EM (γ) transitions from IAS and axial-vector and vector NMEs and their weak couplings

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Thanks the organizers for invitation to NEWS

Subjects to be discussed:

I. Experimental aspects of DBD NMEs.

1. Experimental outputs from DBD and DBD NMEs
2. Charge exchange nuclear and lepton (muon) reactions
3. Axial vector and vector weak couplings

II. Electro-magnetic (EM γ) NMEs for IAS to study DBD.

1. τ– NMEs and weak couplings associated with DBDs.

   M1 /E1 EM-γ NMEs for axial-vector /vector NMEs,

2. IAS-γ cross sections and IAS-γ transition rates.

III. Photo nuclear excitation of IAS for τ+ DBD NMEs.

1. (γ, IAS)cross sections.
2. Neutron angular distribution

I Experimental aspects of DBD

Neutrino-less ββ decays

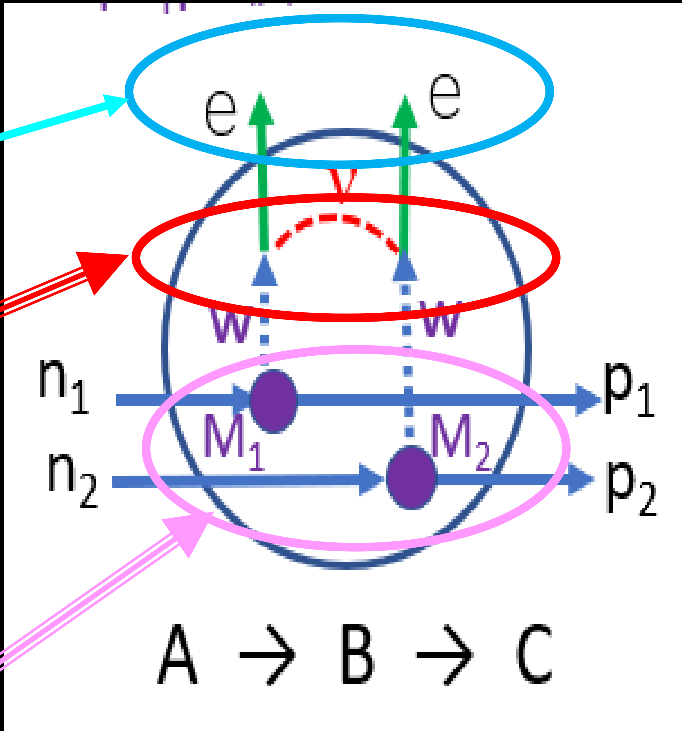
$$1/(T_{1/2}\ G^{0\nu}) = [M^{0\nu}\ m_\nu]^2$$

EXP

Atomic Physics
Phase space pe, Z

Particle physics
Majorana ν, m_ν CP, RHC

Nuclear phys.
$g_A{}^{eff}$ isobar , τ σ correlation



The rate is product of phase, NME, ν-mass, λ, η

$$1/t_{1/2} = T^{0\nu}/\ln 2 = G^{0\nu}\ B(NW)$$

$$1/(t_{1/2}G^{0\nu}) = B(NW) \qquad B(NW)=|M|^2 \qquad M=M^{0\nu}\,K_{\nu R}$$

$G^{0\nu}$ = includes $(g_A=1.27)^4$, $M^{0\nu}$ includes g_A^{eff} g_V^{eff}, depending on M

(1/Gt corresponds to 1/ft = B(GT/F) derived experimentally)

$$K_{\nu R} = [\langle m_\nu\rangle^2 + C_\lambda \langle\lambda\rangle^2 + C_\eta \langle\eta\rangle^2 + \text{interference terms}]$$

$$\langle m\rangle = |\Sigma m_j U_{ej}| \qquad \langle\lambda\rangle = (M_L/M_R)^2\,|\Sigma U_{ej} V_{ej}| \qquad \langle\eta\rangle = \tan\theta_{LR}\,|\Sigma U_{ej} V_{ej}|$$

C_λ and C_η are phase spaces and NMEs in units of those for m_ν

The measured $1/t_{1/2}$ gives product of NME and ν-mass/λ/η

$T^{0\nu}$ and NME gives mass or $T^{0\nu}$ and m gives NME.

NMEs are keys for new physics in DBD beyond SM

L-R symmetric model : $1/t_{1/2} = G^{0\nu}|M^{0\nu}|^2 K_{\nu R},$

$$K_{\nu R} = \left[\left(\frac{\langle m_\nu \rangle}{m_e} \right)^2 + C_{\lambda\lambda} \langle \lambda \rangle^2 + C_{\eta\eta} \langle \eta \rangle^2 + C_{m\lambda} \frac{\langle m_\nu \rangle}{m_e} \langle \lambda \rangle \cos\phi_1 + C_{m\eta} \frac{\langle m_\nu \rangle}{m_e} \langle \eta \rangle \cos\phi_2 + C_{\eta\lambda} \langle \lambda \rangle \langle \eta \rangle \cos(\phi_1 - \phi_2) \right].$$

$<m>=|\Sigma m_j U_{ej}|$ $<\lambda>=(M_L/M_R)^2|\Sigma U_{ej} V_{ej}|$ $<\eta>=\tan\theta_{LR}|\Sigma U_{ej} V_{ej}|$

i. **Light mass process , the effective Majorana mass depends on the mass spectra NH/IH, the mixing-phases, the minimum m_1 .**

ii. **NME within 50% for the NH/IH, within 30% for the phases. within 20 % for consistency among DBD nuclei, not RIs.**

$$(t_{1/2})^{-1} \sim G_{01} M_m^{\,2} m_\nu^{\,2} + G_{02} M^2_\lambda \lambda^2 + G_{09} M_\eta^{\,2} \eta^2 + \text{Cross terms}$$

Phase spaces $G_{01} : G_{02} : G_{09} = 1 : 10 : 0.5\ 10^5$ (recoil term)

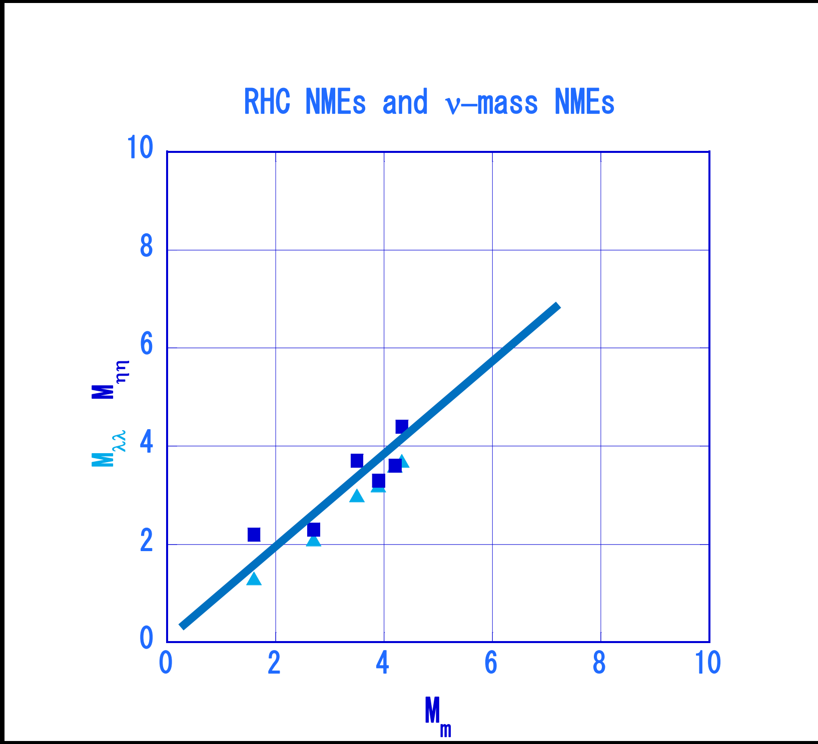
M_m=M(GT)(1-F+T)M

M_λ= Effective NME~ M(GT)

M_η = Effective NME~ M(GT)

$M_\lambda \sim M_h \sim M_m$
in case of QRPA

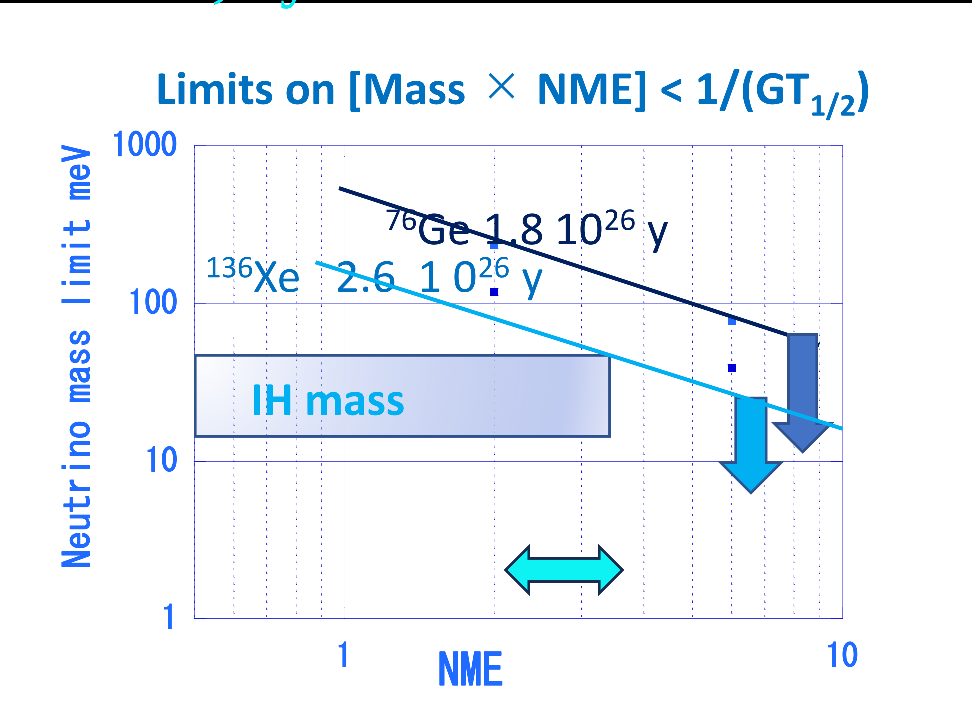
Thus the ν-mass sensitivity in units of me corresponds to the λ and η sensitivities smaller by the phase factors, SQRT of G_{02} and G_{09}= 3 and 700.



Muto et al., Z. Phys. A 334 187

Current limits

Current limits (GERDA PRL 125 252502, KamLAND PRL 130 051801) may reach IH mass, by a factor ~ 3 in ν-mass and $>10^2$ in NT/B



DBD EXPs : $M^{0\nu}$ =2~3.5 smooth function of A, depends little on individual nuclei. DBD isotopes should be selected by detector requirements, ton scale isotopes N and low-BG B.

H. Ejiri, L. Jokiniemi, J. Suhonen P R C Lettere 2 102 2022

NME is crucial for DBD exps.

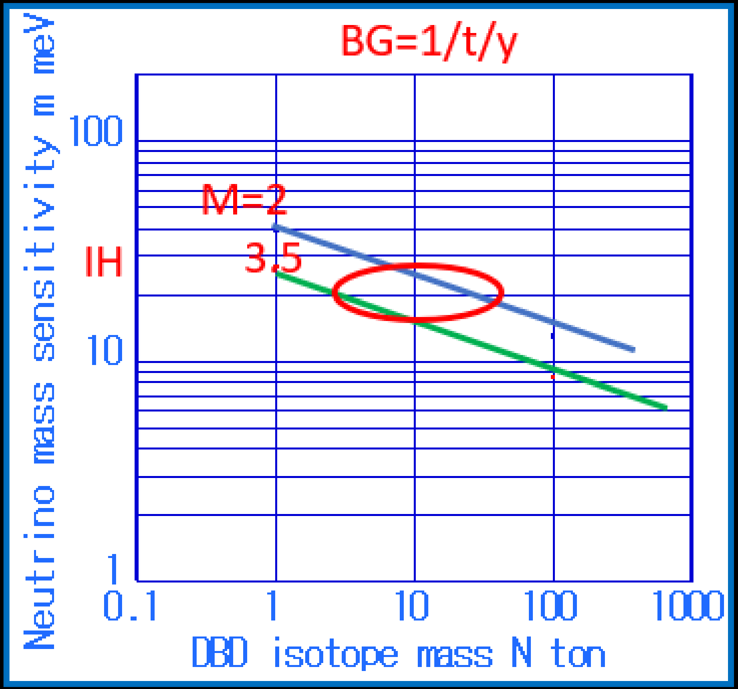
$T=G(\mathbf{M} m_\nu^{eff})^2$ G includes $(g_A=1.27g_v)^4$

1. ν- mass –sensitivity
   (m to be measured)
   $m= k /\mathbf{M} [B/N]^{1/4}$ $k=G^{-1/2}$

   M = NME, B=BG/ty N=Isotope mass

- 40% less in **M** requires 10 more in N
- 2. Identification of the ν-less DBD
- Not new RI peak, but DBD peak,
- Two DBD isotopes give the same
- ν-mass, within 40%, in intensity

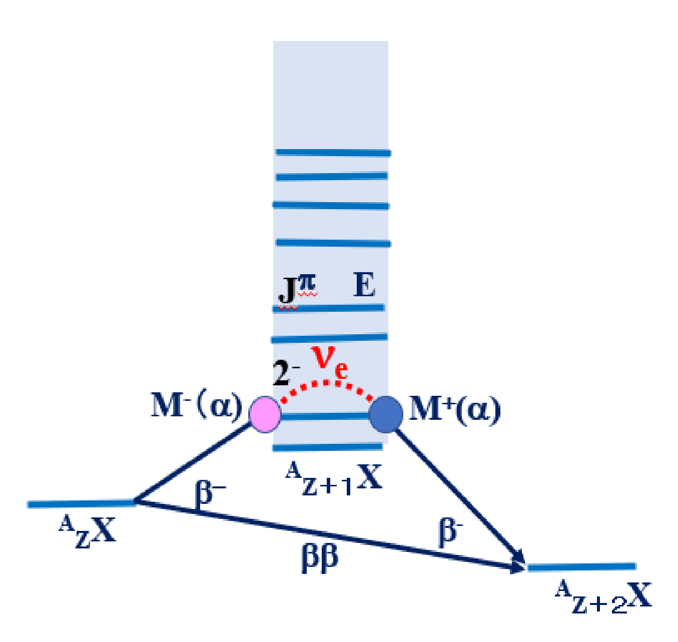
NMEs should be known within 20 %.



$m_\nu= 2\ m_0\ [B/NT]^{1/4}$
$m_0 \sim 40$ meV $/M^{0\nu}$ with ε=0.5
for Ge, Se. Mo. Cd. Te. Xe

8

DBD 0νββ NME



$$M^{0\nu} = \left(\frac{g_A^{\rm eff}}{g_A}\right)^2 \left[M_{\rm GT}^{0\nu} + \left(g_V/g_A^{\rm eff}\right)^2 M_F^{0\nu} + M_T^{0\nu}\right],$$

Quenching due to effects not in model

=1 for free n

Model NMEs

$$M_{\rm GT}^{0\nu} = \sum_k \langle t_\pm \boldsymbol{\sigma} h_{\rm GT}(r_{12}, E_k) t_\pm \boldsymbol{\sigma}\rangle$$

$$M_F^{0\nu} = \sum_k \langle t_\pm h_F(r_{12}, E_k) t_\pm\rangle \,,$$

$$M_T^{0\nu} = \sum_k \langle t_\pm h_T(r_{12}, E_k) S_{12} t_\pm\rangle \,,$$

$H(r_{12}) \sim 1/r_{12}$ ν potential for ν-exchange,

$M^{0\nu} = \Sigma_J\, M(J)$ J= Multipole sum

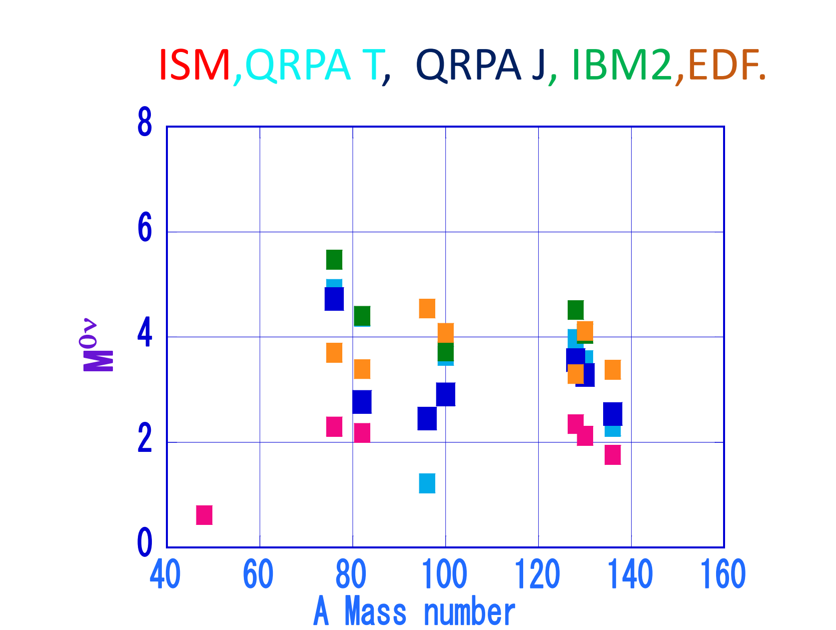
$M(J) = \Sigma_k\, M_k(J)$, Sum over all intermediate state k.

Key elements :

1. **Absolute values for GT and V multipole NMEs**

2, **Effective g_A and g_V for effects beyond models**

Experimental inputs on DBD NMES to help theories.

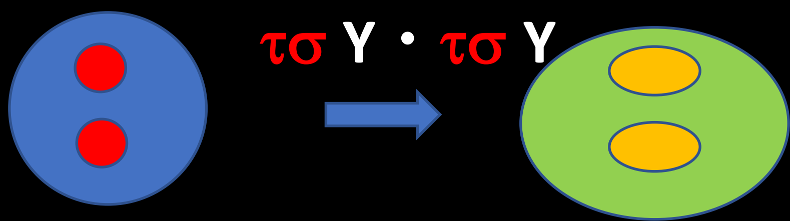


ROPP 2014 Vergados Ejiri Simkovic Menendetz, Suhonen, and many

1. Model NMEs depend on the models, the parameters (weak couplings etc) , H_{ij}, etc.
2. The region of NMEs do not mean the possible region of the NMEs
3. Adjusted g_A, g_{pp} etc for $2\nu\beta\beta$ do not guarantee the right 0ν NMEs.
4. Shell model interactions are not adjusted to fit to β–γ NMEs. ^{71}Ga,^{69}Ga,

   M(SM)/M(EXP)=g_A= 0.75 for 3/2-1/2, g_A =6.1 for 3/2-5/2 .
5. $M^{0\nu}$, M(GT), M(F) in pnQRPA depends 30% on SP levels and g_A parameters for given $2\nu\beta\beta$ NME (Ejiri Jokiniemi, Suhonen PR C Lett. 2023)

Initial and final (ground state) nuclei with relevant nucleons and meson /isobar clouds are quite different .



1. Particle knock-out reaction cross sections ~ 0.6 of SP
2. EM NMEs e^{eff} for E1 ($\tau r Y1$) ~0.3 e and e^{eff} for E2 ($r^2 Y_2$) ~>> e due to destructive and constructive nuclear core polarizations i.e. GR interference or nuclear correlations.
3. $M(\beta)=g_w^{eff} M(\text{Model})$ for effects not included in the model.

   g_V^{eff} ~0.3 for QP model

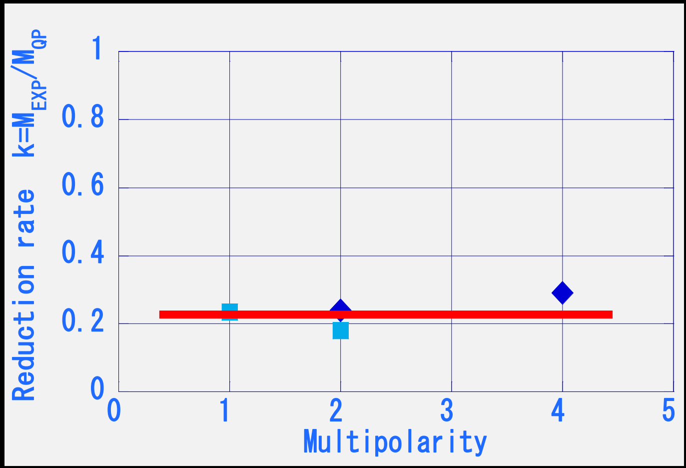
   g_A^{eff} ~0.25 for QP model

   nuclear and non-nuclear

   τ, τσ correlations

   g_A^{eff} ~0.6 for QRPA

   non-nucleonic nuclear medium



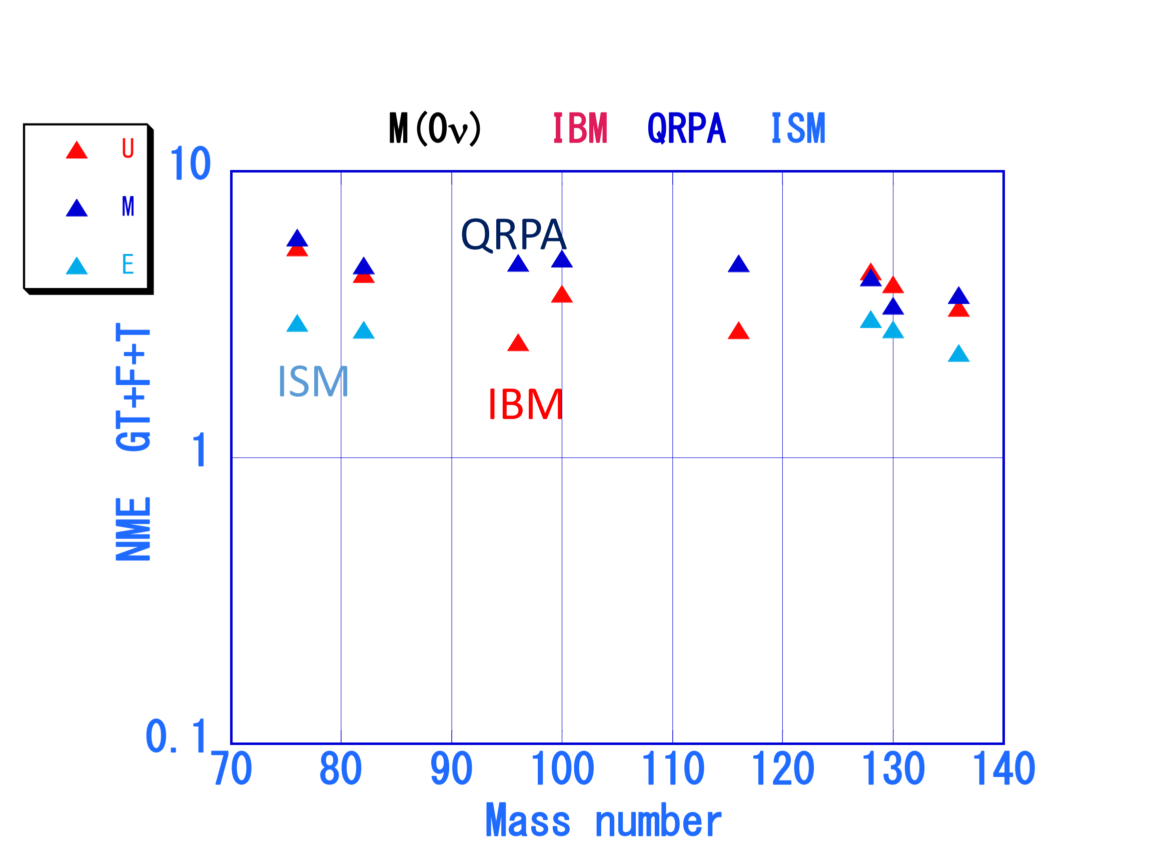
Comparison of NMEs by pnQRPA, ISM, IBM2

$$M^{0\nu} = \left(\frac{g_A^{\text{eff}}}{g_A}\right)^2 \left[M_{GT}^{0\nu} + \left(g_V/g_A^{\text{eff}}\right)^2 M_F^{0\nu} + M_T^{0\nu}\right],$$

QRPA P.R. C98 024608 2018 Jokiniemi, Ejiri Suhonen (g_A=1.0)

ISM J. Menendez, et al. Nucl. Phys. A 818 139 2009. m-4 g_A=1.27

IBM J. Barea, . Kotila F. Iachello PR C 87 014315 2013 g_A=1.27



QRPA Large and smooth as A

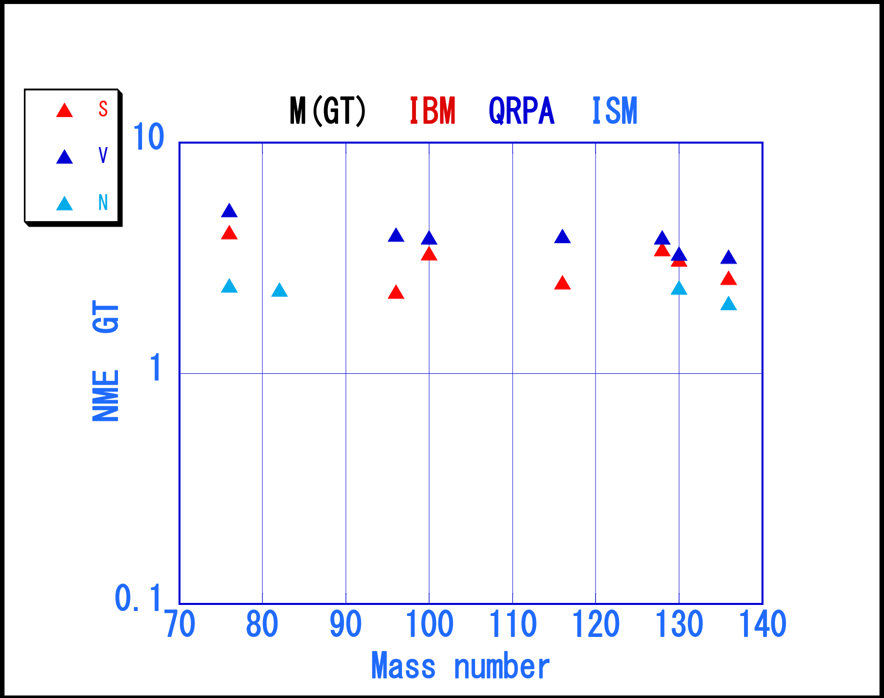
ISM Small and smooth as A.

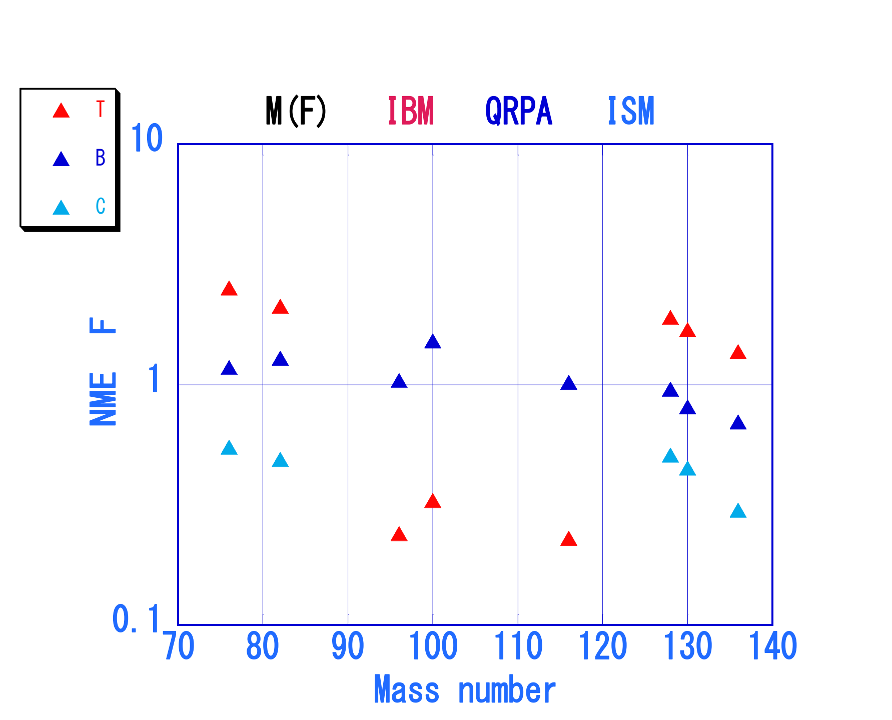
IBM Fluctuate much as A

Axial vector NMEs depend on models.

Thus require model-dependent g_A^{eff} to incorporate the effects beyond models.

and to reproduce 2νββ. NMEs





QRPA Large and smooth as A

ISM Small and smooth as A.

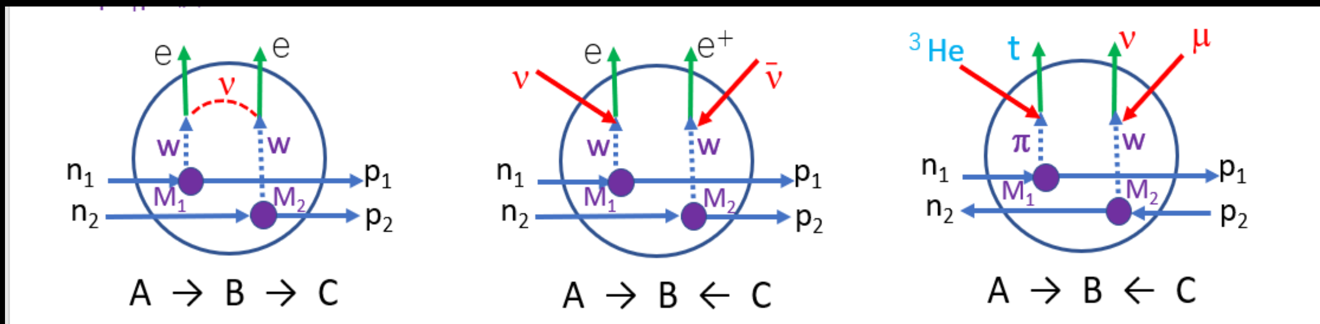
IBM Fluctuate very much as A

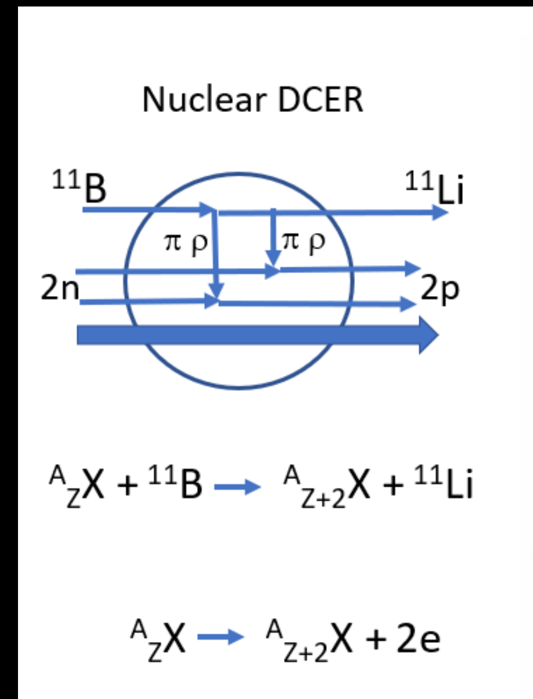
Vector NMEs do depend on models.

Thus require model-dependent g_V^{eff} to incorporate the effects beyond models.

CVC 0^+-0^+ IAS : constant, but not for non-IAS states.

Single and double CERs at RCNP





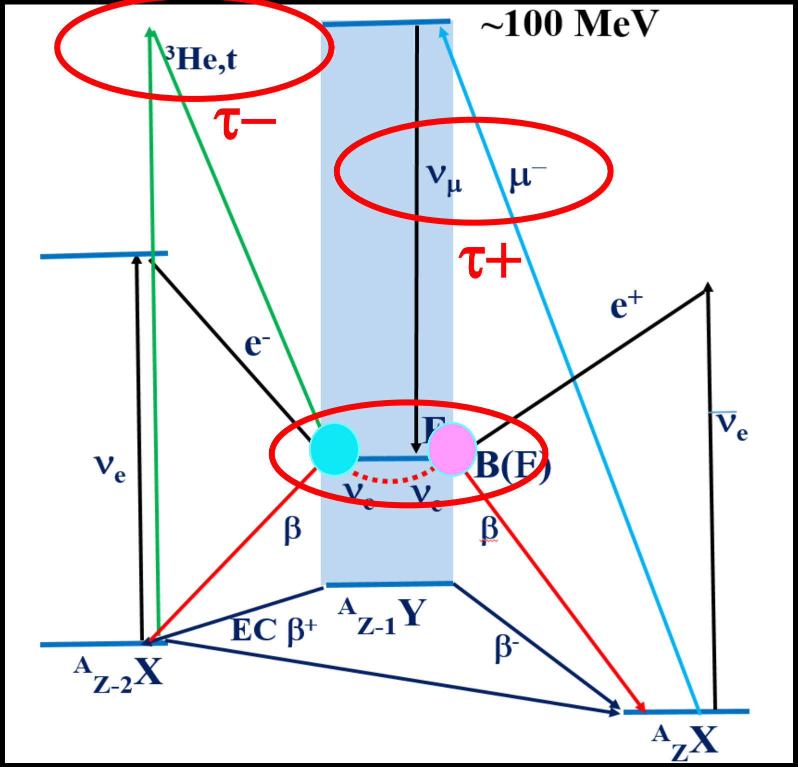
DBD M_1 , M_2 via neutrino potential
by single β, ν, μ. CER NMEs

$M(\alpha, \beta^{\pm}) = (g_A{}^{eff})^{\pm}$ M(QRPA $\alpha\ \beta^{\pm}$) α=GT, SD. SQ, ・ ・

CERs: H. Ejiri, Universe 6, 225 (2020); Frontiers in Physics 9, 650421 (1921).

Nuclear and lepton CERs provide τ $\tau\sigma$ NMEs associated with the τ $\sigma\sigma$ DBD NMEs, & help DBD NME model calculations and evaluations of $g_{A.}$ g_V

Nuclear & μ CERs provide NMEs in the wide ranges of E=1-30 MeV P ~ 60-120 MeV/c, which are similar as DBD with r~2 fm ν-exchange.

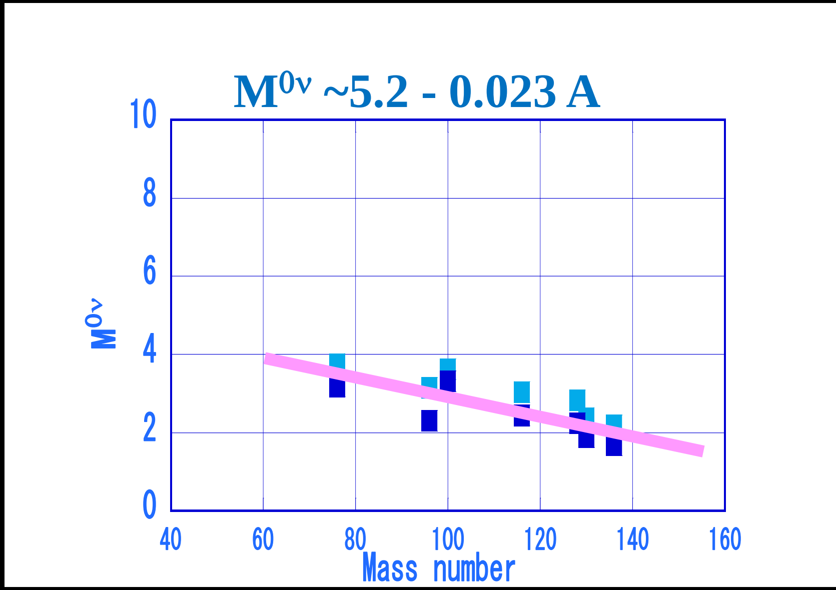


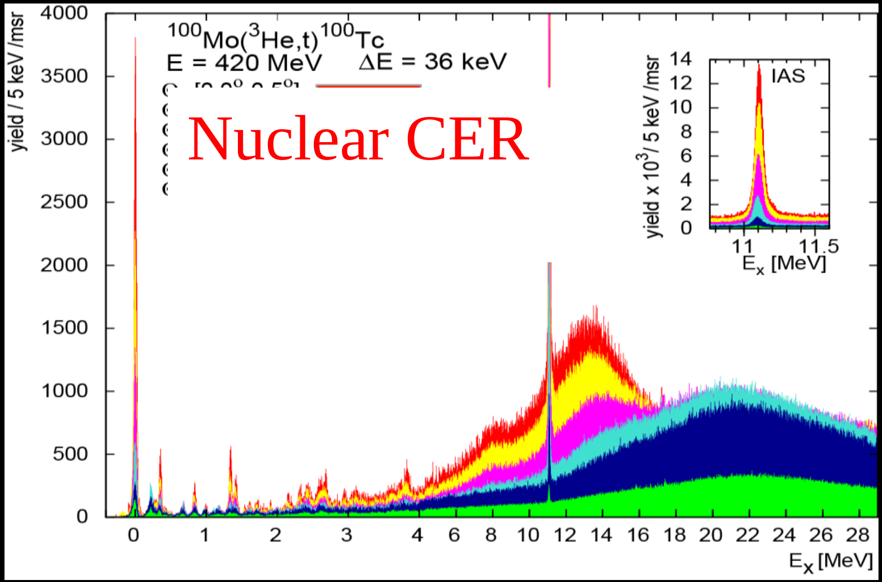
Nuclear & μ CER schemes

RCNP high E-resolution spectrometer

CERs at RCNP with 0.42 GeV ^{3}He.

Axial vector NMEs at E=0-30 GeV.
GT and SD DBD Models
quenched and enhanced $\tau - \tau\sigma$
strengths at low-states and
giant resonances in high E region.





g_A^{eff}/g_A 0.65 ± 0.1,
g_{ph} from SD GR –E and
g_{pp} from 2νββ exps.

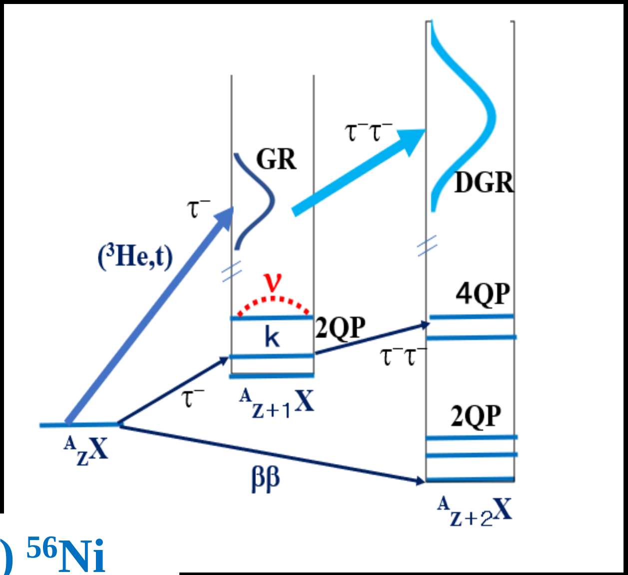
H. Ejiri, L. Jokiniemi, J. Suhonen,
Phys. Rev. C. Lett, 105 L022501 (2022).

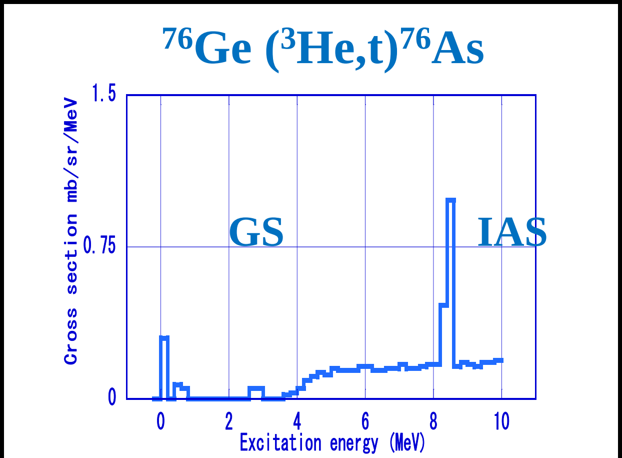
Double Charge Exchange Reaction

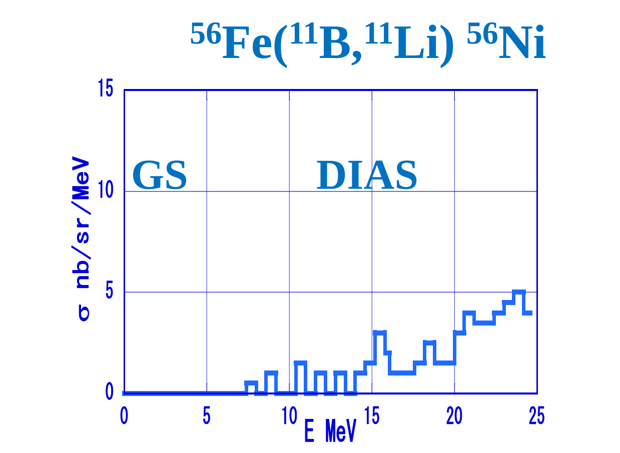
H. Ejiri Universe 2022, 8, 457, Takahisa

RCNP ^{56}Fe(^{11}B,^{11}Li) ^{56}Ni at E=0.88 GeV.

1. $(V_{\tau\sigma}/V_{\tau})^2 \sim 3.4$ enhance τσ GT SD excitation
2. Q value = - 50 MeV. Thus p-transfer 100 MeV/c is same as DBD, and L=1 enhances SD







GT SD NMEs derived by referirng to IAS DIAS cross sections with known B(F)

SCER ^{76}Ge (^{3}He,t)^{76}As excites SD states with strength of 0.1 of QP strength. Then we get the quenching of sqrt of 0.1 = $k_{\tau\sigma} \sim 0.3$ with respect to QP.

DCER ^{56}Fe(^{11}B,^{11}Li) ^{56}Ni excites very little low-QP GT-SD states with strength of 0.01 of QP strength. Then the quenching of sqrt of 0.01=$(k_{\tau\sigma})^2 \sim 0.1$

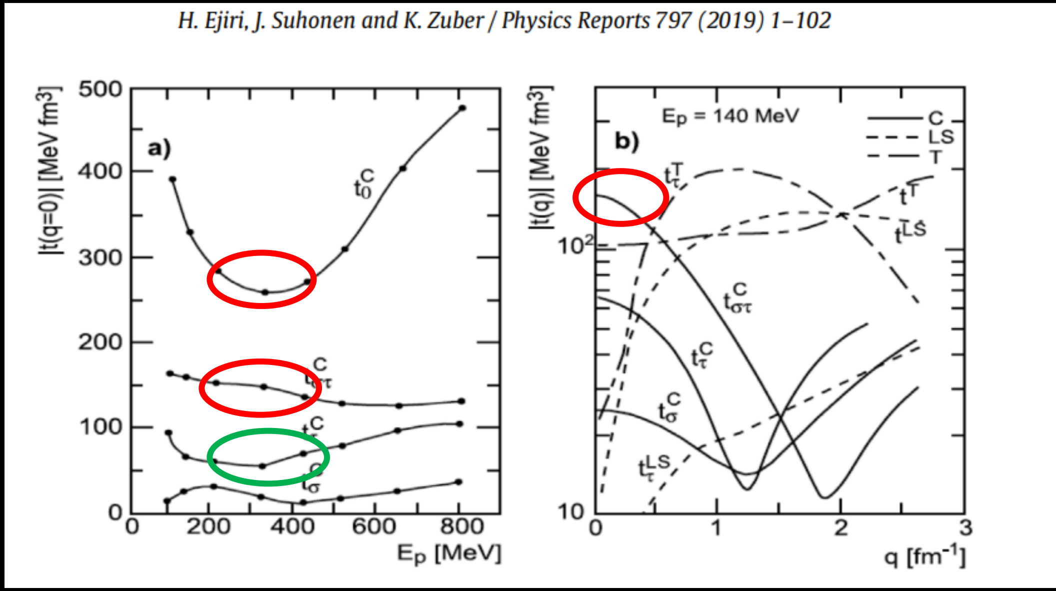
Limits of nuclear CERs

1. Nuclear interactions :
   Strong interactions, large cross sections , easy experiments.
   Complex/multi interaction operators, hard analyses of the data.
   Absolute NMEs are uncertain because of the absorptions and distortion, and complex interaction strength.

2. Limited to relative $\tau\sigma$ (GT) NME.
   E=200 MeV 0. deg. q~0

3. Tensor operator
   Mainly axial vector
   $T(J=i+) = \tau\sigma + \delta\tau[\sigma x Y_2]_1$

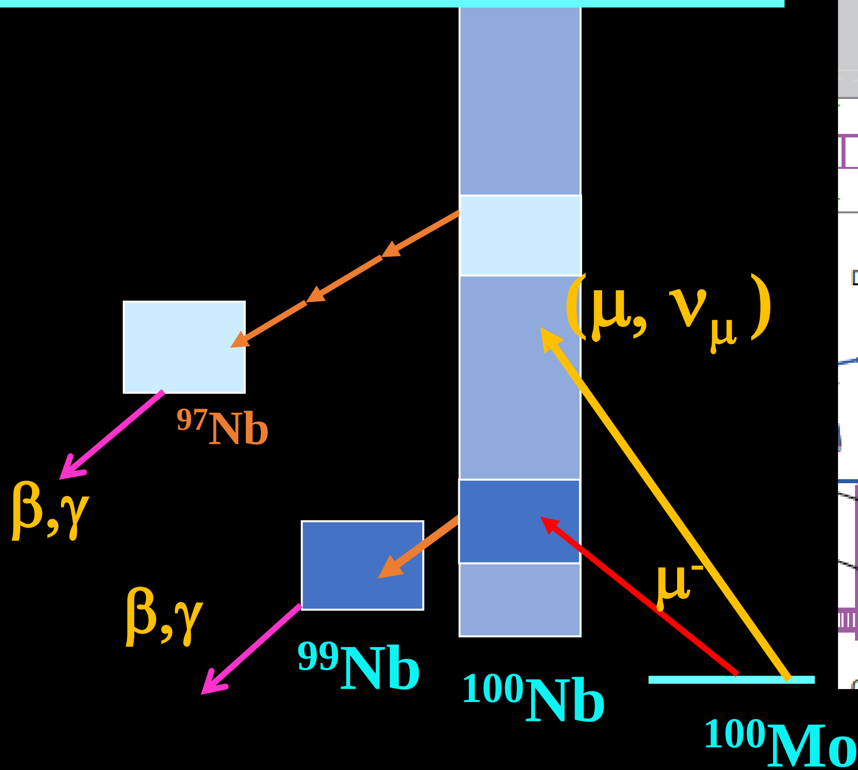
Small vector NMEs

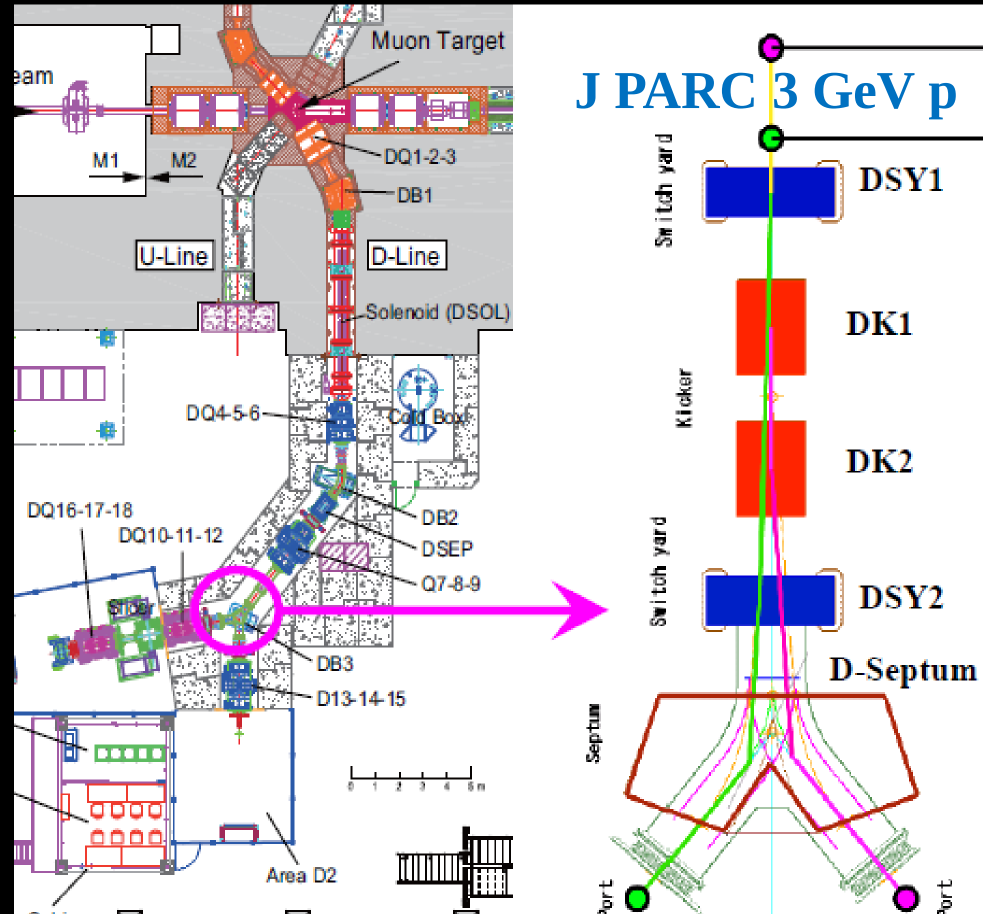


The Nucleon-Nucleon Interaction and Nucleon-Nucleus Scattering
WG Love, MA Franey, F Petrovich - Spin Excitations in Nuclei, 1984 - Springer

CER $(\mu,\nu_\mu$, xn $\gamma)$ $\bar{\nu}-\beta^+$ Responses q~80 MeV

2^- 3^+

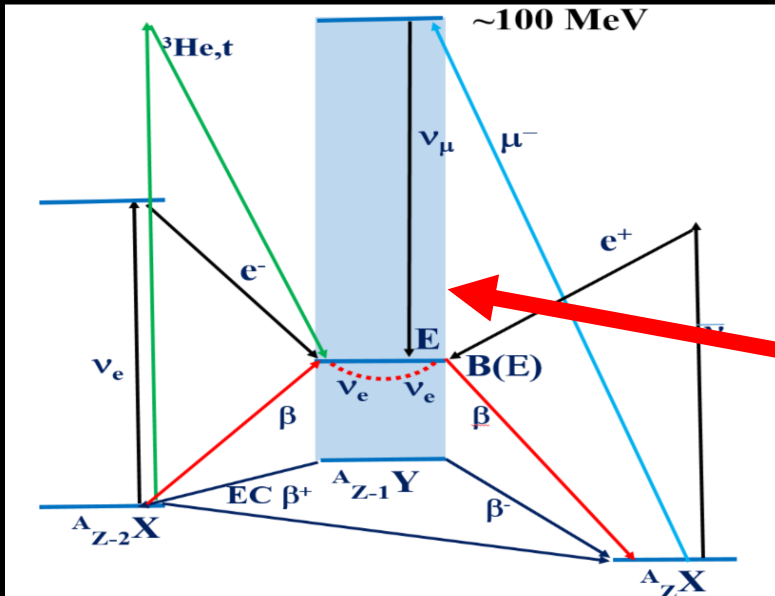


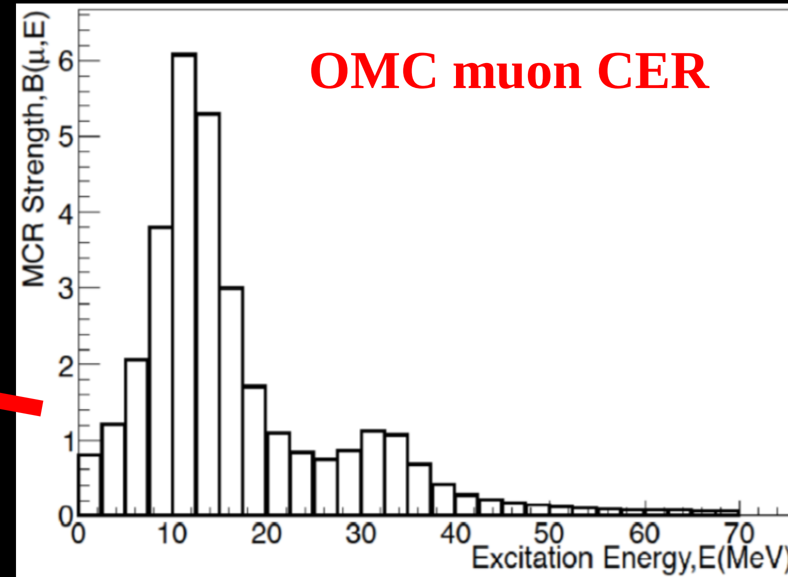


γ_i from $^{100-i}$Nb: relative strength Life time : the absolute strength

H. Ejiri Proc. e-γ conference Sendai 1972, H. Ejiri et al., JPSJ 2014

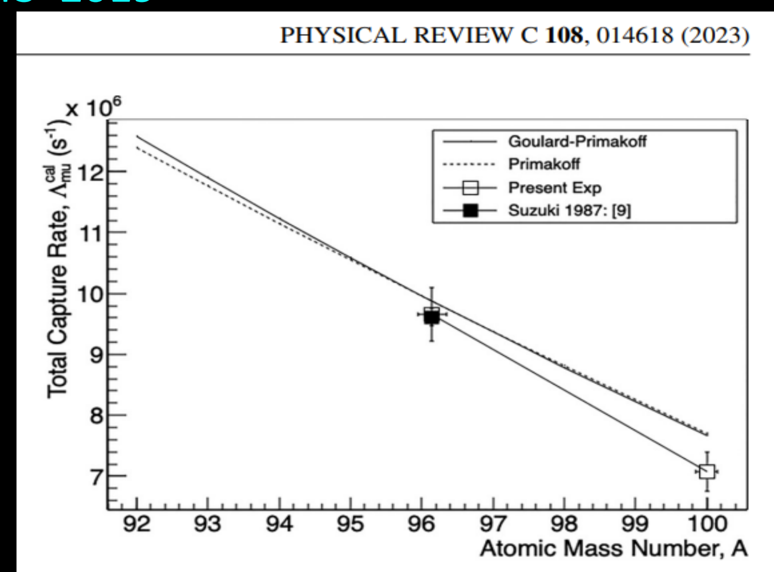
NNR19:I. Hashim , Hashim H. Ejiri et al., PRC 97 (2018) 014617





Hashim　Ejiri et al. PR C 97 2018
Jokimiemi Suhonen Ejiri Hashim PL B 794 143 2019

1. 0－50MeV,　P＝0-60 MeV/c similar to DBD E and P.
2. Gross strength distribution. Not individual states NMEs. Contributions of axial vector, vector, pseudoscalar NMEs. are mixed.
3. Absolute NMEs by life time . Large N-Z dependence



Hashim　Ejiri et al. PR C 97 2018

II. EM γ-IAS for axial-vector and vector NMEs and their couplings associated with DND NMEs

EM and weak interactions have common spin isospin operators

$$T(VL) = g_V \tau^i r^L Y_L, \quad L = 1, 2,$$

$$T(AVL) = g_A \tau^i [\sigma \times r^{L-1} Y_{L-1}]_L, \quad L = 1, 2,$$

$$T(EL) = g_{EL} r^L Y_L,$$

$$T(ML) = g_S [\sigma \times r^{L-1} Y_{L-1}]_L + g_L [j \times r^{L-1} Y_{L-1}]_L$$

$$g_S = \frac{e\hbar}{2Mc} [L(2L+1)]^{1/2} \left[\frac{g_s}{2} - \frac{g_l}{L+1} \right],$$

$$l \pm 1/2 \leftrightarrow l \mp 1/2,$$

$$g_L = \frac{2g_l}{L+1},$$

The EM couplings depend on the isospin, i.e. p or n.

In case of a spin-stretched transition of , the $M1$ g factor is given effectively as

$$g = \sqrt{3/4\pi}(g_s/2 - g_l/2)$$

Then weak NMEs are well studied by measuring corresponding EM NMEs

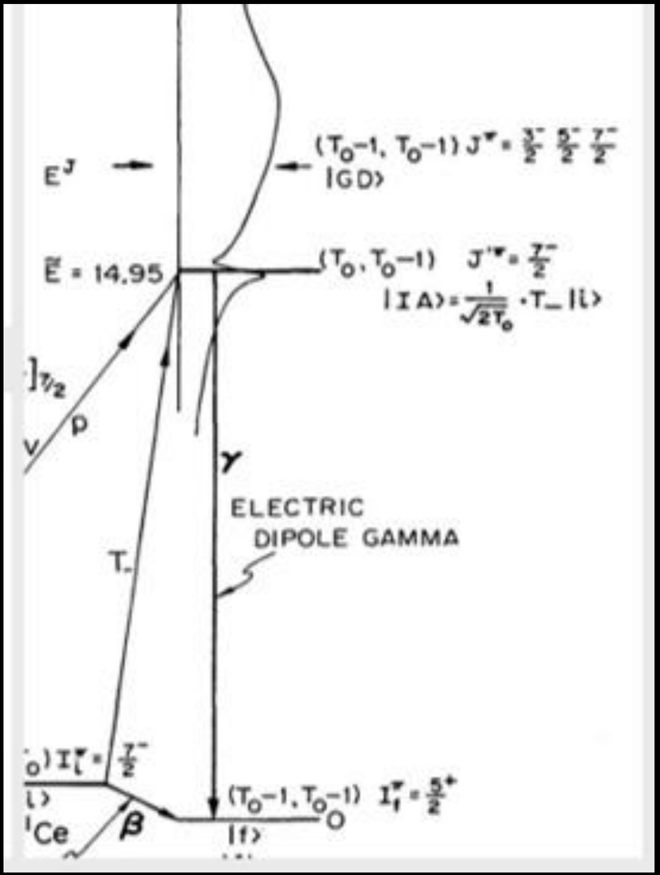
IAS γ by resonant p capture reactions

$$\langle \mathrm{f}|g_\mathrm{v} m^\beta|\mathrm{i}\rangle = \frac{g_\mathrm{v}}{e}\langle \mathrm{f}|[em^\gamma, T_-]|\mathrm{i}\rangle \approx \frac{g_\mathrm{v}}{e}\sqrt{2T_0}\langle \mathrm{f}|em^\gamma \frac{1}{\sqrt{2T_0}} T_-|\mathrm{i}\rangle$$

$$\approx \frac{g_\mathrm{v}}{e}\sqrt{2T_0}\langle \mathrm{f}|em^\gamma|\mathrm{IA}\rangle,$$

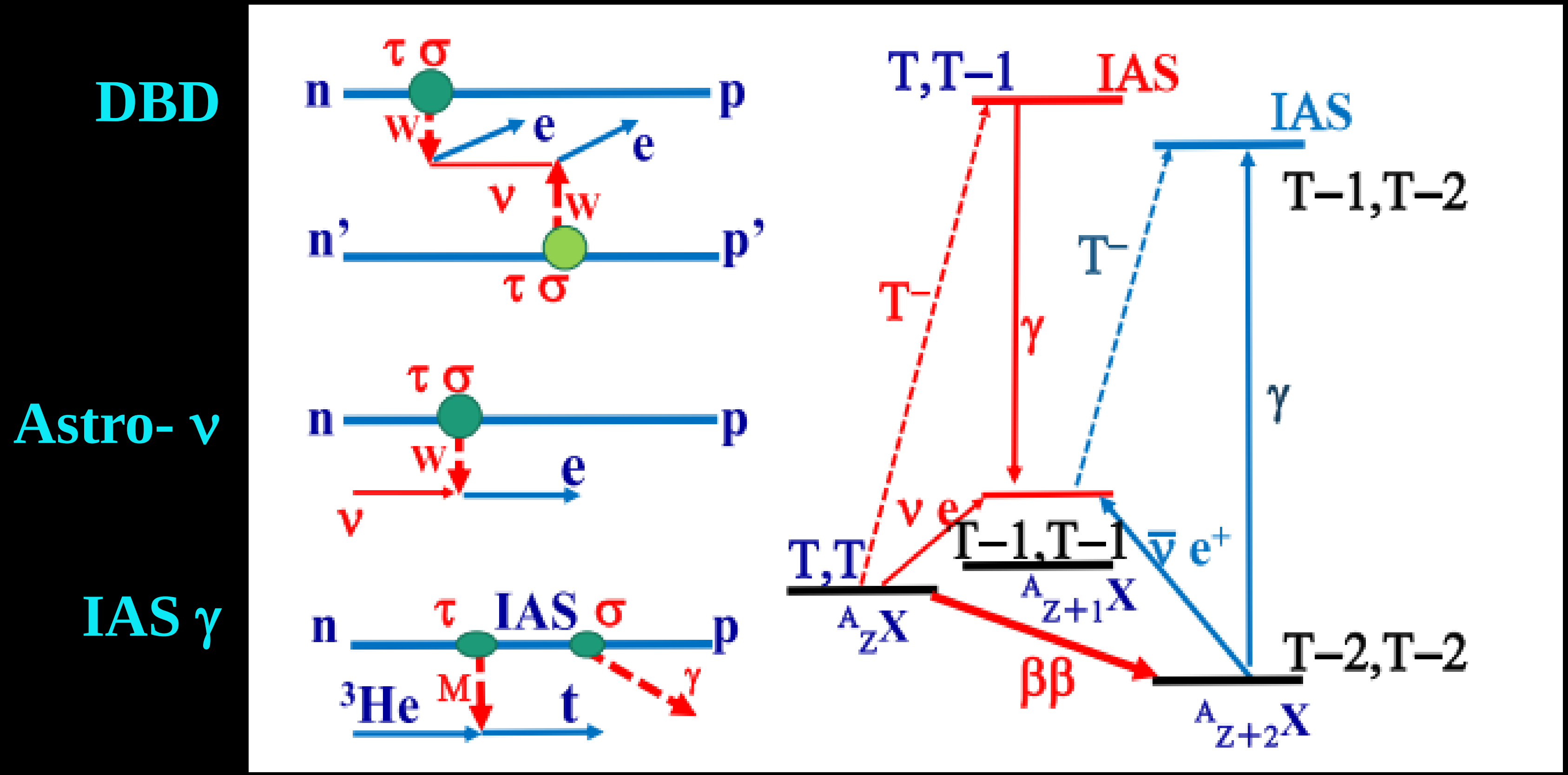
$$\left(\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}\right)_{\theta_0} = \tfrac{1}{8}\lambda\!\!\!^{-2}[|A^\mathrm{I}_{J'}|^2 + \sum_J |A^\mathrm{D}_J|^2 + \sum_J |A^\mathrm{C}_J|^2 + 2\,\mathrm{Re}\,(A^\mathrm{I}_{J'} A^{\mathrm{D}*}_{J'})].$$

$$A^\mathrm{I}_{J'} = i\,\frac{\sqrt{2J'+1}\sqrt{\tilde{\Gamma}_\mathrm{p}\tilde{\Gamma}_\gamma}\,\mathrm{e}^{i\tilde{\phi}}}{(E-\tilde{E}) + i\frac{1}{2}\tilde{\Gamma}_\mathrm{t}}\,.$$



Ejiri H, et al. Phys. Rev. Lett. 2119 1968 373

CER-IAS γ transition schemes and DBD
Axial-vector NMEs



IAS-γ H. Ejiri, Phys. Rev. C. Lett, 108 L011302 (2023).
γ-IAS H. Ejiri, A. Titov, Phys. Rev. C 88 054010 (2013.)

EM-IAS studies : 4 merits

1. EM couplings of e and μ and the interaction operators are well defined compared with nuclear ones in nuclear CERs.
   No distortion effect. No tensor interaction. No multipole mixing.

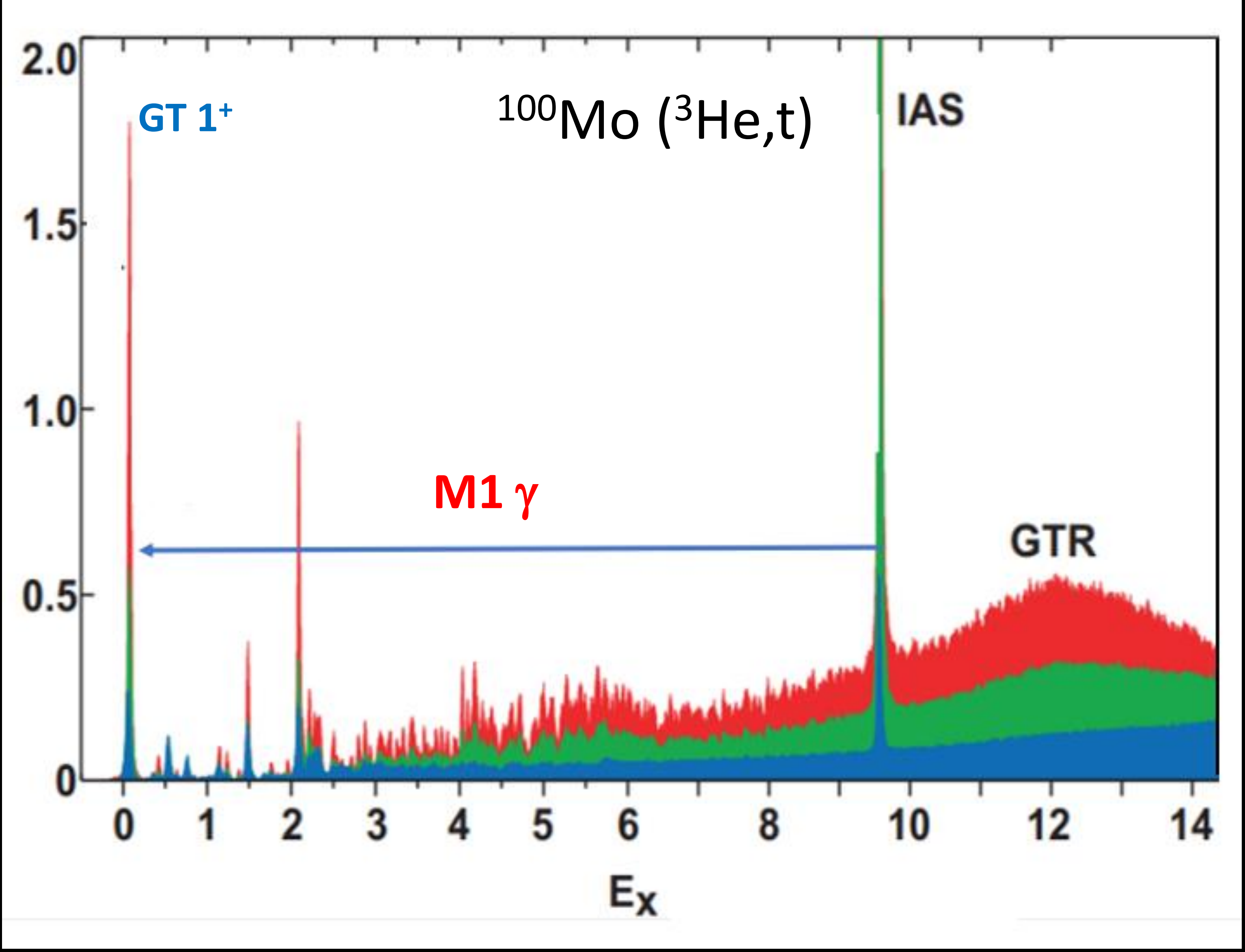
2. IAS is a sharp strong τ-GR with small non-resonant effects.
   Very small (30 keV) width due to isospin-forbidden n decays.
   Then γ-branch versus n-decay gets as large as 10^{-4} or so.

3. BG free exp. is possible by γ-detection in coincidence with CER to IAS.

4. Experiments are feasible by using a γ-detector array and a high energy-resolution spectrometer,

DIAS γ Romeo, Menendez Pena PL B 827 136968 2022.

In case of M1 γ from IAS of ^{100}Mo.



β NMEs with α=GT, V1 are given by γ NMEs with α'=M1,E1 γ from IAS (Ejiri et al, PRL 1968) as

$$M^{-}(\alpha) \approx \sqrt{2T}\, M^{\mathrm{IA}}(\alpha'),$$

IAS-γ cross section (1000-100 nb) is given by product of IAS cross section (10 mb) and γ branching ratio ($10^{-(4\text{-}5)}$) as

$$\frac{d\sigma^{\mathrm{IA}}(\alpha')}{d\Omega} = \frac{d\sigma^{\mathrm{IA}}}{d\Omega}\frac{\Gamma^{\mathrm{IA}}(\alpha')}{\Gamma(T)},$$

γ–width (1-0.1 eV) is given by product of $(E_\gamma)^3 = (10\ \mathrm{MeV})^3 \sim 1000$ and the reduced γ width B^{IA}

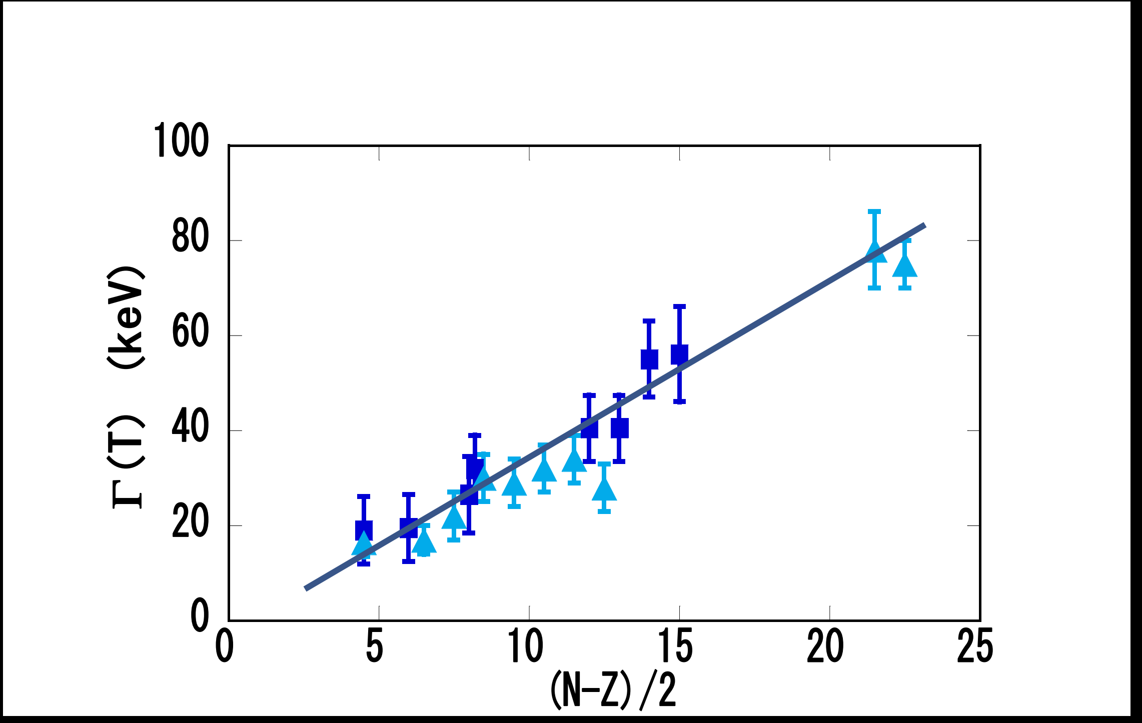
$$\Gamma^{\mathrm{IA}}(\alpha') = K_{\alpha'} E^3_{\alpha'} B^{\mathrm{IA}}(\alpha'),$$

The reduced γ width is given by the square of the IAS γ NME

$$B^{\mathrm{IA}}(\alpha') = g^2_{\alpha'} |M^{\mathrm{IA}}(\alpha')|^2 S^{-1},$$

g_e^{eff} derived from Exp M (E1) /QRPA M (E1) is used to get g_V^{eff}
g_m^{eff} derived from Exp M(M1) /QRPA M(M1) is used to get g_A^{eff}

IAS total widths are known experimentally.



Dark blue ; CER Exp. Present work

Light blue H.L.Harney et al, RMP 58 607 1986

It is given as a function of the isospin z component as

$$\Gamma(T) \approx 3.5T_z\,\text{keV}, \quad T_z = (N-Z)/2.$$

It is a factor 30 smaller than a typical n-decay width because of the isospin forbidden for n decay.

Note 141Ce IAS n width ~ 53 keV

Evaluated IAS γ widths and the cross-sections

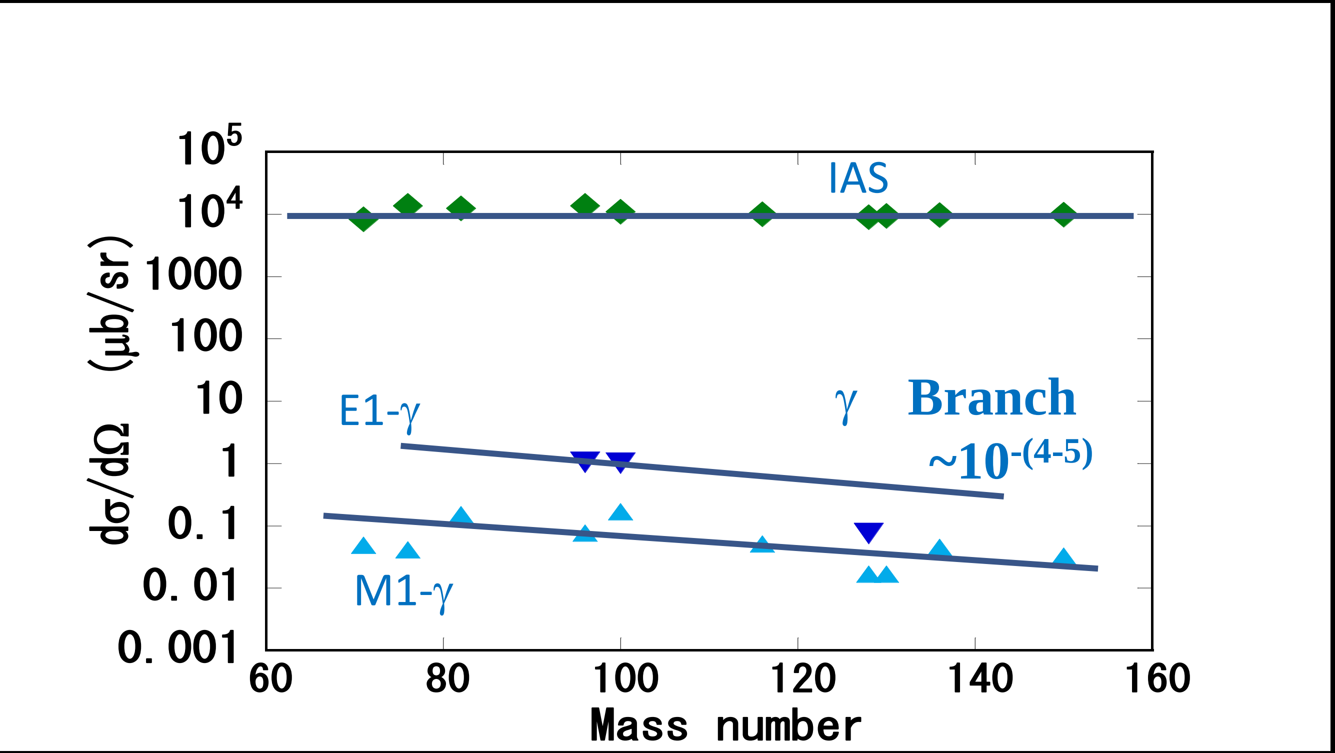
TABLE I. M1γ widths and the IAS γ cross sections for DBD nuclei and ^{71}Ga for the solar νs. Shown are E(IA) in units of MeV, E(GT) in units of MeV, B(GT), B^{IA}(M1) in units of 10^{-2}, Γ^{IA}(M1) in units of 10^{-2} eV, and $\sigma^{IA}(M1)=d\sigma^{IA}(M1)/d\Omega$ in units of nb (10^{-9}b)/sr.

A	E(IA)	E(GT)	B(GT)	B^{IA}(M1)	Γ^{IA}(M1)	σ^{IA}(M1)
^{76}Ge	8.31	1.07	0.14	1.45	6.4	41
^{82}Se	9.58	0.075	0.34	3.0	30.0	150
^{96}Zr	10.9	0.69	0.16	1.25	15.3	76
^{100}Mo	11.1	0	0.35	2.7	43.4	170
^{116}Cd	12.1	0	0.14	0.88	18.0	51
^{128}Te	12.0	0	0.079	0.41	8.2	17
^{130}Te	12.7	0	0.072	0.35	8.2	17
^{136}Xe	13.4	0.59	0.23	1.03	25	45
^{150}Nd	14.4	0.11	0.13	0.54	18.0	35
^{71}Ga	8.91	0	0.085	1.2	9.8	51

A	E(IAS)	E(V1)	B(V1)	B^{IA}(E1)	Γ(E1)	σ^{IA}(E1)
^{96}Zr	10.9	3	6.8	43	220	1080
^{100}Mo	11.1	3	7.5	47	260	1020
^{130}Te	12.7	3	1.0	3.8	36	75

The M1 and E1 widths are 10-50 10^{-2} eV and 30-300 10^{-2} eV
The M1 and E1 cross sections are 50-200 nb and 100-1000 nb.

IAS and IAS-γ cross sections are given below. The γ cross sections are lower by the γ-branching ratio of 10^{-4-5}.



IAS-γ event rate per day in case of a typical case of RCNP

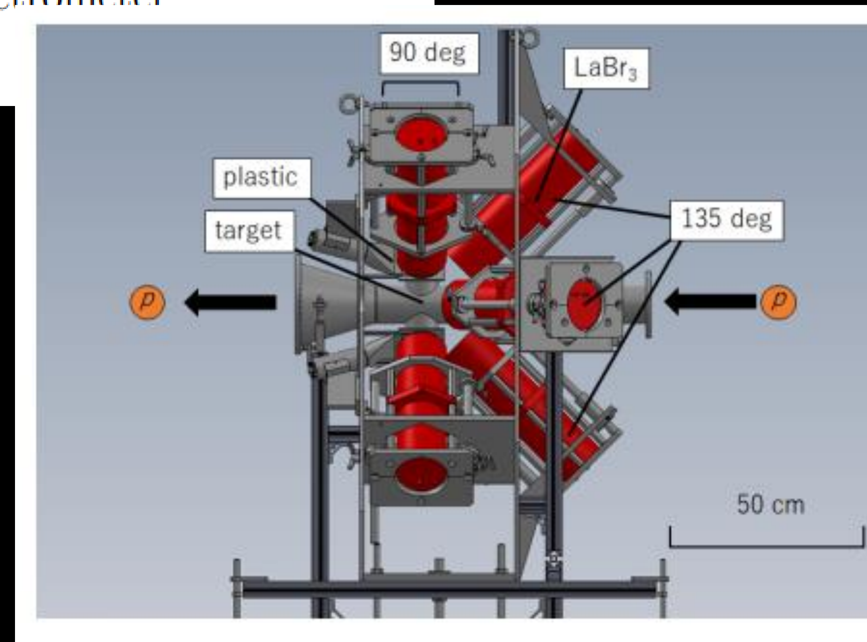
^{3}He beam =20 n pA Target 40 mg/cm2, 3.2 m sr

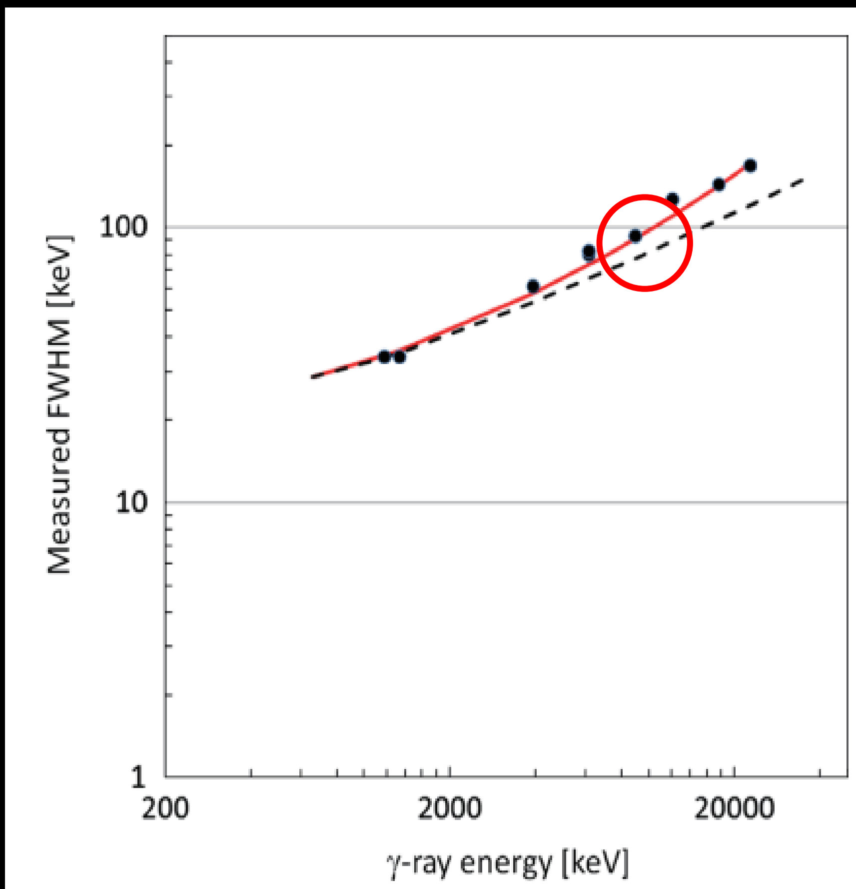
$$R_\gamma = 8A^{-1}10^2(d\sigma^{\mathrm{IA}}(\alpha')/d\Omega)\epsilon_\gamma,$$

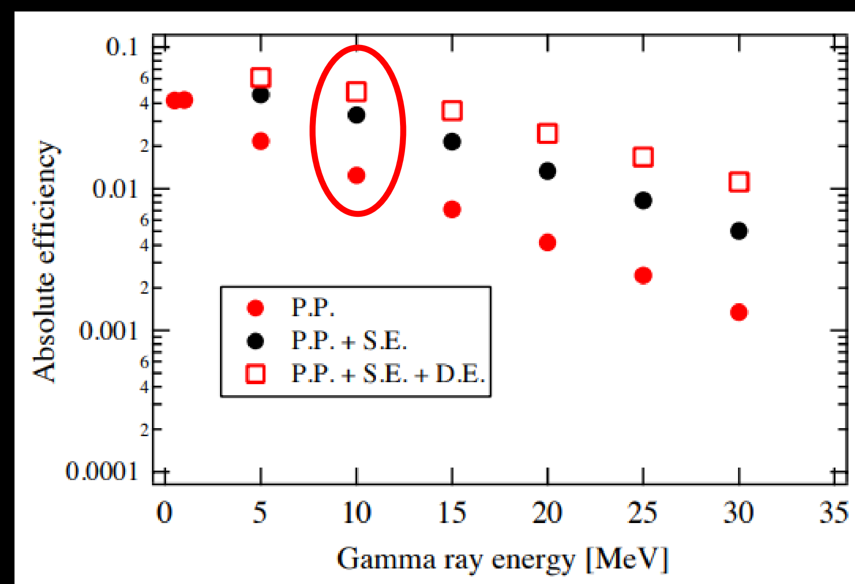
R ~ 50 per day for 100 nb/sr M1 γ ε~6 % efficiency : feasible .

Technical Information on the Scintillation Gamma-Ray Detector Array Coupled with the Grand Raiden Spectrometer

A. Tamii[a], N. Kobayashi[a]



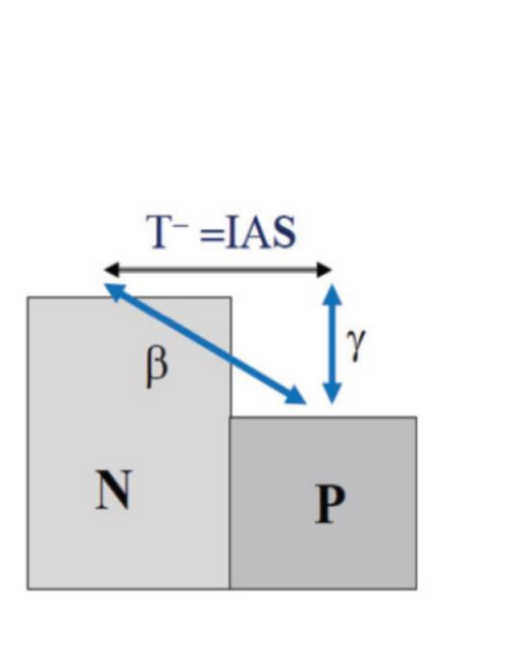




III. Photo nuclear excitation of IAS for DBD NME

Photo nuclear reaction

IAS isospin T from
Ground state with T-1



Ejiri H, Titov. A, et al., Phys. Rev, C 88 2013 054610

$$\sigma(\gamma, n) = \frac{S(2J+1)\pi}{k_\gamma^2} \frac{\Gamma_\gamma \Gamma_n}{(E-E_R)^2 + \Gamma_t^2/4}, \tag{10}$$

where Γ_γ, Γ_t, and Γ_n are the γ capture width, the total width, and the neutron decay width, S is the spin factor, and k_γ is the incident photon momentum.

The integrated photonuclear cross section is given by

$$\int \sigma(\gamma, n) dE = \frac{S(2J+1)2\pi^2}{k_\gamma^2} \frac{\Gamma_\gamma \Gamma_n}{\Gamma_t}. \tag{11}$$

$\Gamma_t \approx \Gamma_n$, where Γ_n is the sum of the neutron decay widths

$$\int \sigma(\gamma, n) dE = \pi^2 k_\gamma^{-2} \Gamma_\gamma,$$

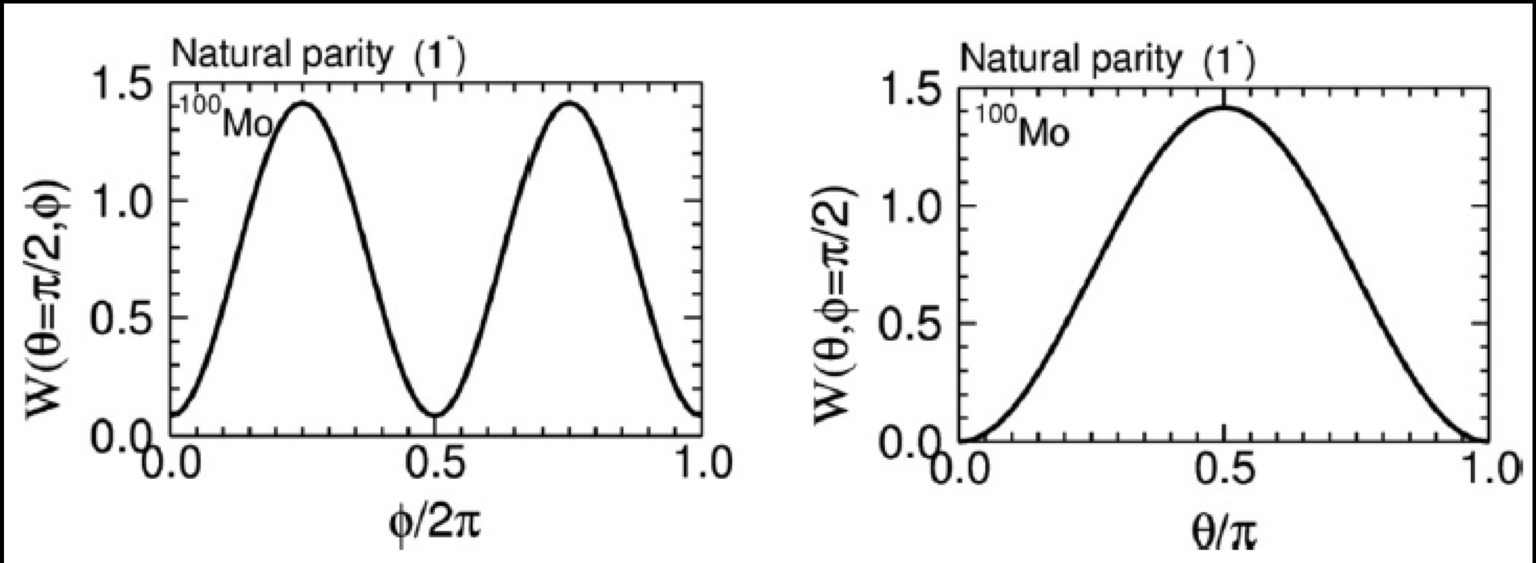
$$\int \sigma(\gamma, n) dE = 2.9 \times 10^{-3} \text{ MeV fm}^2 \quad (E1), \tag{14}$$

$$\int \sigma(\gamma, n) dE = 2.7 \times 10^{-3} \text{ MeV fm}^2 \quad (M1). \tag{15}$$

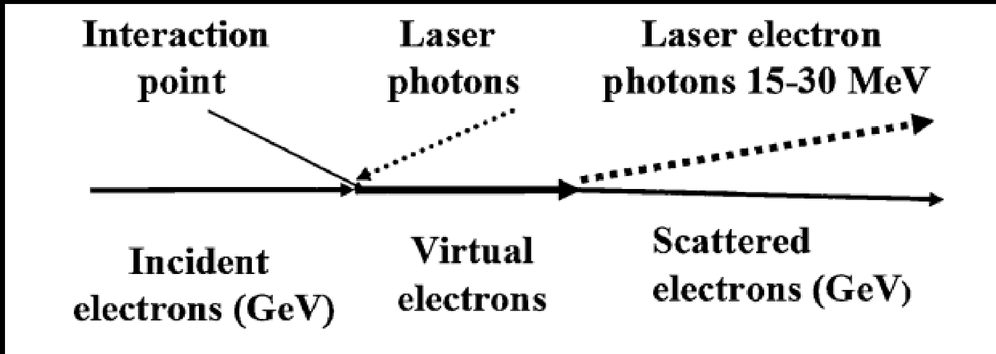
Then the counting rates with a typical target of 10 g/cm^2 are $Y(E1) = 1.7 \times 10^{-6} \epsilon N_\gamma/\text{s}$ and $Y(M1) = 1.6 \times 10^{-6} \epsilon N_\gamma/\text{s}$,

$N_\gamma \approx 10^{8\text{–}9}/(\text{MeV s})$.

$^{100}Ru + \gamma = {}^{100}T = {}^{99}Tc + n$ Angular correlation of n

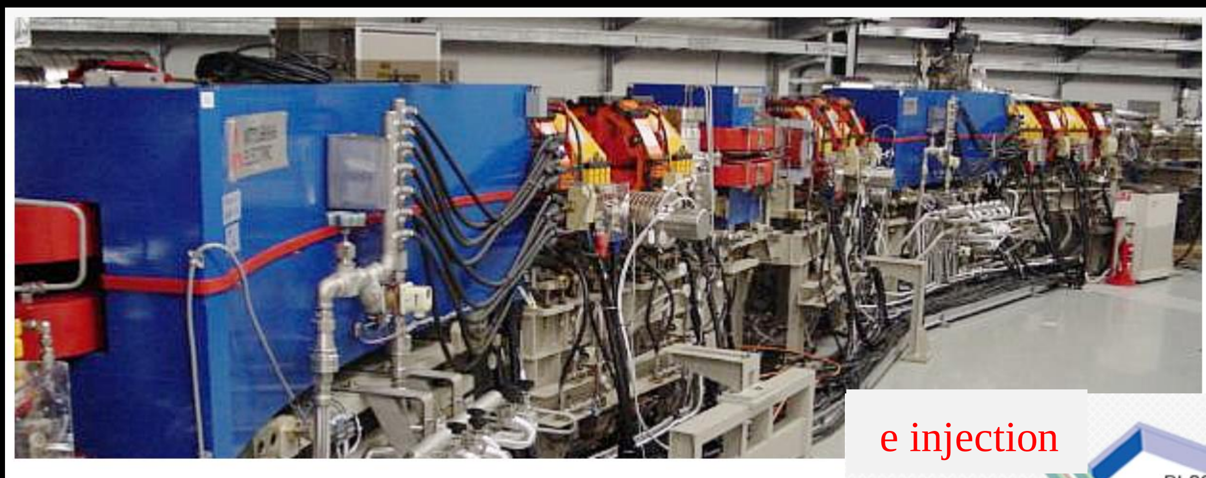


Ejiri H, Titov. A, et al., Phys. Rev, C 88 2013 054610



$$E(\gamma) = \frac{4\gamma_e^2 E(l)}{1 + 4\gamma_e E(l)/m + \gamma_e^2\theta^2}, \qquad (3)$$

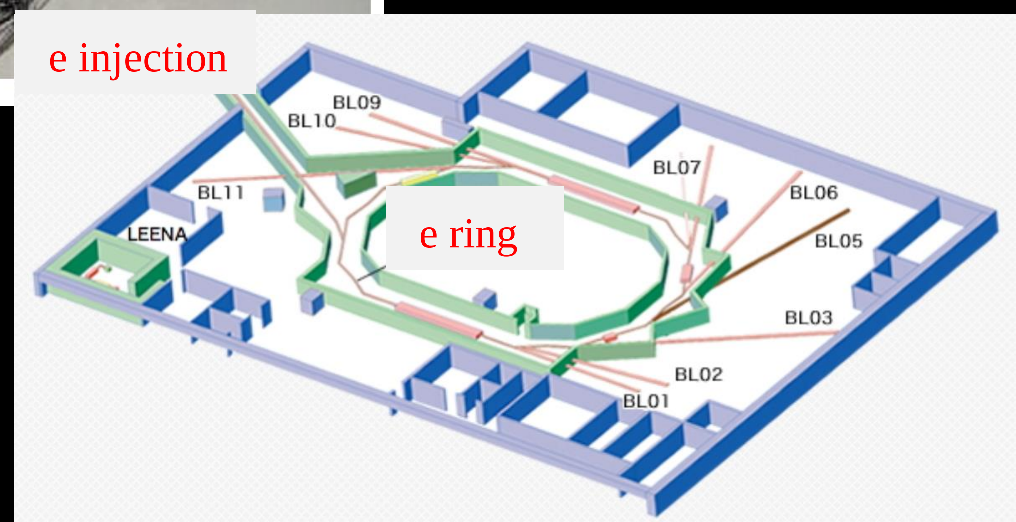
where m denotes the electron mass and $\gamma_e = E(e)/m$ is the Lorentz factor of the incident electron with the energy $E(e)$.



NewSUBARU

10^7/sec possible /1 % width

H. Ejiri, T. Shima et al JPSJ 80 2011, YAG 1.4 eV, E(e)=1 GeV. E=10-20 MeV.



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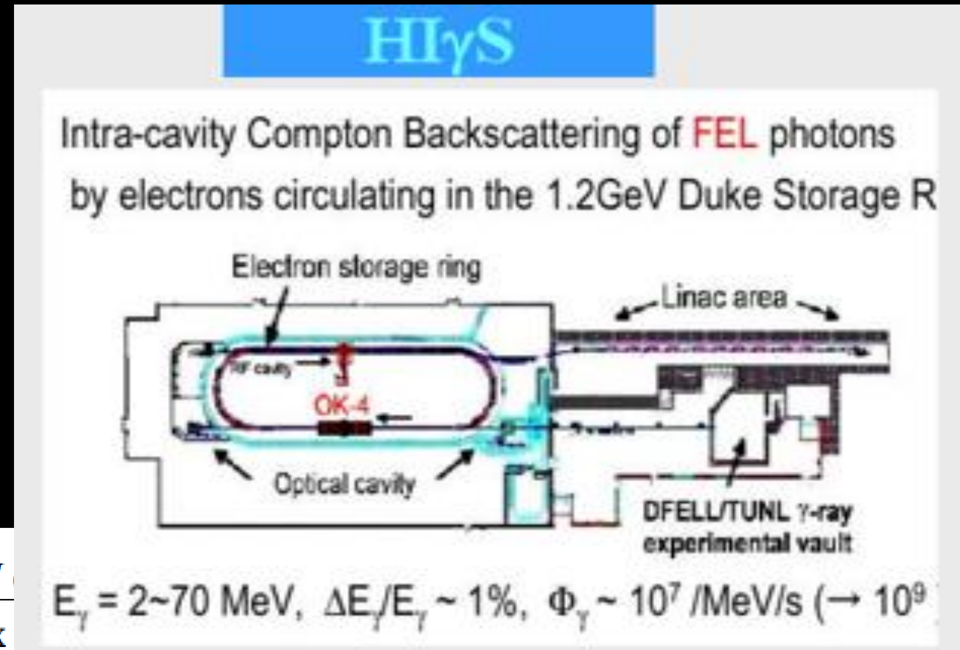


HIGS flux performance table for high-flux, quasi-CW

HIGS Flux Performance Projection		Total Flux CW Operation Two-Bunch (*)	($\Delta E_\gamma/E_\gamma$ = 5% FWHM) (#), (@)	λ [nm]	Linear Pol. with OK-4 Circular Pol with OK-5
No-loss Mode: E_γ < ~16 MeV					
E_γ = 1 – 2 MeV	(E_e = 237 – 336 MeV)	$1 \times 10^8 – 4 \times 10^8$	$6 \times 10^6 – 2.4 \times 10^7$	1064	Linear and Circular (a), (b)
E_γ = 2 – 2.9 MeV	(E_e = 336 – 405 MeV)	$4 \times 10^8 – 1 \times 10^9$	$2.4 \times 10^7 – 6 \times 10^7$	1064	Linear and Circular (a), (b)
E_γ = 2 – 3 MeV	(E_e = 288 – 353 MeV)	$2 \times 10^8 – 6 \times 10^8$	$1.2 \times 10^7 – 3.6 \times 10^7$	780	Linear and Circular (a), (b)
E_γ = 3 – 5.4 MeV	(E_e = 353 – 474 MeV)	$6 \times 10^8 – 2 \times 10^9$	$3.6 \times 10^7 – 1.2 \times 10^8$	780	Linear (a), (b)
E_γ = 3 – 6.3 MeV	(E_e = 353 – 512 MeV)	$6 \times 10^8 – 3 \times 10^9$	$3.6 \times 10^7 – 1.8 \times 10^8$	780	Circular (a), (b)
E_γ = 5 – 8 MeV	(E_e = 380 – 481MeV)	$4 \times 10^8 – 1 \times 10^9$	$2.4 \times 10^7 – 6 \times 10^7$	540	Linear and Circular (a), (b)
E_γ = 8 – 11 MeV	(E_e = 481 – 565 MeV)	$1 \times 10^9 – 2 \times 10^9$	$6 \times 10^7 – 1.2 \times 10^8$	540	Linear (a), (b)
E_γ = 8 – 13 MeV	(E_e = 481 – 615 MeV)	$1 \times 10^9 – 4 \times 10^9$	$6 \times 10^7 – 2.4 \times 10^8$	540	Circular (a), (b)

4. Concluding remarks

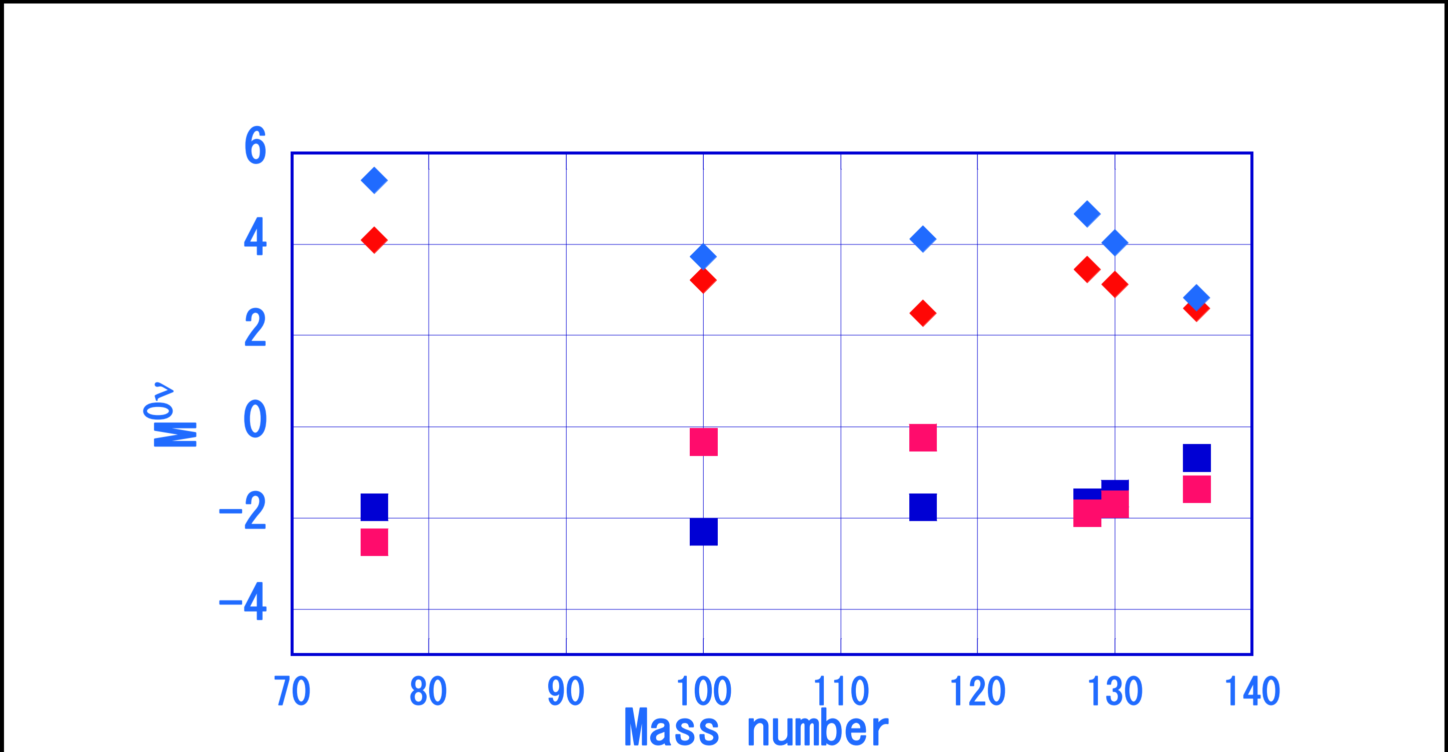
1. DBD exp. rate ($1/t_{1/2}$) provides $1/(G\ t_{1/2}) = B(M^{0\nu}\ m\lambda\eta)$ with
   B = reduced nuclear weak width =product of $M^{0\nu}$ and $m\lambda\eta$,
   as SBD $1/(f\ t_{1/2}) = B(GT/F)$. Then $M^{0\nu}$ is crucial.

2. CE (^3He,t) reactions with E/A~0.1 GeV are mainly axial-vector
   GT-SD, no absolute values , and the tensor term interference.

3. IAS-E1 /M1 γ provides τ^- GT / V1 β NMEs with the g_V, g_A
   since the EM couplings and transition operators are well known.
   Photo-nuclear excitation of IAS provides the τ^+ side NME .

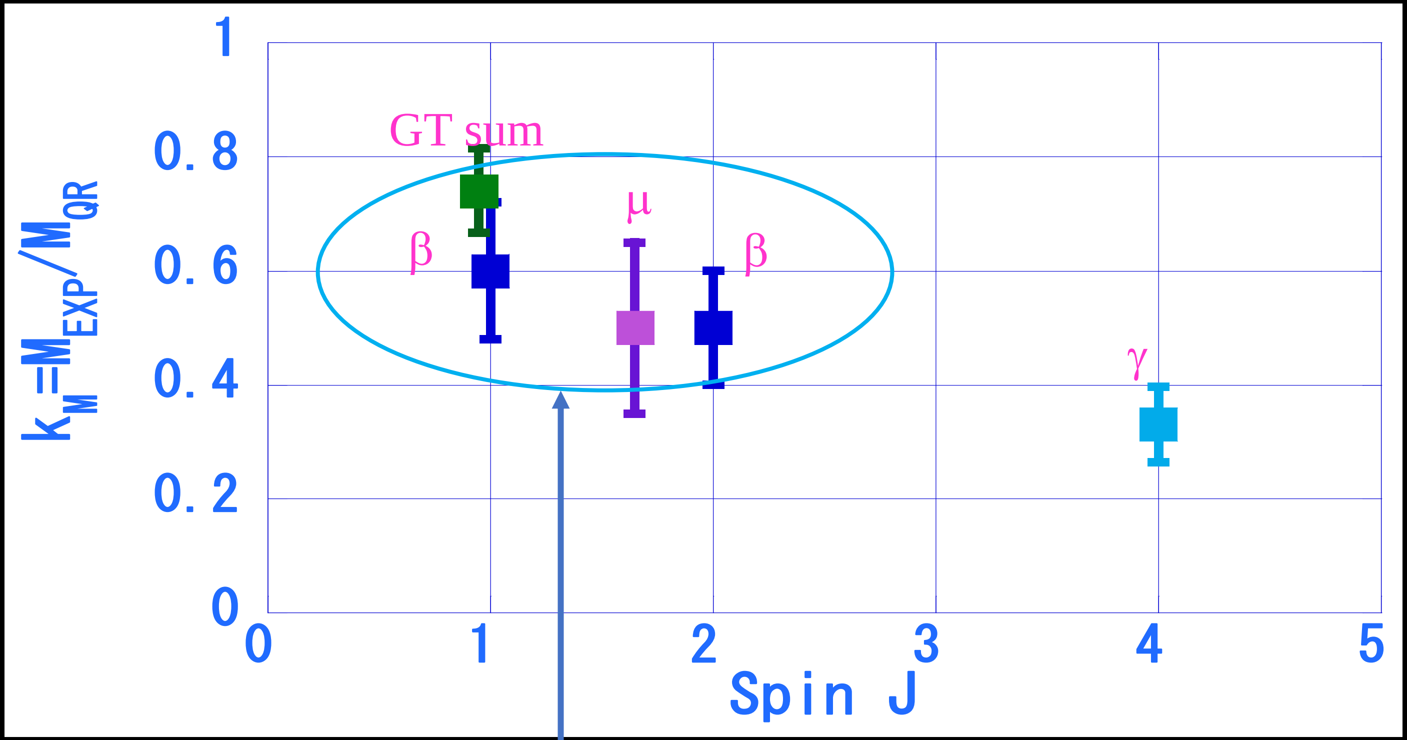
4. Small γ width of eV –sub-eV is overcome by using sharp IAS with
   small width around 30 keV to get some 10^{-4} γ branch.
   Measurements of γ rays in coincidence with CER to IAS makes
   BG-free measurement. The experiments are quite feasible .

Thanks for your attention.



6
4
2
0
−2
−4
$M^{0\nu}$
70
80
90
100
110
120
130
140
Mass number

Renormalization/reductions of axial vector β & γ coupling/NME with respect to QRPA



$g_A^{eff}(\beta\beta)/g_A \sim 0.55\text{-}0.75$

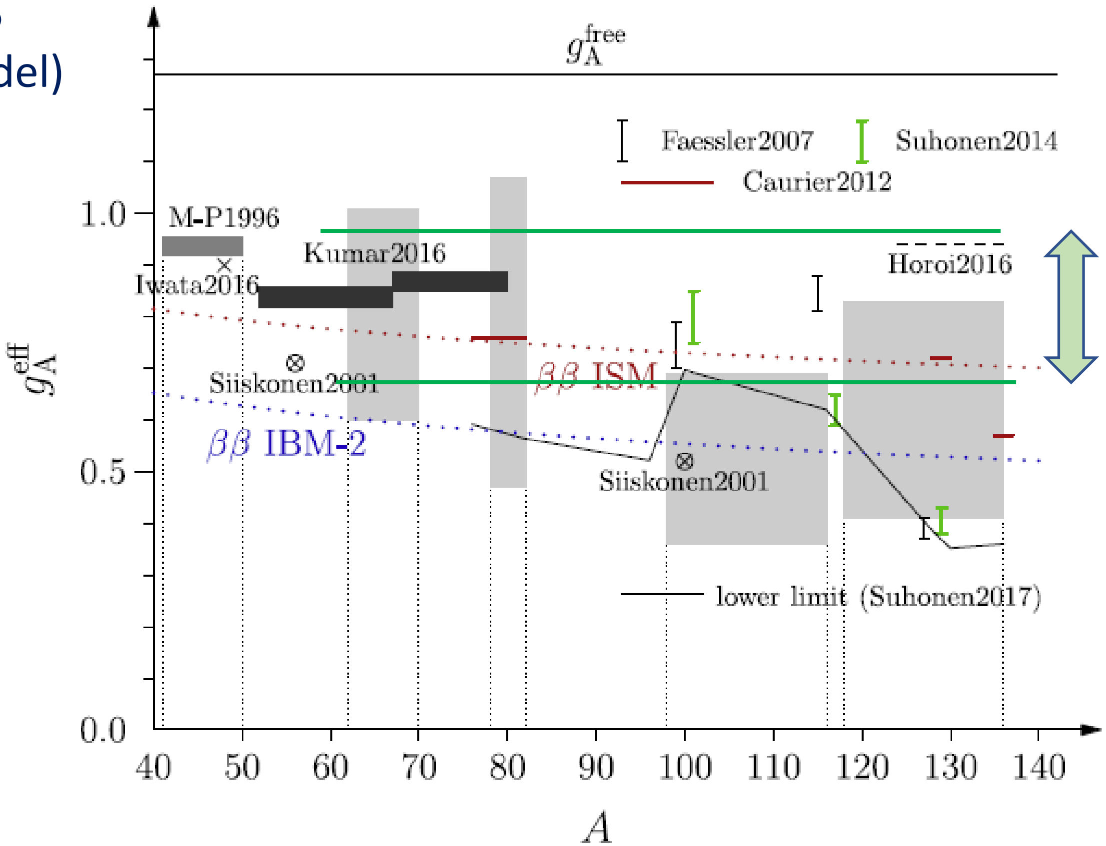
H, Ejiri J. Suhonen J. Phys. G. 42 2015

H. Ejiri N. Soucouti, J. Suhonen PL B 729 2014 .

L. Jokiniemi J. Suhonen H. Ejiri AHEP2016 ID8417598

L. Jokiniemi J. Suhonen. H. Ejiri and I. Hashim PL B 794 143 (2019)

g^{eff} from $2\nu\beta\beta$
M(EXP)/M(Model)



Present
0.74x1.27
0.55x1.27

Fig. 29. Effective values of g_A in different theoretical β and $2\nu\beta\beta$ analyses for the nuclear mass range $A = 41 - 136$. The quoted references are *Suhonen2017* [216], *Caurier2012* [233], *Faessler2007* [242], *Suhonen2014* [243] and *Horoi2016* [235]. These studies are contrasted with the ISM β-decay studies of *M-P1996* [229], *Iwata2016* [230], *Kumar2016* [231] and *Siiskonen2001* [228]. For more information see the text and Table 3 in Section 3.1.2 and the text in Section 3.1.3.

. Ejiri H, Suhonen J and Zuber Z 2019 Phys. Rep. 797 1