MOON

MOON-1 prototype detector
and
R&D for SuperNEMO

Osaka University
M. Nomachi

For
MOON collaboration
And
SuperNEMO collaboration

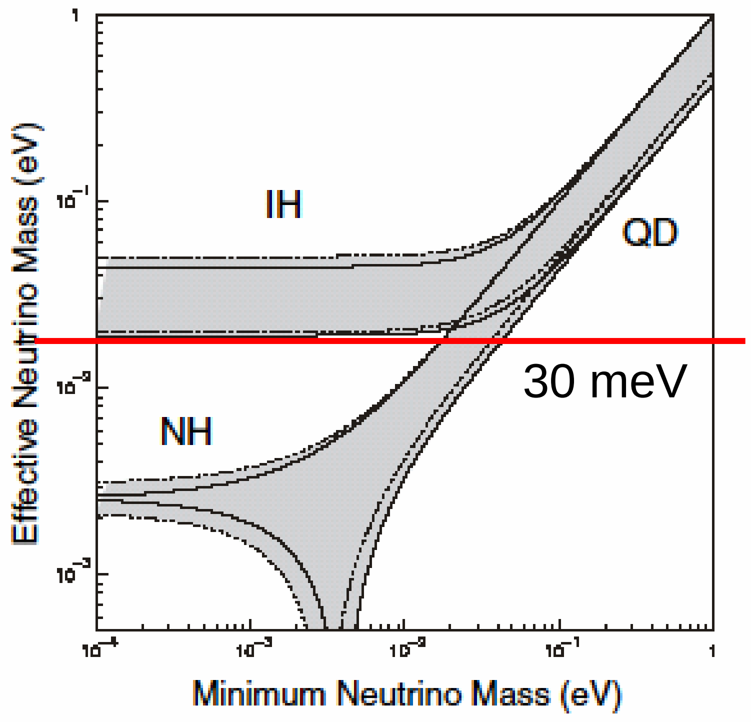
Challenge to 30 meV

- Sensitivity : 30 meV

$$T_{\frac{1}{2}} = 0.5 \sim 2 \times 10^{27}\ years$$

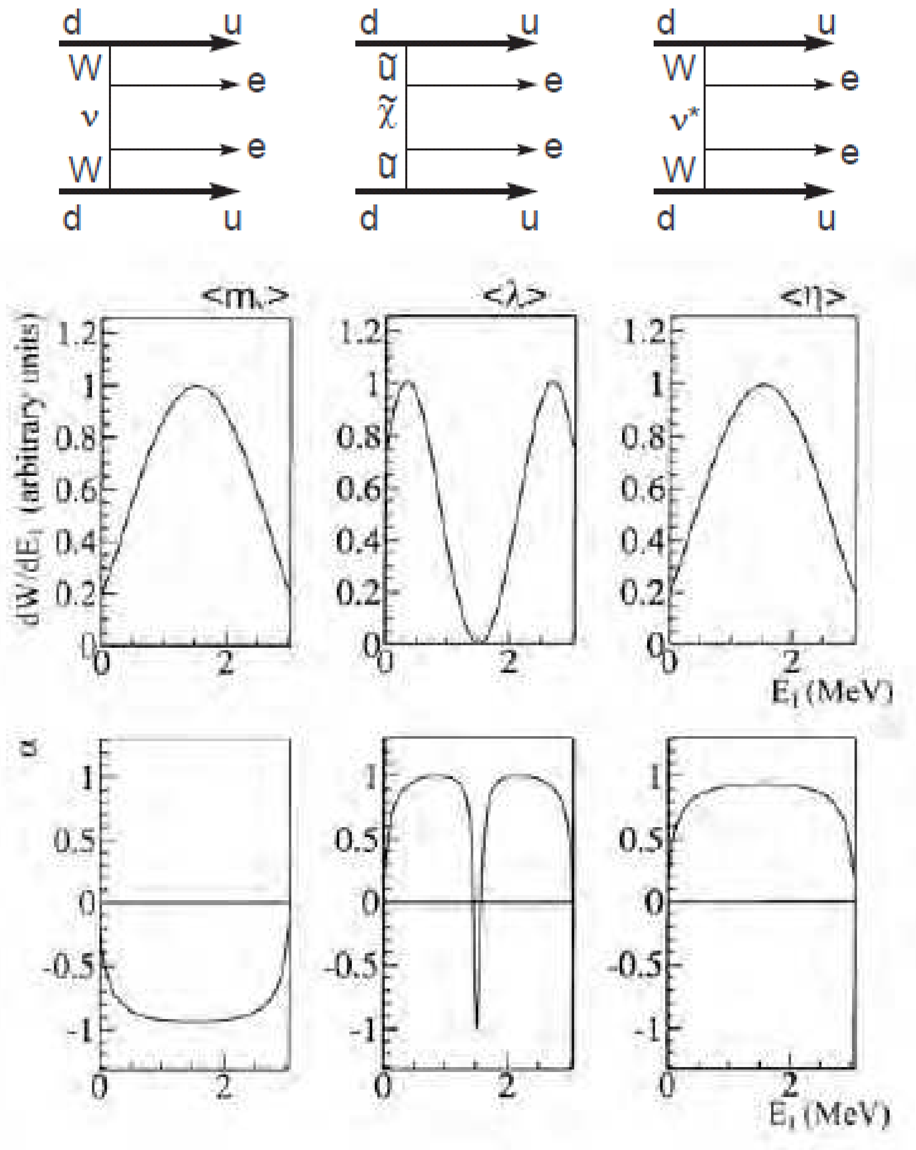
- 2~8 decay / ton / year
- 1t in 40mg/cm^2 foil

2500m^2 or 50m x 50m



Double beta decay Detectors

- **Calorimetric** (Source = Detector)
  - Good efficiency
  - Very good energy resolution is required
  - High purity is required
  - GERDA, MAJORANA, CUORE, CANDLES etc.
- **Tracking-calorimetric** (Source ≠ Detector)
  - Select the best source / more than two sources
    - Reduce the ambiguity of the nuclear matrix element
  - Individual energy measurement
    - It will give an information about the mechanism
  - Energy loss in the source foil is not negligible
  - Limited acceptance
  - ELEGANT-V,NEMO, MOON, DCBA etc.



d
u
W
e
ν
e
W
d
u
d
u
ũ
e
χ̃
e
ũ
d
u
d
u
W
e
ν*
e
W
d
u
<mν>
<λ>
<η>
dW/dE1 (arbitrary units)
1.2
1
0.8
0.6
0.4
0.2
0
2
E1 (MeV)
α
1
0.5
0
-0.5
-1

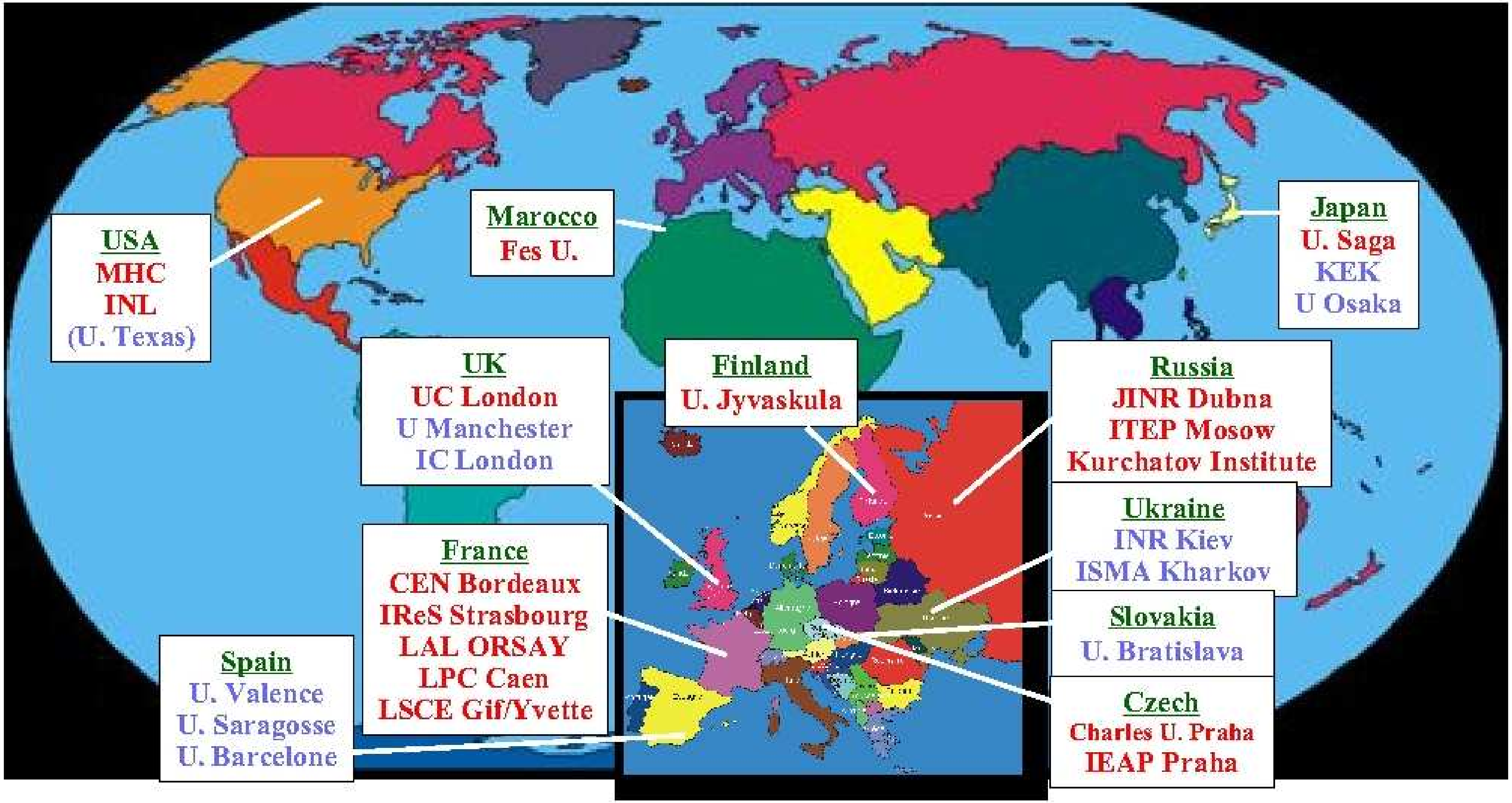
International collaboration
(SuperNEMO)

Double beta decay with Tracking detector

- International collaboration
  - Tracking-calorimetric / Tracking detector
    - NEMO, DCBA, MOON
- Common R&D for future detectors
- Collaborative detector construction for >100kg detector
- Japan: Saga-U, KEK, Osaka-U, Tokushima-U, Hiroshima-U.

SuperNEMO project collaboration

NEMO3 collaboration + new labs ~ **60 physicists, 11 countries, 27 laboratories**

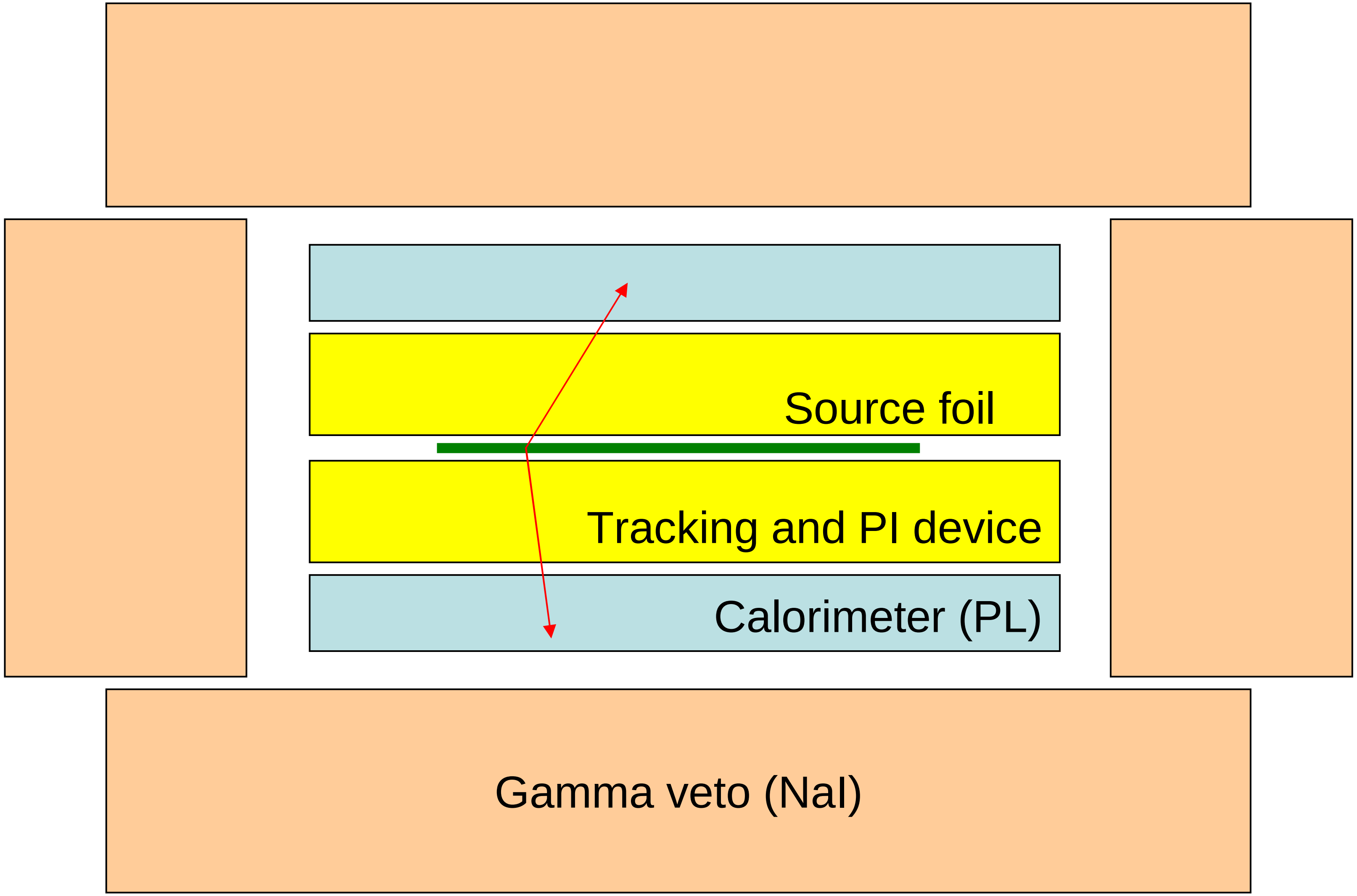


Challenge to 30 meV

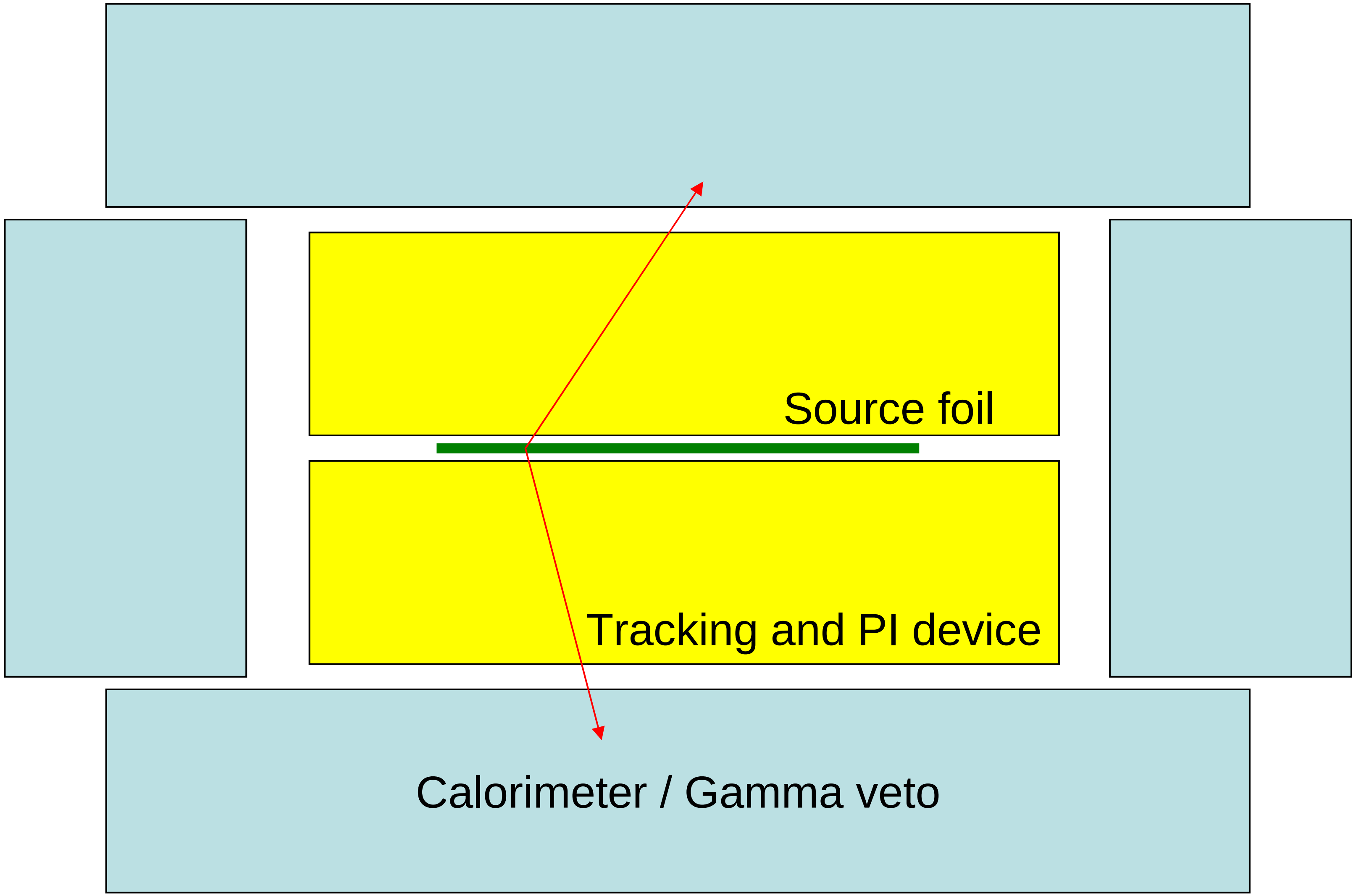
- 0.1~1 t of source (x10,x100)
  - Mass production
  - Large detector
- Better radio purity (1/10)
  - $^{208}Tl < 2$ mBq/t
  - *(If ^{82}Se*: $^{214}Bi <$ **10** mBq/t**)**
- Better energy resolution
  - 7% at 3MeV ➔ 5% →→
- Better space-time resolution
- Efficient active schield

Elegant-V concept

ELEGANT V (Osaka University)
~100g source



NEMO-3 concept



Possible SuperNEMO design

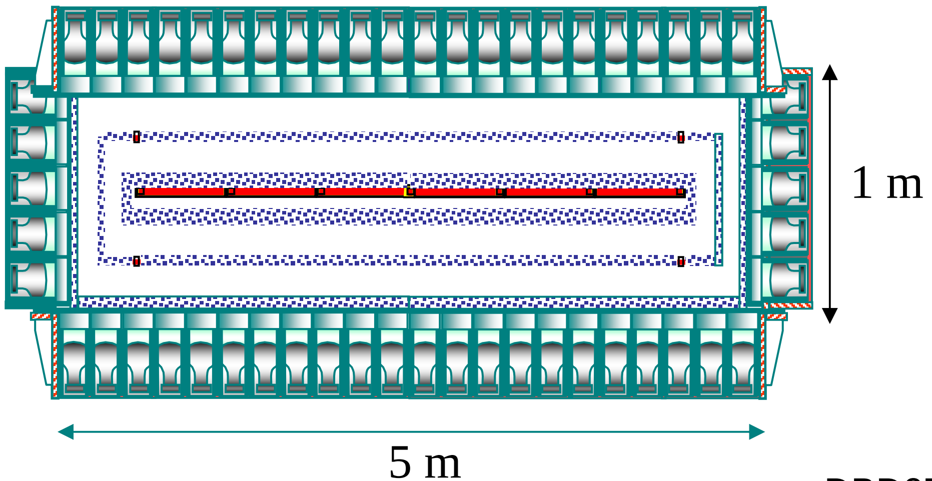
<u>Planar</u> and <u>modular</u> design: ~ 100 kg of enriched isotopes (20 modules × 5 kg)

<u>1 module:</u>

Source (40 mg/cm^2) 4 x 3 m^2

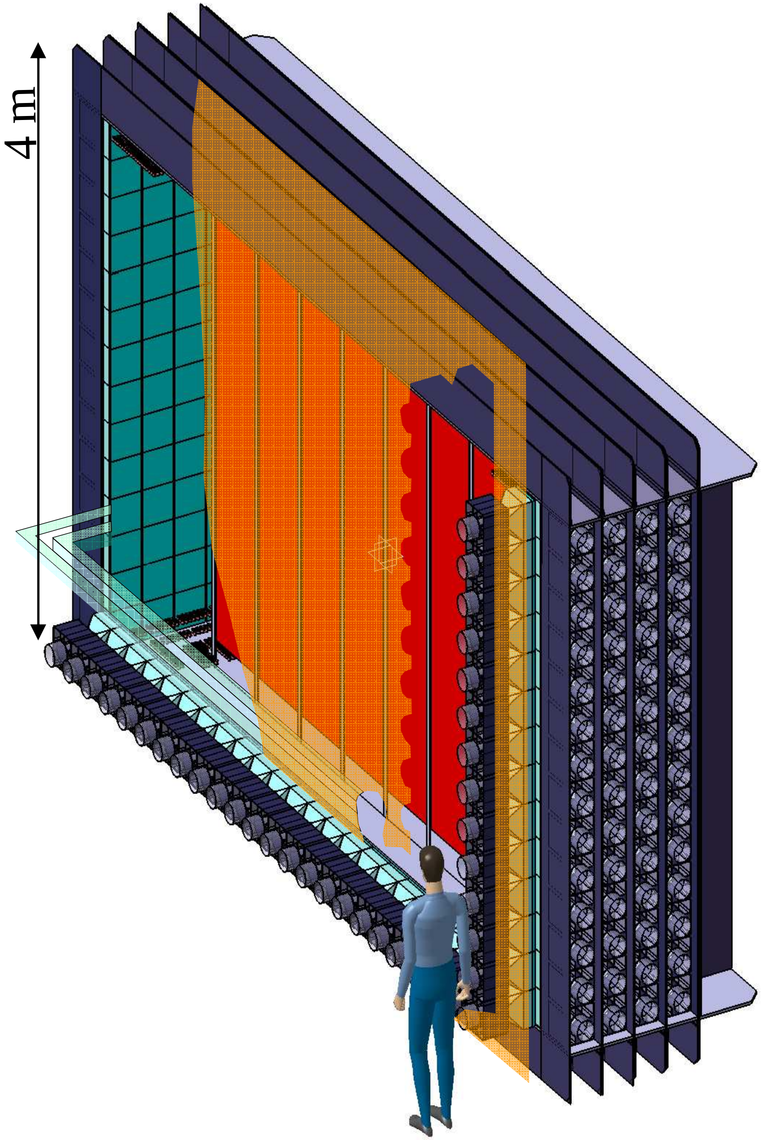
Tracking : drift chamber ~3000 cells in Geiger mode

Calorimeter: scintillators + PM ~1 000 PM if scint. blocs
~ 100 PM if scint. bars



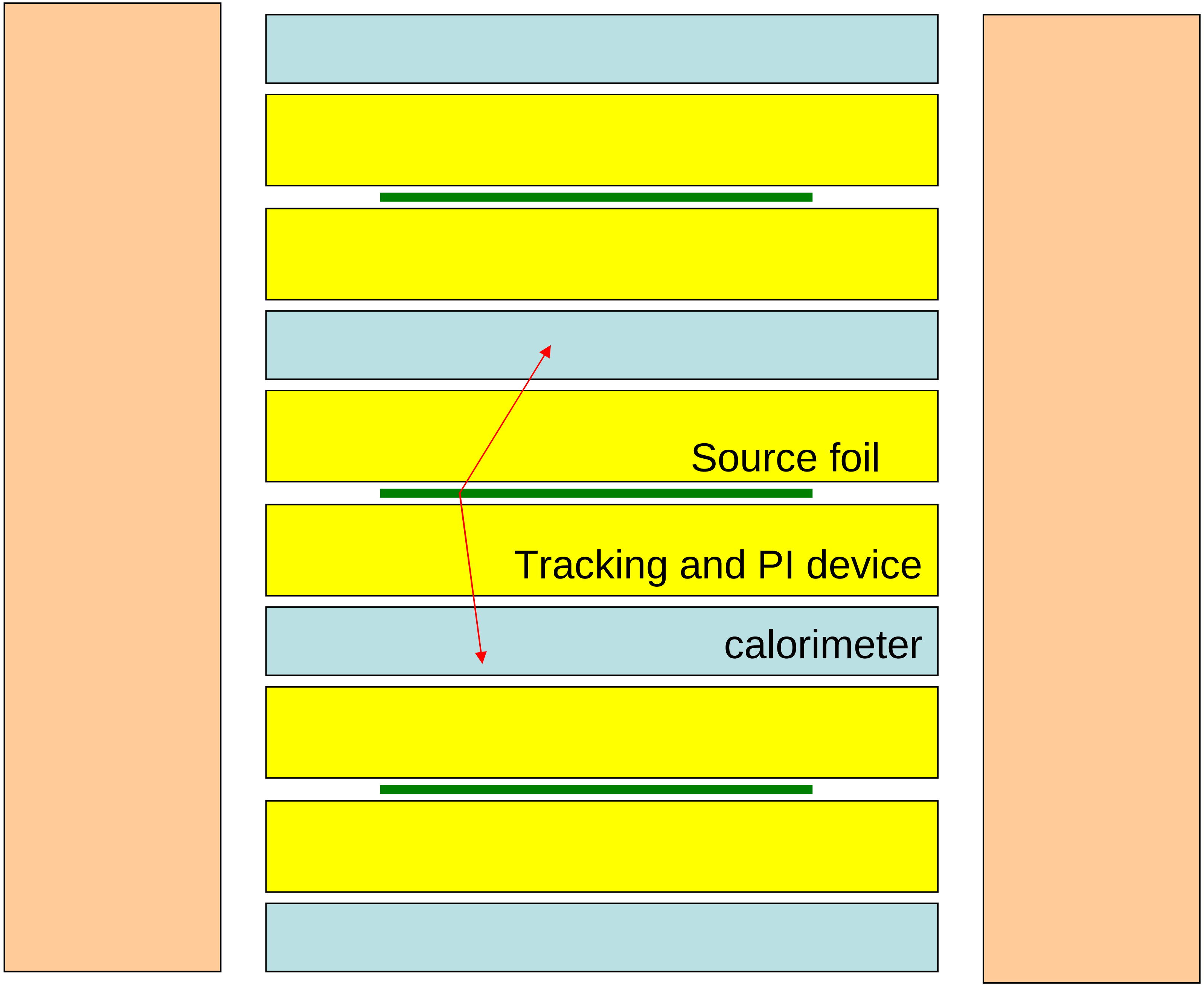
Top view

DBD07



Compact detector
(MOON concept)

MOON concept

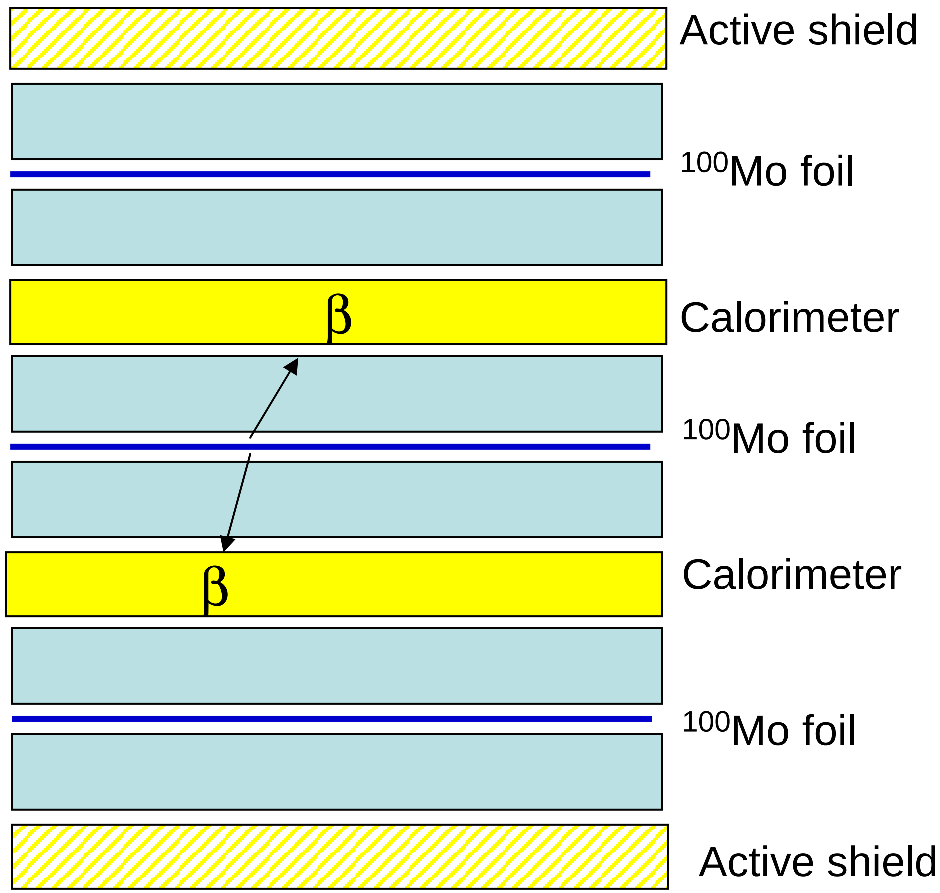


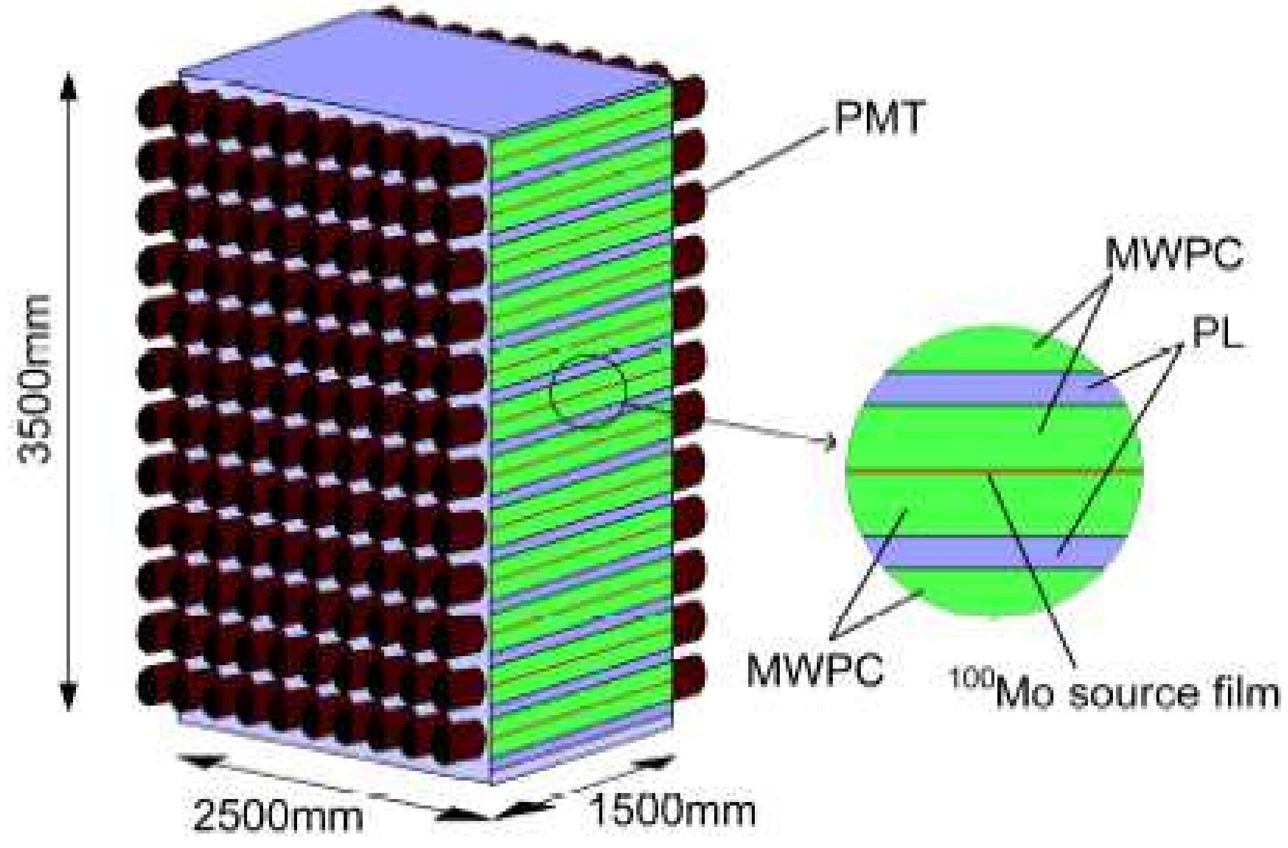
MOON Detector

- **Multi layers module**
  - **^{100}Mo foil & Plastic scintillator**

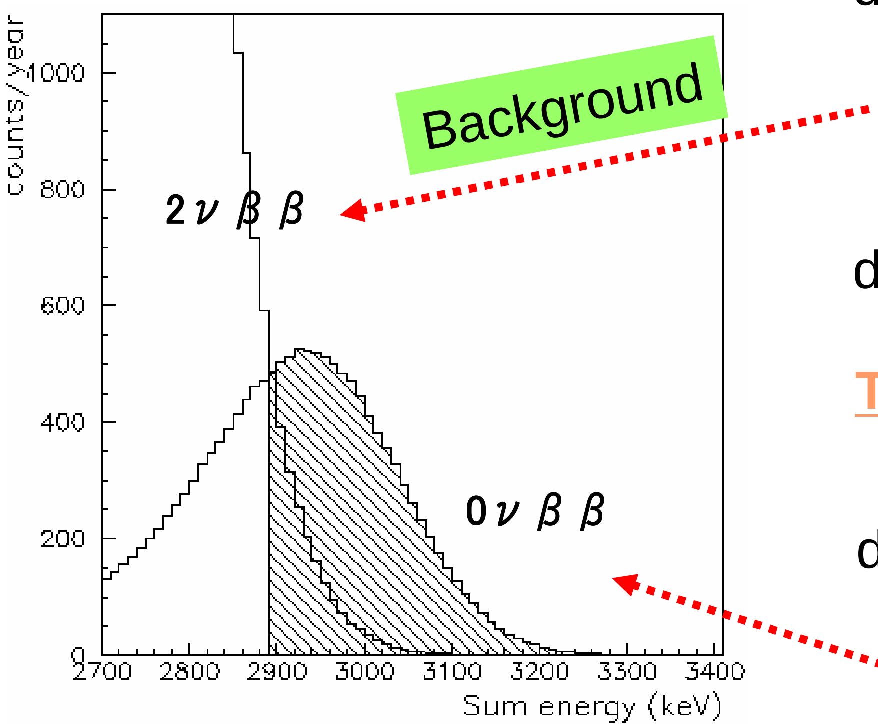
    Mo foil is interleaved with PLs.
  - **Compact 1 t detector**

    PL works both as calorimeter and as active shield
  - **No TOF**
  - **Effective gamma veto**
  - **Particle ID.**
    - **Not in MOON-1 prototype detector**

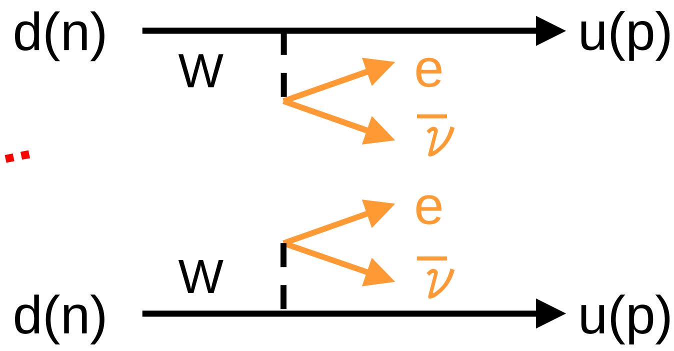




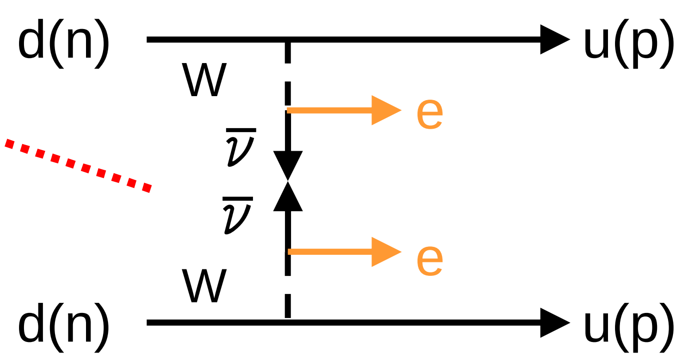
MOON module with 20kg of source



Sum energy of the two beta rays from ^{100}Mo

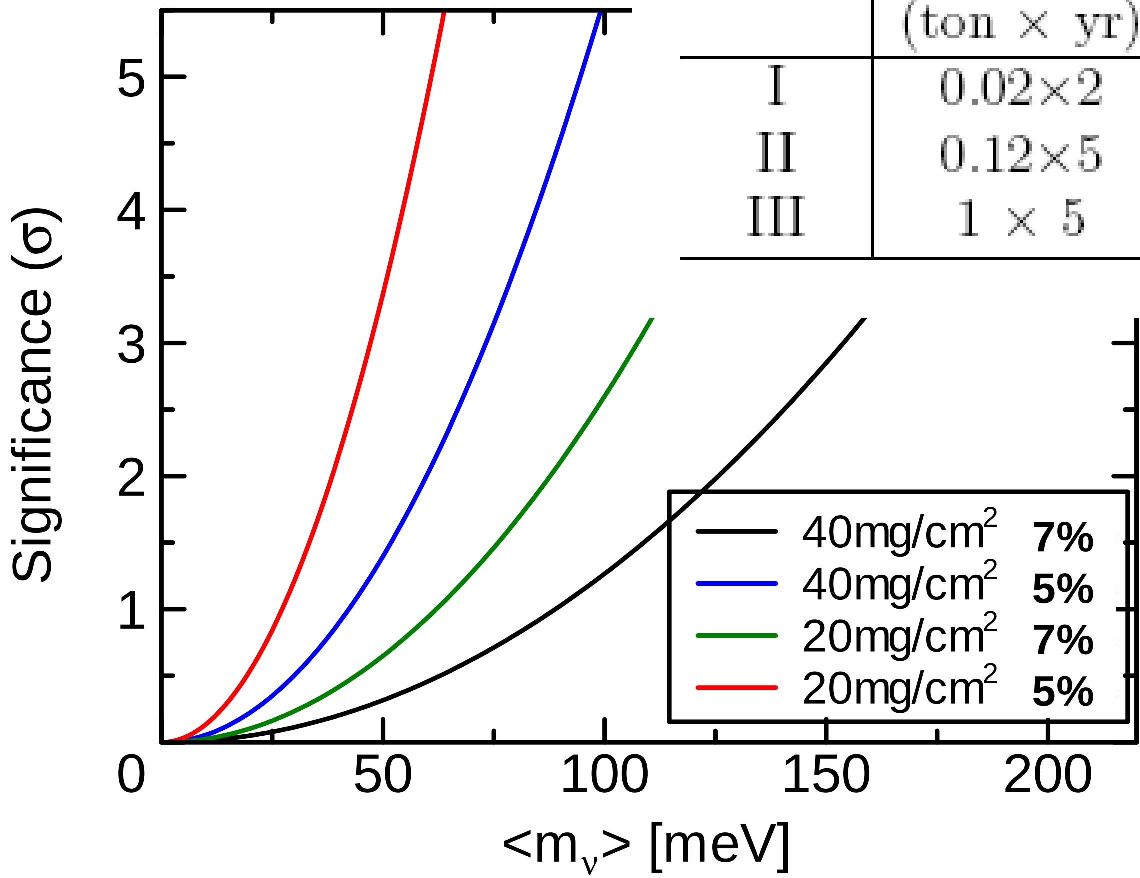


$T_{1/2}$ ($2\nu\beta\beta$): ~ 7 x 10^{18}year



$T_{1/2}$ ($0\nu\beta\beta$): > 10^{23}year

MOON sensitivity



Phase	Run (ton × yr)	Mass sensitivity [meV]	
		^{82}Se	^{100}Mo
I	0.02×2	150(105)	260(190)
II	0.12×5	75(54)	130(95)
III	1 × 5	44(32)	80(56)

2σ sensitivity

Prototype detector

MOON-1 Detector

MOON prototype detector (MOON-1) was developed

to study the energy resolution and multilayer performance.

- **Plastic scintillator (PL)** BC408. equivalent
  $53x53x1cm^3$, 6 layers
- **142g ^{100}Mo(94.5% enrich), $40mg/cm^2$ 3 layers**
- **60 PMTs (^{40}K Free 0.7Bq/PMT)**
  HAMAMATSU, R6236-01 K-MOD
- **126 days measurement in underground lab.**

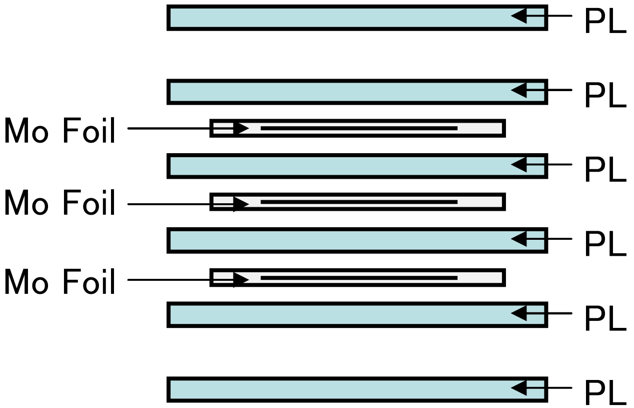
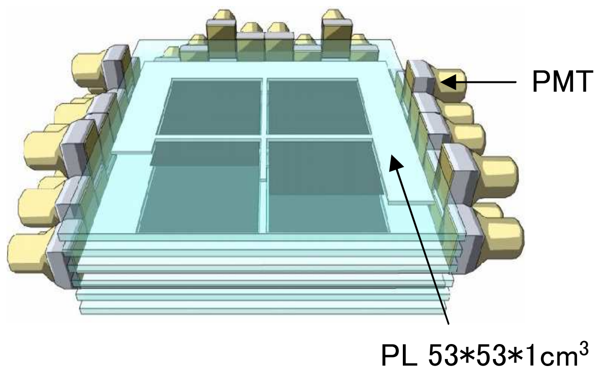


Fig. Cross section view of MOON-1

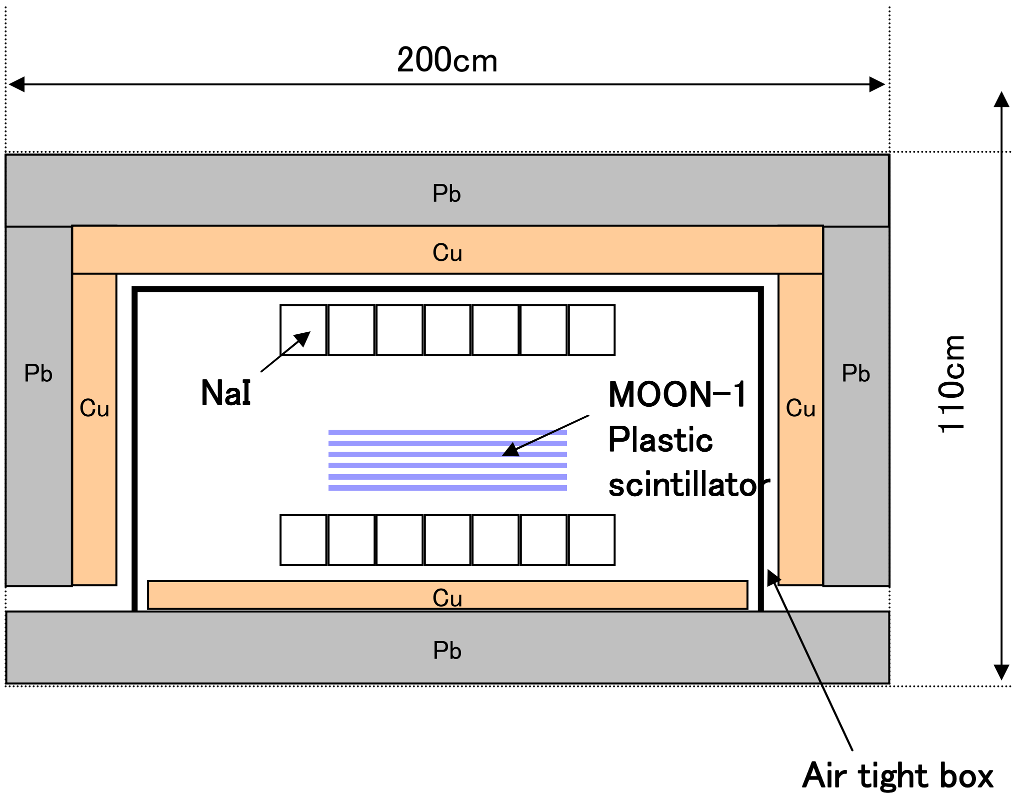


setup

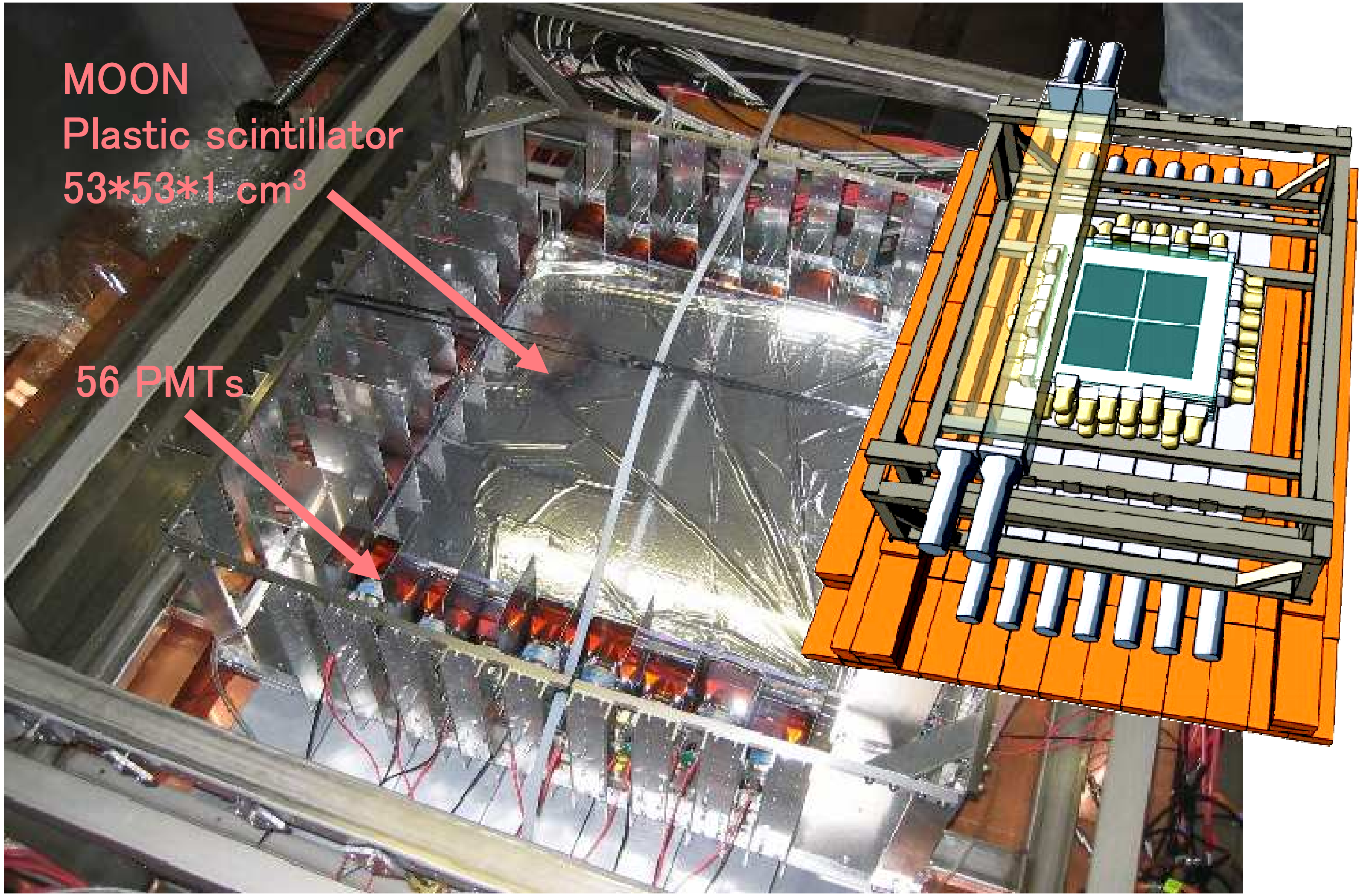
MOON-1 is placed in active/passive shield of ELEGANT-V.

- NaI(Tl) detector
  14 of NaI(Tl) detectors are above and below MOON-1 detector for gamma ray active shield

- Air tight box
  To keep Rn concentration low, N_2 gas was flushing.
  Rn concentration was 125mBq/m^3.
- Lead & Copper passive shield
  The outside of the air tight box is covered with 10cm Cu, 15cm Pb as passive shield.



MOON-1 detector

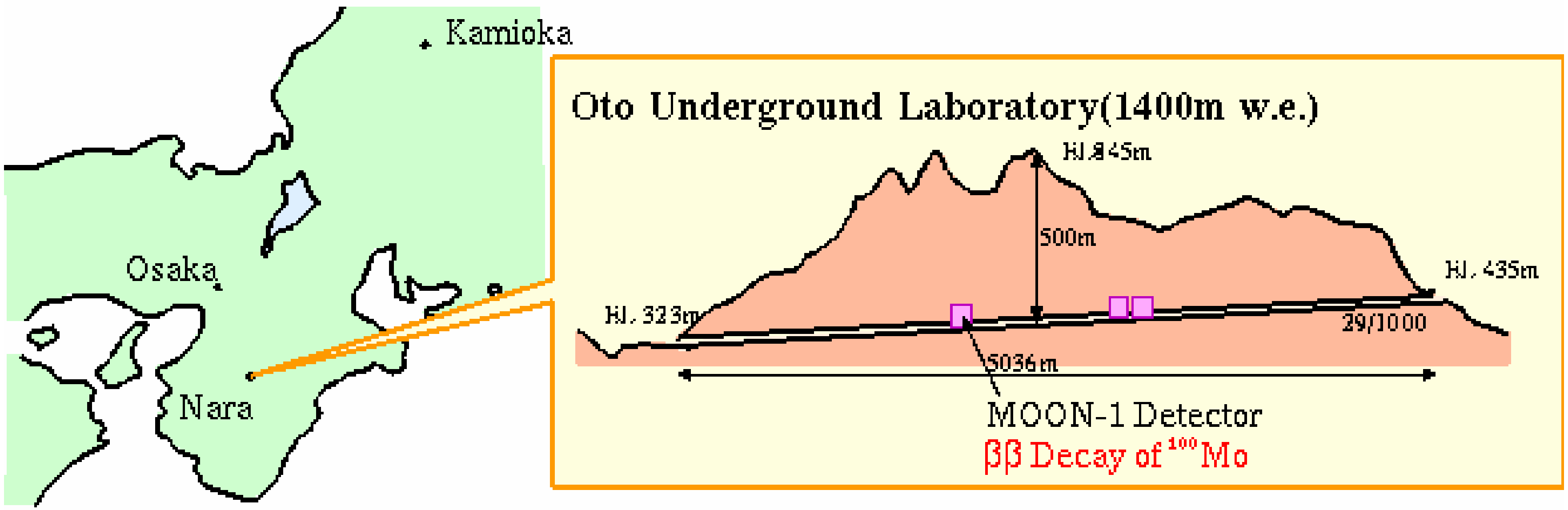


Oto underground Laboratory

- **Depth**
  the lab is placed at 1,300m w.e.

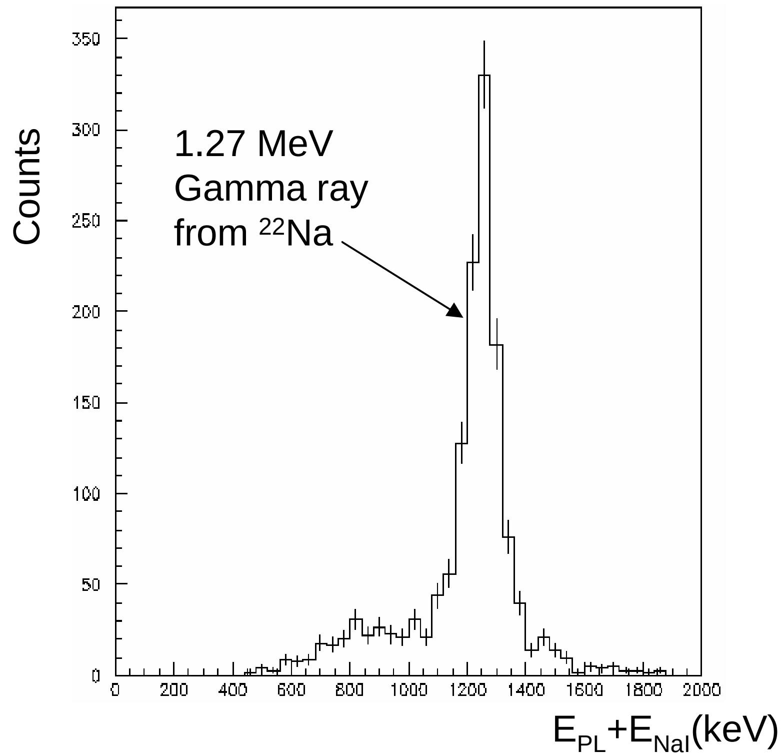
- **BG level**
  The BG level were measured by ELEGANT group[2].
  - **Cosmic Ray: $4x10^{-7}/cm^2/sec$**
  - **Neutron Flux:$4x10^{-5}/cm^2/sec$**
  - **Rn:$10Bq/m^3$**

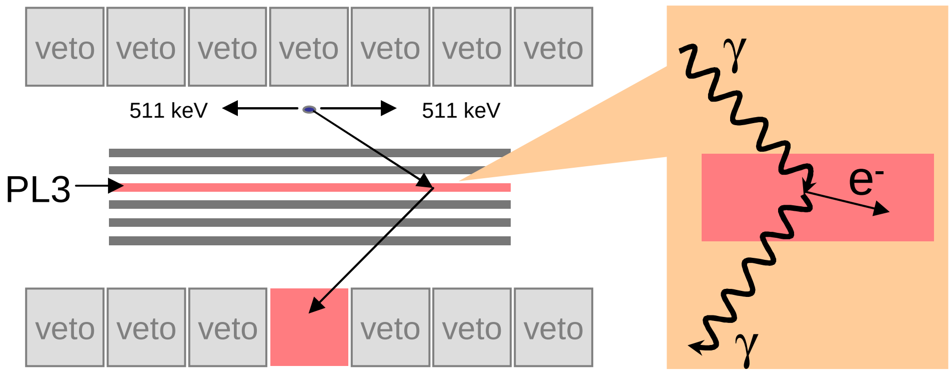
  [2] Nucl. Instr. and Meth. A459(2001)177-181



Energy reconstruction

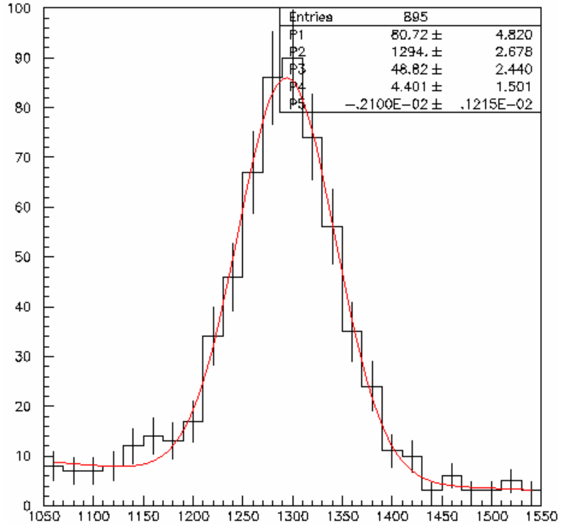
$$E_{\gamma} = E_{electron} + E_{gamma} = E_{PL} + E_{NaI}$$





Reconstructed peak

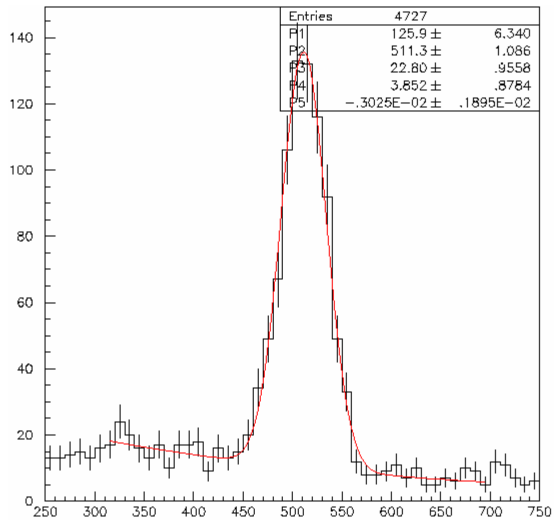
NaI(Tl) peak



E_{PL}+E_{NaI}(keV)

^{22}Na 1.27 MeV

σ_{Σ}=48.8±2.4 keV



E_{NaI}(keV)

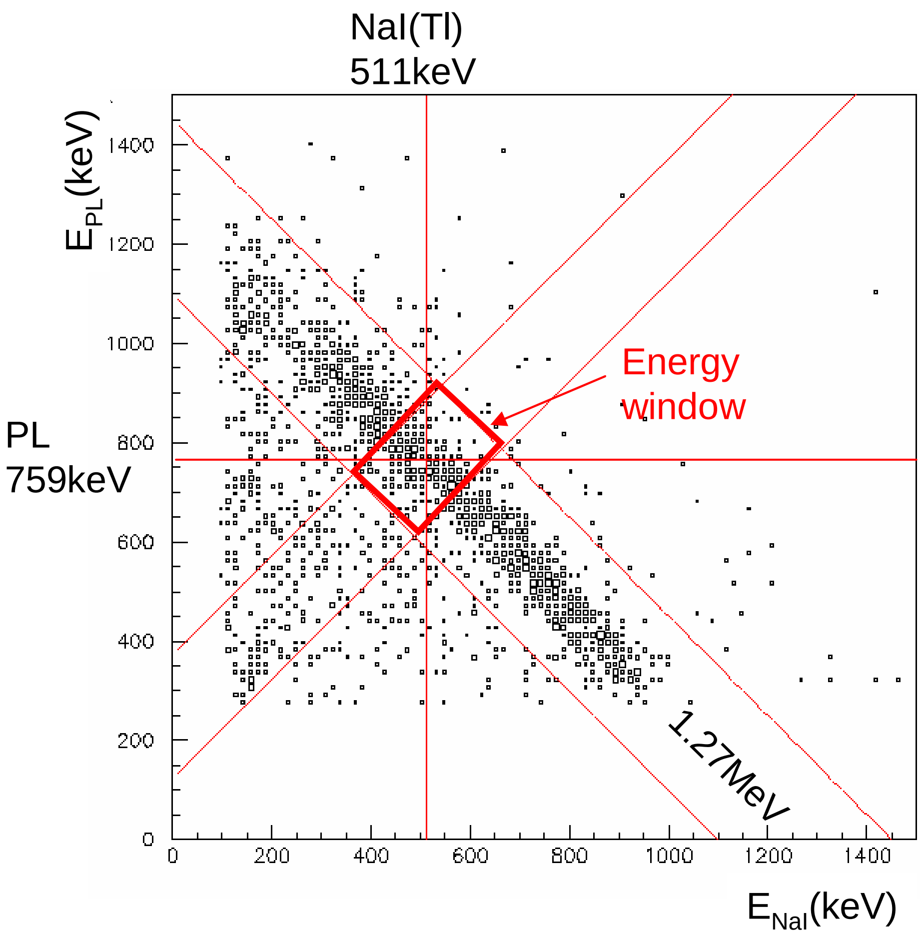
^{22}Na 511 keV

$\sigma_{N\alpha I}$=22.8±0.9 keV

Energy resolution

$$E_{\Sigma} = E_{PL} + E_{NaI}$$

$$\sigma_{\Sigma}^{2} = \sigma_{PL}^{2} + \sigma_{NaI}^{2}$$

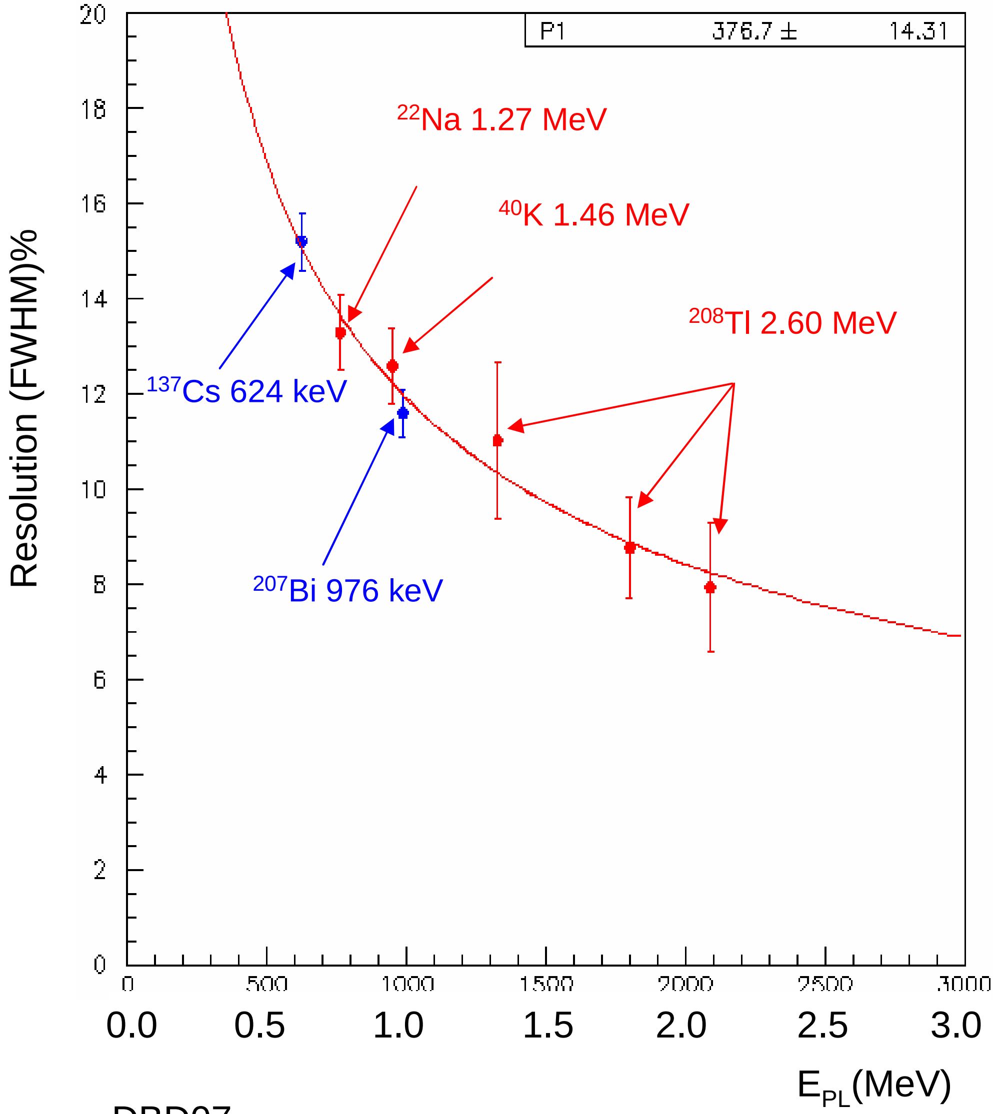


$$\sigma_{PL}\left(E_{\gamma} - 511keV\right) = \sqrt{\sigma_{PL+NaI}^{2}\left(E_{\gamma}keV\right) - \sigma_{NaI}^{2}\left(511keV\right)}$$

MOON-1 Energy resolution

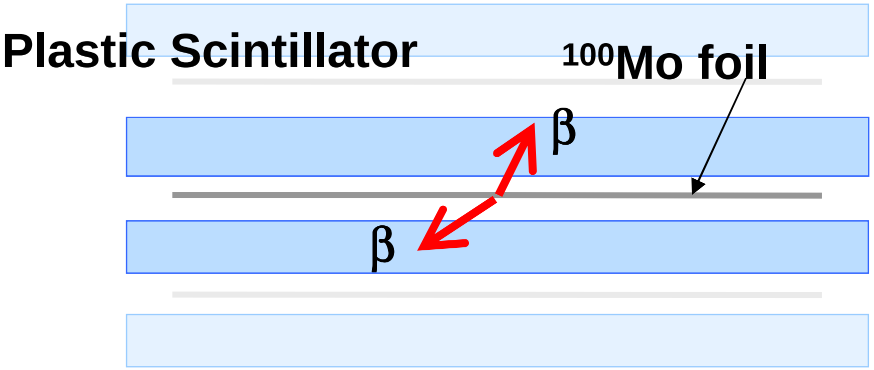
$$R(FWHM) = \frac{(11.9 \pm 0.5)}{\sqrt{E(MeV)}}\%$$

$$R(FWHM)@3\mathrm{MeV} = 6.8\%$$

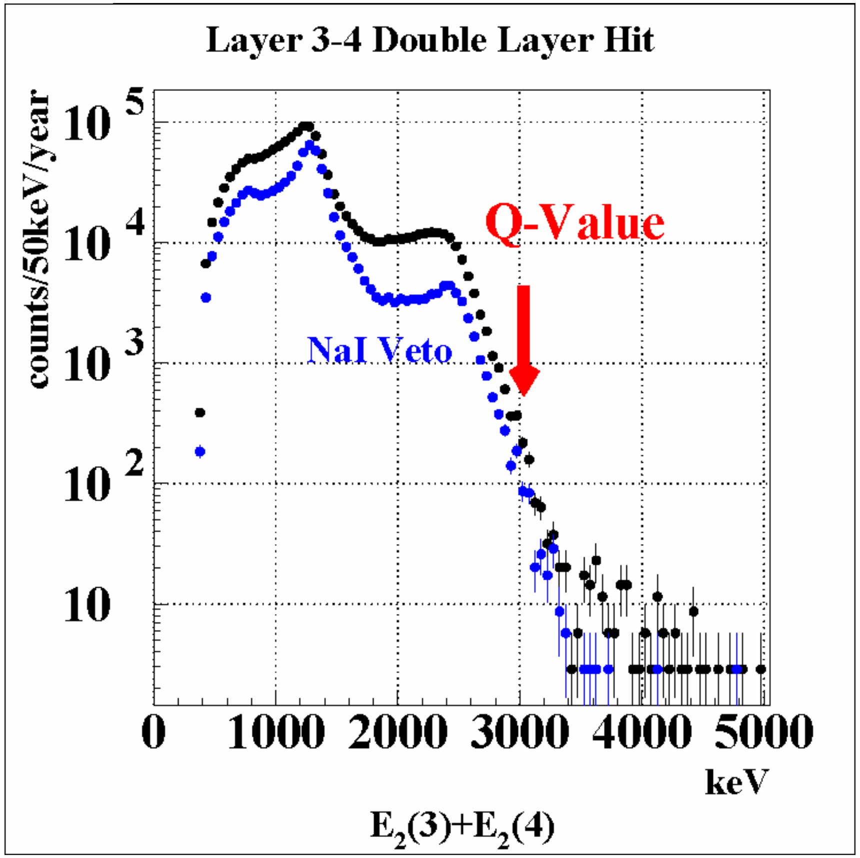


Sum Energy Spectrum

- Hits only at two adjacent plates.
- Electron energy sum should have a peak at Q-value

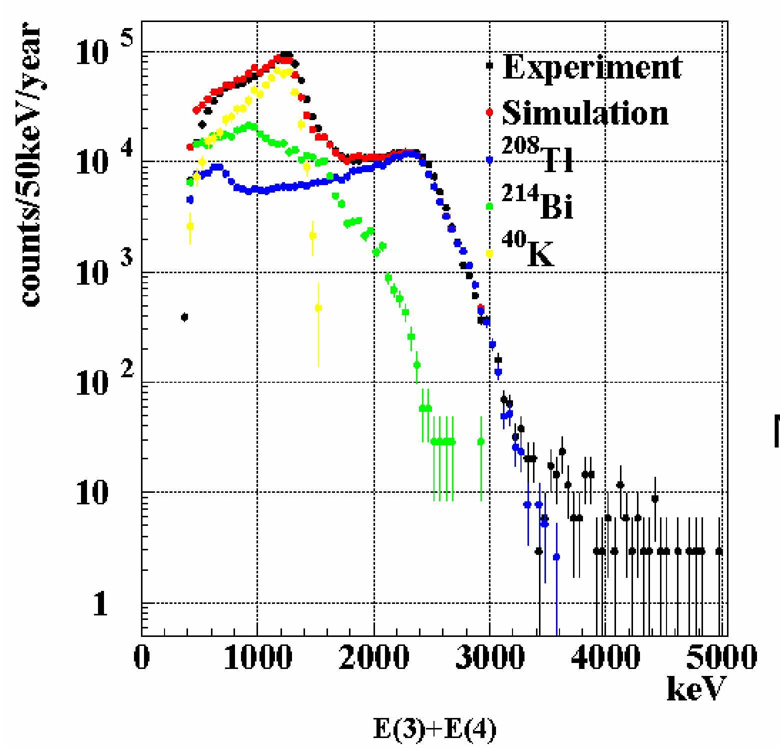


0νββ decay



Sum Energy (Layer 3-4)
(126days data)

Simulation

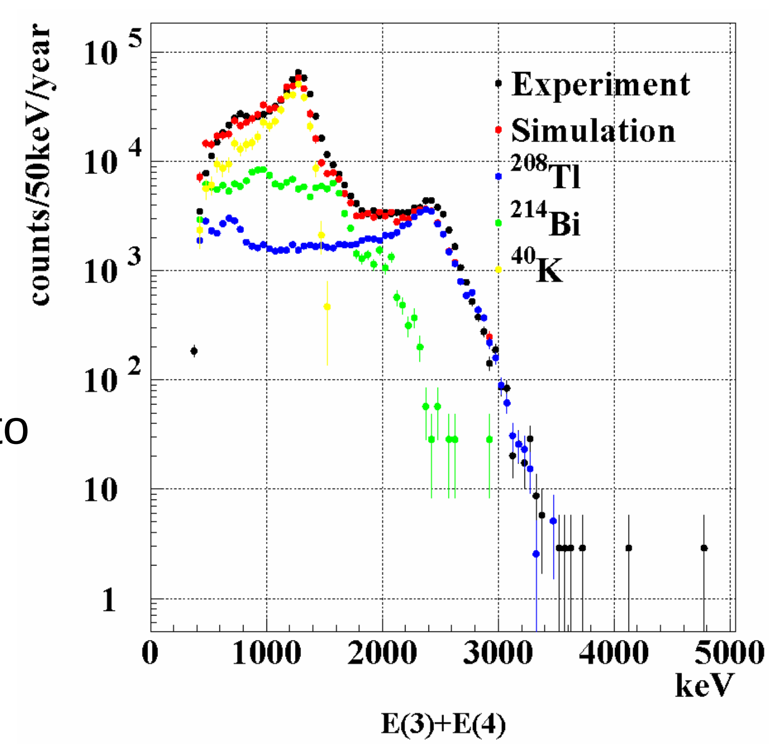


Sum Energy (w.o. NaI veto)

<u>Red：Simulation、Black：Data</u>

Yields in the simulation are fitted to the data

NaI 200keV Veto



Sum Energy (veto with NaI 200keV):

<u>^{208}Tl is a main background</u>

BiPo detector

Ultra Low Background Detector

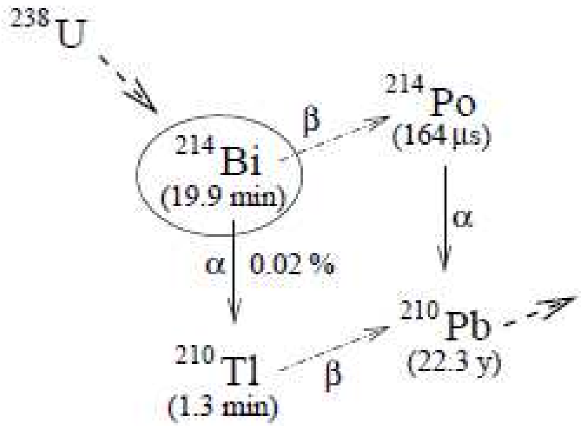
To achieve required purity,
the detector with high sensitivity
BiPo-detector

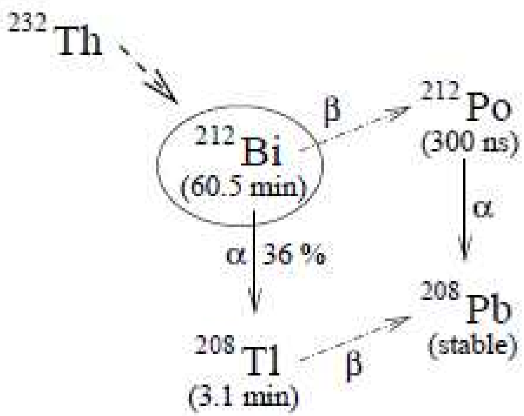
With 5 kg of ^{82}Se source foil (~ 12 m^2, 40 mg/cm^2)

2 μBq/kg of ^{208}Tl ➡ 50 (e^-, delay α) ^{212}Bi decays / month

ε ~ 6 % ➡ 3 decays / month

Background < 1 events/month is required !





Two possible designs to be studied in R&D

- Alpha scintillator with electron tracking detector
  (NEMO-3 technique)

- Multilayers scintillators plates without tracking

  (MOON-1 technique)

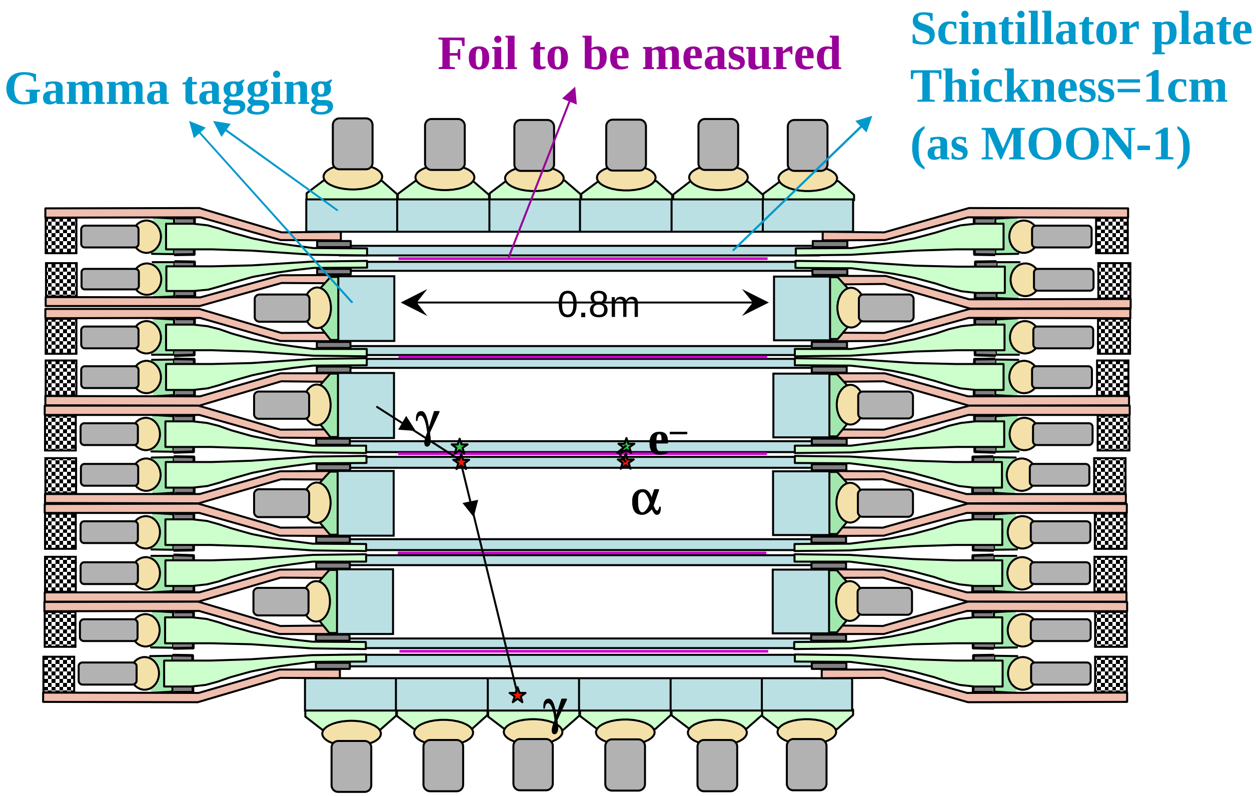
+ R&D Ultra thin scintillating detectors
for electron / α discrimination

Multi layers of scintillator plates

- Efficiency x 4
- Compact geometry
- Measurement of ^{214}Bi is not possible

  (α decay of ^{214}Po $T_{1/2}$ = 164 μs too large → random coincidence bkg)

  ⇒ we may use Radon emanation detector developed by Heidelberg



Summary

The next generation of track-calorimetric detector aims at high sensitive studies of Majorana neutrinos in the QD-IH (Quasi degenerate and inverted mass hierarchy) region by measuring neutrino-less double beta decays with effective mass sensitivity of $<m_{\nu}>$. ~30 meV.

MOON is compact detector to measure tons of isotopes

A prototype detector MOON-1 works, and shows the energy resolution of 7% FWHM for 3 MeV summed energy. It is just meets the requirement.

MOON type multi-layer detector is being proposed in superNEMO collaboration. The technical selection will be done with scientific competition. The proto-type detectors will be installed at Canfranc underground laboratory.

We have the agreement that the next generation of track-calorimetric detector will be constructed in the international collaboration