極低バックグラウンド素粒子原子核研究懇談会
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MOON
present status and perspective

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for the MOON collaboration

- Outline of the MOON detector
- Background rejection & Expected sensitivity
- Related topics
- Summary

MOON collaboration

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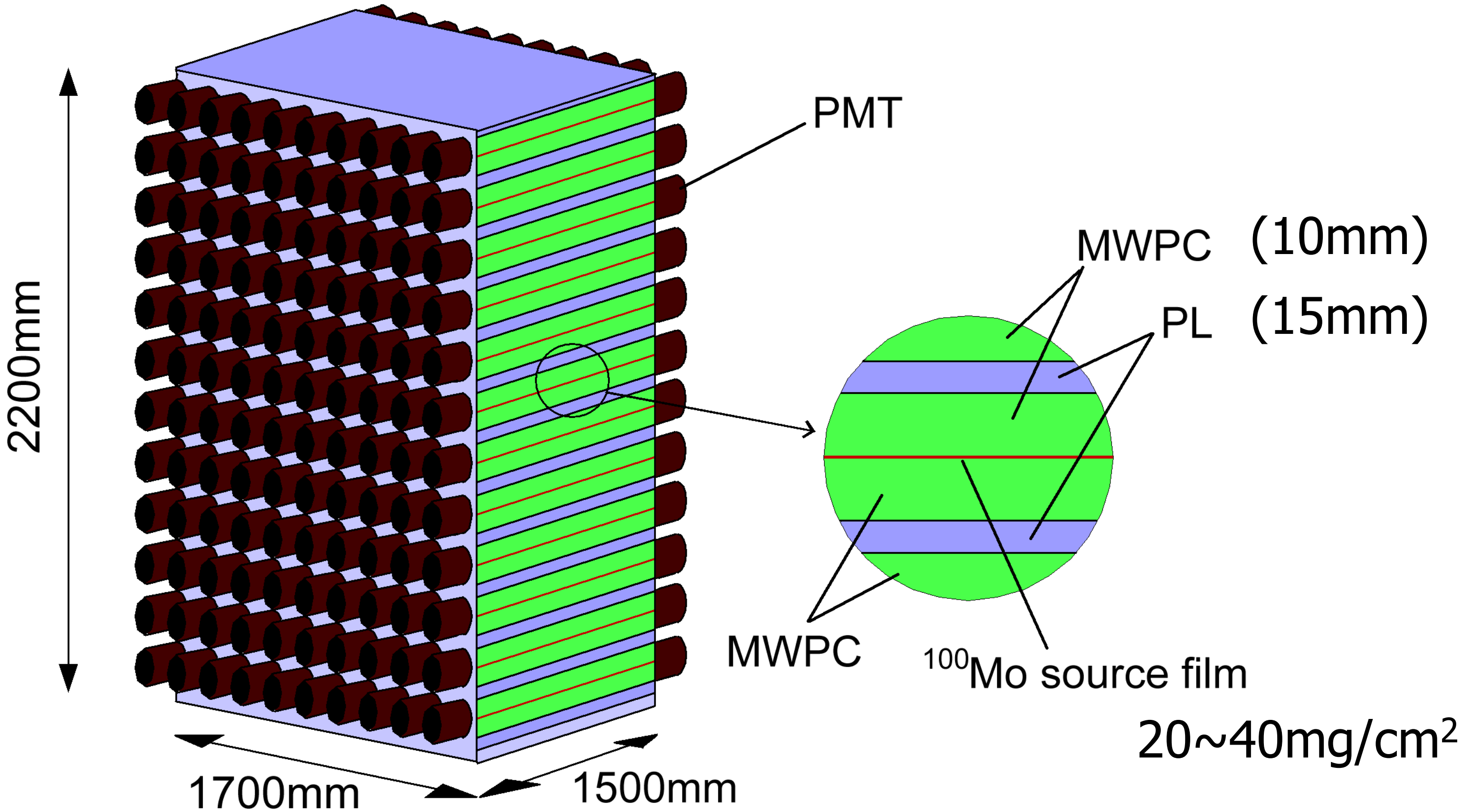
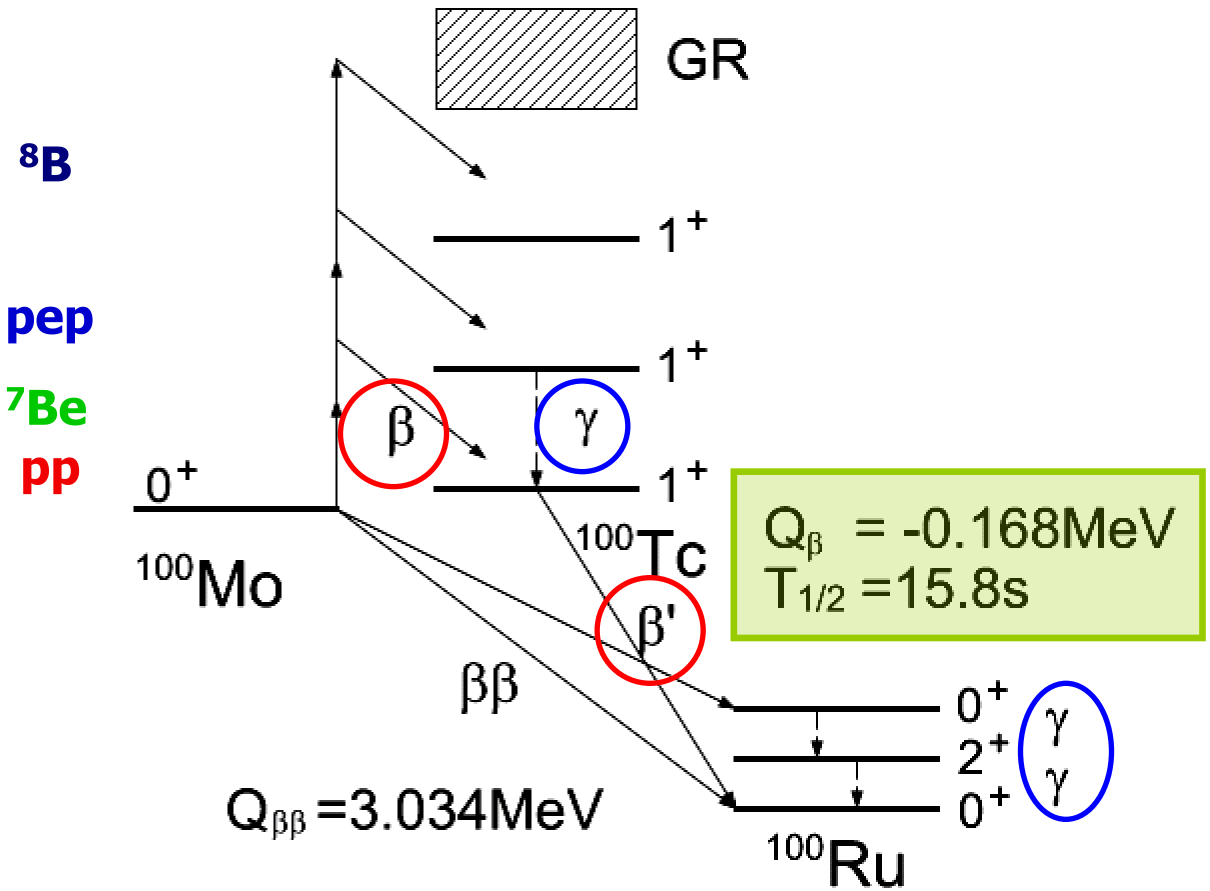
MOON **Mo/Majorana Observatory Of Neutrino**



1 unit = 60 layers = 30kg ββ source (t=40mg/cm^2)

Real-time detection of low-energy solar ν



Detectors

- **Plastic scintillators** (1.7m × 1.5m × 15mm/layer) :
  - β-ray energy & time, γ-ray veto
  - FWHM $\Delta E/(E_1+E_2)$ = 7%@3MeV → 5%

- **Wire chambers** (1.7m × 1.5m × 10mm/layer) :
  - gas mixture; Ar+CO_2
  - particle ID; β/γ
  - correction for position dependent response of PLs
  - delayed anti-coincidence with α, β
  - position separation of 5mm × 5mm
    (wire-spacing + charge-division or anode × cathode)

- **Active shields** : thick PL or NaI

Features

Multi-layers of source foils, scintillators and wire chambers

- capability to measure different ββ nuclei
- sensitivity to ββ energy- and angular- correlations
- good selectivity of ββ and BG
  with information of E, t, position

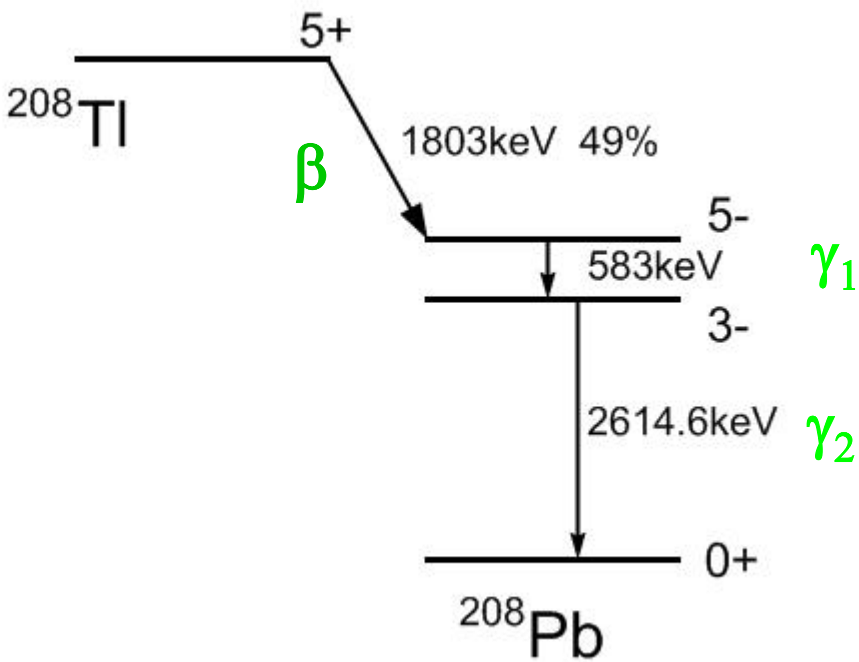
Compact and modular structure

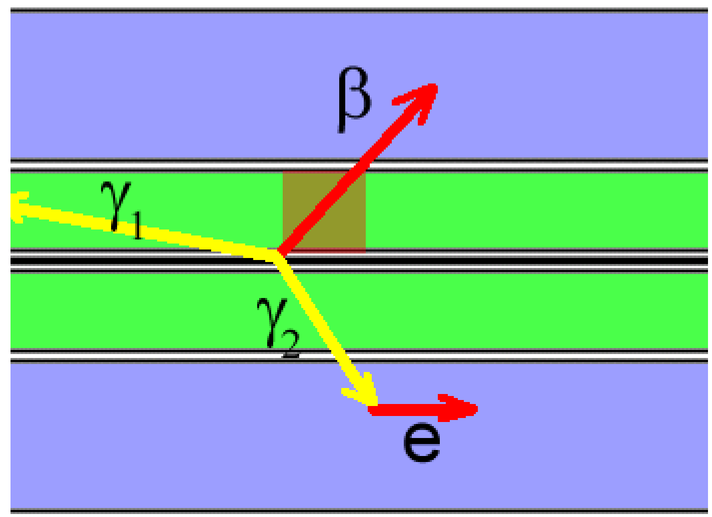
- scalable from sub-tons to multi-tons
- easy to shield against external & internal BG's
- large acceptance

Backgrounds

- Radioactive impurities with large Q_β : ^{214}Bi, ^{208}Tl
- (n,n′γ), (n,γ) by μ-induced neutrons
- 2νββ : $\tau_{2\nu}/\tau_{0\nu} > \sim 1/10^5$

^{208}Tl (Q_β=4.999MeV) : β-γ-γ in source foil

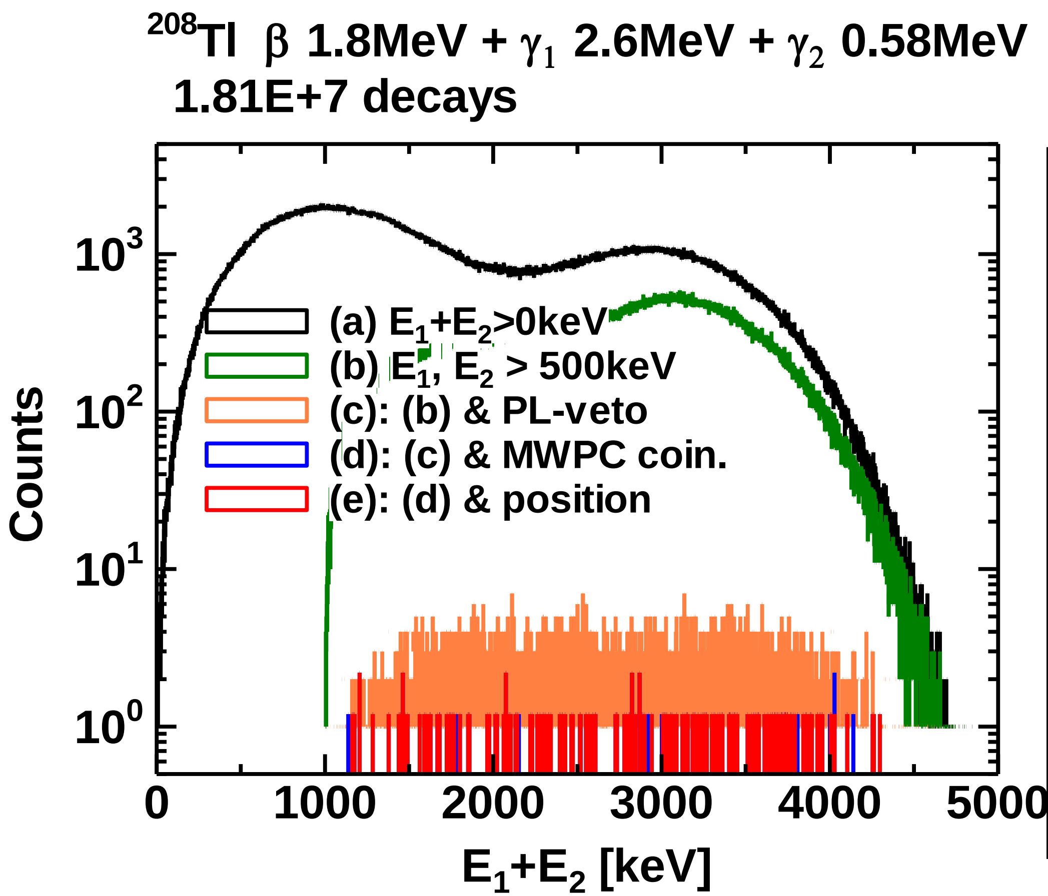




--- to be rejected with

- anti-coincidence by γ_1
- coincidence with MWPCs on both sides of source

Response for 1.8MeV β+583keV γ+2614keV γ



20mBq/ton ^{208}Tl in ^{100}Mo

Gate condition	Counts in 2.9-3.2 MeV [/ton/yr]
E_1+E_2 > 0keV	5280
E_1, E_2 > 500keV	2640
Veto by other PL	9
MWPCs on both sides coincidence	0.32
Track consistency	0.28

➡ **~0.3 events** for 1 ton·yr measurement

Neutron-induced γ-rays

Main components of MOON detector; ^{12}C, ^{1}H, ^{100}Mo, etc.

	Quantity [mole/unit]	σ (inelastic) (average) [b]	σ (capture) (thermal) [b]
^{12}C	1.1×10^5	0.4	0.0034
^{1}H	2.2×10^5	0	0.332
^{100}Mo	200	0.9	0.2
^{82}Se	244	0.8	0.799
^{150}Nd	133	1.25	15.9

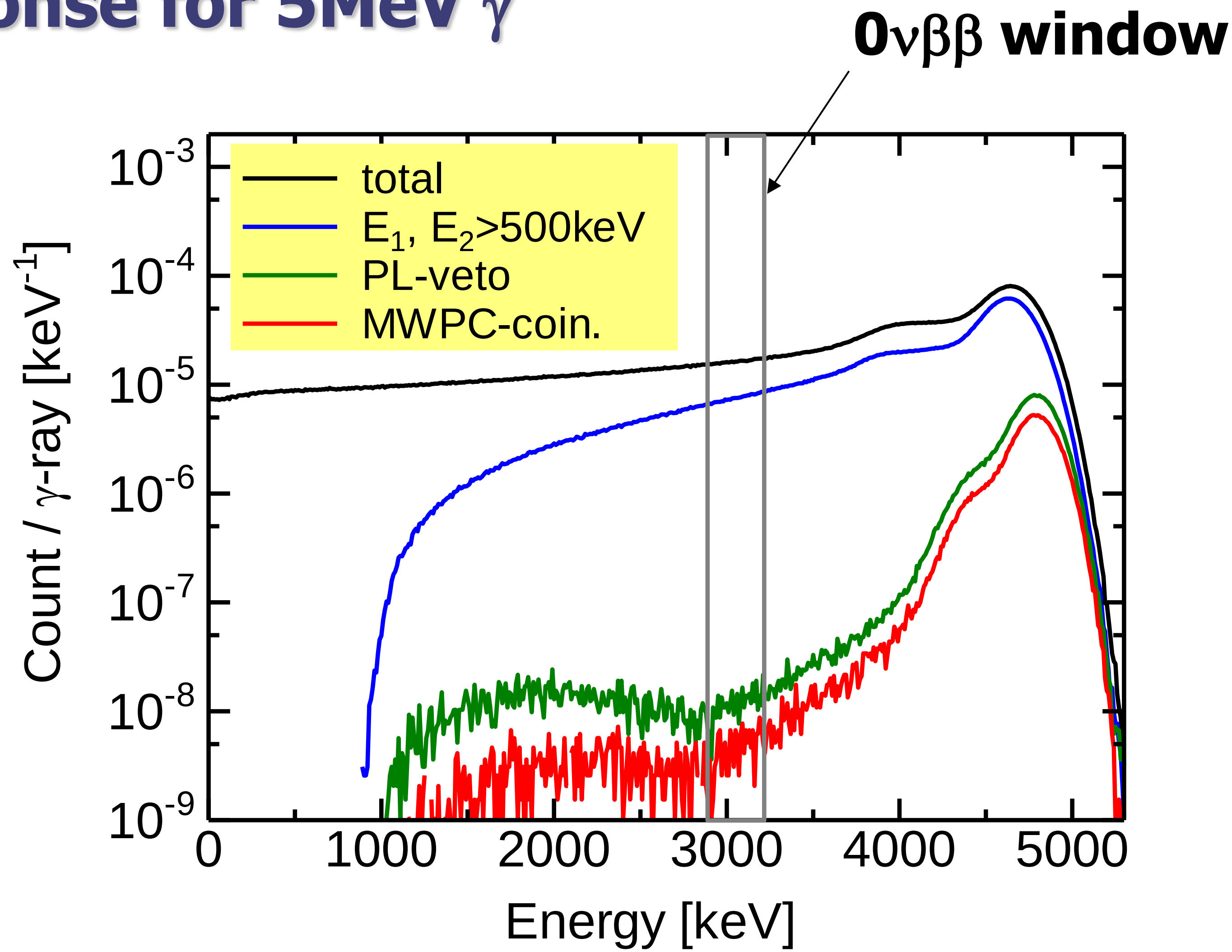
$^{1}H(n,\gamma)^{2}H$; Q=2.225MeV << $Q_{\beta\beta}$ of ^{100}Mo, ^{82}Se, ^{150}Nd…

Production rates of neutron-induced γ

Reaction	R_γ [unit^{-1} s^{-1}]
^{12}C inelastic (4.44MeV)	2.1×10^{-6}
^{100}Mo inelastic	3.3×10^{-8}
^{12}C thermal capture	1.9×10^{-8}
^{100}Mo thermal capture	5.5×10^{-9}
Total	2.2×10^{-6}

Φ_n (E_n < 20MeV) ~10^{-8} n/cm^2/MeV/s at 2000m w.e. (Gaitskell 2001)

Response for 5MeV γ

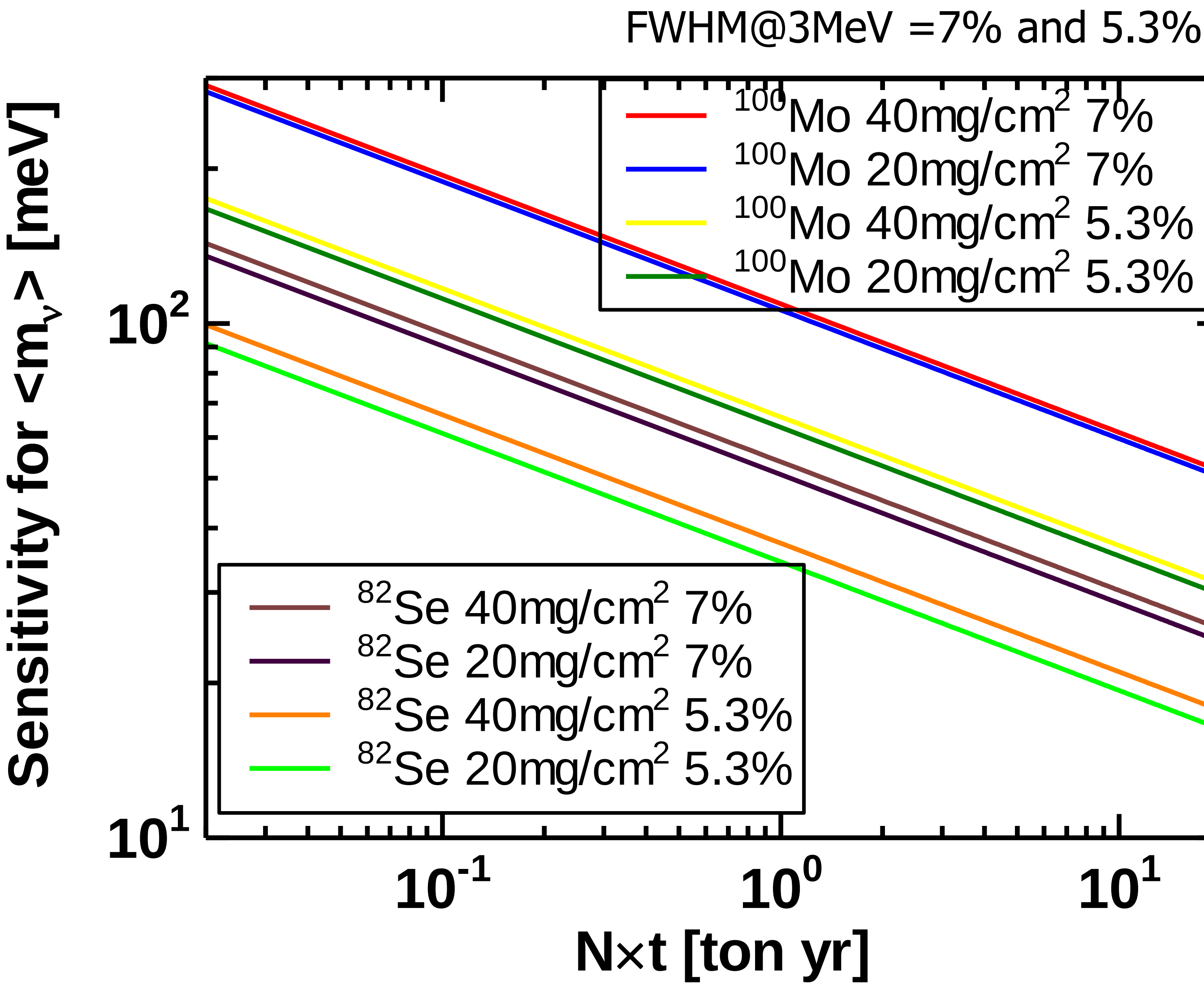


~0.2 events for 1 ton·yr measurement at 2000m w.e.

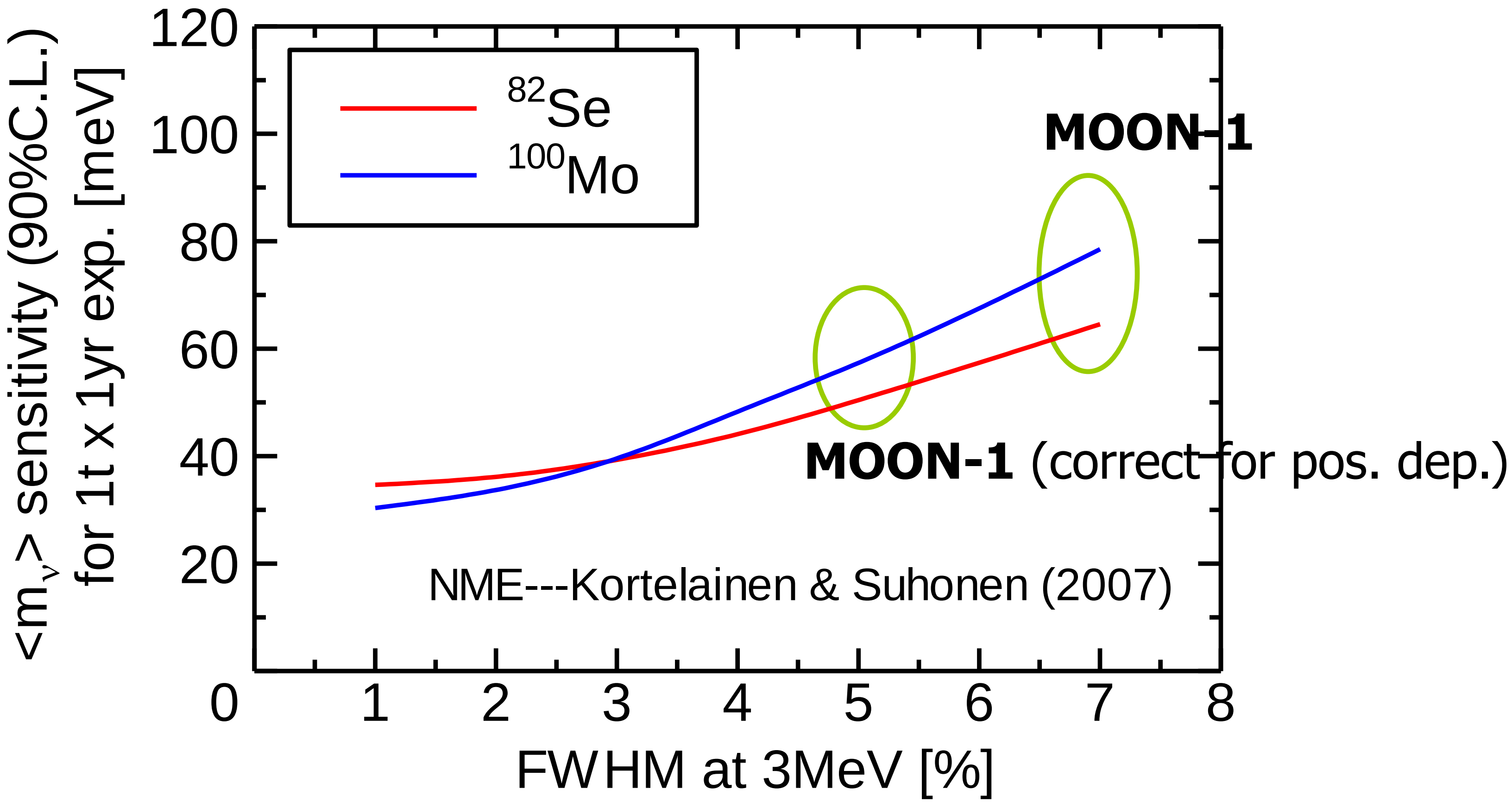
Estimated background rates ; summary

Background source	Rate [/ton/yr]
^{208}Tl β-γ-γ in source	$<\sim 0.6$
^{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

Sensitivity for $<m_\nu>$



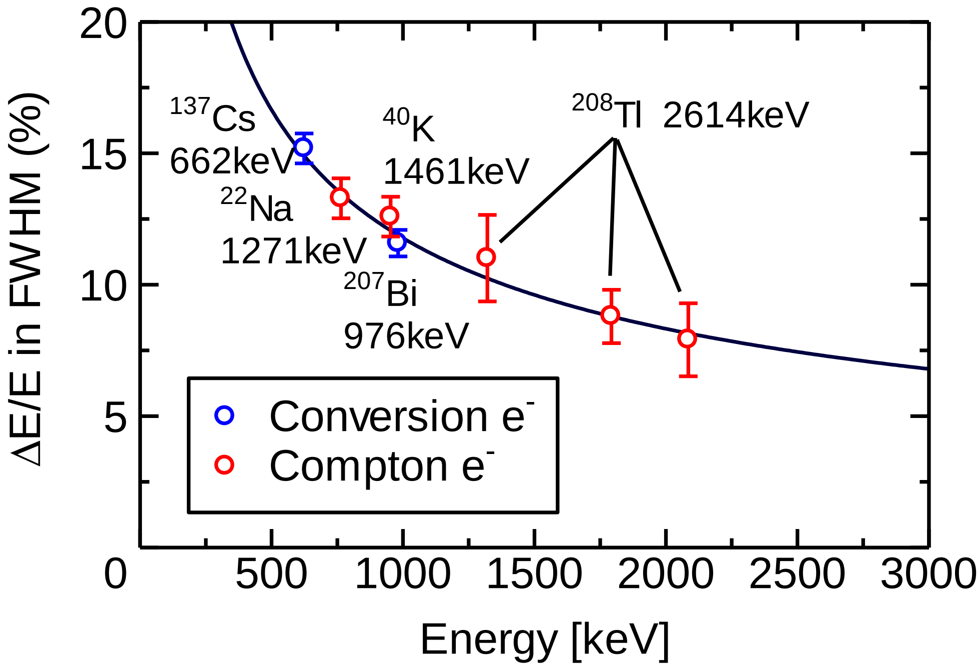
Sensitivity vs. Energy resolution

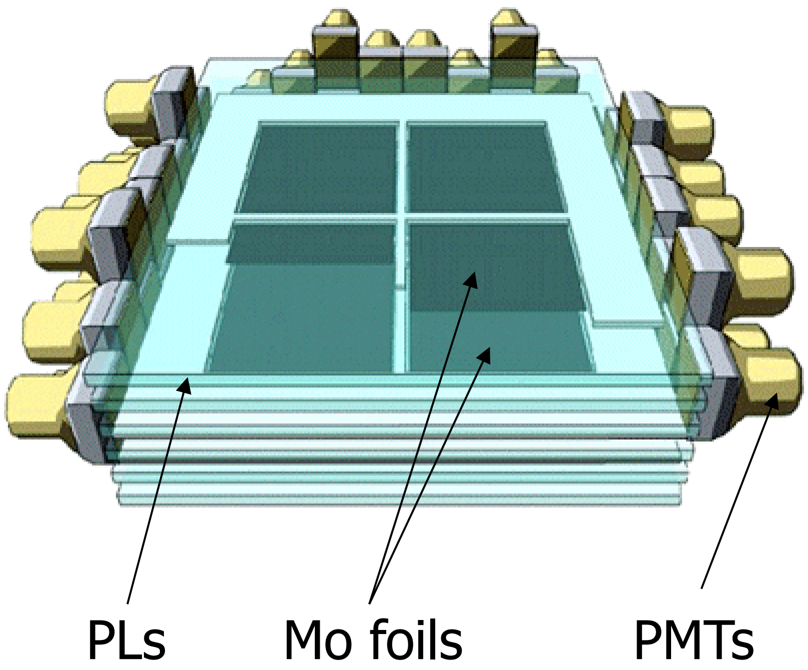


MOON-1

H. Ejiri, Czeck. J. Physics, 56 (2006) No 5, 459.
H. Nakamura, M. Nomachi et al., JPSJ 76, 114201 (2007)

6-layers of PL 53×53×1cm^3, Mo-Foil 142g @20mg/cm^2×2





ΔE/E(FWHM) = 7% at 3MeV

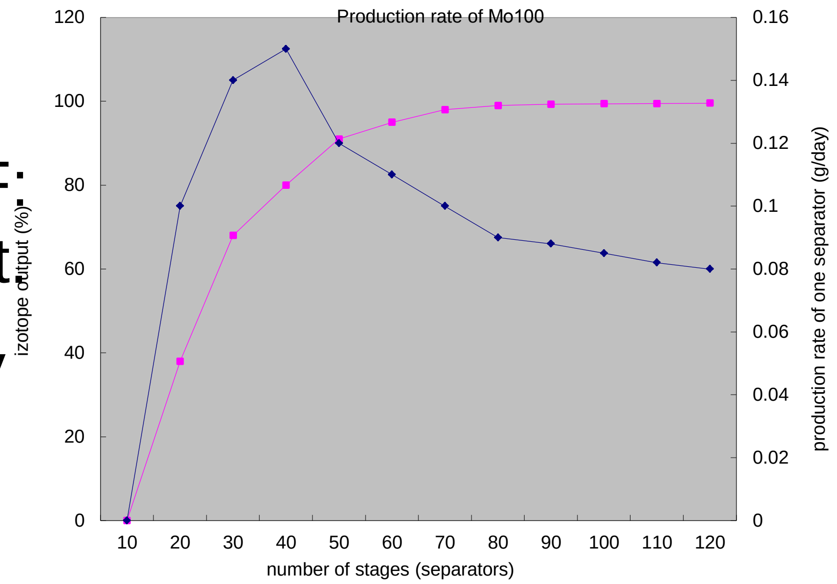
→ 5% with correction for position dependence

^{100}Mo enrichment

Ready for multi-ton 9.6% to 90%
Centrifugal technology at VNIIEF:
Osaka JINR VINIIEF joint project.

6K centrifuges of MoF_6 100 kg/y
Medical uses by (γ,n)(μ,n)

H.Ejiri T.Shima et al., JSPS , 2012, 2013



Road map

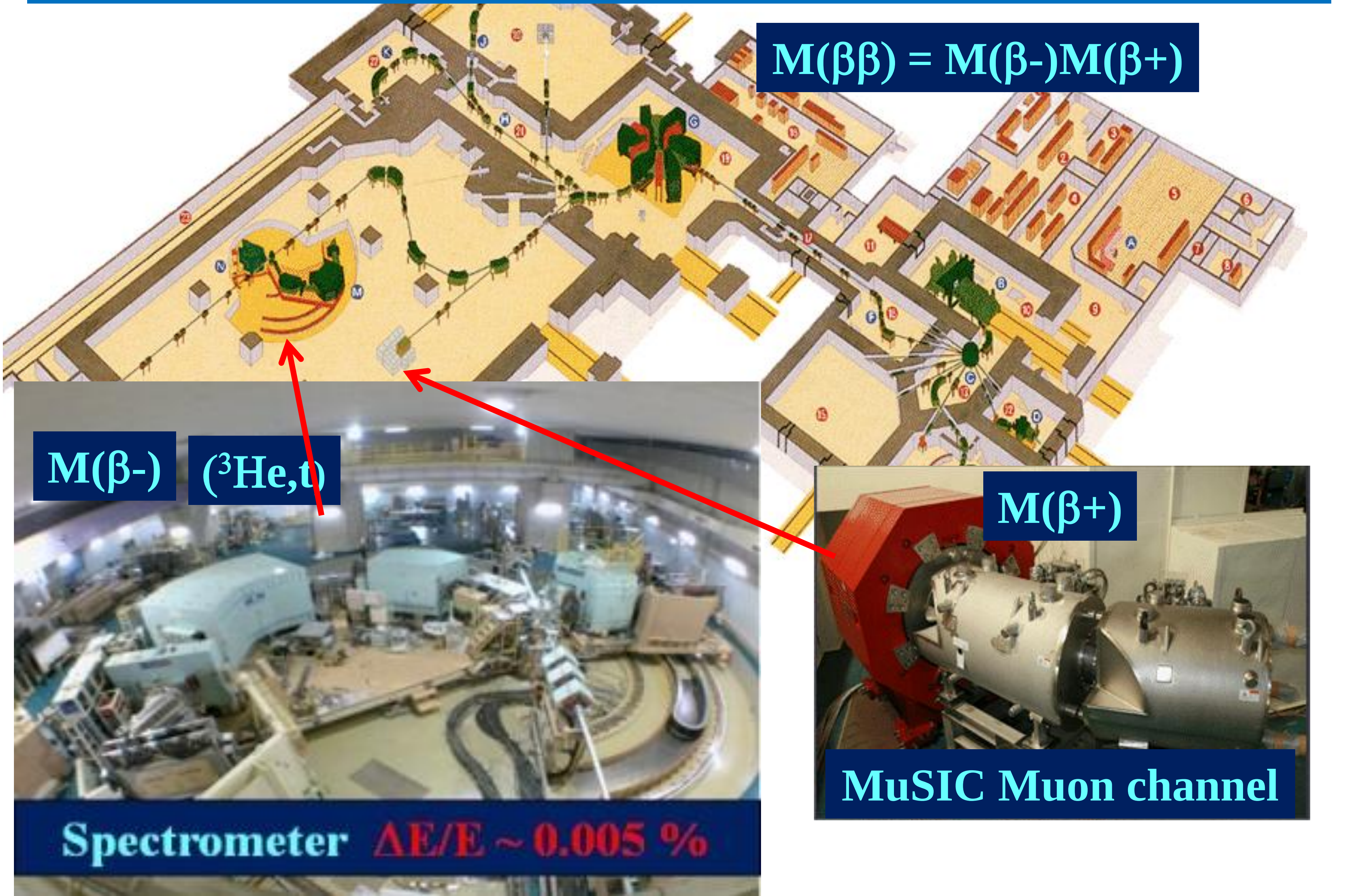
FWHM= 5.3% or 4% @3MeV

Phase	$N_{\beta\beta}$ [t] × T [y]	$T_{1/2}$ [10^{26} y]	$\langle m_\nu \rangle$ [meV] (90%CL) ^{82}Se		^{100}Mo		# of unit	Cost [GYen]
			5.3%	4%	5.3%	4%		
1	0.03 × 2	0.45	76	54	133	77	1	1
2	0.12 × 4	3.5	46	32	79	46	4	4
3	0.48 × 4	10.1	32	22	56	32	16	16

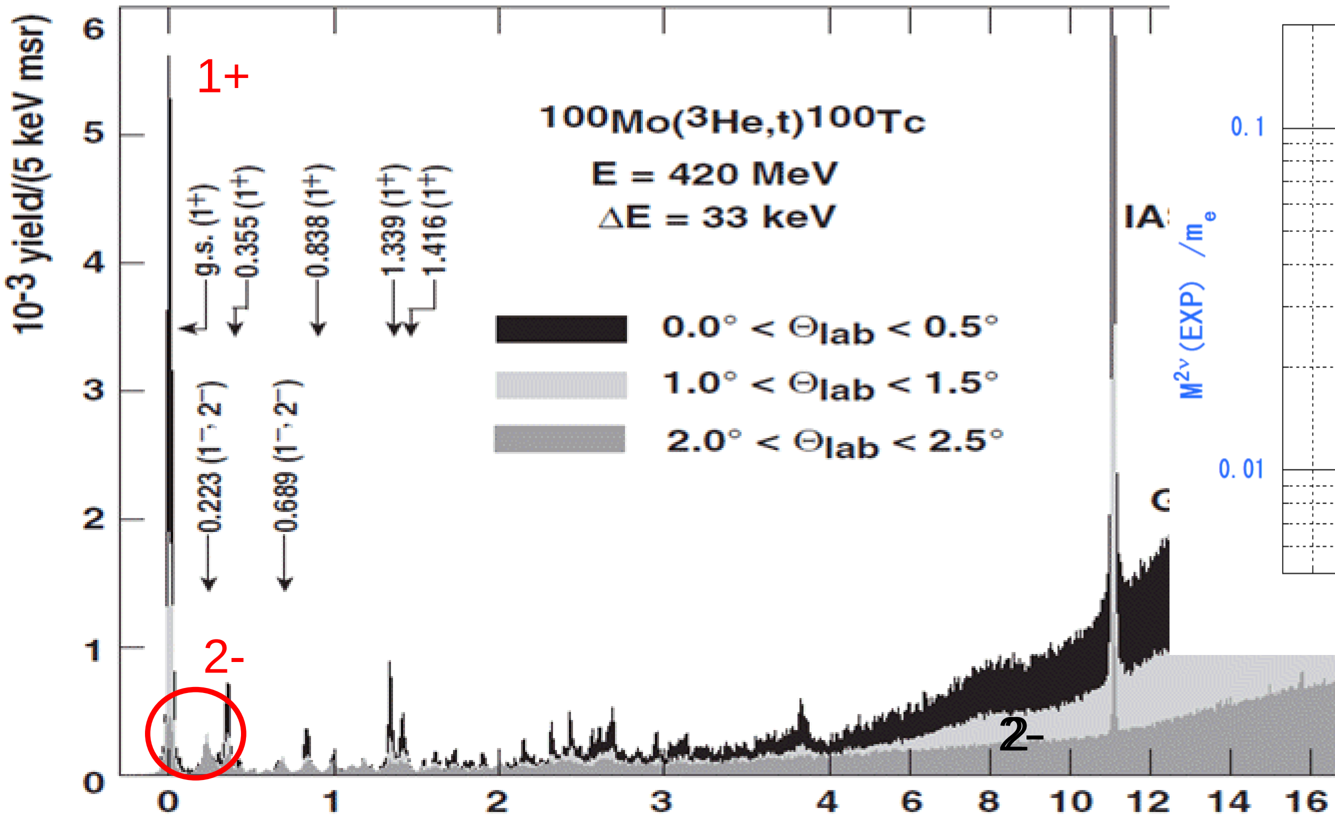
FY	2013	2014	2015	2016	2017	2018	2019	2020	2021
Phase-1	R&D	Construction	Construction	Commissioning	Run	Run			
Phase-2			R&D for PL	R&D for PL	Construction	Construction	Run	Run	Run
Phase-3	Study for matrix element		Selection of isotope; Se or Mo		R&D for FPD	R&D for FPD	Construction	Construction	Construction

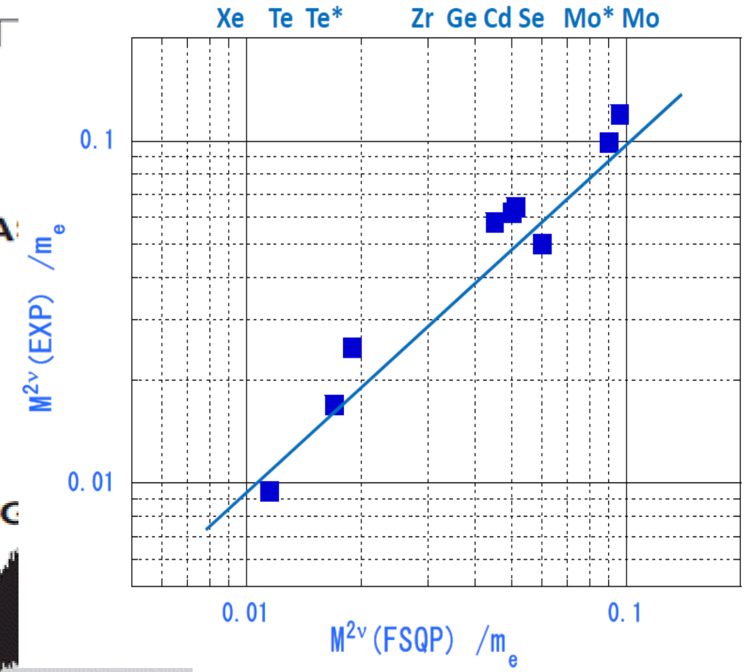
RCNP Osaka Cyclotron Exp. for ν-response studies

H. Ejiri, D. Frekers, T. Shima et al.



RCNP PR C 2012-13, Ge, Se, Zr, Mo, Te, Xe DBD



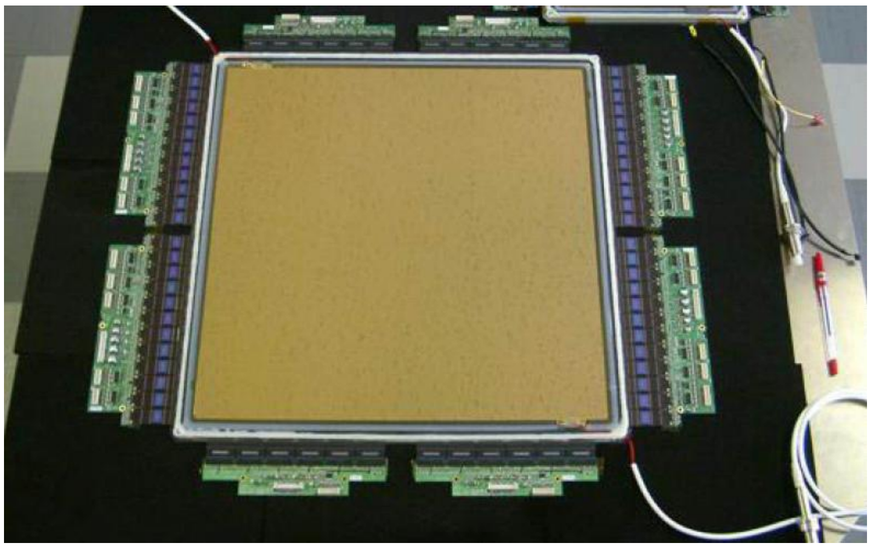


H. Ejiri JPSJ
78 (2009)
81(2012)

$M^{2\nu}$ with M(1+) by CER reproduce $M^{2\nu}$(EXP) **g_A (exp) =0.9.**

M(J=2-) for $M^{0\nu}$ is observed/identified. The exp. suggests CER provides information on $M^{0\nu}$ and on g_A=0.5.

Flat Panel Detector for digital X-ray radiography



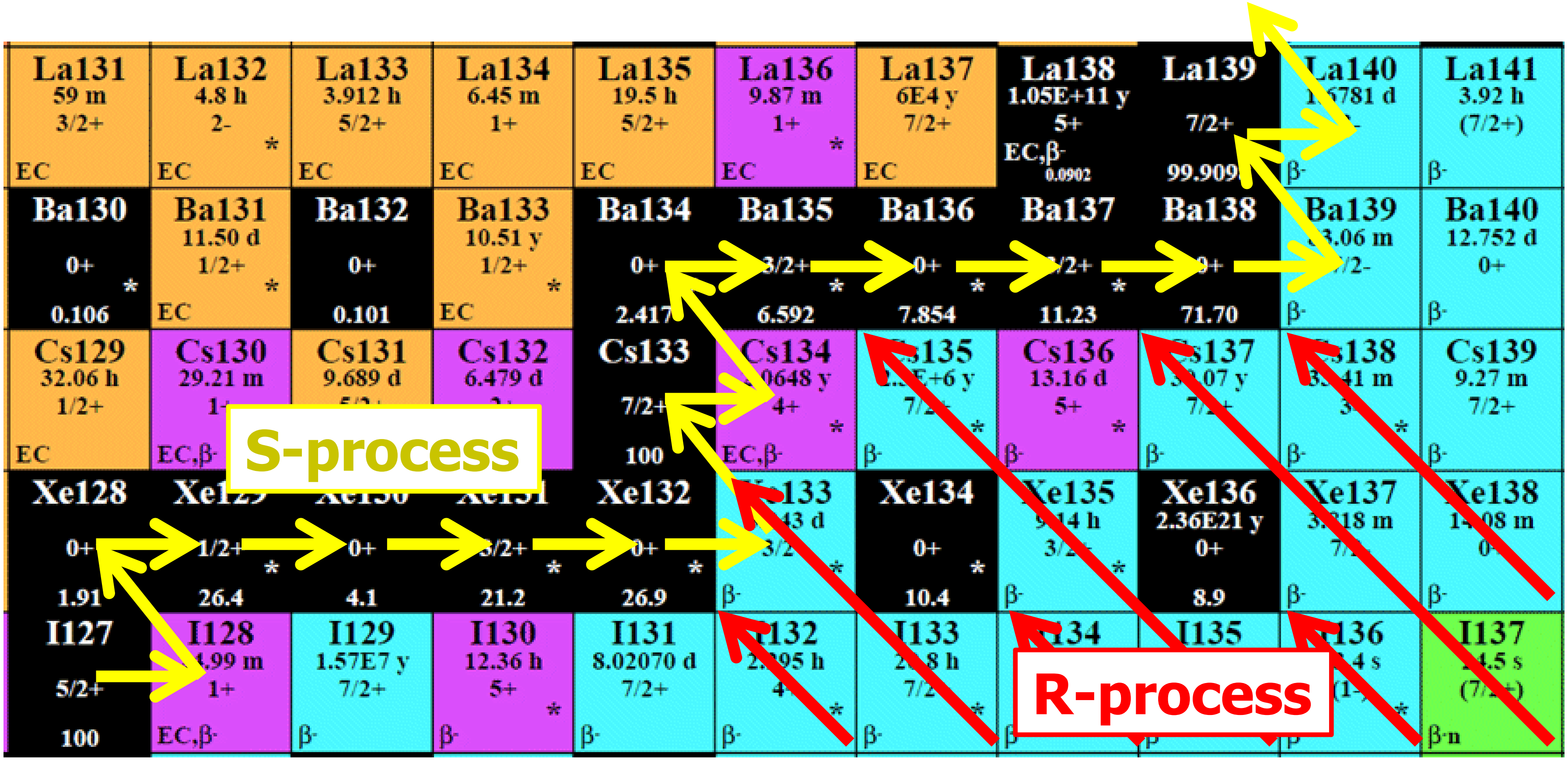
SHIMADZU 17” × 17” FPD
(8M pixels)

- amorphous Se SSD
- position-sensitive
- available on market

→ **Active source plane**

- position resolution for vertex
- measure energy loss in source
  → improve effective ΔE
- detect delayed α-rays

Another aspect of ββ nuclei

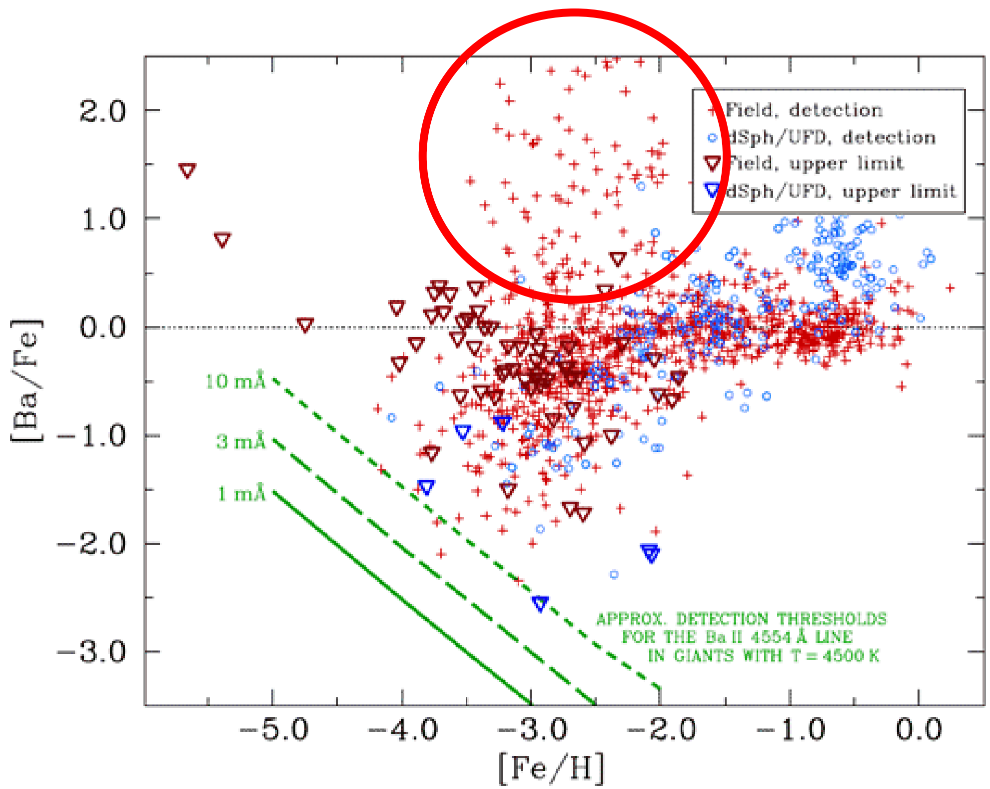


Parent of ββ decay = pure r-nuclei

Daughter of ββ decay = pure s-nuclei

Barium

in solar-system abundance is mainly from s-process,
but is dominated by r-process in metal-poor stars.



I.U. Roederer, 2012

$$f_{odd} = \frac{N(^{135}Ba) + N(^{137}Ba)}{N(Ba)}$$

= 0.11±0.01 for s-only

0.46±0.06 for r-only

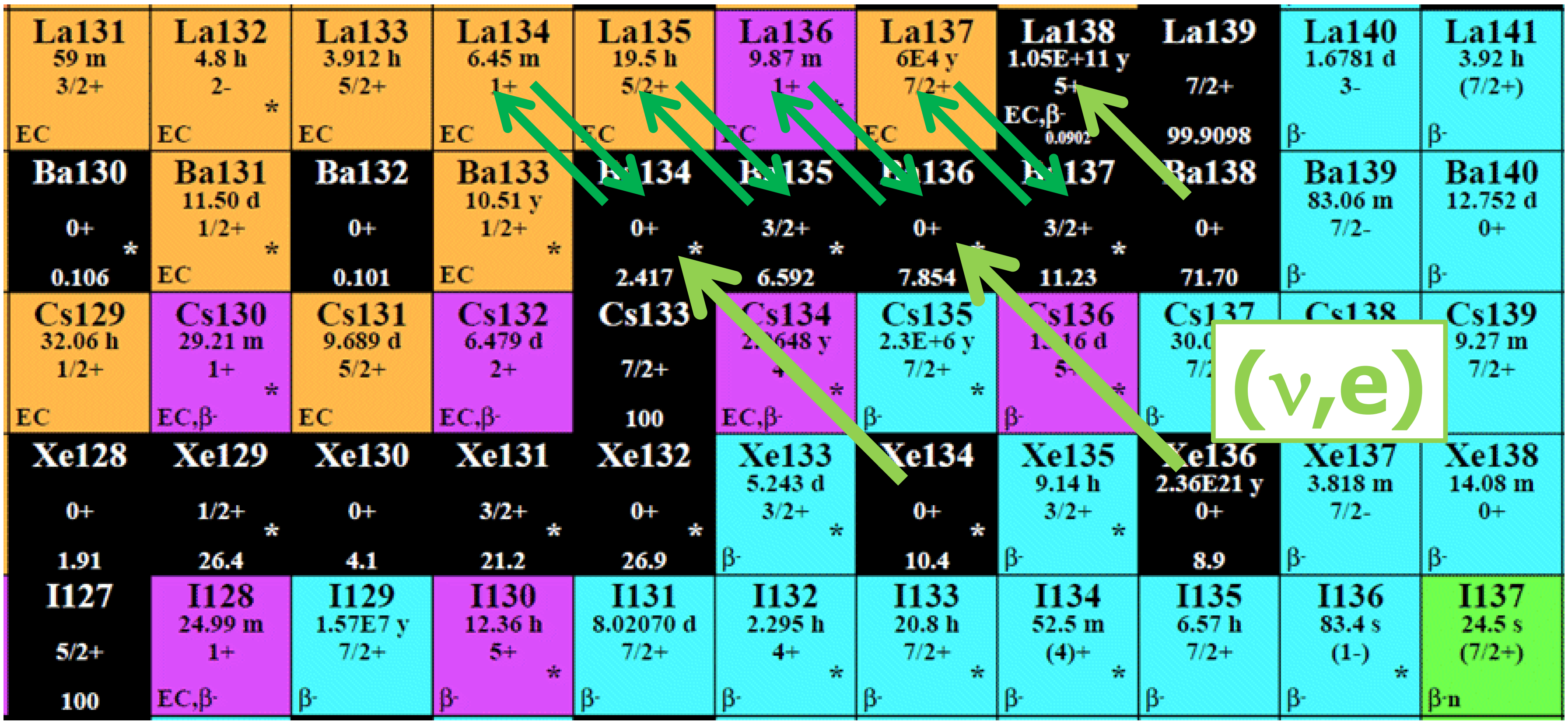
0.17 in solar system

(Anders & Grevesse 1989)

0.18±0.08 for MP stars

Gallagher, Aoki, Honda et al. 2012

ν-process

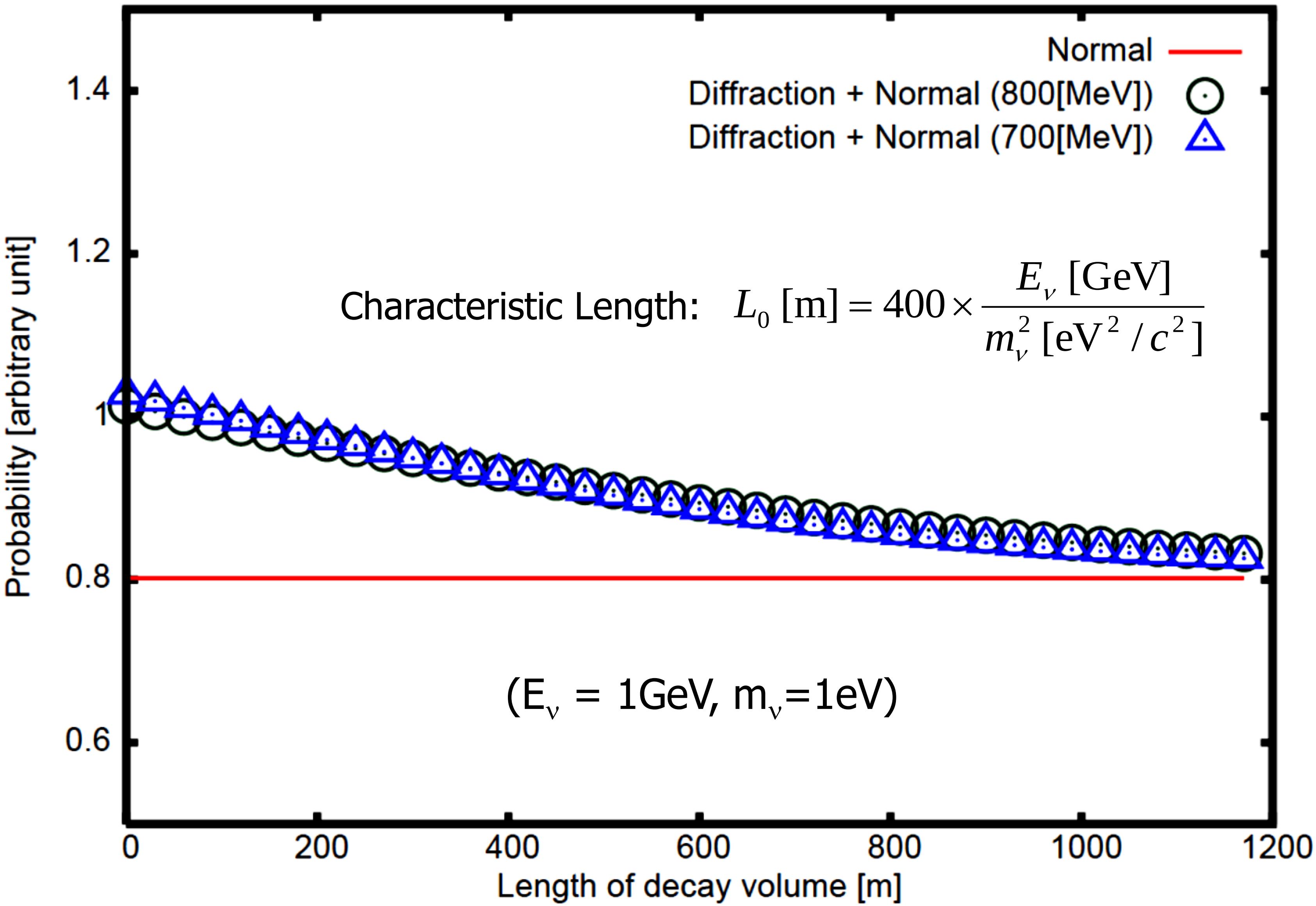


^{134,136}Xe(ν_e,e) may play crucial role in production of ^{134,136}Ba in r-process.

Cf. ^{138}La is well reproduced with ν-process on ^{138}Ba.

Summary

1. **MOON** is one of the feasible solutions for next-gen. $0\nu\beta\beta$ experiment, because of its high efficiency, good resolutions (E, x, t), compactness, scalability, etc.
2. Sensitivity; $<m_\nu>$ ~ 20 - 60 meV for 2 ton·yr (~16Gyen).
3. Applicable to astronomical ν detection, measurement of ν-induced reaction on $\beta\beta$ nuclei for nuclear astrophysics, study of ν-diffraction effect, etc.
4. Study of spin-isospin response of $\beta\beta$ nuclei is crucial to choose a good $\beta\beta$ source.
5. Collaboration with Milan group for development of scintillating bolometer ($CaMoO_4$)



K.Ishikawa and Y.Tobita, arXiv:1106.4968

- independent of type of ν (Dirac or Majorana)
- sensitive to absolute value of ν rest mass

Experiment	L_{near} [km]	L_{far} [km]	E_ν [MeV]	L_0 [km] (m_ν=50meV)	L_0 [km] (m_ν=10meV)
K2K	0.3	250	1200	192	4800
T2K	0.28	295	600	96	2400
KamLAND	-	180	3	0.48	12
OPERA	-	730	17000	2720	68000
LSND	-	0.03	35	5.6	140
Double Chooz	0.4	1	3	0.48	12

$L_0 \propto E_\nu$, $\Omega \propto 1/L_0^2 \propto 1/E_\nu^2$, $\sigma_\nu \propto E_\nu$

$\therefore$ Event rate $\propto 1/E_\nu$

\- - - Lower energy neutrinos are more useful.

Example. ^{11}C (Q_β=960.2keV, $T_{1/2}$=20.33min.) for ν source

L_0 = 61.2m for m_ν=50meV, 1.54km for m_ν =10meV

Detector：2m × 2m × 2m, ^{11}C： 10^{13}Bq ⇐ BRILLIANT@RCNP

⇒ Event rate: ~1cpm@61.2m

~2.3cpd@1.54km