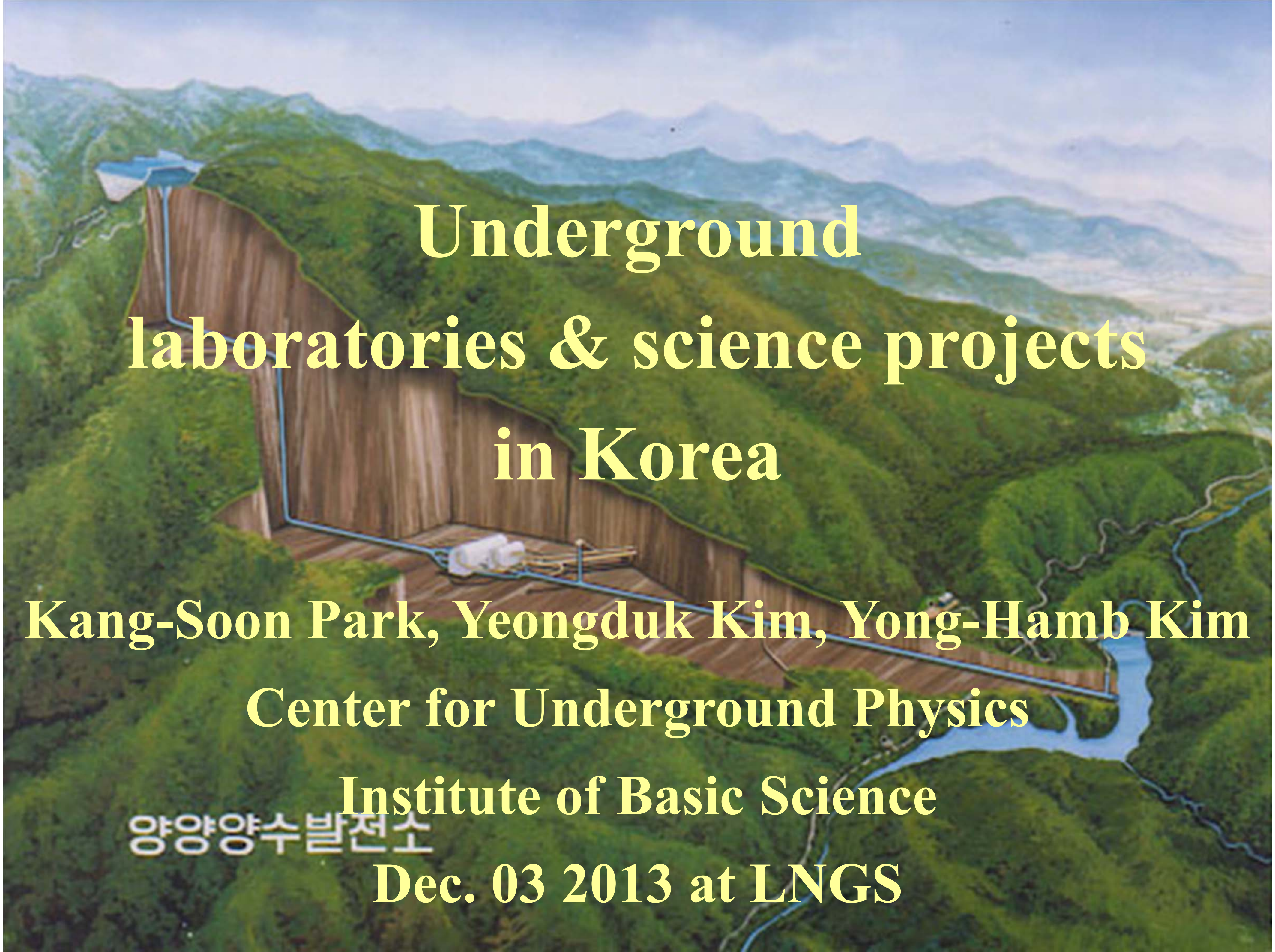
Underground laboratories & science projects in Korea

Kang-Soon Park, Yeongduk Kim, Yong-Hamb Kim
Center for Underground Physics
Institute of Basic Science

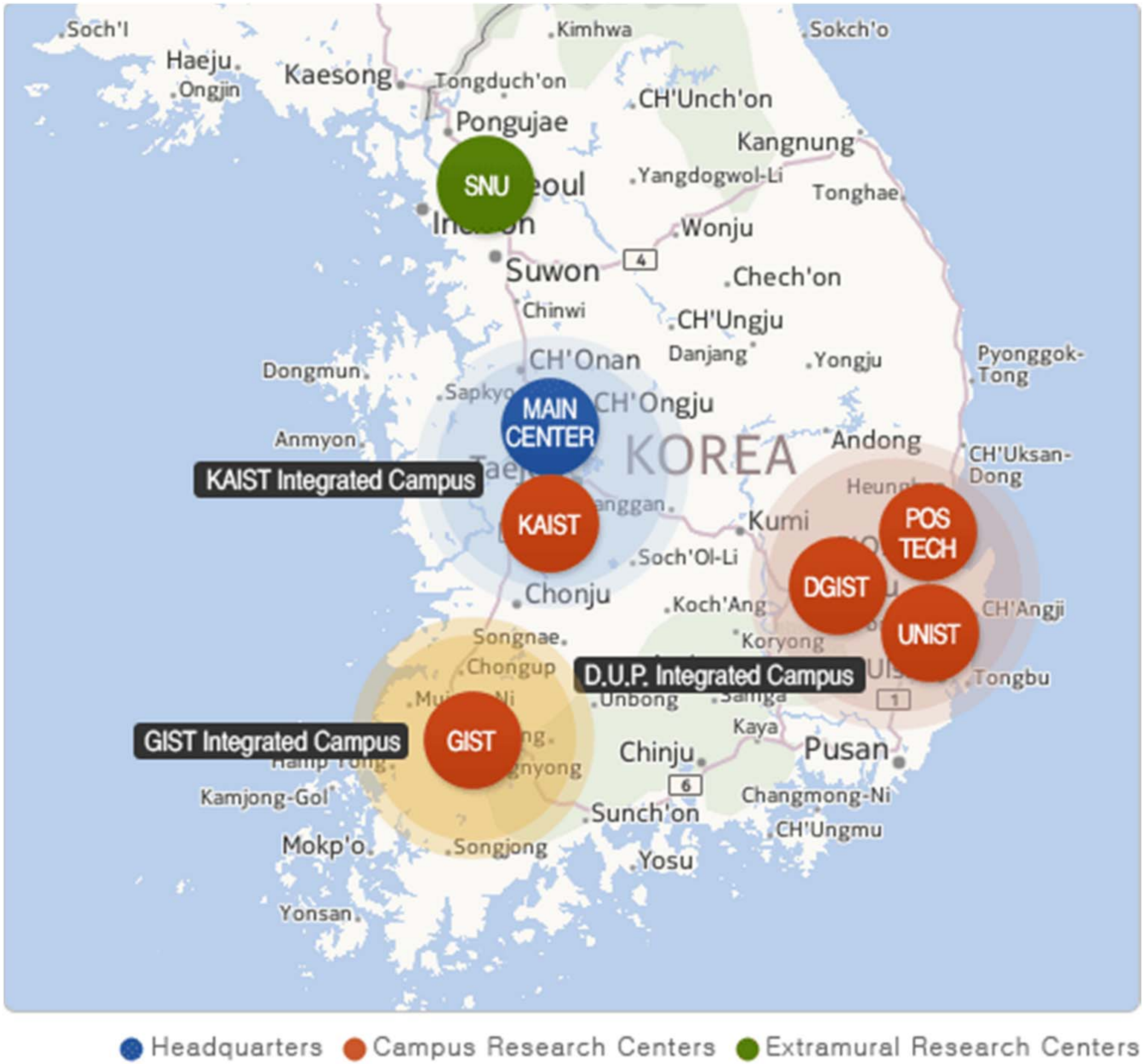
Dec. 03 2013 at LNGS



Outline

1. Introduction to CUP at IBS
2. Underground Labs
3. Dark Matter Search Project - KIMS
4. Double Beta Decay Project – AMoRE

Institute of Basic Science (IBS)



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Benchmarked RIKEN & MAX-PLANK Institute.

Heavy-ion accelerator facility & IBS research centers

Center for Underground Physics (CUP)

- CUP began on July 2013
- Now, 17 Ph.Ds, 15 students, 3 technicians, 2 administrations.
- Director : Yeongduk Kim
- Group Leaders : Hong Joo Kim, Yong-Hamb Kim
- Research Area : Dark Matter, Double Beta Decay, Underground Nuclear Astrophysics, Sterile neutrino search at reactor, Low temperature Detector Development etc.
- Major Projects: **1. KIMS (ongoing dark matter search)**
  2. AMoRE (planed $0\nu\beta\beta$ search)

YangYang(Y2L) Underground Laboratory

KIMS (Dark Matter Search)

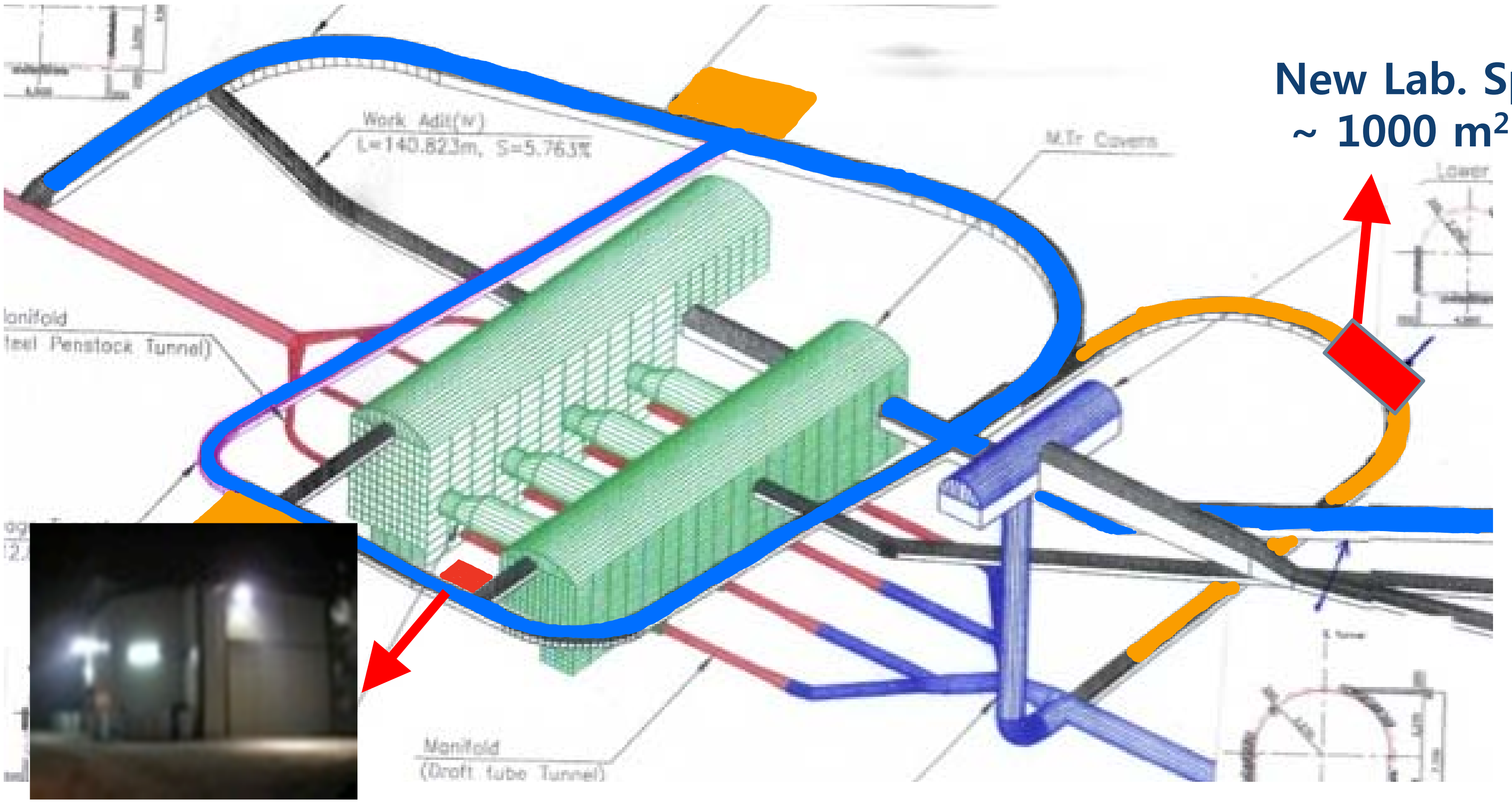
AMoRE (Double Beta Decay Experiment)

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

Lab space in Y2L

New lab space will be ready by early 2014 at the unused tunnel

New Lab. Space
~ 1000 m^2

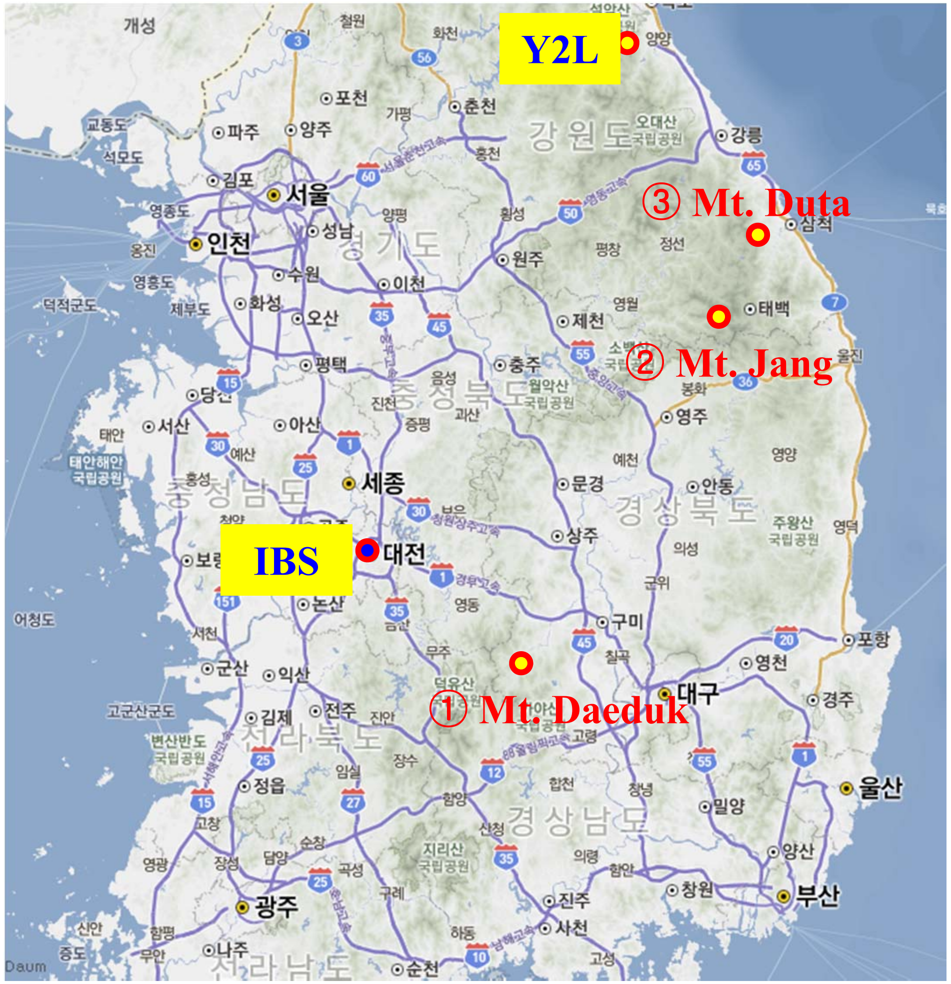


Current Lab. ~ 100m^2

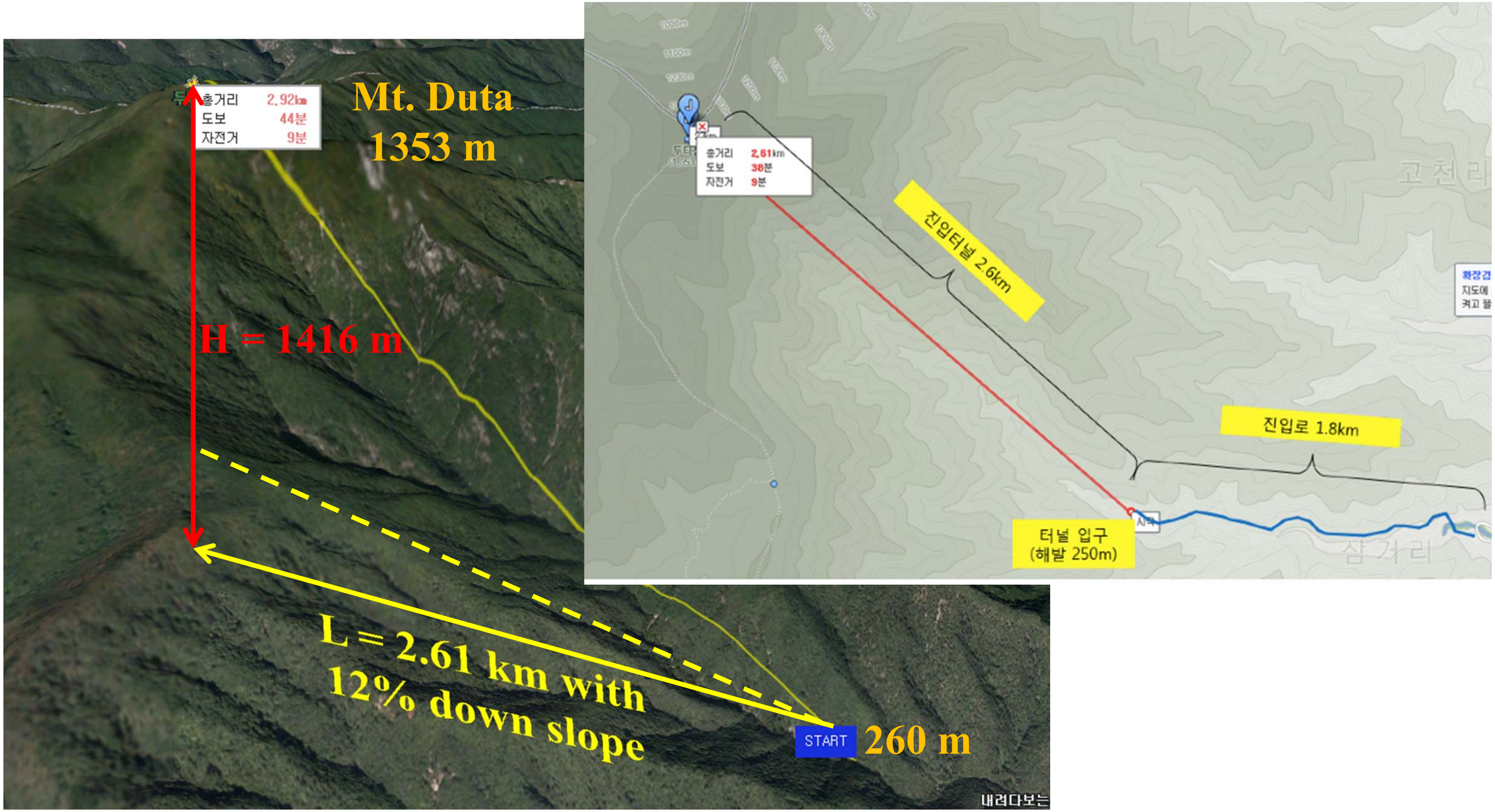
Can we go deeper?

final 3 candidates

No.	Mt.	Location	L of Tunnel (m)	overburden (m)	from IBS (km)	from Y2L (km)
1	Daeduk	Gimcheon, Kyungbuk	2400	1088	110	413
2	Jang	Yeongwol, Gangwon	1730	1066.6	230	167
3	Duta	Samcheok, Gangwon	2610	1416.2	330	117



Possible 1400m deep Underground Lab



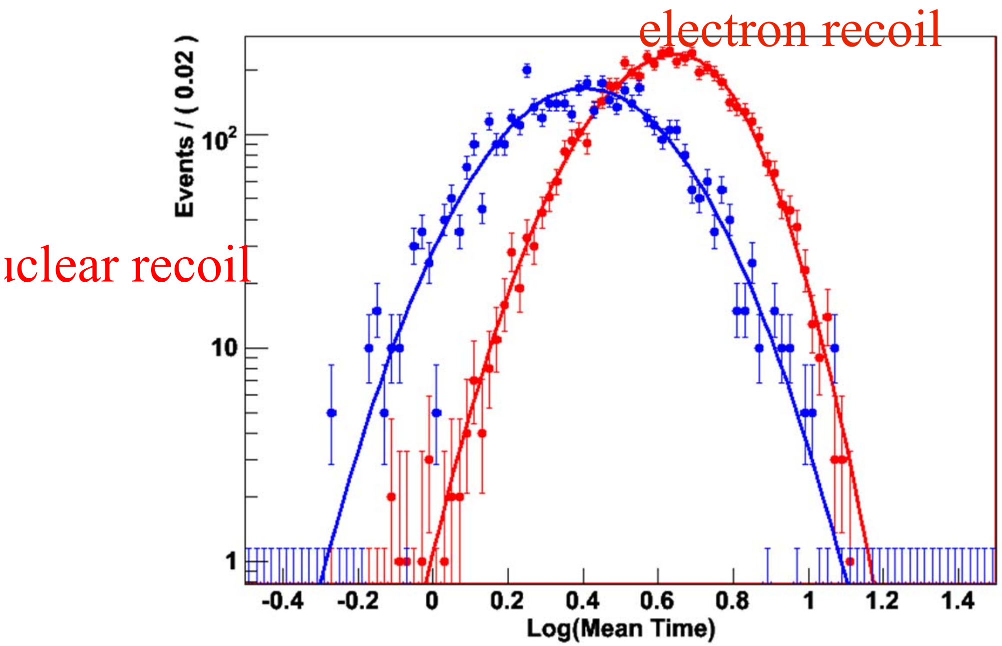
New underground lab for CUP in Duta by 2016

CUPID !


KIMS
(Korea Invisible Mass Search)

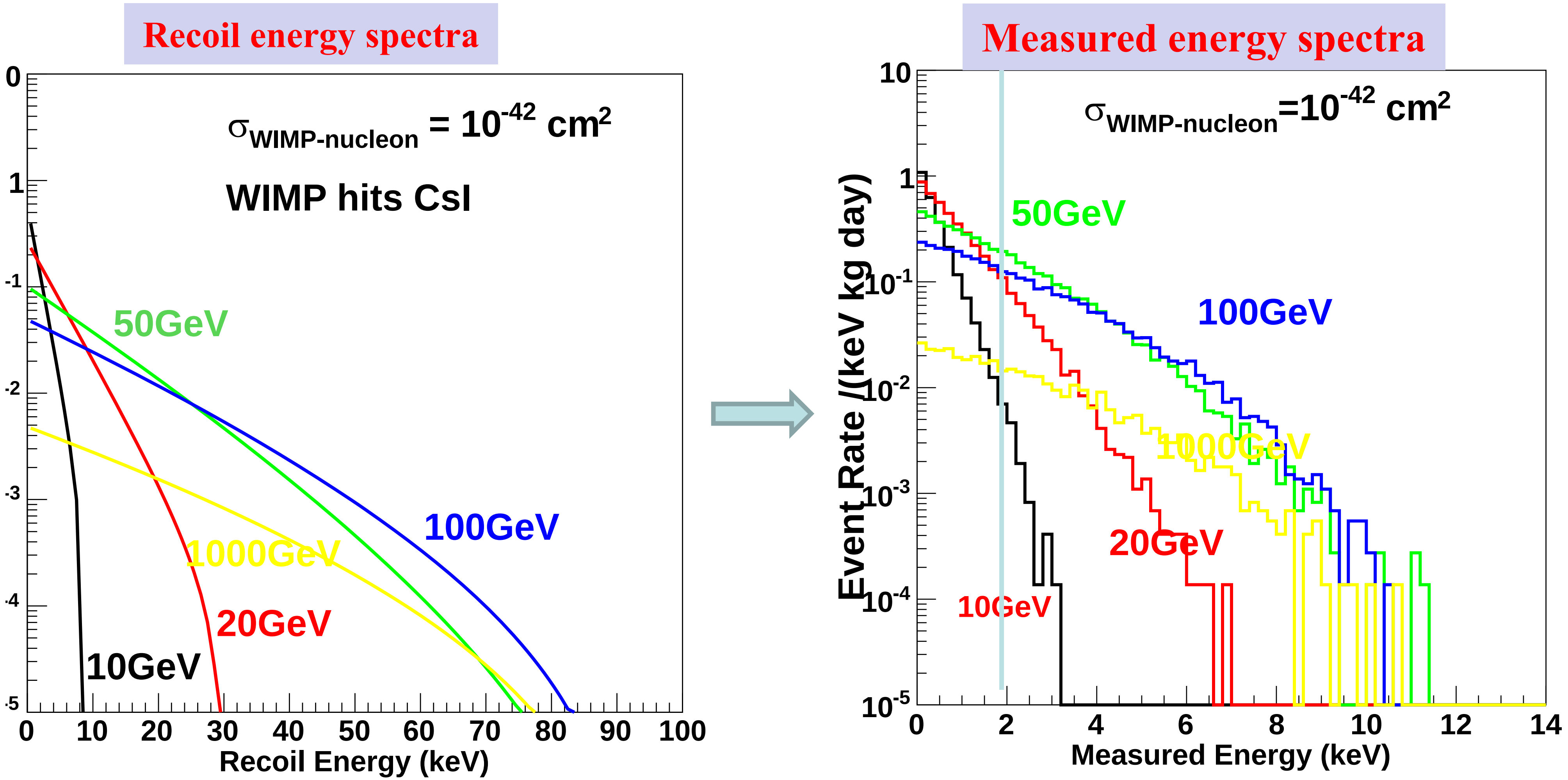
Advantages of CsI(Tl) for WIMP Search

- Easy to get large mass with an affordable cost
  - ➔ Good for AM study
- High light yield ~60,000/MeV
- Pulse shape discrimination
  - ➔ Moderate background rejection
- Cs-133, I-127 (SI cross section ~ A^2)
- Both Cs-133, I-127 are sensitive to SD interaction



Isotope	J	Abun	<Sp>	<Sn>
^{133}Cs	7/2	100%	−0.370	0.003
^{127}I	5/2	100%	0.309	0.075
^{73}Ge	9/2	7.8%	0.03	0.38
^{129}Xe	1/2	26%	0.028	0.359
^{131}Xe	3/2	21%	−0.009	−0.227

Recoil Energy Spectra



a few tens of keV

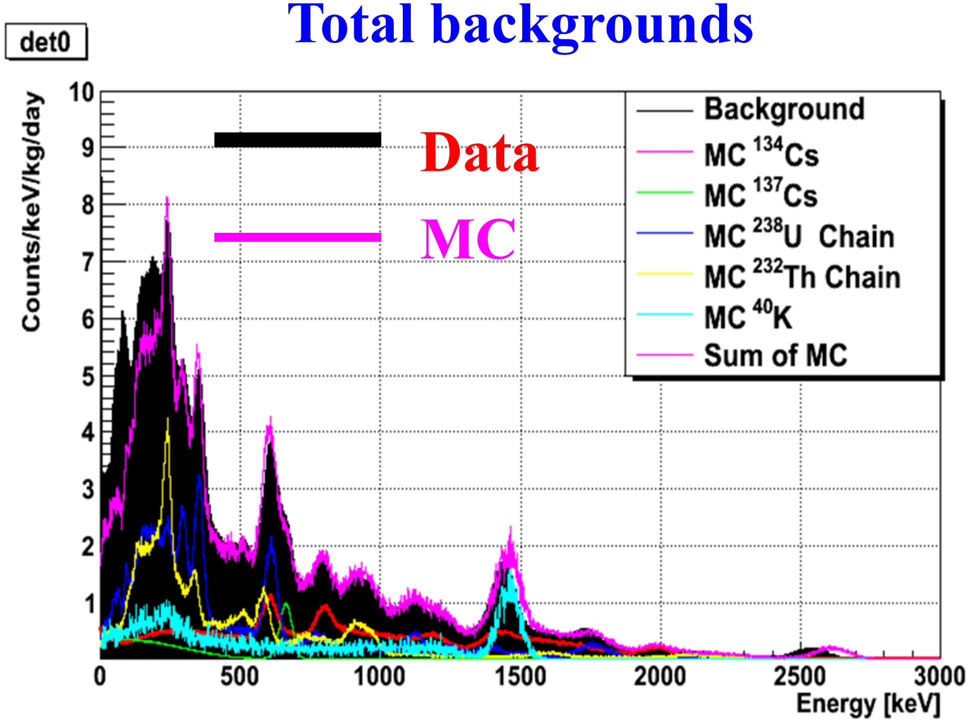
a few keV

Quenching Effect, energy resolution are critical to compare experiments.

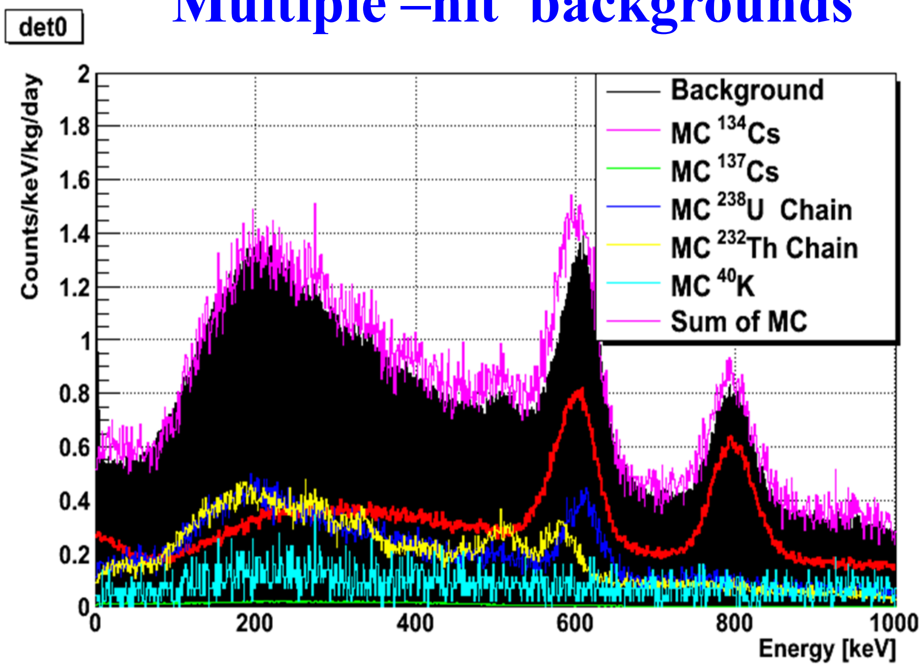
Data with 12 crystals

- 12 crystals (104.4kg) installed in the Cu shield.
- 2.5 year data (Sep. 2009 – Feb. 2012)
- Background Level : 2~3 cpd/kg/keV
- Source calibration with ^{55}Fe & ^{241}Am
- 1 year of data (Sep. 2009 – Aug. 2010) published with PSD analysis.
- Backgrounds are well understood.

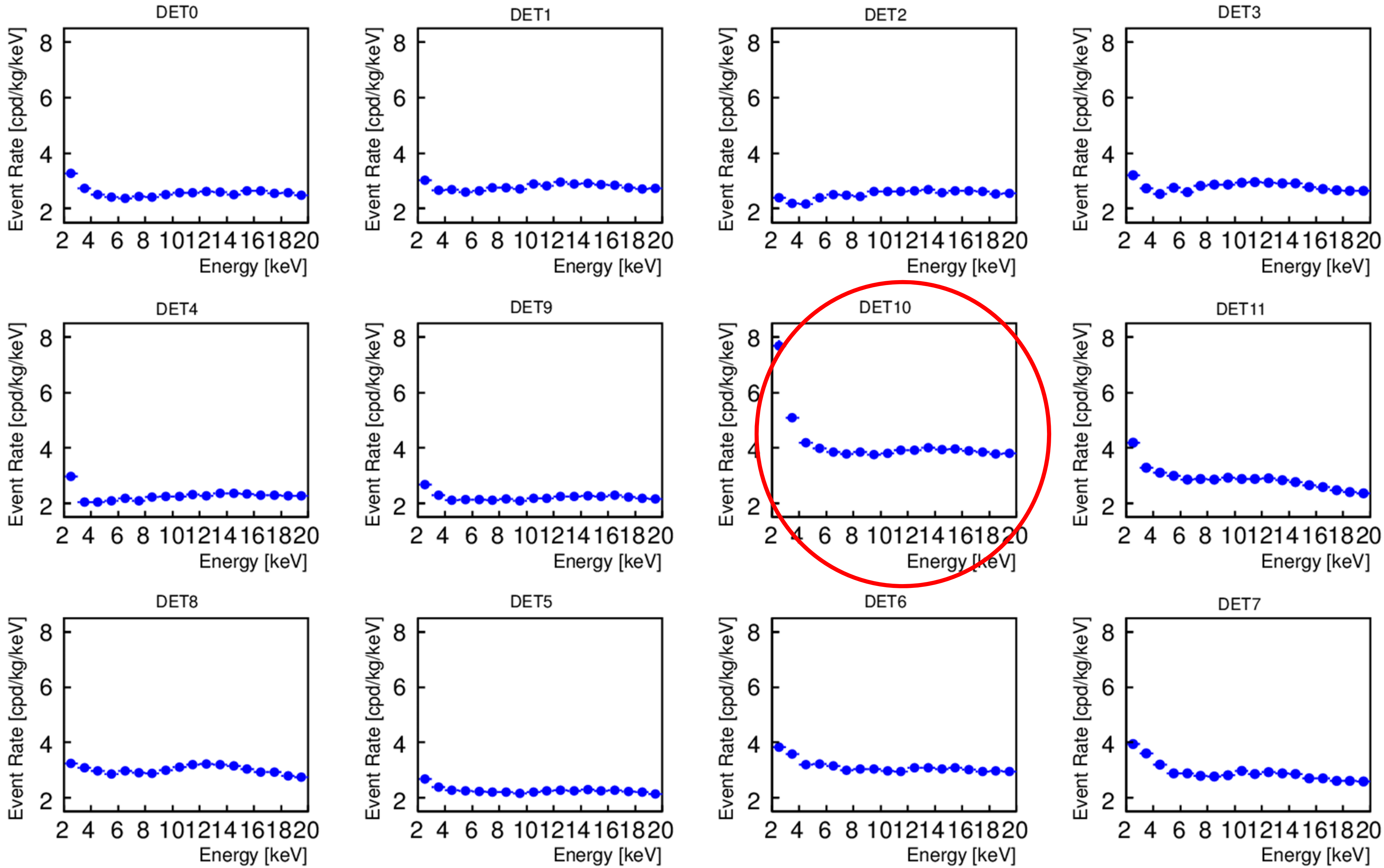
Total backgrounds



Multiple –hit backgrounds



Energy spectra w/ efficiency correction



Analysis was done by 11 detector except DET10 because of higher background rate

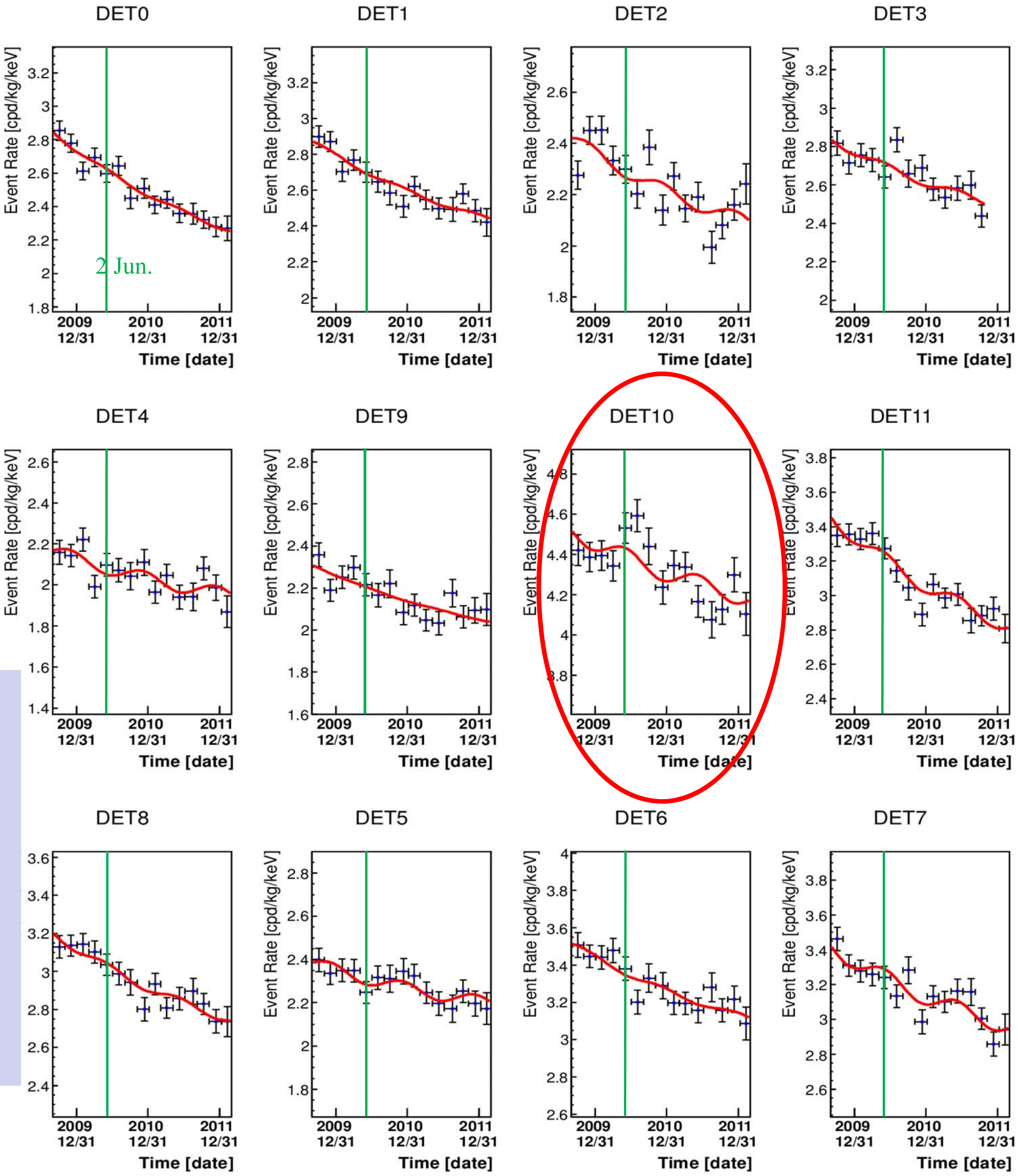
3-6 keV

$$R = A_{decay} e^{-\frac{t-t_0}{\tau}} + bkg + A\cos\frac{2\pi}{365}(t - t_{peak})$$

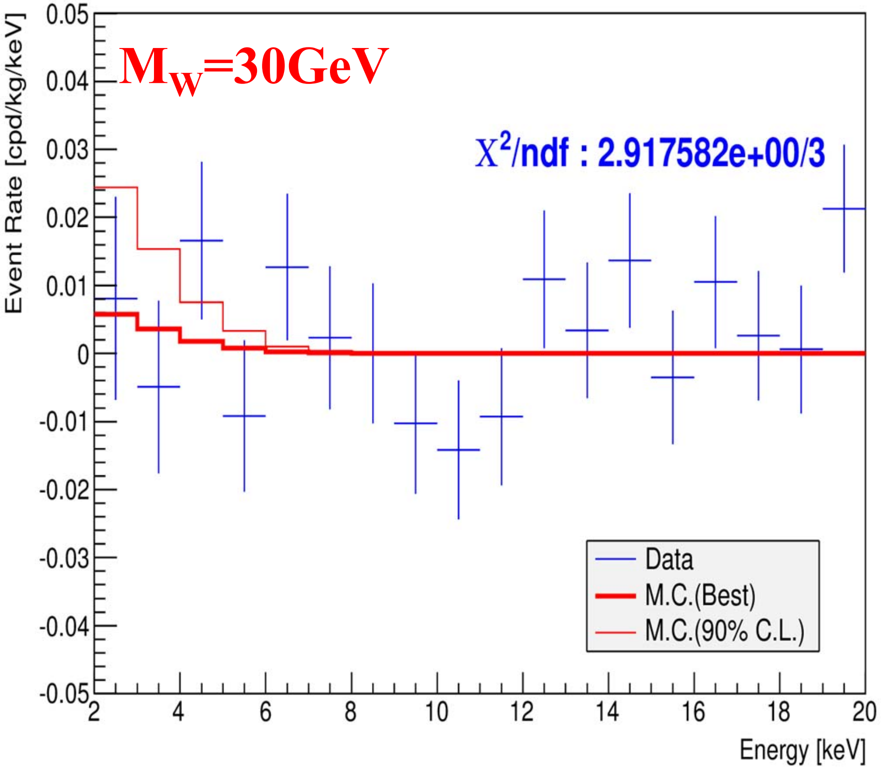
$$\tau = 2.980y,$$

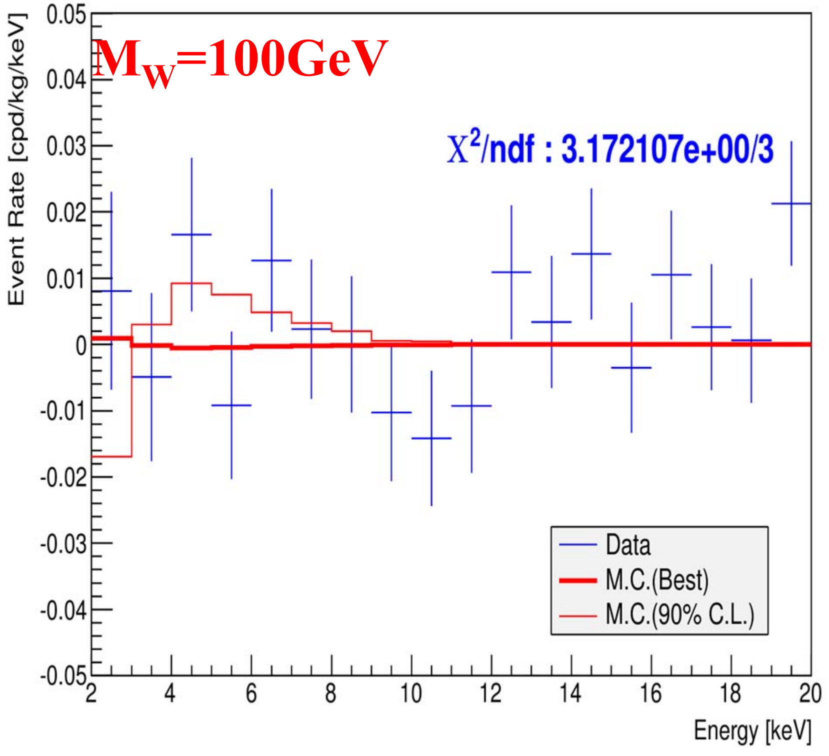
$$t_{peak} = 153 (\text{June } 2)$$

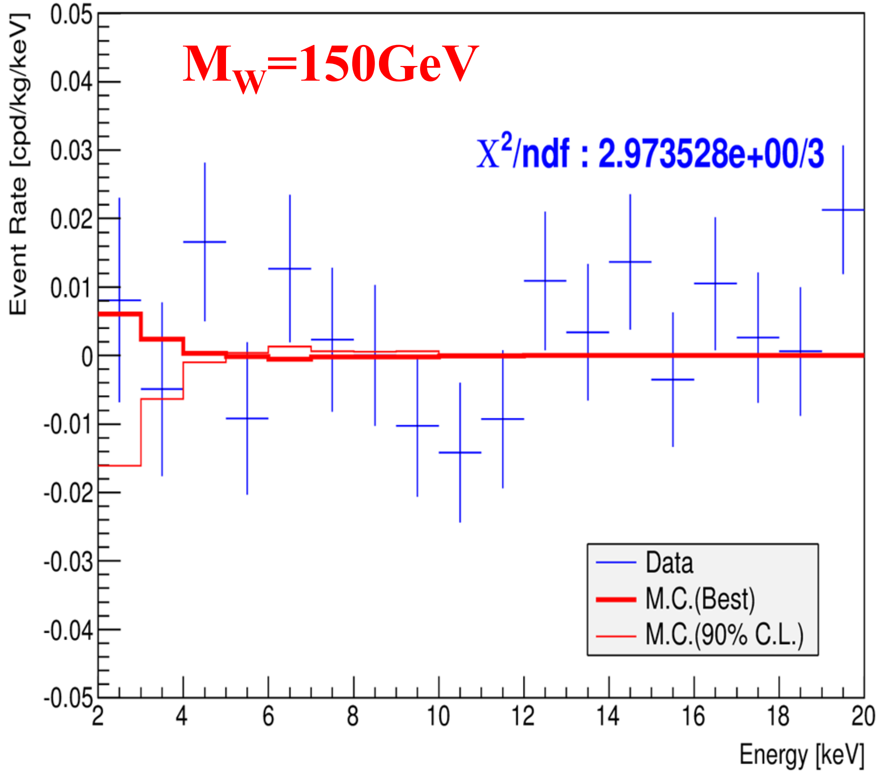
- **Annual modulation amplitude is obtained including the exponential decay of ^{134}Cs for 2.5 years of data.**
- **The mean amplitude from 3 keV to 6 keV is 0.0008±0.0068 cpd/kg/keV**



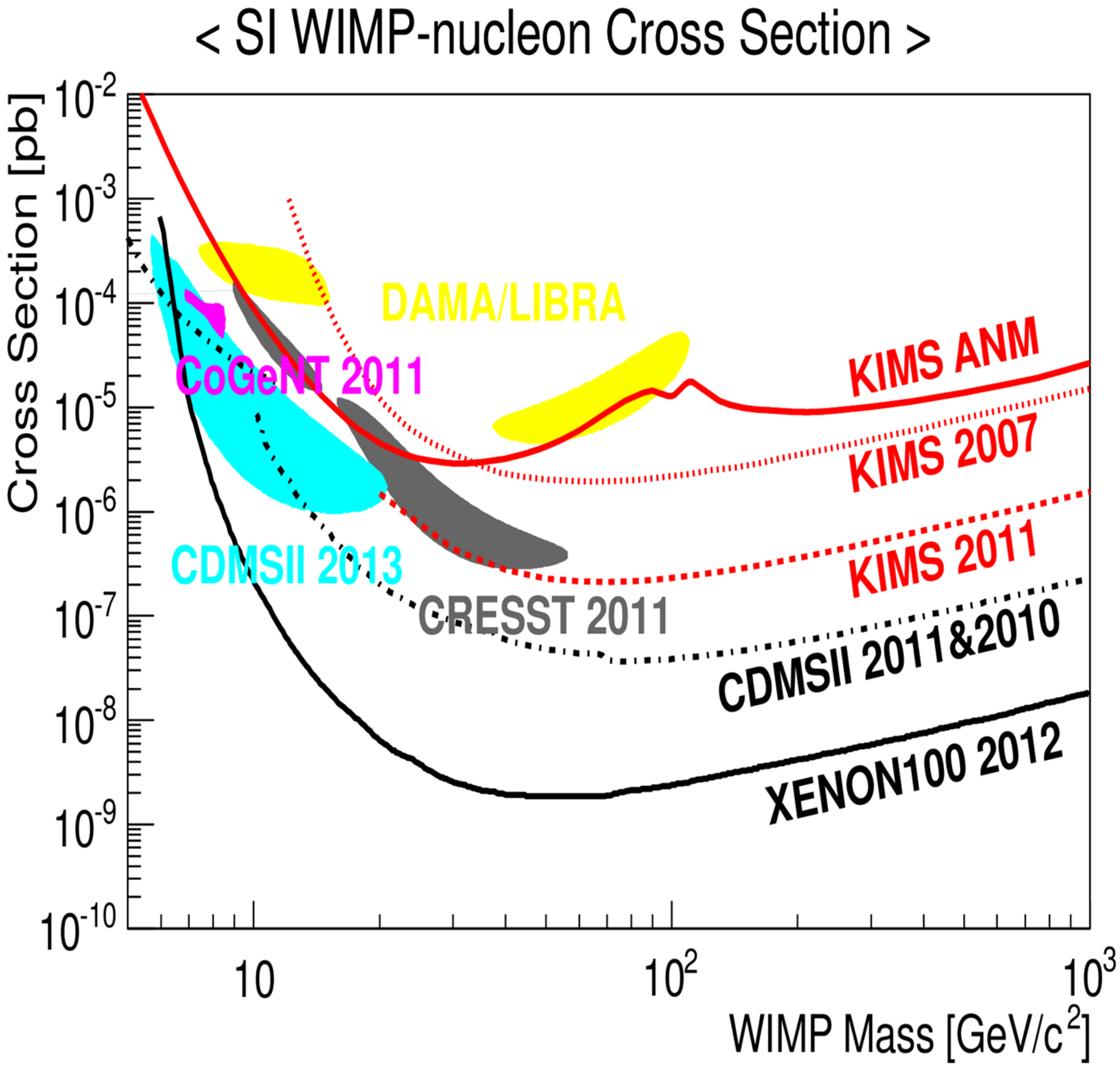
M.C. Simulation & fitting

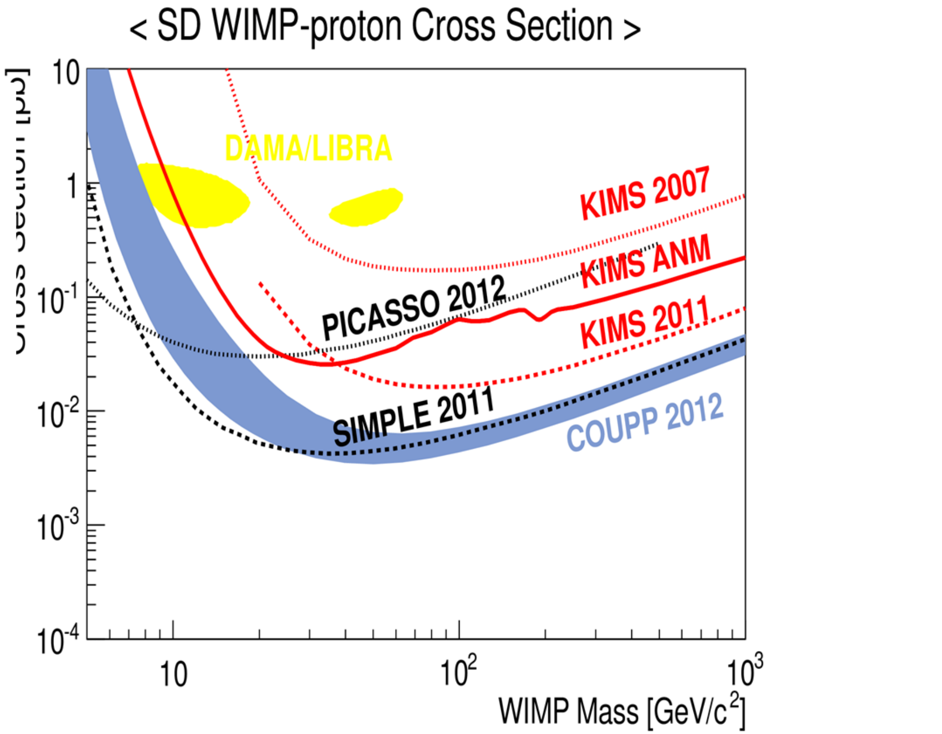


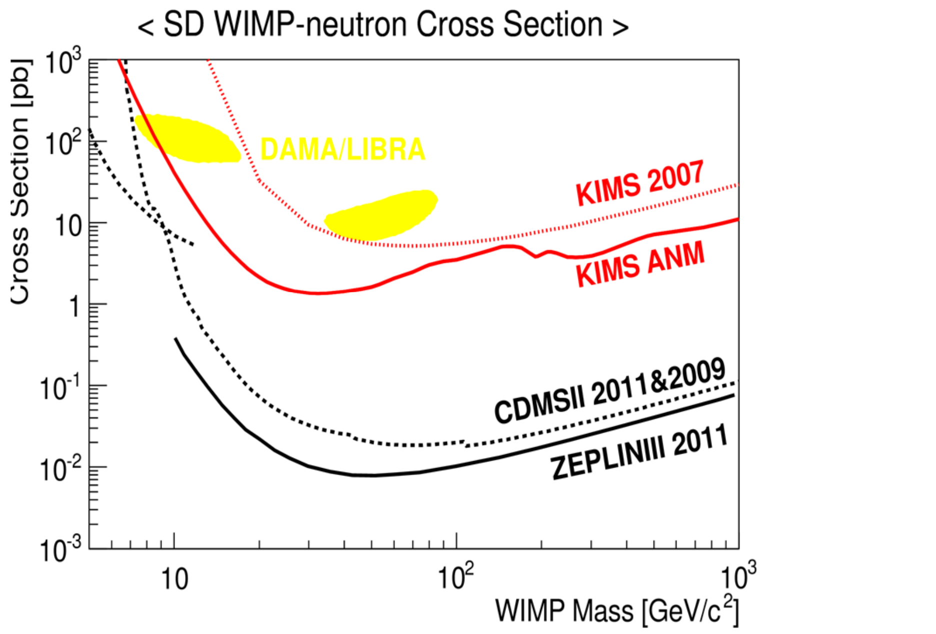




Cross Section Limit

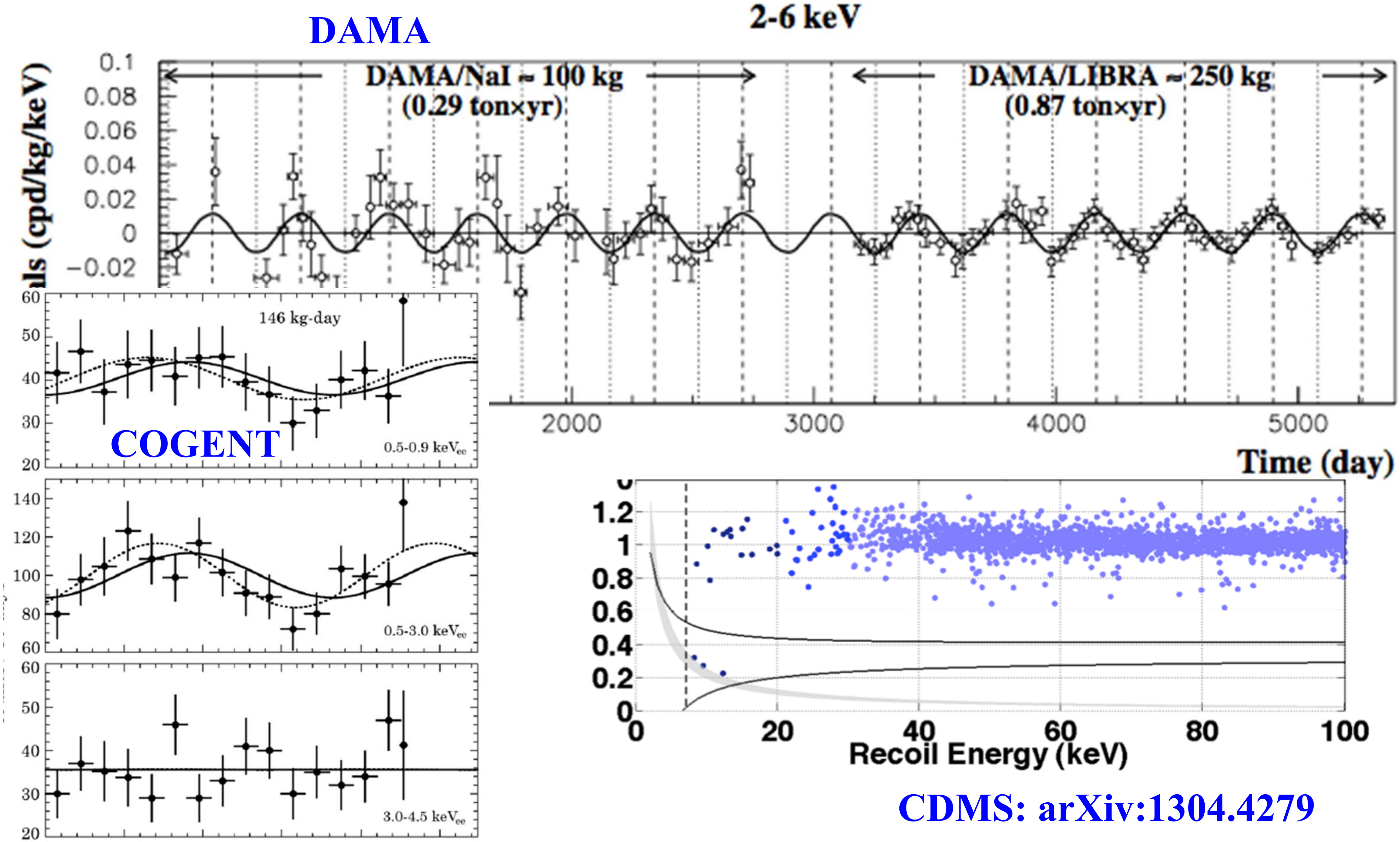






Dark Matter status

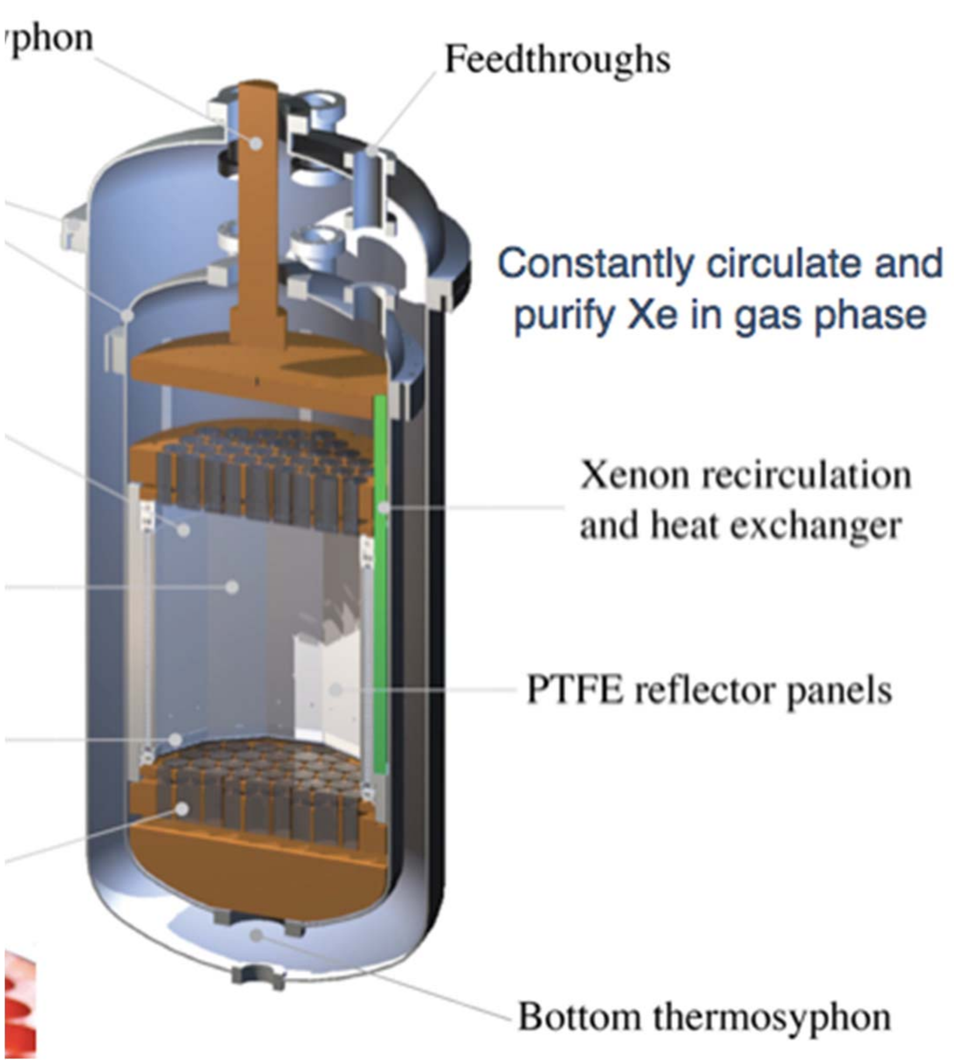
Low mass WIMP signal vs null results from CDMS and XENON ?



CDMS: arXiv:1304.4279

LUX (Large Underground Xenon) experiment

- Total 370kg LXe, D=47cm, H=48cm → 250 kg.
  - 118kg, 85.3 days run → 10065 kg days

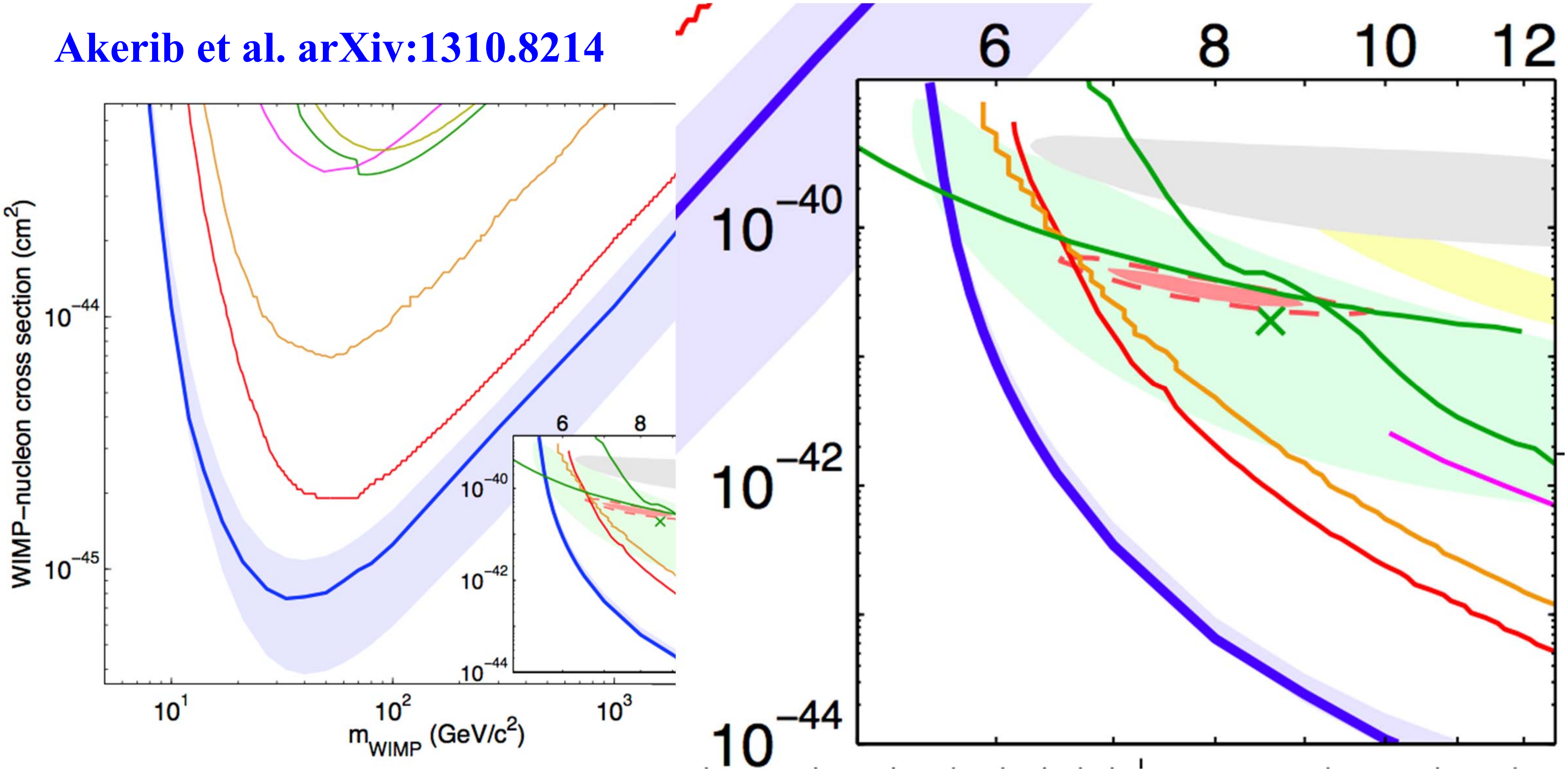


y 11-12, 2012, deployed in autumn of 2012

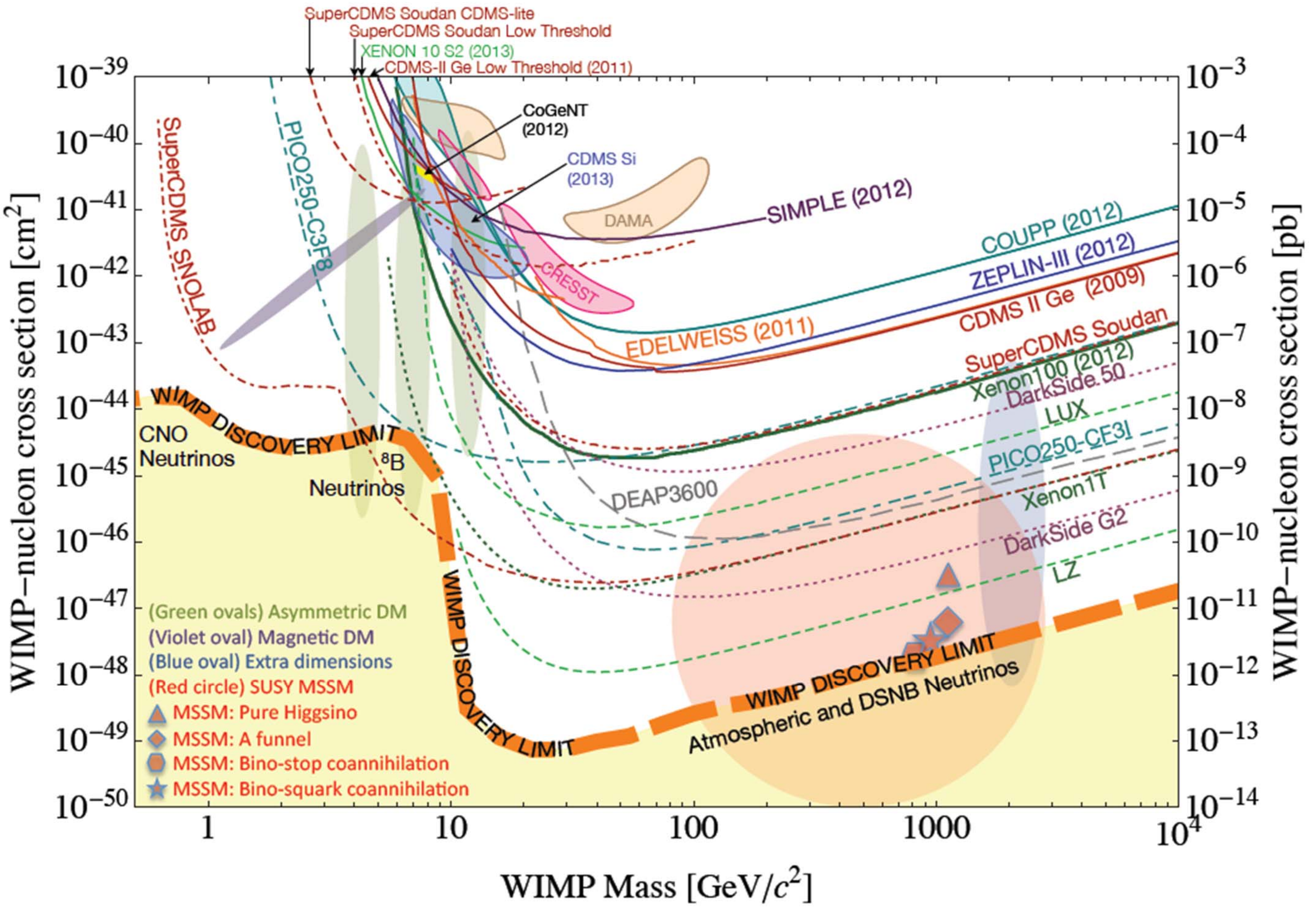
LUX contradicts all low mass claims !!

→ Does this mean all the low mass signals are rejected ?

Akerib et al. arXiv:1310.8214



SNOWMASS projection for Dark Matter: next decade



KIMS+ Projects @ CUP

I. KIMS-CsI : Upgrade of CsI(Tl) crystal detector

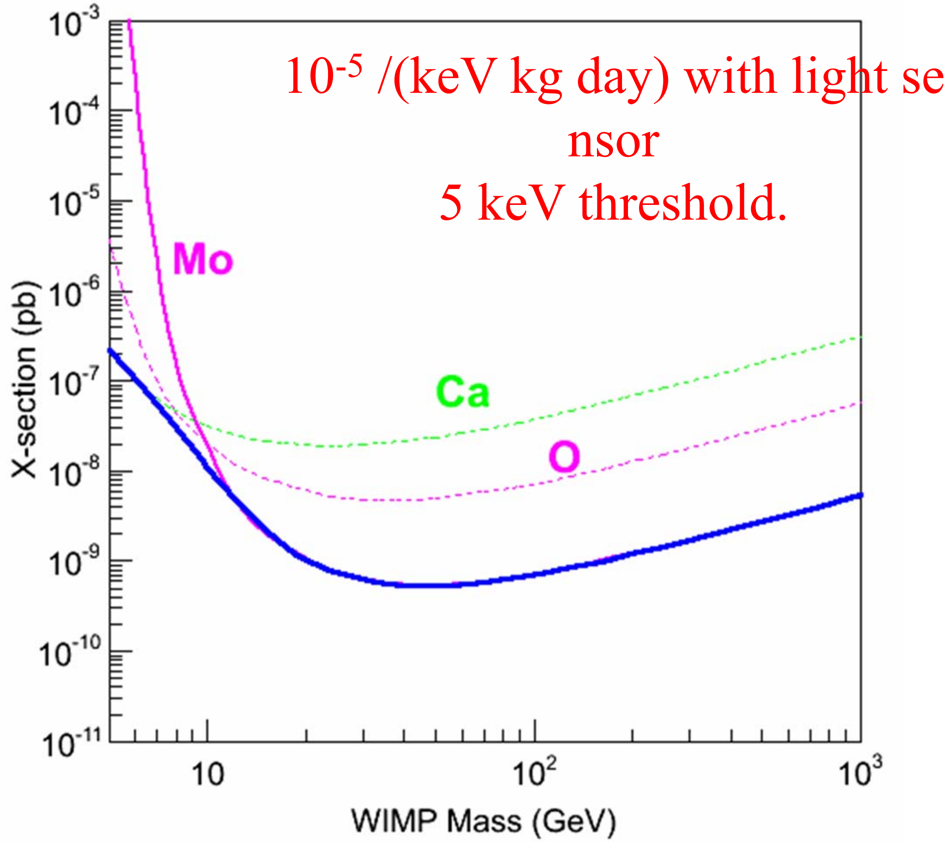
- Lower threshold ~ 1.5keV, <1dru, counts/(keV kg day).
- This will help to clear issues about the modulation signals of DAMA.

II. KIMS-NaI : new NaI(Tl) detector

- Duplicate DAMA experiment with ultra-low background NaI(Tl) crystals.
- 200kg run in 2015-2016

III. KIMS-LT

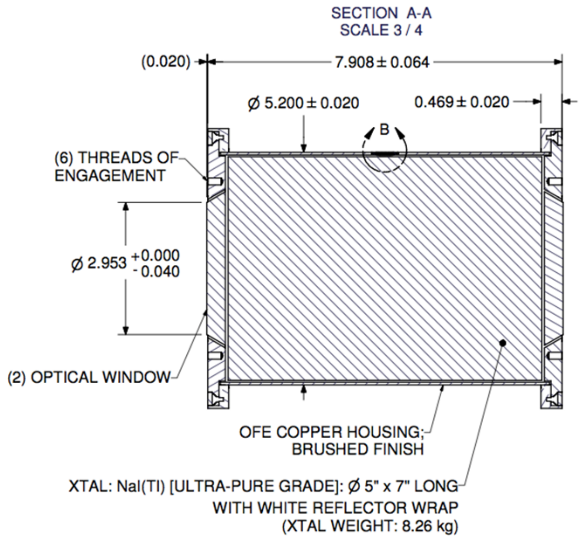
- $^{nat}Ca^{nat}MoO_4$ crystals ~ 200 kg year.
- High sensitivity in low mass WIMP.
- 2019-2022



KIMS-NaI

NaI(Tl) detector R&D

- New low-K NaI crystal is under R&D (ANAIS,DM-ICE,KIMS-NaI, SABRE).
- Alpha Spectra (AS) crystal to KIMS - now installed.
- BH will grow 5 crystals with Sigma-Aldrich powder.
- SICCAS is beginning to grow NaI crystals.



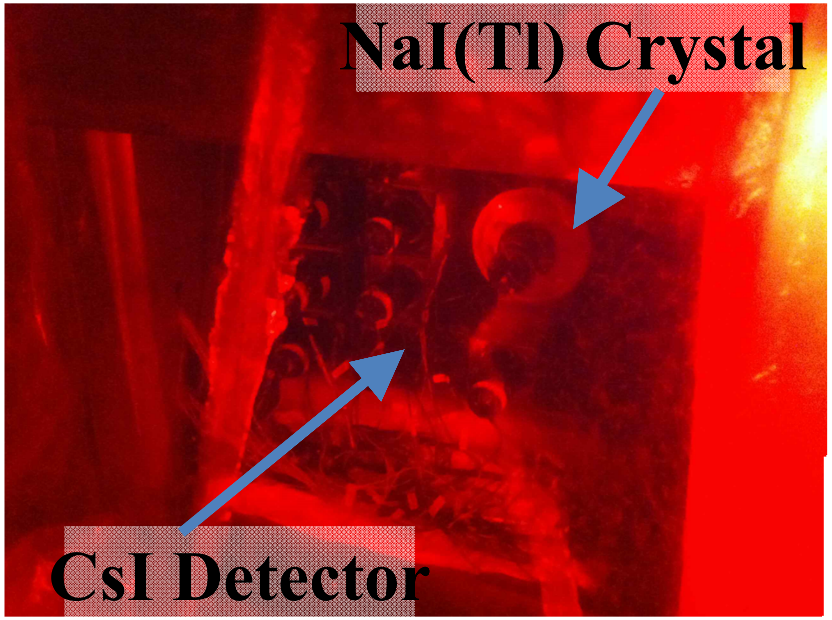
Crystal delivered to KIMS

Powder Measurements

Samples	Measurements	^{nat}K (ppb)
Sigma Aldrich - crystal grade	HPGe(KIMS)	<266
Sigma Aldrich - Astro grade	HPGe(KIMS)	<183
Alpha Spectra, C	HPGe(KIMS)	<262
Sigma Aldrich – Astro grade	HPGe(DM-ICE)	<126
Sigma Aldrich – Astro grade	ICP-MS (SA)	~4

It's difficult to reach 10 ppb level measurements with powder !
Current plan is to grow crystals and measure K.

KIMS-NaI Experiment

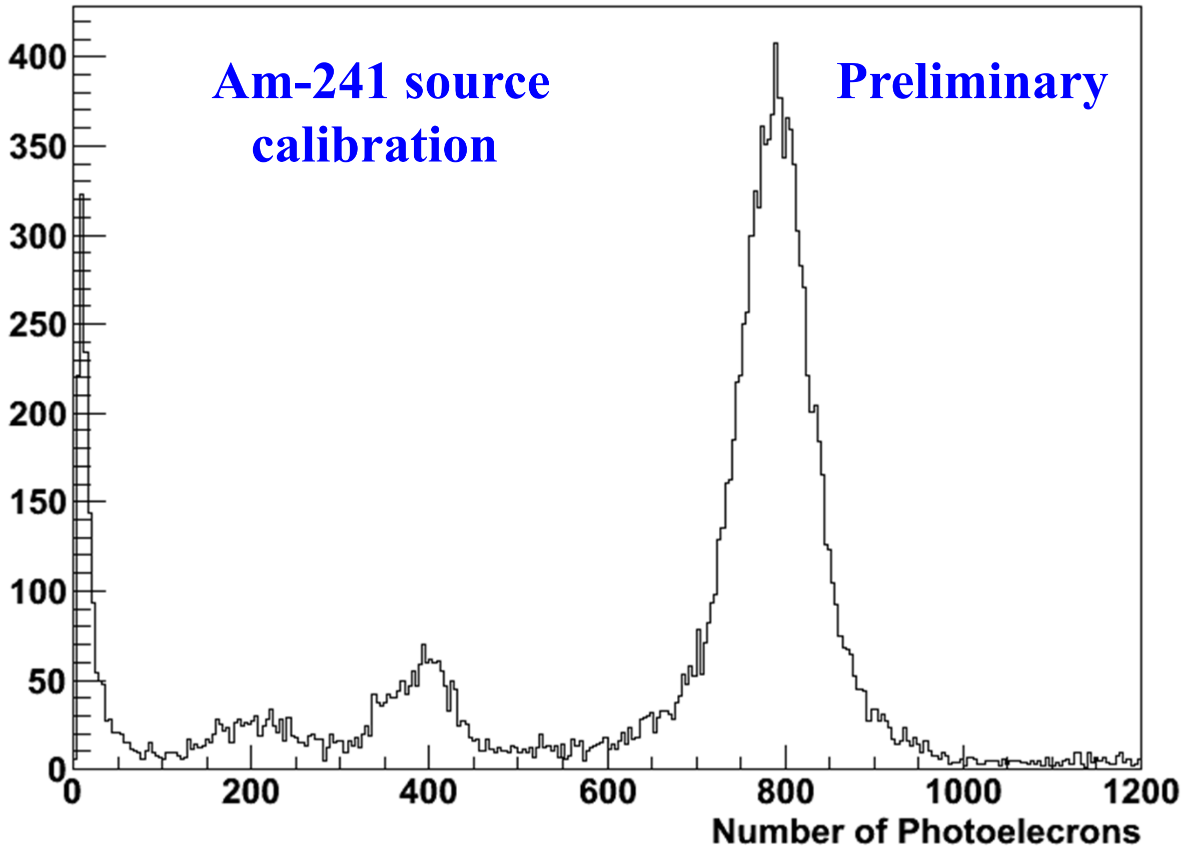


- Direct confirmation for DAMA.
- NaI(Tl) 200kg exp at CUP.
- 2013 : 2 crystals are installed.

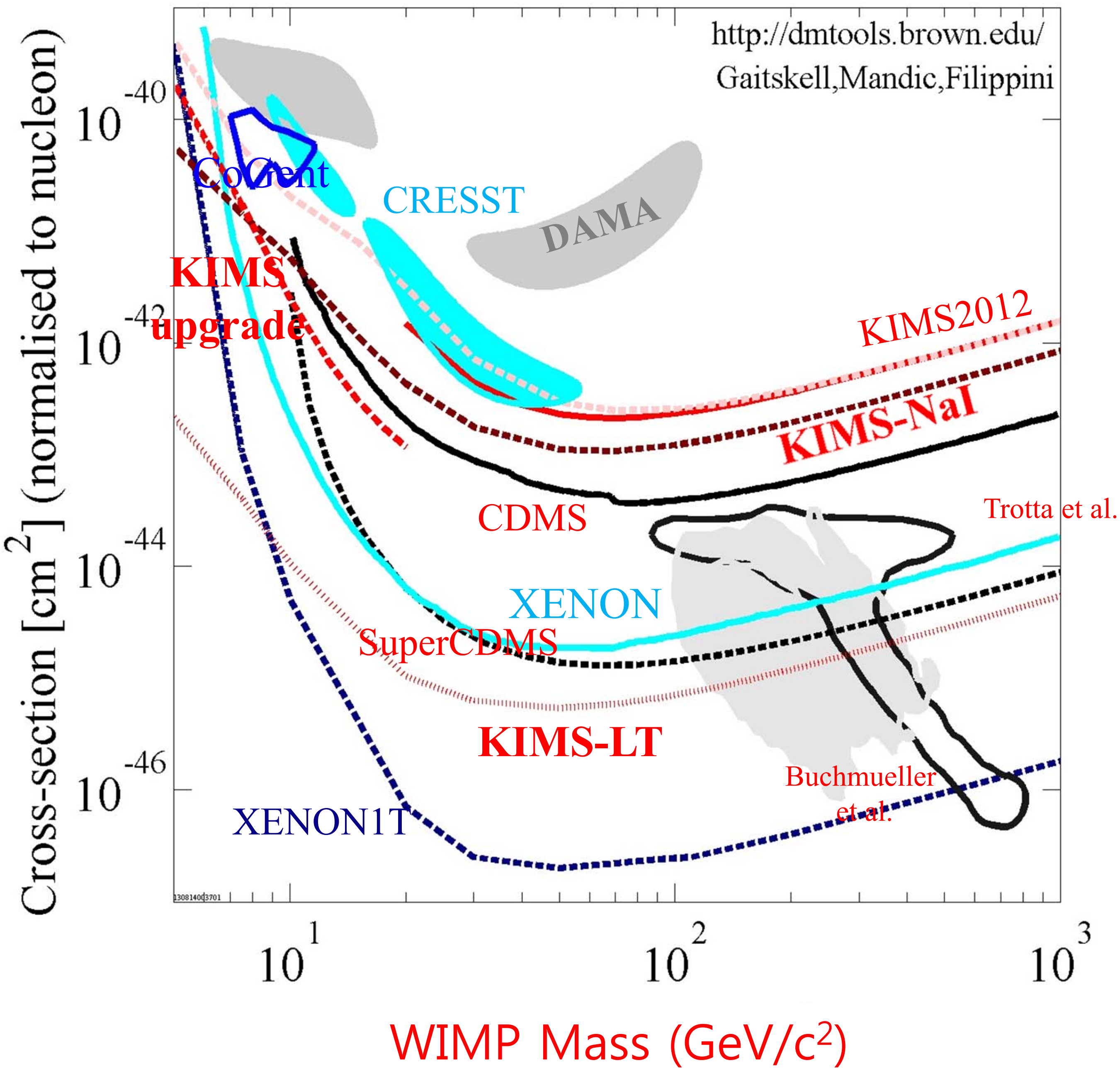
13.3 +/- 0.3
photoelectrons /keV

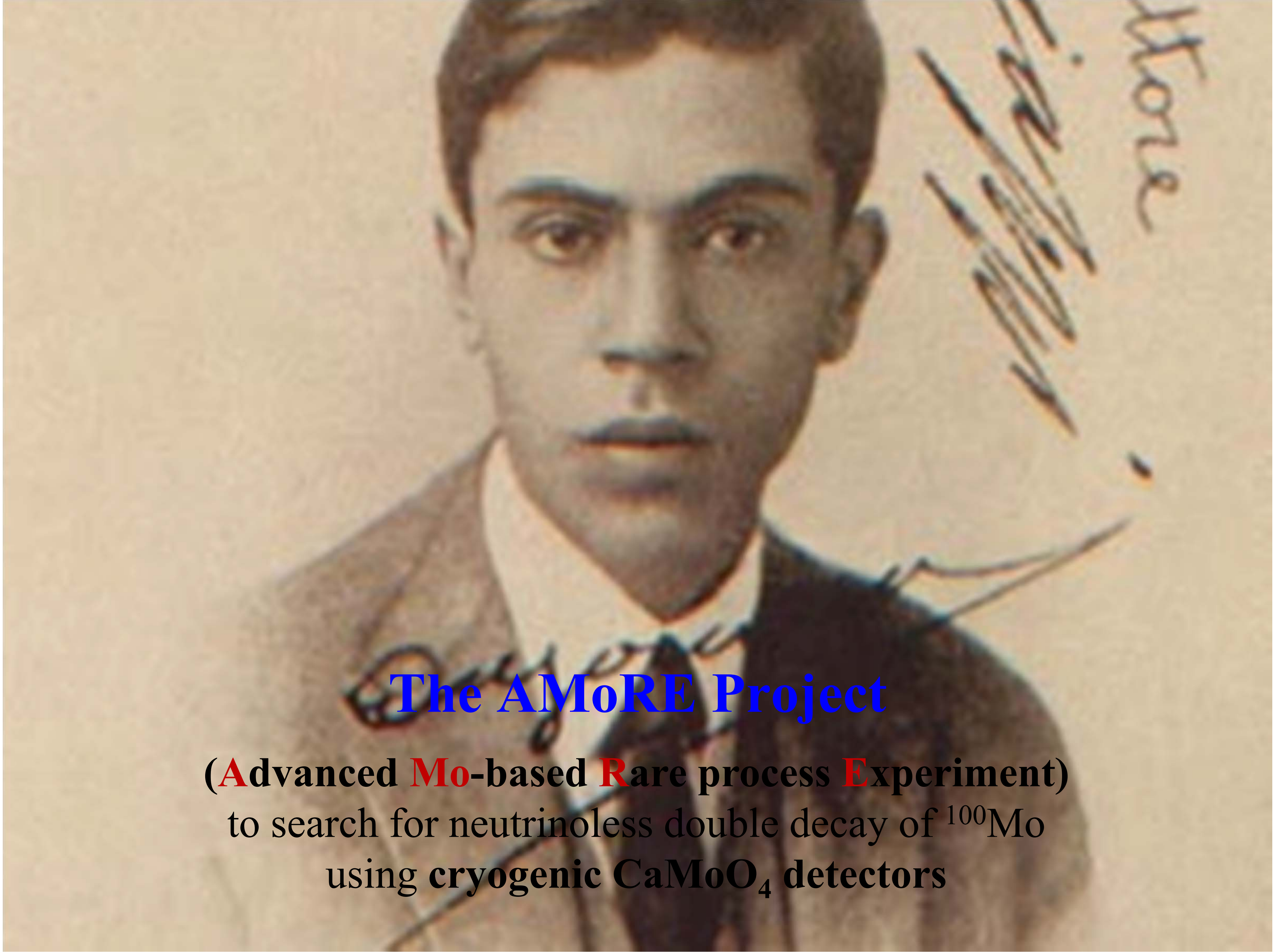
Cf. DAMA/LIBRA
6-10 photoelectrons/keV

DAMA ~ 1dru
Purification → <1 dru



Summary & Sensitivities of KIMS+





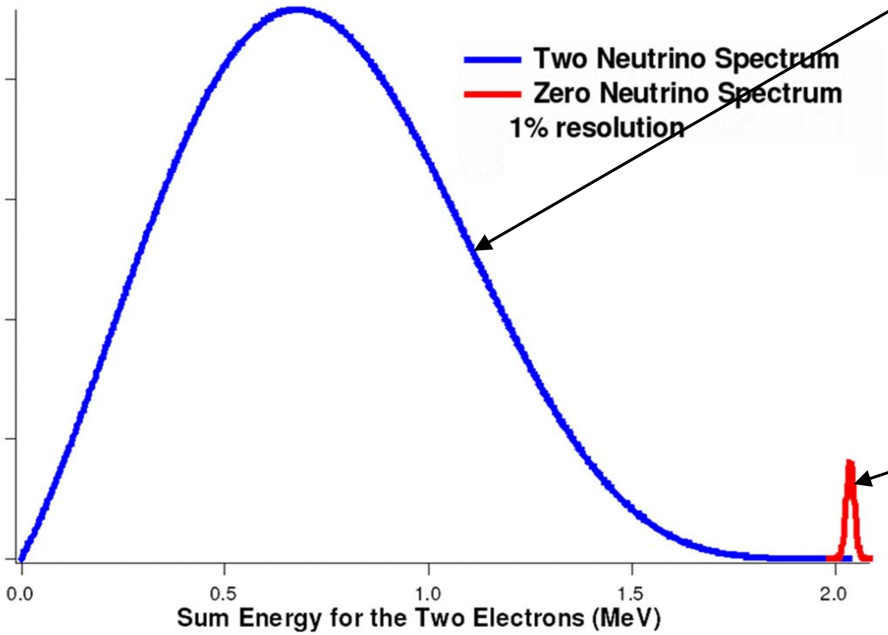
The AMoRE Project

(Advanced Mo-based Rare process Experiment)

to search for neutrinoless double decay of ^{100}Mo

using **cryogenic $CaMoO_4$ detectors**

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

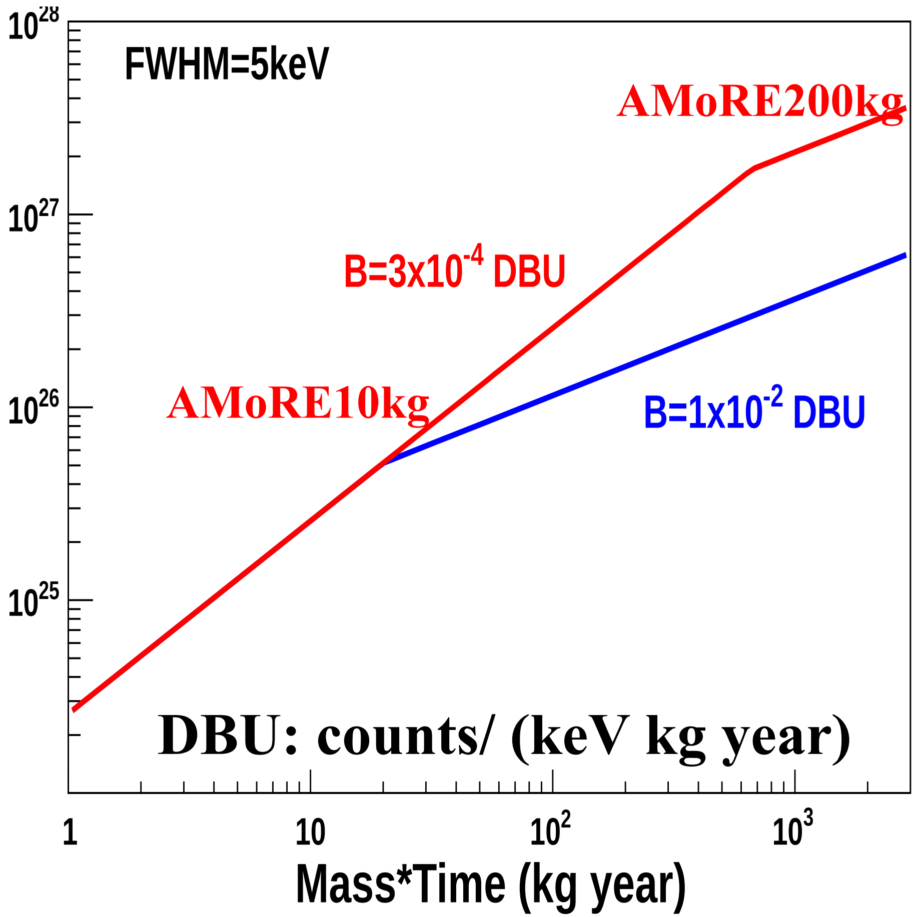
Experimental Sensitivity on 0νββ search

For sizeable background case;

Isotopic Abundance, Detection Efficiency, Detector Mass, Time

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

Atomic mass, Background level (count/keV kg year), Energy Resolution



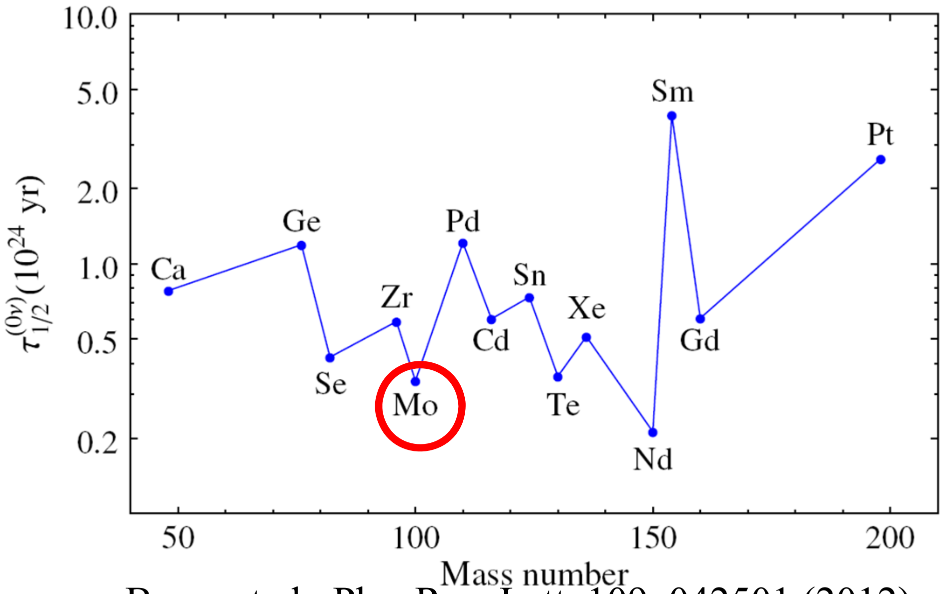
For "zero" background case;
of background events ~ 0 (1)

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

^{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

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



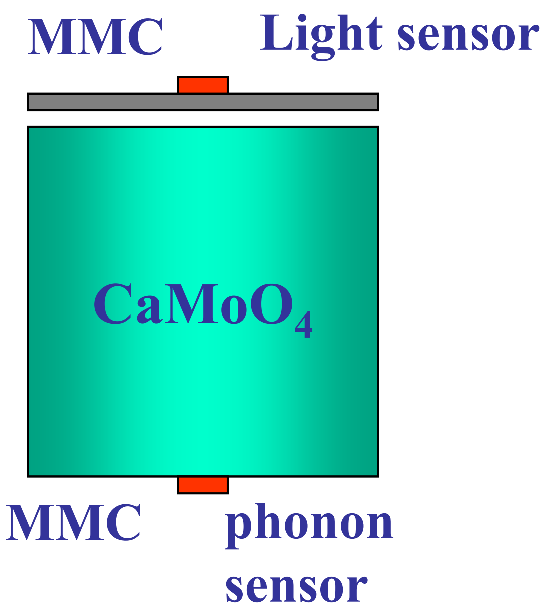
Barea et al., Phy. Rev. Lett. 109, 042501 (2012)

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

AMoRE detector technology

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

Low Temp. Detector
Source = Detector



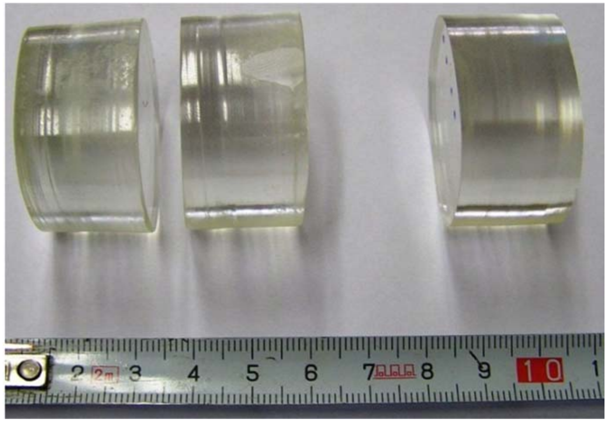
<10-50 mK>

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

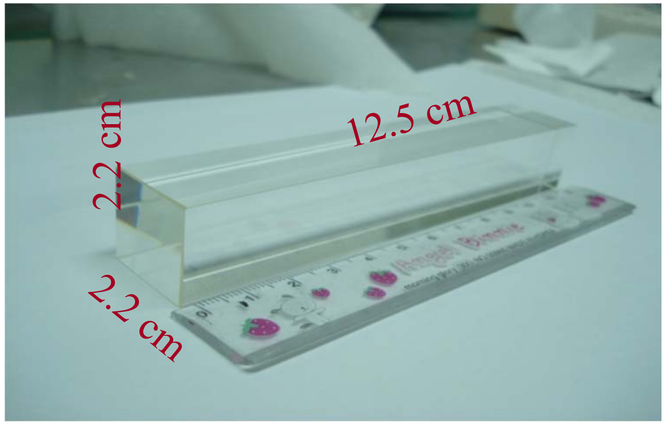
MMC (Metallic Magnetic Calorimeter)
- Magnetic temperature sensor (Au:Er) + SQUID
- Sensitive low temperature detector with highest resolution
- Wide operating temperature
- Relatively fast signals
- Adjustable parameters in design and operation stages

$CaMoO_4$ crystal development

Korea(2003)

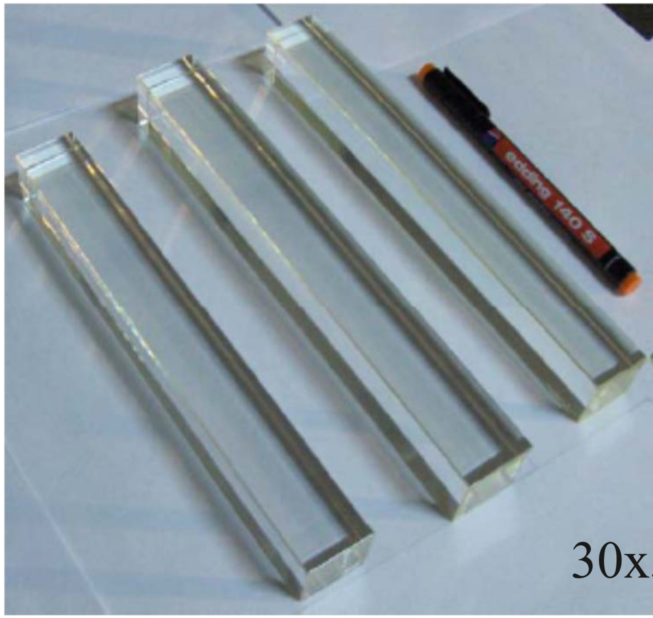


Ukraine-CARAT(2006)



Russia(2006)

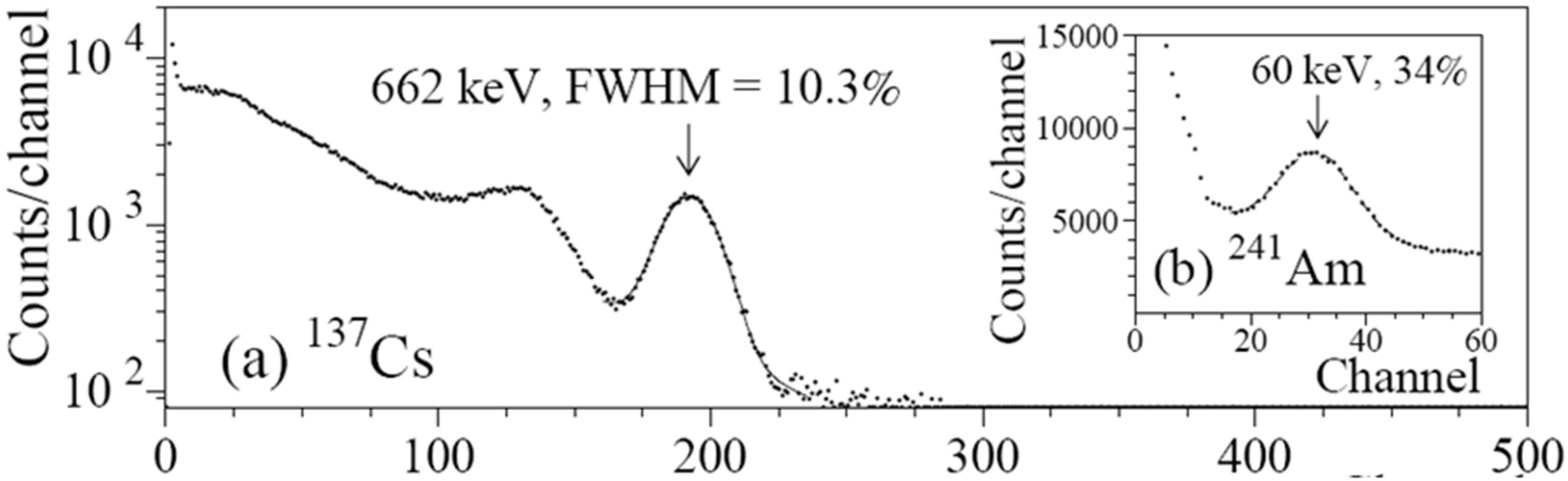
IEEE/TNS 2008

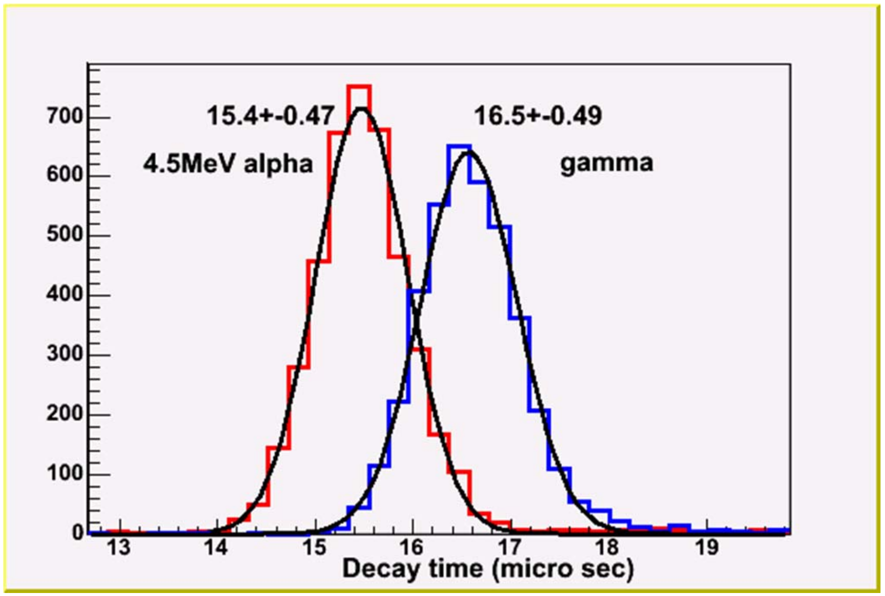


30x30x200mm

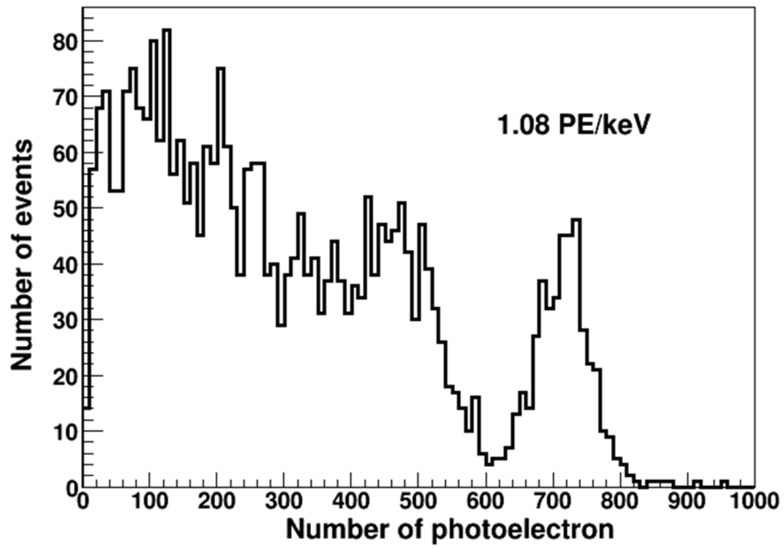
$CaMoO_4$ characterization

NIMA 584, 334 (2008)





IEEE TNS 57 (2010) 1475

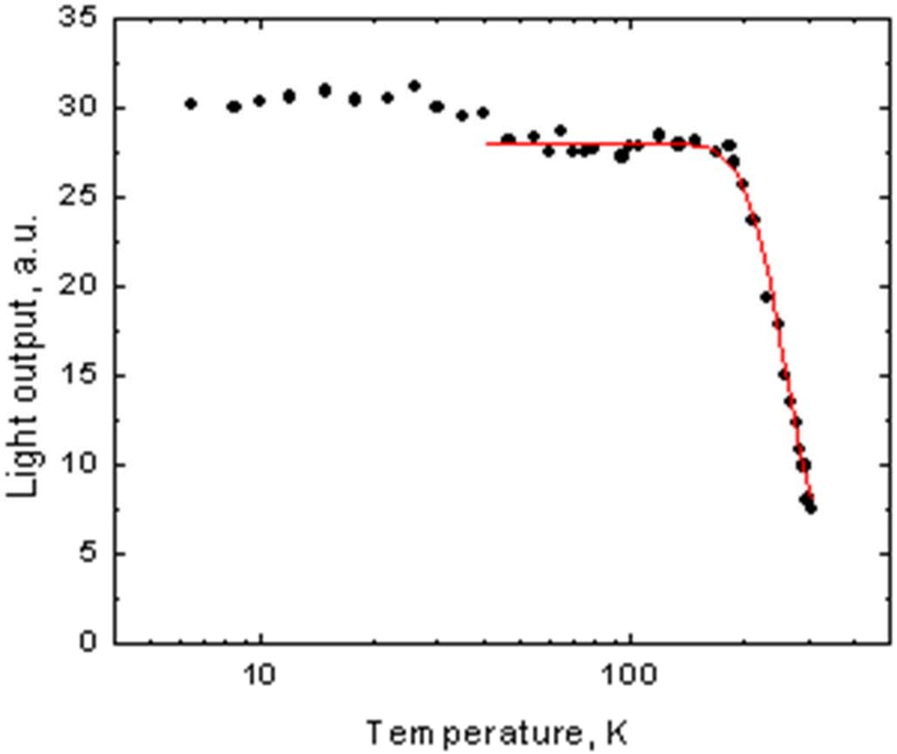


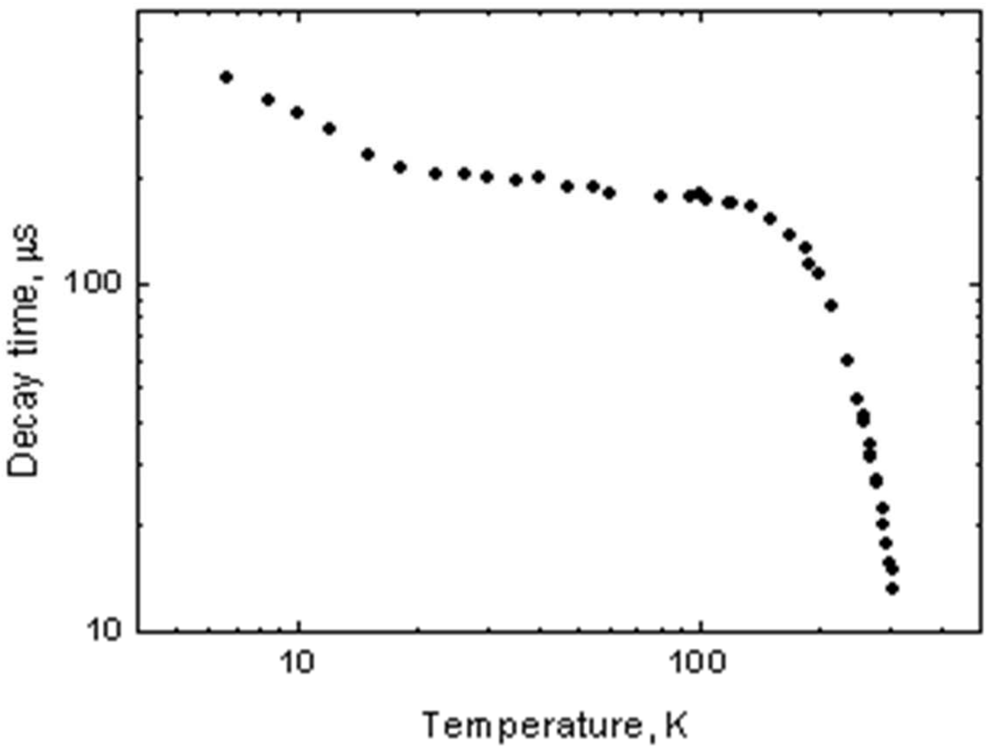
4% FWHM at 3 MeV

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

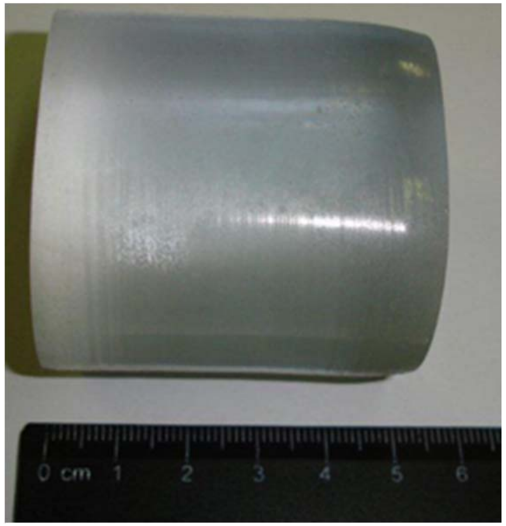
$^{40}Ca^{100}MoO_4$ crystals from Russia

- SB28

weight 196 g

- SB29

weight 390 g



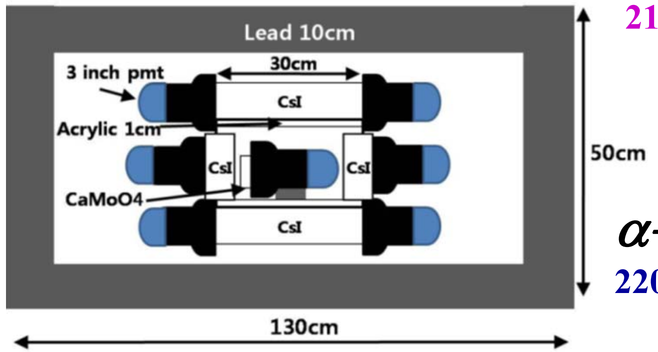
- S35

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



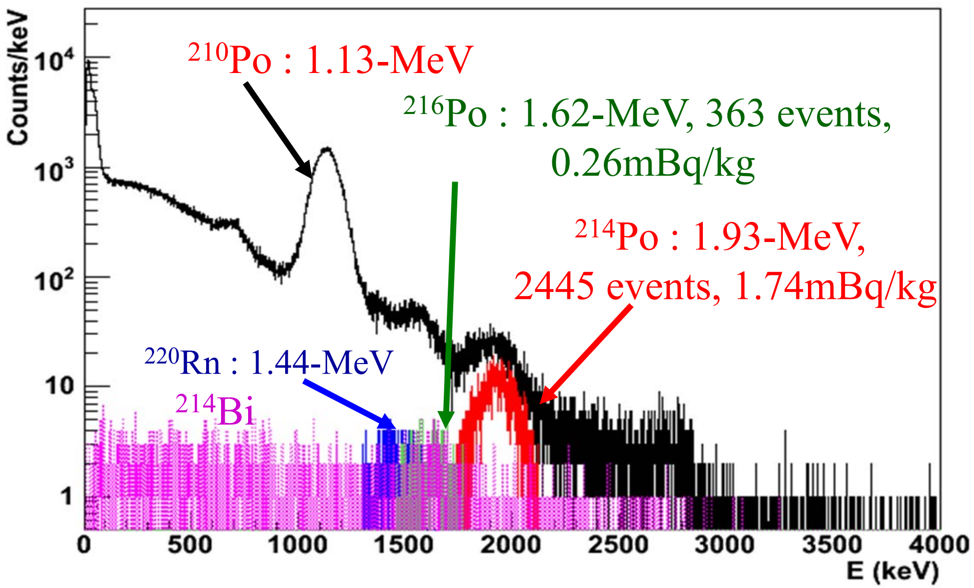
β–α **decay in ^{238}U**

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

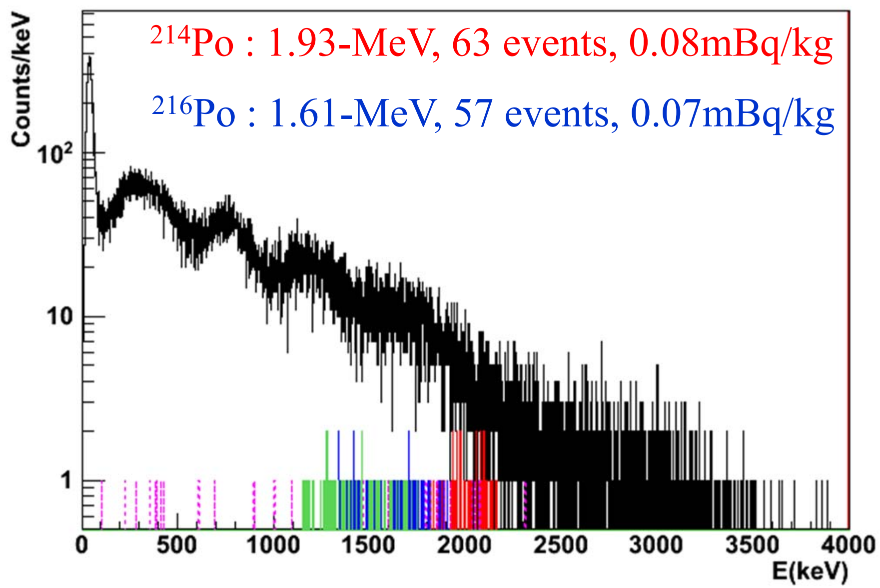
α–α **decay in ^{232}Th**

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

Crystal S35

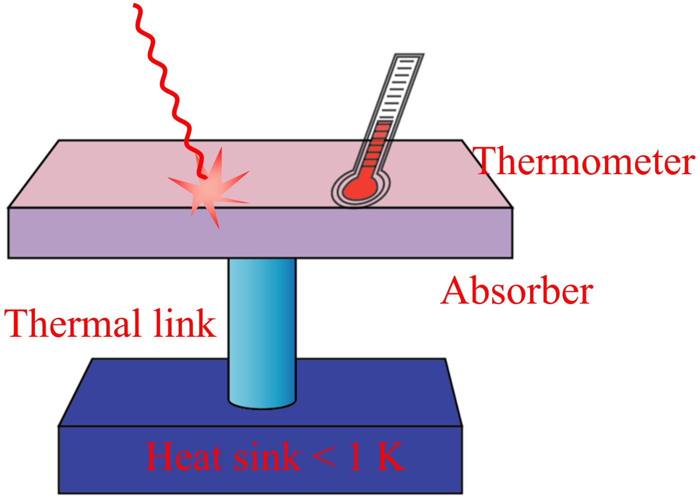


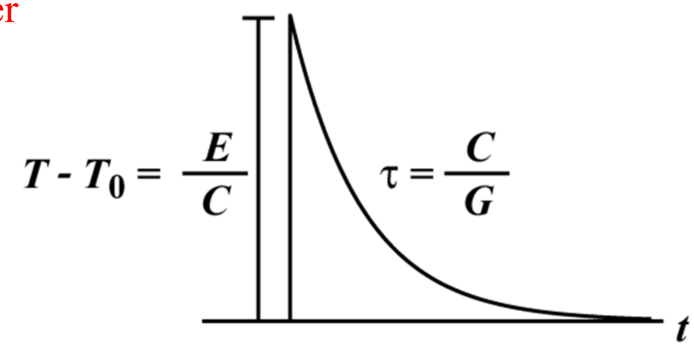
Crystal SB28



Low temperature detectors (Calorimeters)

Energy absorption → Temperature



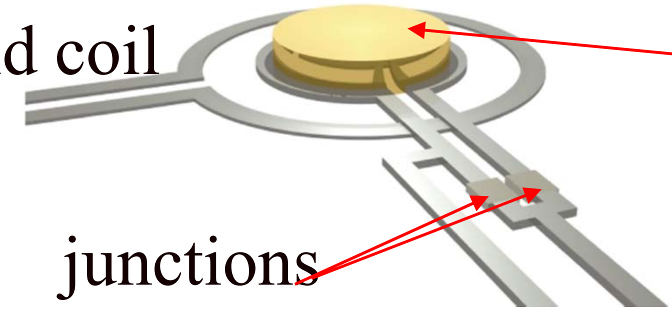


Choice of thermometers

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

Metallic Magnetic Calorimeter (MMC)

Field coil

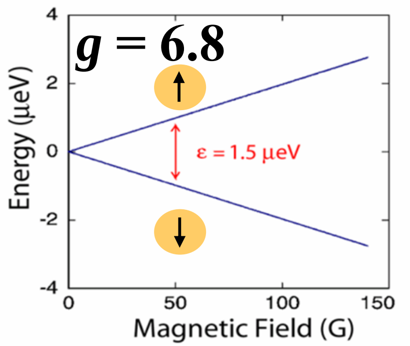


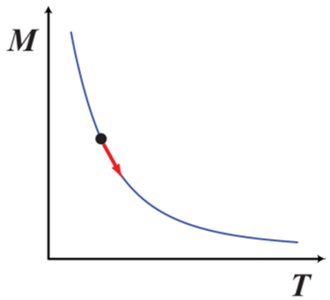
junctions

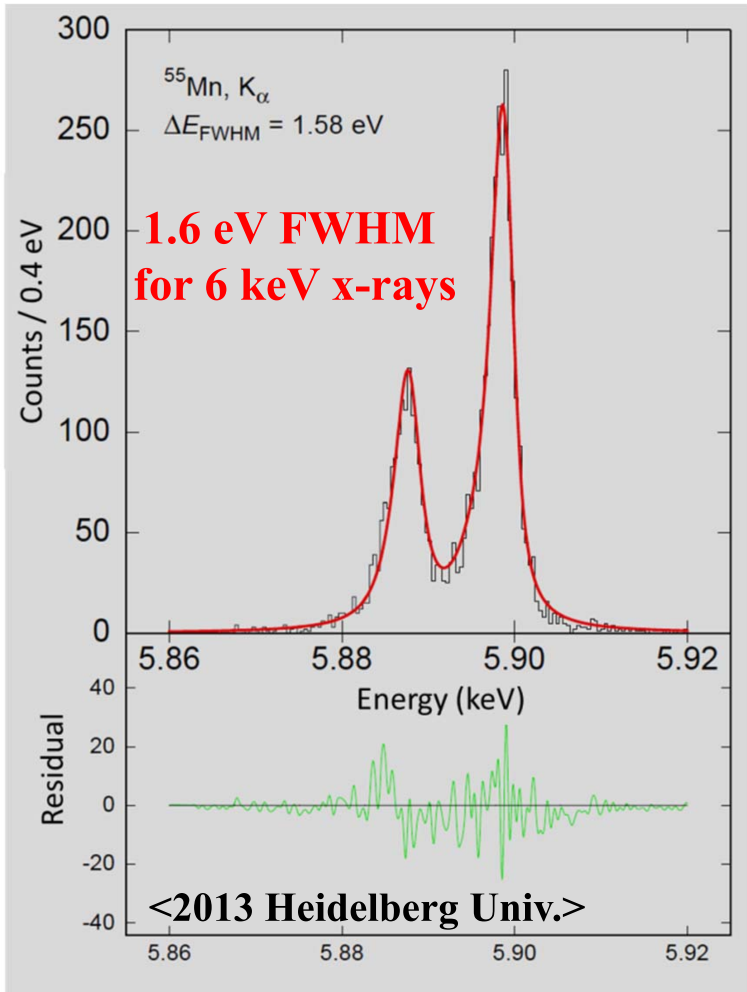
Magnetic material Au:Er(10~1000ppm)

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

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



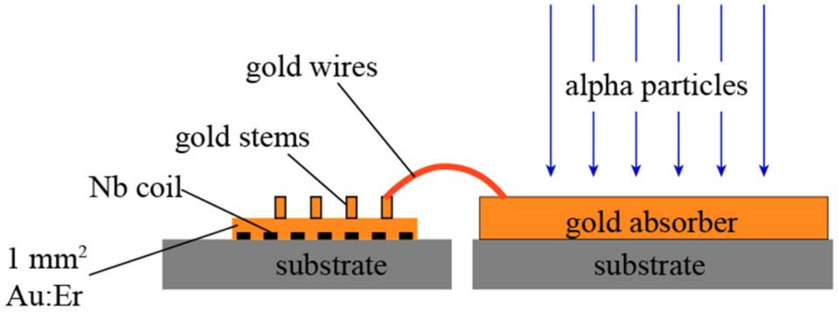


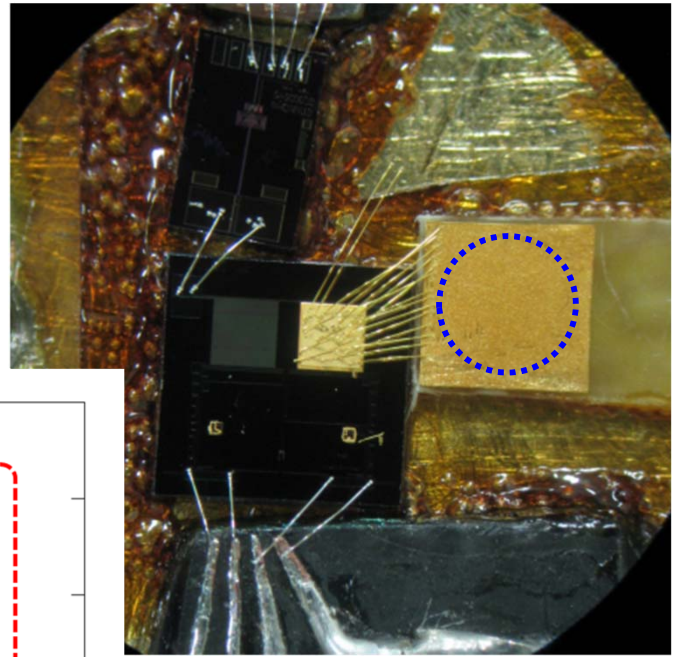


5 mT $\rightarrow$ $\Delta\varepsilon = 1.5\ \mu eV$

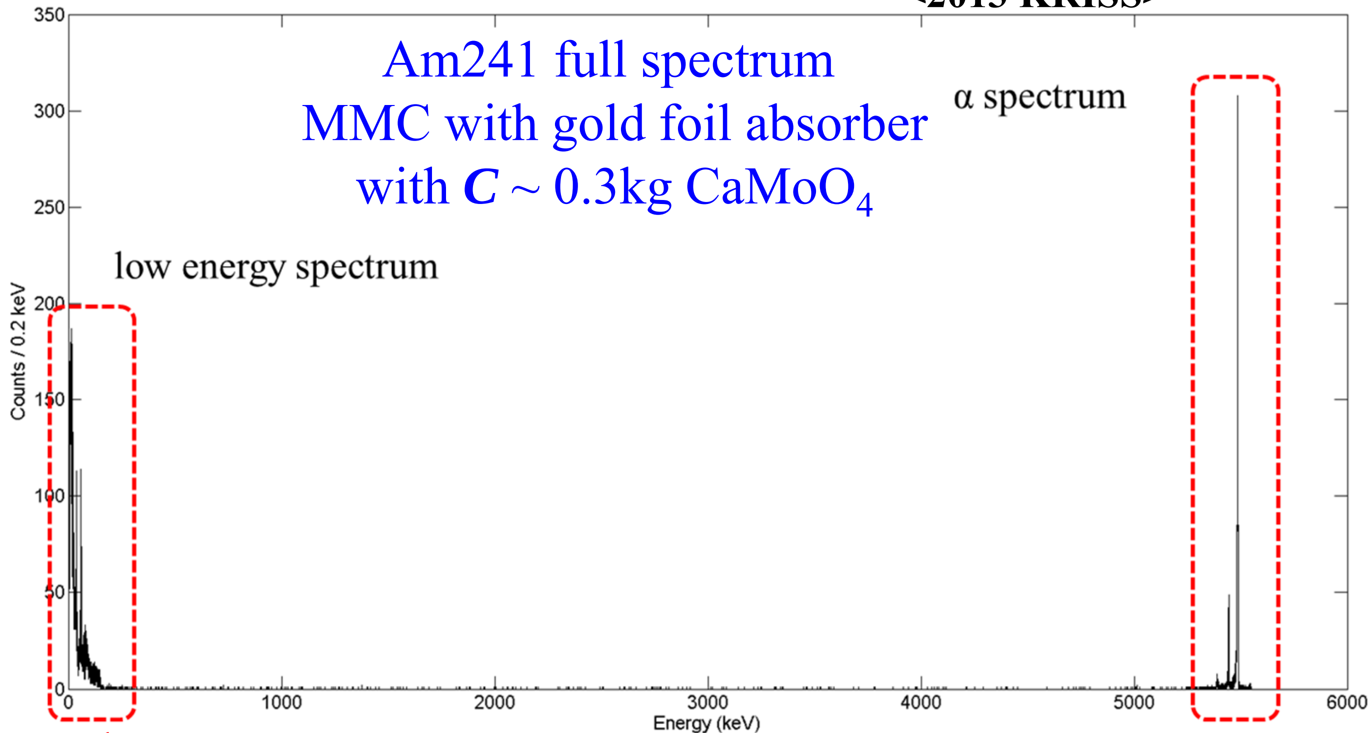
1 keV $\rightarrow$ 10^9 spin flips

Alpha spectrometer using MMC





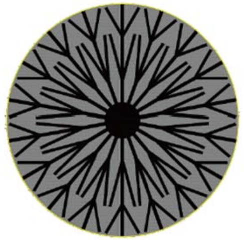
<2013 KRISS>



0.7keV FWHM
for 60keV γ

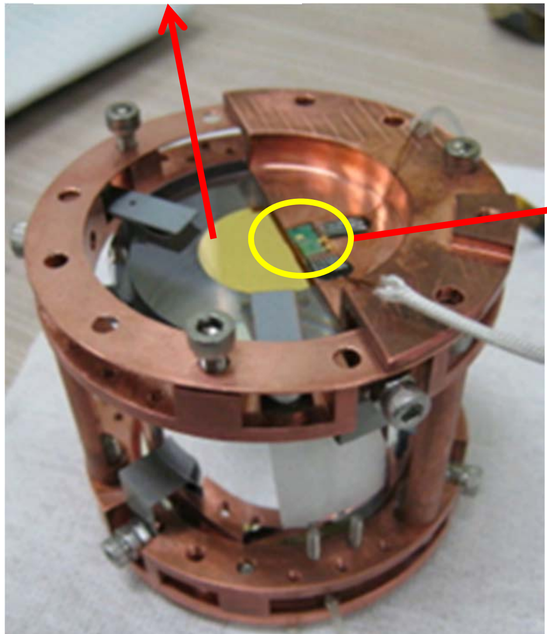
1.2keV FWHM Gaussian width
for 5.5MeV α

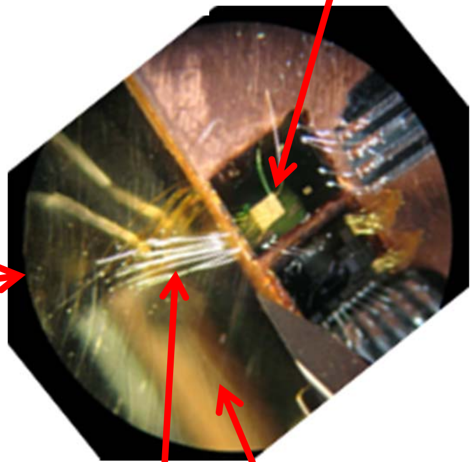
Phonon sensor for AMoRE



Phonon collector
Patterned gold film

MMC



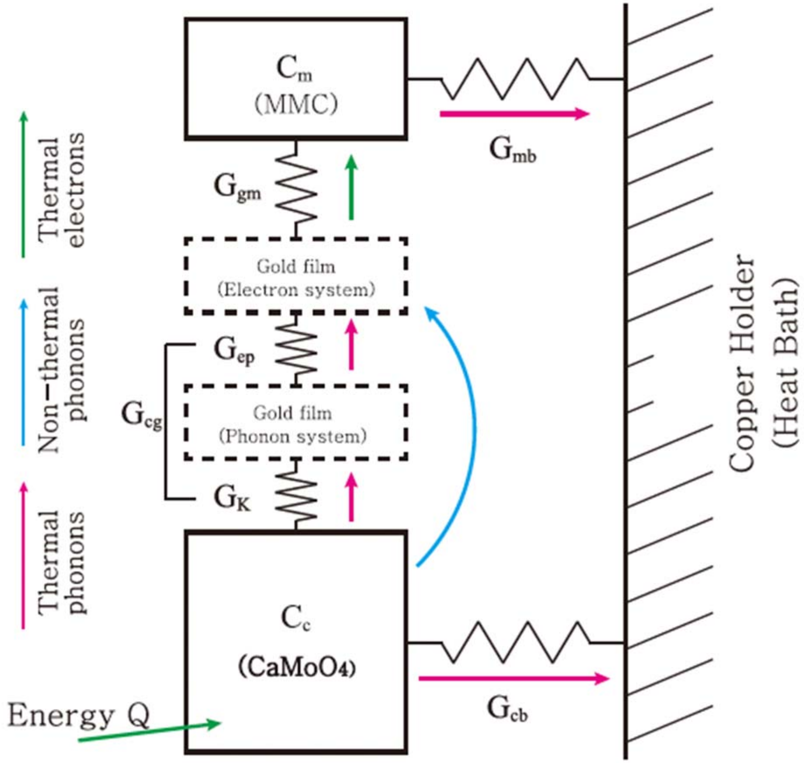


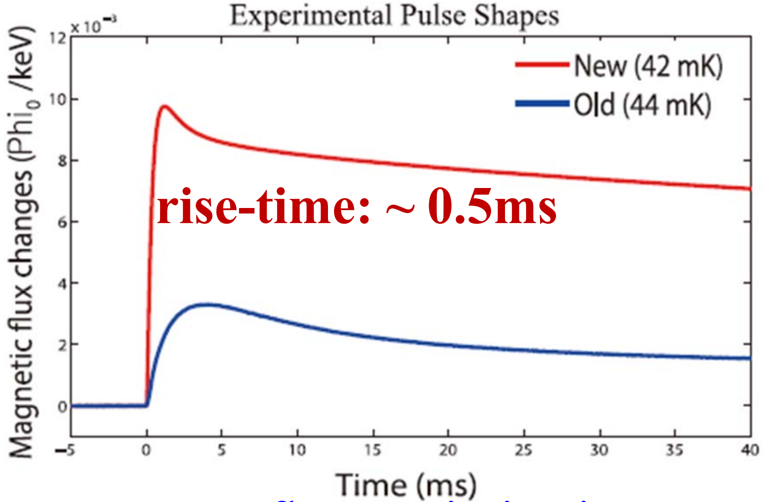
Gold film

Gold wires
(thermal connection)

216 g $CaMoO_4$

We measure both thermal and athermal phonons.

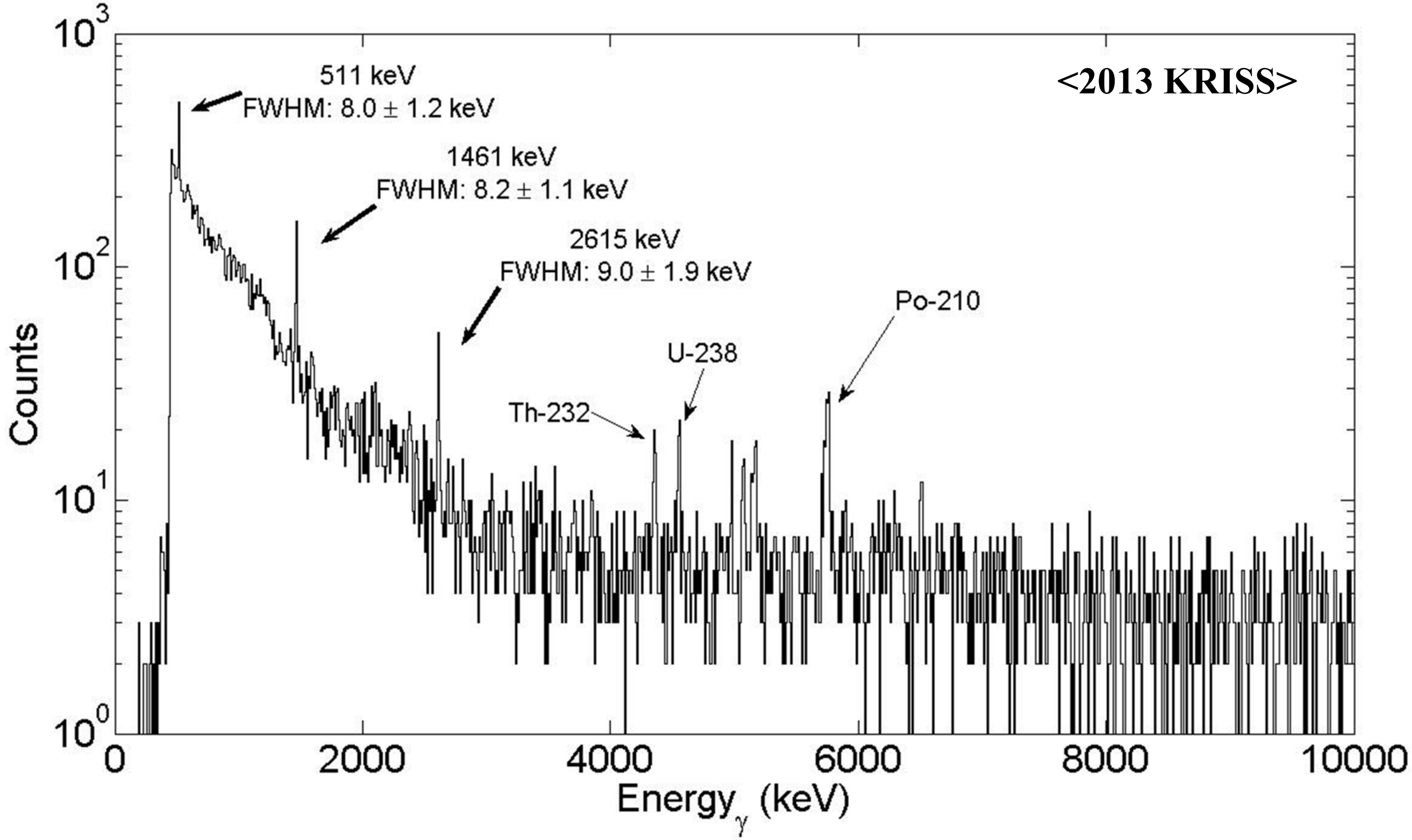




<Heat flow optimization>

Detector R&D in an over-ground lab

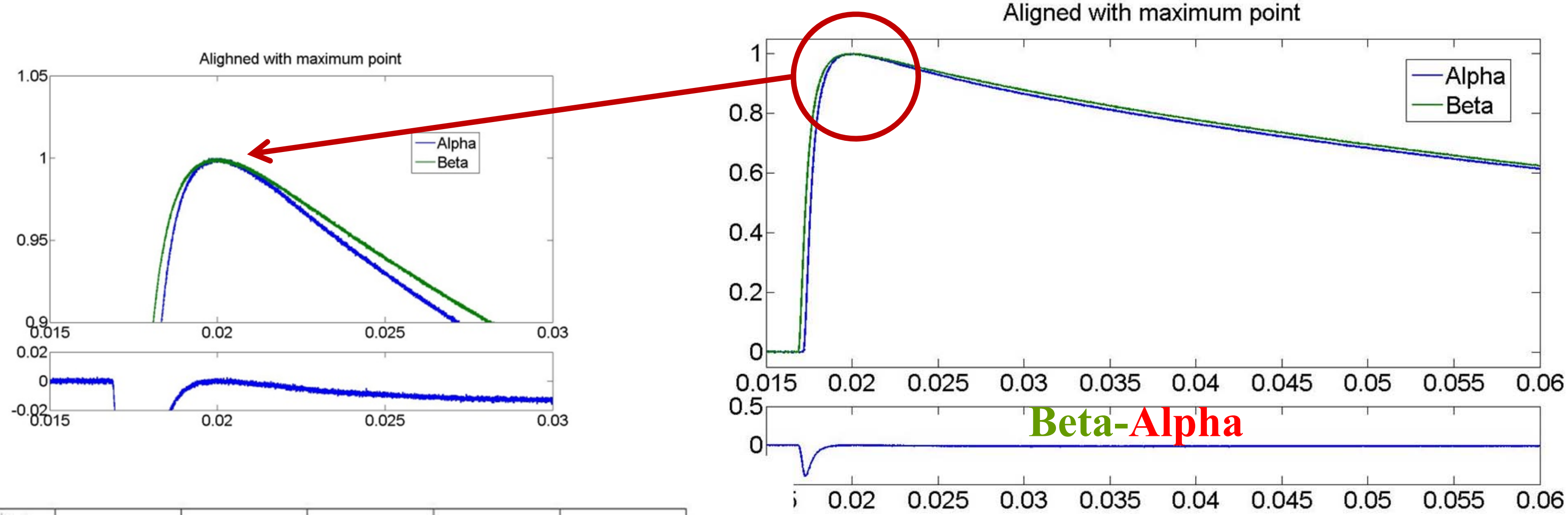
216 g $CaMoO_4$(natural) with a phonon sensor only.

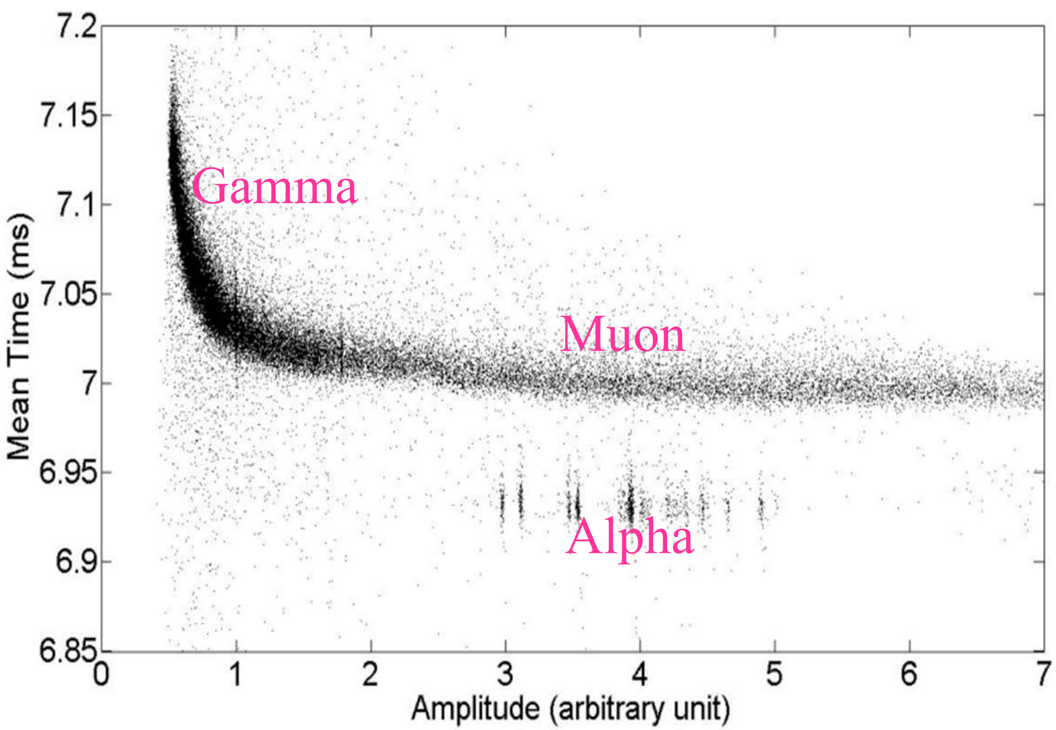


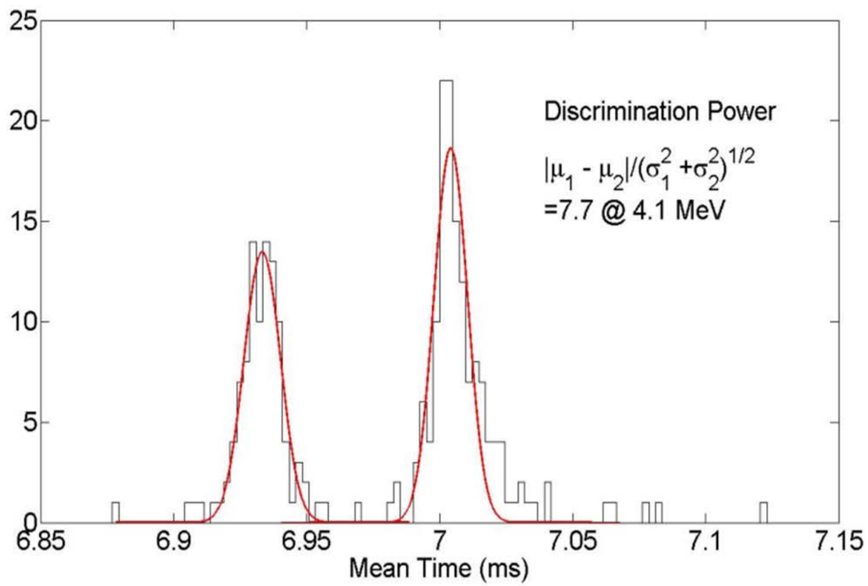
Energy (keV)	511	1461	2615
FWHM (keV)	8.0 ± 1.2	8.2 ± 1.1	9.0 ± 1.9

Pulse Shape Discrimination

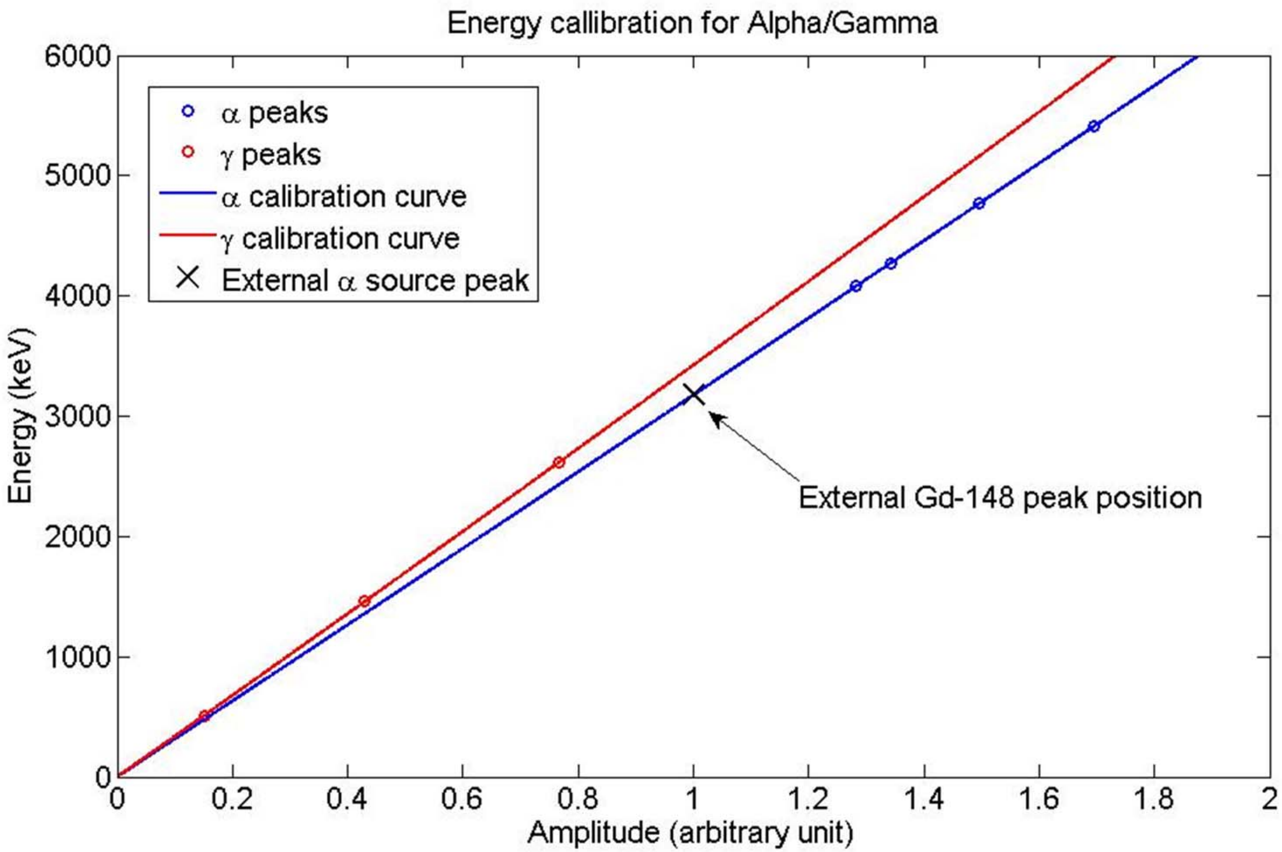
α and β events show different pulse shapes in phonon signals.





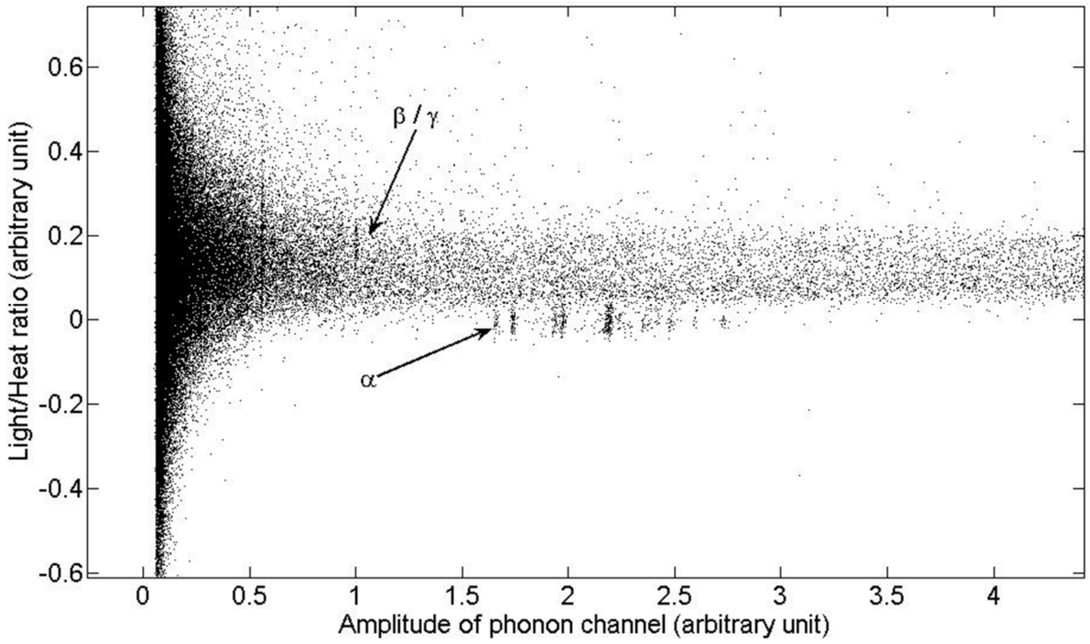


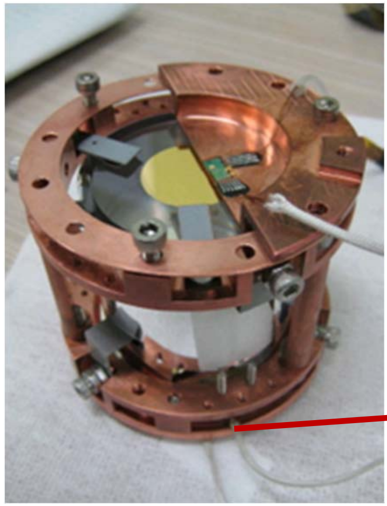
Energy calibration

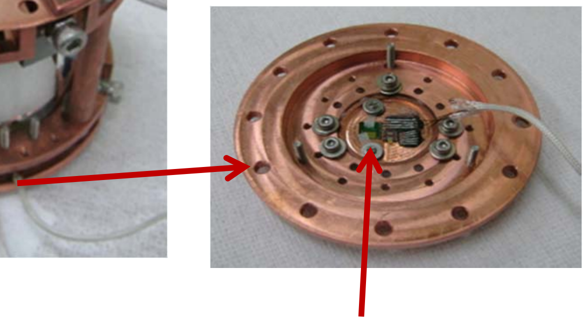


- Alpha/Beta events show different energy scale (~7% @ 2.6 MeV).
- The detector shows good linearity for both of alpha and gamma signals.

Photon Detector Measurement

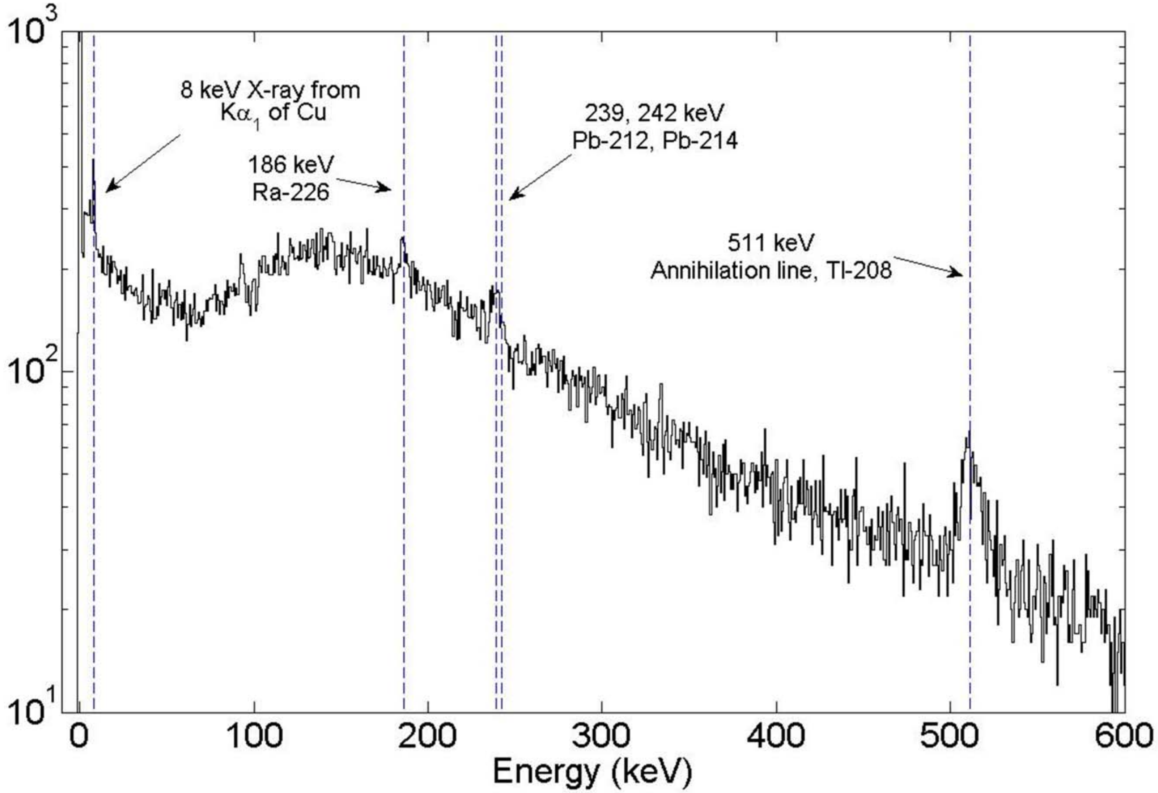


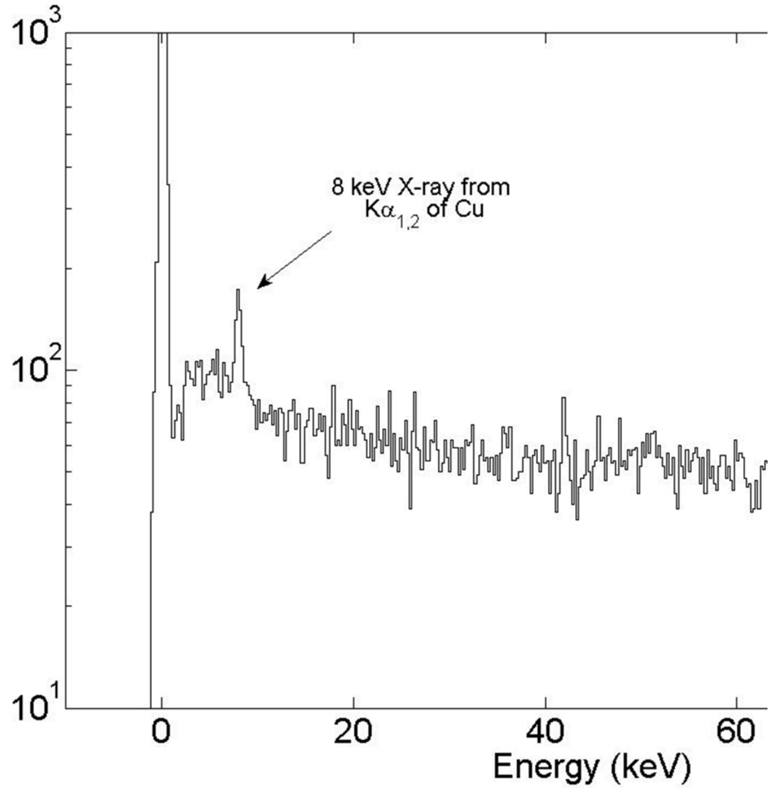




- We measured small photon signals because of small covering area (~20 mm^2).
- α and β particle events show different light yields.
- Now we are developing photon detectors with 1-2 inch Ge wafers.

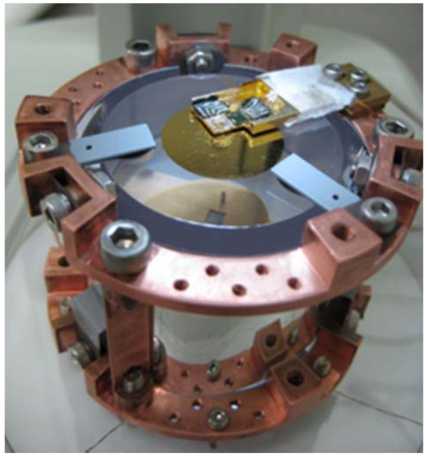
Low energy signals at lower temperatures



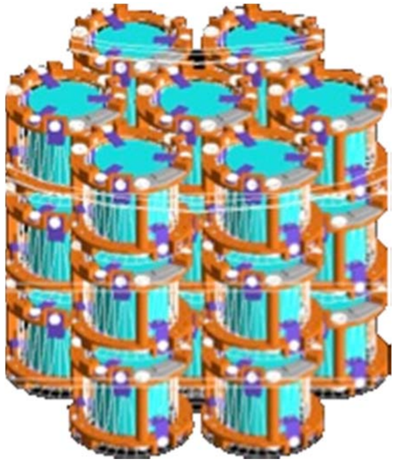


- 10 mK → larger but slower signals.
- One point (511 keV) linear calibration.
- 8 keV x-ray peak resolved.
- 1.5 keV signals can be clearly triggered.
- Further studies should be done in low background environment

Now and Future AMoRE



216 g
<Now, 2013>

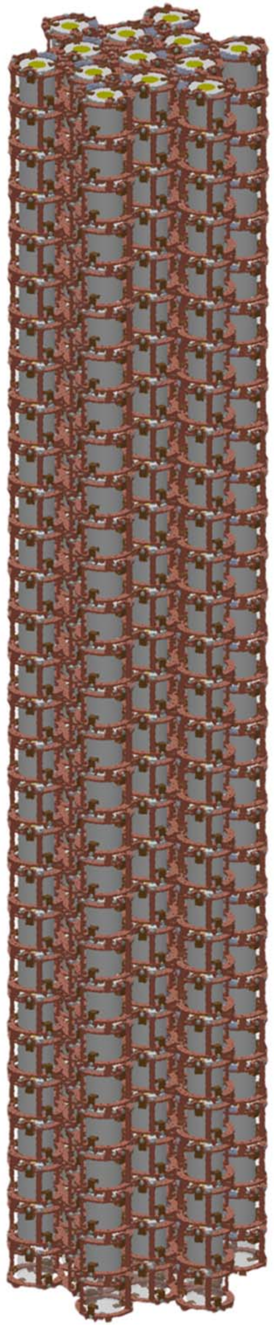


CMO: ~ 300g
5 layers-7 columns

<AMoRE10, 2015~6>
In Y2L

Each Cell : D=70 mm, H=80 mm.
CMO (D=50mm, H=60mm, 506g)
30 layers(2.4 m height)-13 columns
or 20 layers(1.6 m height)-19 columns

<AMoRE200, 2018~9>
In CUPID?



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: AMoRE10 at Y2L, AMoRE200 at CUPID?

Mass	10 kg	200 kg
Background $(\text{keV kg year})^{-1}$	10^{-2}	3×10^{-4}
Sensitivity(m_{ee}) (meV)	80-250	20-50
Schedule	in 3 years	in 8 years

Thank you

Kick-off started for the CUP !

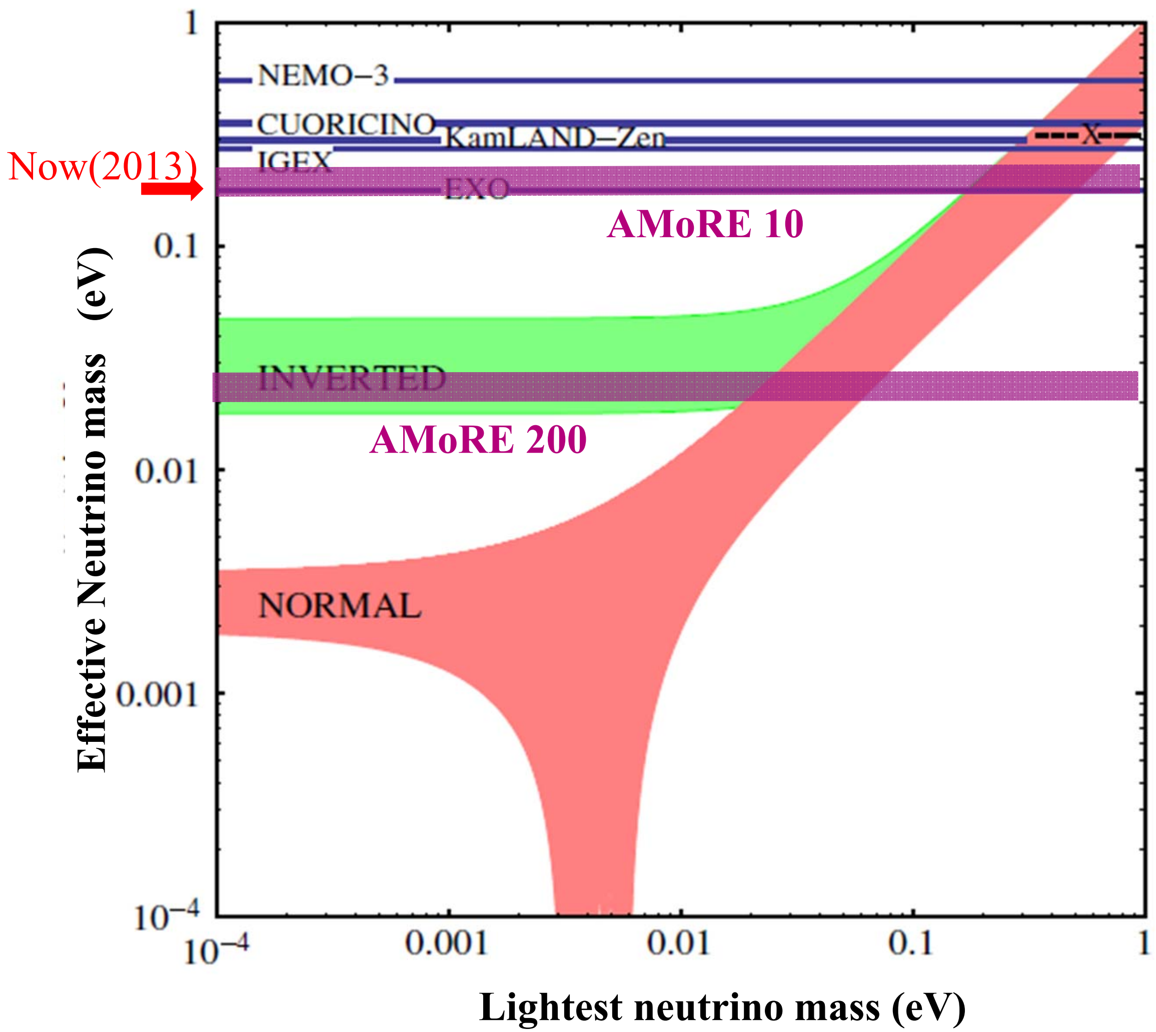
Major backgrounds from radionuclides

Background source	Activity (μBq/kg)	Background (10^{-4} cnt/keV/kg/yr)	Bkg reduced by PSD (10^{-4} cnt/keV/kg/yr)
Tl-208, internal	10 (^{232}Th)	0.36	
Tl-208, in Cu	16 (^{232}Th)	0.22	
BiPo-214, internal	10	0.11 [1)]	$\leq$ 0.01
BiPo-214, in Cu	60	1.8 [1) 2)]	$\leq$ 0.18
BiPo-212, internal	10 (^{232}Th)	0.08 [1)]	$\leq$ 0.01
BiPo-212, in Cu	16 (^{232}Th)	0.36 [1) 2)]	$\leq$ 0.04
Y-88, internal	20	0.19	
Σ int. (w/o $2\beta2\nu$)		0.74	$\leq$ 0.57
Σ Cu		2.40	$\leq$ 0.44
Rand. coinc. from $2\beta2\nu$ decays of ^{100}Mo	8.7×10^3 (single events)	3.1	1.2[3)]
Total		**6.2**	**$\leq$ 2.2**

1) Can be reduced $\times$0.1 by alpha/beta PSD.
2) Can be reduced by Teflon coating of Cu (to remove surface alphas).
3) Can be reduced further by the leading edge separation with Δt=0.5 ms.

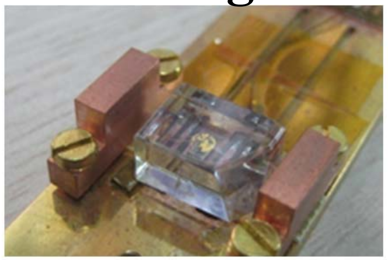
Muon background : 1.36×10^{-4} counts/(keV kg year)

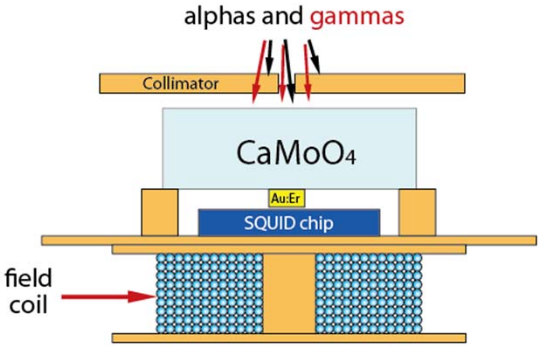
AMoRE Sensitivity



Before & Now

0.6 g



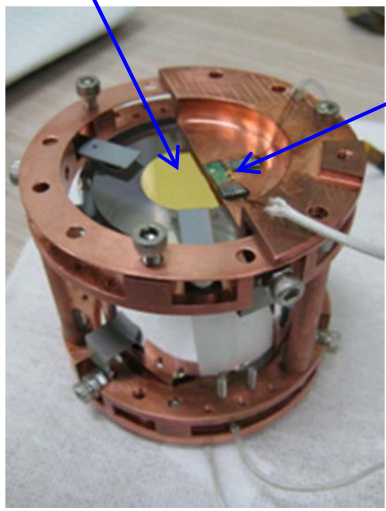


2009
CMO + Susceptometer

ϕ2 cm phonon collector

216 g

MMC sensor



2013
CMO + Meander MMC
Heat flow optimization