Dark matter search (KIMS) and Neutrino-less double beta decay search (AMoRE)

Korea **I**nvisible **M**ass **S**earch
Advanced **Mo**-based **R**are process **E**xperiment

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The 7th APCTP-BLTP JINR Joint Workshop
Modern Problems in Nuclear and Elementary Particle Physics, Baikal, Russia
July 14-19, 2013

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    - ☐ Development of $CaMoO_4$ crystals
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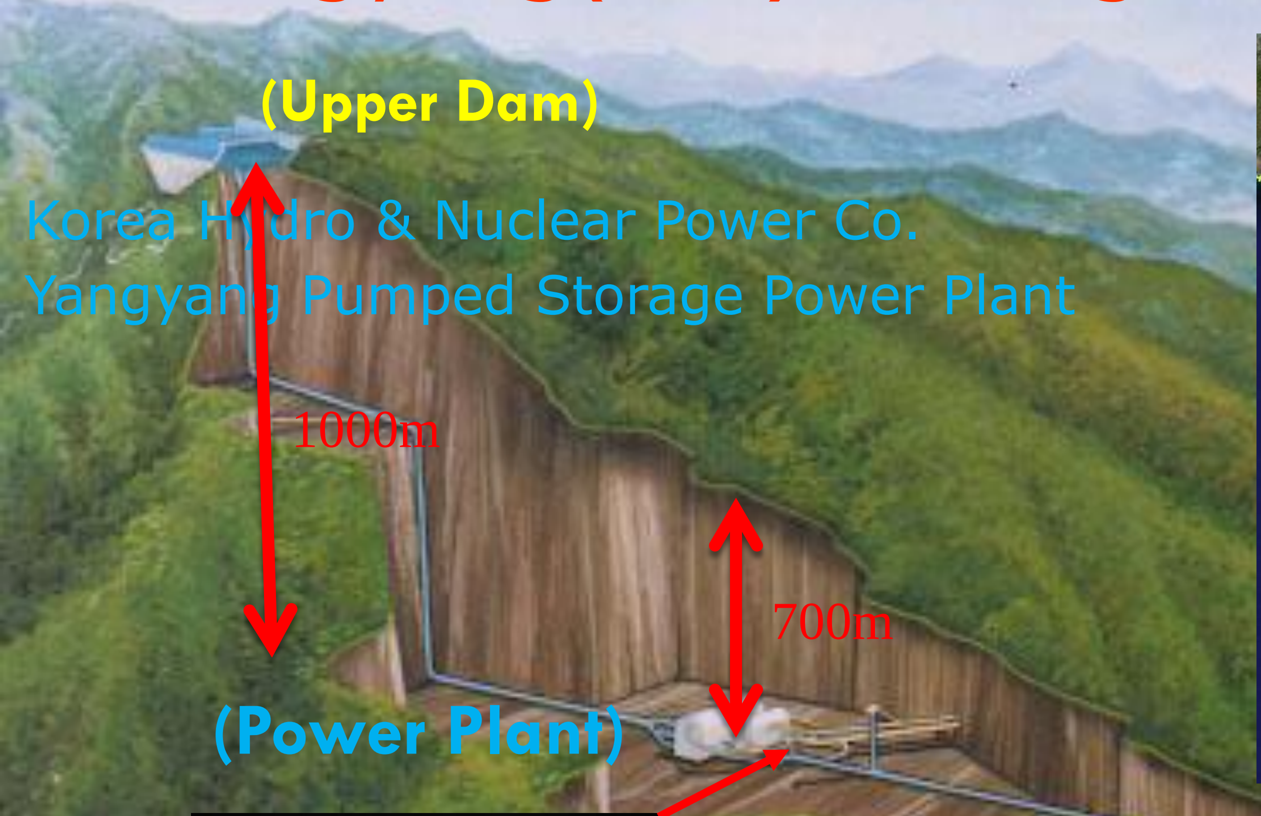
    - ☐ Prospects

Biginning 1997-

- **1997 : First discussion on WIMP search (cryogenic detector).**
- **1998-2002 : Feasibility studies on CsI(Tl) crystals for DM search.**
- **2003 : Construction of Y2L.**
- **2003 : Proposed a double beta decay using $CaMoO_4$ (CMO).**
- **2005. 12 – 2006. 3 4 CsI crystal ran → limits (PLB & PRL paper)**
- **2005-2007 : Large CMO grown by Russian collaborator.**
- **2009. 9 – 2012. 8. 12 CsI crystals → PSD limits (PRL paper)**
- **2009 : AMoRE collaboration formed.**
- **2010-11 : Characterization of $^{40}Ca^{100}MoO_4$ & background study**
- **2007- : CMO R&D in bolometer mode.**
- **2012. 10 – 2013. 12 12 CsI crystals in test mode. → PMT upgrades.**
- **2014 : Center for Underground Nuclear, Particle, Astrophysics (CUNPA) got funded by IBS**

II Yangyang(Y2L) Underground Laboratory

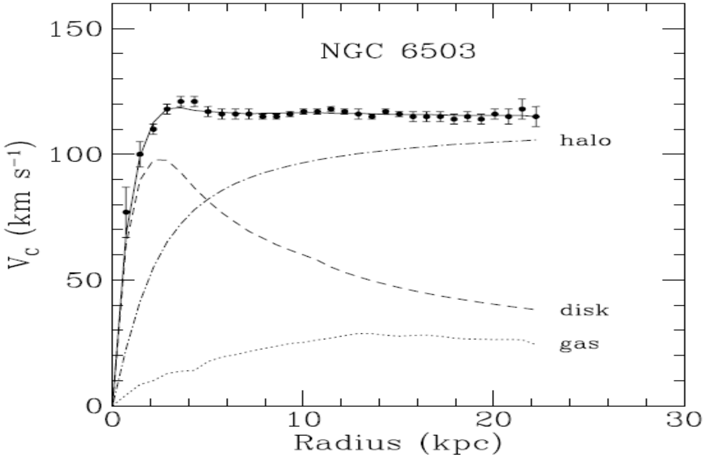


KIMS (Dark Matter Search)

AMoRE (Double Beta Decay Experiment)

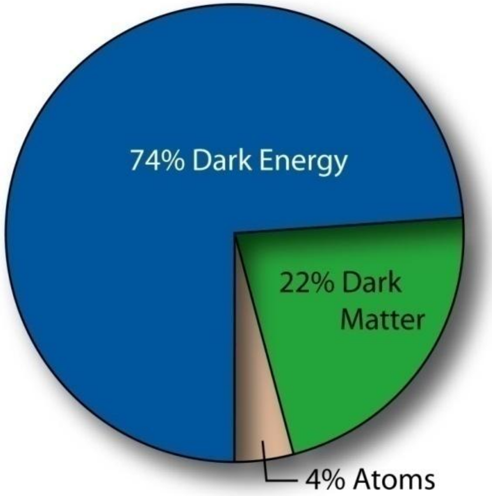
Minimum depth : 700 m / Access to the lab by car (~2km)

Evidences for Dark Matter (~25% of Universe)

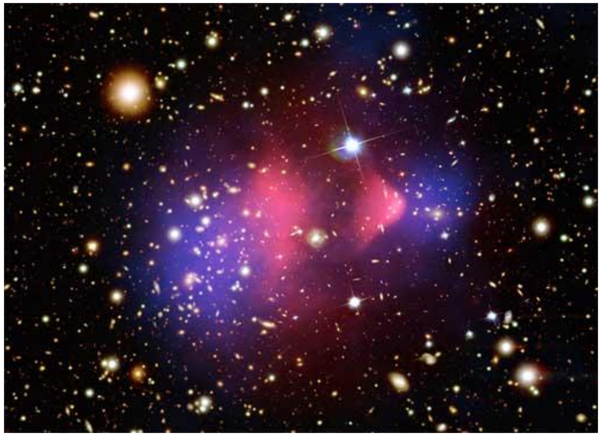


Rotation curve for Galaxy

Gravitational Lensing



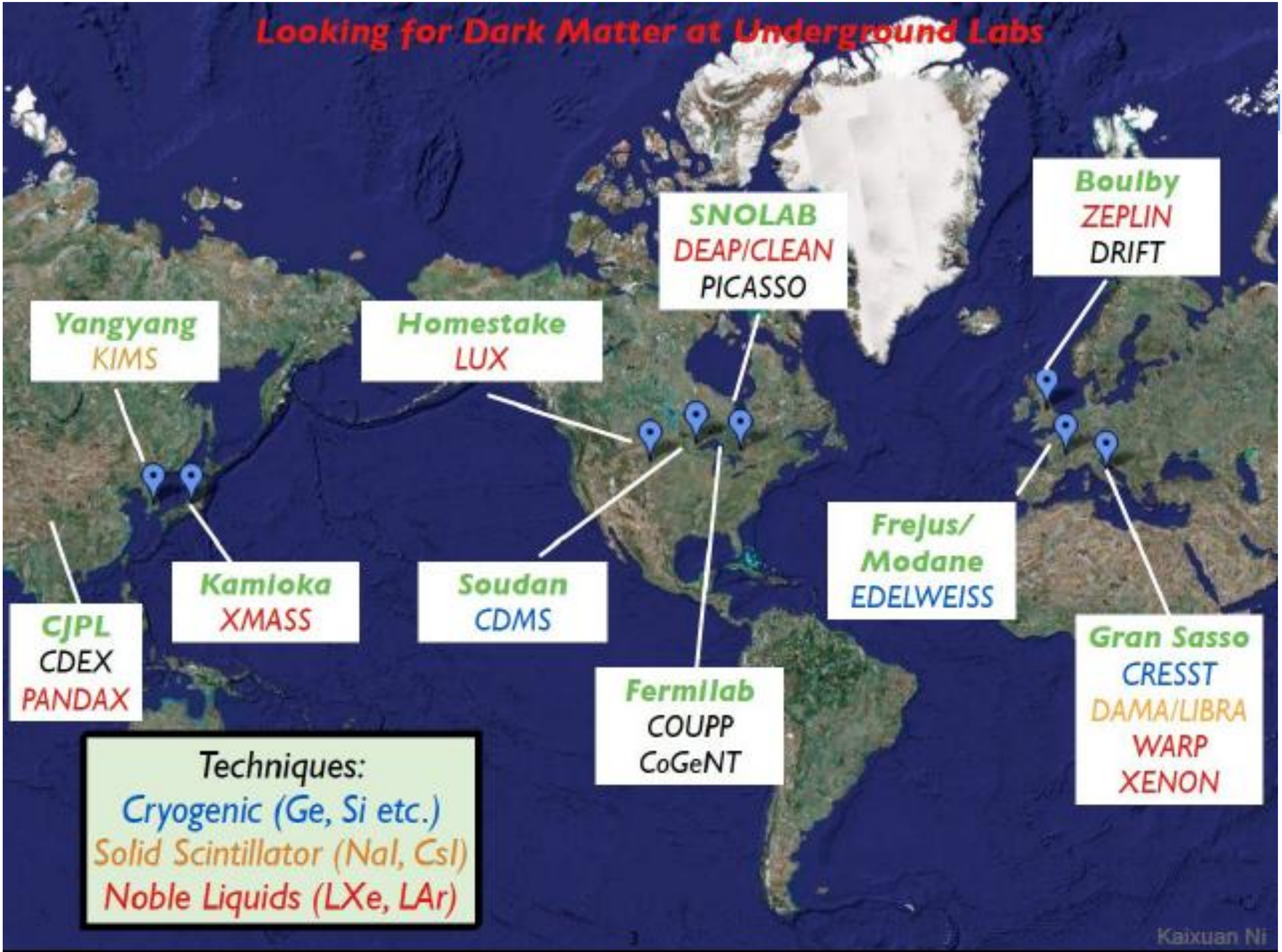
Parameters of ΛCDM by WMAP



Bullet cluster

Not visible, but gravitationally evident!

Looking for Dark Matter at Underground Labs



Techniques:
Cryogenic (Ge, Si etc.)
Solid Scintillator (NaI, CsI)
Noble Liquids (LXe, LAr)

Why CsI(Tl) Crystals for WIMP search?

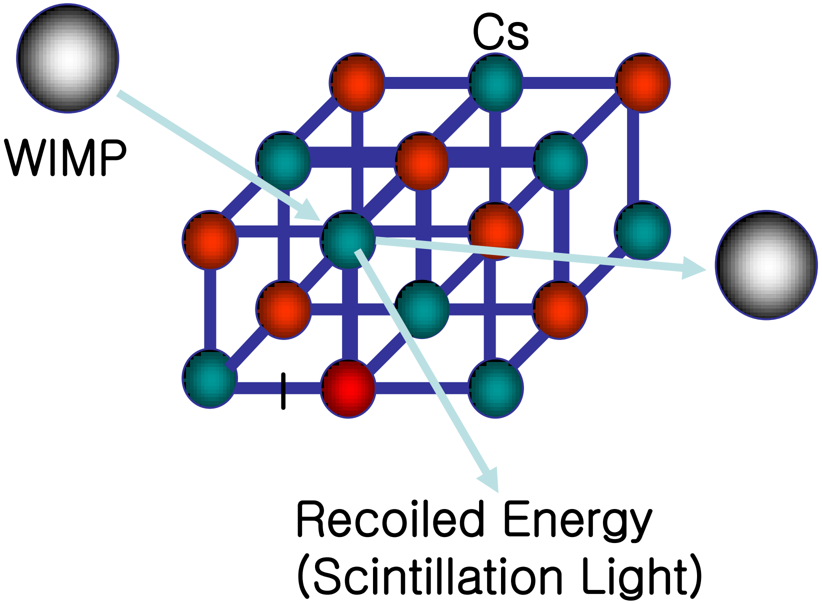
- Large mass with an affordable cost
  - ➔ Good for AM study
- High light yield ~60,000/MeV
- Pulse shape discrimination
  - ➔ Moderate background rejection
- Easy fabrication and handling
- Cs & I (SI cross section ~ A^2)

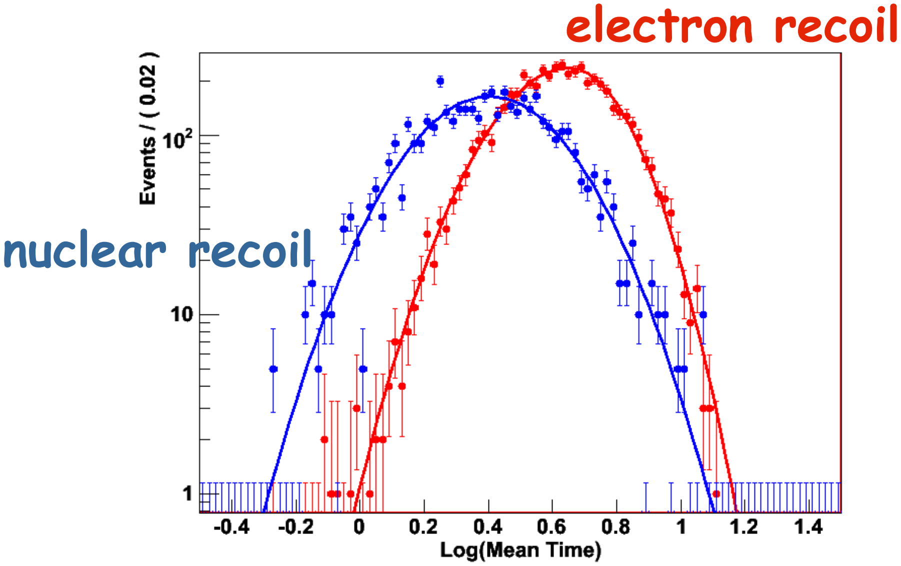
  Cs &,I are sensitive to SD interaction

CsI(Tl) Crystal 8x8x30 cm^3 (8.7 kg)

3" PMT (9269QA) : Quartz window, RbCs P.C.

~5 Photo-electrons/keV





KIMS (Korea Invisible Mass Search)

2000 @ CPL, began in the vinyl room


2003.2.27

***Seoul National University*:** H.C.Bhang, J.H.Choi, S.H. Choi, K.W.Kim, S.C.Kim, S.K.Kim, J.H.Lee,J.I.Lee , J.K.Lee, M.J.Lee, S.J.Lee, J.Li, X.Li, S.S.Myung,S.L.Olsen, I.S.Seong

***Sejong University*:** U.G.Kang, Y.D.Kim

***Kyungpook National University*:** H.J.Kim, J.H.So, J.Y.Lee

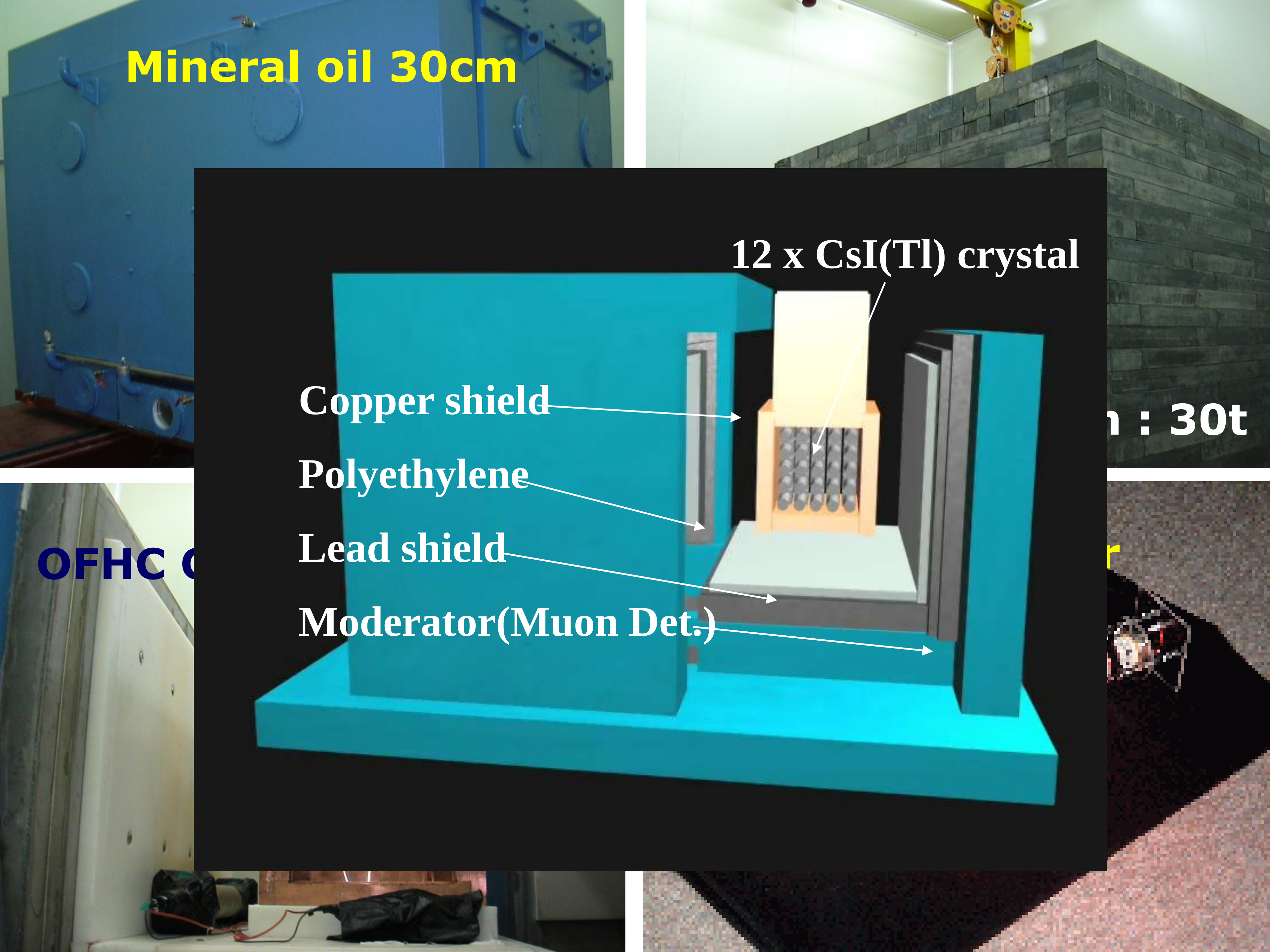
***Yonsei University*:** Y.J.Kwon

***Ewha Womans University*:** I.S.Hahn

Seoul City University : Douglas Leonard

***Korea Research Institute of Standard Sciences* :** Y.H.Kim, K.B.Lee, M.K. Lee

***Tsinghua University* :** Y.Li, Q.Yue, J. Li

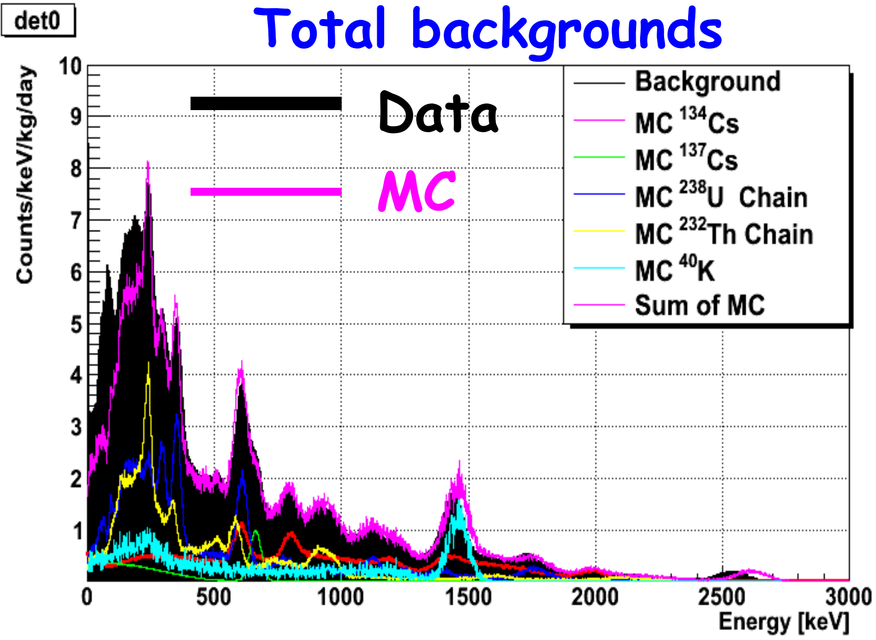

Mineral oil 30cm
n : 30t
OFHC C
r
12 x CsI(Tl) crystal
Copper shield
Polyethylene
Lead shield
Moderator(Muon Det.)

KIMS with 104.4 kg CsI(Tl)

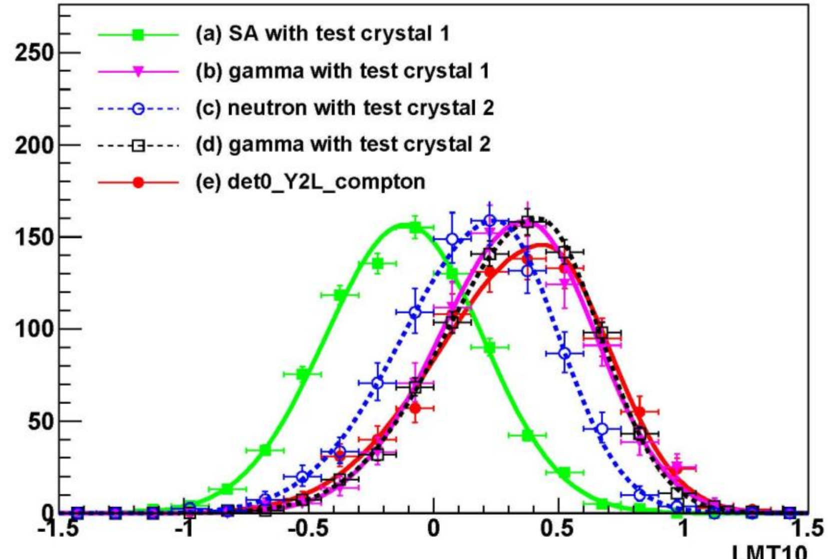
12 crystals(104.4kg) in operation

- 2.5 year data (Sep. 2009 – Feb. 2012)
- Background Level : 2~3 cpd/kg/keV
- Source calibration with ^{55}Fe & ^{241}Am
- Backgrounds are well understood.

Total backgrounds



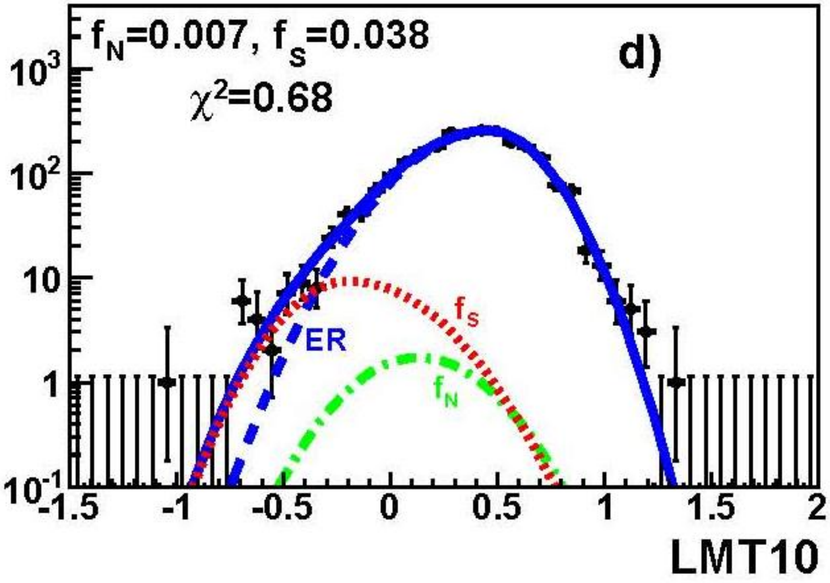
Pulse shape discrimination



Nuclear recoil event rates (PSD analysis)

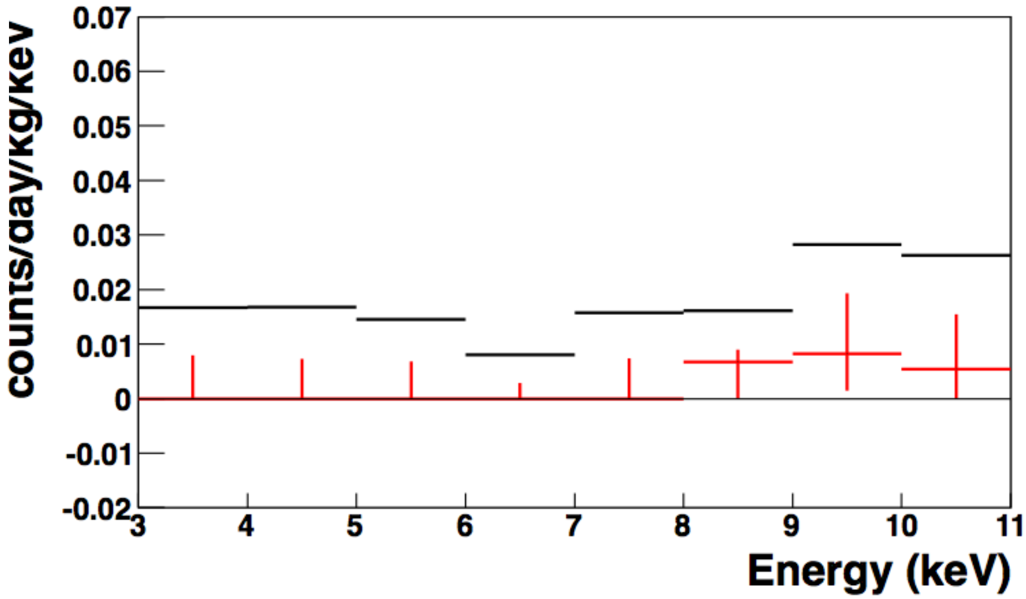
$\mathrm{Pdf} = f0 \times F_{NR} + f1 \times F_{SA} + (1-f0-f1) \times F_{gamma}$

The posterior pdf for f0 & f1 is obtained from Bayesian analysis method.



Example : 6 keV bin, DET09

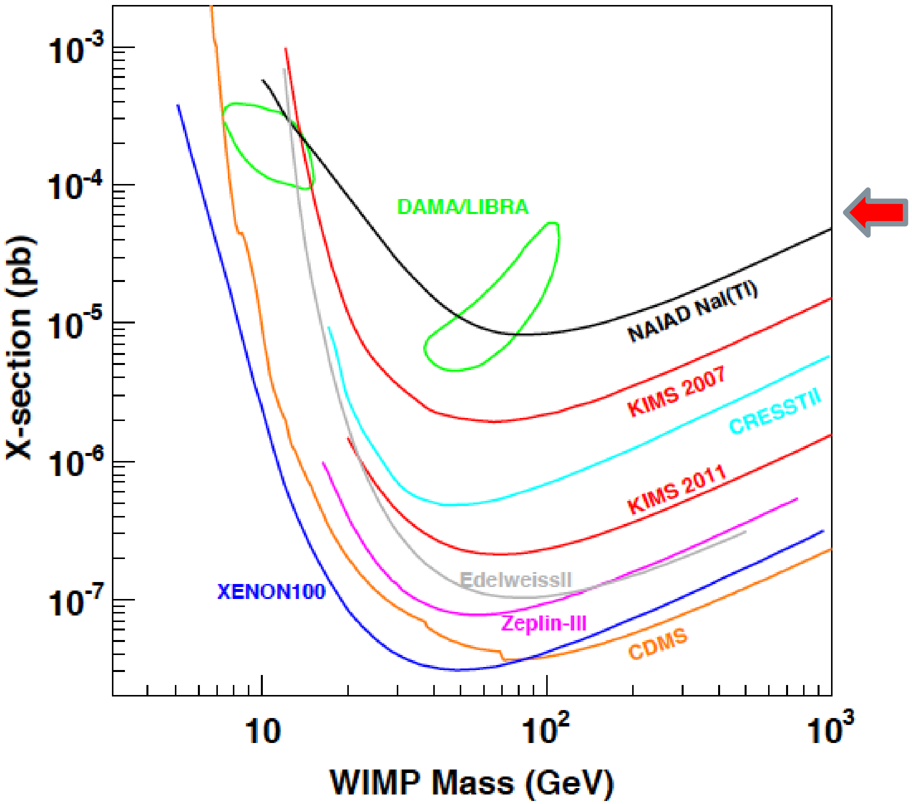
1 year data excluding det0, 8, 11



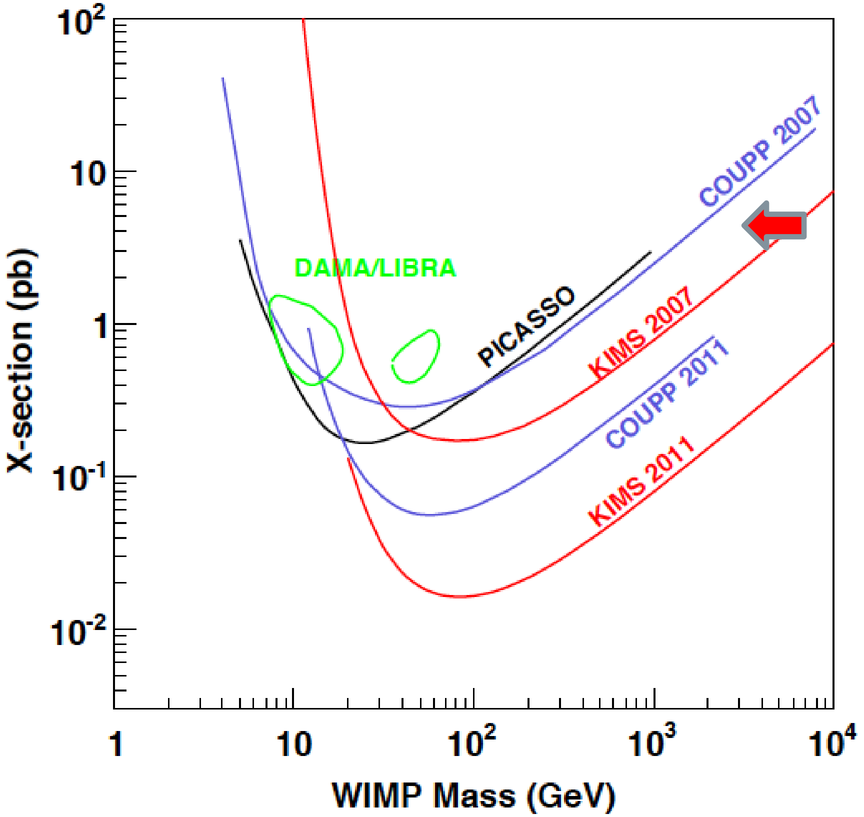
PSD result on WIMP search @KIMS

Total exposure: 24524.3 kg days
S.C. Kim et al., PRL 108 181301 (2012)

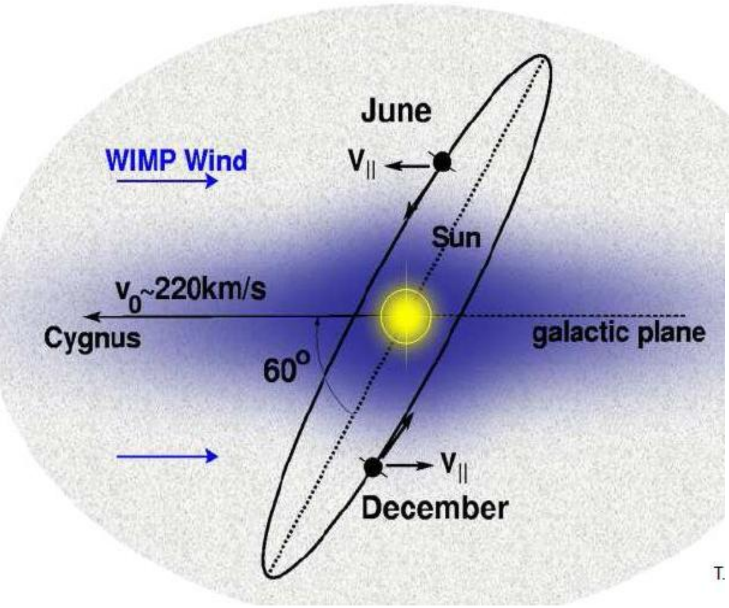
SI WIMP-nucleon



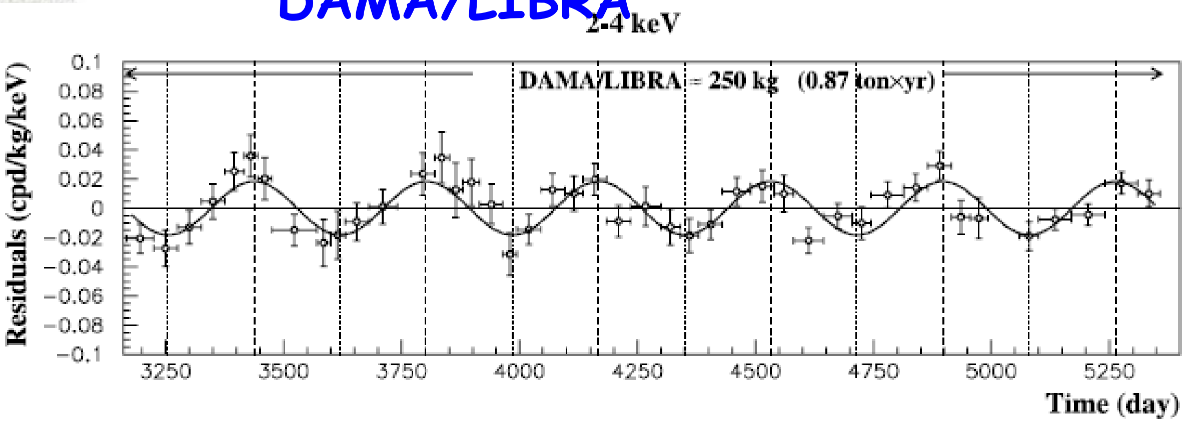
SD WIMP-proton



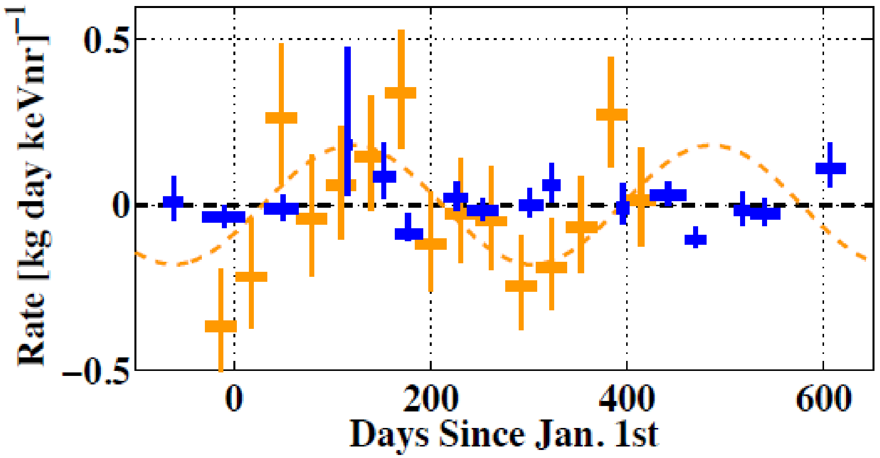
Annual Modulation Signals

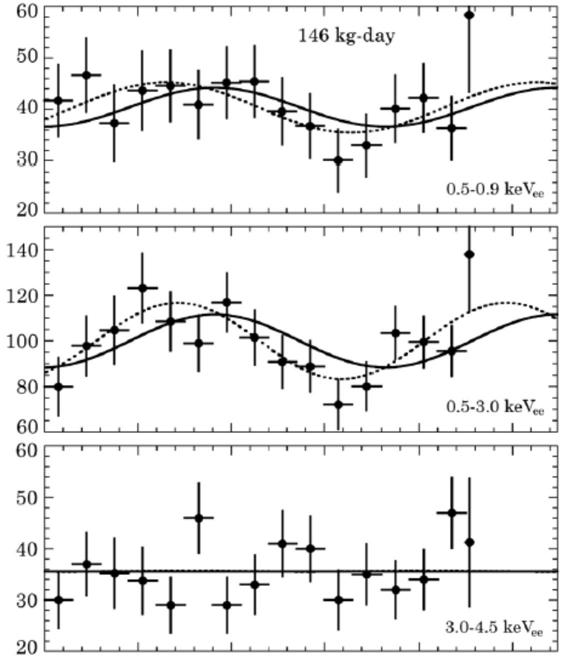


DAMA/LIBRA

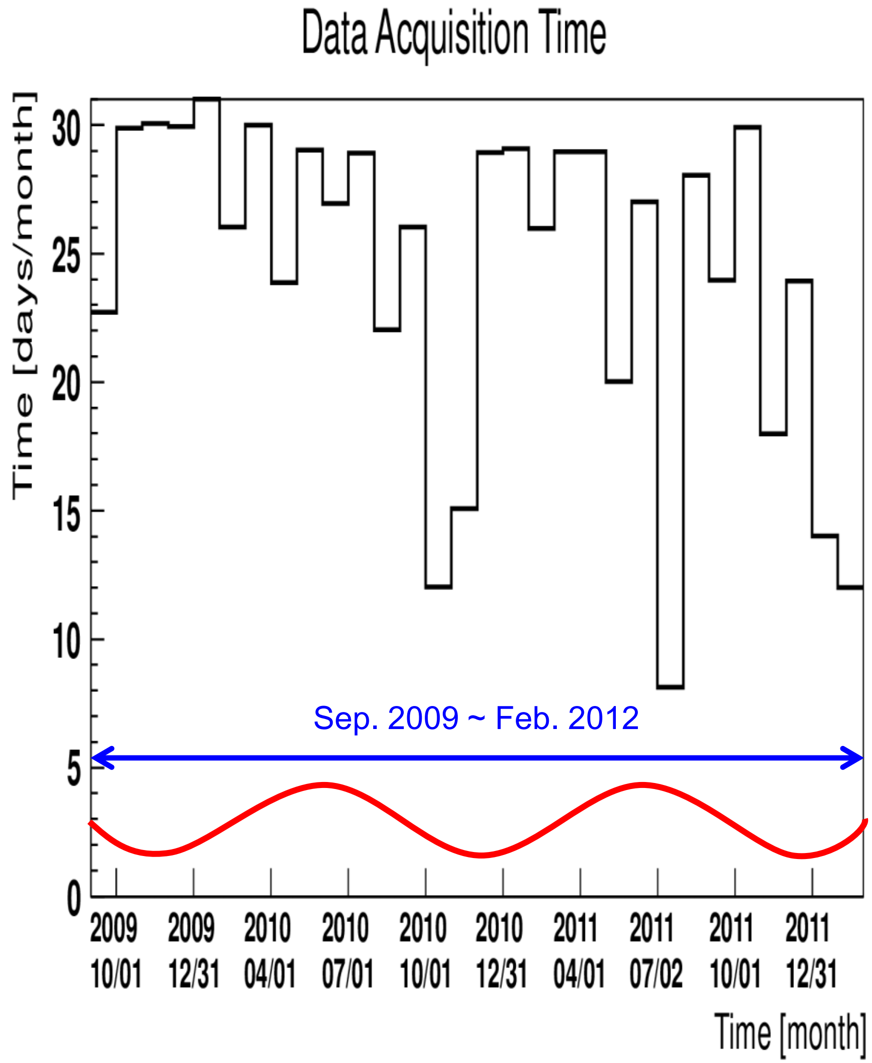


CDMS didn't see annual modulation.
arXiv:1203.1309

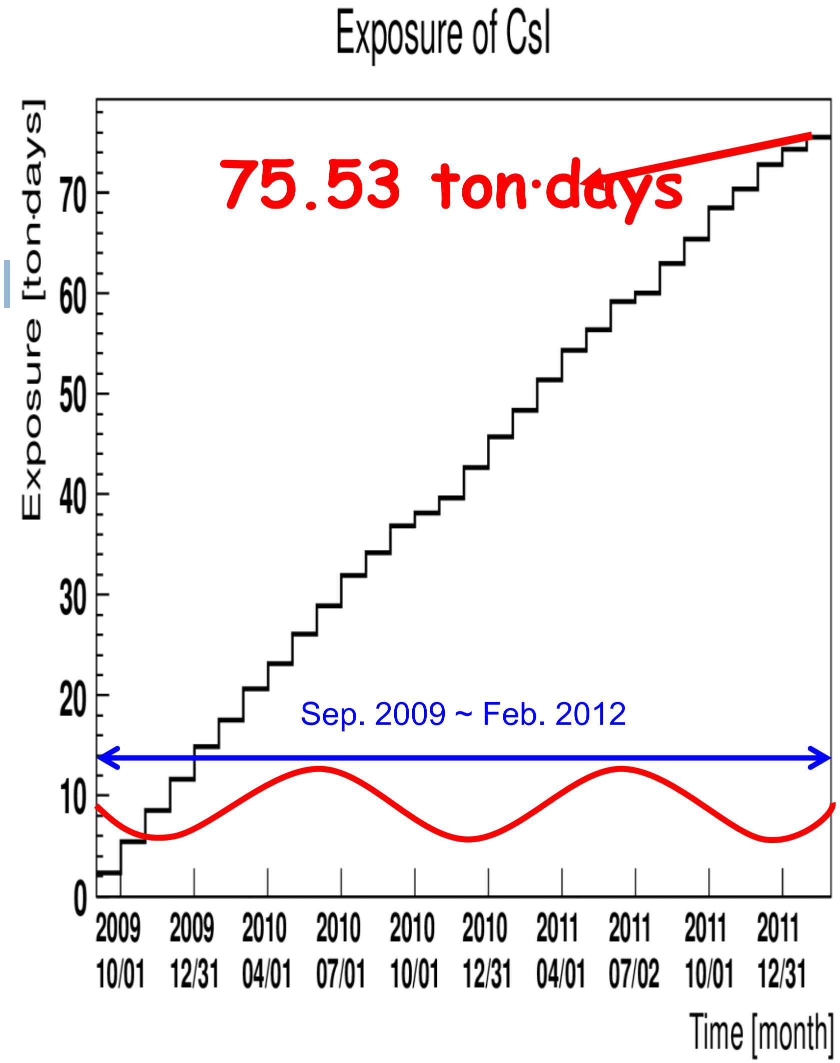




COGENT



Sep. 2009 ~ Feb. 2012



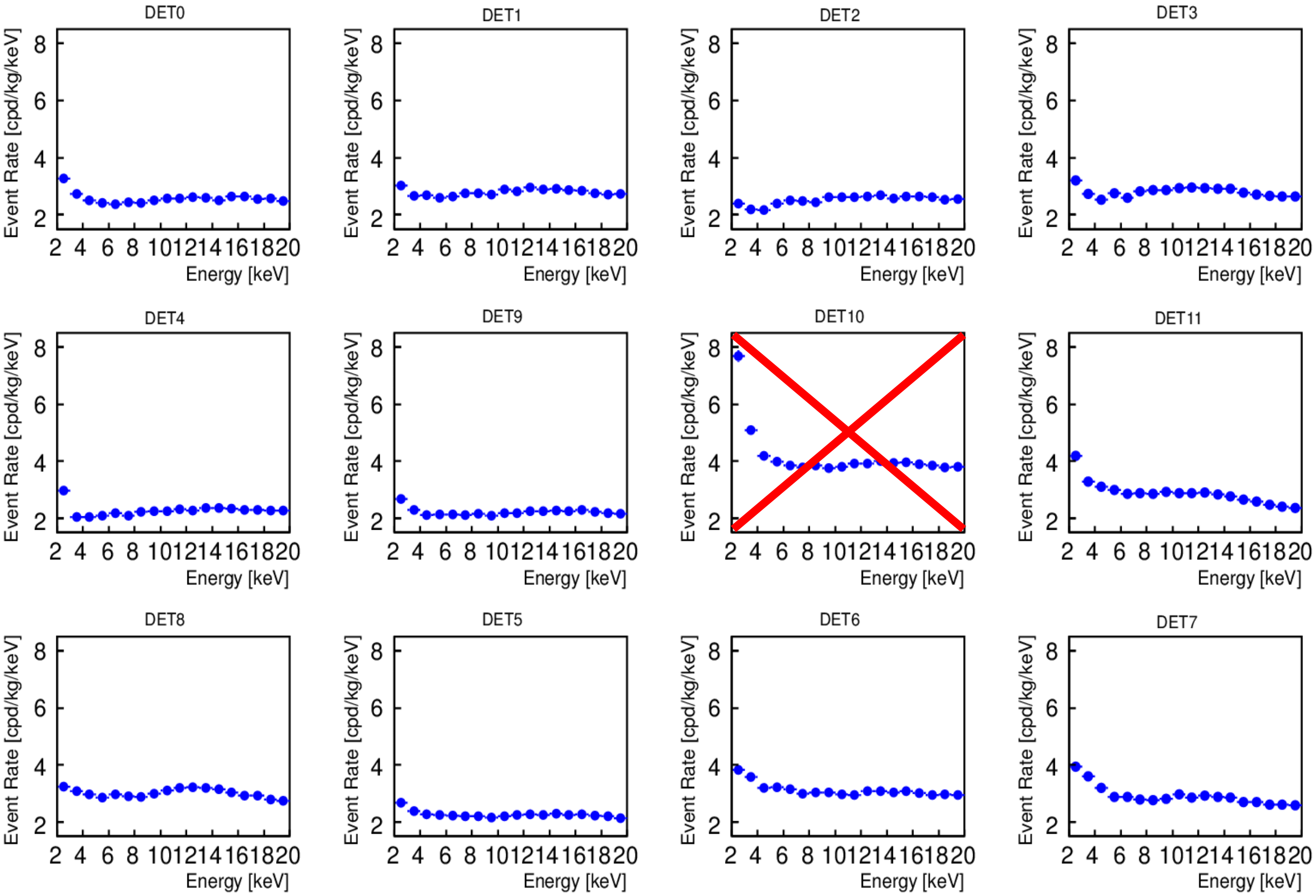
75.53 ton·days

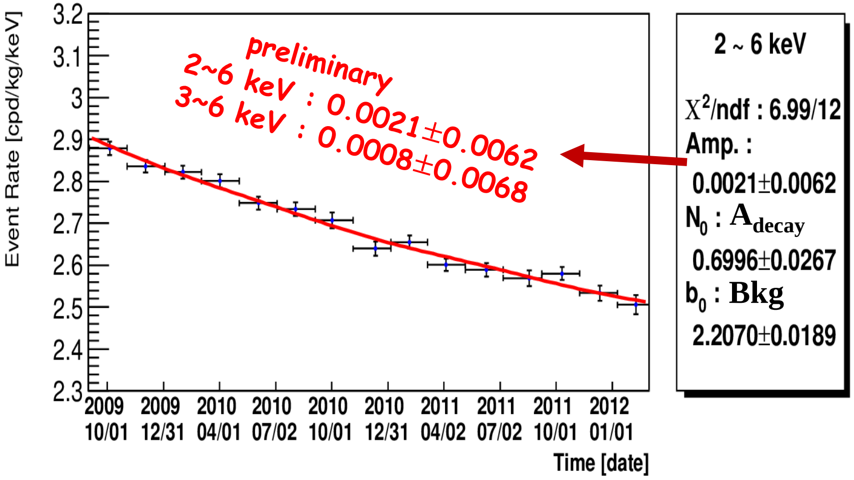
Sep. 2009 ~ Feb. 2012

Data taking :75.53 ton·days during 2.5 years

Energy Spectrum

2~4 cpd/kg/keV





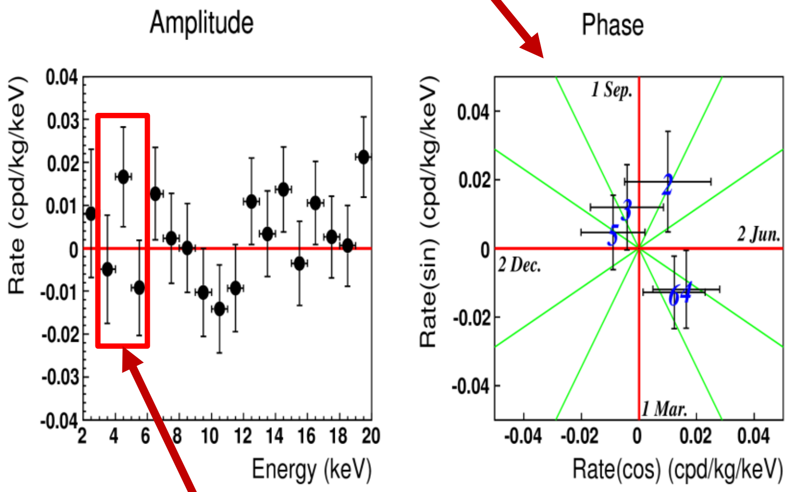
preliminary

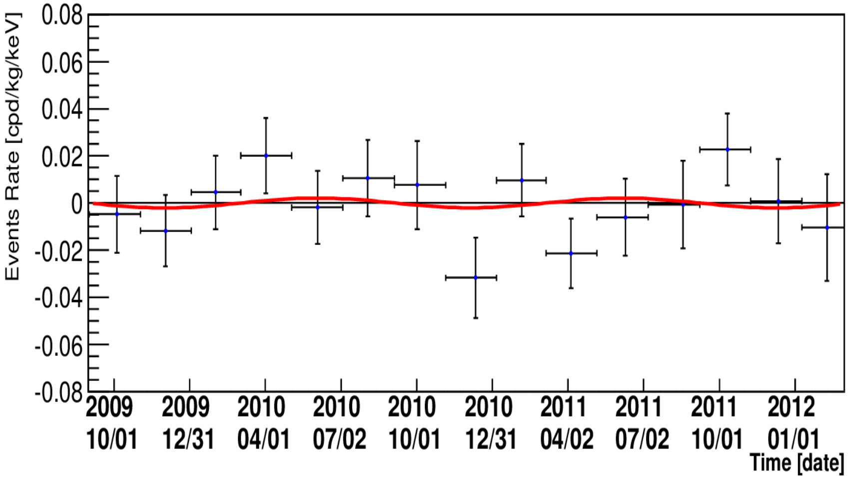
2~6 keV : 0.0021±0.0062

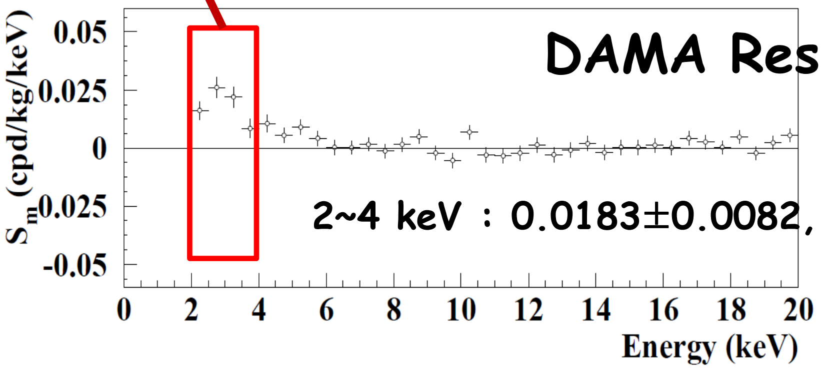
3~6 keV : 0.0008±0.0068

$$f(t) = A_{decay}e^{-\frac{t-t_0}{\tau}} + Bkg + A\cos\frac{2\pi}{\omega}(t-t_{1\,free})$$

$$= A_{decay}e^{-\frac{t-t_0}{\tau}} + Bkg + A\cos\frac{2\pi}{\omega}(t-t_{1\,fixed}) + B\sin\frac{2\pi}{\omega}(t-t_{1\,fixed})$$





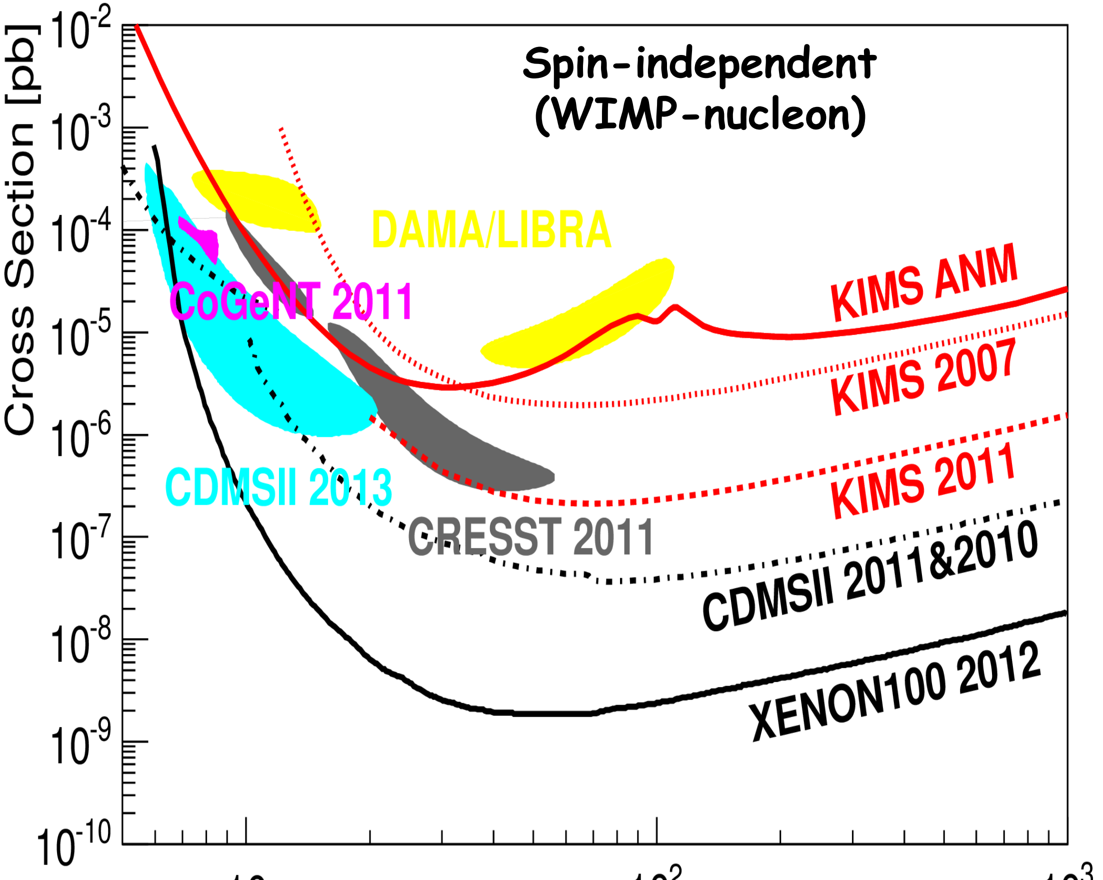


DAMA Result

2~4 keV : 0.0183±0.0082, 8.3σ

- □ 2~6 keV : 0.0021±0.0062 (0.0122 90% CL Positive Limit),
- □ 3~6 keV : 0.0008±0.0068 (0.0119 90% CL Positive Limit)

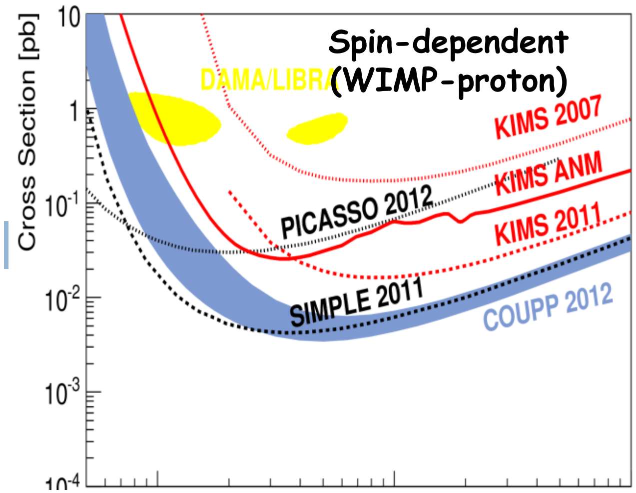
< SI WIMP-nucleon Cross Section >



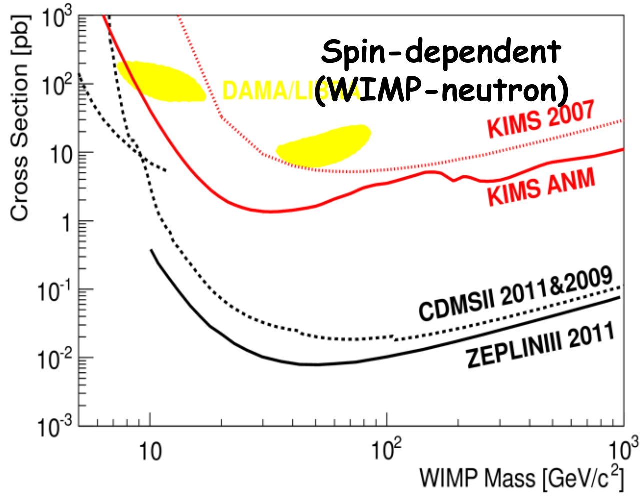
WIMP Mass [GeV/c^2]

preliminary

< SD WIMP-proton Cross Section >



< SD WIMP-neutron Cross Section >



Spin-independent : $\sigma^{SI}_{W-n} = \sigma_0 \frac{\mu_n^2}{\mu_A^2} \frac{1}{A^2}$, **Spin-dependent :** $\sigma^{SD}_{W-n,p} = \sigma_0 \frac{\mu_{n,p}^2}{\mu_A^2} \frac{3}{4} \frac{J}{(J+1)} \frac{1}{<S_{n,p}>^2}$

KIMS Perspectives

I. Upgrade of CsI(Tl) crystal detector

- Change PMTs to more sensitive and lower noise ones.
- Lower threshold ~ 1.5keV, < 1 counts/(keV kg day).

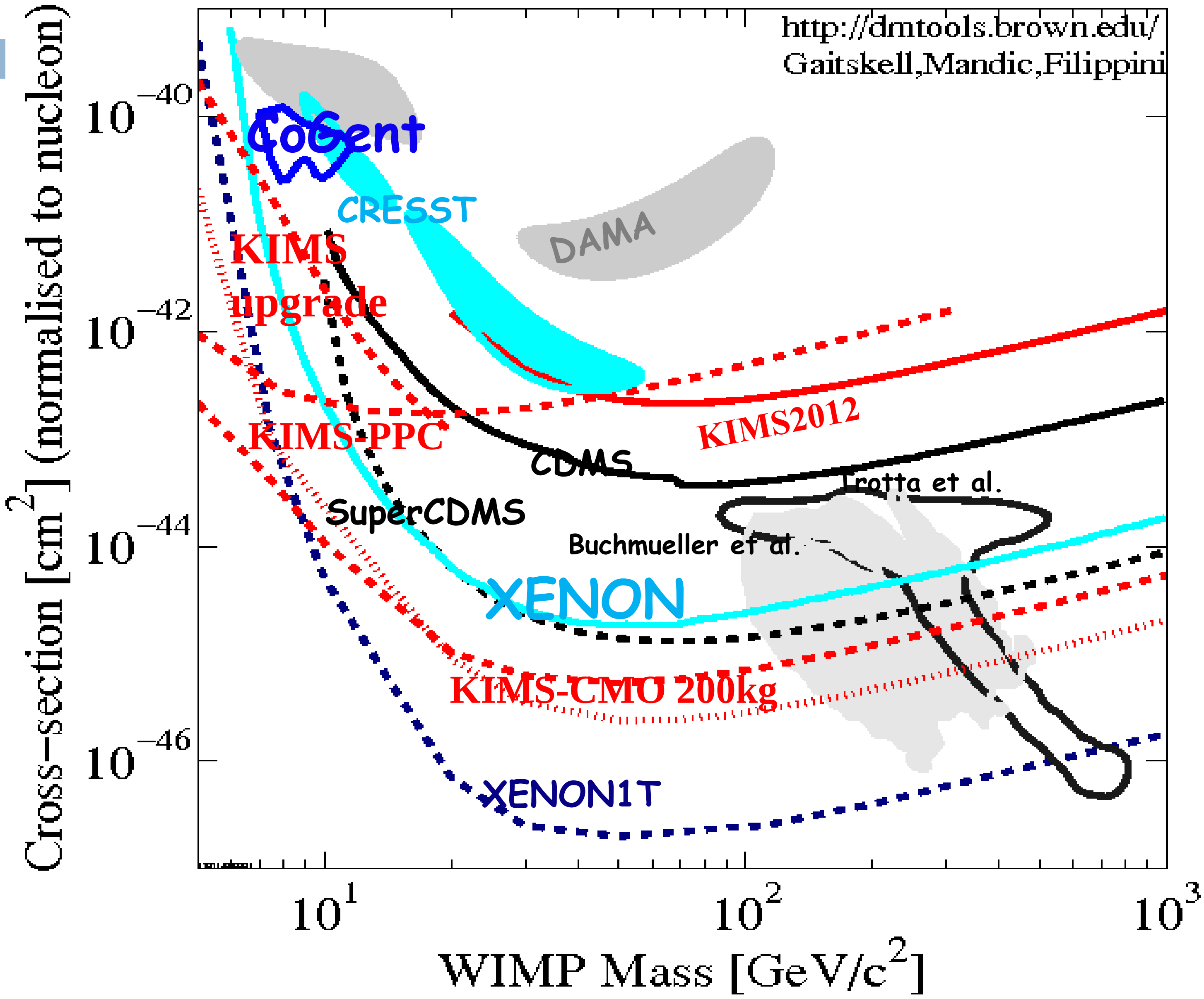
II. KIMS-NaI

- Duplicate DAMA experiment.
- Develop ultra-low background NaI(Tl) crystals through international collaboration (ANAIS, DM-ICE group @ south pole)
- KIMS is ready to house NaI(Tl) crystals and 1st crystal will be installed at Y2L this summer.

III. KIMS-CMO200 (AMoRE-DARK)

- $^{nat}Ca^{nat}MoO_4$ crystals ~ 200 kg year data.
- High sensitivity in low mass WIMP.
- Good nuclear recoil separation is expected. Need to be developed.

WIMP search perspectives & KIMS



Double beta decay process

2ν ββ decay

2nd order beta decay

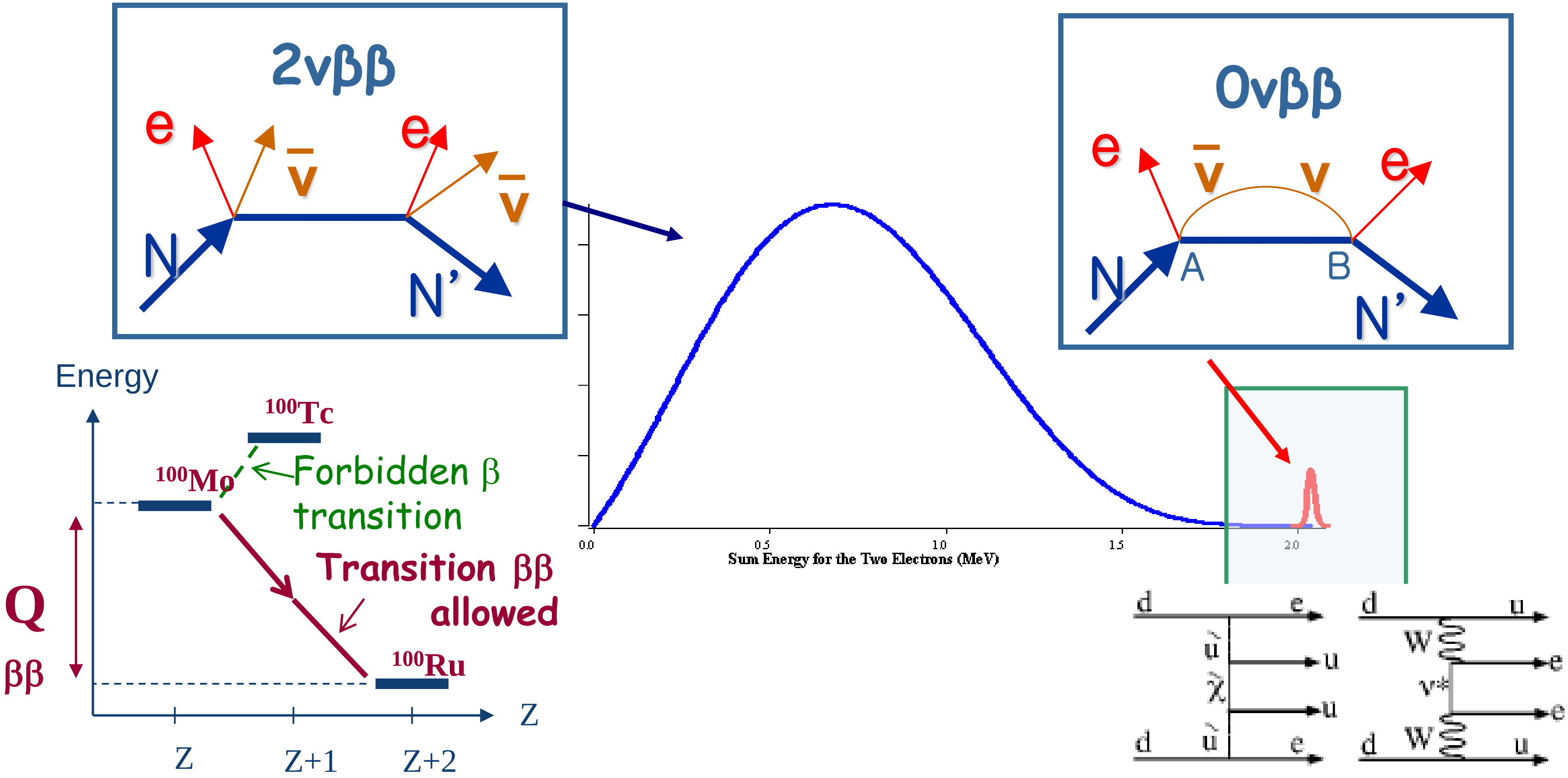
Rare nuclear decay

($>10^{18}$ years)

0ν ββ decay

1) ν mass>0 & Majorana particle

2) New Physics

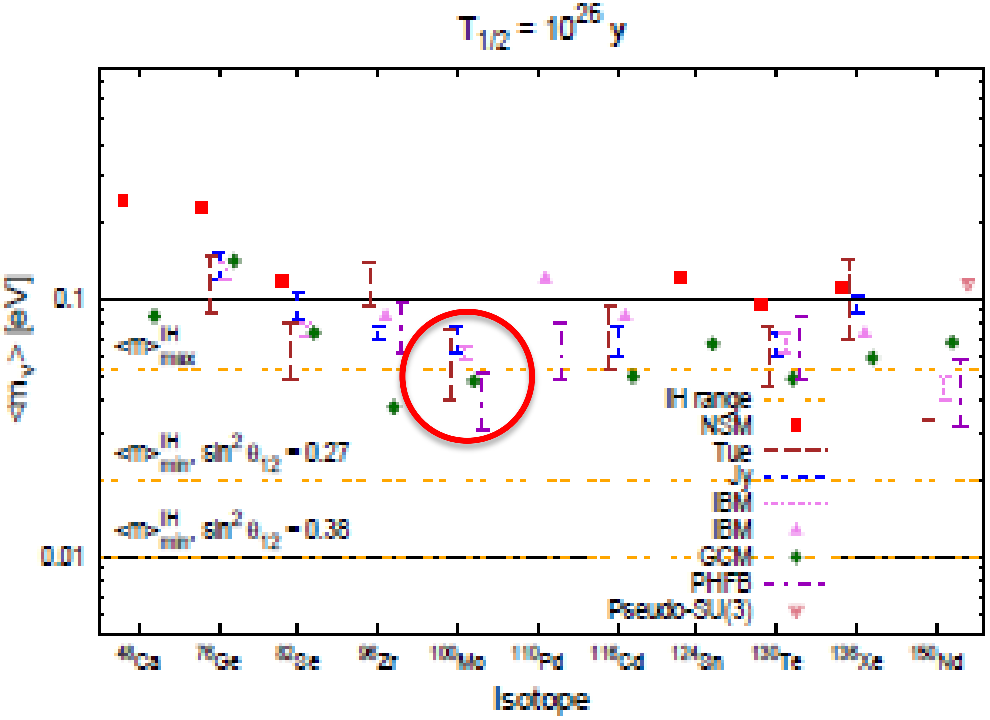


Theoretical Issues

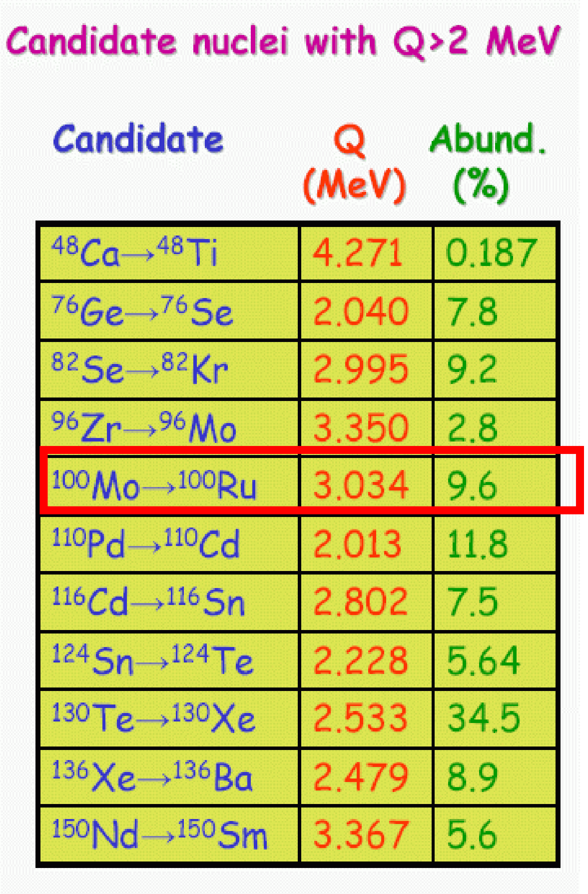
$1/T^{0\nu}_{1/2} = G^{0\nu}(E_0,Z)\ |M^{0\nu}|^2 \langle m_{\beta\beta}\rangle^2/m_e^{\ 2}$

$G^{0\nu}(E_0,Z)$ **: phase space factor (~** $Q_{\beta\beta}^{5}$**) : higher Q-value is better.**

- **$M^{0\nu}$-Nuclear Matrix Element, hard to calculate**
  - **Model dependent**
  - **Motivation to measure several isotopes**



Werner Rodejohann, Int. J. M. Phys., 2011

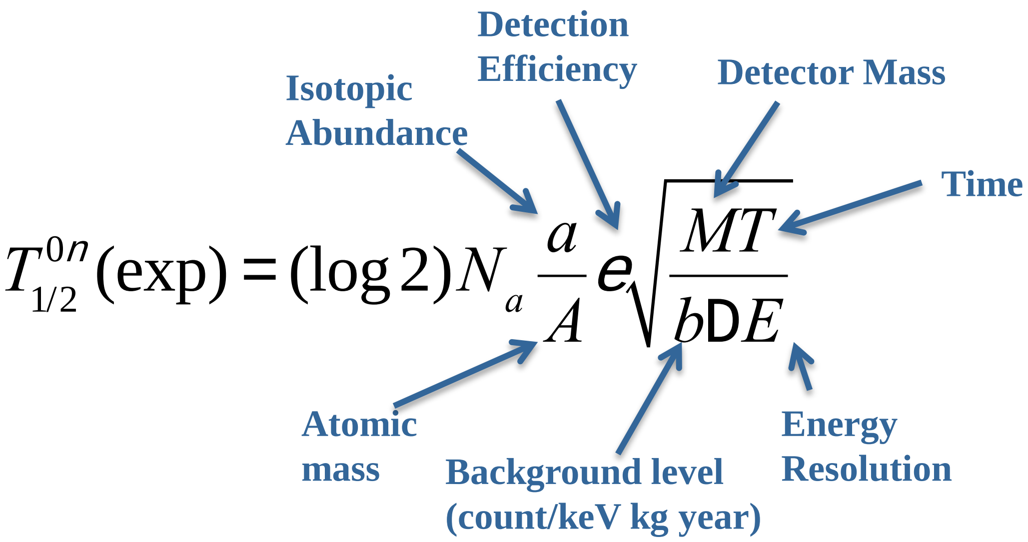


Candidate nuclei with Q>2 MeV

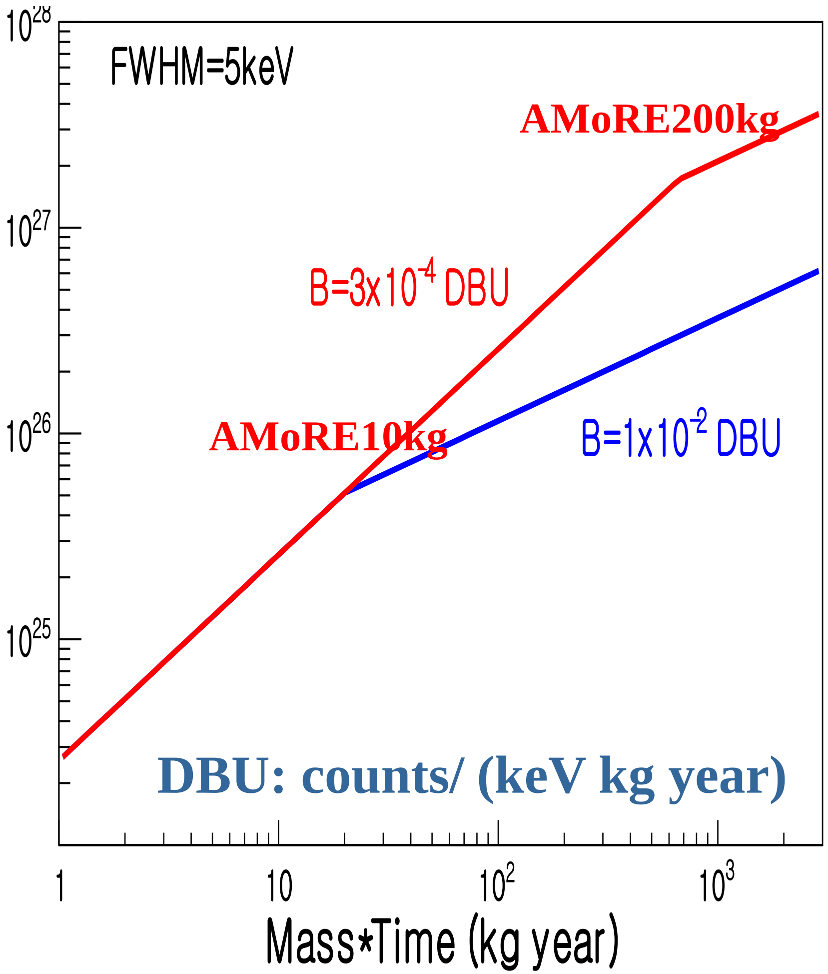
Candidate	Q (MeV)	Abund. (%)
$^{48}Ca \rightarrow {}^{48}Ti$	4.271	0.187
$^{76}Ge \rightarrow {}^{76}Se$	2.040	7.8
$^{82}Se \rightarrow {}^{82}Kr$	2.995	9.2
$^{96}Zr \rightarrow {}^{96}Mo$	3.350	2.8
$^{100}Mo \rightarrow {}^{100}Ru$	3.034	9.6
$^{110}Pd \rightarrow {}^{110}Cd$	2.013	11.8
$^{116}Cd \rightarrow {}^{116}Sn$	2.802	7.5
$^{124}Sn \rightarrow {}^{124}Te$	2.228	5.64
$^{130}Te \rightarrow {}^{130}Xe$	2.533	34.5
$^{136}Xe \rightarrow {}^{136}Ba$	2.479	8.9
$^{150}Nd \rightarrow {}^{150}Sm$	3.367	5.6

AMoRE Experimental sensitivity

For sizeable background case;



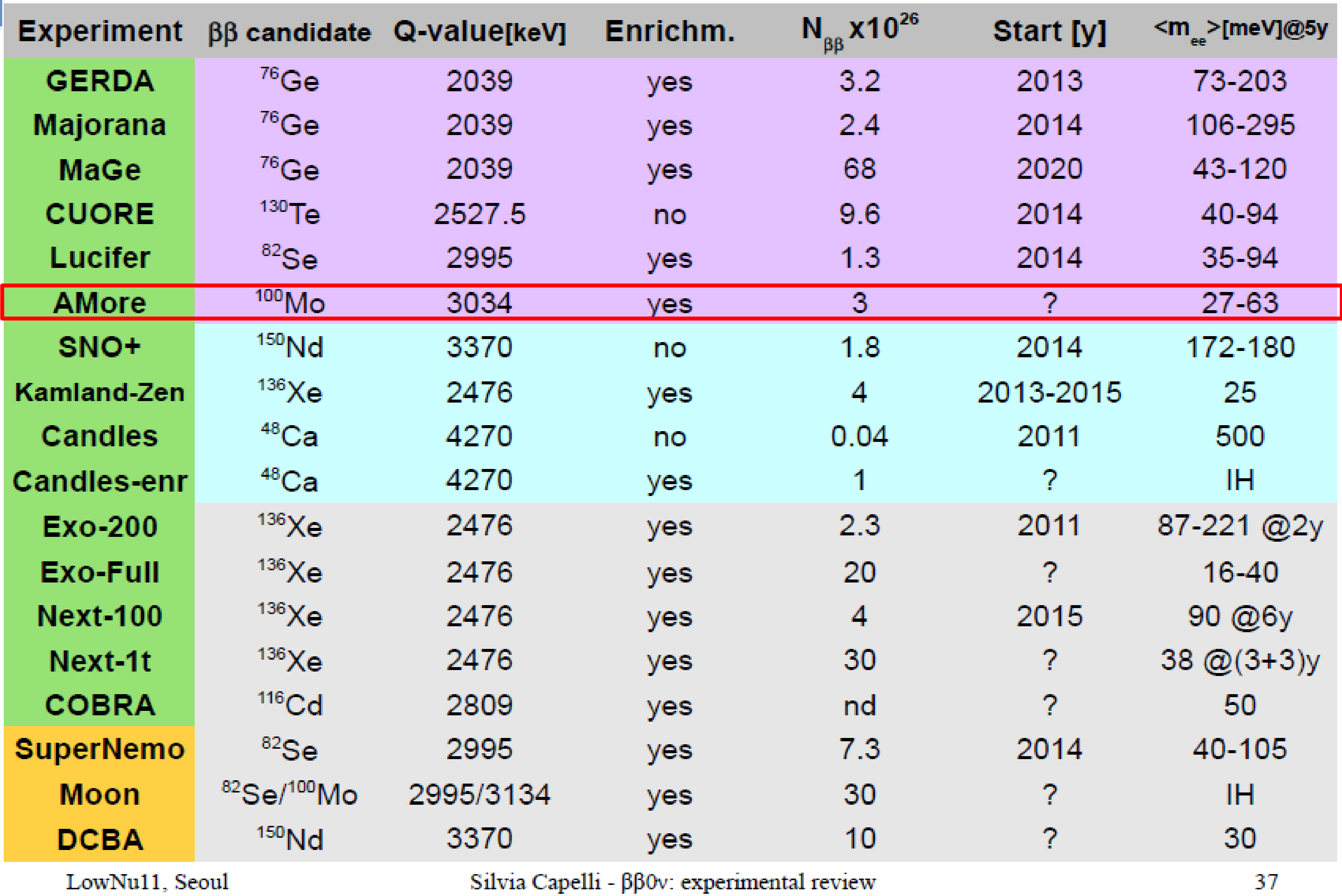
$$T_{1/2}^{0n}(\exp) = (\log 2) N_a \frac{a}{A} e \sqrt{\frac{MT}{b\mathrm{D}E}}$$



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

$$T_{1/2}^{0n}(\exp) = (\log 2) N_a \frac{a}{A} e \frac{MT}{n_{CL}}$$

AMoRE has one of best sensitive exps.



Experiment	ββ candidate	Q-value[keV]	Enrichm.	$N_{\beta\beta}$ x10^{26}	Start [y]	$<m_{ee}>$[meV]@5y
GERDA	^{76}Ge	2039	yes	3.2	2013	73-203
Majorana	^{76}Ge	2039	yes	2.4	2014	106-295
MaGe	^{76}Ge	2039	yes	68	2020	43-120
CUORE	^{130}Te	2527.5	no	9.6	2014	40-94
Lucifer	^{82}Se	2995	yes	1.3	2014	35-94
AMore	^{100}Mo	3034	yes	3	?	27-63
SNO+	^{150}Nd	3370	no	1.8	2014	172-180
Kamland-Zen	^{136}Xe	2476	yes	4	2013-2015	25
Candles	^{48}Ca	4270	no	0.04	2011	500
Candles-enr	^{48}Ca	4270	yes	1	?	IH
Exo-200	^{136}Xe	2476	yes	2.3	2011	87-221 @2y
Exo-Full	^{136}Xe	2476	yes	20	?	16-40
Next-100	^{136}Xe	2476	yes	4	2015	90 @6y
Next-1t	^{136}Xe	2476	yes	30	?	38 @(3+3)y
COBRA	^{116}Cd	2809	yes	nd	?	50
SuperNemo	^{82}Se	2995	yes	7.3	2014	40-105
Moon	^{82}Se/^{100}Mo	2995/3134	yes	30	?	IH
DCBA	^{150}Nd	3370	yes	10	?	30

LowNu11, Seoul

Silvia Capelli - ββ0ν: experimental review

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AMoRE Collaboration (June 2013)

- Korea (49)

  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(24)

  Kyungpook national University : H.J.Kim, J.So, Y.S.Hwang, J.Y.Lee, G. Rooh, S.Khan, L. Ali(7)

  Sejong University : Y.D.Kim, E.-J.Jeon, K. Ma, J.I.Lee, W.Kang, J.Hwa (5)

  Korea Research Institute of Standards and Science : Y.H.Kim, K.B. Lee, M.K. Lee, W.S. Yoon, H.J. Lee, S.J. Lee, Y.S. Jang, Y.N. Yuryev, H.S.Park, J.H.Kim, J.M.Lee (11)

  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)

- 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(11)

  INR(Institute for Nuclear Research) : F.Danevich, V.Tretyak, V.Kobychev, A.Nikolaiko, D.Poda, R.Boiko, R.Podviianiuk, S.Nagorny, O.Polischuk, V.Kudovbenko, D.Chernyak(11)

- China(3)

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

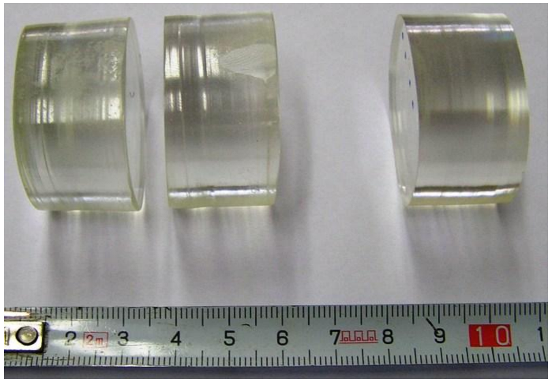
- Germany(3)

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

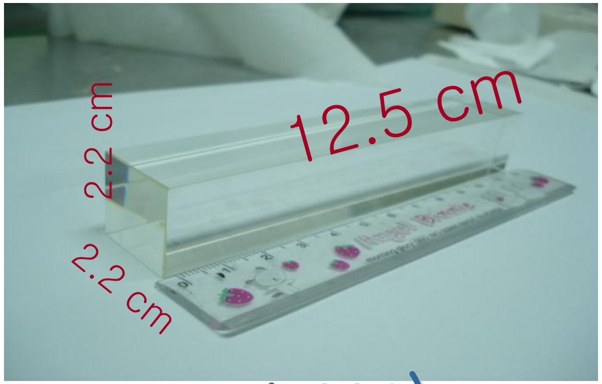
5 countries
13 institutions
84 collaborators

$CaMoO_4$ crystal development

Korea(2003)

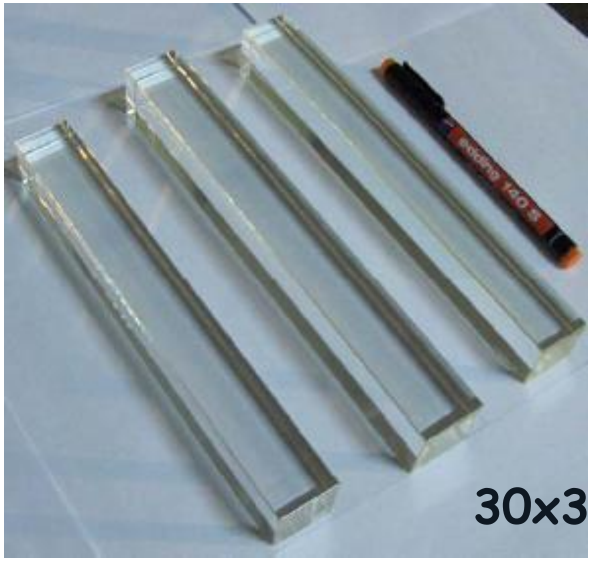


Ukraine-CARAT(2006)



Russia(2006)

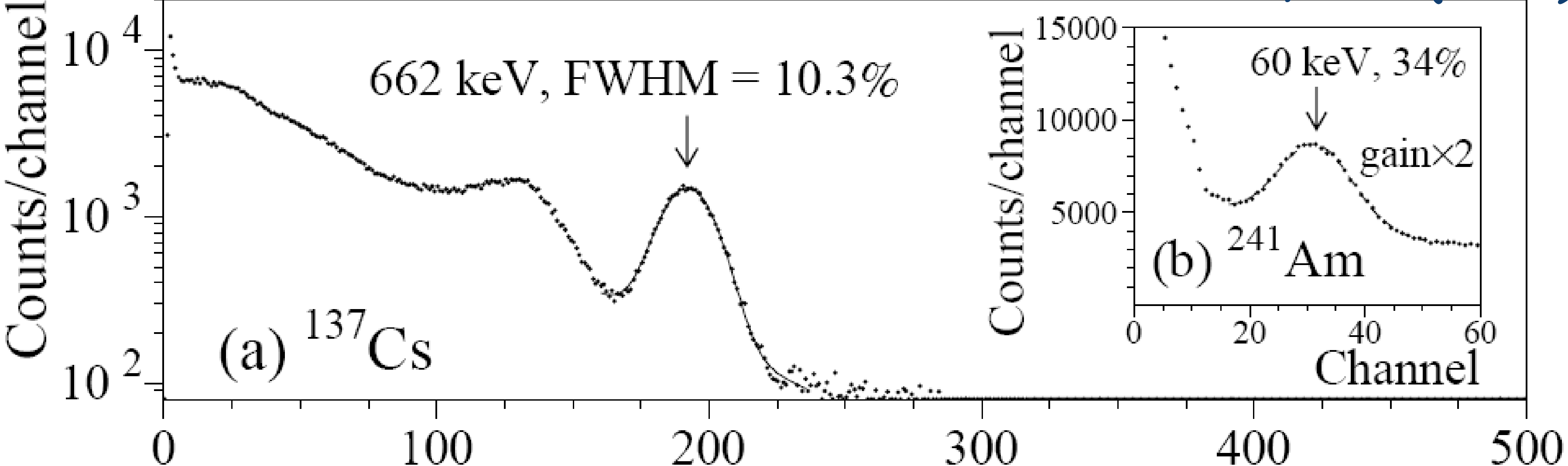
IEEE/TNS 2008

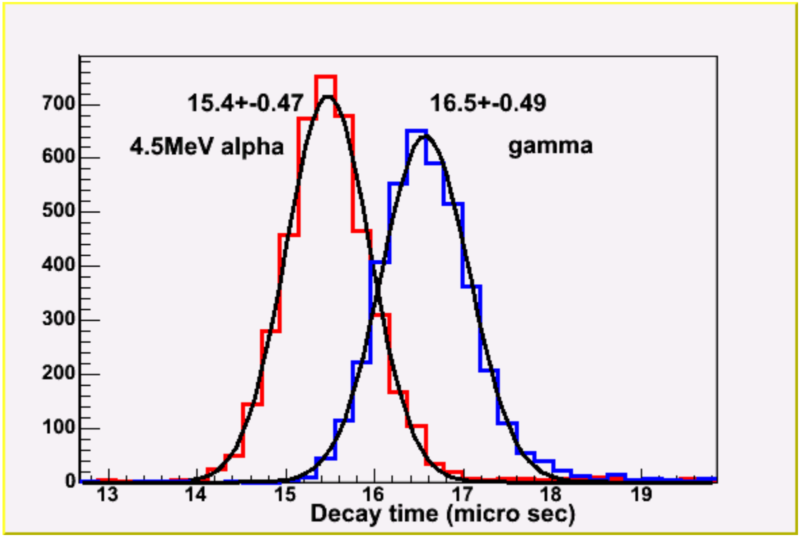


30x30x200mm

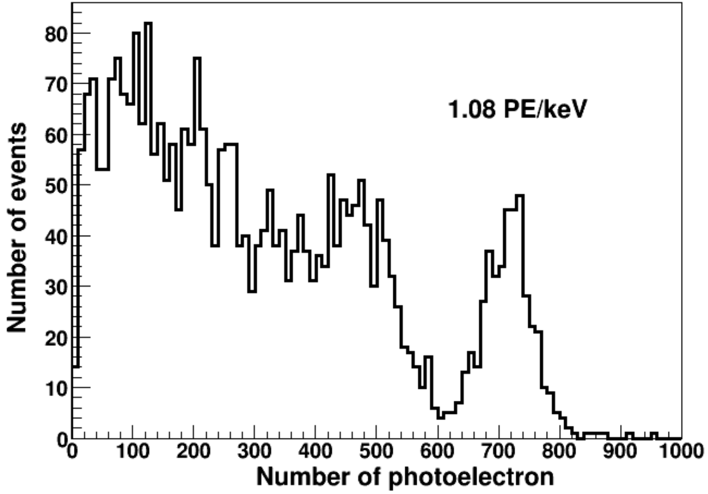
CaMoO$_4$ Characterization:

NIMA 584, 334 (2008)





IEEE TNS 57 (2010) 1475



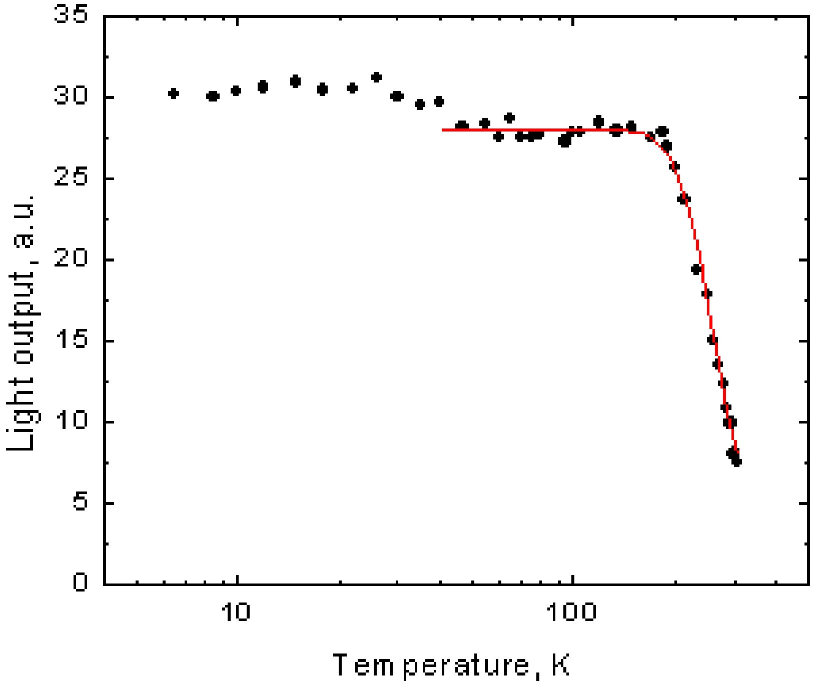
4% FWHM at 3 MeV

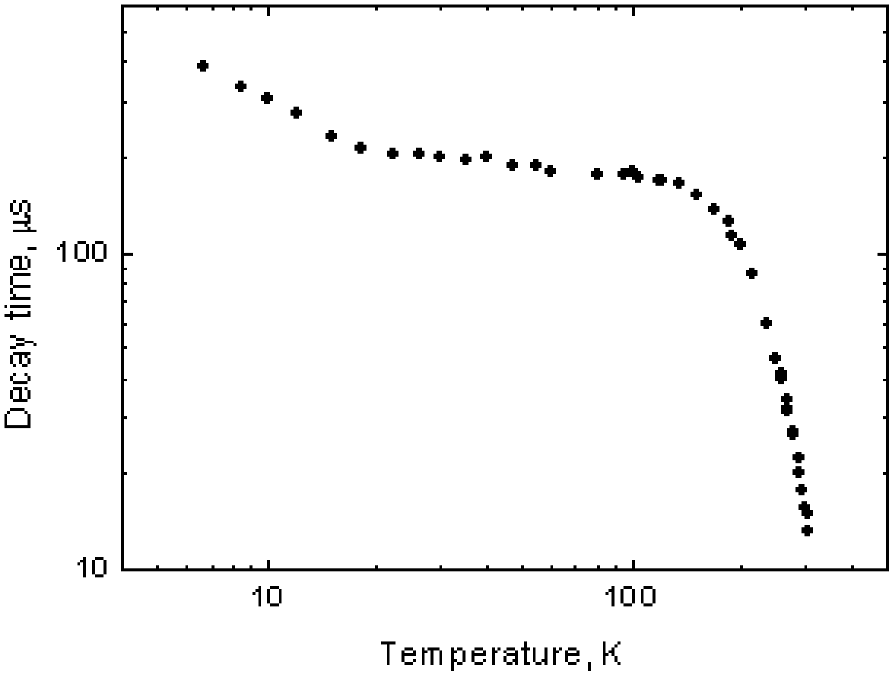
Only with photoelectron statistics

Temperature dependence of $CaMoO_4$

From RT to 7K, light yield increase factor 6

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





CMO absolute light yield @RT: 4900+-590 ph/MeV

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

-> Light yield at cryogenic temp. : ~ 30,000 ph/MeV

-> Highest light yield among Mo contained crystals.

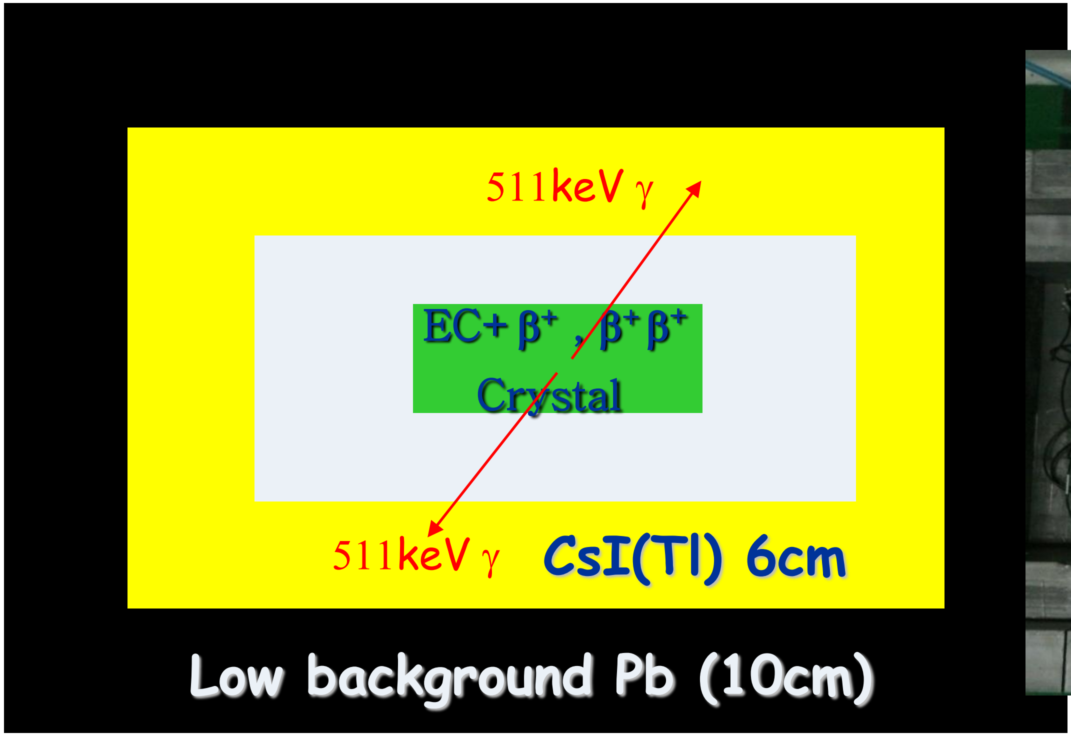
4π CsI(Tl) active setup with Pb shielding at Y2L

1) 2ν EC+ β^+ , $\beta^+\beta^+$ study with 2 back to back γ tagging

(1) Sr-84 : $SrCl_2$ (4.6×10^{17} yr by 90%CL)

(2) Mo-92 : $CaMoO_4$ (2.3×10^{20} yr NIMA 654, 157 (2011))

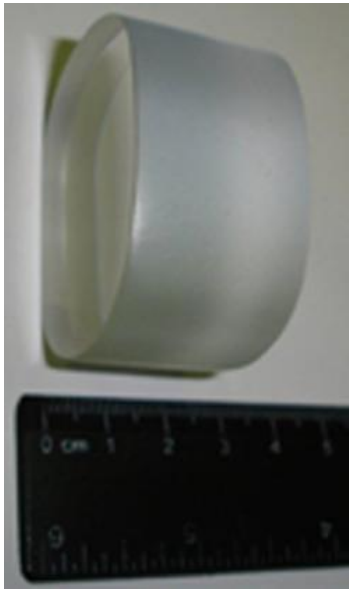
2) CMO internal background study with active veto



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

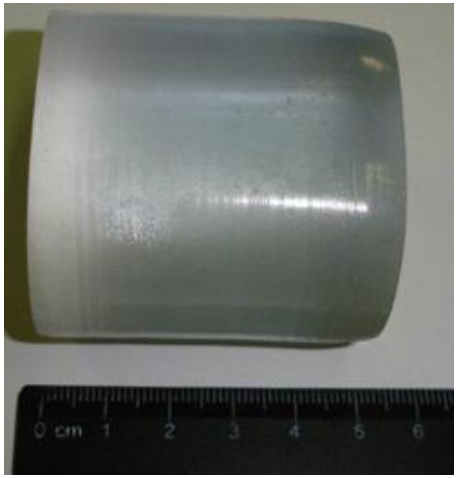
- **SB28**

weight 196 g



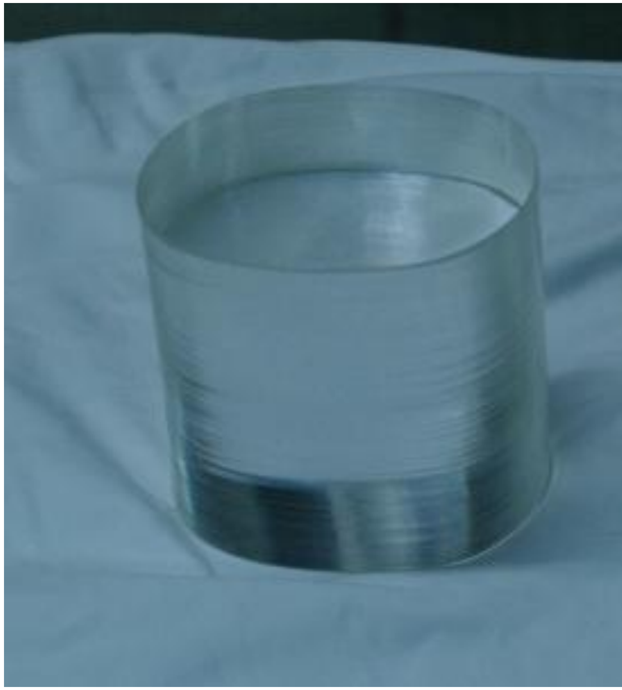
- **SB29**

weight 390 g



- **S35**

weight ~300 g



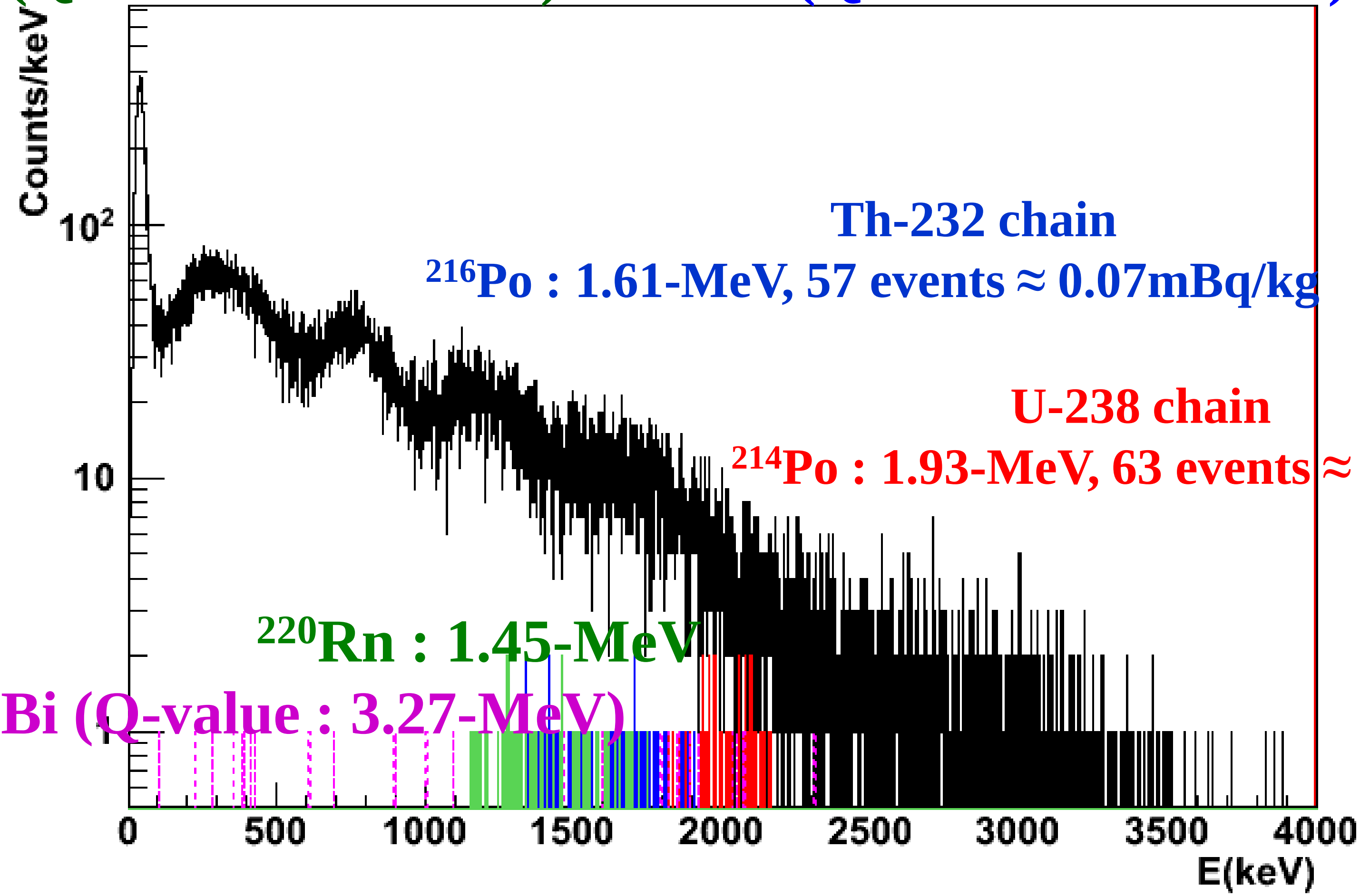
Background spectra of SB28

$\beta-\alpha$ decay in ^{238}U

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

$\alpha-\alpha$ decay in ^{232}Th

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



Th-232 chain

^{216}Po : 1.61-MeV, 57 events ≈ 0.07mBq/kg

U-238 chain

^{214}Po : 1.93-MeV, 63 events ≈ 0.08mBq/kg

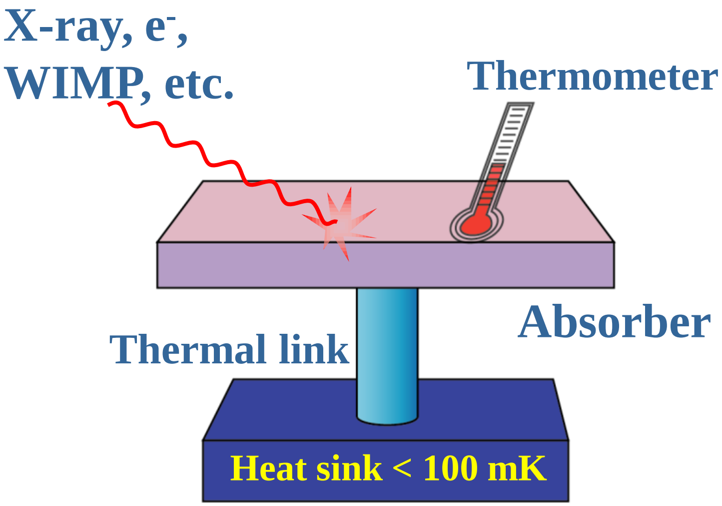
^{220}Rn : 1.45-MeV

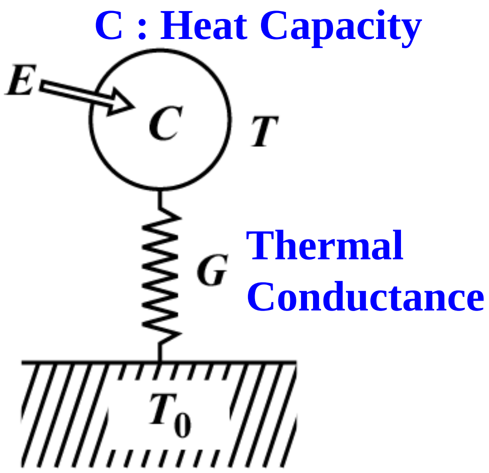
^{214}Bi (Q-value : 3.27-MeV)

Basic idea of Low Temperature Detectors

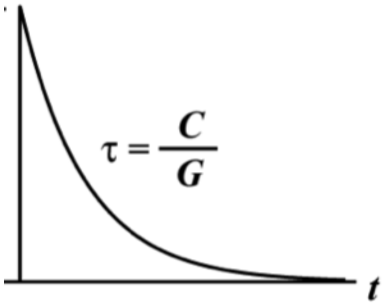
We want to use bolometer technique to increase the sensitivity of 0νββ search with CMO crystal.

Energy absorption ➔ Temperature increase





$$T - T_0 = \frac{E}{C} e^{- t/t}$$



Total deposited energy measured → Ultimate energy resolution.

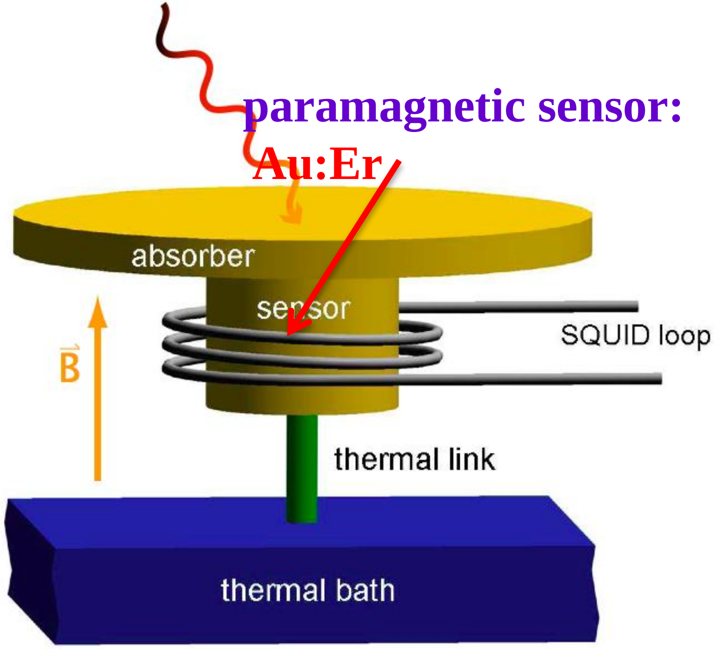
MMC (Metallic Magnetic Calorimeter) for LTD

Principle of operation

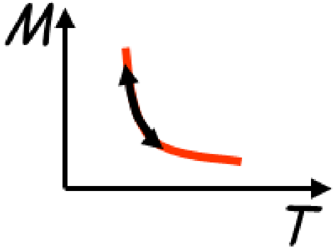
1. Energy absorption in CMO crystal.
2. Phonon & Photon generation.
3. Temperature increase (gold film).
4. Magnetization of MMC decrease.
5. SQUID pickup the change.

Advantage of MMC

- Fast rising signal. (critical for lower 2νββ random coincidence.)
- Fairly easy to attach to absorber.
- Excellent Energy resolution

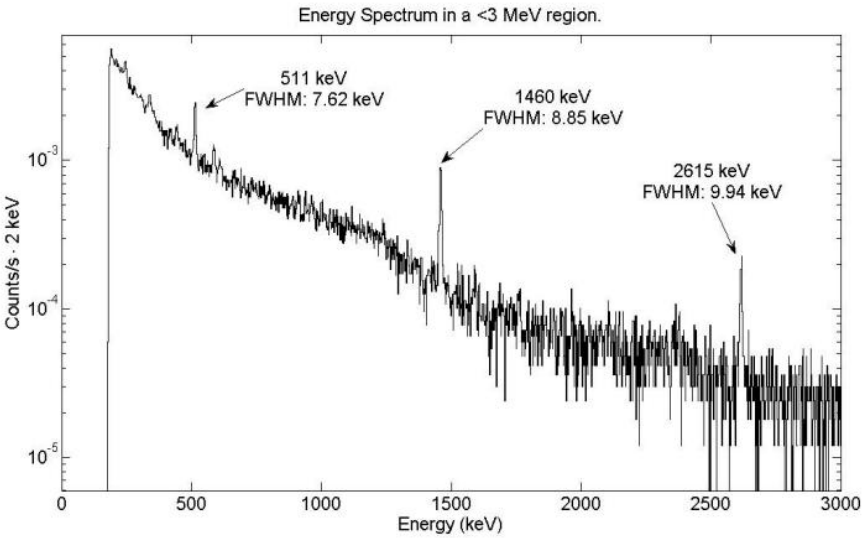


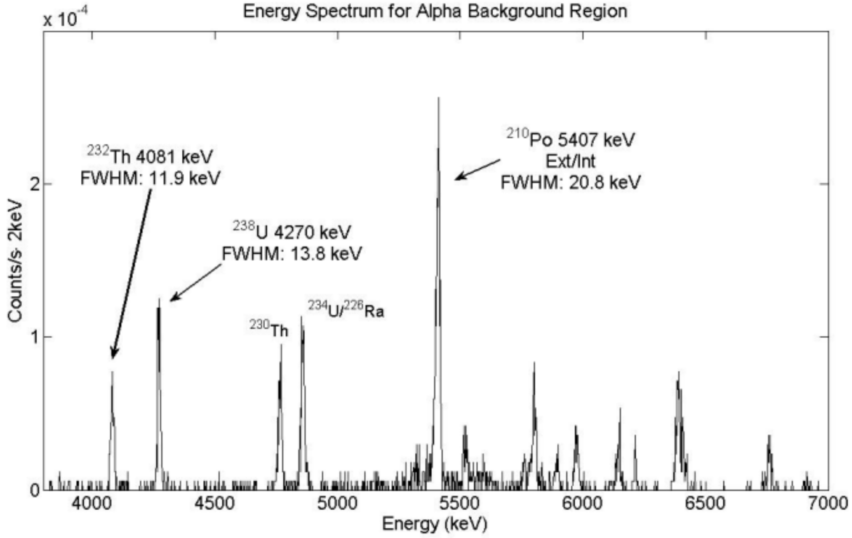
paramagnetic sensor: Au:Er



Large CMO crystal (216 g) was tested

Energy Resolution





- 194 hour measurement at the overground laboratory (KRISS).

	1461 keV	2615 keV
FWHM (keV)	8.85 ± 0.62	9.94 ± 1.28

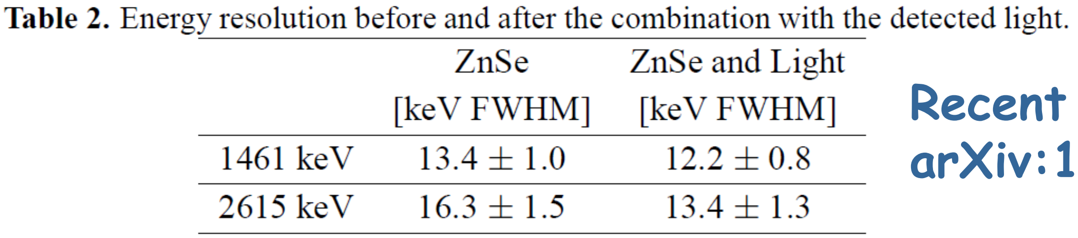
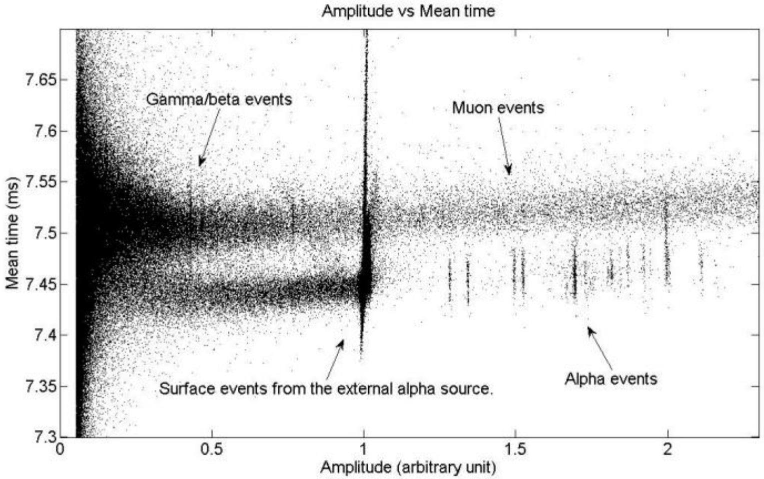


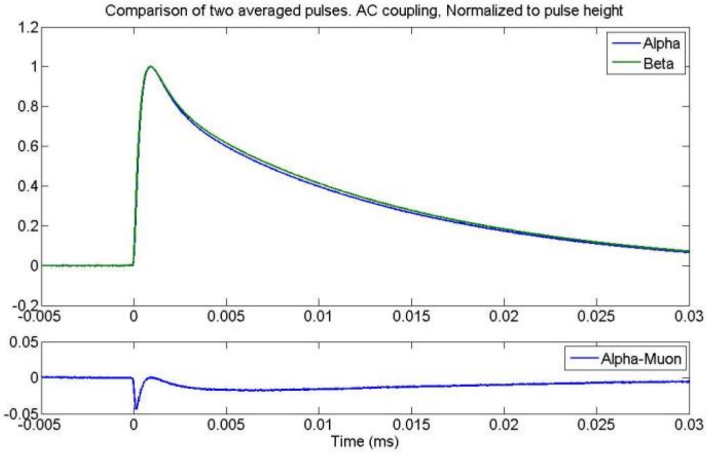
Table 2. Energy resolution before and after the combination with the detected light.

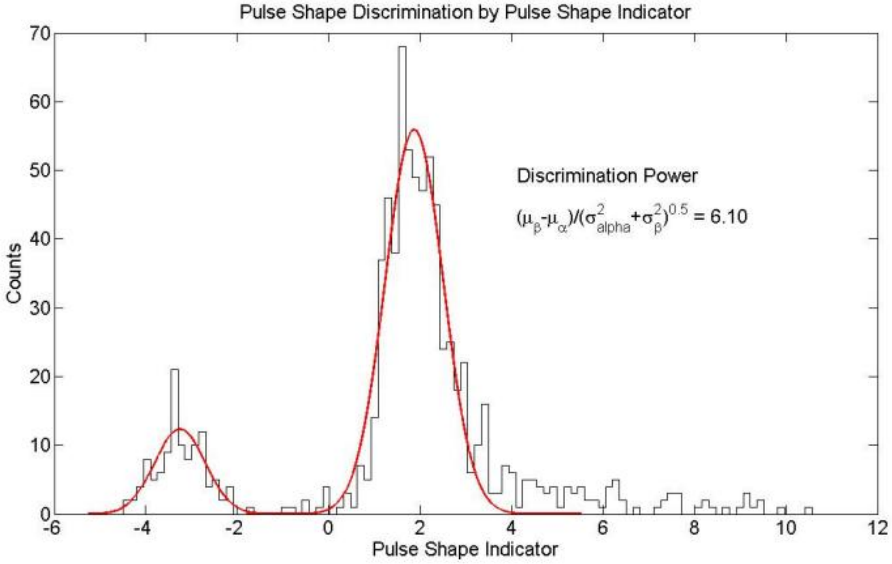
	ZnSe [keV FWHM]	ZnSe and Light [keV FWHM]
1461 keV	13.4 ± 1.0	12.2 ± 0.8
2615 keV	16.3 ± 1.5	13.4 ± 1.3

Recent R&D result of Lucifer group.
arXiv:1303.4080v1

Pulse shape discrimination capability

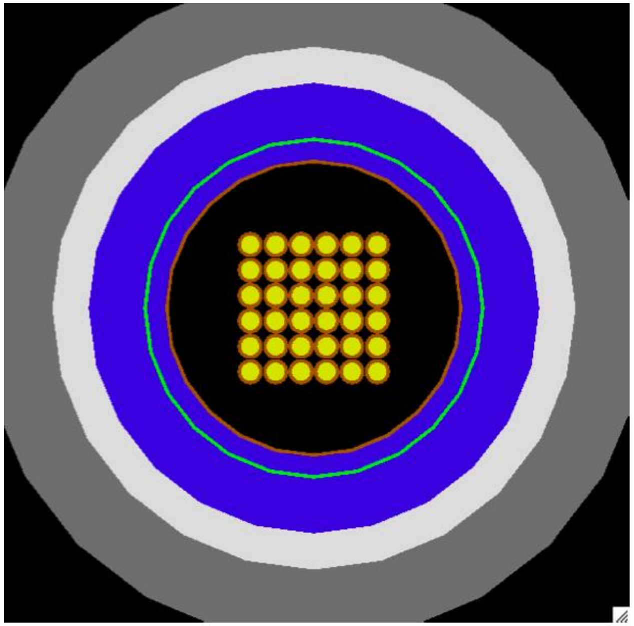


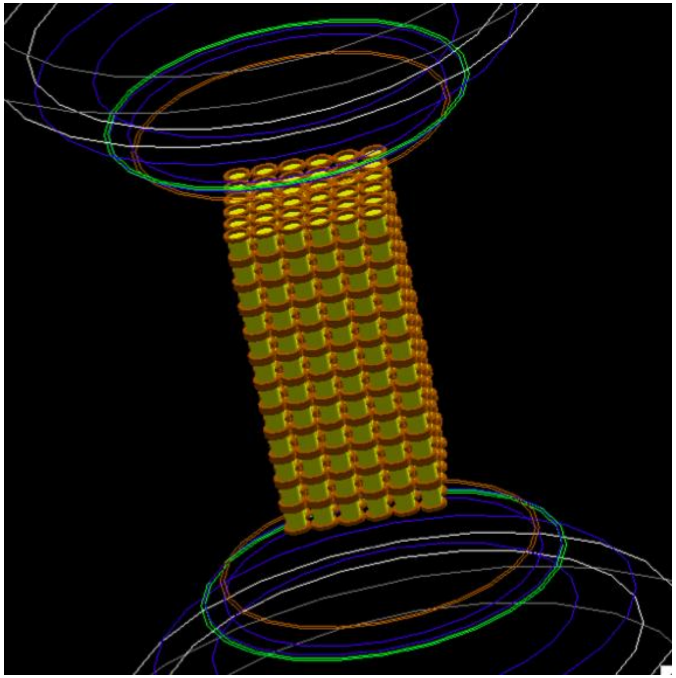




1. **α/β events show different pulse shapes (FOM=6).**
2. **Light sensor study is under way (better α/β separation)**

GEANT4 Simulation of for AMoRE @ Y2L





Shielding
20cm PE +
10cm Scin +
15cm Pb +
1cm Al + 5cm Pb +
1cm Cu+

- **CaMoO4**
  ^{40}Ca 100%, ^{100}Mo 100%
  cell size: D(5cm)xH(5cm) 0.426kg
  Total 432 (6 x 6 x 12 array) 184kg
- **CaMoO4 support : Cu (1cm, ring structure)**

Simulation study of material backgrounds

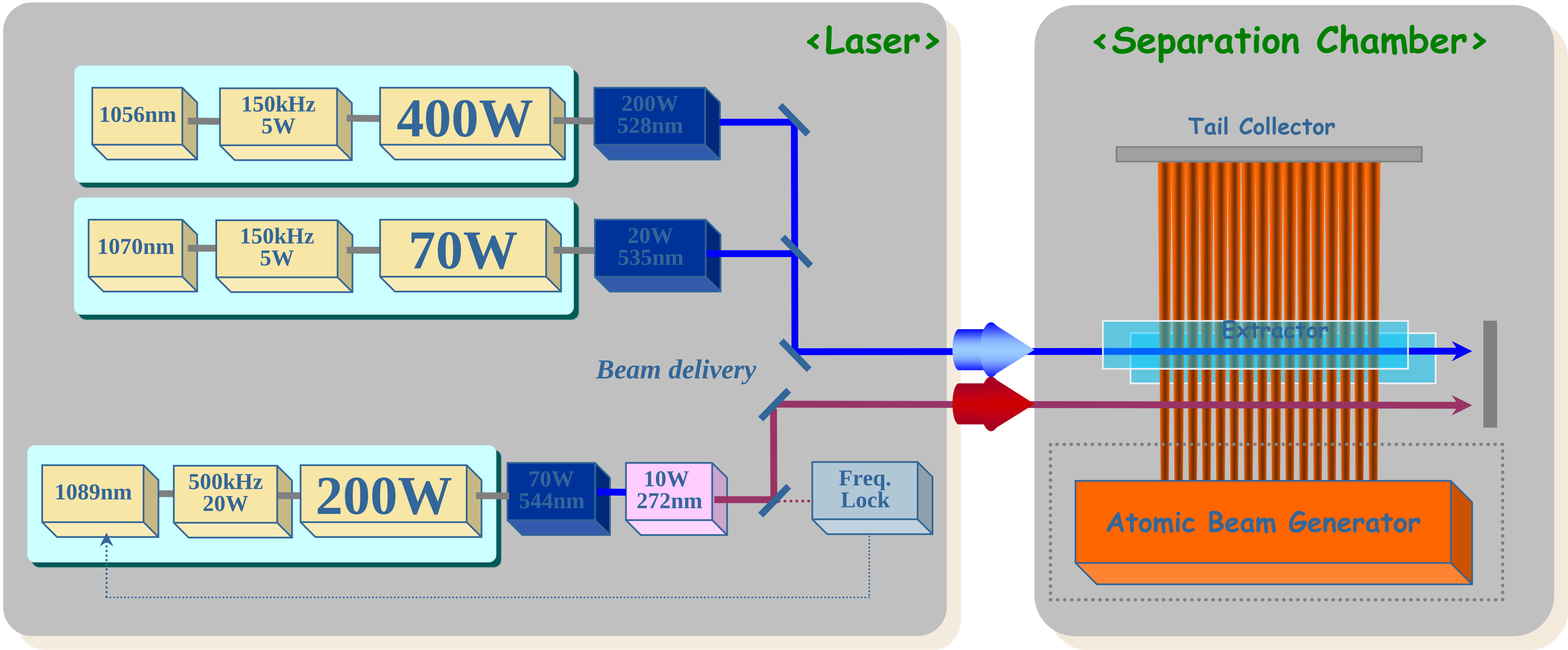
Background source	Activity [μBq/kg]	Background [10^{-4} DBU]	Anti-Coincidence Reduction factor
^{208}Tl, internal	10	0.36	5
^{208}Tl, in copper	16	0.22	4
^{212}BiPo, internal	10	0.08	1.2
^{212}BiPo, in copper	16	0.36	1.1
^{214}BiPo, internal	10	0.11	2.4
^{214}BiPo, in copper	60	1.8*	2
^{88}Y, internal	20	0.19	2.3
Random pileups from 2ν2β	**2.6×10^{3}**	**1.2**	**1**
Total		4.3	

*** Can be reduced further by teflon coating on the Cu surface.**

^{48}Ca Enrichment/Depletion at KAERI (Korea Atomic Energy Research Institute)

- ALSIS (Advanced Laser Stable Isotope Separation)

-> AMoRE-Ca (^{48}CaMoO4 crystal) for ^{48}Ca 0-DB search Possible



AMoRE Summary and Prospect

- Large volume of low background $^{40}Ca^{100}MoO4$ have been developed and characterized.
- Cryogenic MMC technique with CMO is successful.
- CUNPA got funded (AMoRE project included).
- AMoRE-10kg will be constructed in 3 years.
- If Phase-I is successful, we will move to Phase-II and explore neutrino mass of 20-50 meV region.

	Phase I	Phase II
Mass	10kg	200kg
Background (keV kg year)$^{-1}$	10^{-3}	10^{-4}
Sensitivity (m_{ee}) (meV)	80–250	20–50
Schedule	2015–2016	2017–2019

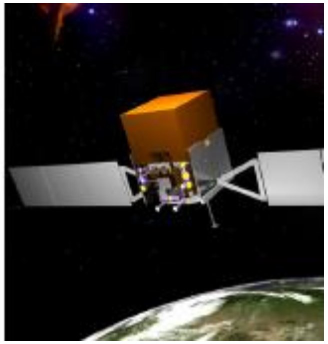

Thank you for Attention

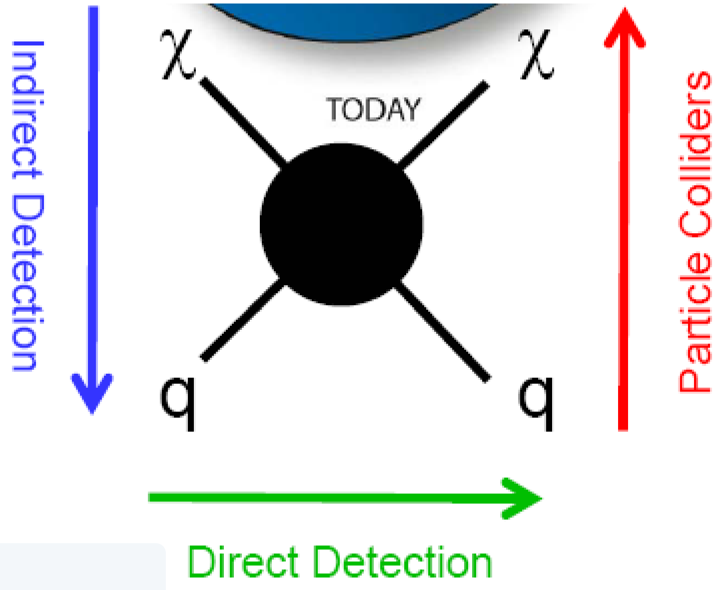
WIMP Searches

1) Indirect Search
   - Detect secondary particle (neutrino, electron, positron, gamma…) produced by annihilation of WIMPs
   - Space, Ground, Underground experiment

2) Direct Search : Detect elastic WIMP scattering at underground

3) Search at Collider experiment : LHC





Y2L(YangYang Lab) 10th year (2003-2012)

2000 @ CPL, began in the vinyl room

Year 2013 is the 11th year of Y2L.
We have running Y2L for 10 years.

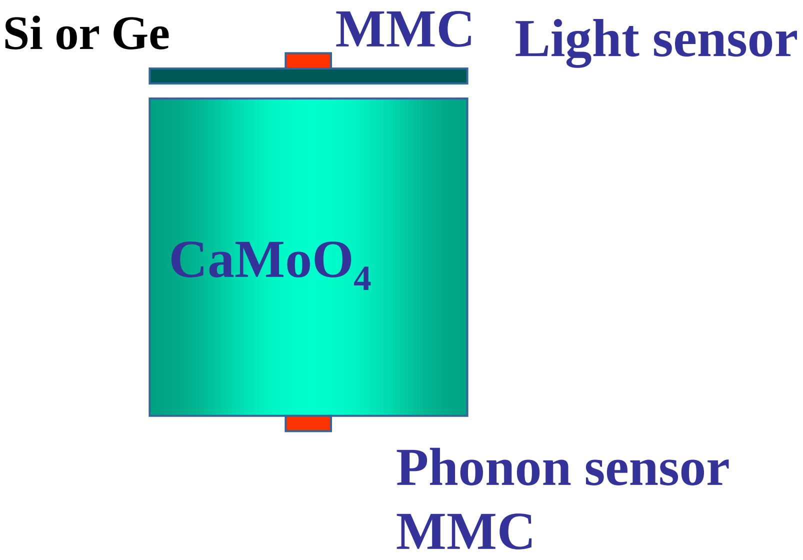
1st installation of shielding for KIMS experiment.

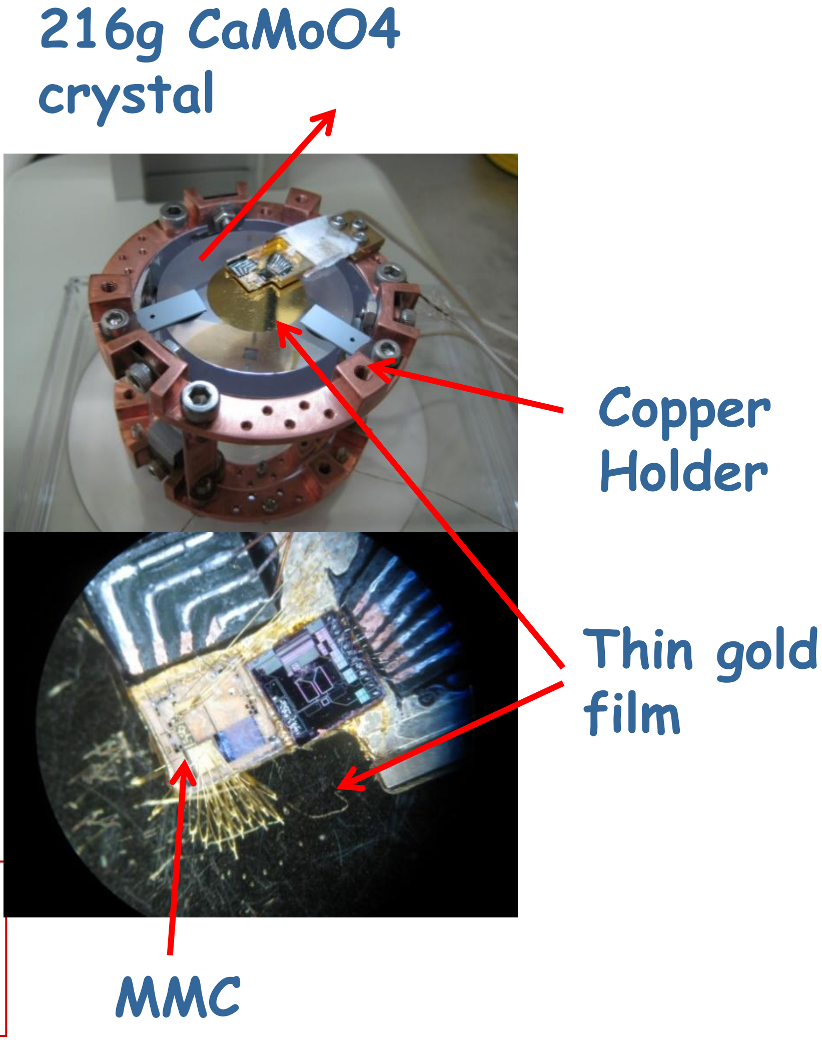

2003.2.27

Detection scheme for the AMoRE Project

CMO ($^{40}Ca^{100}MoO_4$)

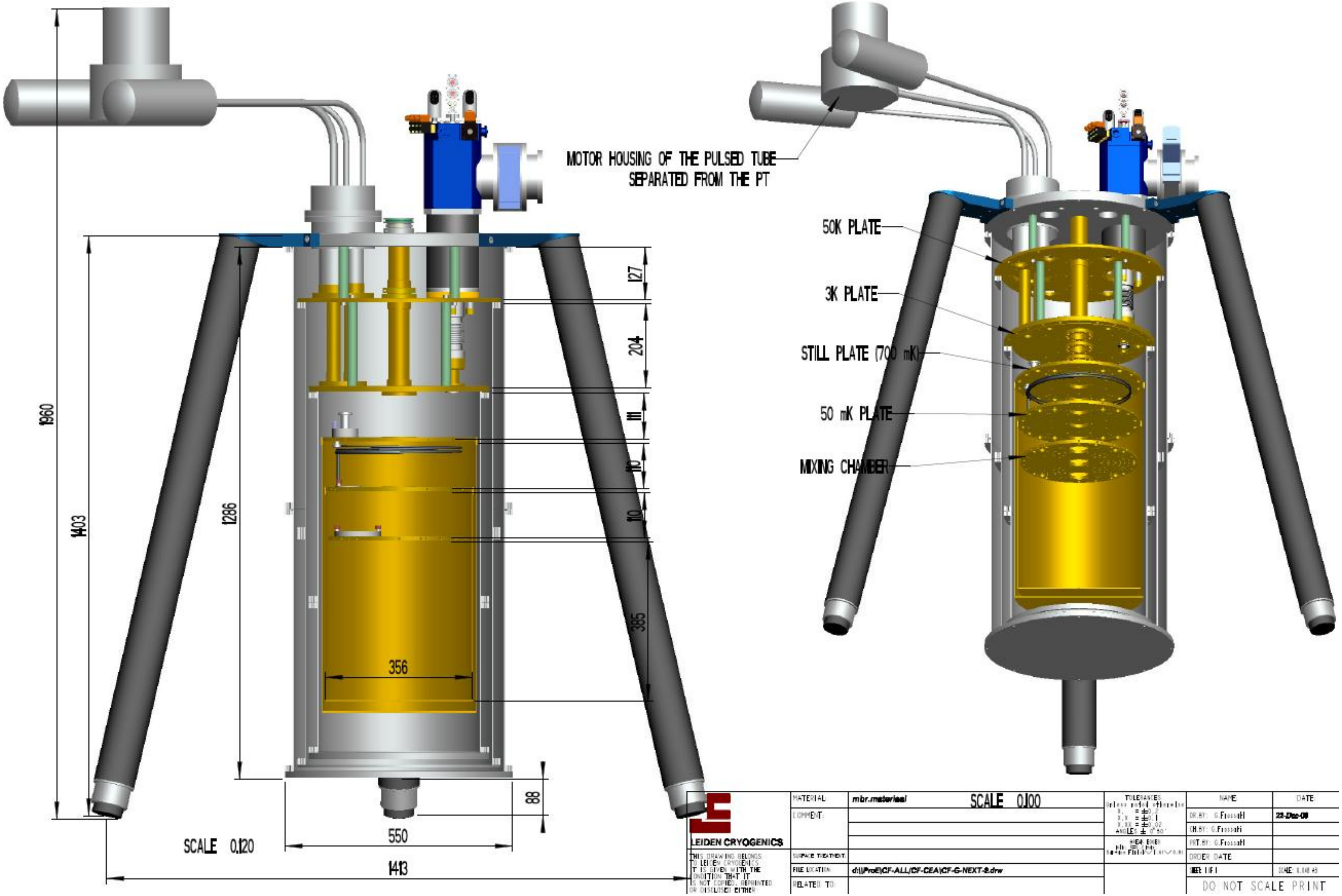
- Scintillating crystal
- High Debye temperature: T_D = 438 K,



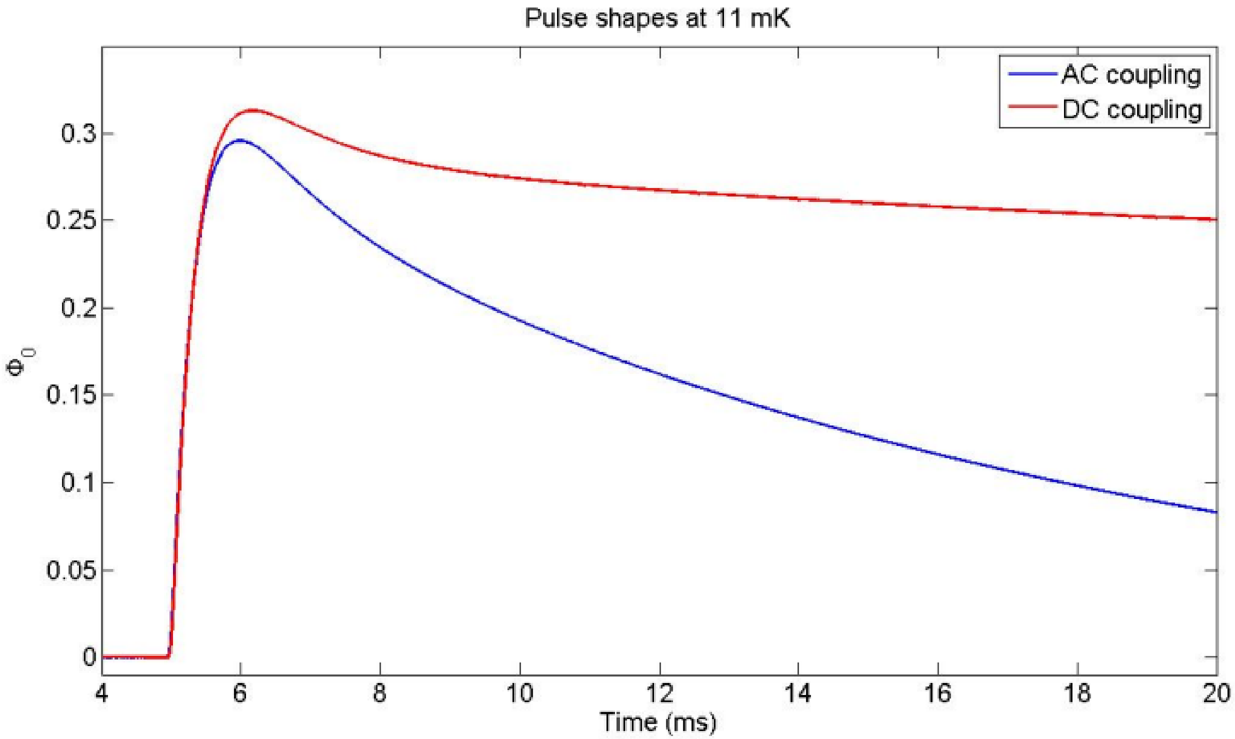


Two detection channels : phonon + light
-> alpha induced background rejection

Dilution refrigerator for AMoRE-10



Pulse shape



- Signals showed 0.5 ms rise-time at 30 mK.
- Fast rise-time is quite important for $2\nu\beta\beta$ random coincidence rejection.
- Faster rise-time than bolometer technique (factor 10)

B.A. Barabash, J. Phys. G: Nucl. Part. Phys. 39(2012)085103

Isotope enrichment Price Level

Isotope	Criteria for the Best 0νββ Isotope						0νββ Project
	$Q_{\beta\beta}$ (MeV)	$G_{0\nu}$ (y^{-1})	$T^{2\nu\beta\beta}_{1/2}$ (10^{20} y)	Isotope Enrichment			
				Abundance (%)	Method	**Price Level**	
^{130}Te	2.533	1.70	6.8	33.8 → 95	GC	0.3	CUORE
^{136}Xe	2.462	1.81		8.9 → 90	GC	0.2	EXO
^{76}Ge	2.039	0.24	15	7.8 → 90	GC	1 ($80/g)	GERDA MAJORANA
^{82}Se	2.995	1.08	0.92	9.2 → 90	GC	1.5	SuperNEMO
^{100}Mo	3.034	1.75	0.07	9.6 → 90	GC	1	AMORE
^{116}Cd	2.802	1.89	0.28	7.5 → 90	GC	2.5	
^{48}Ca	4.274	2.44	0.44	0.187 → 25	EMIS ALSIS	160 < 5	CANDLES
^{150}Nd	3.667	8.00	0.08	5.6 → 90	EMIS	170	
^{96}Zr	3.350	2.24	0.23	2.8 → 60	EMIS	400	-

Production capacity of Mo-100 at the ECP

The ECP (Electrochemical plant) Zelenogorsk, Russia
Current capacity is 0,6 kg of Mo-100/month (7-8 kg/ year).

The working gas for Moly enrichment (MoF6) is extremely corrosive: once a machine is dedicated to Moly enrichment, there is no going back. You simply scrap the machine when the program is completed.

We received preliminary assurances that a scale-up of current production is planned because of worldwide shortage of Mo-99 for Tc99m generator production.

New proved technology: production of Mo-99 in the activation reaction:

98Mo(n,g)99Mo (reactor) and 100Mo(gamma,n)99Mo (e-linac)

As result, new productivity will be about 2,4 kg of Mo-100 per month
~ 28 kg per year

=> Is it possible to produce in China?

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

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

- $^{100}MoO_3$ oxide with mass of Mo–100 : 2,5 kg

Enrichment: Mo–100 = 96,1%

Impurities (the results from ICP MS measurements):

U <= 0.00007 ppm (< 0,07 ppb) and <= 0.0002 ppm (< 0,2 ppb)
Th <= 0.0001 ppm (< 0,1 ppb) and <= 0.0007 ppm (< 0,7 ppb)
^{226}Ra < 2,3 mBq/kg, ^{228}Ac < 3,8 mBq/kg

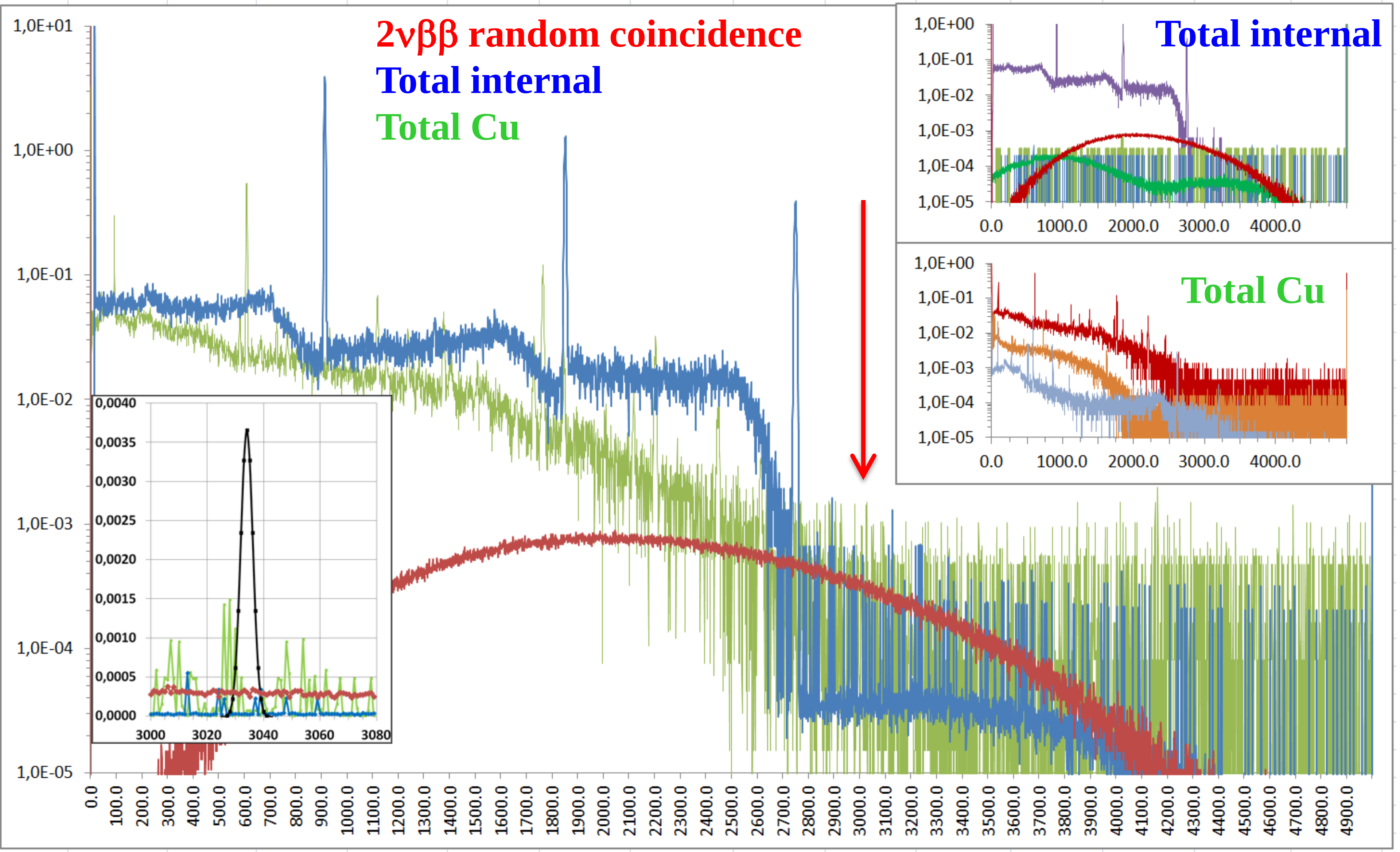
Current capacity is 0,6 kg of Mo–100 per month (7–8 kg per year).

The industrial separator SU20
Lesnoy, Sverdlovky region

27 kg of Ca–40 ($^{40}CaCO_3$) is available now at EKP, Lesnoy

Ca–48 < 0,001%

Plots for all material backgrounds



Dark matter sensitivity of CaMoO$_4$ cryogenic experiment

— CaMoO$_4$

— CDMS 2008

- - - SuperCDMS 25kg

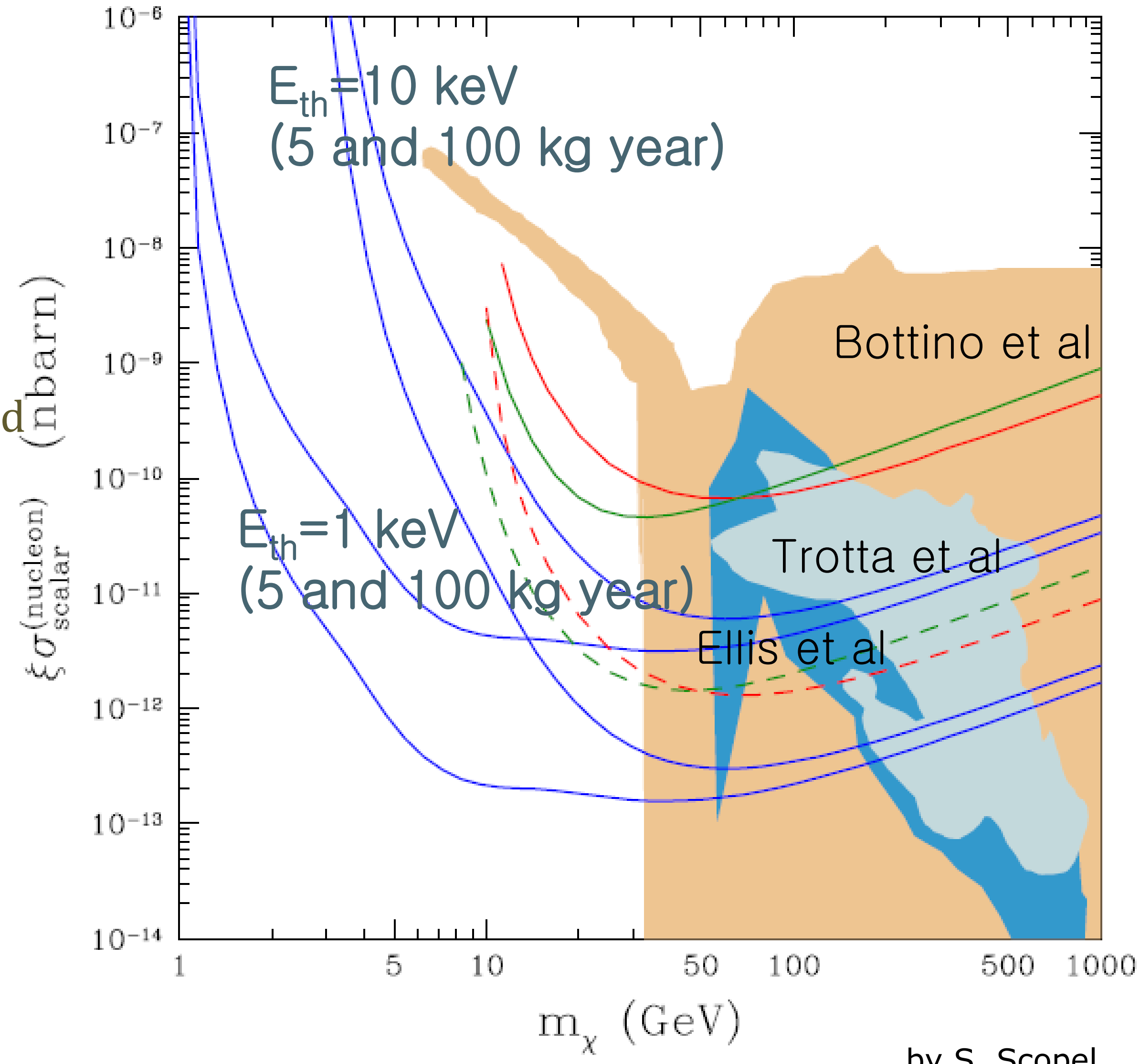
— XENON10 2007

- - - XENON100 6000 kgd

🟧 CMSSM, Ellis et al

🟦 CMSSM, Markov chain Trotta et al

🟩 Effective MSSM, Bottino et al



by S. Scopel