come to the Seminar on Neutrinos & MOON

Hiro Ejiri

MOON for ββ–ν, and low energy solar and supernova ν's.

Molybdenum Observatory Of Neutrinos

http://ewi.npl.washington.edu

Hiro Ejiri JASRI Spring-8, RCNP Osaka Univ.

For the MOON collaboration

Neutrino as a window for new astro particle physics

- Particle physics : ν oscillations gives ν flavor mixing and square of ν mass differences.
- Majorana or Dirac in nature ?
- Absolute ν masses and mass spectra ?
- CP phases ?

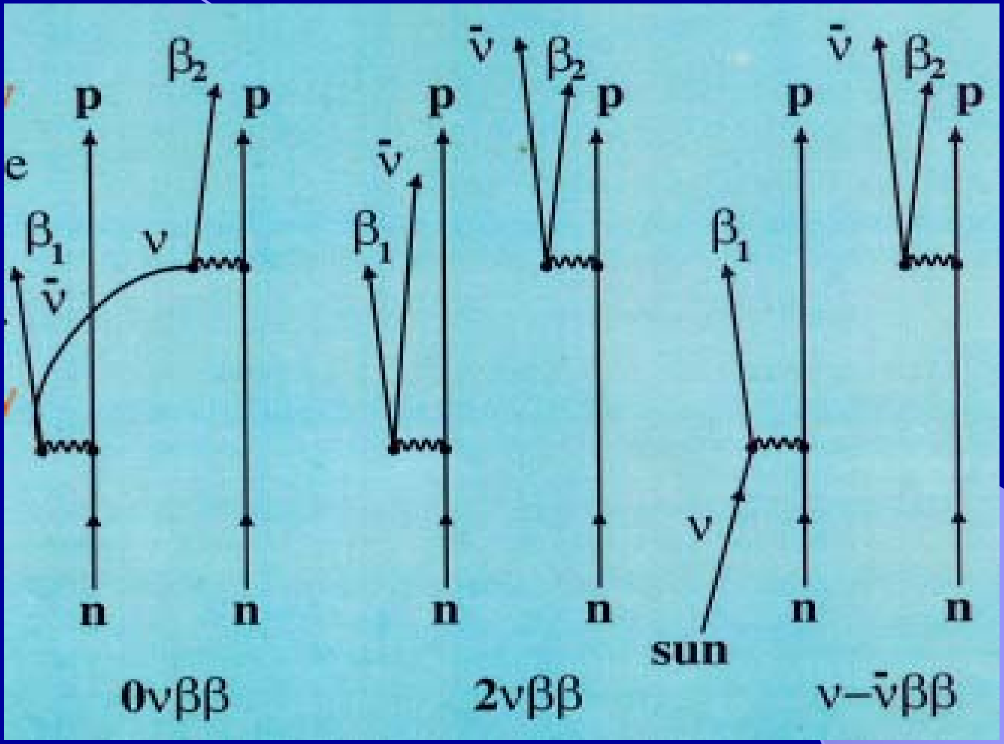
- Astrophysics : ν's from the sun and SN are observed.
- Major pp-ν from the sun ?
- ν spectra from SN ? and anti-ν the earth ?

- Nuclear physics : ν's are studied in nuclei as micro laboratories.
- How do nuclei respond for ν's ?

MOON Objectives

ν studies in ^{100}Mo : large responses for ββ–ν & low E $ν_e$'s .

- **Double beta (ββ) decays**
- **with $m_ν$~0.03 eV.**
- **Low E solar and SN $ν_e$.**



- **Two charged particle (β,β)**
- **spectroscopy with high**
- **localization in time & space.**

- **MOON, a super module of**
- **~1 ton ^{100}Mo & scintillators with modest volume and realistic purity**

H.Ejiri,, Phys, Rev. Lett.,85 (2000) 2917

Contents

- 1. MOON for ββ decays and ν masses
- 2. MOON for astro ν's:
  Low energy solar and supernova ν's
- 3. MOON detector
- 4. Detector R&D
- 5. Concluding remarks

1.MOON for Double Beta Decays and Neutrino Masses

•

ββ schemes

$2\nu\beta\beta$ $\Delta L=0$

M(τστσ) Res.

$0\nu\beta\beta$ $\Delta L=2$

Majorana nature

$$< m_\nu > = \Sigma\, m_j c_j v_j^2$$

Absolute mass scale

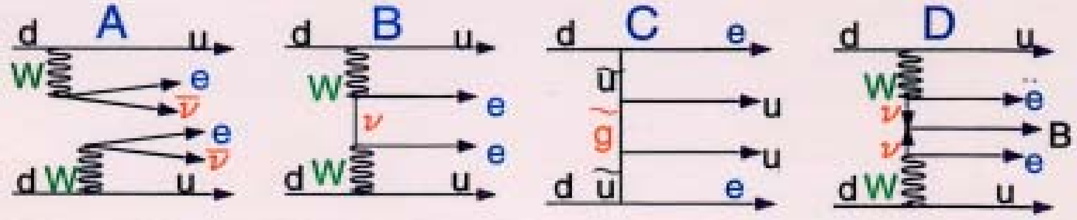
in 0.1-0.01 eV range

as suggested by ν

oscillatioin

$M^{0\nu}$ is crucial.

Katrin absolute e-ν mass.



A. $2\nu\beta\beta$ within SM

$T^{2\nu}=G^{2\nu}|M^{2\nu}|$ $\quad G^{2\nu} \propto Q_{\beta\beta}^{11}$

$M^{2\nu} \propto M_{GT}(\sigma\tau\sigma\tau)+M_F(\tau\tau)$ S-wave β

B. $0\nu\beta\beta$ with m_ν, $M(W^R)$, R/L Mixing

$T^{0\nu}=G^{0\nu}|M^{0\nu}|^2(\langle m_\nu\rangle+\langle\lambda\rangle+\langle\eta\rangle)^2$ $\quad G^{0\nu} \propto Q_{\beta\beta}$

$M^{0\nu} \propto M(h(r_{12}), p_1\ p_2, \sigma_1\sigma_2\tau_1\tau_2)$

Neutrino Potential, Recoil, etc for ν-exchang

$\langle m_\nu\rangle = \Sigma m_j U_{ej}^2$

$\langle\lambda\rangle = \lambda\,\Sigma U_{ej}\cdot V_{ej}$ $\quad \lambda=(M_W^L/W_W^R)^2$

$\langle\eta\rangle = \eta\,\Sigma U_{ej}\cdot V_{ej}$ $\quad \eta = W_L/W_R$ Mixing

C. $0\nu\beta\beta$ with SUSY Exchange ($\tilde{g}$)

$T^{0\nu}(\tilde{g})=G\,f^2 M(\tilde{g})\,A\,(M(\tilde{g}))/(M(\tilde{u}))^4$ $\quad f=L-B\neq 0$ Int.

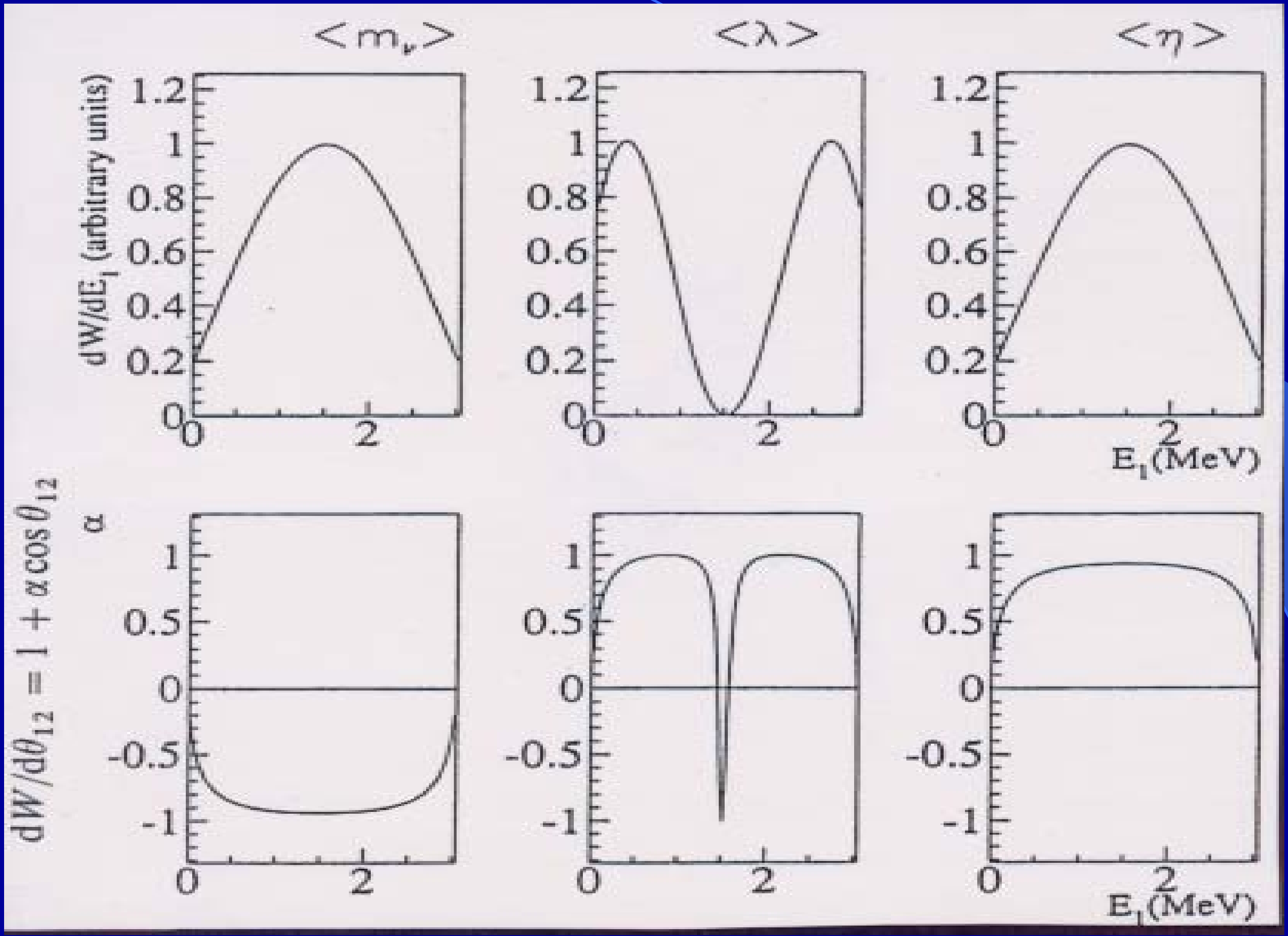
D. $0\nu\beta\beta$ M with Majoron (G-Boson for L-B Breal

$T^{0\nu M} = G^M(M^B)^2 \langle g_M\rangle^2$

$\langle g_M\rangle = \Sigma g_{jk} V_{ej}\cdot V_{ej}$ $\quad g_M$: M-ν Coupling

Energy and Angular Correlations

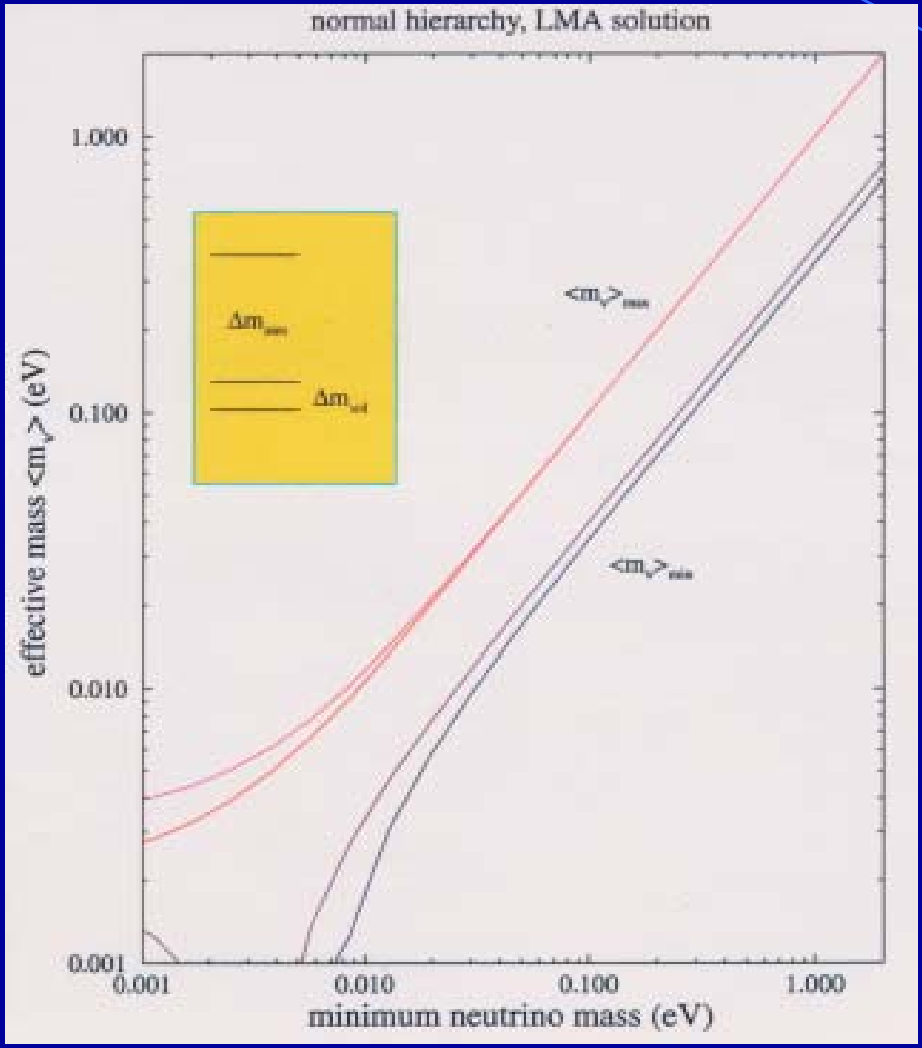
Doi Kotani Takasugi 85

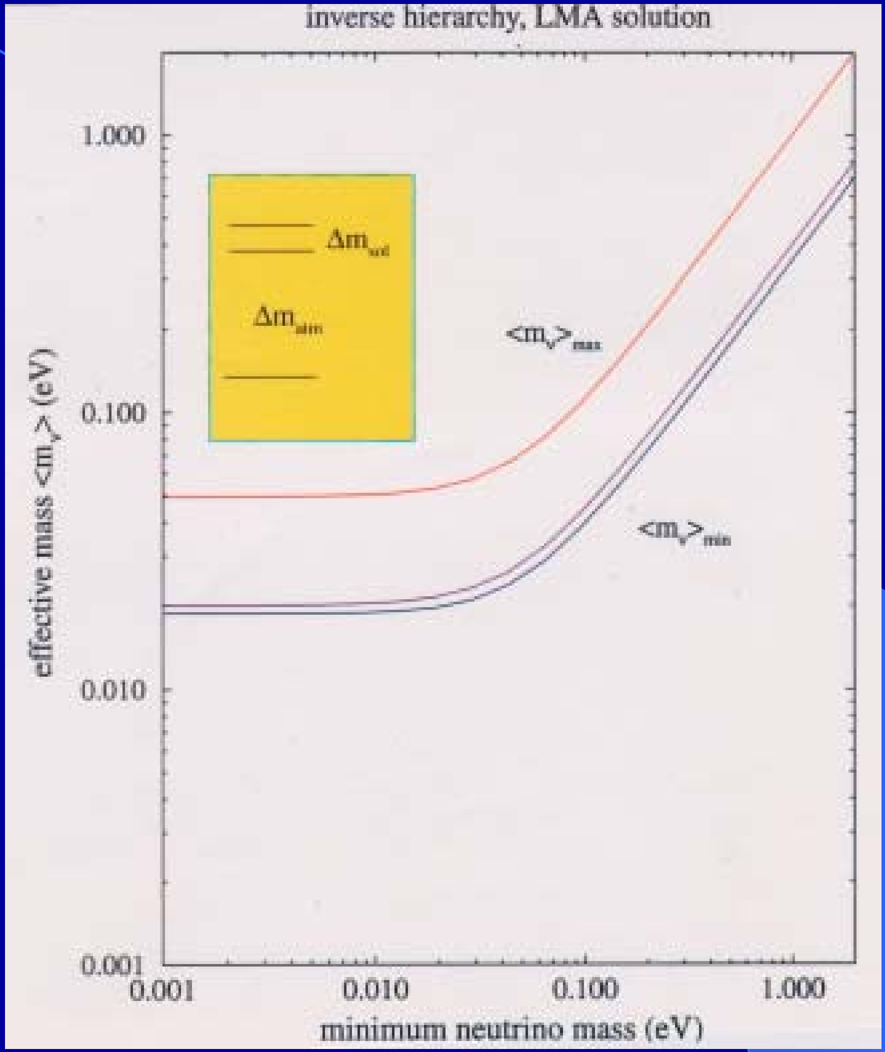


- ν mass term by energy (E1 ~ Q/2) &
- angular (180 deg.) correlations.

Effective ββ Neutrino masses

P.Vogel 2001 Normal and Inverse hierarchy with LMA





Present Status of ββ for ν mass

Inclusive ββ

- ^{128}Te Geo-chemical (MPI, others) < 1.6 eV
- ^{76}Ge H.M. IGEX , Ge Detectors < 0.3-1.3 eV,
- ^{130}Te Cryogenic Bolometor < 1.3-2.5 eV

Exclusive ββ spectroscopic studies.

- ^{100}Mo ELEGANT, ^{150}Nd, < 1.5 – 3 eV
- NEMO will search for ~ 0.3 eV region.
- All depend on nuclear matrix elements.

Limited by the detector sensitivities of S_D~ 0.3-1.5 eV.

$$m_\nu^{-1} \sim M^{0\nu}\, k(Z)\, Q_{\beta\beta}^{2.5}\; N_{\beta\beta}^{1/2}/[\Delta E\, N_{BG}]^{1/4}\, t^{1/4}$$

- Large Sensitivity: Large Detector with $N_{\beta\beta}$ ~ tons to get the ν-
- mass sensitivity of 0.01~0.05 eV.
- Next generation ββ detectors of 0.01~0.05 eV with tons of nuclei
- ^{76}Ge, ^{130}Te, ^{136}Xe, ^{100}Mo

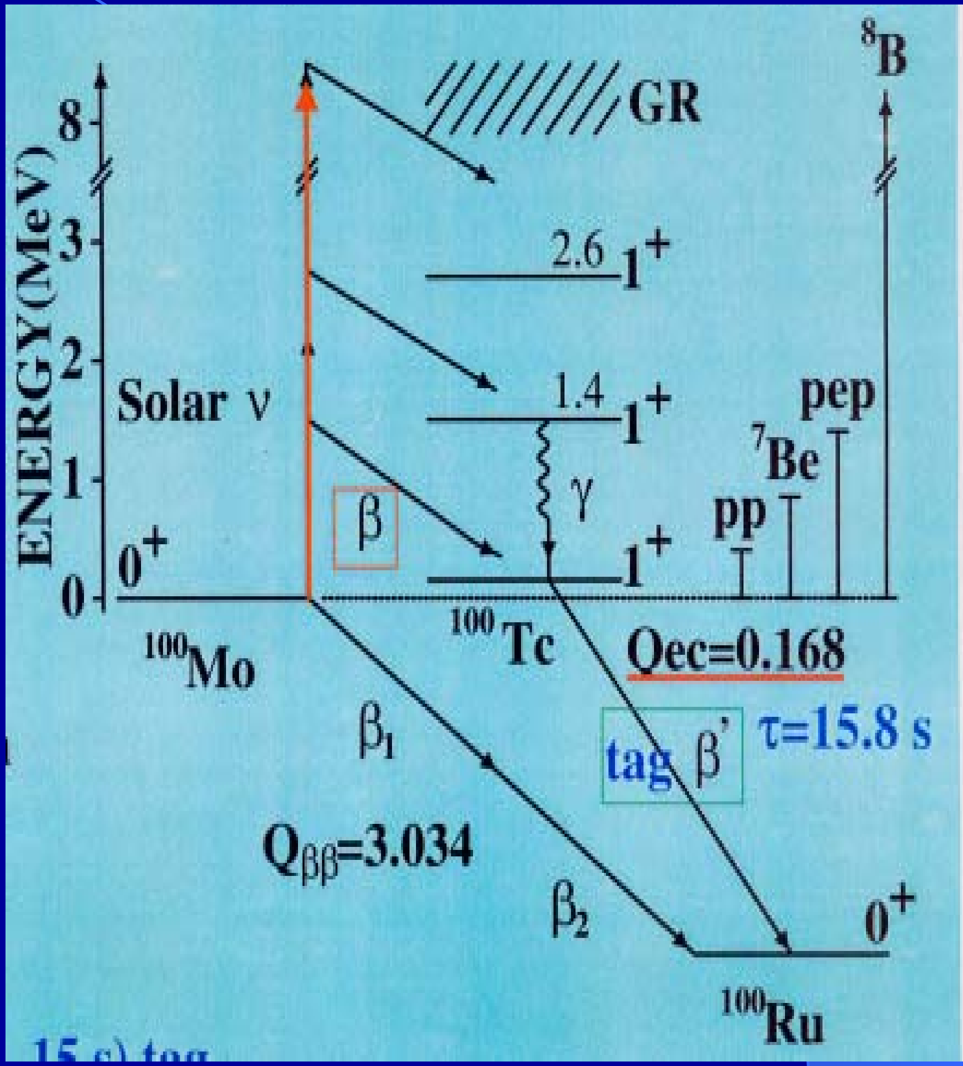
Unique features of MOON for ββ

1. Large Q = 3.034 MeV leads to
   large rate 160 SNU for
   <m> = 0.05 eV, 31/y/ton,
   The large 0νββ signal
   well above RI BG .

2. Excited 0+ by γ–γ no 2νββ, RI.

3. ββ angular correlations
   to identify the m_ν term .

4. Localization in space and time
   leads to high selectivity of S with
   modest purity of b~mBq/t, ppt.

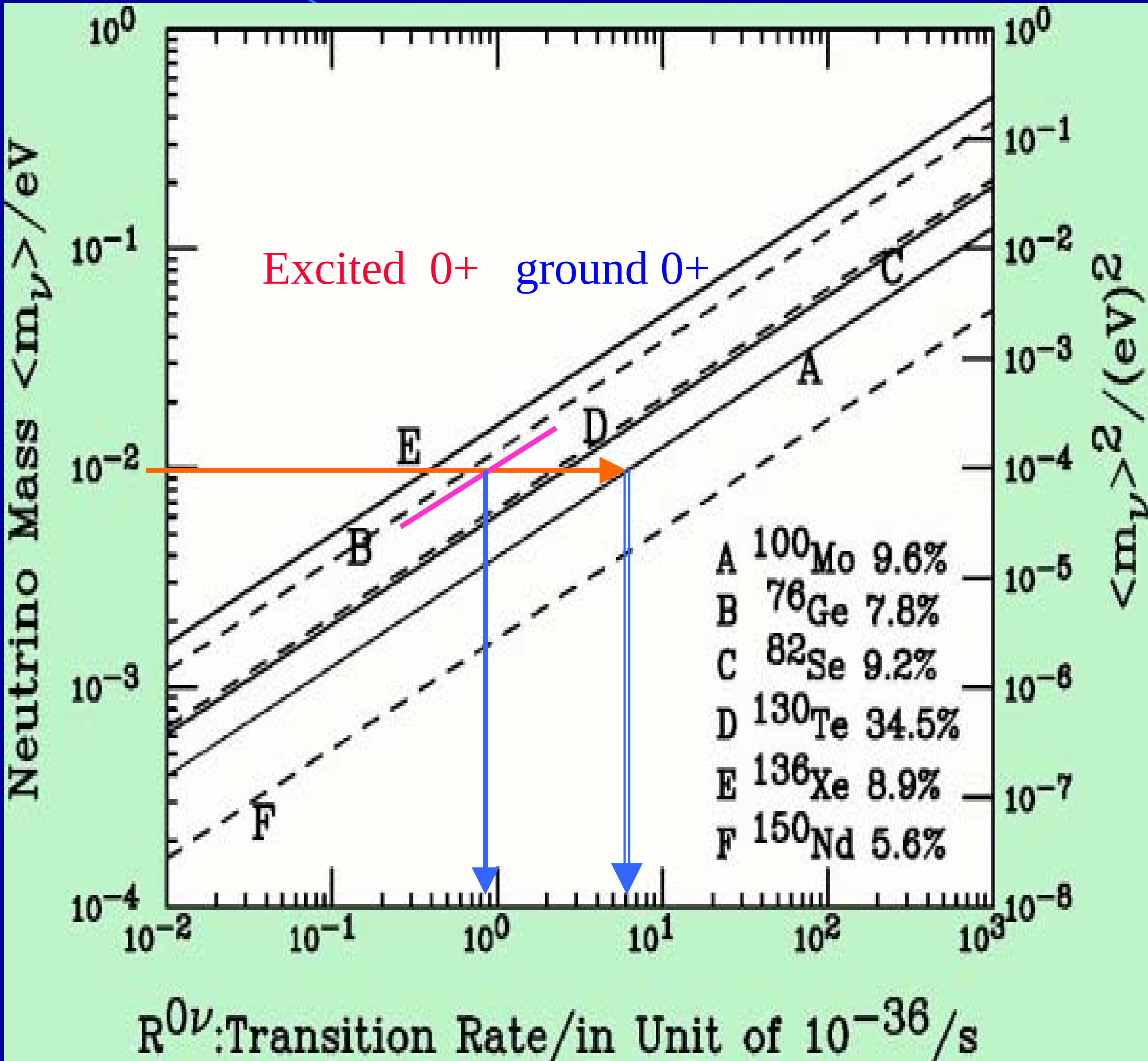


Large nuclear response for 0νββ

- Large $Q_{\beta\beta}$ = 3.034
  large rate of 0νββ
- 160 SNU for
  <m> = 0.05 eV

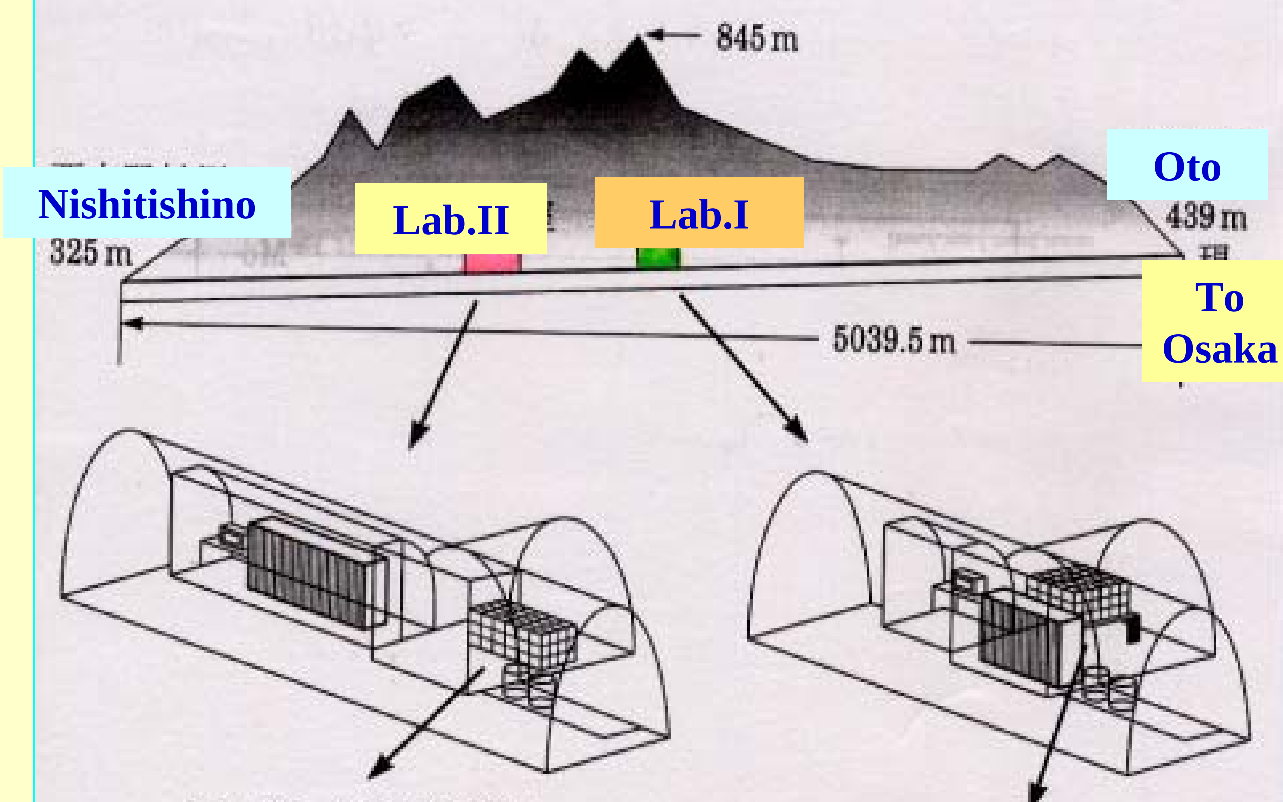
Raw rate

31/y/ton ^{100}Mo
for 0.05 eV
ν mass



Oto Cosmo Observatory

100 km south of Osaka, near Int. Airport



ELEGANT V	ELEGANT VI
Double beta decays of ^{100}Mo and dark matters	Double beta decays of ^{48}Ca and dark matters

Large signal above most of BG

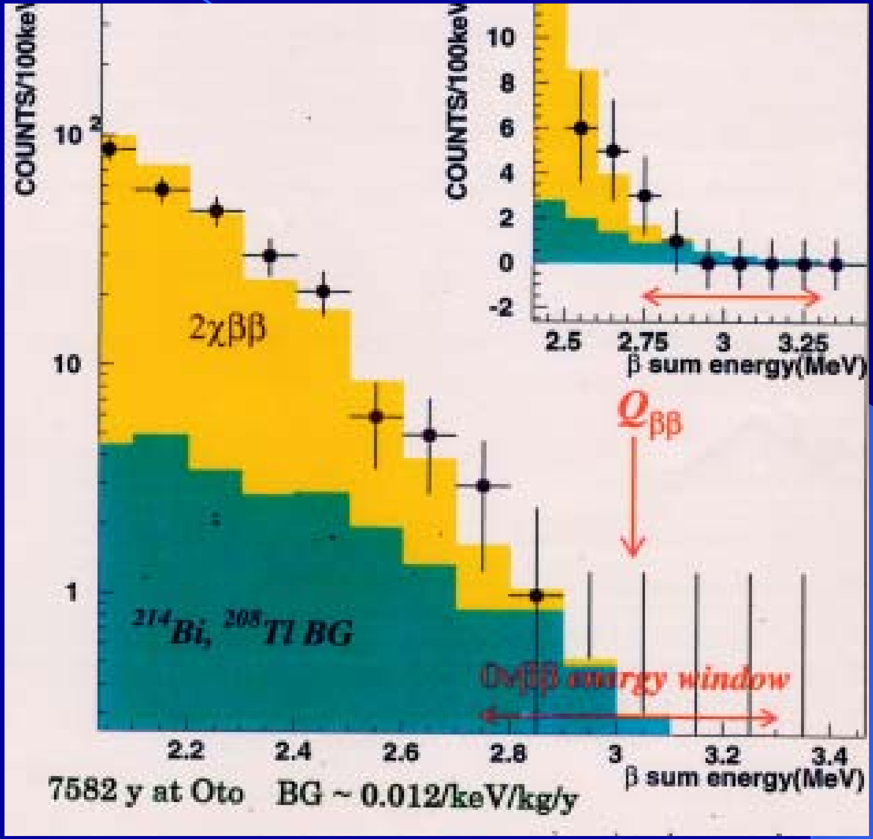
Eβ + Eβ = 3.034 MeV,
above most of U-Th
natural and cosmogenic
BG RI's.

Low BG < 0.012 / keV / kg /y.
Effective (BG ΔE)$^{1/2}$ ~ 1.2
same as present Ge (0.8).

Effective Signal ~ 10 larger.
Main BG 2νββ

Ge 0.2 / keV / kg / y

^{100}Mo 0νββ by ELEGANT V



$<m_n> < 1.5$ (2.0) eV

H.Ejiri, et al., Phys. Rev. C 63 '01, 65501

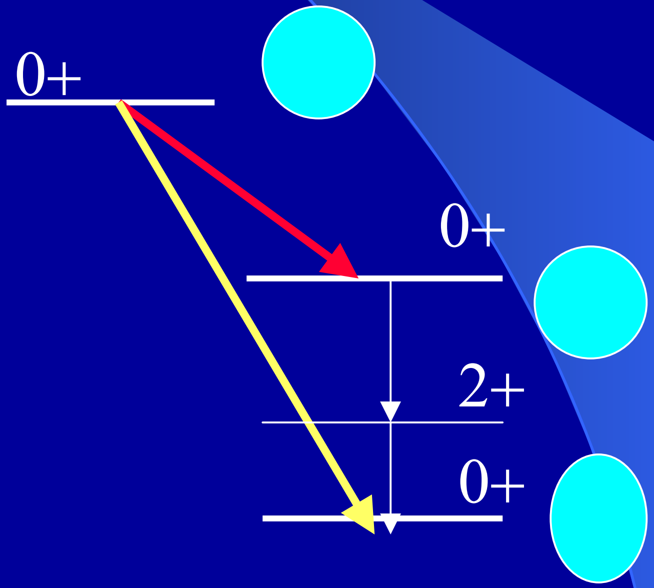
Decay to the 1.132 MeV excited 0+ state

Possible Shape Change leads a larger $M^{0\nu}$. Weighted sum of $T^{0\nu}$ for both the 0+ states is less sensitive to the nuclear structures.

Excited 0+ state transition with deduced $2\beta\beta$ and RI BG by γ–γ coincidence

$T^{2\nu}$ ~7 10^{20}y * Ratio to the g.s is 0.01 by Q^{10}, but $T^{0\nu}$ may be 0.1 by Q^{5}

$T^{0\nu}$ / $T^{2\nu}$ is larger by 10 than that for the ground state transition.



* DeBraekelee et al, Barabash et al

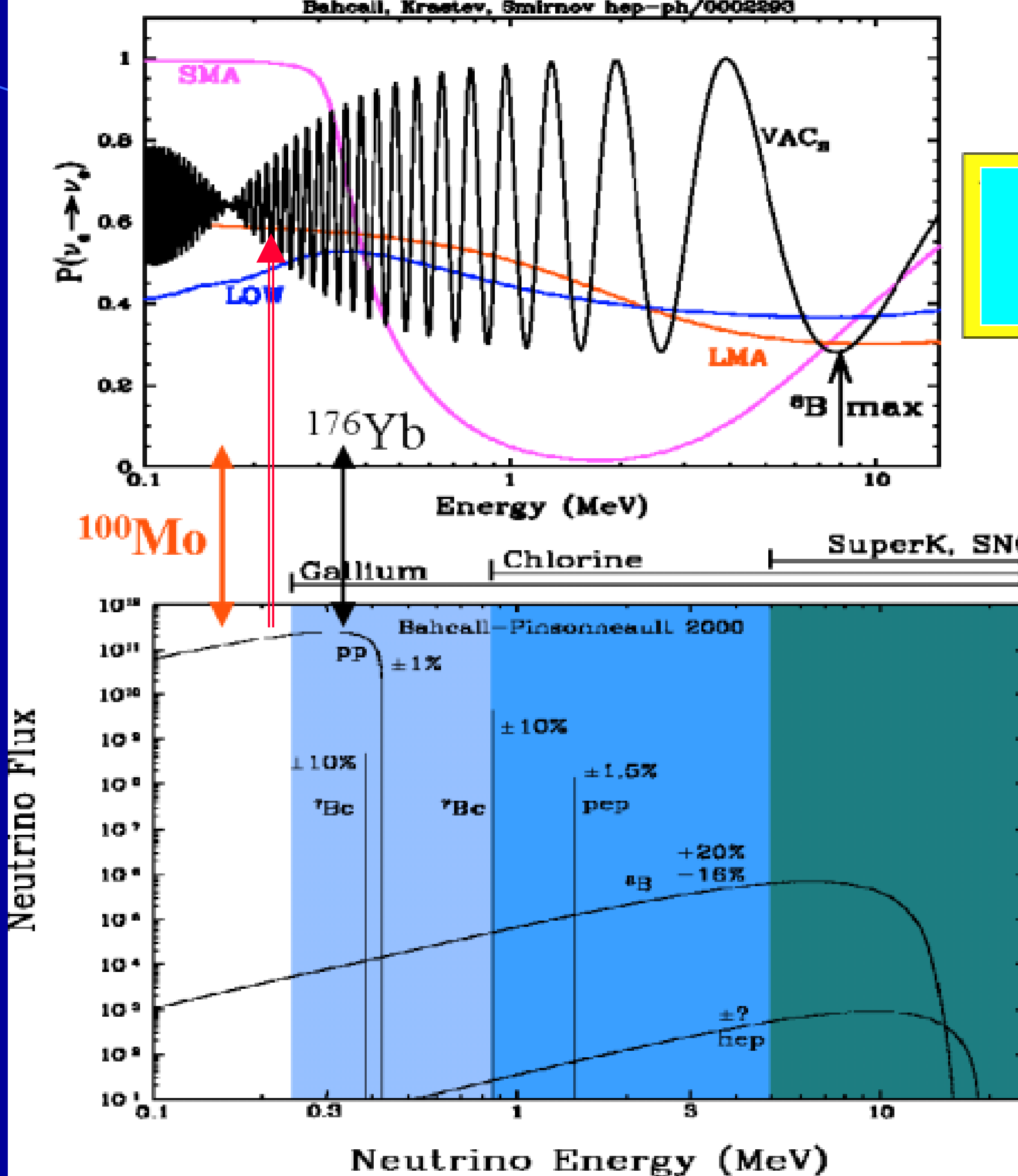
2. MOON for Astro Neutrinos

- Low energy solar neutrinos
- Low energy supernova neutrinos

Solar ν

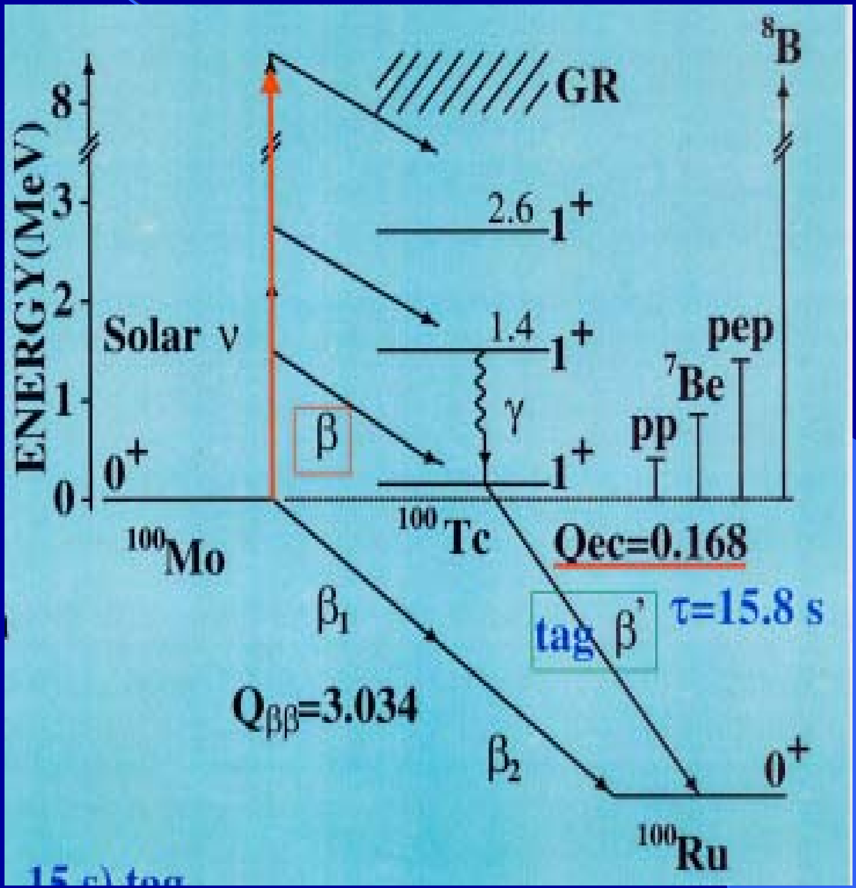
- ν oscillation and solar process
- SK, SNO, Gallex-SAGE, Cl
- No low E real-time
- CC of major
- pp and ^{7}Be ν 99%

- Sensitive to mixing angle as well.



Unique features for solar ν

- 1. Large CC rates with low E_{th}
-
- 2. GS: pp-ν and ^{7}Be-ν,
- B(GT) from EC. Ratio of pp/ ^{7}Be is independent of the B(GT).
- 3.Realtime studies of CC
- 4.The two β (charged particles) coincidence to localize signals in space & time to cut RI, $\beta\beta$ BG.
- 5. Complementally to GNO, BOREXINO, LENSE



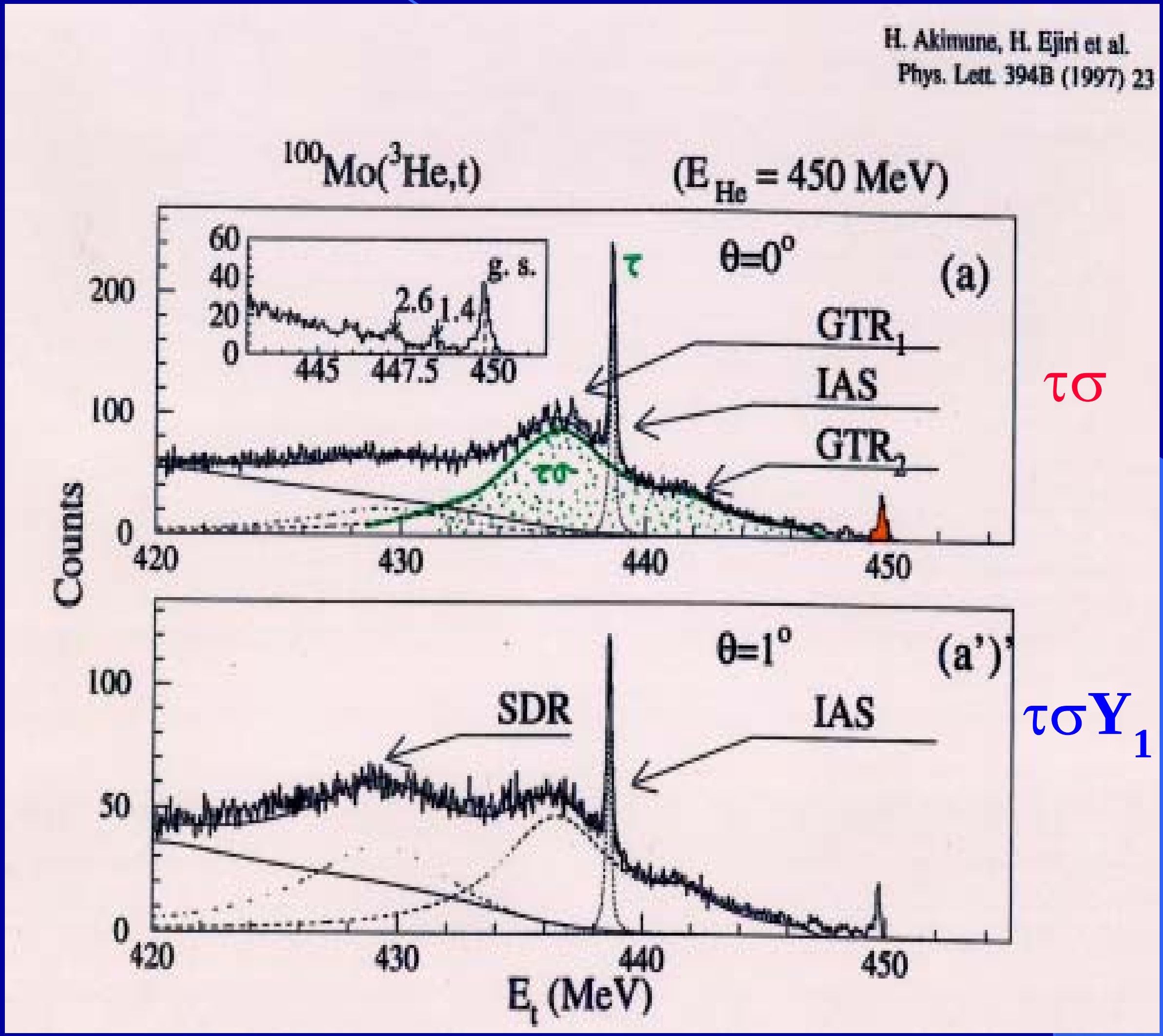
Nuclear responses for solar neutrinos

Nuclear Responses for Neutrinos:

Charged Current Spin ($\tau\sigma Y_l$)

Charge Exchange Spin-flip Reactions

H.Ejiri, Phys. Rep. 338 (2000) 265



$\tau\sigma$

$\tau\sigma Y_1$

Solar-ν capture rates in units of SNU

Nucleus	-Q(MeV)	pp	^{7}Be	^{13}N	pep	^{15}O	^{8}B	Total
^{2}H[a]	1.442	0	0	0	0	-	6	6
^{37}Cl[a]	0.814	0	1.1	0.1	0.2	0.3	6.1	7.9
^{40}Ar[b]	>1.505	0	0	0	0	0	7.2	7.2
^{71}Ga[c]	0.236	70.8	35	3.7	2.9	5.8	12.9	132
^{100}Mo[d]	**0.168**	**639**	**206**	**22**	**13**	**32**	**27**	**965**
^{115}In[a]	0.120	468	116	13.6	8.1	18.5	14.4	639
^{127}I[e]	0.789	0	9.4	-	-	-	13	24.6

GT Strength & Capture rate

	I_i	Spin factor	$B(GT)$ g.s.	1st	Sum
^{71}Ga	(3/2)+	0.25	0.089	0.005 (0.175MeV)	3.8
^{100}Mo	0+	1	0.33	0.13 (1.4MeV)	3.3

$1/(2I_i+1)$

a; Bahcall 88 b; Bhattacharya 98 c; Ejiri 98 d; Ejiri 99 e; Engel 91

- Raw rates /one ton ^{100}Mo /y are 40 for ^{7}Be-ν and 120 for pp-ν

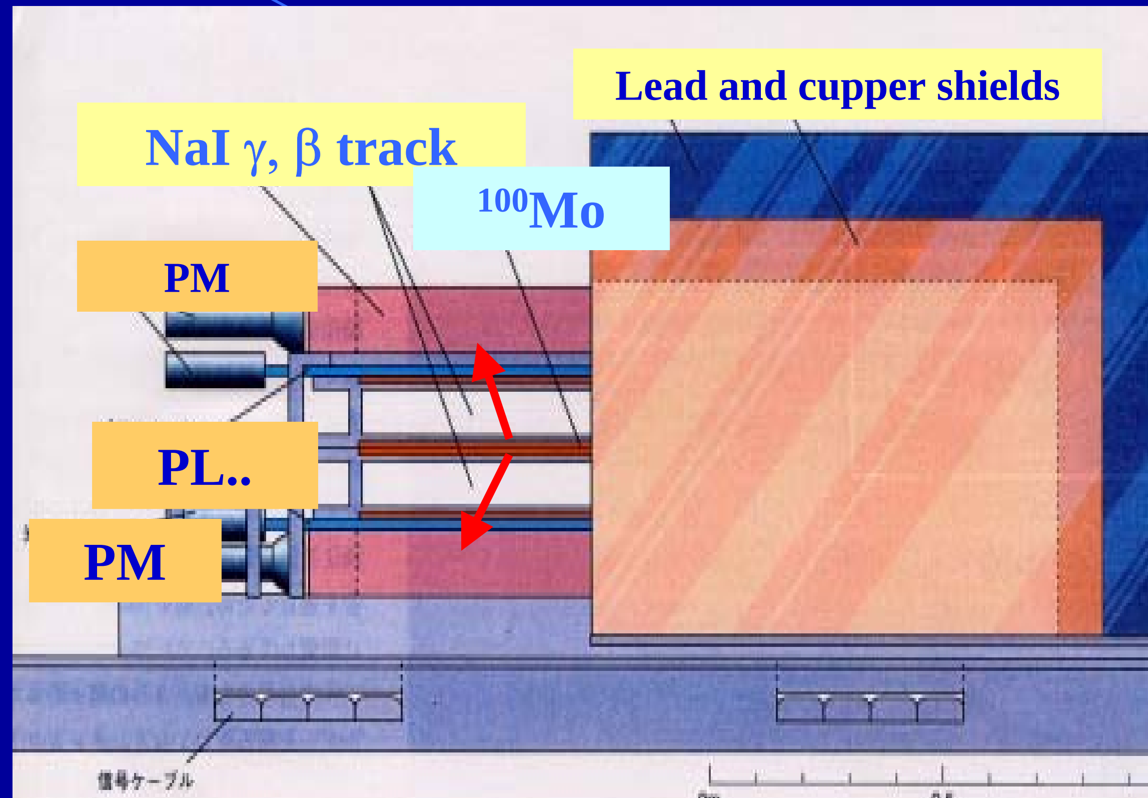
3. MOON Detector

ELEGANT V (ELEctron GAmma Neutrino Telescope)

Electron and γ detectors for $\beta\beta-\nu$ and DM

EL-III. ^{76}Ge $\beta\beta$
Ge crystal with NaI.

EL V for
$\beta\beta$ of ^{100}Mo, ^{116}Cd
β-ray energy and time
by plastic scintillators.
γ-ray by NaI
DM –nucleus recoil
energy by NaI



EL. V . left side shield is open.

H. Ejiri, et al.,NIM A302 1991 303

EL.VI for ^{48}Ca$\beta\beta$ and
DM by ^{19}F
CaF_2 crystal array

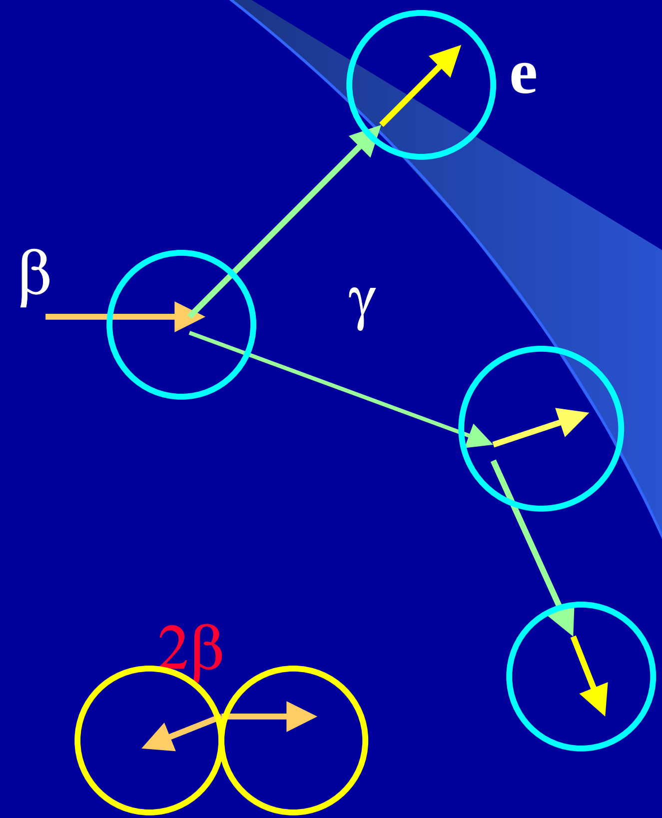
Requirements for MOON

- Large volume/mass of ^{100}Mo M~0.25 - 1 ton
- Centrifugal / laser separation NIIEF/Livermore
- Two β coin. Δt ~ns for ββ, Δt~1-30s solar-ν.
- Dynamic range E_β ~0.1-40 MeV
- Energy resolution σ~ 0.03~0.05 /(E MeV)$^{1/2}$
- 2~3 % for 3MeV 0νββ and 15 % for pp-ν
- Position resolution
- 1/K ~ 10^{-6} ton ~ 2cm (ββ)
- ~10$^{-9\sim8}$ ton ^{100}Mo, 2 m m, a few mg.
- Purity ~ 0.1 ppt 10^{-3} Bq/ton for U, Th isotops.
-

Signal selection by localization of signals in 4-dimentional space-time in detector

- A. SSSC :Signal Selection by Spatial Correlation

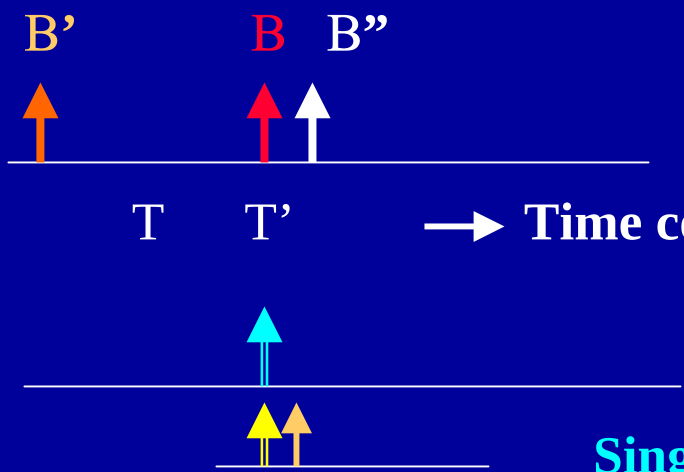
- $\Delta P \sim (\Delta x \sim 2 \sim 0.2$ cm /2 m$)^3$
- $10^{-6\sim9}$/ m^3 1 MeV γ range 8 cm
- Signal is 2β
- $\beta\beta$ or solar $\nu-\beta$ followed by β
  Single-successive sites
  2 ~ 6 cells
- BG $\beta-\gamma$ e E0 - IC X ray
- Compton e γ
- Multi separated sites



- SSSC reduces most of RI's BG by 1-2 orders.

SSTC Signal Selection by Time Correlation

- B

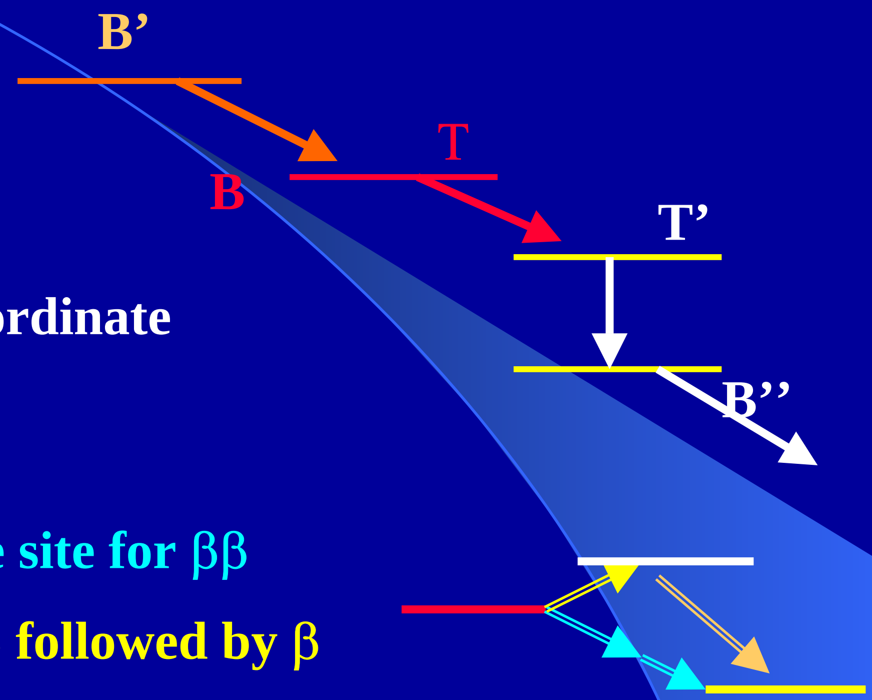


→ **Time coordinate**

- **A**

Single site for ββ

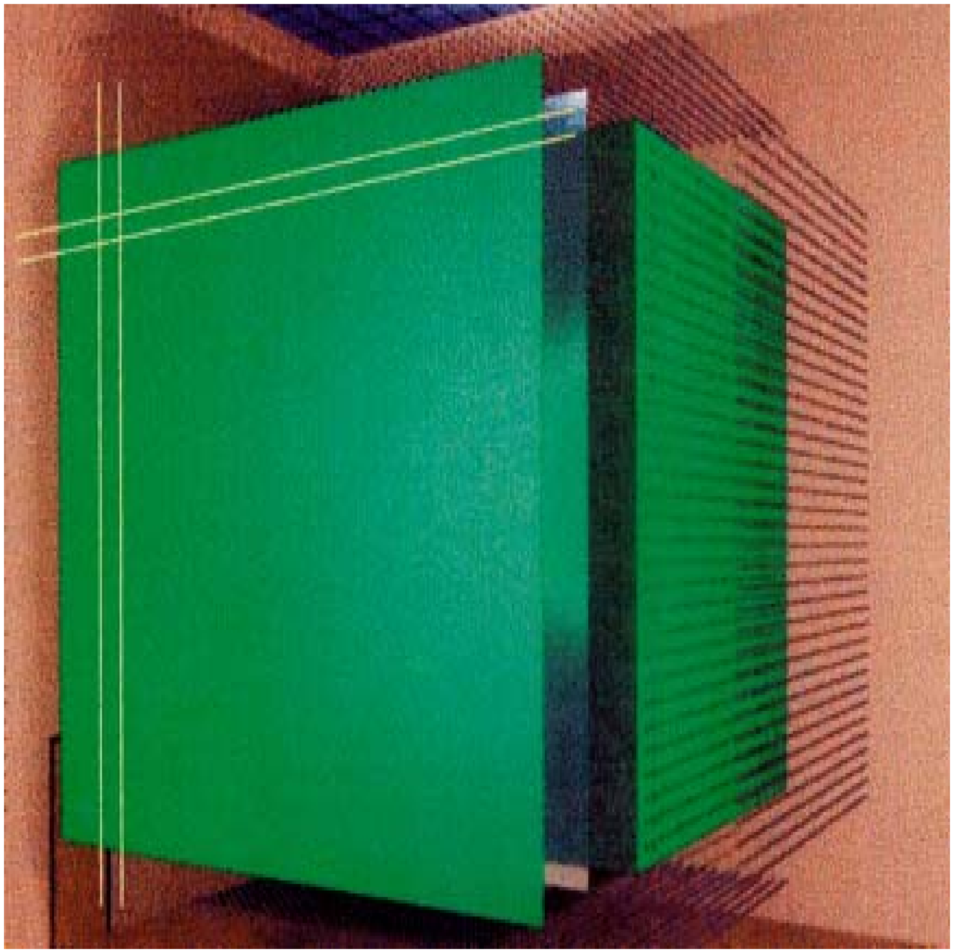
- **2 sites within 30 sec for solar β followed by β**

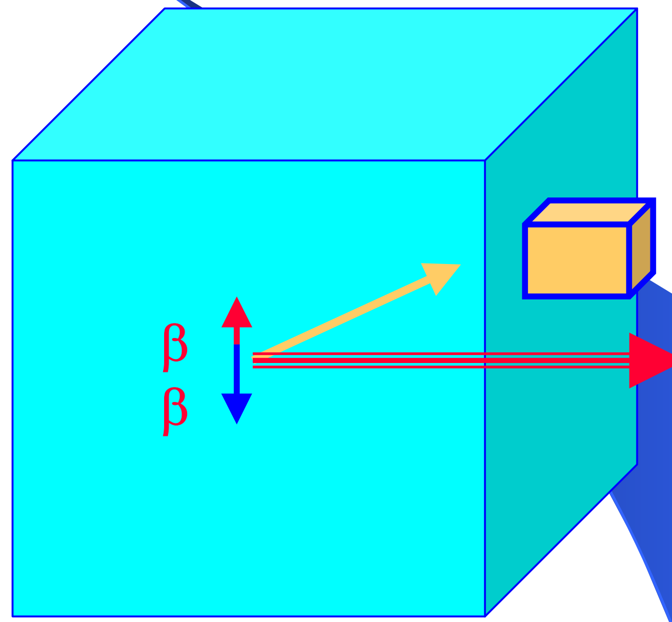


- **Time correlated pre- and post decay signals, B’ and B’’.**
- **Time window T ’ < < 1/all event rate / unit cell detector:**
- **High K = 1/ΔP ~ $10^{6\text{-}9}$ and modest low / purity of S-BG rates :**
- **b < 10^{-3} Bq / ton reduce by 2 orders of magnitude of natural and cosmogenic RI’s with $T^{B}_{1/2}$ < 2.5 (K / b) 10^{-10} ~days.**
-

Signal extraction methods

Multi fiber/sensors





Position A. Scintillation fibers

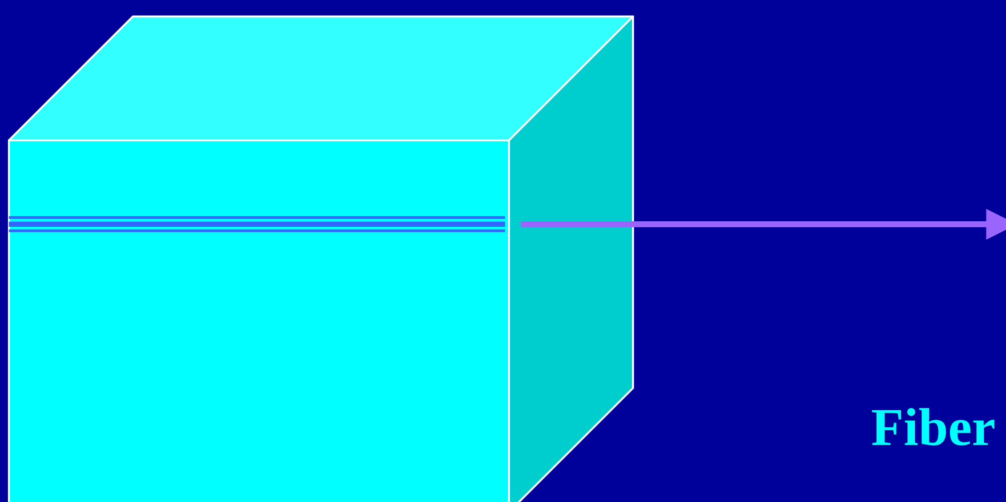
Energy   C. Photon sensors

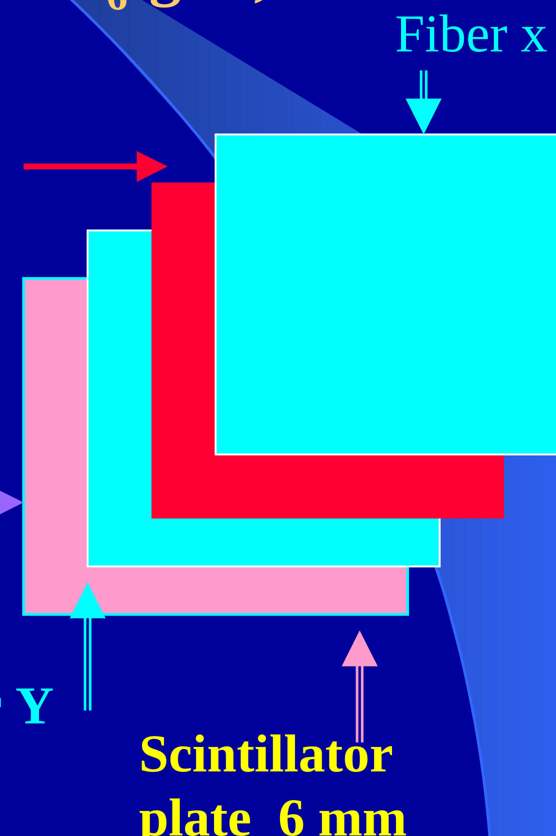
Hybrid detector

1. **Position read-out by fibers with 2m - 2 mm - 0.5 mm**
2. **Energy read-out by 2–dimentional plane scintillator with E resolution σ ~ 2 % FWHM ~ 4.5 % including the Mo film.**
3. **Modest volume with enriched Mo and modest cost of MA / PM**
4. **Rate 0.5 t ^{100}Mo/ 5 y with 6 K centrifuges MoF_6 gas ,**

One unit 2m – 2m – 1.7 m : 240 modules

One module 2 m – 2 m – 7 mm



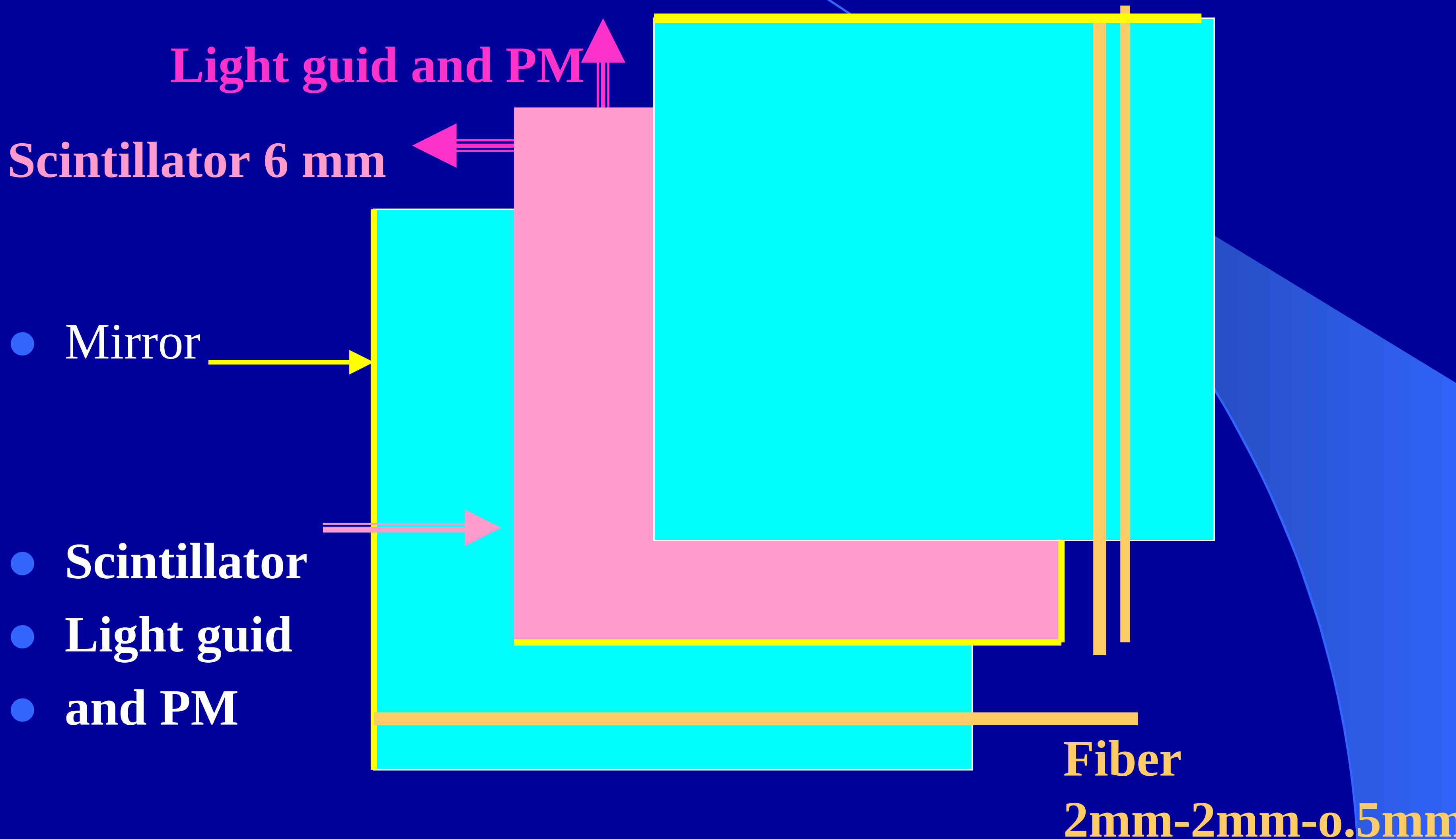


Mo film

Fiber Y

PL Fiber and PL plate scintillator

One module 2 m – 2 m – 7 mm



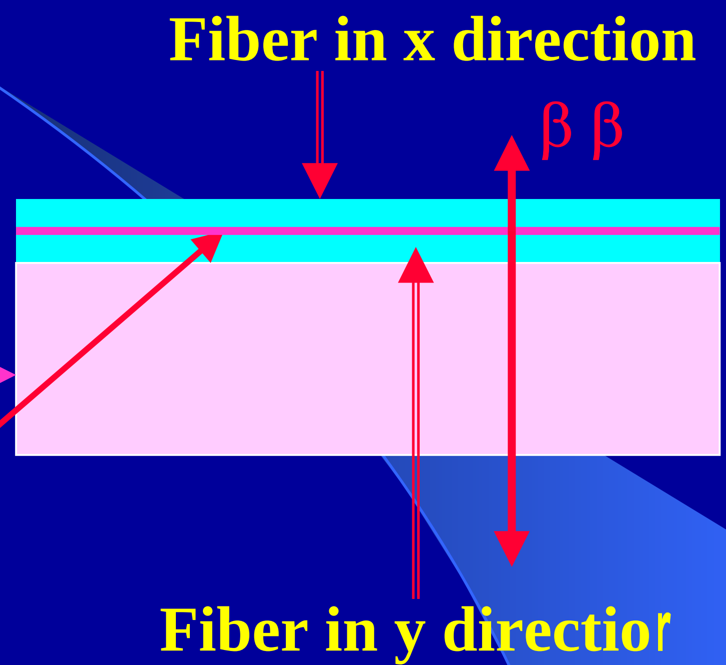
Detector configuration

Position: Fiber (scintillation)

2 mm width and 0.5 mm thickness.

x (top) and y (bottom) directions

pp-ν stops in a fiber/Scintillator.



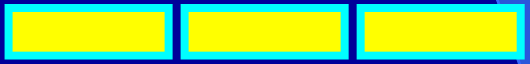
Energy: mostly by scintillator plate

with σ ~ 2 % 2 m – 2 m – 6 mm.

(2-layer for β)

Mo/Pl = 0.025 g /cm^2 / 0.75 gr. 3.3 %

Unit A



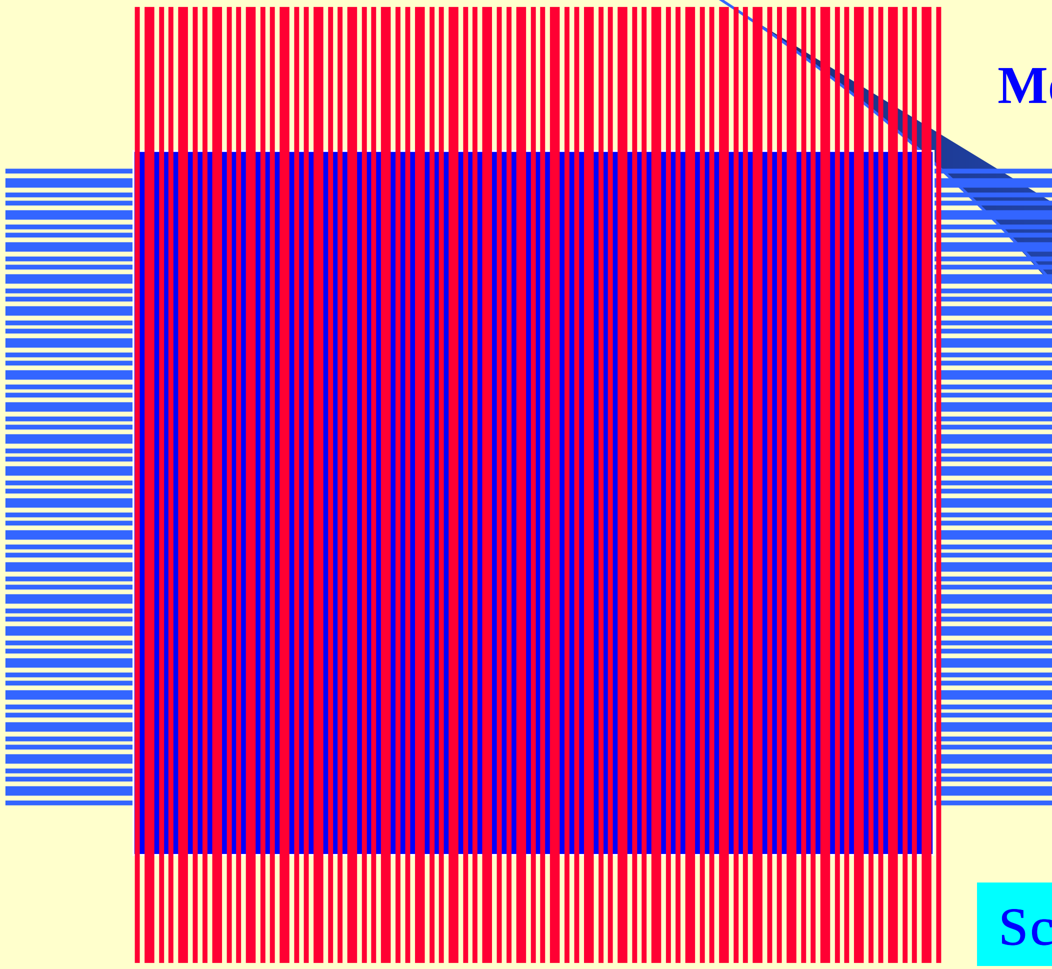
Mo 0.25 ton = PL 7.5 ton , 7 m^3

2 m – 2m – 1.7 m.

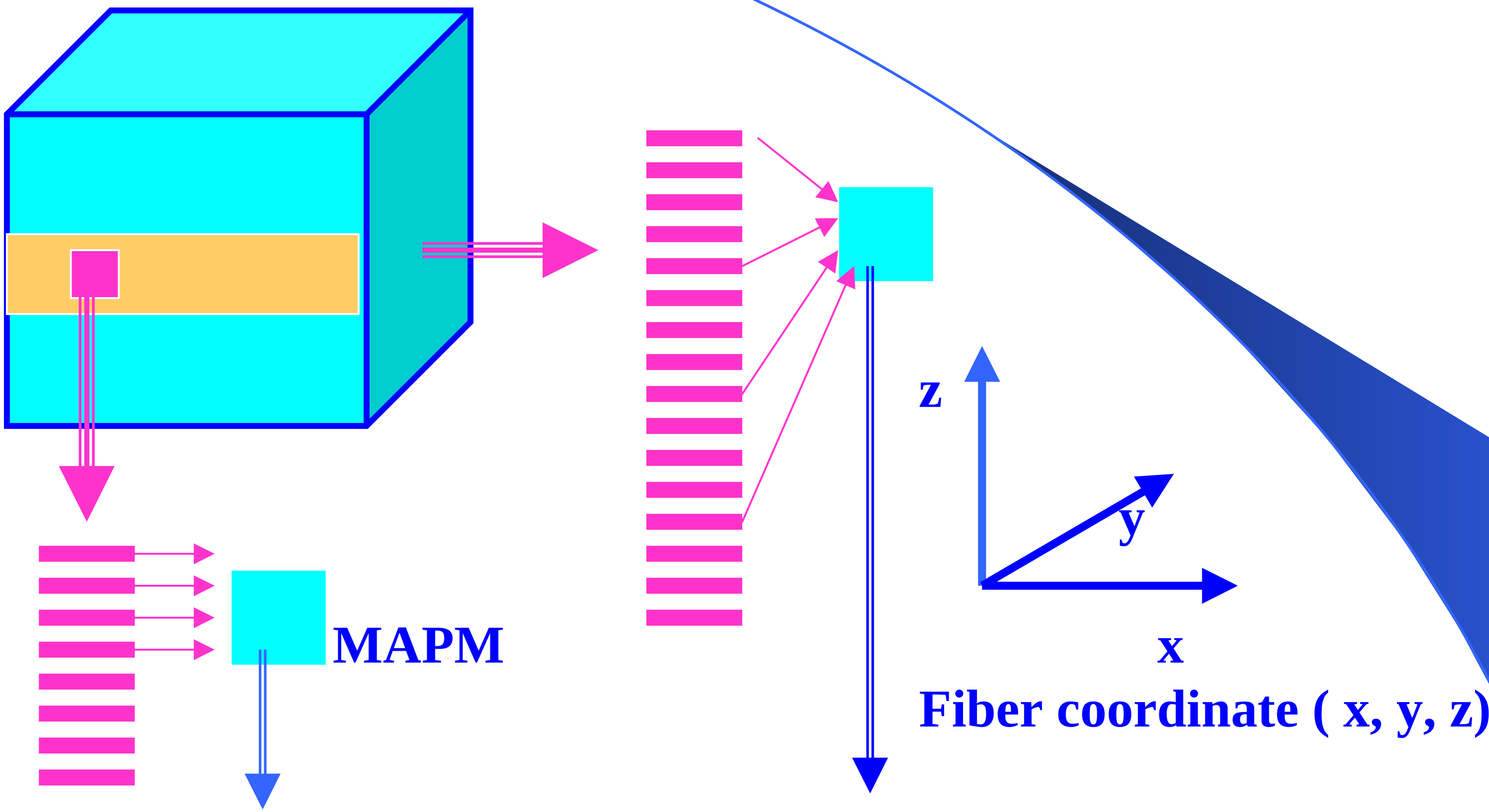
Unit A, B, C, Mo 0.75 ton (^{100}Mo 0.64 ton , 2m – 2m – 5 m)

MOON

Plastic fiber-Mo Ensemble



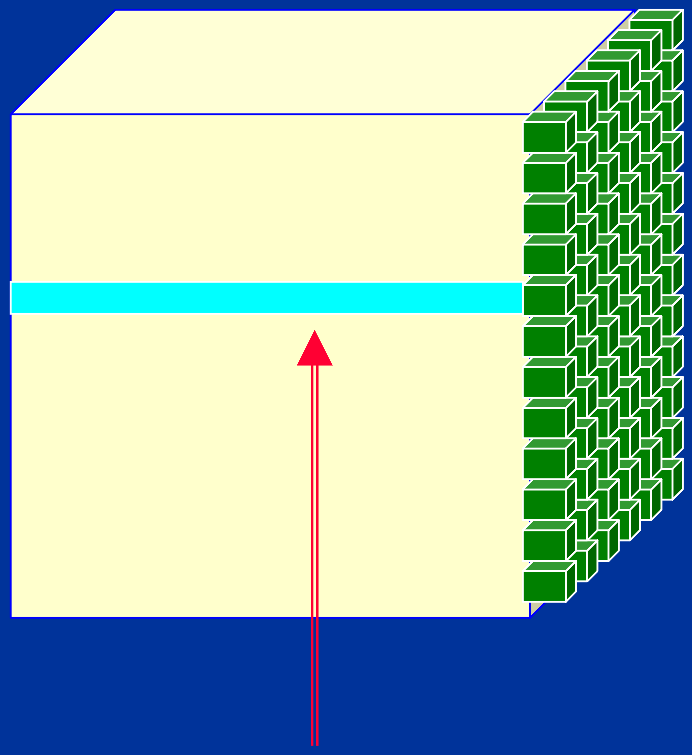
Multiplexing MAPM read out



(x, z) =
(i,m+0)
(i,m+1)
(i,m+2)
(i,m+3)

(y, z) =
(j,n+0)
(j,n+1)
(j,n+2)
(j,n+3)

Scintillator plates read out



One module 7 mm

Photon sensors on surfaces
one unit 2m *2m * 1.7 m. 0.25 t

- **Large photon collections (~50 %) to get ΔE = 1.5 % in σ for 3 MeV.**

2. Low position resolution 10^{-5}

3. PM:5 cm Φ 3.5 K./ x,y sides
for one unit 2m 2m 1.7 m

4. Position read out by fibers 10^{-9}

Sensitivity of $\langle m_\nu \rangle$ for Hybrid Detector

	MOON 1	MOON II	MOON III
N (^{n}Mo) y ton	0.001 t * 3y	0.25 ton * 3 y	+ 0.75 ton * 7 y
N(0ν) /0.05 eV	0.025	5	40 4 (excited 0+)
N(2ν)	0.01	2.3	18 0
$\langle m_\nu \rangle$ eV *	0.3 [a]	0.05	0.03 ~0.03
$\langle m_\nu \rangle$ eV **	0.2~ 0.5	0.03~0.08	0.02 ~ 0.05

* BG 3 σ sensitivity.

** Nuclear matrix element uncertainty factor 2.5

a: Signal : 1

N=31*ε*M*0.85*Y*$(m/0.05)^2$: ε ~0.3 cut efficiency, M : Mo in ton, Y years.

N(2ν) = 3.5 *M* 0.85 * Y

BG(^{214}Bi) = 0.2 y t with pre β and post α . BG << N□(2ν).

EL V N / y ton ~ 2 10^{-4} t *2 y ; 1.5 eV 68 %

Solar ν sensitivity

	pp-ν	^{7}Be-ν
Raw yield / 1 y ton	121	39
LMA	70	20
Yield after cut / y t	33	14
BG $2\nu\beta\beta$ / cut y t	< 1	< 1
BG ^{214}Pb-Bi / cut y t	~1	~1

- **MOON III**

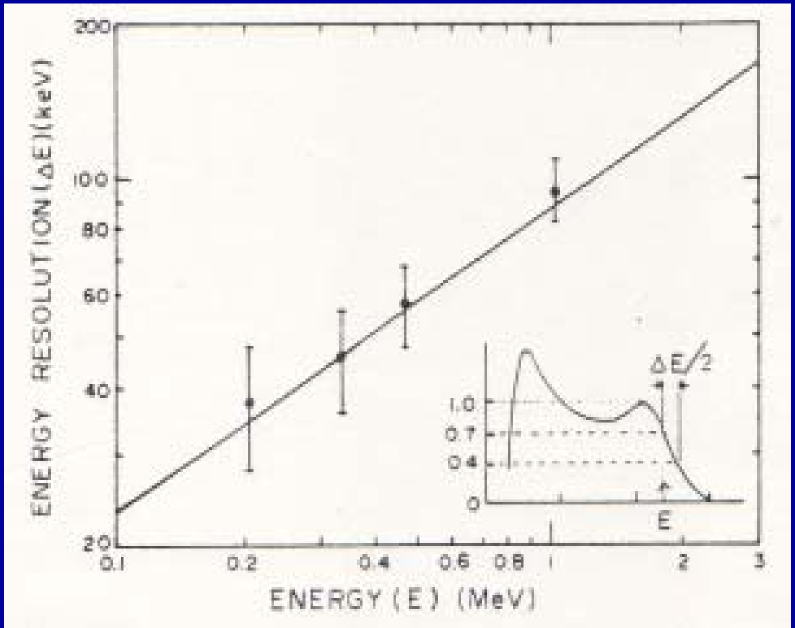
Yield / 6 y t	198	84
Statistic σ	7%	11 %

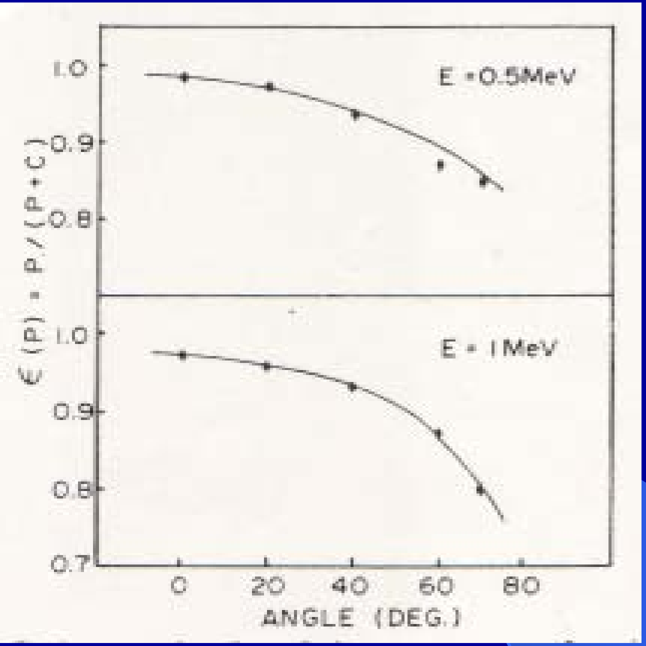
- $2\nu\beta\beta$ 1.6 10^{17} ε $\Delta T/K = 0.5$ / y t, $\Delta T = 10^{-6}$ y, K / t = 10^{9}, ε= 0.003
- ^{214}Pb-Bi 0.1 ppt 20 min. with post α(0.03 gr range)

4. Detector R & D

Efficiency and Energy resolution of PL.

One dimensional flat bar with 1 m – 0.12 m – 15 mm





ΔE(FWHM) = 160 keV at 3 MeV,

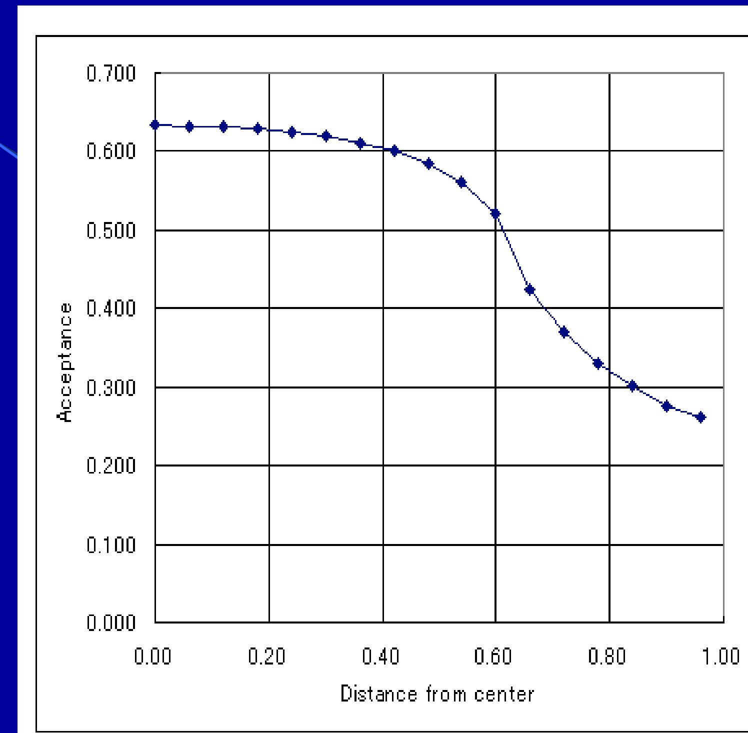
σ = 2.25 % in agreement with evaluation

Peak efficiency including angle cut and back scattering 0.35

- **H. Ejiri et al. NIM A302 1991 304**

Energy resolution and Efficiency

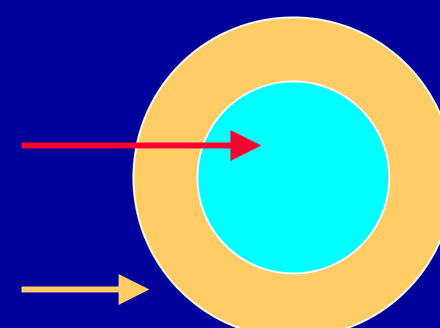
	EL V 1-dimensional (Flat bar)	MOON Hybrid 2-dimensional (Flat plate)
N_{pe} / MeV	12 K	12K
t both end	0.3	0.55
ε(pe) PM	0.22	0.22
N_{pe} / MeV	740	1450
σ / MeV	4 %	2.6 %
σ / 3 MeV	2.2%	1.5 %



Disk (plate) Nomachi

- t for $n_1 = 1.58$, $n_2 = 1.0$
- two dimension square 0.63 * 0.9
- Target thickness 40 keV
- σ ~ 10 keV ~ 0.3 % for ββ

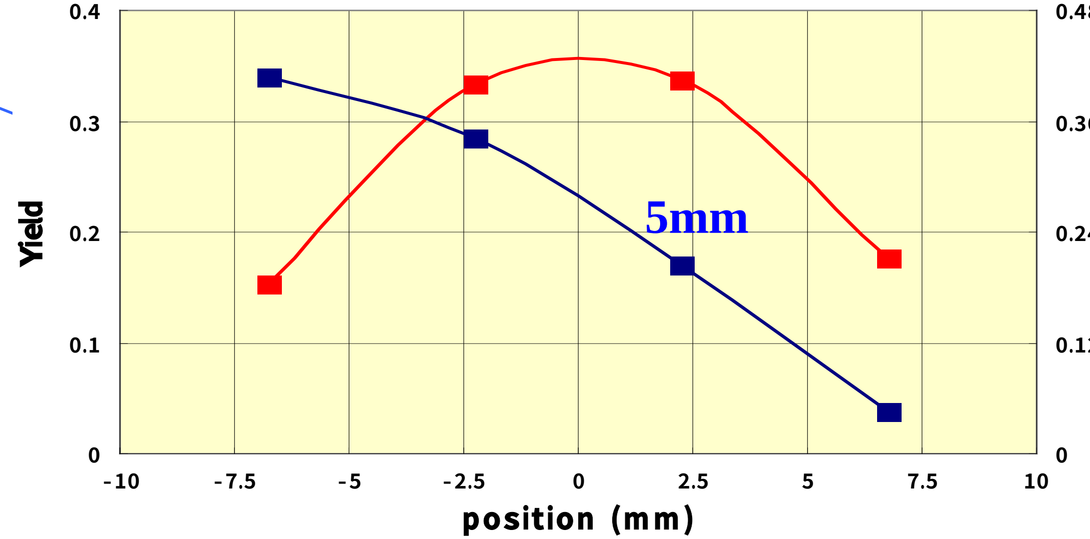
Scinti

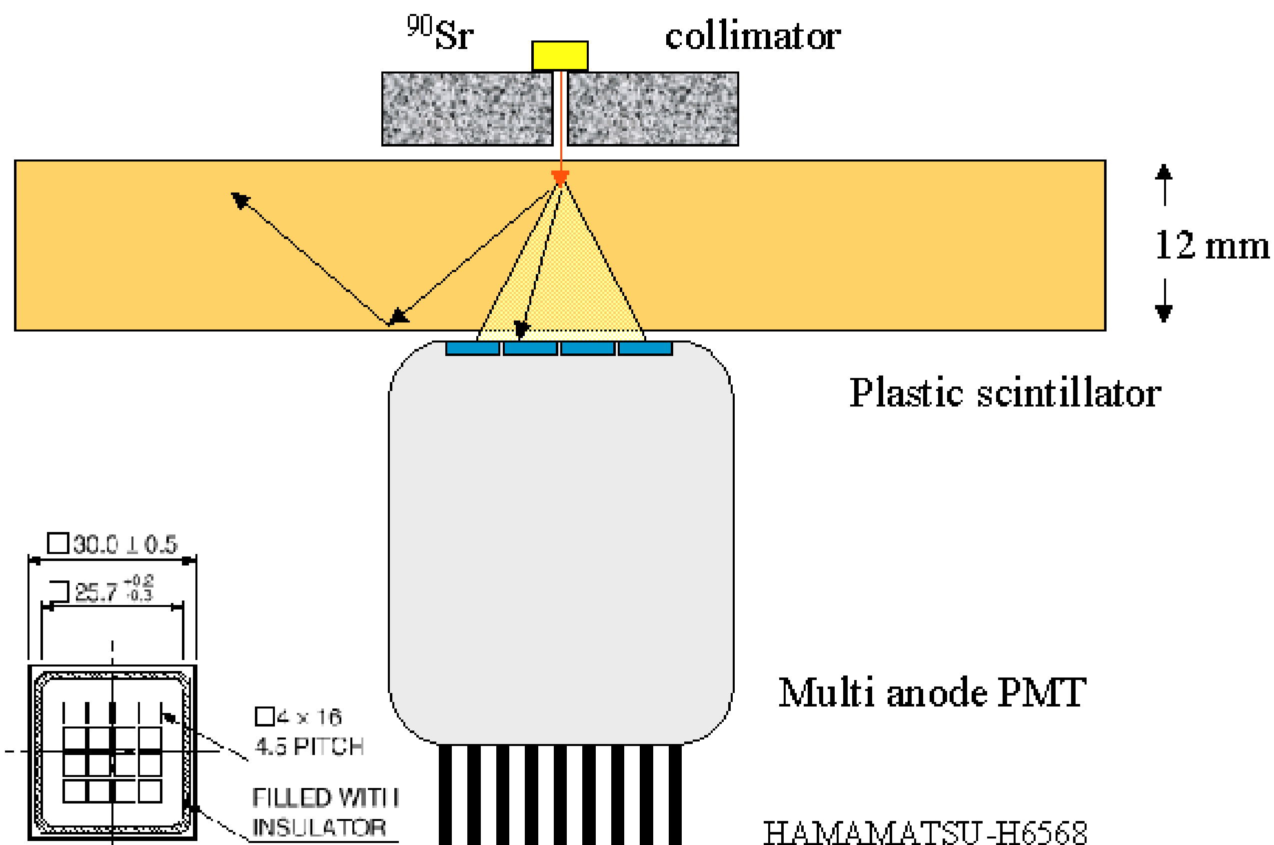


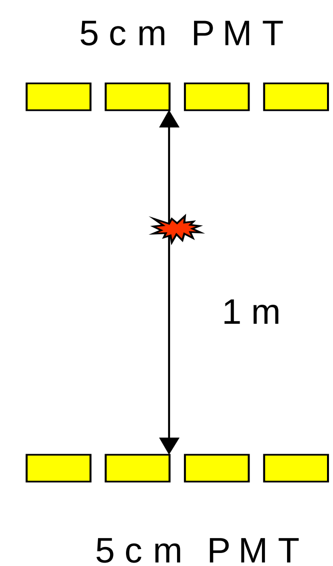
PM

Position resolution

1.5 mm with 4mm PM anode

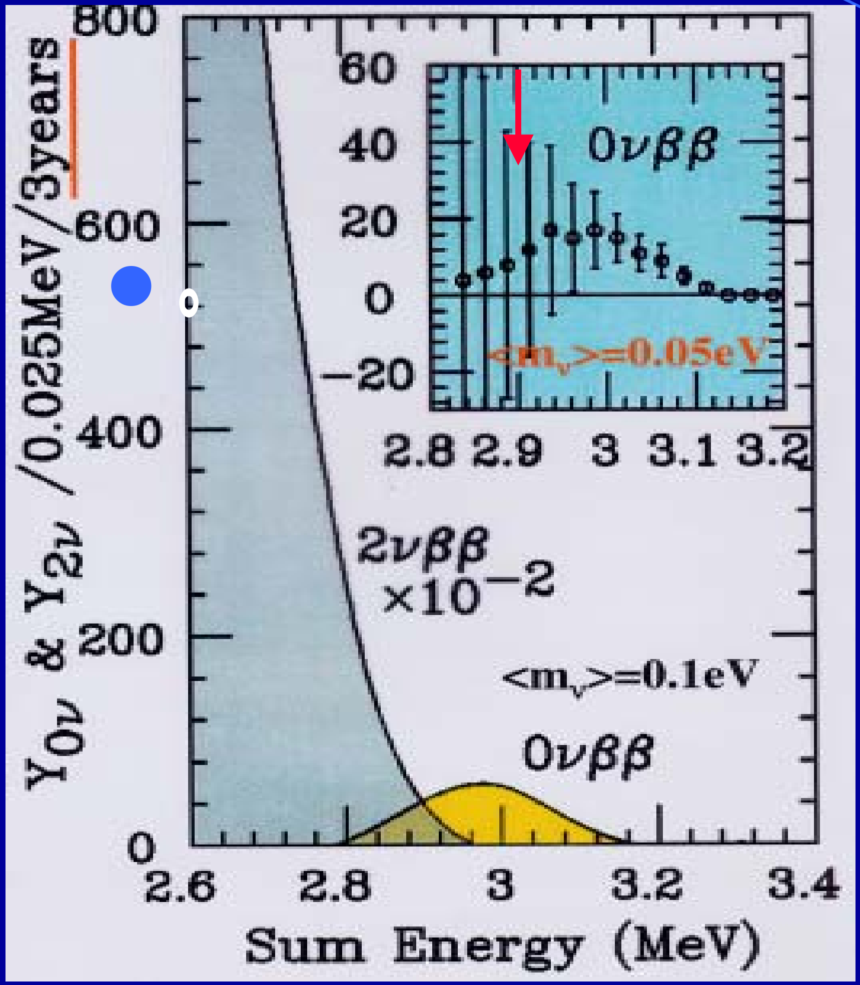


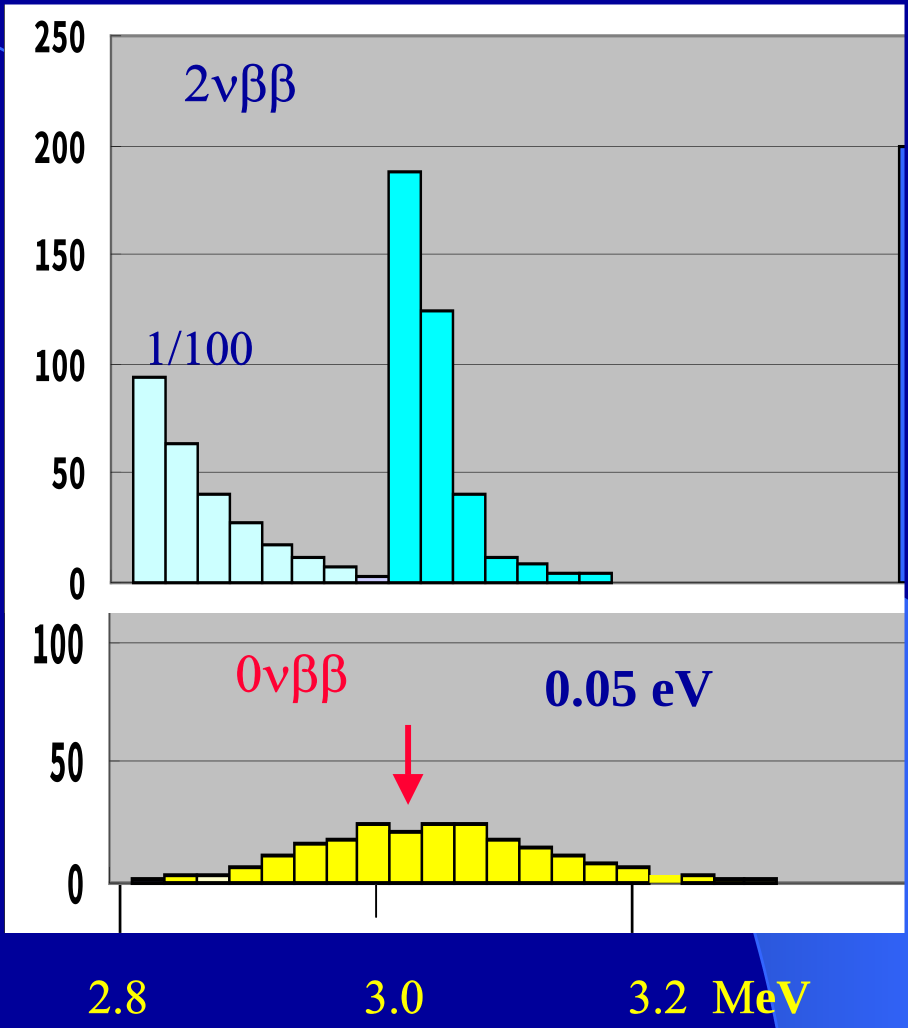




m r.m.s. is expected

ββ spectrum with 10 t y ^{100}Mo with PL





<m> ~ 0.05 eV RQRPA (Volonon/ Tubingen) . σ = 3 %

Left: 0.05 g / cm^2 and right: 0 g . Peak shift 70 KeV

5. Concluding remarks

Summary

- 1. ^{100}Mo with the large responses for ββ–ν (gs, excited 0+), solar-ν, and sn-ν are used for ν studies in Mo micro labs.

- 2. MOON(Mo Observatory Of Neutrinos) : realtime two β spectroscopy for 0νββ with Majorana sensitivity of m_ν ~0.03 eV low E solar & supernova ν's by inverse β tagged by successive β

- 3. MOON is a super module of Mo/^{100}Mo & scintillators with modest volume(10 m^3) and realistic purity(0.1ppt).
- High position resolution and adequate time window for two β rays reduce all kinds of correlated and accidental BG.

- 4. Enriched ^{100}Mo can be obtained by centrifugal and/or laser
- separation methods.
- 5. MOON detector is used for any external sources and others.

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MOON

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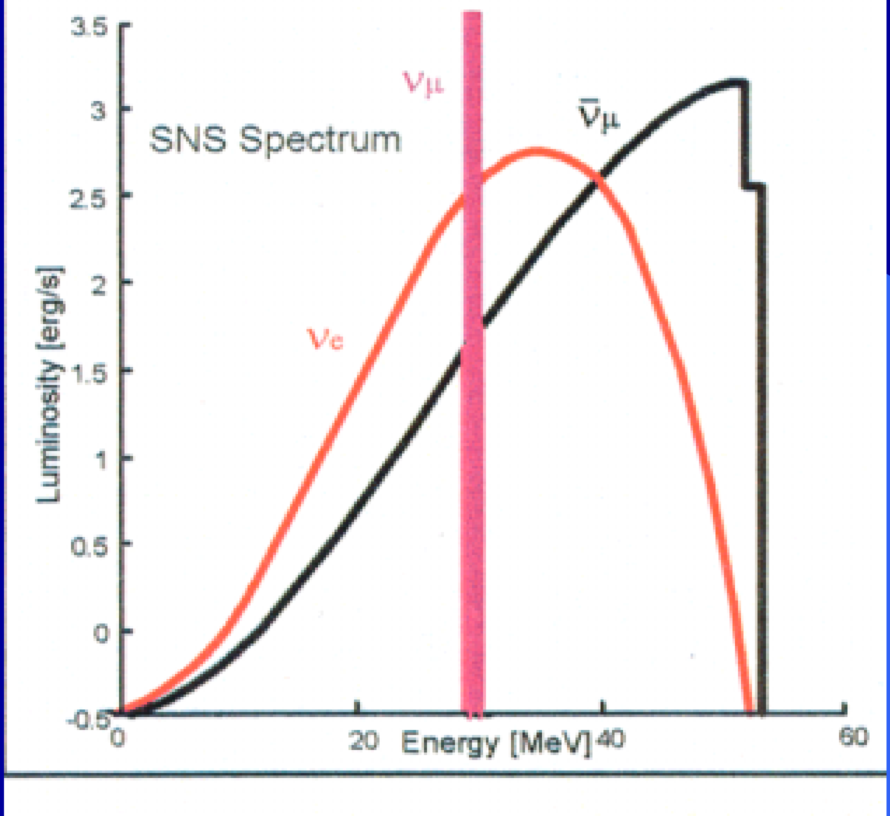
Weak probes/processes

1. ν **beams, direct way but need intense ν beams of**

- **10^{15}/sec and large detectors(10 tons) because of σ ~ 10^{-41-42} cm^2**
- **Stopped π^+ p + Hg → n π^+ $\pi^+ \rightarrow \mu^+ + \nu_\mu$ $\mu^+ \rightarrow e^+ + \nu_e + \underline{\nu}_\mu$**

Souse	E GeV	N_p	N_ν
SNS	1	6 10^{15}	7 10^{14}
JHF	3	1.2 10^{15}	3 10^{14}

- **ORLaND/MOON type detectors**



2. μ^- **by (μ,ν_μ) captures for T_+ up to 100 MeV**

- **with very large σ.**

INTERNATIONAL STATEMENT ON NEUTRINOLESS DOUBLE-BETA DECA

Nov. 2002

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1. **DBD is the only practical method to study such fundamental ν properties as the Majorana nature of neutrinos, the mass spectrum, the absolute mass scale, possibly the CP violation..**

2. **Neutrino oscillation studies imply that next-generation DBD with ~10 meV should discover non-zero effective Majorana electron ν mass if ν mass spectrum is of the quasi-degenerate type or with inverted hierarchy.**

3. **A coordinated approach to executing next-generation DBD exp. and international collaboration for new DBD are indispensable**

4. **Improvements of the precision in theoretical evaluations of the matrix elements by coherent works of nuclear theory groups.**

5. **Cooperate internationally to ensure that at least one experiment could be done involving each promising isotope .**

6. **Deep underground clean laboratory space, which is open to the international science community.**

7. **DBD should be discussed among nuclear particle fields as well.**

8. **Form an international DBD network for next-generation DBD**

The Ist Yamada Symposium On

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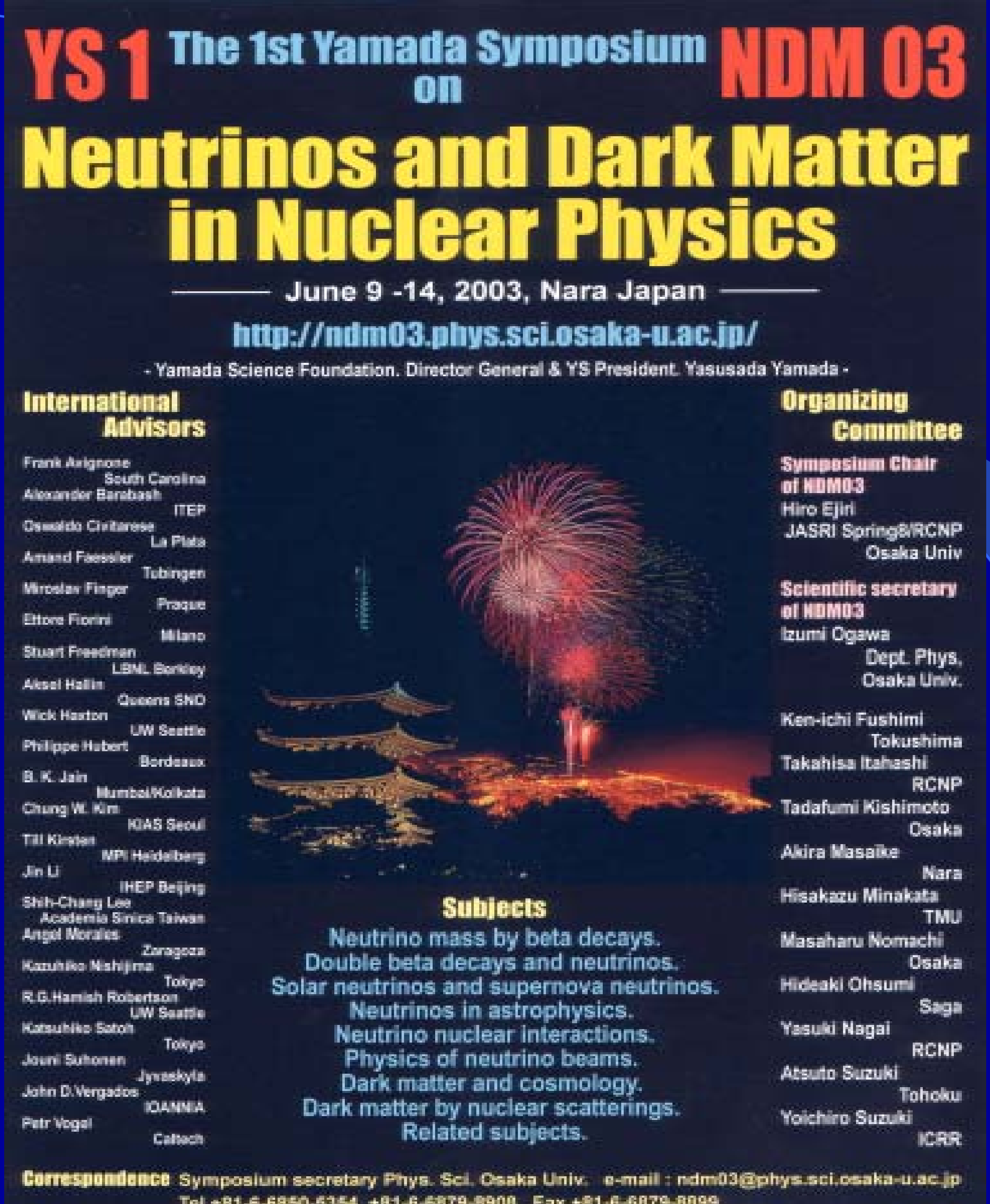
D. Dark matter and cosmology. Dark matter by nuclear scatterings.
E. Related subjects.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Welcome to

MOON collaboration to give rise to.

Thank you


Mehr Light
Hiro Ejiri at Shounam