NDM12@Nara

MOON
(Mo Observatory Of Neutrinos)

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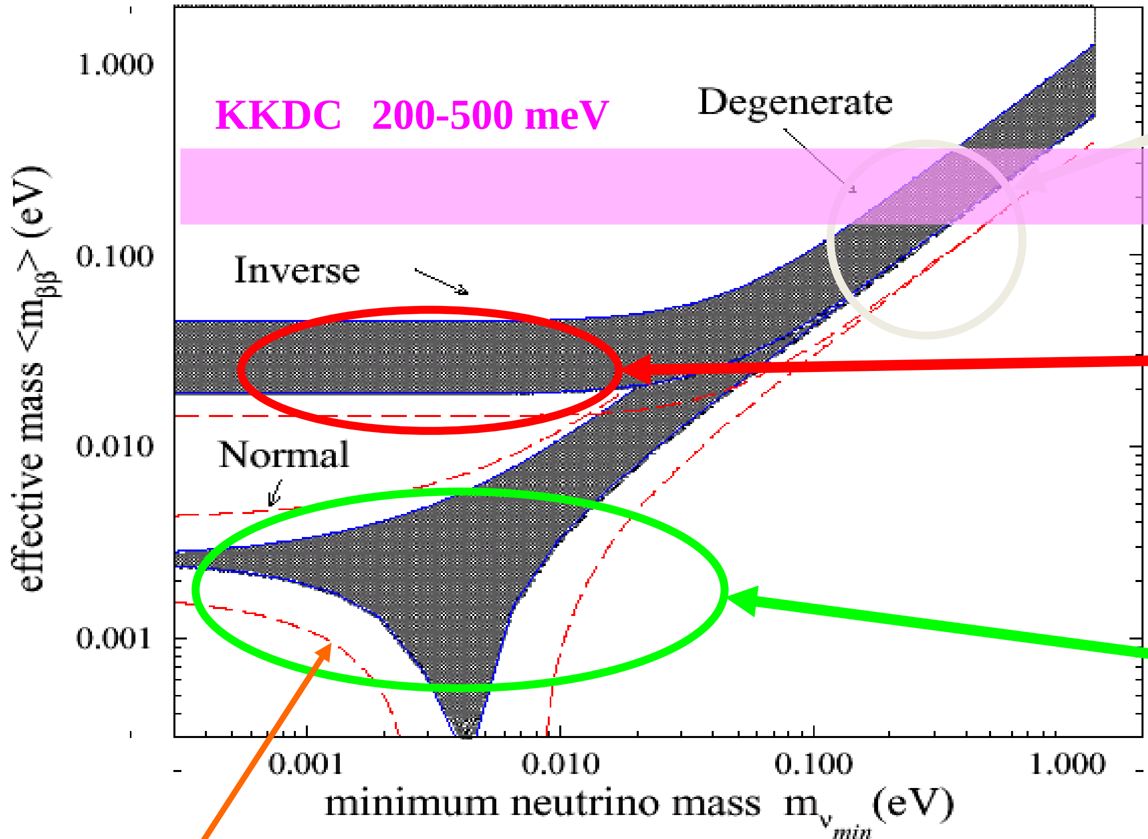
for the MOON Collaboration

- Objectives/Features of MOON
- Several Detector Options
- R&D, Expected Sensitivity

H. Ejiri et al., PRL 85 (2000) 2917
H. Ejiri, Czeck. J. Physics, 56 (2006) No.5, 459
H. Ejiri et al., Eur. Phys. J. Special Topics 162 (2008) 239

MOON Objective

～*Goal of next-generation DBD experiments*～



QD: 100~200 meV

IH: 50~25 meV

Next-generation:

Super-NEMO, MOON

NH: 4~2 meV

Future experiment

$\theta_{13}{}^{2}$

- Challenge to 30 meV :$T_{1/2}$≈10^{27} years (several decays/ton/year)
- Require a few tons of ^{100}Mo
- 1 ton in 40 mg/cm² foil 2500 m² or 50m x 50m

Experimental techniques

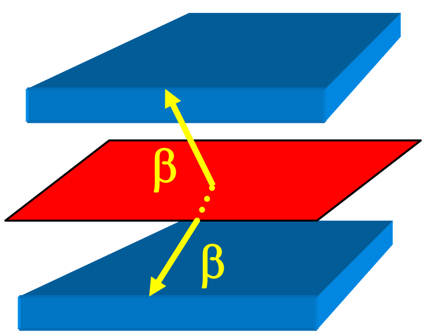
With background:

$$T^{0\nu}_{1/2}(y) > \frac{\ln 2 \,.\, \mathcal{N}}{k_{C.L.}} \cdot \frac{\varepsilon}{A} \cdot \sqrt{\frac{M \;.\; t}{N_{BG} \,.\, \Delta E}}$$

M: masse (g)
ε : efficiency
$K_{C.L.}$: Confidence level
$\mathcal{N}$: Avogadro number
t: time (y)
N_{BG}: Background events ($keV^{-1}.g^{-1}.y^{-1}$)
Δ**E**: energy resolution (keV)

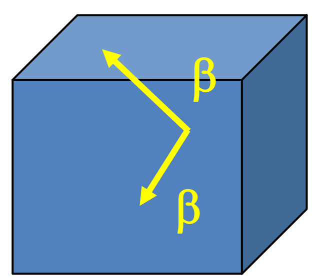
Today, no technique able to optimize all the parameters

Track-calo
Source ≠ detector



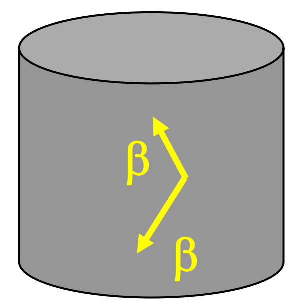
N_{BG}, isotope choice

Calorimeter
(Loaded) Scintillator
Source = detector



ε, M

Calorimeter
Semi-conductors
Source = detector



ε, ΔE

Spectroscopic detectors

ELEGANT- MOON,
DCBA
NEMOIII - Super NEMO

1. E_{12}-Θ_{12} identify m_ν term

2. Detector ≠ source
   Select ββ nuclide by
   $Q_{\beta\beta}$, Z, Enrichment, 2νββ

3. Small RI-BG :E(RI) < $Q_{\beta\beta}$
   β/α,γ separation

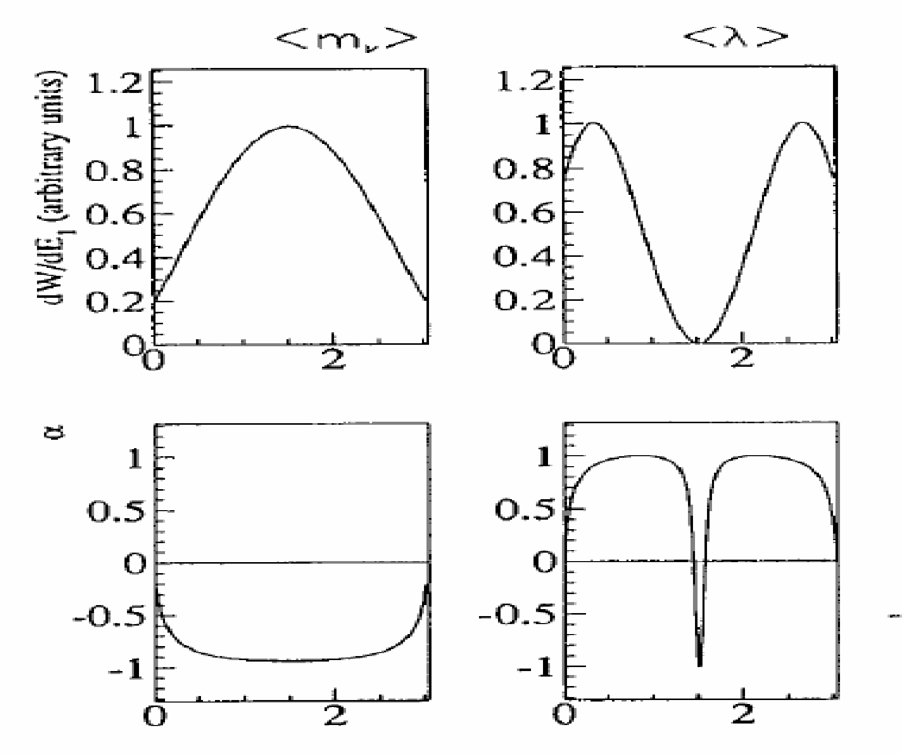


Fig. 4. Energy and angular correlations for the
caused by the mass and right-handed current term
Top: Calculated single-β spectra. Bottom: β_1 —
coefficients α defined by $W(\theta_{12}) = 1 + \alpha \cos\theta_{12}$.[4)]

Major BG : 2νββ tail in oνββ window. **E-resolution** !

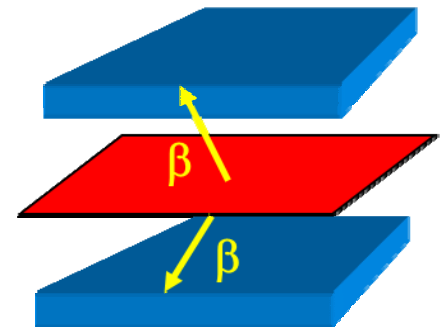
Estimated background rates ; summary

Background source	Rate [/ton/yr]
^{208}Tl β-γ-γ in source	<~0.6
^{214}Bi β-γ in source	~0.1
^{214}Bi β ($1^- \rightarrow 0^+$)	<0.01
Two external 2614keV γs acc. coin. (for 0.1Bq/kg ^{232}Th)	~0.03
Neutron-induced γ	0.2~1
^{100}Mo $2\nu\beta\beta$ (FWHM=5%)	4.1
Total	~6

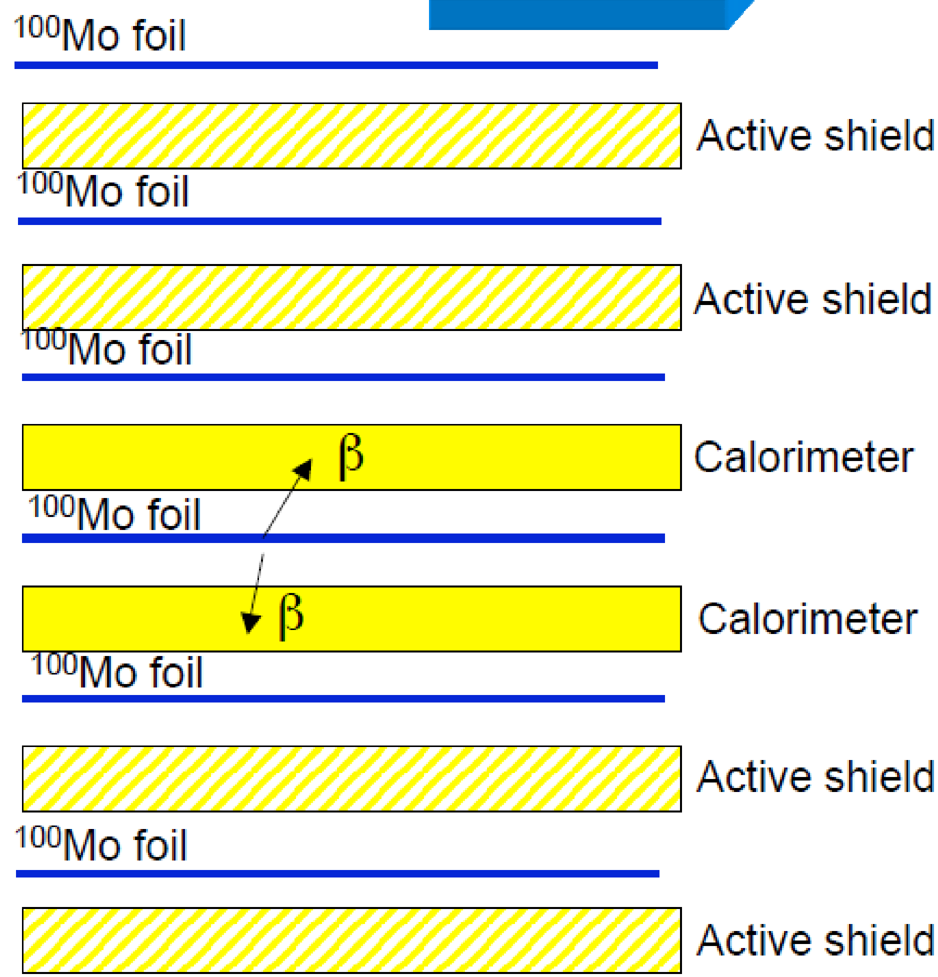
T. Shima et al., J. Phys: Conf.120 (2008) 052055

MOON-1 detector

Track-calo
Source ≠ detector

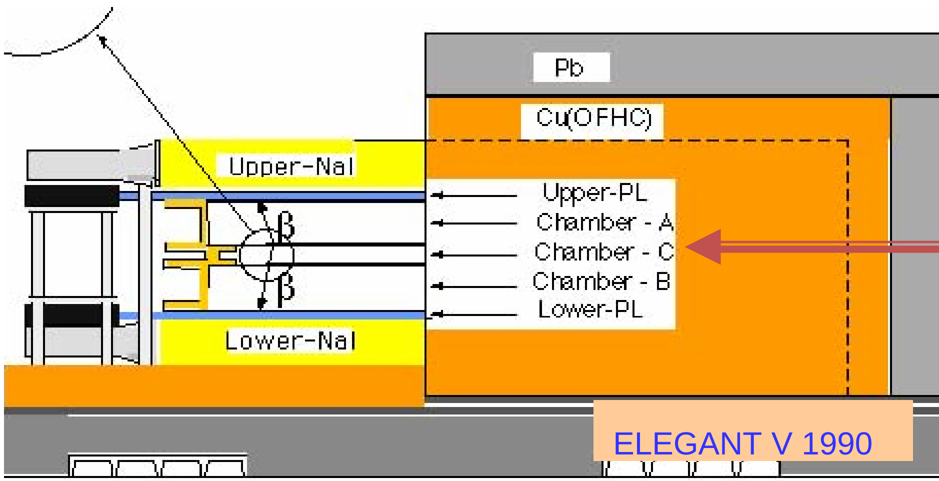


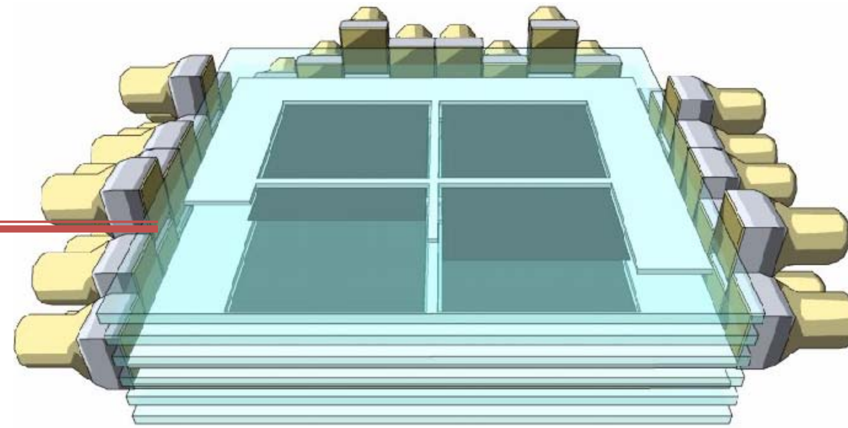
- Multi layers module
  - ^{100}Mo foil & Plastic scintillator
    Mo foil is interleaved with PLs.
  - Compact
    PL works both as calorimeter and as active shield
  - No TOF
  - Particle ID may be necessary.
    - Not in MOON-1 prototype detector
    - No tracking detector
    - Delta E / E telescope
    - No magnetic field



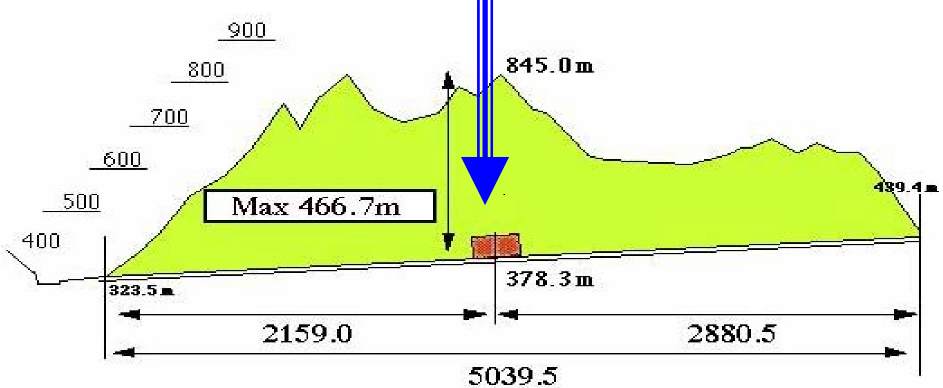
MOON 1 prototype detector

PL 6 layers: 53x53x1cc (BC408.equ.) ^{100}Mo: 142g 40mg, 3 layers

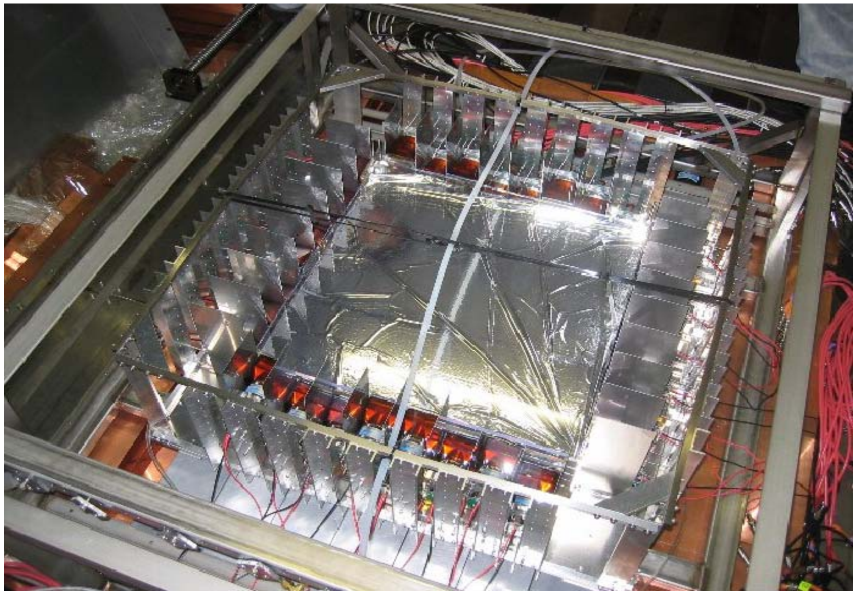




H. Ejiri et al., PRC63 (2001)065501



1400 m.w.e.

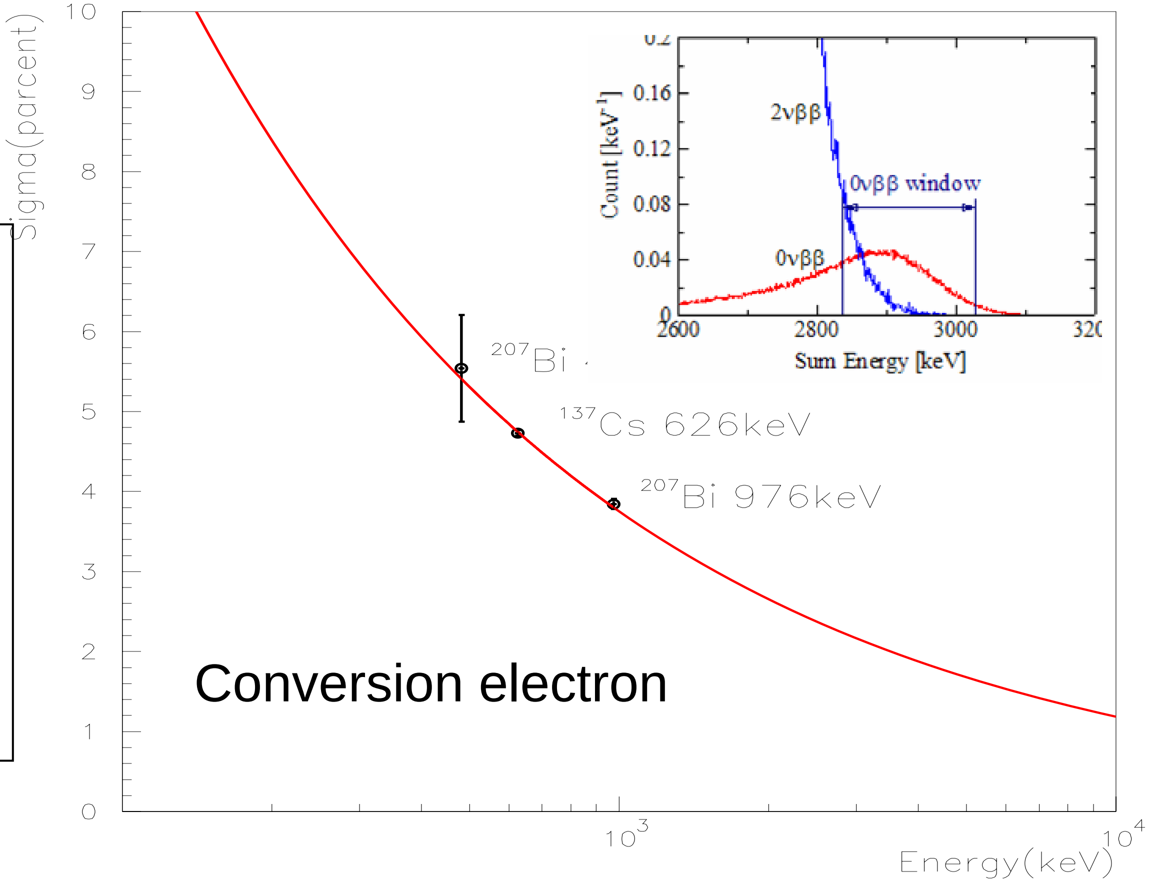


Energy resolution

Cs 625 σ= 4.73 ±0.04 %
Bi 976 σ= 3.84 ±0.06 %

ββ 3.0MeV σ= 2.1±0.1 %

Ensure search for
IH (25-50 meV) mass with
large scale PL plates.



	MOON	ELEGANT V	NEMO III
σ 3 MeV ^{100}Mo, ^{82}Se	2.1 %	3 %	~4.3%
BG(2ν) ratio ~σ^5	1	5	40
m_ν meV for 1 ton･yr	50 meV	(~1eV)	300 meV

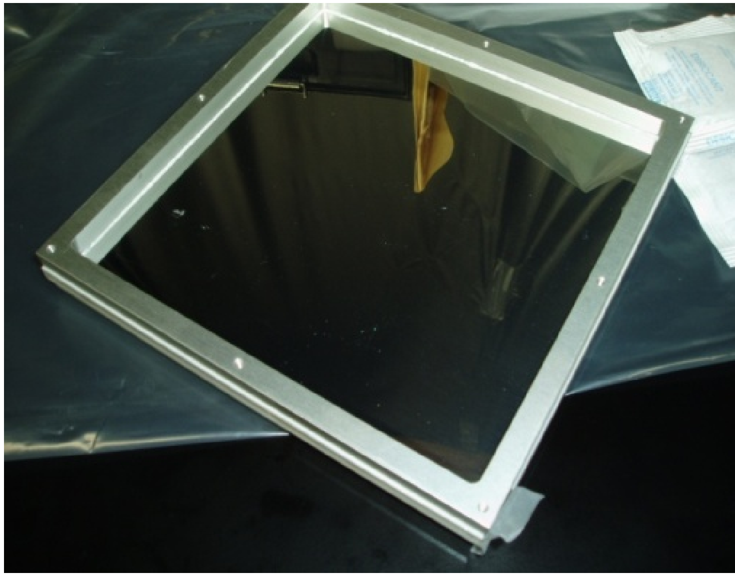
H. Ejiri, Eur. Phys. J. Special Topics 162 (2008) 239
H. Nakamura, et al., JPSJ 76(2007)114201, Rad. Res. 170(2008)811

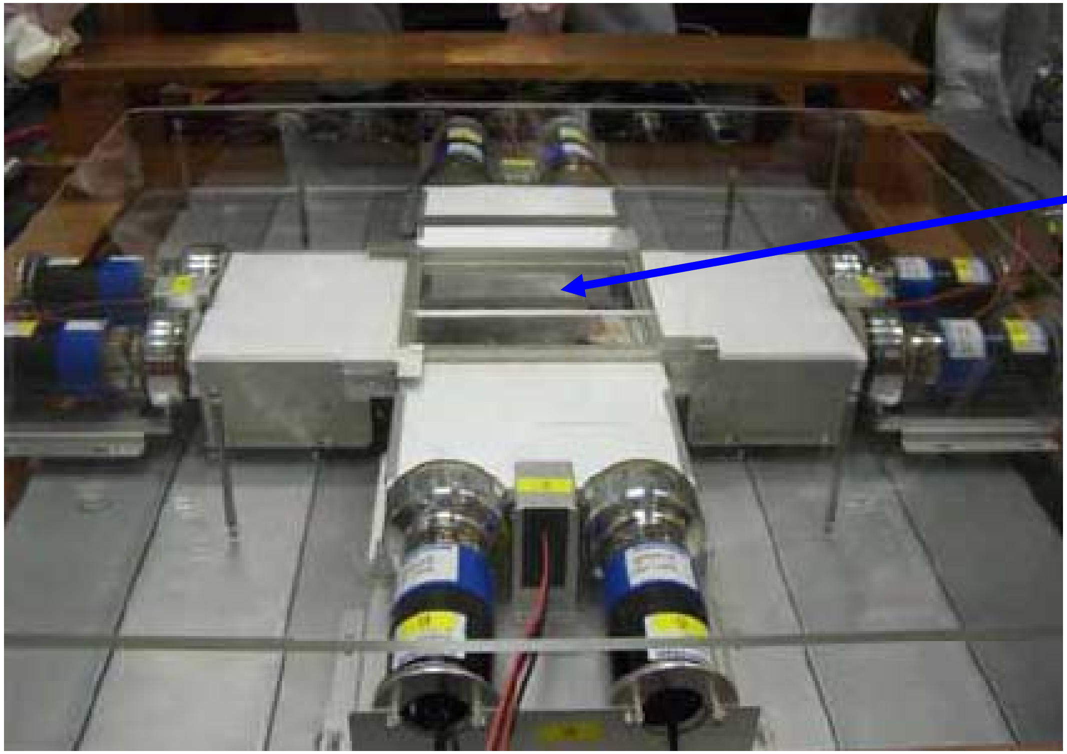
Thin and Large area NaI(Tl) scintillator

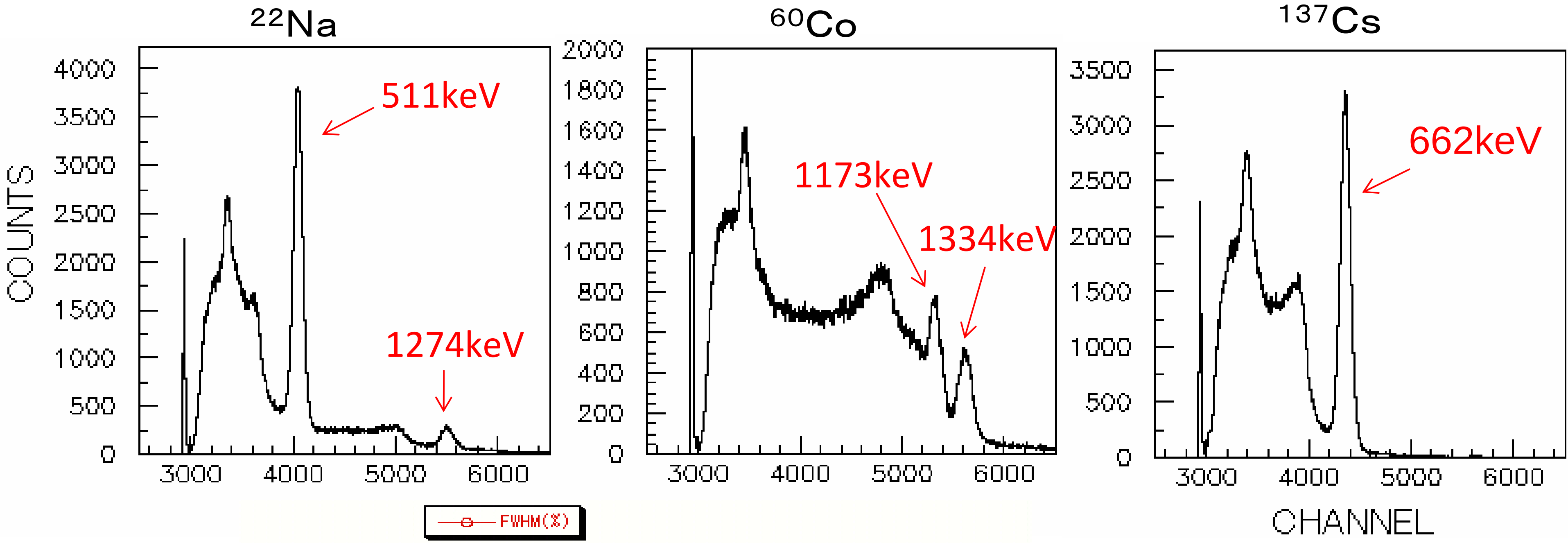
- provided by Horiba, Ltd.
- better energy resolution for $\beta\beta$ and BG γs
- sensitivity for $\beta\beta$ to excited states

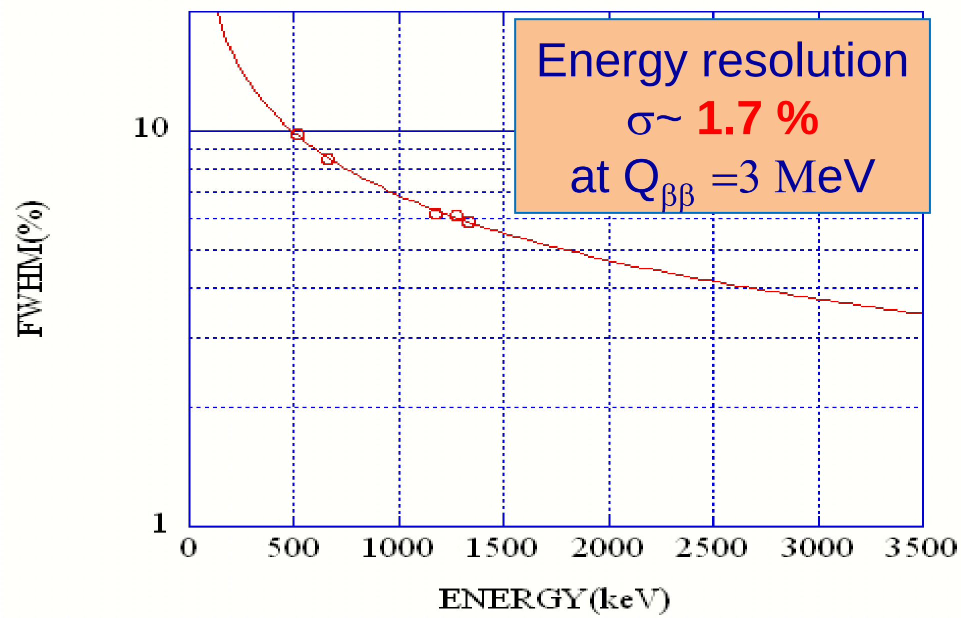
2 layers : 18cm X 18cm X 0.5cm

4 x 2 modules of 3 inch PMT &
1 module of 0.75 inch square PMT









K. Fushimi et al., J. Phys: Conf.203(2010) 0120654

Sum energy spectra of 0 ν β β and 2 ν β β rays in the 0 ν β β pe

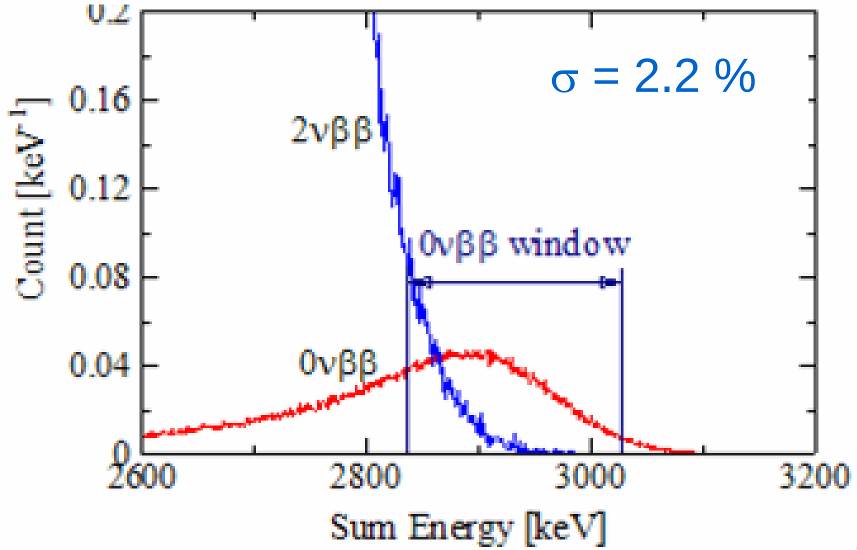
0.6 ton year run

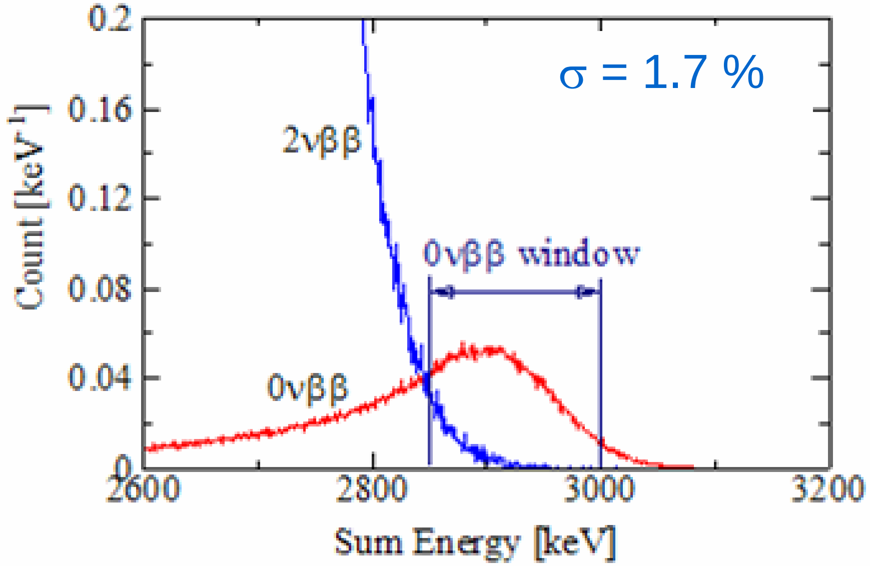
with

50mg/cm^2 β β source

^{82}Se,<m$_\nu$>=75 meV

$Y^{0\nu}$ ~ 20/2 ton year





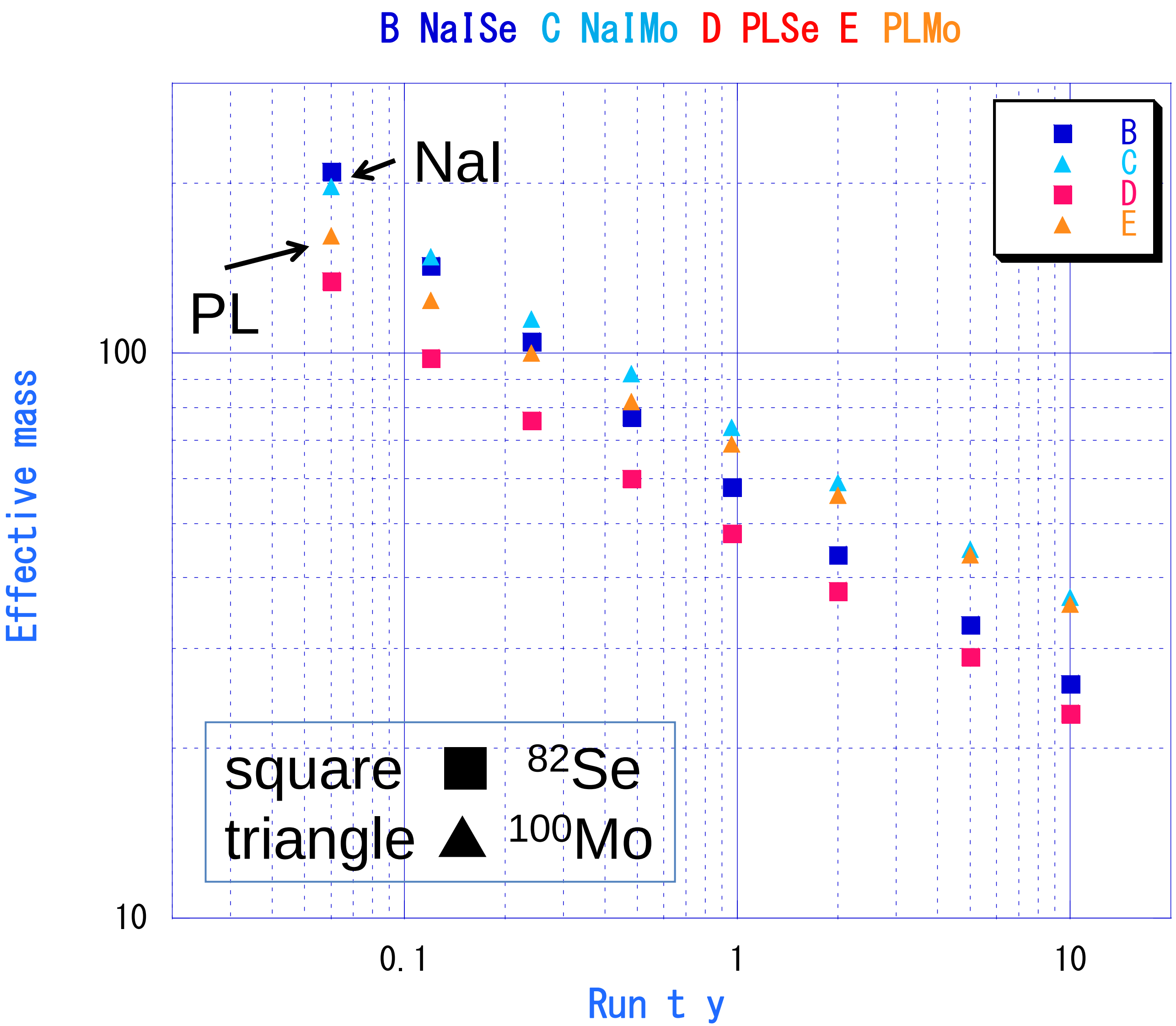
H. Ejiri et al., Eur. Phys. J. Special Topics 162 (2008) 239

^{82}Se : BG = B(RI) + B(n) + B(2νββ)

BG origin	Case A	BG(A)/t y	Case B	BG(B)/t y
2νββ	σ=2.2 %	4.1	σ=1.7 %	1.5
^{208}Tl	60 mBq/t	0.3	20 mBq	0.1
^{214}Bi	300mBq/t	0.01	100mBq	0.003
Cosmic n	2000 m w.e	0.01	2450 m w.e	0.007

Effective ν -mass sensitivity with E-resolutions of

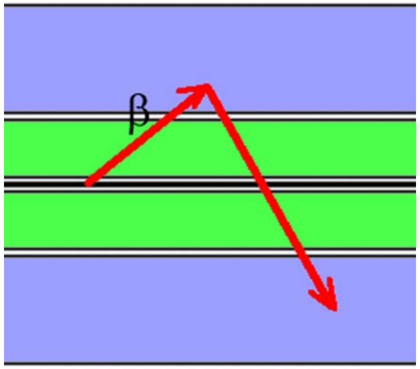
σ =2.2 (PL) and 1.7%(NaI)



H. Ejiri, Prog. Part. Nucl. Phys. 64 (2010) 249

BG due to electron back scattering in NaI

20mBq / ton ^{214}Bi
(Q=3.27MeV):single β in ^{100}Mo



Plastic Scintillator (15mm)
+ MWPC (10mm)

Gate condition	Counts in 2.9-3.2 MeV [/ton/yr]
$E_1+E_2 > 0$keV	990
E_1, $E_2 > 500$keV	8.3
Veto by other PL	8.1
Coincidence of MWPCs on both sides	0.0005
Track consistency	0

<1%

NaI(Tl) Scintillator (5mm)
+Si (100μm)

Gate condition	Counts in 2.9-3.2 MeV [/ton/yr]
$E_1+E_2 > 0$keV	726
E_1, $E_2 > 500$keV	77
Veto by other NaI	75
Coincidence of Si's on both sides	69
Track consistency	59

>10%

EGS5 by T. Shima

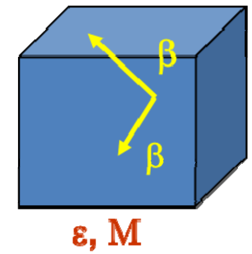
~0 events

~60 events

Molybdenum-loaded Liquid Scinti.

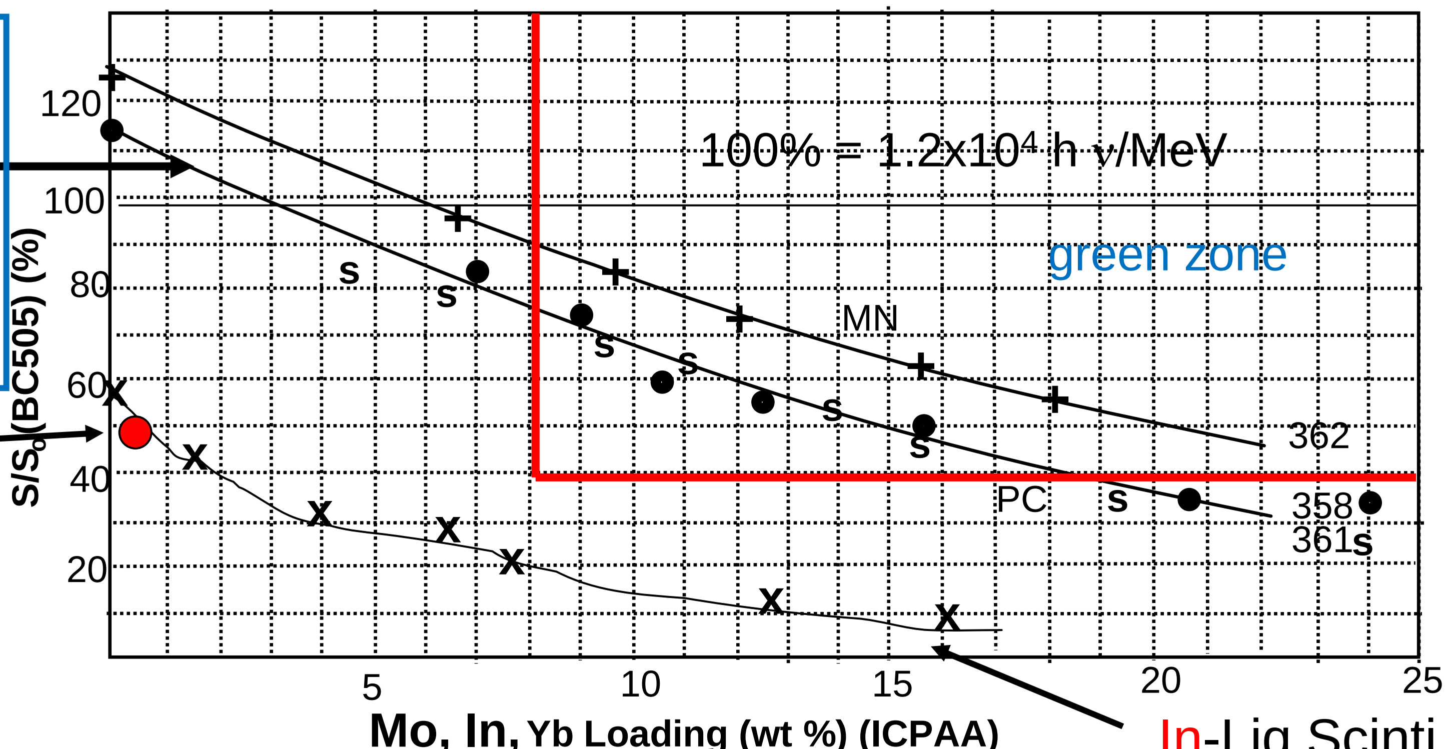
Calorimeter
(Loaded) Scintillator
Source = detector

- Mo carbonyl is slightly soluble in pseudocumene/toluene, etc
- Mo-loaded TL to be roughly half the light output of BC505
- σ=4.3～4.9%@3MeV is quite encouraging, given that no effort was made to optimize the fluor concentration or light collection efficiency (cf. same order as the NEMO3)



Bell labs Yb Liq. Scint. in methyl-naphthalene (MN) & pseudocumene (PC) [Raghavan April 2001]

$Mo(CO)_6$
P. J. Doe,
D. I. Will ,
V.M. Gehman
at UW, Seattle



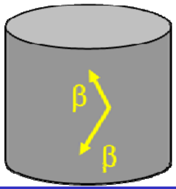
In-Liq.Scinti.
Suzuki & Inoue(1990), Pfeiffer et al(1979)

V.M. Gehman et al., NIM A622 (2010) 602

Molybdate Scintillating bolometer

in collaboration with Mirano/Rome group

Calorimeter
Semi-conductors
Source = detector



Good Scintillation light

$PbMoO_4$

ZnSe

$CdMoO_4$

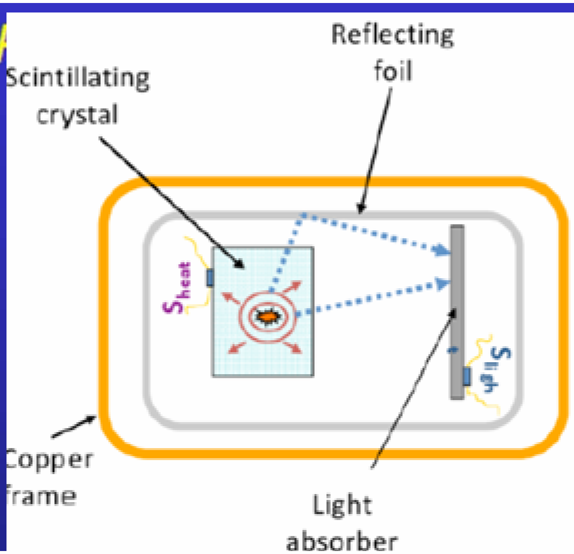
$SrMoO_4$

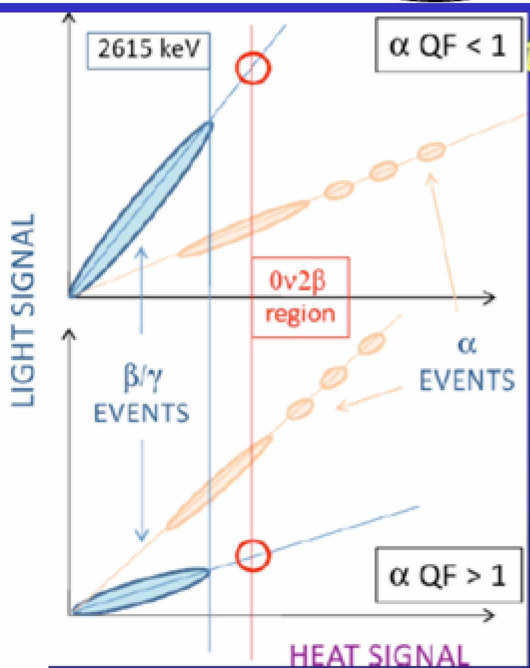
$CdWO_4$

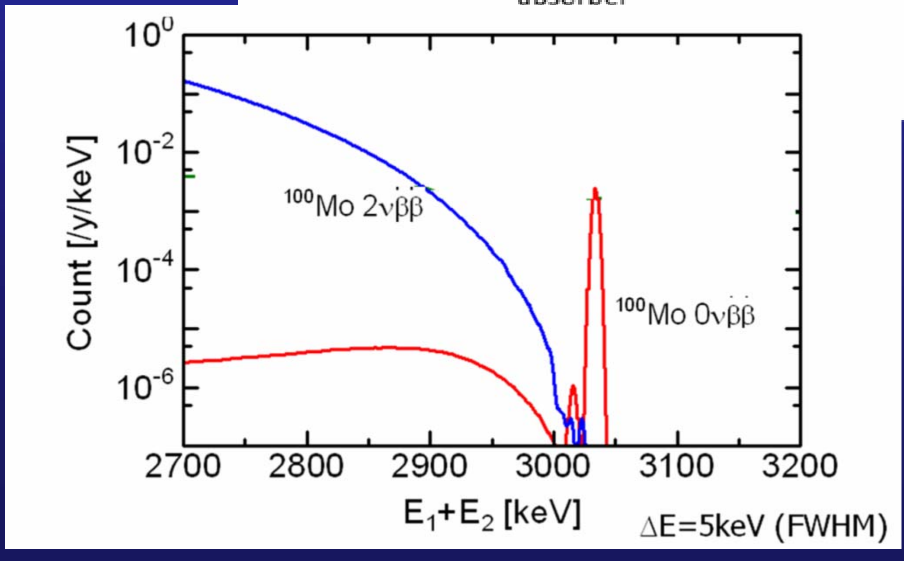
CaF_2

$CaMoO_4$

$ZnMoO_4$







P. Gorla et al.,
J. Low Temp. Phys.
151 (2008) 854.

Summary

- MOON is one of the feasible solutions for next-generation $0\nu\beta\beta$ experiment, in terms of good energy resolutions , compactness, scalarbility, etc.
- NaI scintillator is attractive because of its better energy resolution, large stopping power for β -rays, and high sensitivity to γ -rays. However, it will require better resolution for track multiplicity, in order to suppress BG due to electron back scattering in NaI.

	MOON-PL	MOON-NaI	MOON -LS
σ @3 MeV	2.1 %	1.7 %	~4.3%

MOON collaboration

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