



Perspectives of Double Beta Decays and Neutrinos in Nuclear Physics

**Thanks Profs. S. Jullian , D. Lalanne and their colleagues
for this wonderful NDM06**

**Hiro Ejiri
JASRI Spring8 and RCNP Osaka Univ. NDM06**

An aerial photograph of a coastal area. A winding road or path is visible, cutting through a landscape of green vegetation and some rocky terrain. The road starts from the bottom left and curves towards the top right. The background shows a mix of green and brownish-grey areas, possibly representing different types of land or water levels.

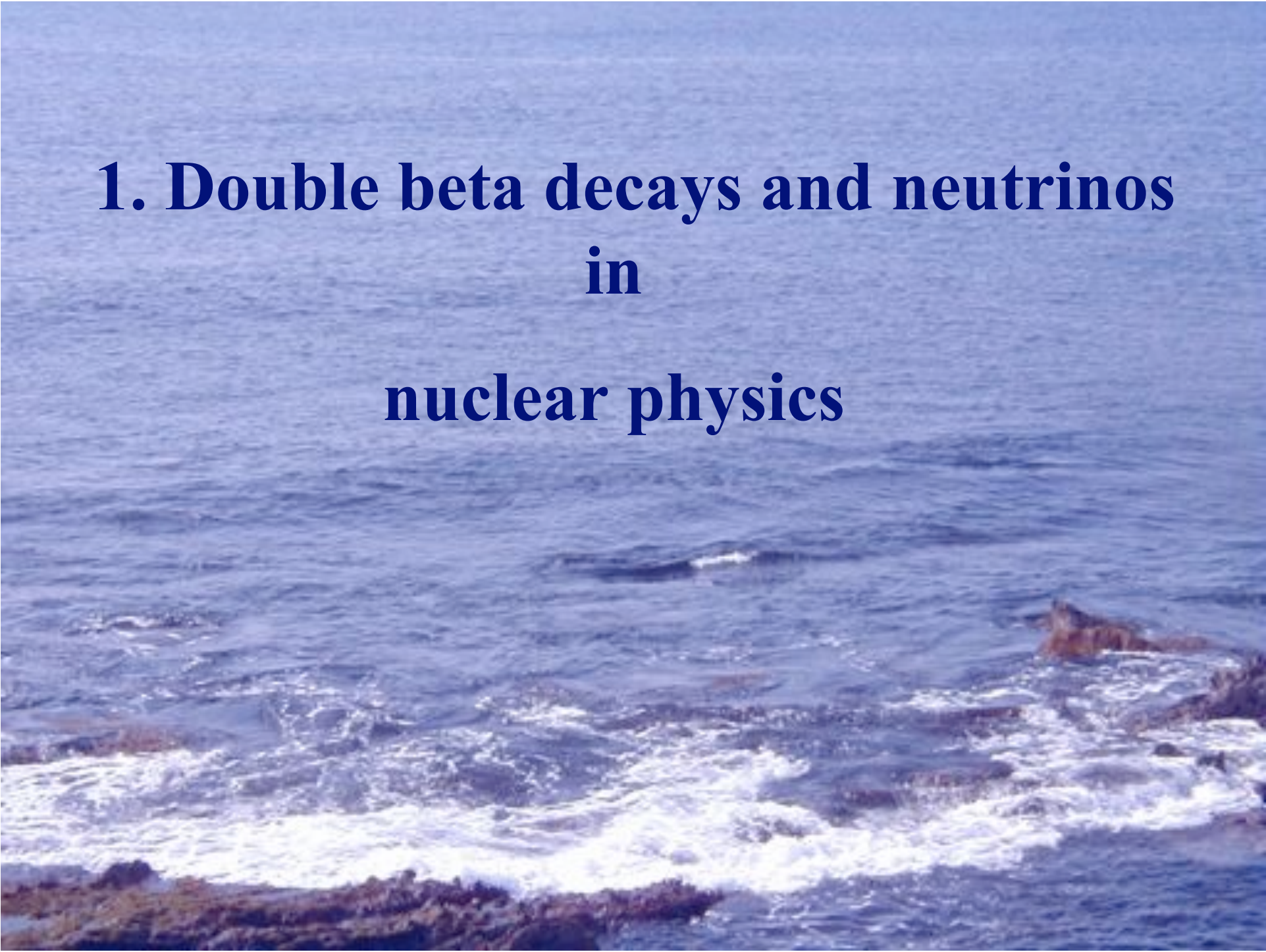
1. Double beta decays and neutrinos in nuclei

2. Double beta decay experiments

3. Nuclear matrix elements

4. Concluding remarks

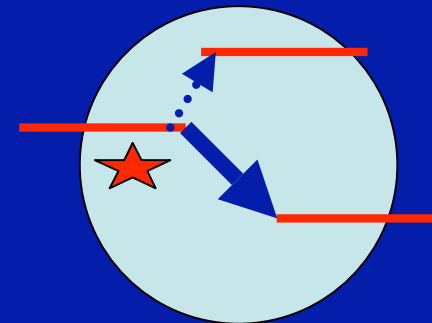
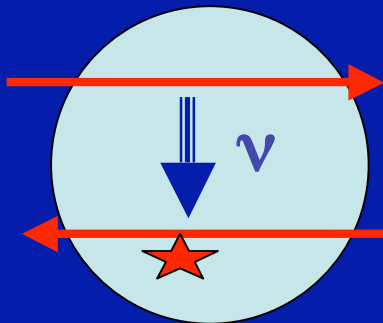
Brief comments on DBD, and not a summary of DBD of NDM06



1. Double beta decays and neutrinos in nuclear physics

Neutrino study by $\beta\beta$ in nuclear micro lab.

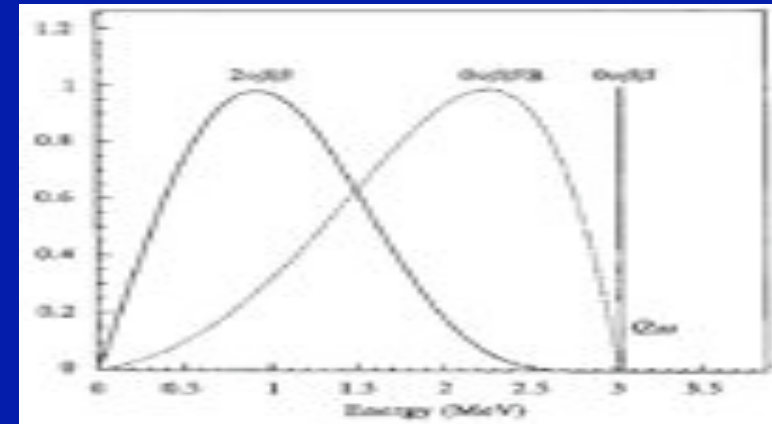
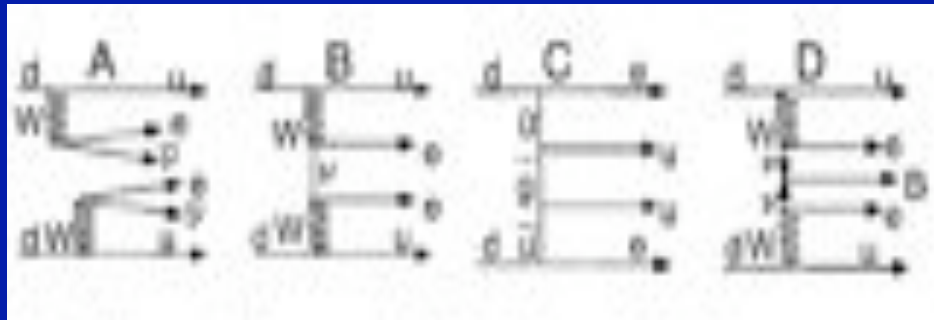
- 1. Nuclei are excellent micro-lab's /microscope to study fundamental properties of ν & weak interactions.
- 2. Microscopes with enlargement by 10^7 for $0\nu\beta\beta$ decays with ν -exchange between 2 n in nuclei and filtering power against huge single β BG's which are energetically forbidden.
low-E collider (Jullian) with ultra luminosity (10^{-13} cm 10^{30})



- 3. Nuclear response $M^{0\nu}$, which is sensitive to nuclear structures, is crucial to design DBD exps, extract ν mass.

ν & Weak interactions in $\beta\beta$ decays

DBD theories B. Kayser, S. Petcov W. Rodejokann

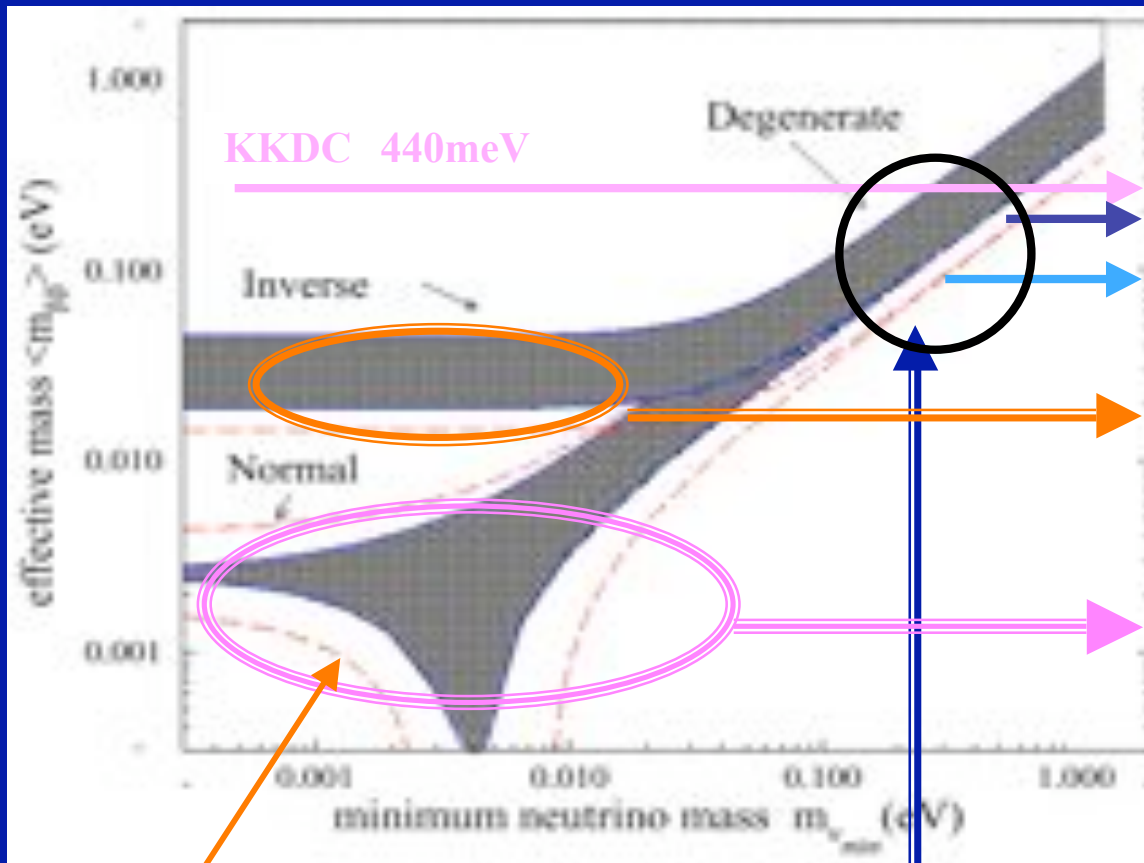


$$2\nu\beta\beta \quad \Delta L=0 \quad T^{2\nu} = G^{2\nu} |M^{2\nu}|^2 \quad M^{2\nu} = M(\tau\sigma\tau\sigma) \text{ Res.}$$

$$0\nu\beta\beta \quad \Delta L=2 \quad T^{0\nu} = G^{0n} |M^{0\nu}|^2 |\langle m \rangle|^2, \text{ RHC, SUSY, Maoron.}$$

- $\beta\beta$ is the most sensitive and realistic way to study
 - 1. Majorana nature of ν , $\nu = \text{anti-}\nu$
 - 2. Majorana ν mass scale and spectrum in the range
 - of 50-5 meV suggested by recent ν studies.

• Effective masses and $\beta\beta$ experiments



QD 100~200 meV

NEMO3 CUORITINO

Future 1 100 meV

IH: Future II 25 meV

NH: Future III 2 meV

$$\theta_{13}^2 e^{i\phi_3} (\delta m_A^2 + m_1)^{1/2},$$

Phase +/- ~ 2 IH/NH ~ 10

QD: Cosmological 200 ~ 300 meV

$\Sigma m < 680$ meV Hannerstad

Single $\beta \sim 200$ meV Drexlin

2. Double beta decay experiments

DBD experiments E. Fiorini

Present DBD exps X. Sarazin

Future DBD exps A. Guiliani

Individual 9 future projects



Mass sensitivity m_ν by $\beta\beta$

$$T^{0\nu} = G |M^{0\nu}|^2 |m_\nu|^2, \quad G \sim Z^2 Q_{\beta\beta}^5.$$

$$N^{0\nu} > 2 [N_{BG}]^{1/2} \quad 95\% \text{ CL}$$

- $S_n = G (M^{0\nu})^2$
- $N_{BG} \sim N(2\nu\beta\beta) + RI$ per ton of $n_{\beta\beta}$
- $m_\nu \sim 16 S_n^{-1/2} (n_{\beta\beta}/B)^{-1/4} (A/100)^{1/2}$
- $S_n / 10^{-24}$ per y (ev)² $B = BG$ per $n_{\beta\beta} = 1$ ton, $\varepsilon \sim 0.6$, $t = 5$ y
 - Present experiments \sim a few 100 meV by $n_{\beta\beta}/B$
 - Next exps with a few 10 meV,
- $n_{\beta\beta}/B$ has to be increased by an order 4, each orders 2
 - Large detector with $n_{\beta\beta} \sim$ tons to get at least a few signals.
 - Centrifugal separation & laser separation

- **BG/t y and $n_{\beta\beta}$ required for IH m_ν 30 meV**

$\varepsilon \sim 0.6$ efficiency, $t = 5$ y 2σ CL

$M^{0\nu} = 2.5$ for all except 1.25 for Ca Nd with deformation change

	m_ν	B / y t	$n_{\beta\beta}$ ton	
• ^{76}Ge	$42 (B / n_{\beta\beta})^{1/4}$	0.5	2	
^{130}Te	$31 (B' / n_{\beta\beta})^{1/4}$	1 *	1	TeO₂
• ^{48}Ca	$23 (B / n_{\beta\beta})^{1/4}$	4.2	1	
• ^{82}Se	$21 (B / n_{\beta\beta})^{1/4}$	4.2	1	
• ^{100}Mo	$18 (B / n_{\beta\beta})^{1/4}$	7.7	1	
^{136}Xe	$22 (B / n_{\beta\beta})^{1/4}$	3.5	1	
• ^{150}Nd	$18 (B / n_{\beta\beta})^{1/4}$	7.7	1	

- **Signal is among many RI BGs and $M^{0\nu}$ is sensitive to nuclear structures. Need 3 ~ 4 experiments with different $\beta\beta$ nuclides and different methods .**

A. Calorimetric detector

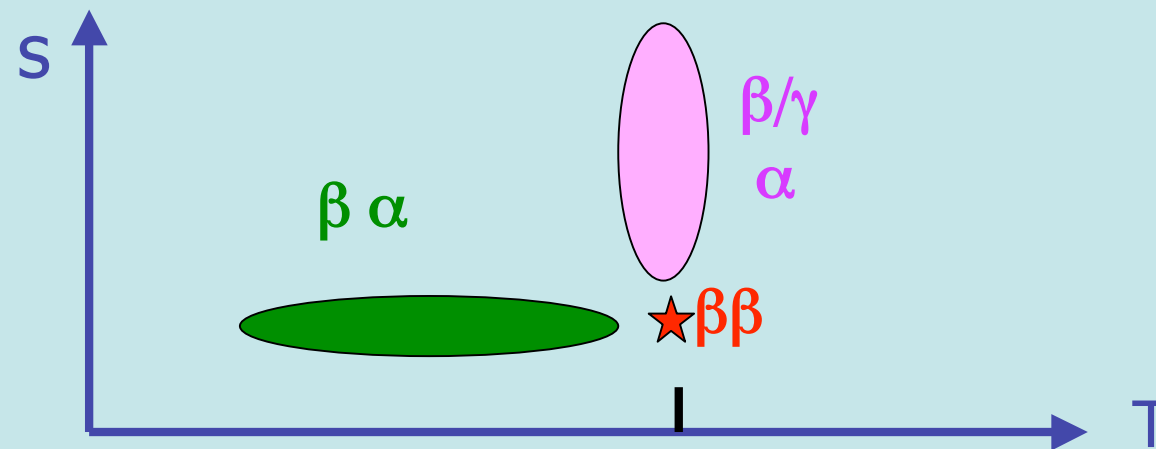
^{76}Ge (GERDA, MAJORANA),
 ^{130}Te (CUORITINO CUORE); ^{100}Mo and others
High E resolution, $E < 2.6 \text{ MeV}$. Mostly RI BG

$$m_\nu \sim 40 \sim 30 / (B / n_{\beta\beta})^{1/4}$$

$$n_{\beta\beta} \sim 0.1 \text{ t}, \quad B \sim 1 / \text{t y}, \quad 80 \sim 50 \text{ meV}$$
$$2 \text{ t} \quad 0.3 / \text{t y} \quad 26 \sim 15 \text{ meV}$$

A. SSSC :Signal Selection by Spatial Correlation rejects $\beta\text{--}\gamma$, α .

B. SSTC :Signal Selection by Tim Correlation rejects most $\beta\text{--}\alpha$.



A. Calorimetric detector II

^{48}Ca (CANDLES)

Signal rate: $A \sim 0.2\%$ laser : ton scale

BG rate $Q=4.3\text{ MeV} > \text{Most RI}$,

BG $2\nu\beta\beta$

^{136}Xe (EXO)

$Q = 2.4\text{ MeV} < \text{Most RI}$

No RI BG by **Ba tagging**,

BG $2\nu\beta\beta$: good $\sigma \sim 2\%$ by ion and scintillation reads

^{150}Nd (SNO+)

$Q = 3.368 \pm 50\text{ meV}$

$M^{0\nu}$ is reduced ?? by change of deformation

1k ton detector with 0.1% of 56% enriched ^{150}Nd

B Spectroscopic detectors

ELEGANT- MOON

NEMOIII - Super NEMO

DCBA

$E_{12}-\Theta_{12}$ identify m_ν term

Detector \neq source

Select $\beta\beta$ nuclide by

$Q_{\beta\beta}$, Z, Enrichment, $2\nu\beta\beta$

Small RI-BG : $E(\text{RI}) < Q_{\beta\beta}$
 $\beta/\alpha, \gamma$ separation

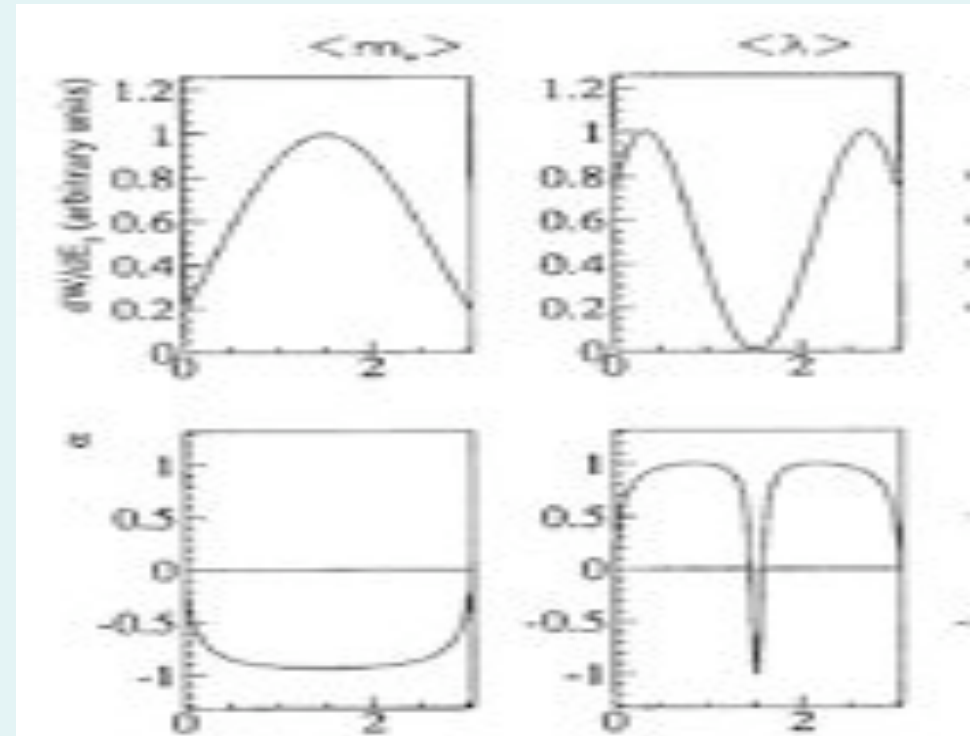


Fig. 4. Energy and angular correlations for the mass and right-handed current term. Top: Calculated single- β spectra. Bottom: $\beta_1 - \beta_2$ coefficients α defined by $W(\theta_{12}) = 1 + \alpha \cos \theta_{12}$.

Major BG : $2\nu\beta\beta$ tail in $0\nu\beta\beta$ window. E-resolution !

E resolution and mass sensitivity / 5 ty

$$m_\nu(\text{min}) = \frac{19}{S} = \frac{19}{S_N S_{2\nu} M S_D}$$

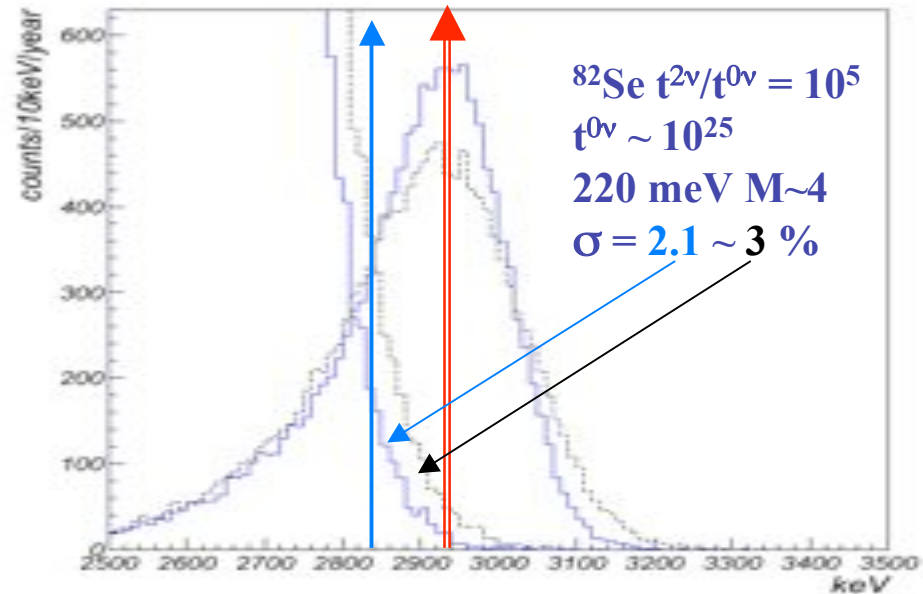
$$S_N = |G^{0\nu}/m_\nu^2|^{1/2} [A/100]^{-1/4}$$

$$S_{2\nu} = |t_{1/2}^{2\nu}|^{1/4}$$

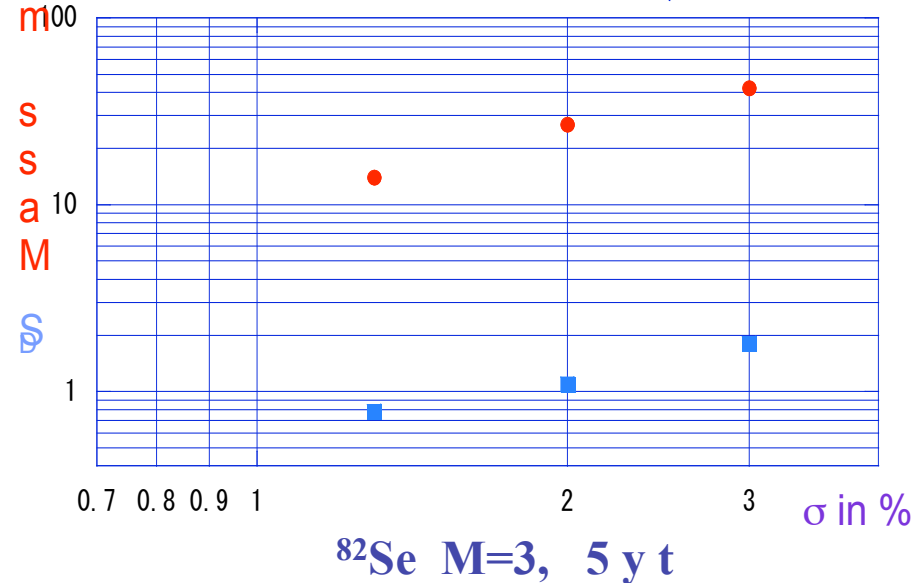
$$S_D = |t^{0\nu}|^{1/2} [t^{2\nu} 10^7]^{-1/4}$$

($G^{0\nu}/m_\nu^2$ is in unit of 10^{-34}eV^{-2} , and $t_{1/2}^{2\nu}$ is in unit of 10^{26}y .)

- $\sigma \sim 3 \sim 2 \%$ realistic
- $\sigma \sim 1.5 \%$ realistic challenge
- \sim Statistics resolution of PL

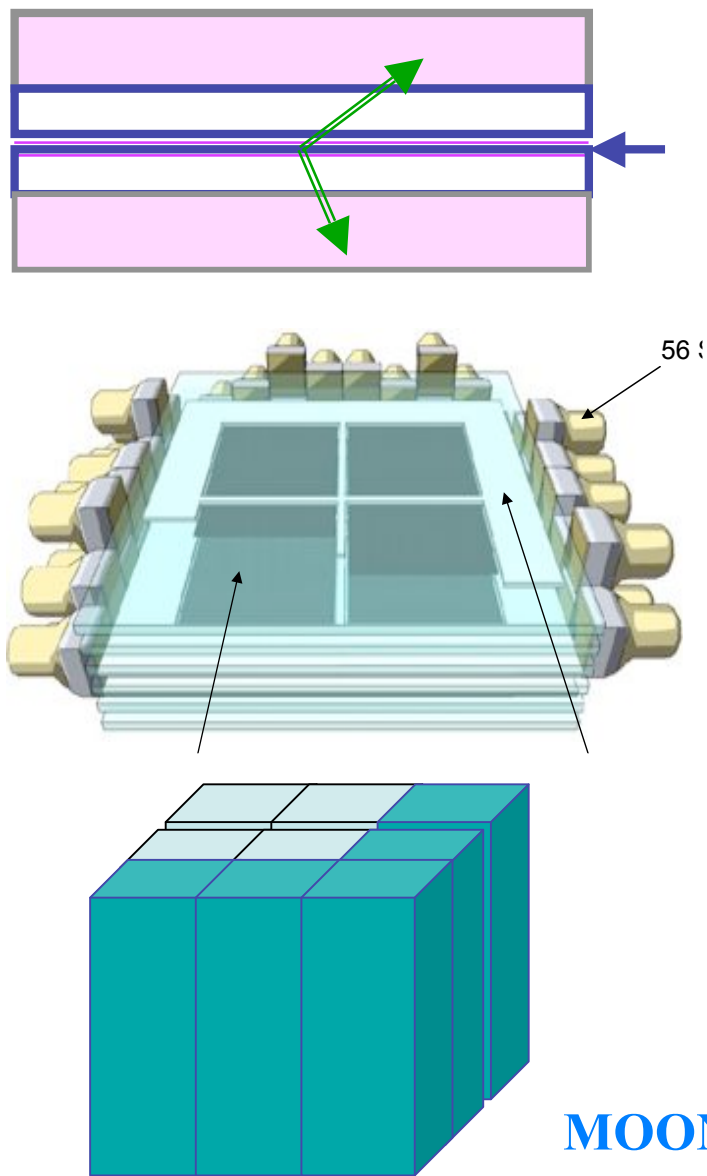


Mass and detector sensitivities / resolution

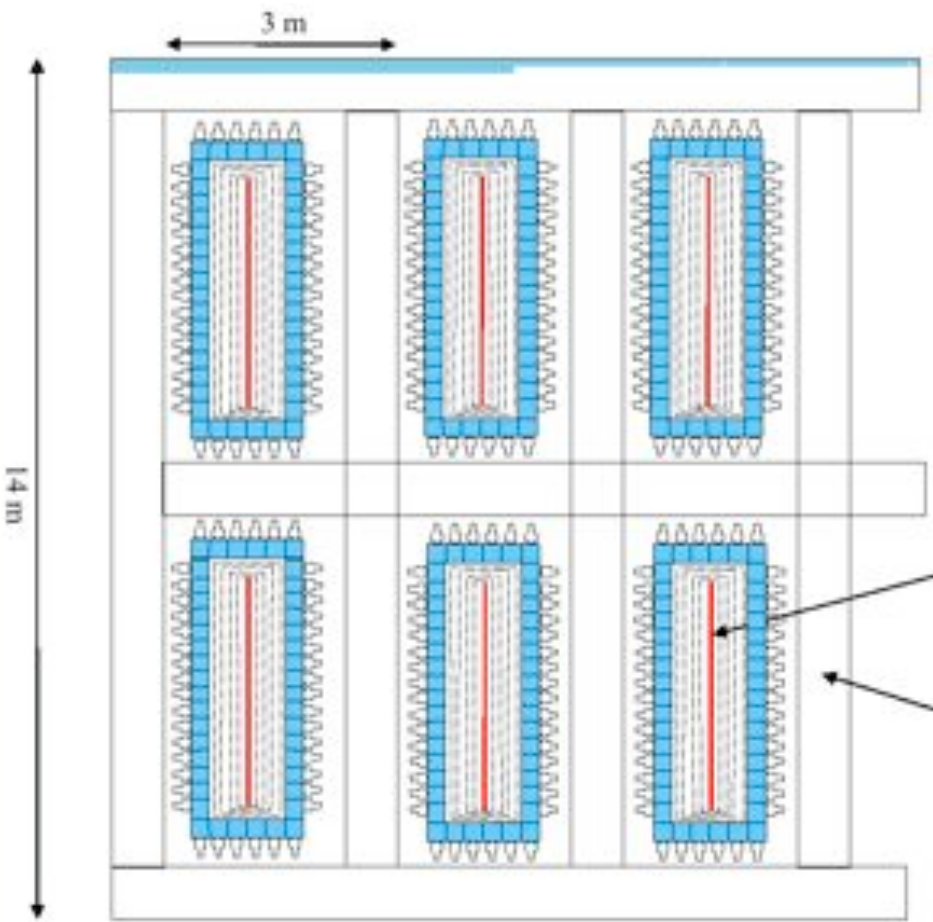


MOON / ELEGANT 1990

Super NEMO / NEMO 3



9-units of 100 modules 20 kg



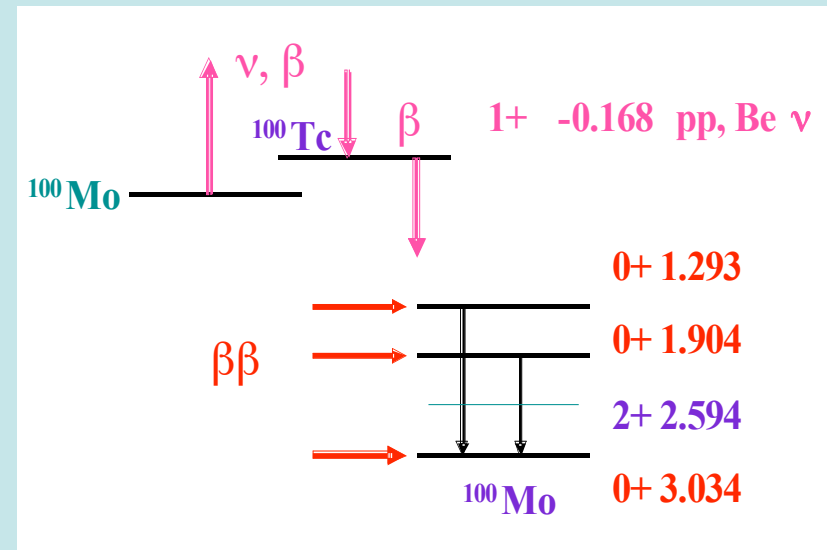
	Detector	modules	Source kg	V m ³ /t
MOON	Multi-layer	100	180	0.5K
S-NEMO	Single	20	100	11K

Ground and excited 0+ states

$$1. S/(BG^{2\nu})^{1/2} \sim T^{0\nu}/(T^{2\nu})^{1/2} \\ \sim Q^5/(Q^{10})^{1/2} \sim \text{no } Q\text{-dep.}$$

if M are similar ?

$$2. E(\text{gr}) = E_{\beta\beta}(\text{gr}): 3 \text{ MeV} \\ E(\text{ex}) = E_{\beta\beta}(\text{ex}) + E_{\gamma\gamma} \\ \text{Same } E, \text{ smaller RI BG}$$



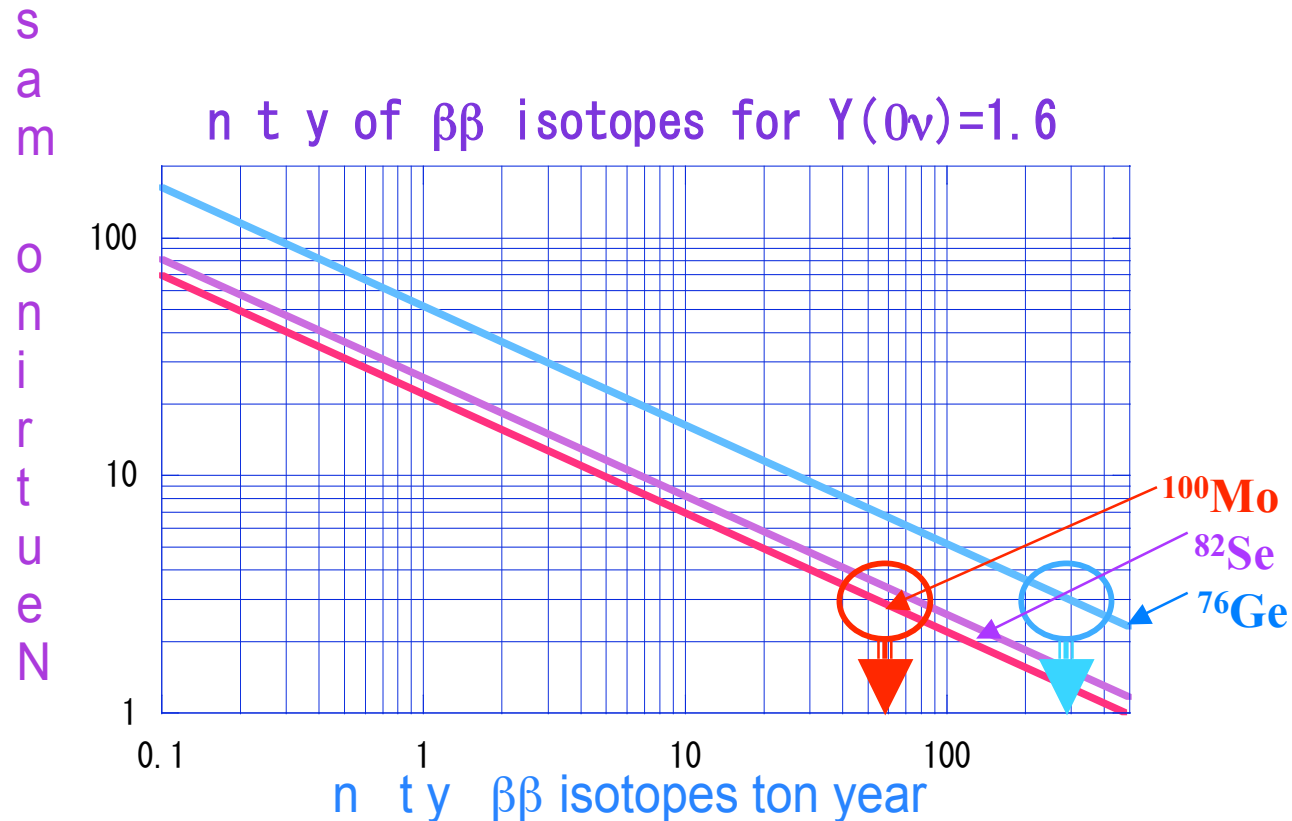
3. $T^{0\nu}(\text{gr}) / T^{0\nu}(\text{ex})$ depends on deformation, mixing of two 0+ states, 0ν mechanisms.

	Isotope	Q(gs)	Q(ex)	G(gs)	G(ex)
•	^{82}Se	2.992	1.517	1.9	0.23
	^{100}Mo	3.034	1.903	3.2	0.77
	^{150}Nd	3.368	2.628	13.4	~ 3.0

* ^{150}Sm 1.255 MeV excited state is deformed as ^{150}Nd gs.

Normal hierarchy NH with 2-4 meV

$Y^{0\nu} > 1.6$ for $0\nu\beta\beta$ with 1σ CL, $M=3$, $\varepsilon = 0.5$, $BG \ll 1$



- A:** ^{82}Se 5 t - 10 y $BG(2\nu\beta\beta) \sim 0.015$ for $\sigma = 1.3\%$ & E cut.
Bi ~ 0.007 / t y with 1.25 m Bq / t and good position R.
- B.** ^{76}Ge 30 t - 10 y $BG \ll 0.003$, $BG \sim 0.3$ / t y at present

3. Nuclear matrix elements of double beta decays

Shell model: A. Poves

QRPA: O. Civitarese V. Rodin

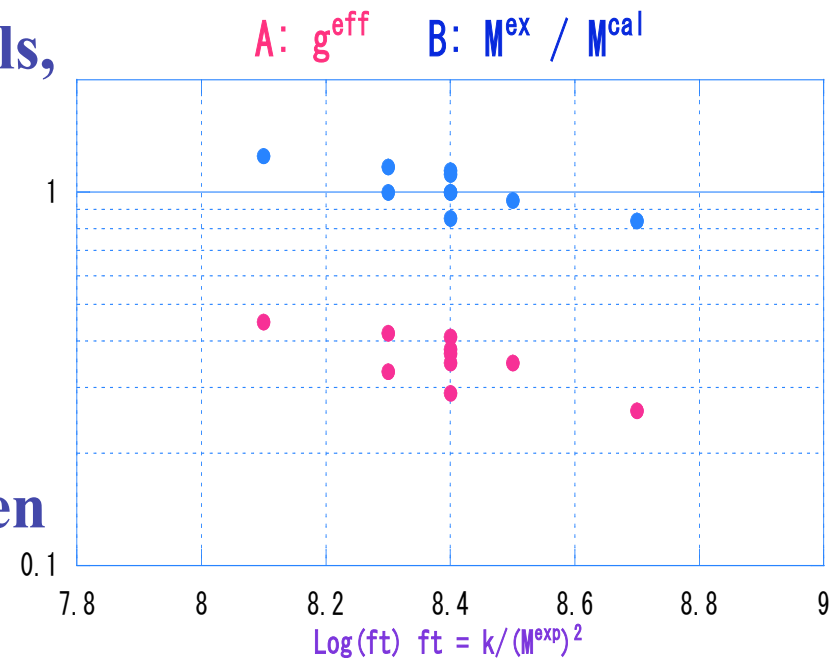
Bosonic ν in $2\nu\beta\beta$: F. Simkovic

1. Effective coupling constant and model space

$M^{0\nu}$ sensitive to model space, g_A , short-range correlation, GR(J), etc.

- $g^{\text{eff}}/g = M(\text{exp})/M(\text{P: cal})$.
Coupling with GR, higher shells, non-nucleon deg. g_A and others
 $g^{\text{eff}}/g \sim 0.3$ for $\tau\sigma Y_1$ modes with $J = 2^-$ (2d5/2-2p1/2, 1g9/2-1f5/2)

2. Non-nucleonic degree of freedom
 Δ isobar where ν exchange between
2 d-quarks in Δ
 π exchange current contribution



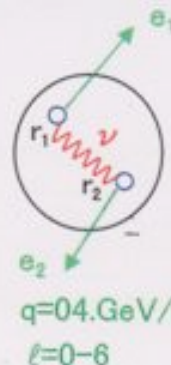
Nuclear Responses ($M^{0\nu}$) for $\beta\beta$

H.Ejiri, Phys. Rep. 338 '00 265

Nuclear Responses for $0\nu\beta\beta$

$$H(r_1, r_2, \tau_1, \tau_2, \sigma_1, \sigma_2) \sim f(r_1, r_2) \tau_1 \tau_2 \sigma_1 \sigma_2 \dots$$

$$f(r_1, r_2) = 1/|r_1 - r_2|$$



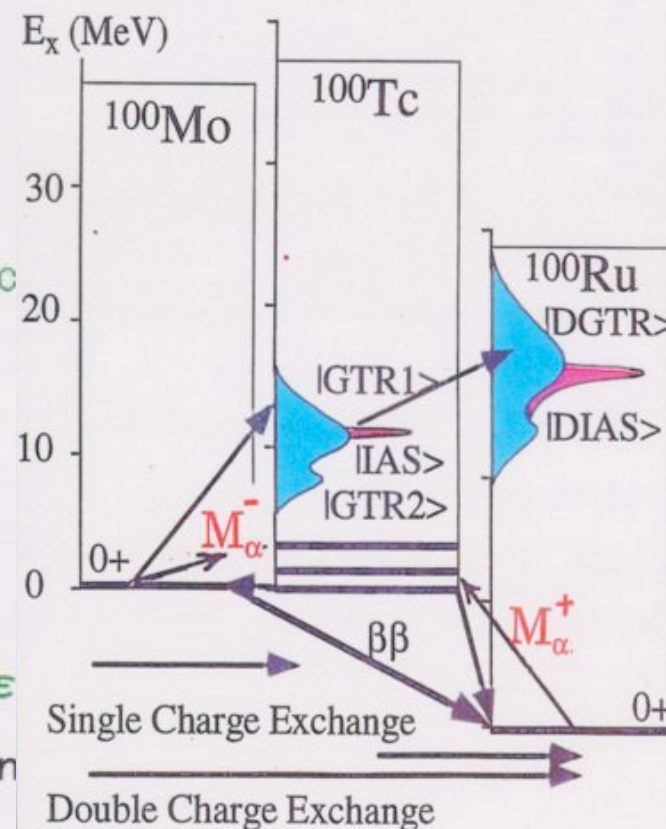
Separable Form for Nucleon $r_n < r_i, r_j < \text{Nuclear } R_N$

$$f(r_1, r_2) \sim \sum_{\ell} f_{\ell} h_{\ell}(r_1) h_{\ell}(r_2) \quad \text{Ejiri, Belyaev}$$

$$M^{0\nu} \sim \sum f_{\ell} \langle 0_f | T_{\ell}^+ | i \rangle \langle i | T_{\ell}^+ | 0_i \rangle \quad T_{\ell} = h_{\ell}(\gamma) \tau \sigma$$

$$M^{0\nu} \sim \sum M_{\ell}^+(\text{SP}) M_{\ell}^-(\text{SP}) + (M_{\ell}^+(\text{GR}) M_{\ell}^-(\text{GR})) \rightarrow \varepsilon$$

Studied by τ^- and τ^+ Charge Exchange Reaction
($^3\text{He}, t$) and ($t, ^3\text{He}$) reactions

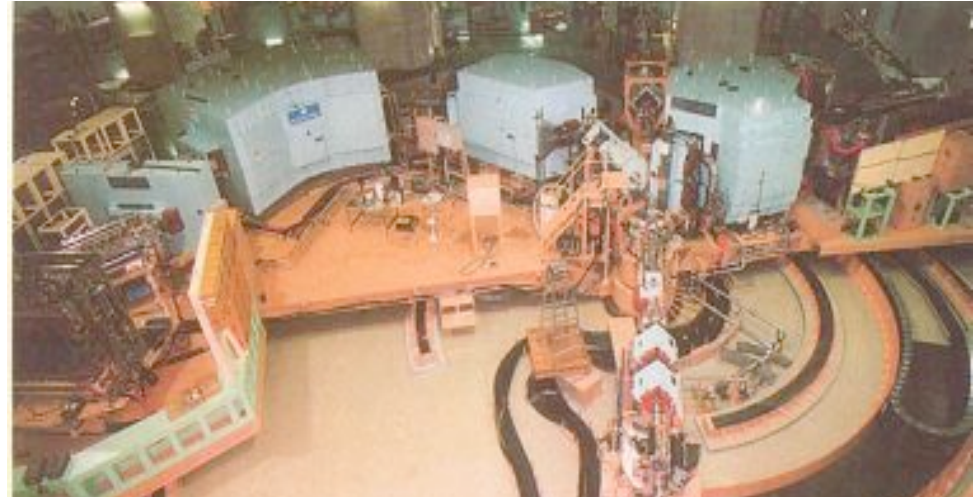
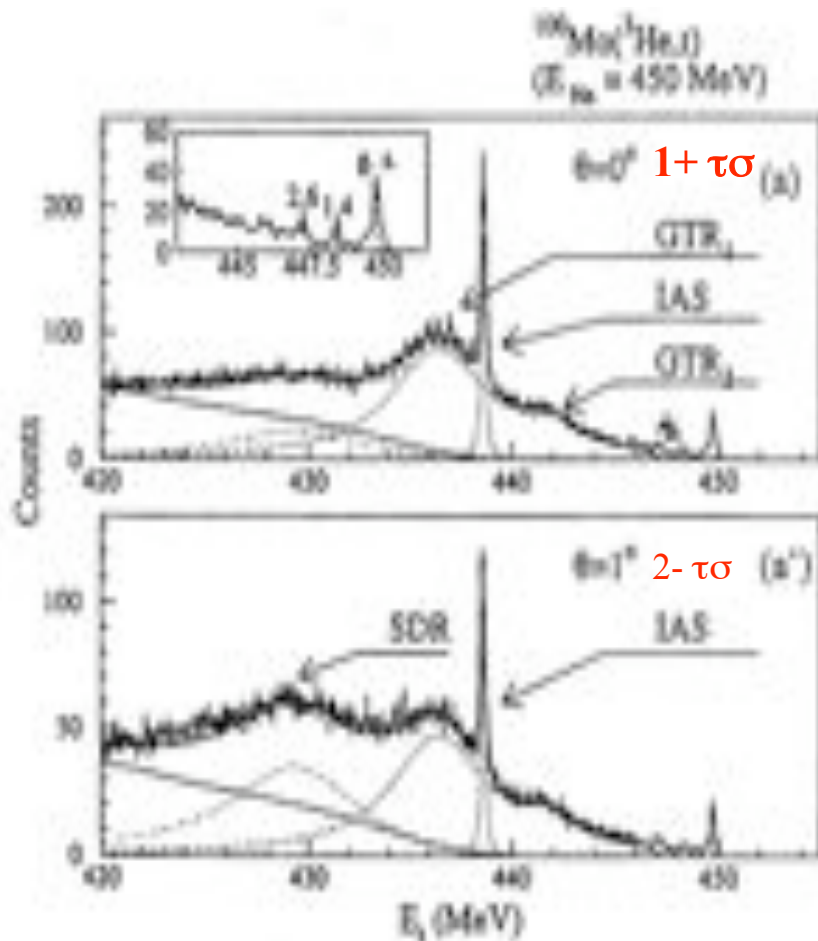


Charge exchange reactions, transfer reactions, EC
provide nuclear structure information relevant to $M^{0\nu}$

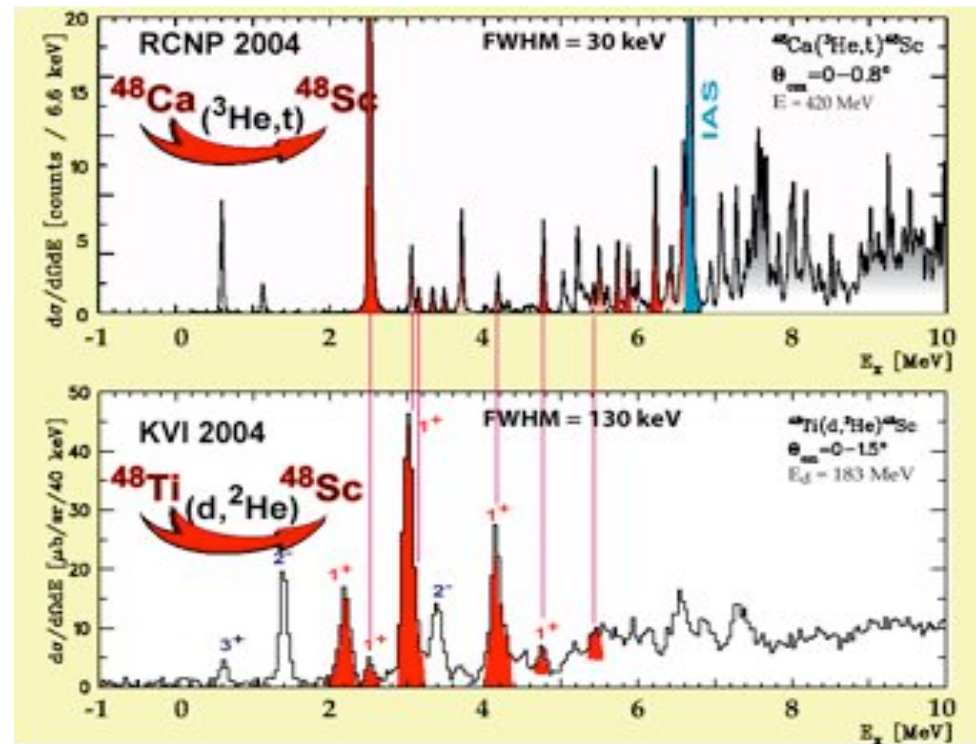
RCNP Osaka, MSU, KVI, TRIUMF, UW,

Nuclear probes

RCNP Osaka High ΔE
 τ - σ response at low and
 high $1+$ $2-$ states



Freckers



Electron beam injection from 1.5 GeV
Shifting 4 injection
1.0 GeV

Forward experiment
Backward experiment
Compton region
Long Compton
Storage ring
1.5 GeV
New SUBARU
Compton region
Optical Element
Experimental preparation area

Beam line "BL01"
for laser-Compton γ exp.

E_{γ} ; 17 ~ 40 MeV (1.06 μ Nd-YVO₄)

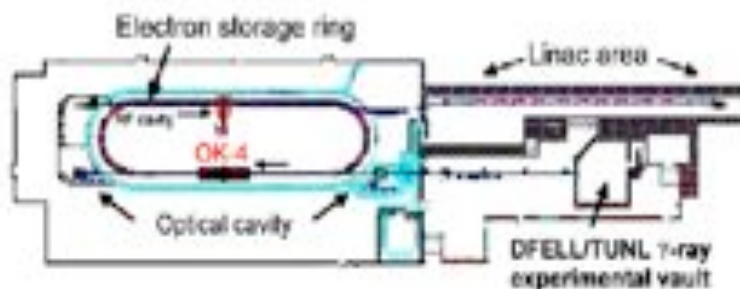
 $\Phi_{\gamma} \sim 10^8 \text{ photons/s, } \Delta E_{\gamma}/E_{\gamma} = 2\%$

K. Aoki, S. Miyamoto,

NIM A516 (2004) 228-2

H_γS (High Intensity γ -ray Source)

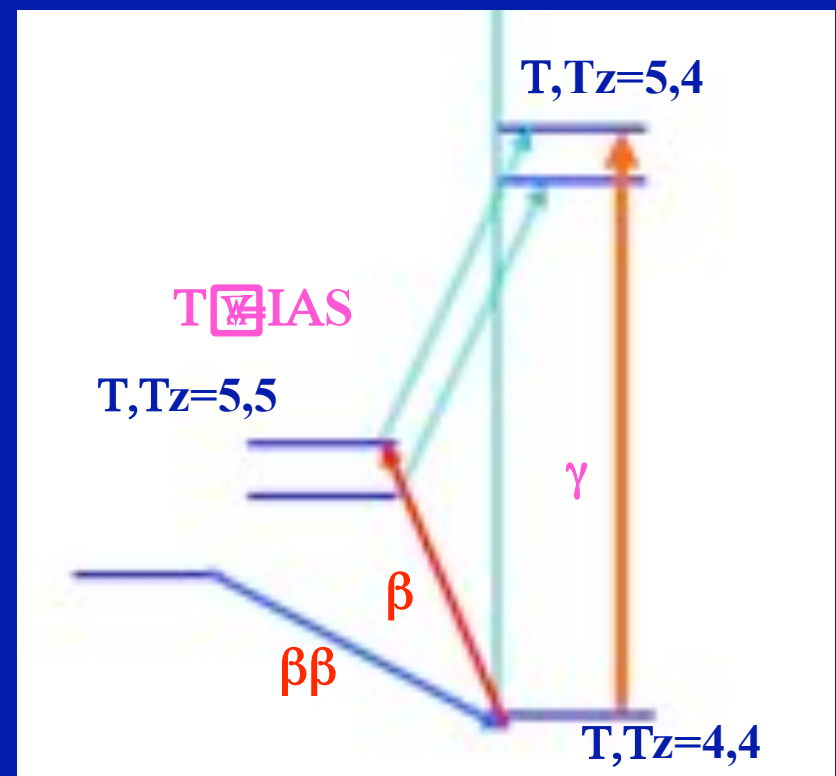
- Intra-cavity Compton Backscattering of FEL photons by electrons circulating in the 1.2GeV Duke Storage Ring



■ $E_\gamma = 2\text{--}70\text{ MeV}$, $\Delta E_\gamma/E_\gamma \sim 1\%$, $\Phi_\gamma \sim 10^7\text{ /MeV/s}$ ($\rightarrow 10^9$)

Photon probes

Real photons with multi MeV
Energy spectra with peak at the max e
Pol. for E1-M1 vector axial vector
IAS/GR interference gives the phase.



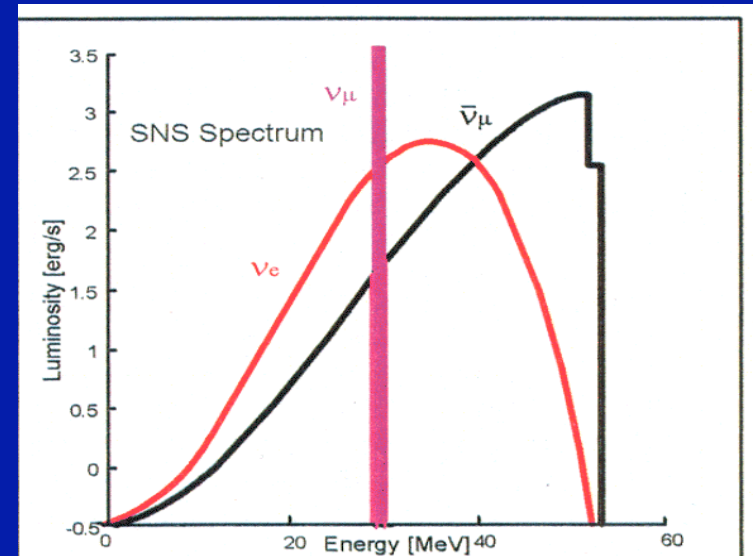
H. Ejiri PR 38 '78

Neutrino probes

SNS Stopped π^+ $p + \text{Hg} \rightarrow n \pi^+$

$\pi^+ \rightarrow \mu^+ + \nu_\mu$ Intense ($\sim 10^{15}/\text{sec}$) ν 's with large detectors (10 tons) for $\sigma \sim 10^{-41-42} \text{ cm}^2$

Y. Efremenco



4. Concluding remarks



Concluding remarks

1. DBD with 0.5 - 5 t y are unique and realistic for the Majorana ν and absolute ν -masses in QD-IH. Laser separation is interesting.
2. DBD exps with different methods, different $\beta\beta$ isotopes and/or states are indispensable. Calorimetric detectors made of $\beta\beta$ nuclei and spectroscopic (two- β identifying) detectors with non-detector $\beta\beta$ source are complementary and necessary.
3. Nuclear theories for $M^{0\nu}$ are crucial to design DBD exps, select best $\beta\beta$ nuclides, and to get ν -masses. Nuclear experiments with nuclear, photon and even ν probes provide information on nuclear structures relevant to $0\nu\beta\beta$.
4. DBD detectors are used for solar- ν (MOON), DM etc.
5. Internationally coordinated approaches on DBD exps. and DBD nuclear particle theories are strongly encouraged.

INTERNATIONAL STATEMENT ON NEUTRINOLESS DOUBLE-BETA DECAY

Avignone F, Barabash A, Ejiri H, Elliott S, Fiorini E,
Haxton W, Gratta G, Jullian S, Kochetov O, Minakata H,
Lalanne D, Morales A, Morales J, Petcov S, Suhonen J.

<http://www.rcnp.osaka-u.ac.jp/~ejiri/DBD-Lett>

1. Fundamental ν properties studied by DBD: (1) Majorana nature & $\Delta L \neq 0$, the ν mass spectrum & mass scale, possibly CP. DBD is realistic for studying these fundamental ν properties.
2. 2. Next-generation DBD exps with $\langle m \rangle \sim 25$ meV discover non-zero effective ν mass if ν 's are Majorana and the QD or IH.
3. Form an international DBD network in order to endorse a coordinated approach to executing next-generation DBD probes

MAJORANA/GERDA, MOON/SuperNEMO , etc are encouraged

Neutrino Nuclear Responses in $\beta\beta$ NNR-05

Durham, UK, May-2005 (K. Zuber)

CAST-Spring-8, JP, Dec-2005 (H. Ejiri)

Open Letter

... We, the undersigned, have met to endorse a coordinated approach to provide experimental information relevant to DBD matrix elements, which are of vital importance for new generation DBD.

The present and planned experiments at RCNP, KVI, MSU and others provide unique opportunities for the experimental studies of the $\beta\beta$ matrix elements.

H.Ejiri, D. Freckers, M. Harakeh, K. Zuber, R. Zegers, others.

A photograph of a sunset or sunrise over a body of water. The sun is low on the horizon, creating a bright, horizontal band of light that reflects on the water's surface. The sky is filled with soft, golden clouds. In the foreground, the dark silhouettes of hills or mountains are visible against the bright light of the sun.

Thank you for your attention

The matrix elements are assumed to be $M = 3$.

a) Mass sensitivity for $S_D \approx 0.55$ with a modest energy-resolutions of $\sigma \approx 3\%$.

b) Mass sensitivity for $S_D \approx 0.9$ for detector with a good energy-resolutions of $\sigma \approx 2.2\%$.

Isotope	A %	$Q_{\beta\beta}$ MeV	S_N	$S_{2\nu}$	$m_\nu(\text{min})^a$	$m_\nu(\text{min})^b$
^{82}Se	9.2	2.992	0.28	0.98	42	27
^{100}Mo	9.6	3.034	0.35	0.53	62	36
^{116}Cd	7.5	2.804	0.34	0.75	45	27
^{130}Nd	5.6	3.368	0.71	0.51	31	19

$$m_\nu(\text{min}) = \frac{19}{S} = \frac{19}{S_N S_{2\nu} M S_D},$$

$$S_N = |G^{0\nu}/m_\nu^2|^{1/2} [A/100]^{-1/4},$$

$$S_{2\nu} = |t_{1/2}^{2\nu}|^{1/4},$$

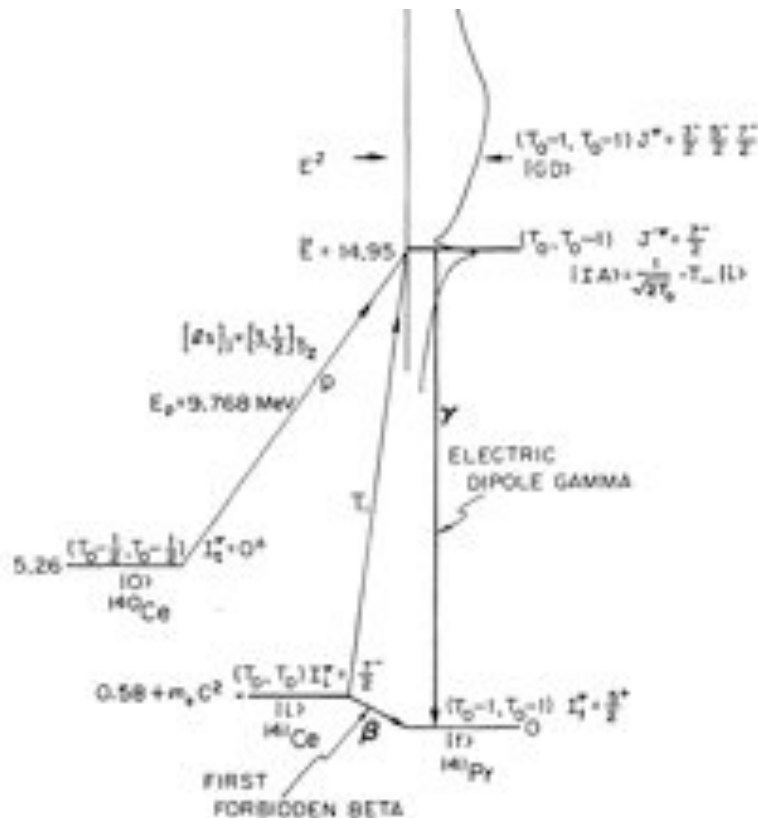
$$S_D = |e^{0\nu}|^{1/2} [e^{2\nu} 10^7]^{-1/4},$$

($G^{0\nu}/m_\nu^2$ is in unit of 10^{-24}eV^{-2} , and $t_{1/2}^{2\nu}$ is in unit of 10^{20} y.

M^β from IAS γ

IAS-GR interference gives
 M^β and sign

H. Ejiri PRL 21 '68, H. Ejiri PR 38 '78

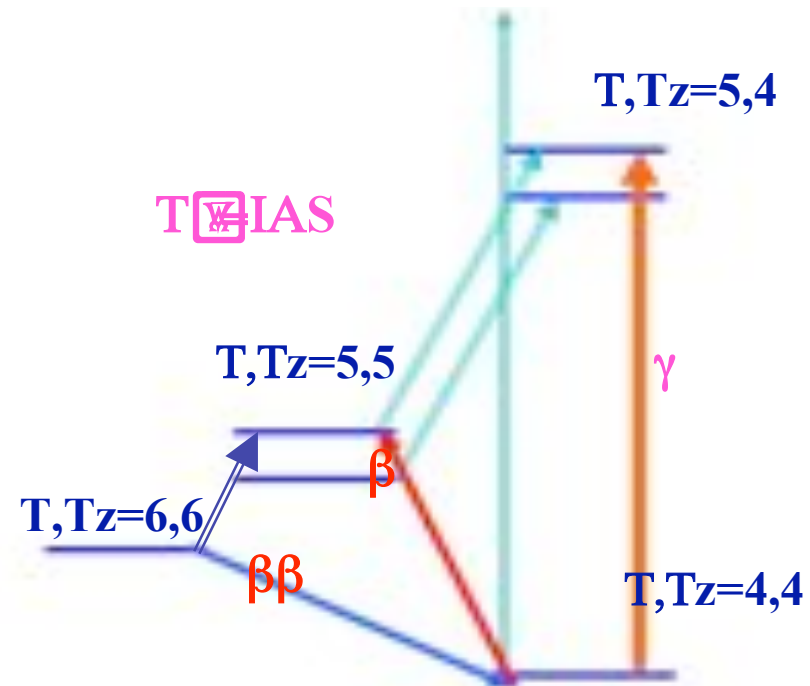


$$g, m_{1\beta}^\beta = g, \sum_{1\beta} a_{1\beta}^+ \langle v | r Y_{1\beta} | \lambda \rangle b_{1\beta}.$$

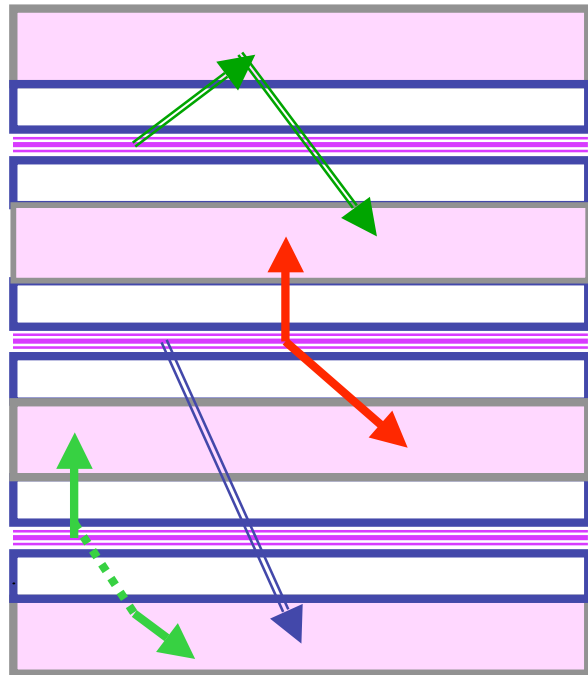
$$|g, M^\beta| = \sqrt{2T_0} |e M_{1\beta}^\beta| \frac{\theta_r}{e}$$

$$g, i\zeta \theta^\beta = -g, i\zeta m^\beta (\Lambda - 1.2\Lambda_1 - 1),$$

where $\langle m^\beta \rangle = \langle r \rangle$, $\Lambda = -i\langle \alpha \rangle / \zeta \langle r \rangle$ and $\Lambda_1 = i\langle \sigma \times r \rangle / \langle r \rangle$.
 $\langle r \rangle$ from IAS γ , Λ from CVC, and one gets $(\sigma \times r)$.



Position sensitive detector



← PL 1200-1200-15 mm for

Energy 0.5 -2.5 MeV with $\sigma \sim 2.1 \%$ at Q.

← Drift/MWPC chamber 1160-1160-8 mm.

Position $\Delta X \sim 1\text{mm}$, $\Delta Y \sim 50 \text{ mm}$ by charge ratio.

Angular distribution by the total charge

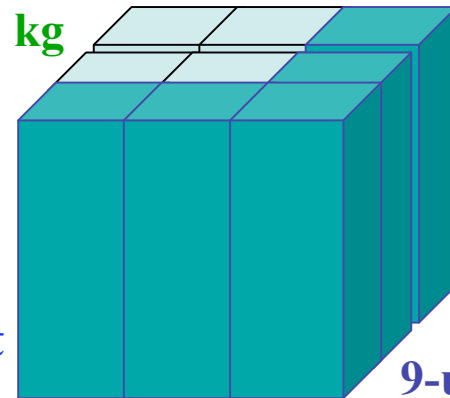
← $\beta\beta$ source 1000-1000 mm 20 mg/cm²

4 units 120 kg

One module $\beta\beta$ source 1m-1m 20 mg/cm² = 0.2 kg

PL+2DF 1.2 m – 1.2 m 2.5 cm

One unit 150 modules, 30 kg, 1.2m – 1.2m – 4m, 3.3 t



9-units 270 kg

Future experiments

Transition amplitude ; $A(0\nu\beta\beta) = m_\nu S_N S_D$

$S_N = G M^{0\nu} Q_{\beta\beta}^{5/2}$ Nucl. Sensitivity Large $M^{0\nu} Q_{\beta\beta}$
 $S_D = [N_{\beta\beta} / N_{BG}]^{1/4}$ Detector Sensitivity $N_{\beta\beta}$ ton $N_{BG} \sim 1/t$ y

Isotope	A %	$Q_{\beta\beta}$ MeV	$S_N 10^{-24} y^{-1} (eV)^{-2}$	Experiment/collaboration
^{48}Ca	0.187	4.276	0.11	CANDLES ^a
^{76}Ge	7.8	2.039	0.22	MAJORANA ^b GENIUS ^c GERDA ^d
^{82}Se	9.2	2.992	0.86	Super-NEMO ^e
^{100}Mo	9.6	3.034	2.02	MOON ^f
^{116}Cd	7.5	2.804	0.90	COBRA ^g CAMEO ^h
^{130}Te	34.5	2.529	0.73	CUORE ⁱ , COBRA ^g
^{136}Xe	8.9	2.467	0.13	EXO ^j , XMASS ^k
^{150}Nd	5.6	3.368	11.3	DCBA ^l



Detector : not $\beta\beta$ source, one multi-purpouse detector

GeV-MeV Laser Electron photons

- **GeV LEPS Spring-8 are unique probes**
- **Real photons in a wide energy range of multi GeV – MeV**
- **Energy spectra with peak at the max energy.**
- **Polarizations $\sim 100\%$ for E1-M1 vector axialvector**



MOON $\beta\beta$ experiments

Ground and excited + states

$$S/(N)^{1/2} \sim T^{0\nu}/(T^{2\nu})^{1/2} \sim Q^5/(Q^{10})^{1/2} \text{ const}$$

$$E(\text{GR}) = E(\text{ex}) = E_{\beta\beta}(\text{ex}) + E_{\gamma\gamma}$$

Isotope G(ex)	Q(gs)	Q(ex)	Q(ex)	G(gs)	G(ex)
• ^{82}Se	2.992	1.517		1.9	0.23
• ^{100}Mo	3.034	1.903		3.2	0.77
• ^{150}Nd	3.368	2.628	2.113	13.4	~ 3.0 ~ 1.3

Unique features of $0\nu\beta\beta$ experiments for ν studies

1. Unique realistic probes for the Majorana ν mass in 10 meV
2. Exps in nuclear labs to enhance S/N, but involve $M^{0\nu}$, sensitive to nuclear structures.
3. Signals within many RI BGs, which are not quite well known.
4. Need 3 ~ 4 experiments with different $\beta\beta$ nuclides and methods .
5. Ground and excited $0+$ states in ^{100}Mo , ^{150}Nd , etc.
Similar sensitivity, different methods,
Ground and excited $0+$ states mixing
leads the sum less sensitive to the deformation

Nuclear Matrix elements : theories

Shell model: A. Poves

QRPA: O. Civitarese V. Rodin

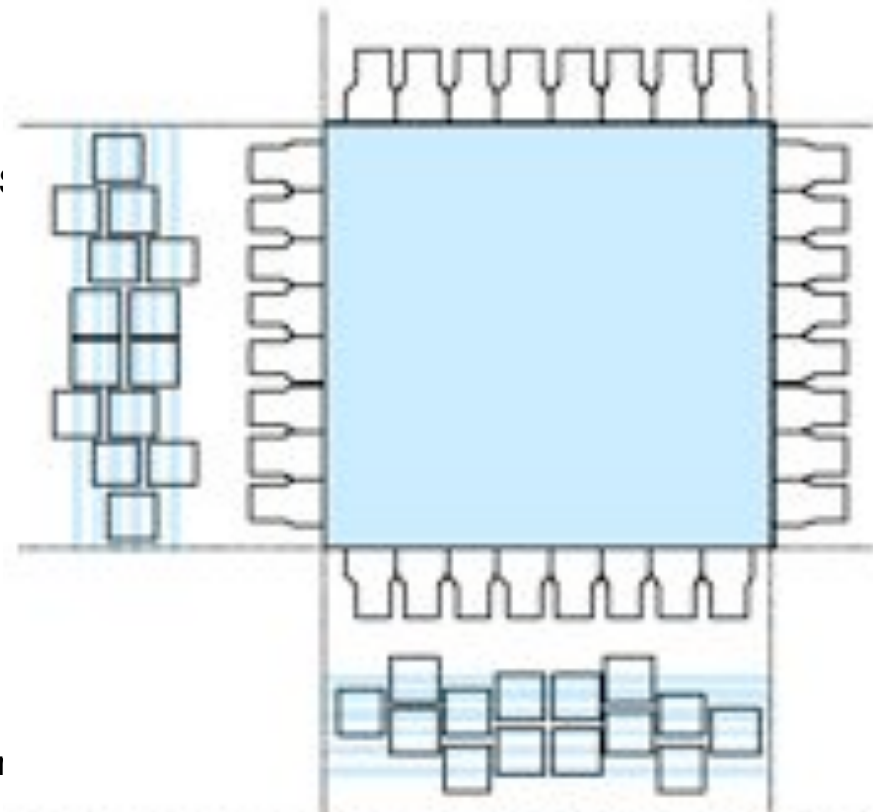
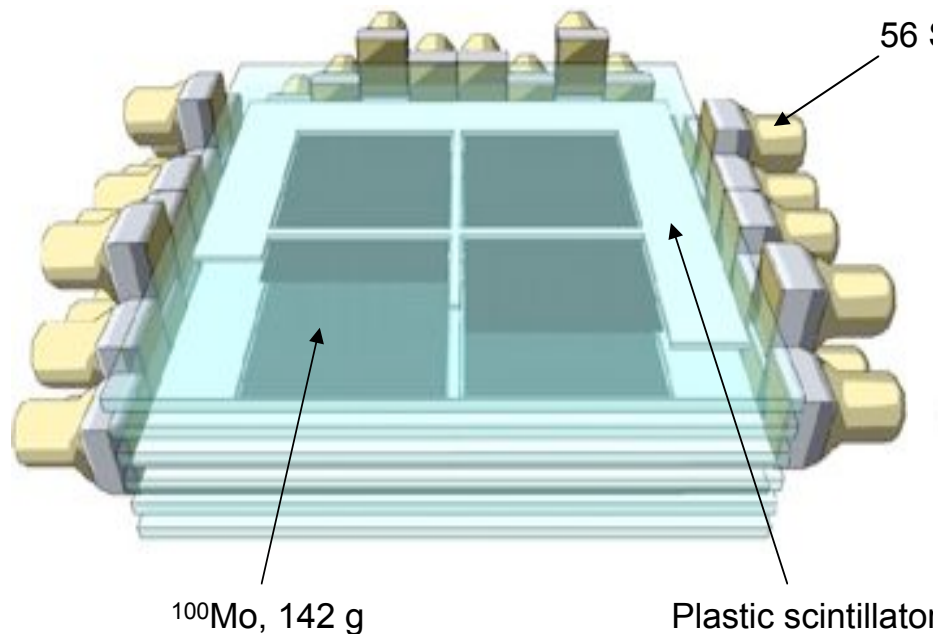
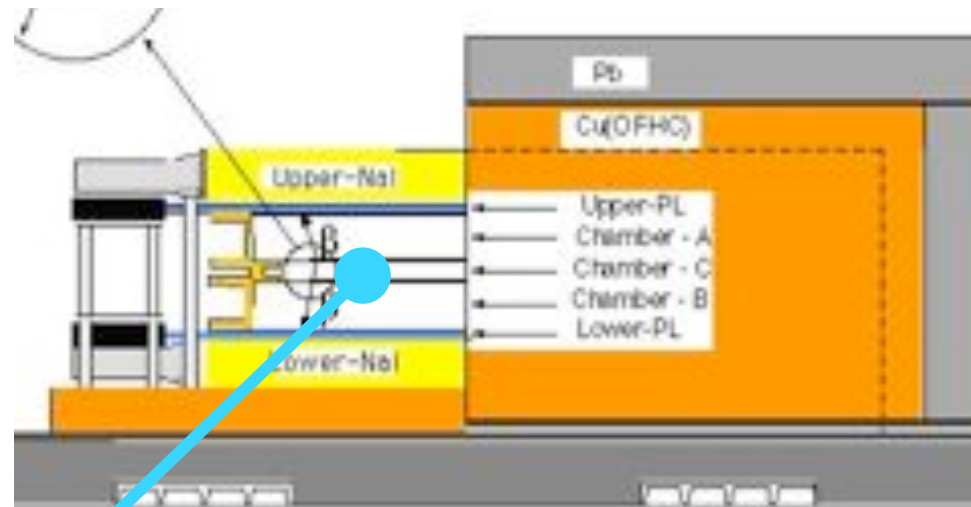
Bosonic ν in $2\nu\beta\beta$: F. Simkovic

Effective coupling constants g_A

MOON 1 Proto type

Inside the ELEGANT V
Pb-Cu NaI shield since April 2005.

6-layers of PL $53 \times 53 \times 1 \text{ cm}^3$ Mo-
Foil $160 \text{ g} @ 20 \text{ mg/cm}^2 \times 2$



1. Effective coupling constant and model space

- $M^{0\nu}$ sensitive to model space, g_A , short-range correlation, GR(J), etc.

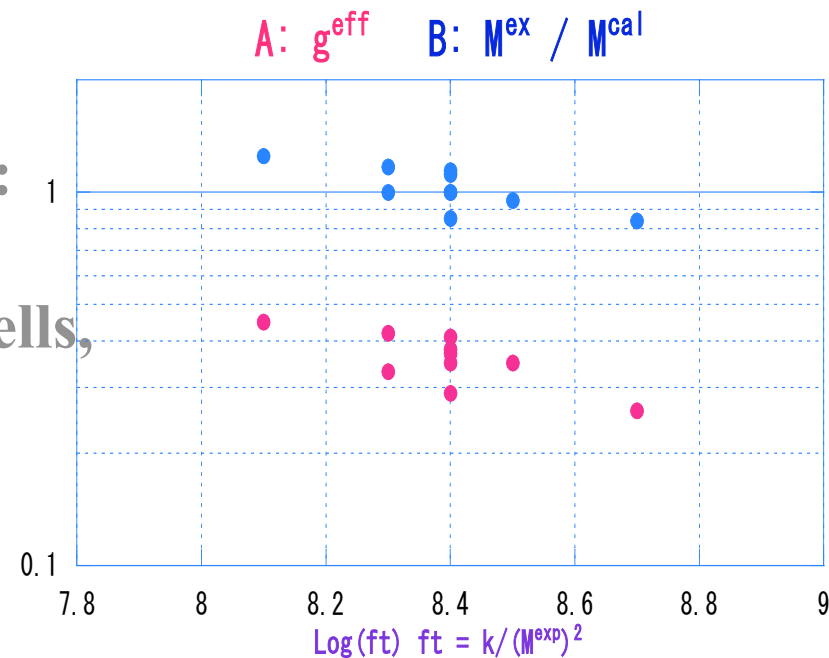
- B. Empirical theory/calculation.

- $1 = P + Q$ P: low lying states:

- $g^{\text{eff}}/g = M(\text{exp})/M(\text{P: cal})$.

Coupling with GR, higher shells, non-nucleon deg. g_A

g^{eff}/g for individual $\tau \sigma l J$ is from relevant exp. value.



$g^{\text{eff}}/g \sim 0.3$ for $\tau\sigma Y_1$ modes with $J = 2^-$ ($2d_{5/2}-2p_{1/2}$, $1g_{9/2}-1f_{5/2}$)