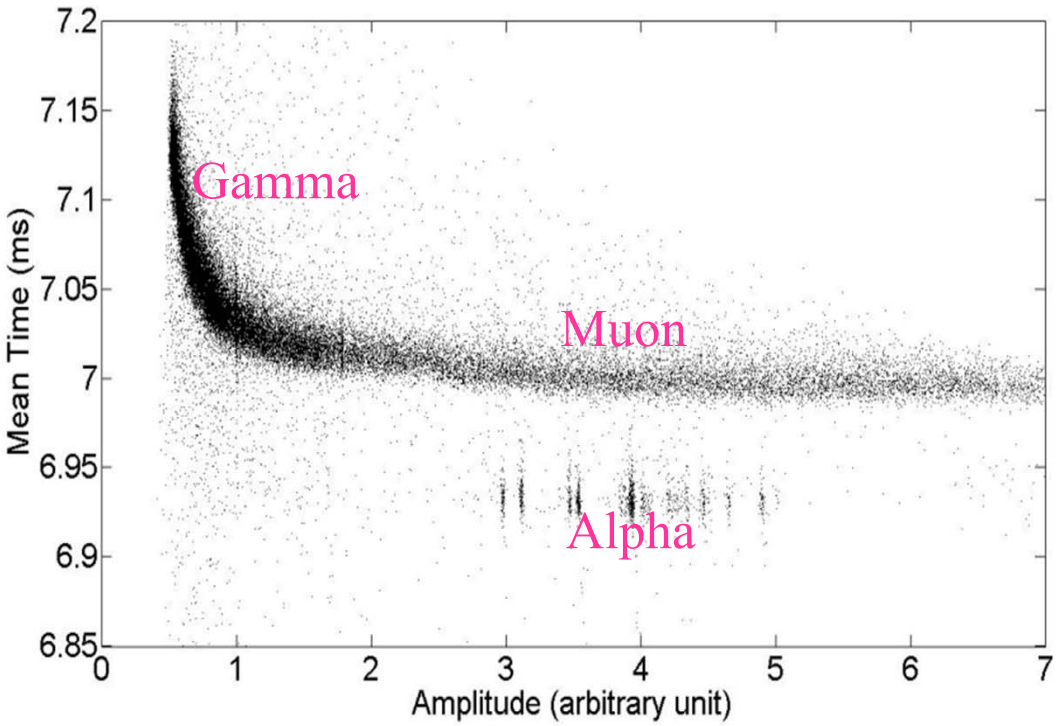
Energy (keV)	511	1461	2615
FWHM (keV)	8.0 ± 1.2	8.2 ± 1.1	9.0 ± 1.9

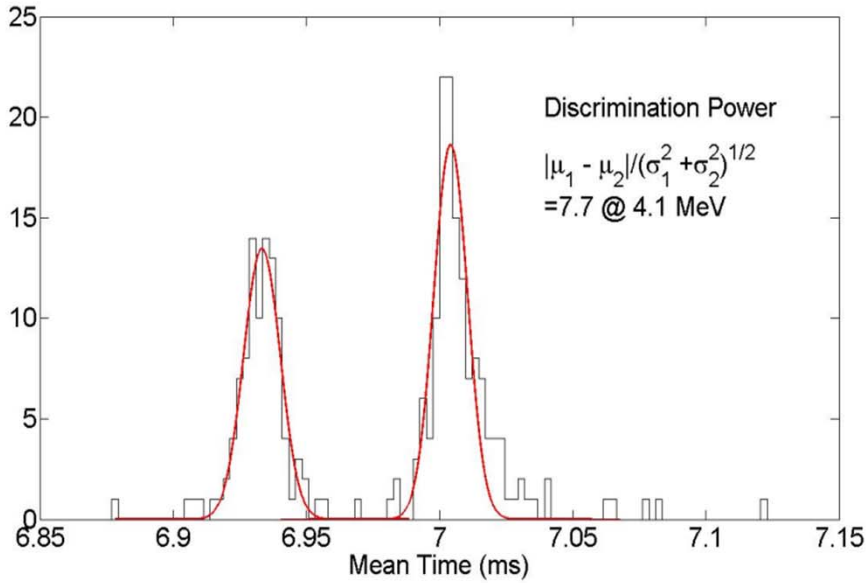
Pulse Shape Discrimination

α and β events show different pulse shapes in phonon signals.

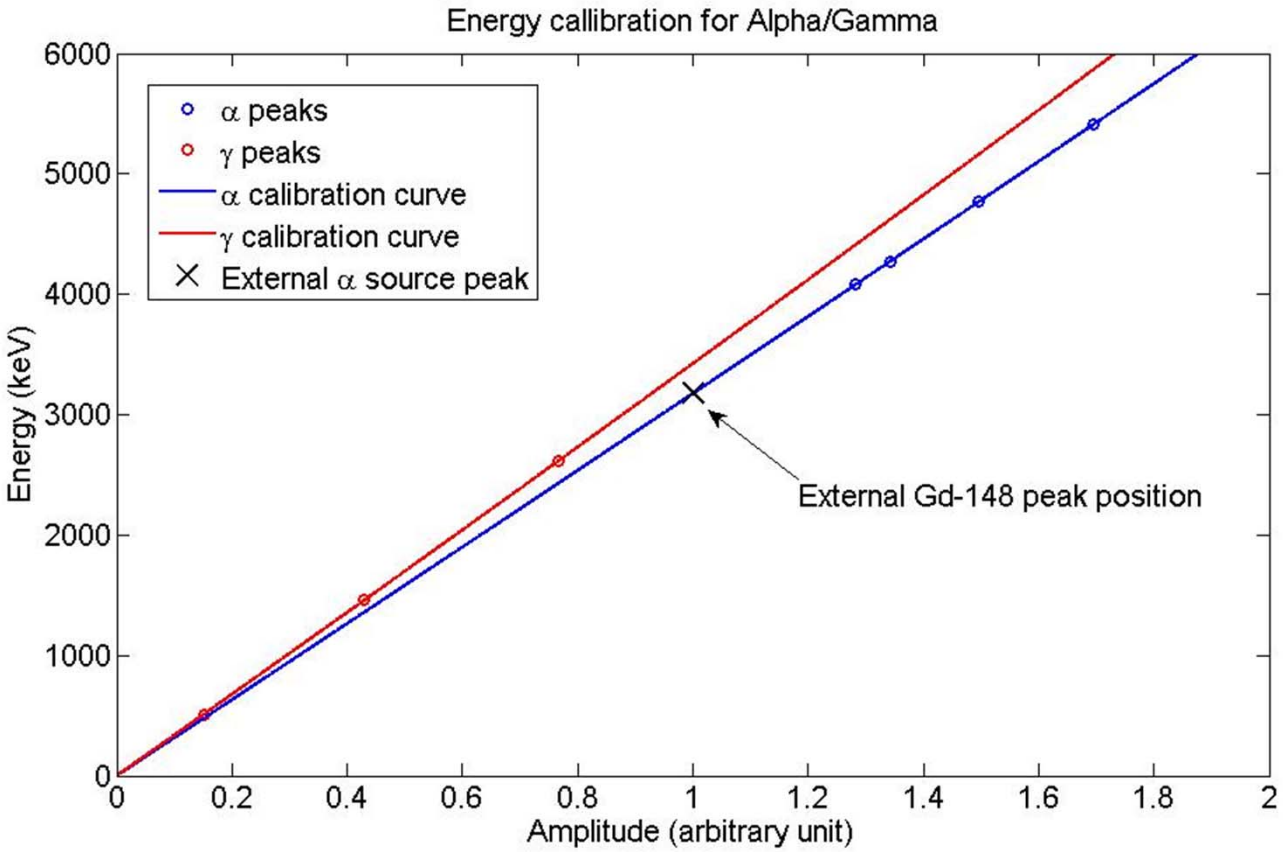






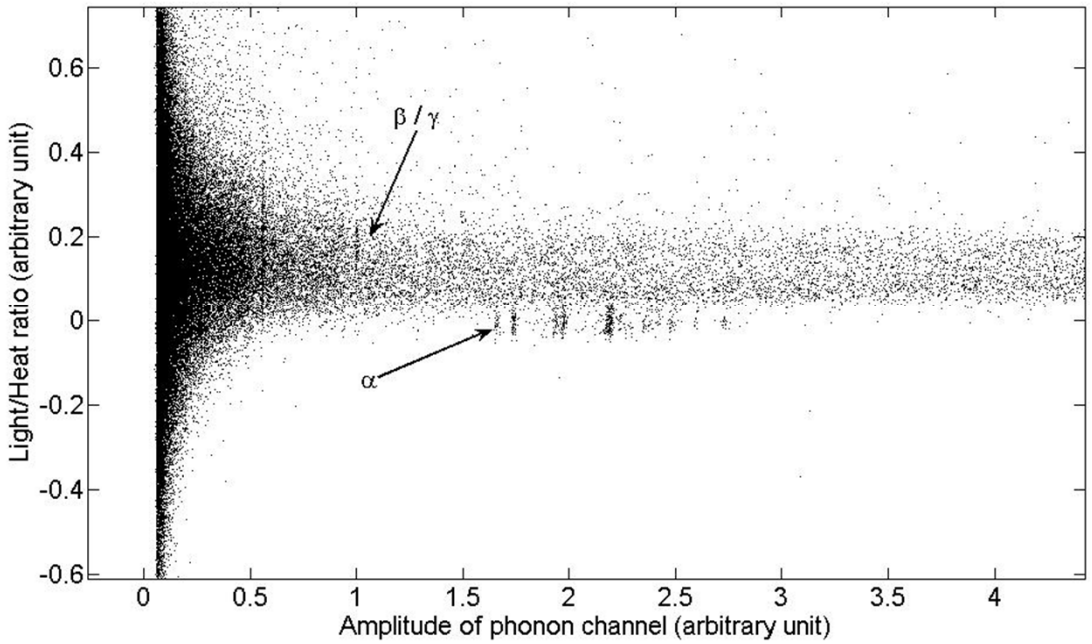


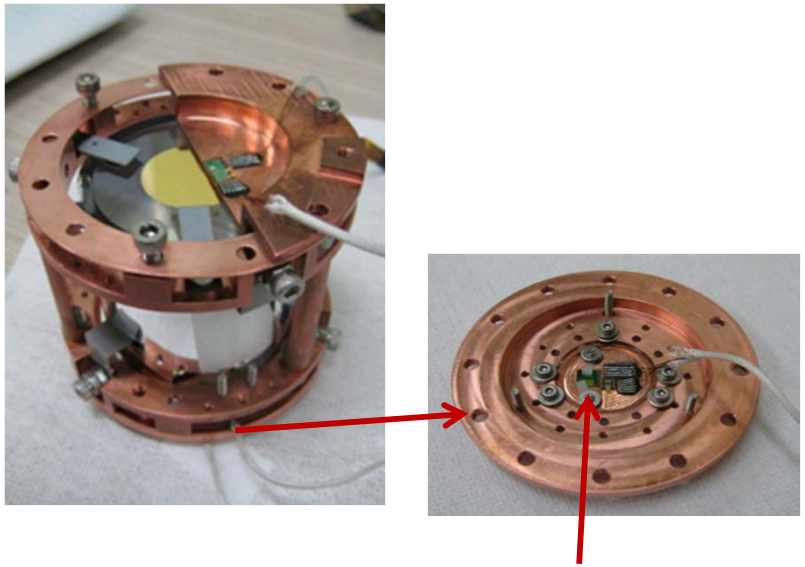
Energy calibration



- Alpha/Beta events show different energy scale (~7% @ 2.6 MeV).
- The detector shows good linearity for both of alpha and gamma signals.

Photon Detector Measurement





Photon detector

- We measured small photon signals because of small covering area (~20 mm^2).
- α and β particle events show different light yields.
- Now we are developing photon detectors with 1-2 inch Ge wafers.

Summary of the AMoRE project

- Crystal: $^{40}Ca^{100}MoO_4$, doubly enriched scintillating crystals
- ^{100}Mo enrichment = 97%
- Temperature: 10-50 mK
- Energy Resolution: 5 keV @ 3 MeV

  (Now ~9keV w. one phonon only in over-ground)
- Single Detector Mass: 300-500g
- Location: Y2L or a new lab
- Fully funded now.

	Phase I	**Phase II**
Mass	10 kg	200 kg
Background (keV kg year)$^{-1}$	10^{-2}	3×10^{-4}
Sensitivity(m_{ee}) (meV)	80-250	20-50
Schedule	in 3 years	in 10 years

Thank you

Amare the AMoRE project !