Experimental Aspects of DBDs beyond the standard model and Nuclear matrix elements

Hiro Ejiri RCNP Osaka

Greenary Nimph 翠の精

Experimental Aspects of DBDs

1. DBDs beyond the Standard Mdel.
2. The light Majorana ν mass
3. Nuclear matrix elements (NMEs)
4. Experimental approaches to NMES
5. Remarks and perspectives

Thanks Prof. Hinohara and the organizers.

1. Ejiri H 2005 J. Phys. Soc Jpn. 74 2101

2. Vergados J, Ejiri H , Simkovic F 2012 Rep. Prog. Phys. 75 ,106301

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

1. Hashim I, Ejiri H, Shima T, et al., Phys. Rev, 2018 97, 014617.
2. Ejiri H 2019 Frontiers in Physics 10.3389/fphys. 0003
3. Ejiri H, 2019 J. Phys. G. Nucl. Part. Phys. 46 125202
4. Jokiniemi L, Suhonen J, Ejiri H, Hashim I, PL B 2019 795 143.
5. Ejiri H , CER collaboration . 2020 J. Phys. 47 LT 01.

6. Ejiri H, Universe 2020 6, 225

7 . Ejiri H, Advances High Energy Phys. 2021 ID 6666720

8. Ejiri H, Frontiers Physics, 2021 650421

I. DBDs beyond the standard EW model

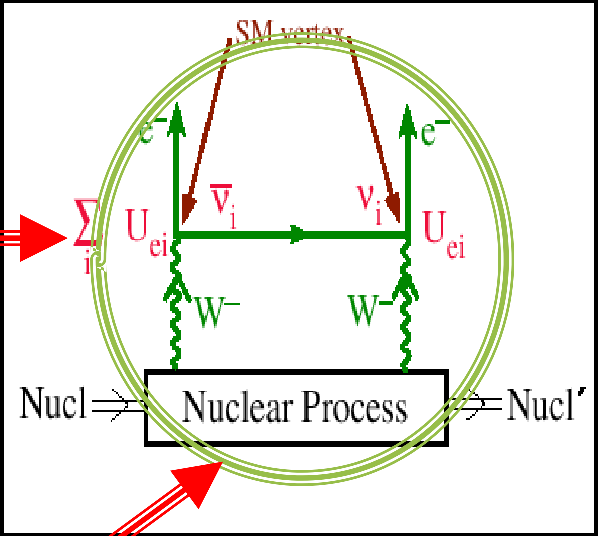
Neutrino-less ββ decays

$0\nu\beta\beta$ $A = B + \beta + \beta$

Lepton number ΔL=2 beyond SM.

Particle astro physics

Majorana ν, m_ν CP, RHC



$$T^{0\nu} = G^{0\nu} [M^{0\nu} \; f_\nu]^2$$

EXP

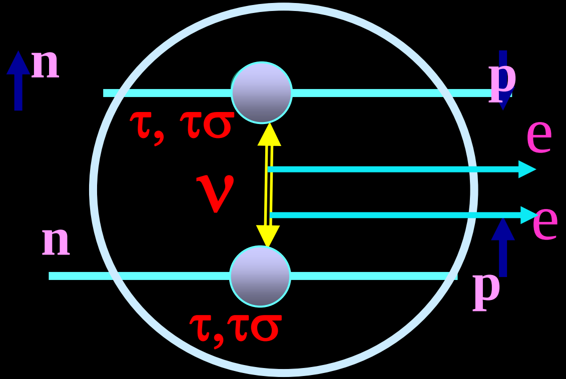
Kinematic
Phase Space

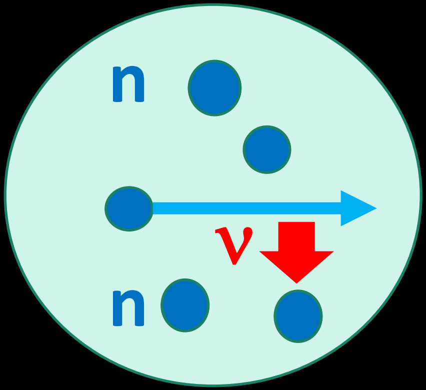
NNR,
Nucl. phys. g_A
short-range, Δ, π
τ σ correlation

Why DBD : $\sigma \sim 10^{-83}$ cm^2 T$\sim 10^{-36}$/sec

A femto (10^{-15}cm) nuclear collider

Luminosity/3 t L$\sim 10^{76}$/cm^2 /sec = 3 10^{83}/cm^2 /y



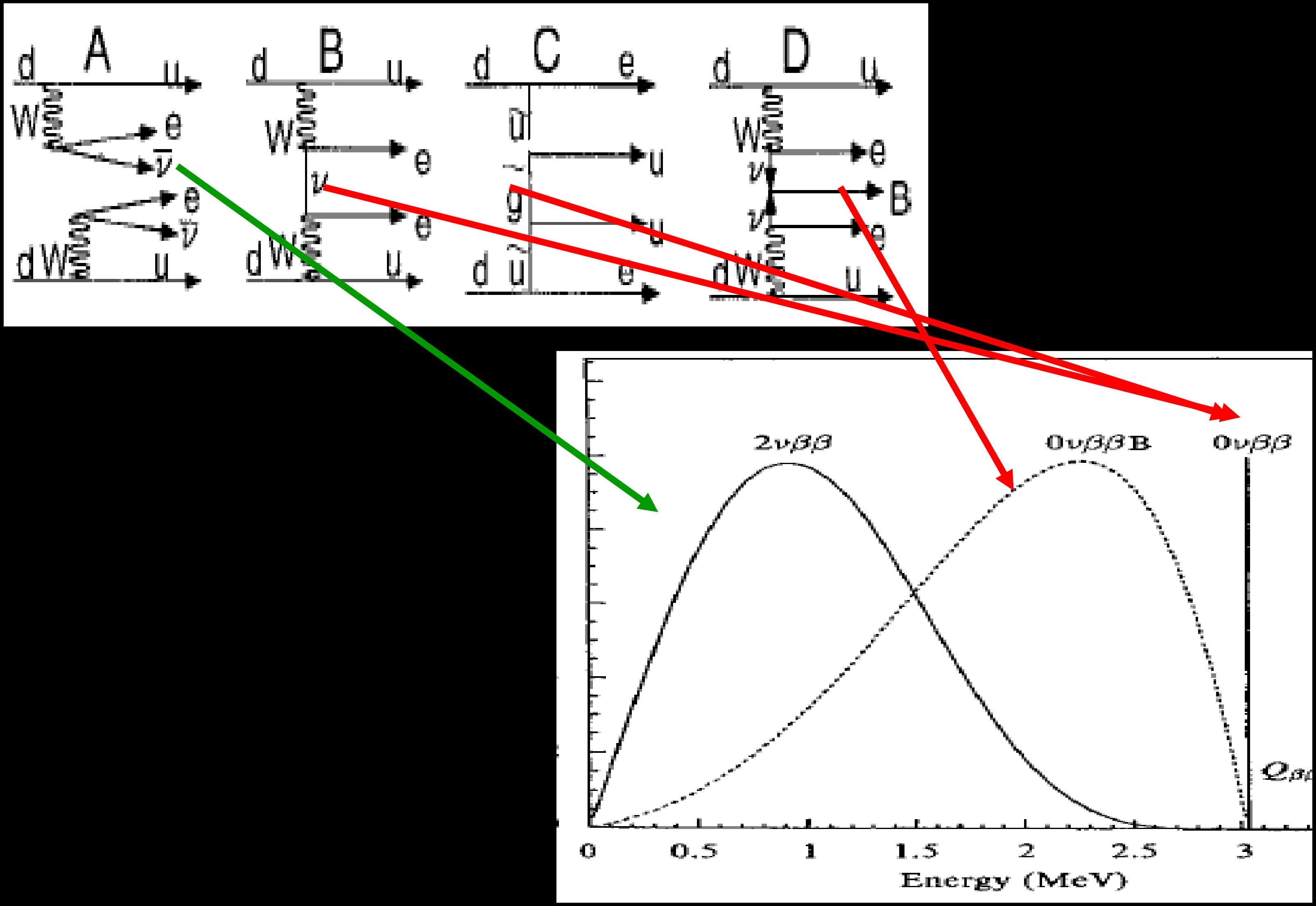


3 ton 10^{30} neutrons with 1/3 light velocity in a bahn area

A few counts per ton year in case of IH 20 meV M=2

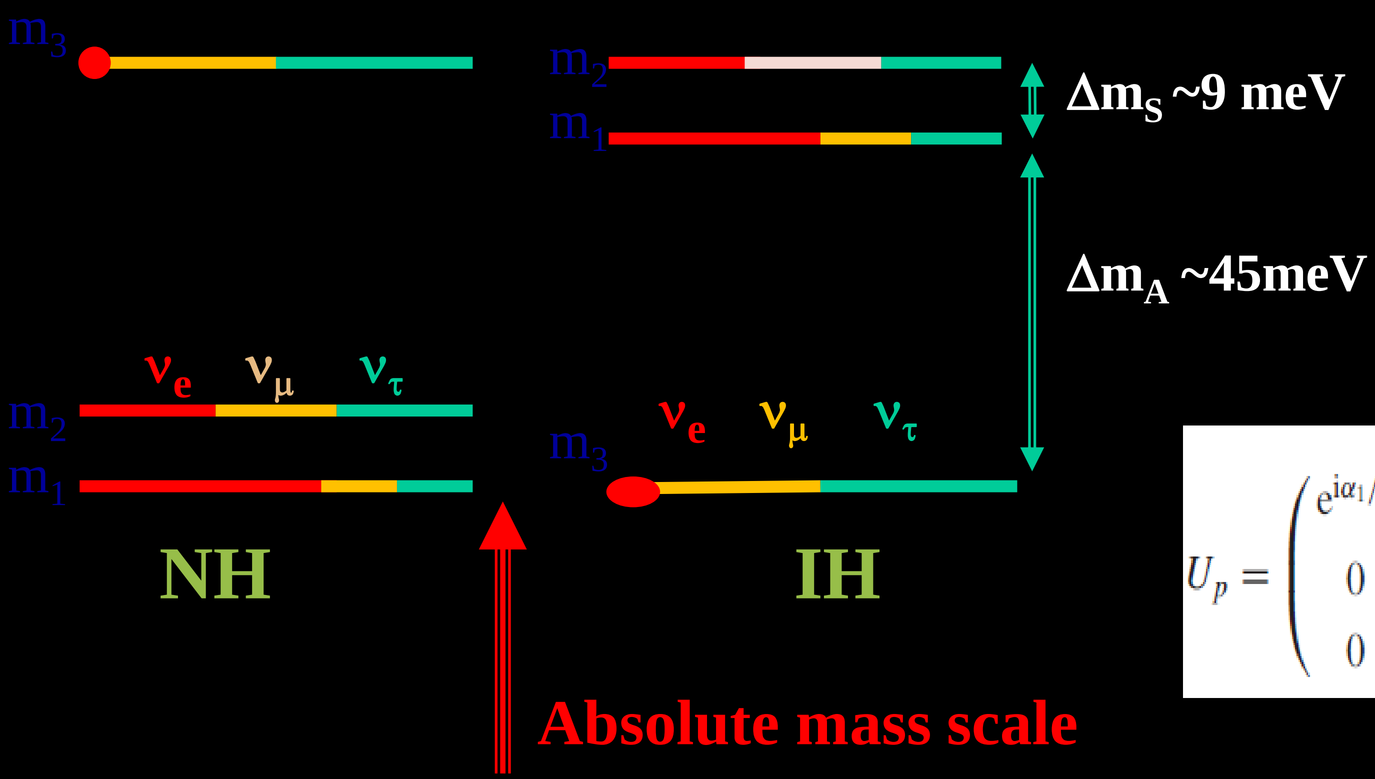
LHC L$\sim 10^{33}$ /cm^2 /sec

1. Energy spectra to select the 0νββ 2-3 body processes



ν matrix and masses

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} C_{12}C_{13} & C_{13}S_{12} & S_{13}e^{-i\delta} \\ -S_{12}C_{23} - C_{12}S_{23}S_{13}e^{i\delta} & C_{12}C_{23} - S_{12}S_{23}S_{13}e^{i\delta} & S_{23}C_{13} \\ S_{12}S_{23} - C_{12}C_{23}S_{13}e^{i\delta} & -C_{12}S_{23} - S_{12}C_{23}S_{13}e^{i\delta} & C_{23}C_{13} \end{pmatrix} U_p \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix},$$



Δm_S ~9 meV

Δm_A ~45meV

NH

IH

Absolute mass scale

$$U_p = \begin{pmatrix} e^{i\alpha_1/2} & 0 & 0 \\ 0 & e^{i\alpha_2/2} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$< m_\nu > = |\Sigma\, U_i^2 \;\exp(i\, \phi_i)\; m_i| \qquad \phi_\iota = \alpha_2 - \alpha_1, \quad \phi_\iota = \alpha_2 - 2\delta$$

is given by using U_i Δm_S, Δm_A given by ν oscillations

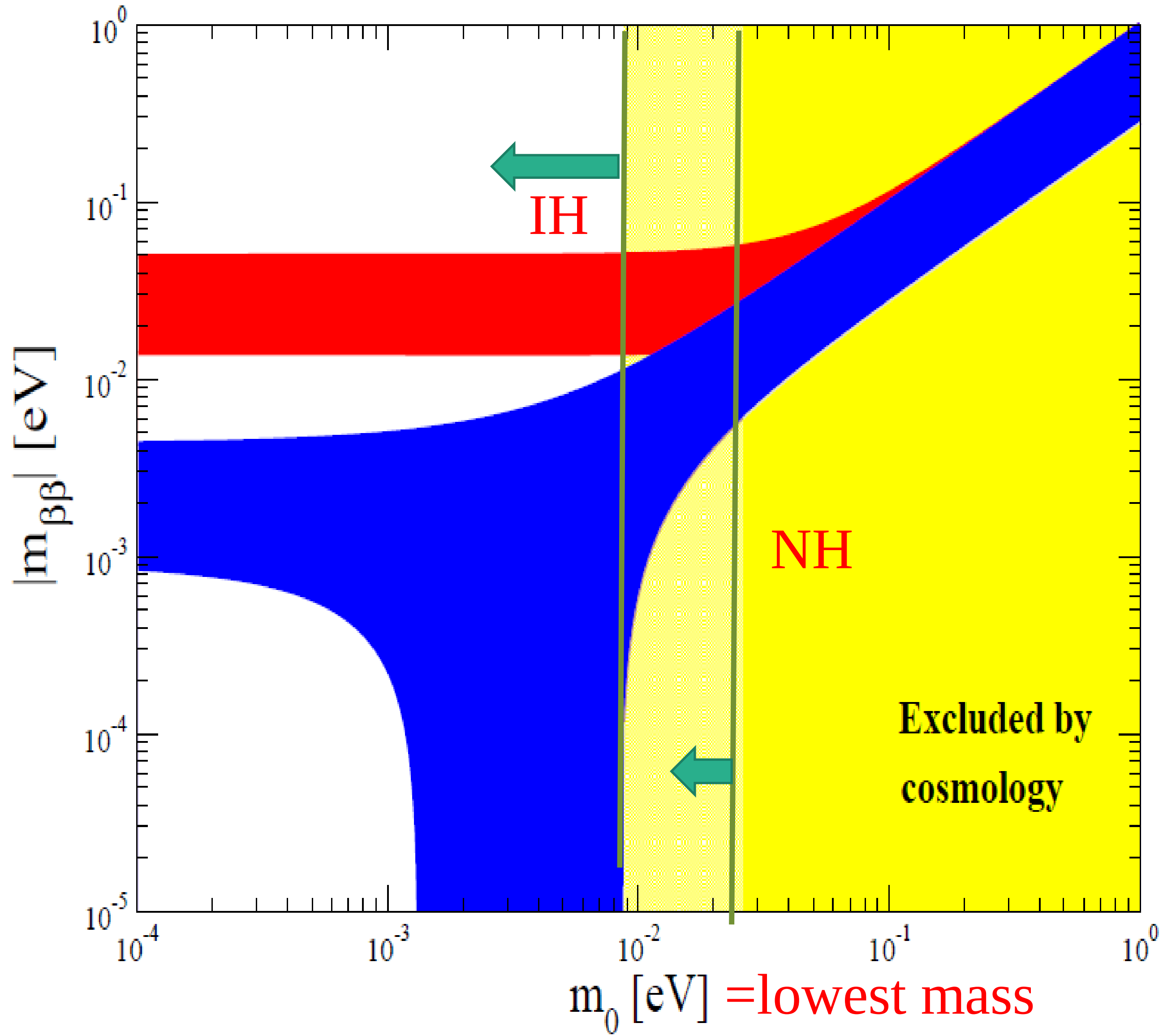
Mass hierarchy

If m^{eff} is

>15 meV IH
< 12 meV NH

➢

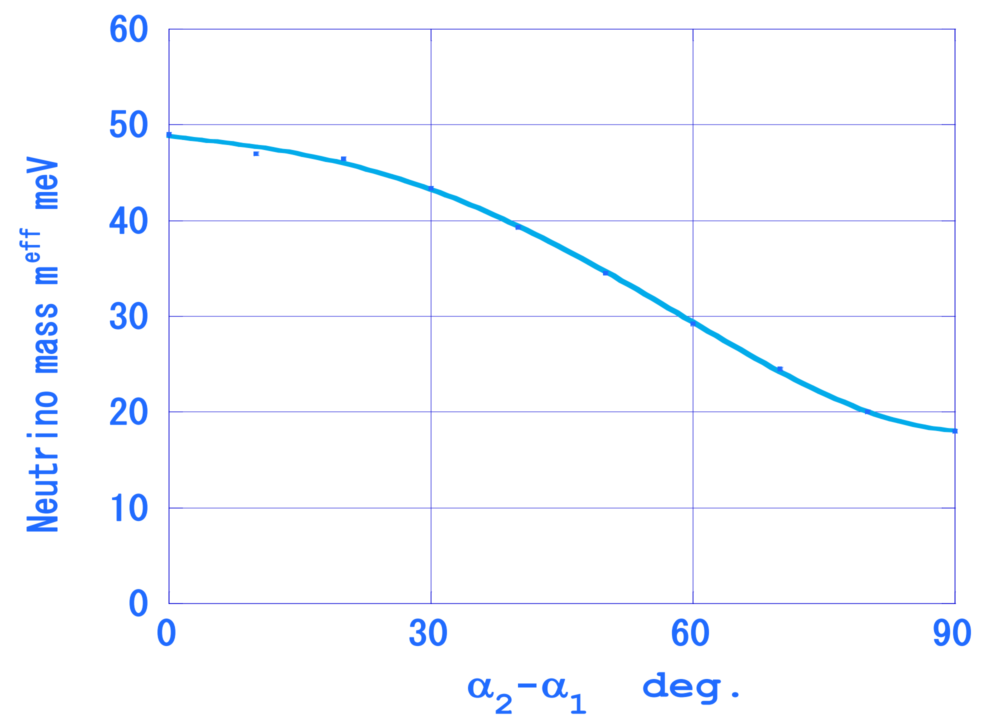
Need m^{eff}, $M^{0\nu}$ within 30 %



J. Vergados, H. Ejiri, F. Simkovic, ROPP. 75 (2012) 106301.

H. Ejiri, J. Phys. Soc. Jpn. 74 (2005) 2101.

IH mass $m_3 << m_1 < m_2$
$<m> \sim m(A) (1-\sin^2 2\theta_{12} \sin^2\alpha_{12})^{½}$



Phase difference = $\alpha_2-\alpha_1$ to be measured . 0-$\pi/2$: m= 50-18 meV ± 5 meV, i.e.NME ± 15 % to get the phase difference $\pm\pi/12$

L-R symmetric model : Left right weak currents

$$T^{0\nu} = G^{0\nu}|M^{0\nu}|^2 K_{\nu R},$$

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

RHC L/R weak boson mass ratio λ and mixing θ

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

$<\eta>=\tan\theta_{LR}|\Sigma U_{ej} V_{ej}|$

C. Θ_{21} and E_{12} correlations to identify LHC/RHC

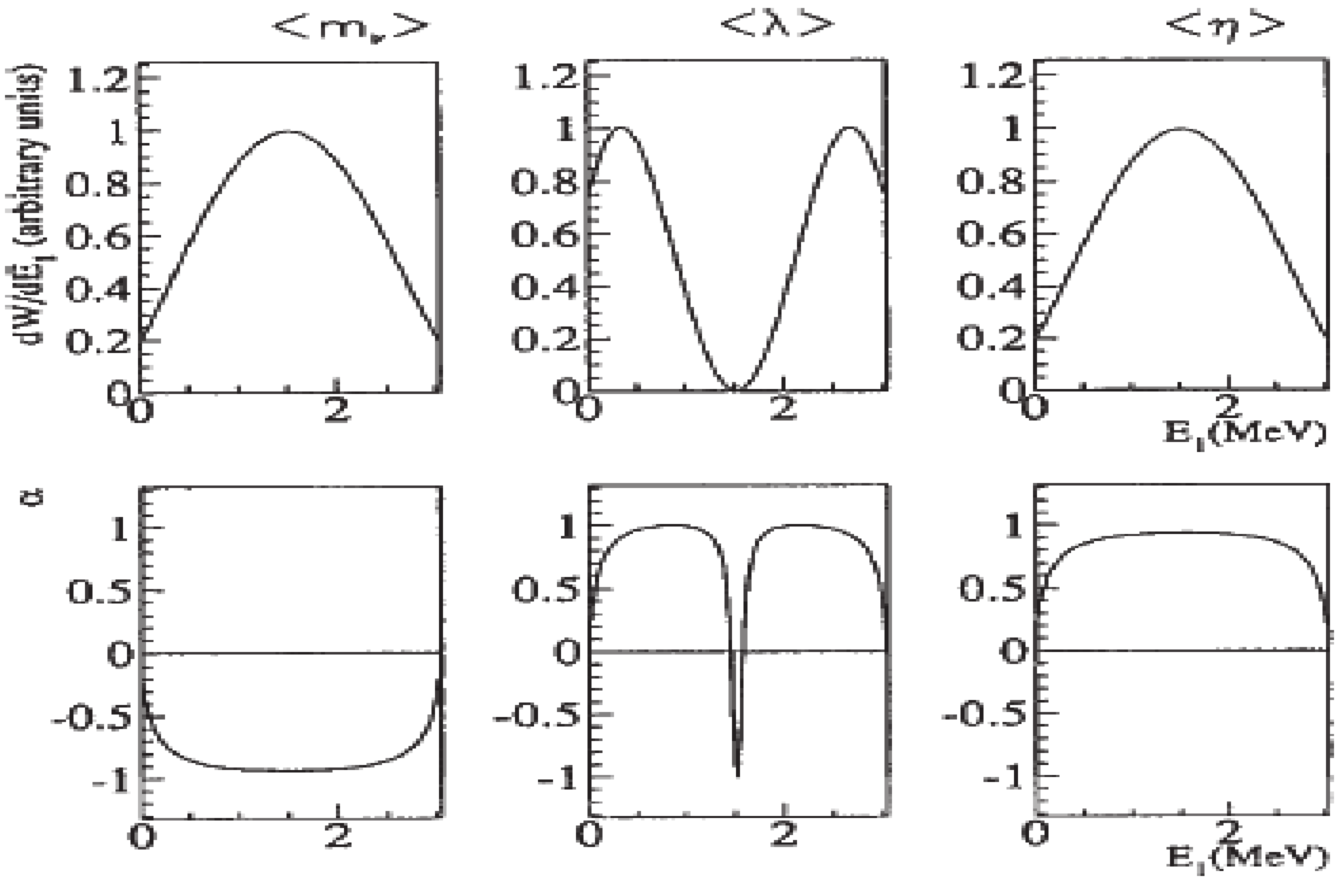
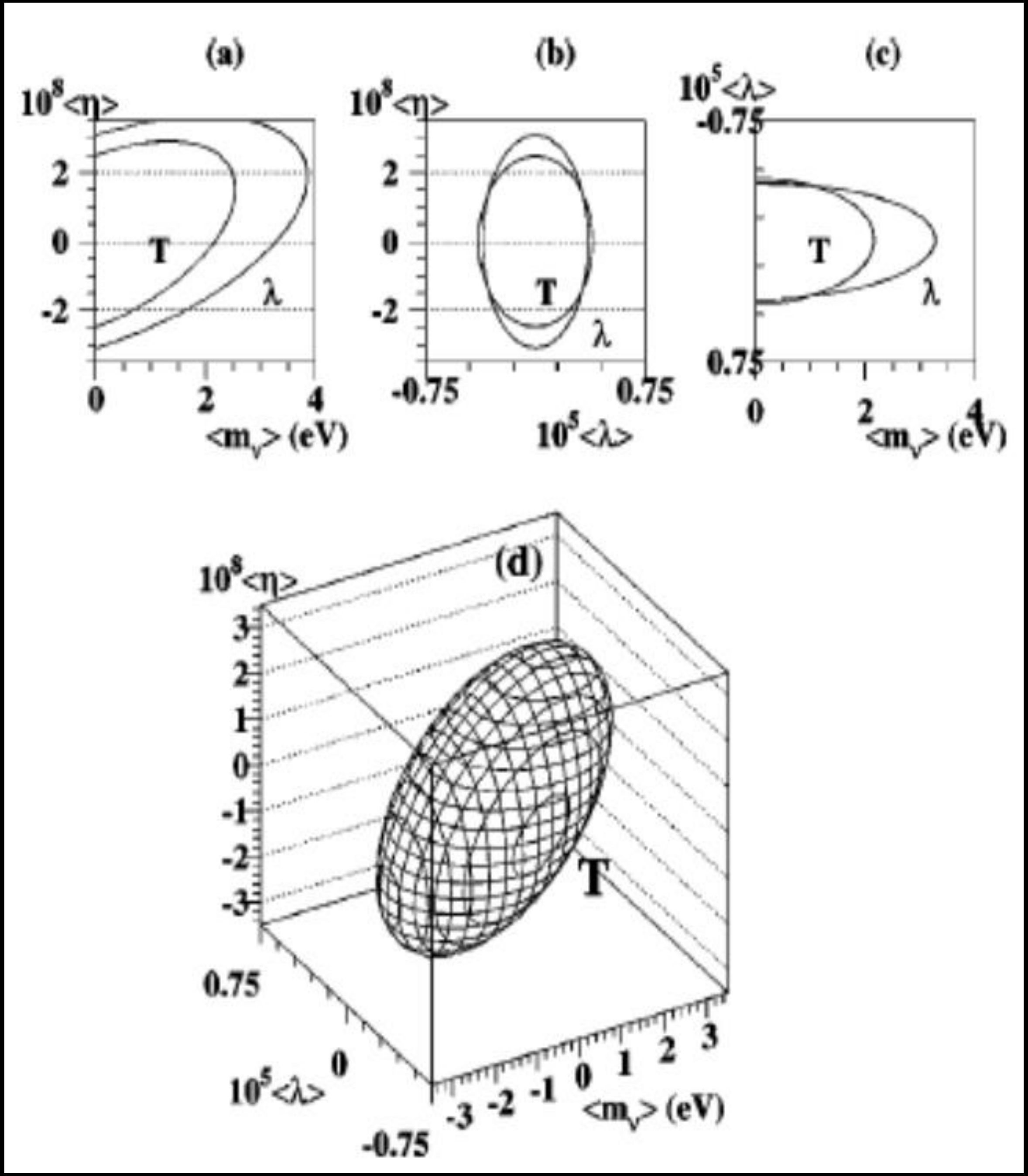


Fig. 4. Energy and angular correlations for the ^{100}Mo $0\nu\beta\beta$ process caused by the mass and right-handed current terms of $\langle m \rangle$, $\langle \lambda \rangle$ and $\langle \eta \rangle$. Top: Calculated single-β spectra. Bottom: $\beta_1 - \beta_2$ angular correlation coefficients α defined by $W(\theta_{12}) = 1 + \alpha \cos \theta_{12}$.4)

$\langle m \rangle \sim 0.3$ eV, $\langle \lambda \rangle \sim 7\ 10^{-7}$, $\langle \eta \rangle \sim 4\ 10^{-9}$

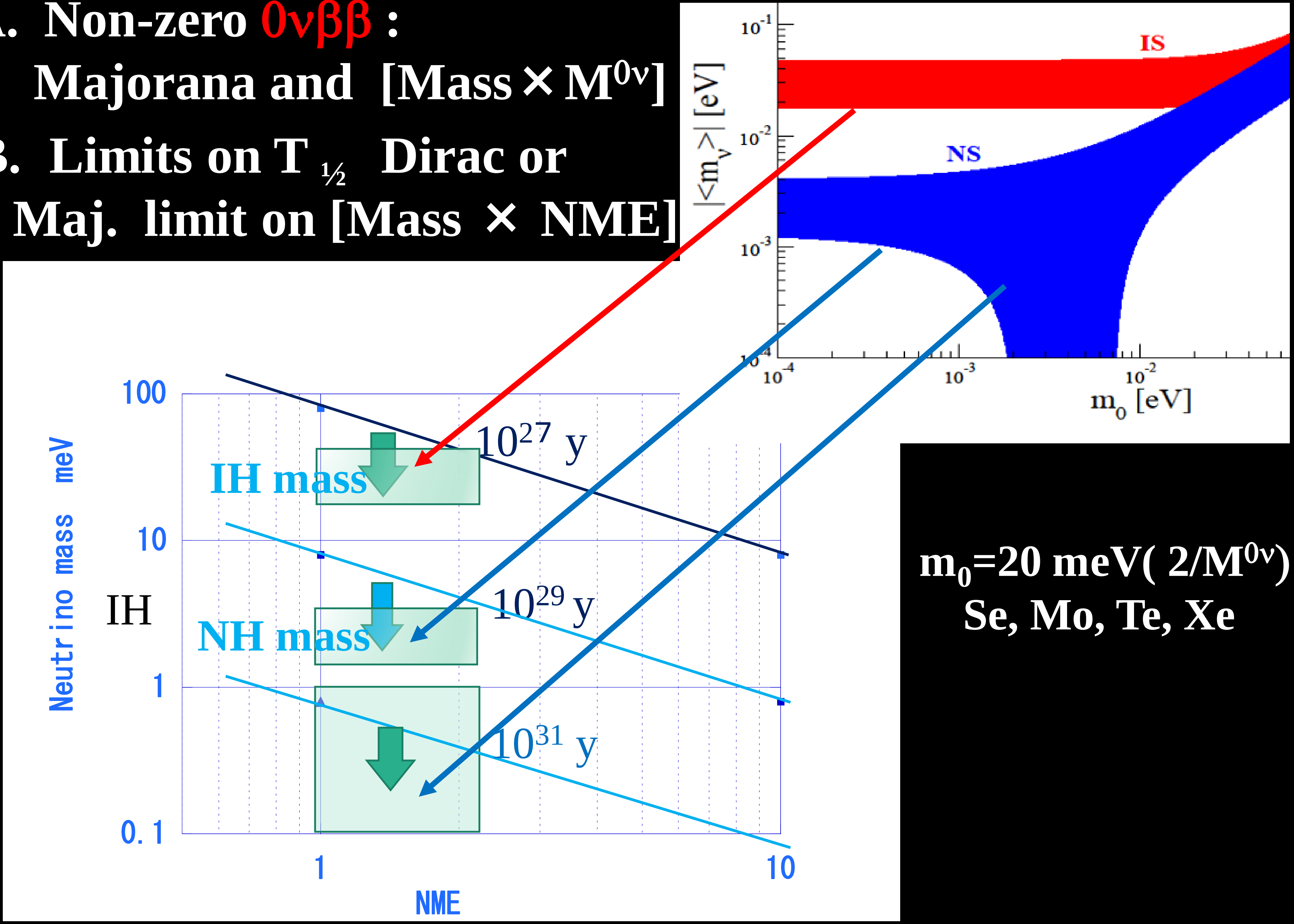


H. Ejiri , N. Kudomi et al
ELEGANT
PR C 63 2001 065501
100Mo tracking detector

II. Majorana ν mass IH and NH

A. Non-zero $0\nu\beta\beta$:
Majorana and [Mass × $M^{0\nu}$]

B. Limits on $T_{1/2}$ Dirac or
Maj. limit on [Mass × NME]



m_0=20 meV($2/M^{0\nu}$)
Se, Mo, Te, Xe

Key elements for ν-mass by DBD

$T^{0\nu} = G[M m_\nu^{eff}]^2$ m_ν^{eff} : m_0 phase, mass hierarchy

$T^{0\nu}$, M are 2 key elements for m_ν^{eff} G phase space

ν- mass –sensitivity (m to be measured)

$m = [k / M][B/N]^{1/4}$ $k = G^{-1/2}$ M=NME

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

- A: $T^{0\nu}$ Exp. 10^{-27-30}/y. N- multi-ton B 1/t y

B : M No direct exp. No accurate theory yet

Exp. to help theory evaluate M

$m = 1.5\, m_0 [B/N]^{1/4}$ for 0.5 detector efficiency

N: Isotopes ton, B : BG per ton year T=5 y

$m_0 = k/M$ M=NME

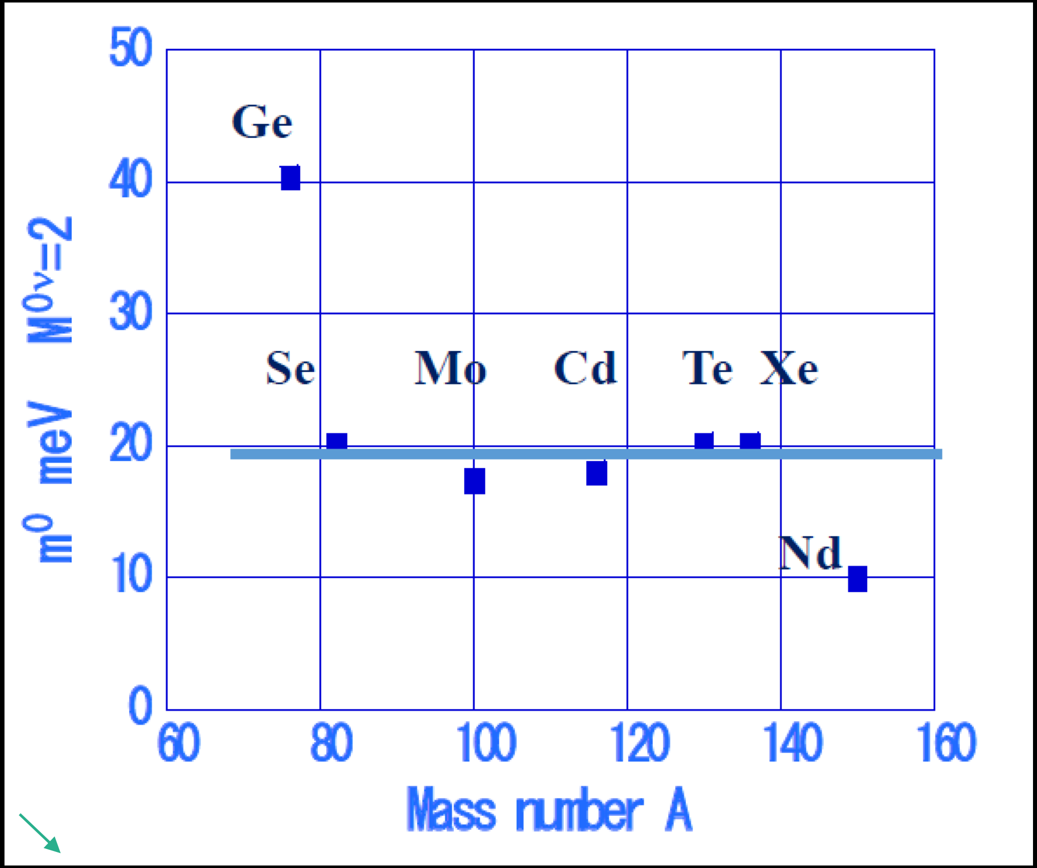
$m_0 \sim 20$ meV in case of M=2

B=1, N=1,

30 meV IH

B=0.01. N=100

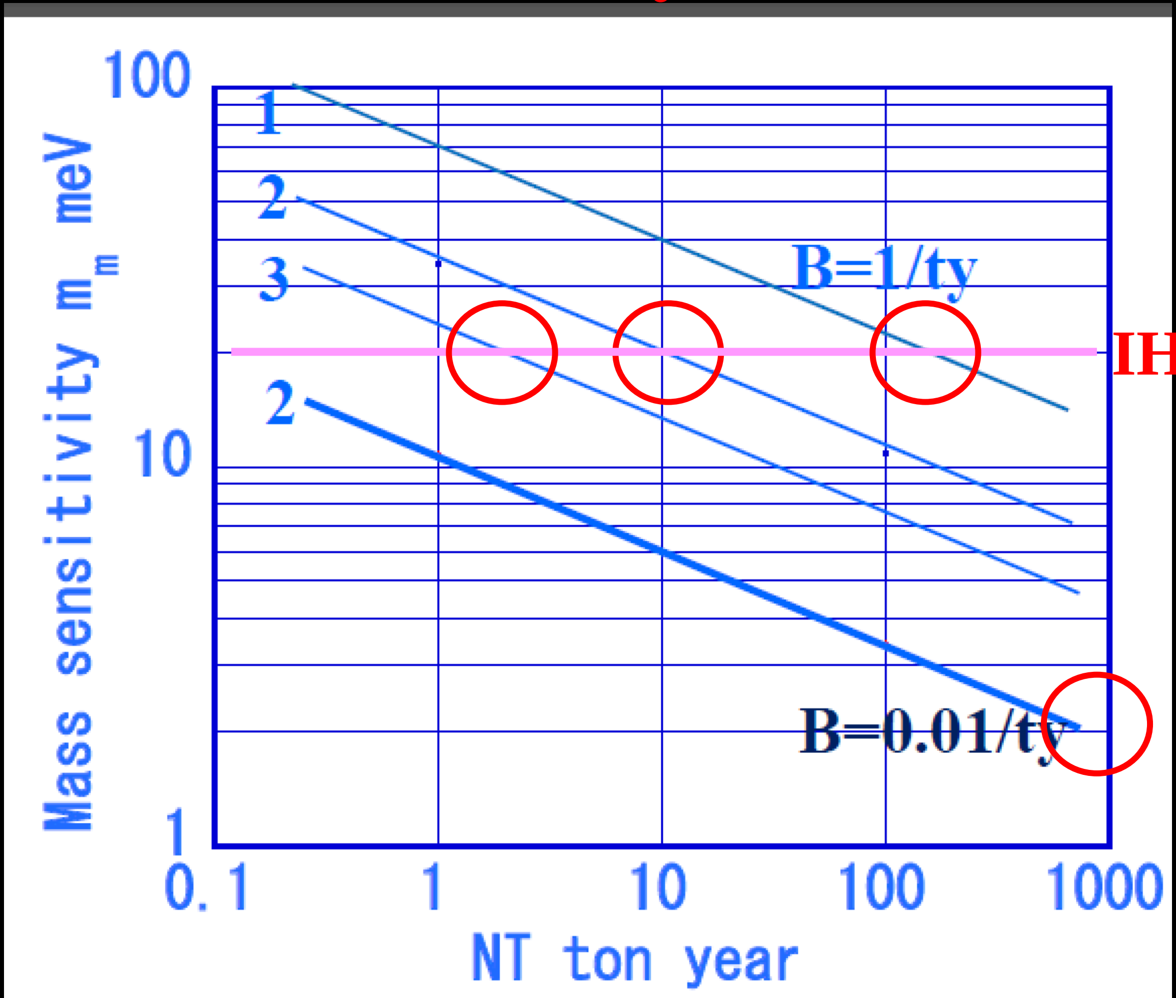
3 meV NH



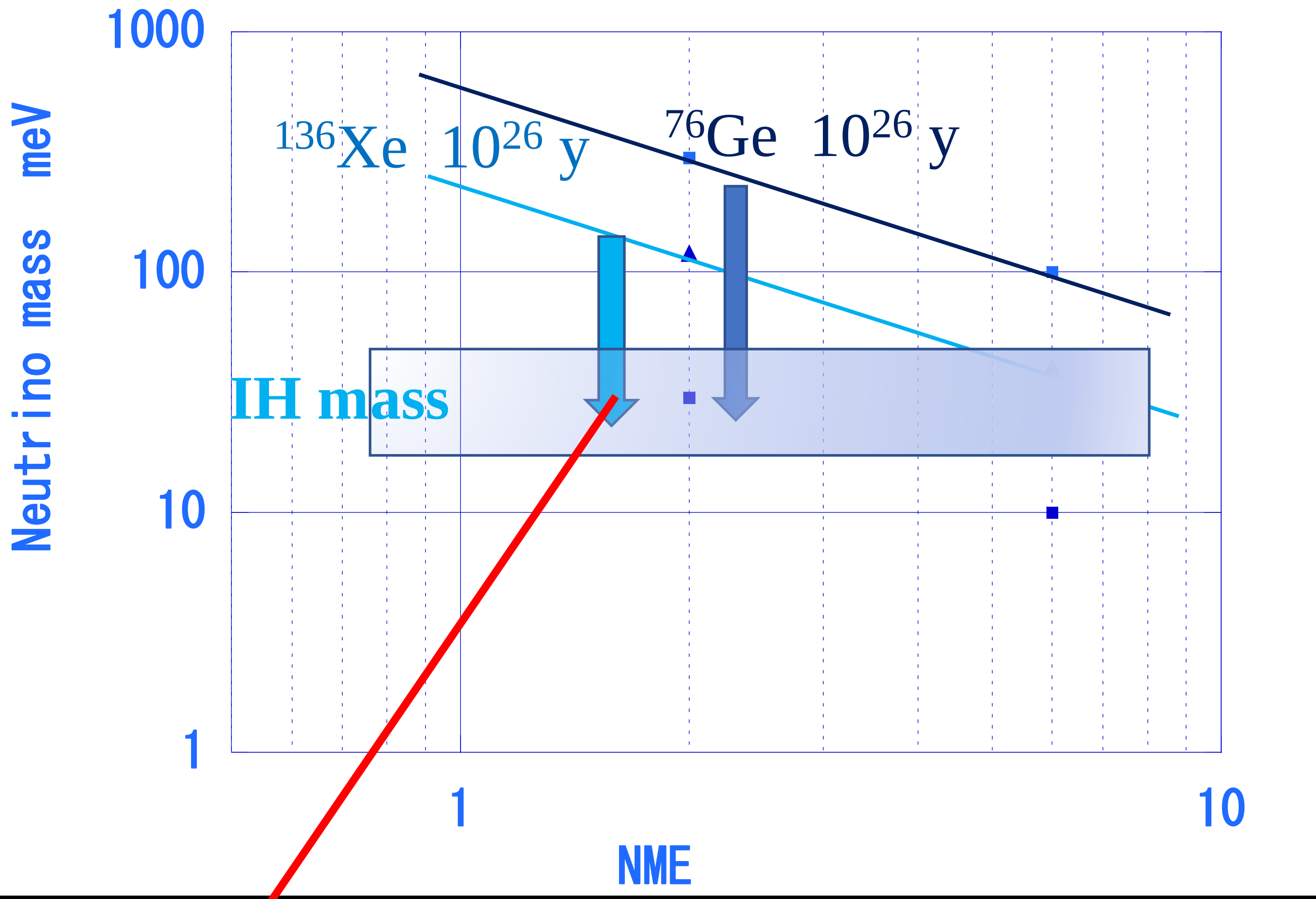
DBD $0\nu\beta\beta$ NMEs and DBD mass sensitivity

$$m = k\,[m_0]\,[B/N]^{1/4}$$

$M^{0\nu}=k^2$ M(QRPA) ~ 2 , m_0 =18 meV ε~0.5



Limits on [Mass × NME] < k/$T_{1/2}$

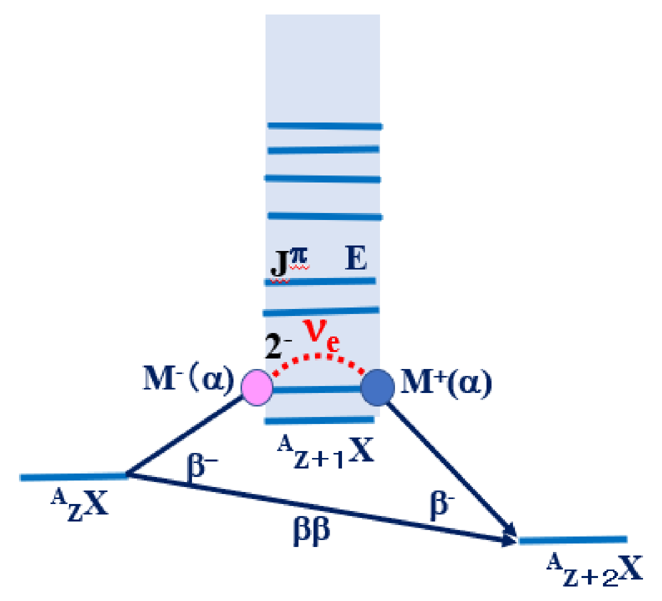


Current 0.8 -0.5 10^{26} for Ge and Xe. To reach IH mass,
A factor >10 in ν-mass and >10^4 in NT/B

3 DBD nuclear matrix element (NME)

DBD 0νββ NME

$$M^{0\nu} = \left(\frac{g_{\mathrm{A}}^{\mathrm{eff}}}{g_{\mathrm{A}}}\right)^2 \left[M_{\mathrm{GT}}^{0\nu} + \left(g_{\mathrm{V}}/g_{\mathrm{A}}^{\mathrm{eff}}\right)^2 M_{\mathrm{F}}^{0\nu} + M_{\mathrm{T}}^{0\nu}\right],$$



Quenching
due to
effects
not in model

Model NMEs

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

$$M_{\mathrm{F}}^{0\nu} = \sum_k \langle t_\pm h_{\mathrm{F}}(r_{12}, E_k) t_\pm \rangle ,$$

$$M_{\mathrm{T}}^{0\nu} = \sum_k \langle t_\pm h_{\mathrm{T}}(r_{12}, E_k) S_{12} t_\pm \rangle ,$$

$H(r_{12}) \sim 1/r_{12}$ neutrino potential for 2 n for ν-exchange .

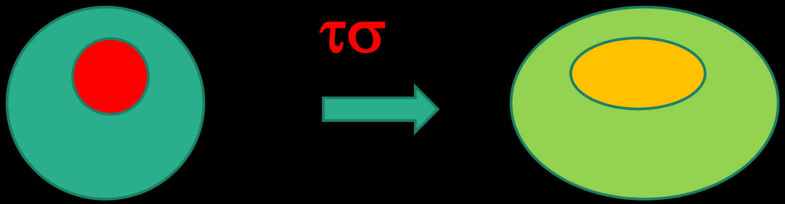
$M^{0\nu} = \Sigma_J M(J)$ J= 1^+ GT, 2^- SD, 3^+ SQ multipole sum

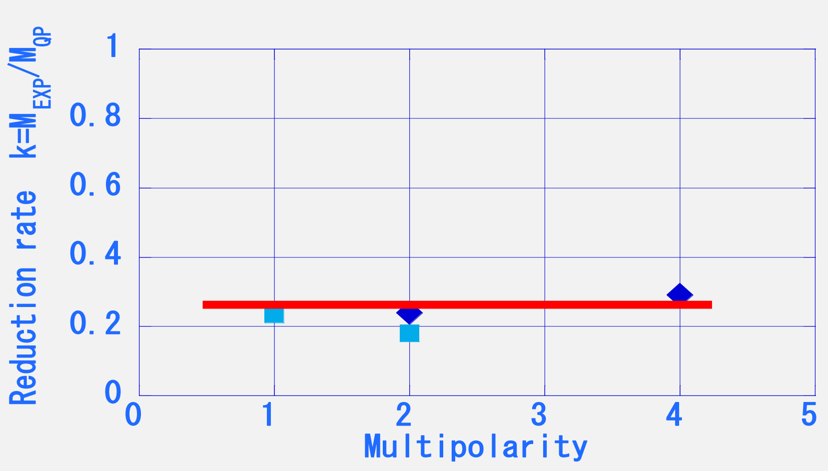
$M(J) = \Sigma_k M_k(J)$, Sum over all k state with spin J

DBD NME : Three major problems , A. B. C.

A: Very small fraction of the strength

Initial and final (ground state) nuclei and nucleons are very different , reduce overlap between them



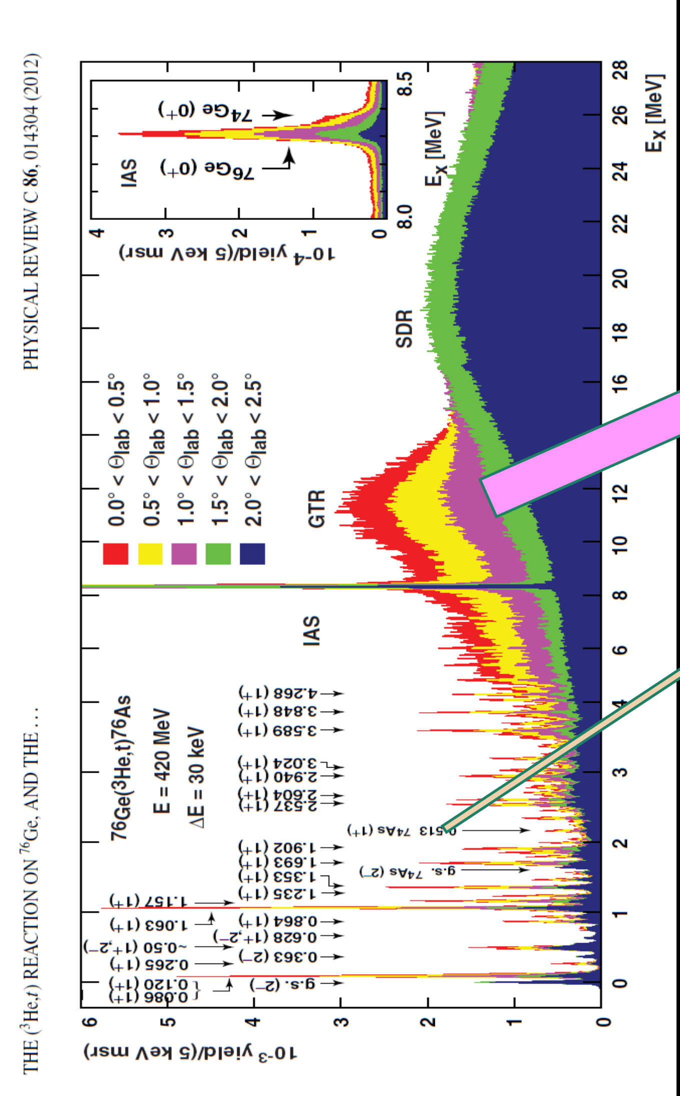


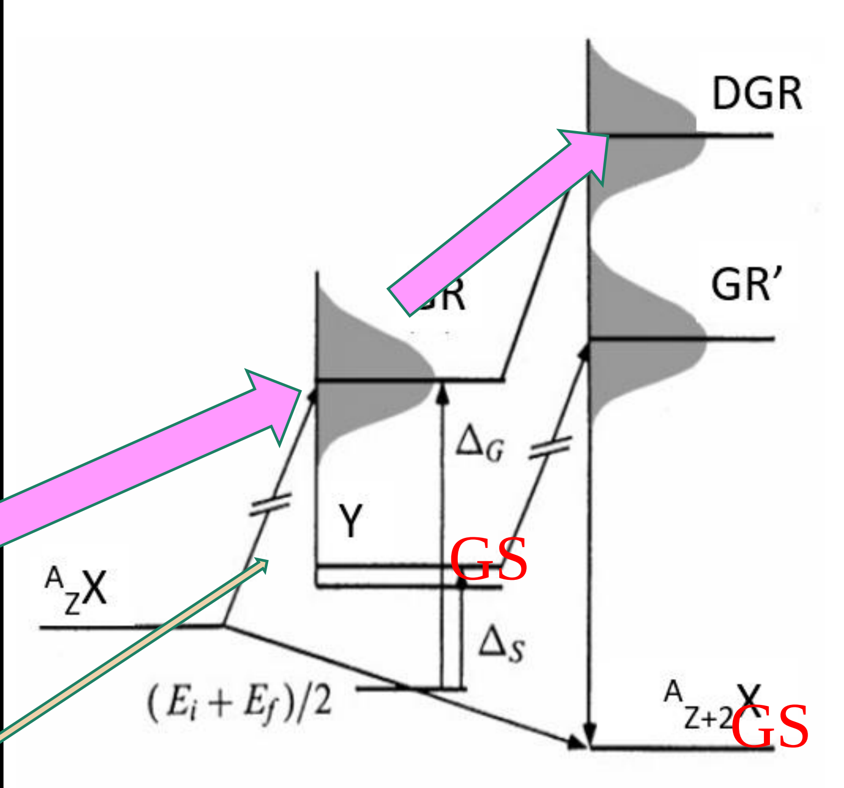
M(EXP)/M(QP) (Quasi-particle)

Single β k=k(τσ) k(NM)~0.25

Double β M ~ 0.05

Very small fraction of the strength

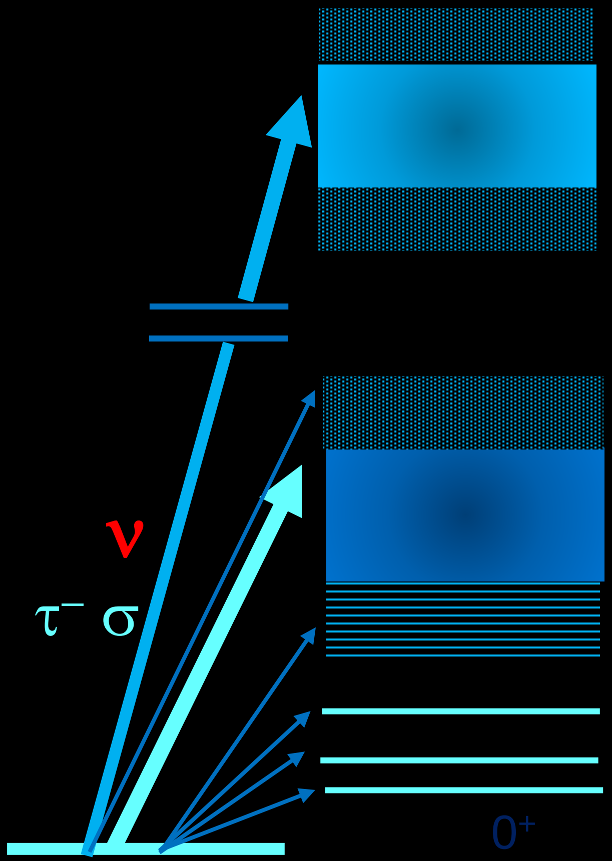




Single β $|M(GS)|^2 = 1\ 10^{-2}$ Sum
DBD β $|M(GS)|^2 = 4\ 10^{-4}$ Sum

Closure approximation <i|T|GS>
GS should pick up 10^{-4} strength

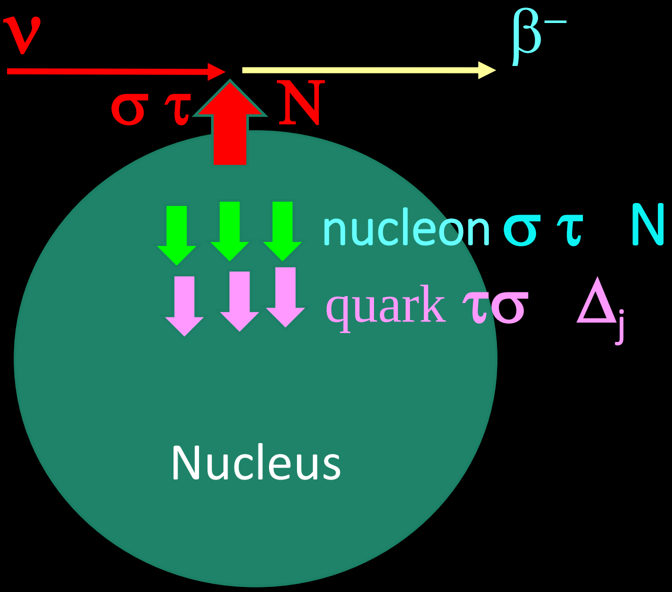
B: Weak int.: spin isospin τσ N^{-1}N GR and N^{-1}Δ GR



GR= σ τ flip
Σ [$N_i^{-1}\,\Delta_j^{+}$]]

GR=
Σ [$N_i^{-1}\,P_j$]

[$N_1^{-1}\,P_1$] [



Nuclear medium
τσ polarization

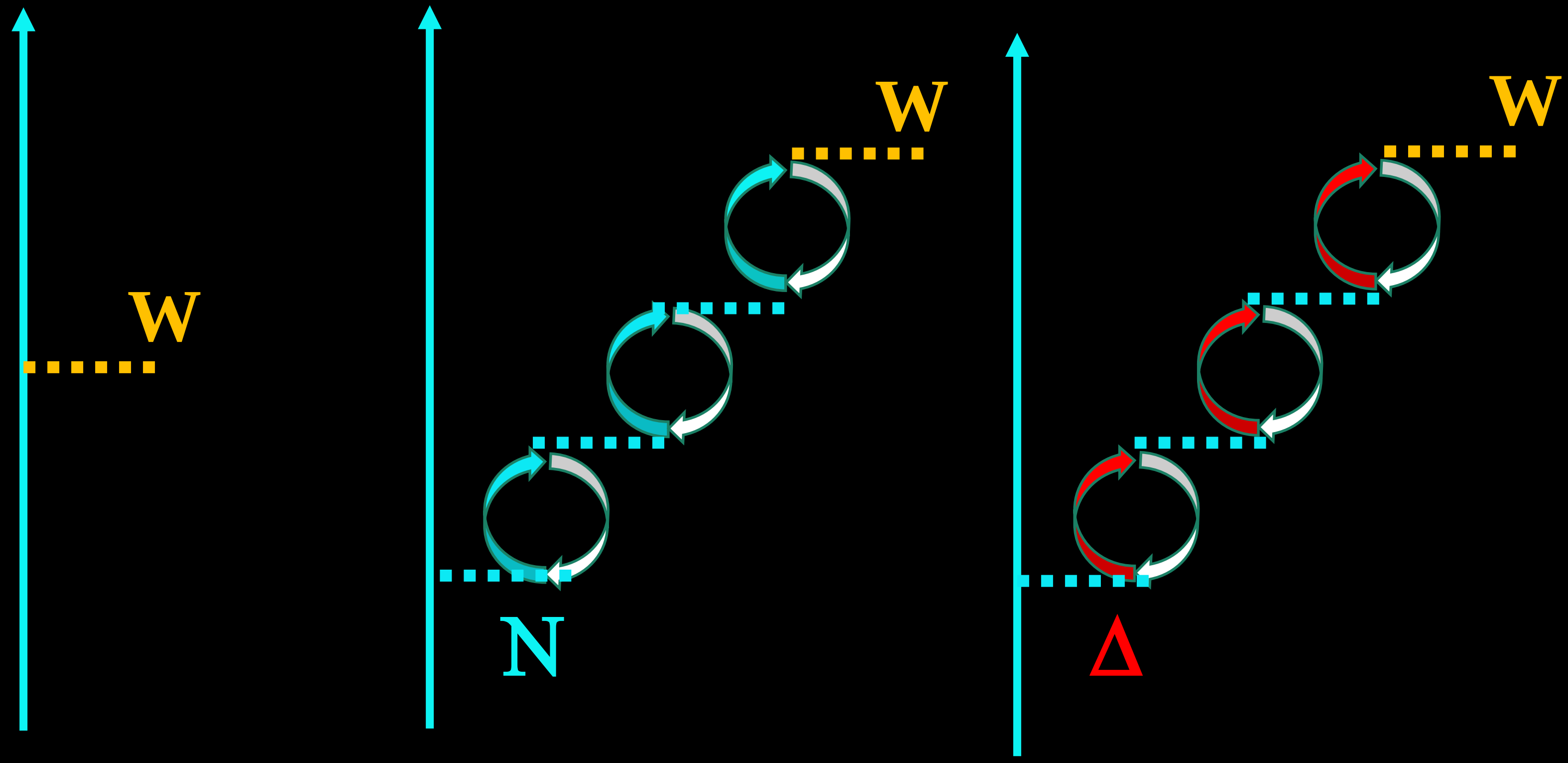
1⁺ 2⁻

$$|I\rangle = |NP\rangle - \varepsilon\,|GRn\rangle - \delta\,|GR\,\Delta\rangle$$

$$M^{\beta} \sim k^{eff}\,M_0 \qquad k^{eff}\,(\tau\sigma) \sim 1/(1+\chi_{\tau\sigma})$$

$$k^{eff}\,(\Delta) \sim 0.6$$

$\chi_{\tau\sigma}$: susceptibility

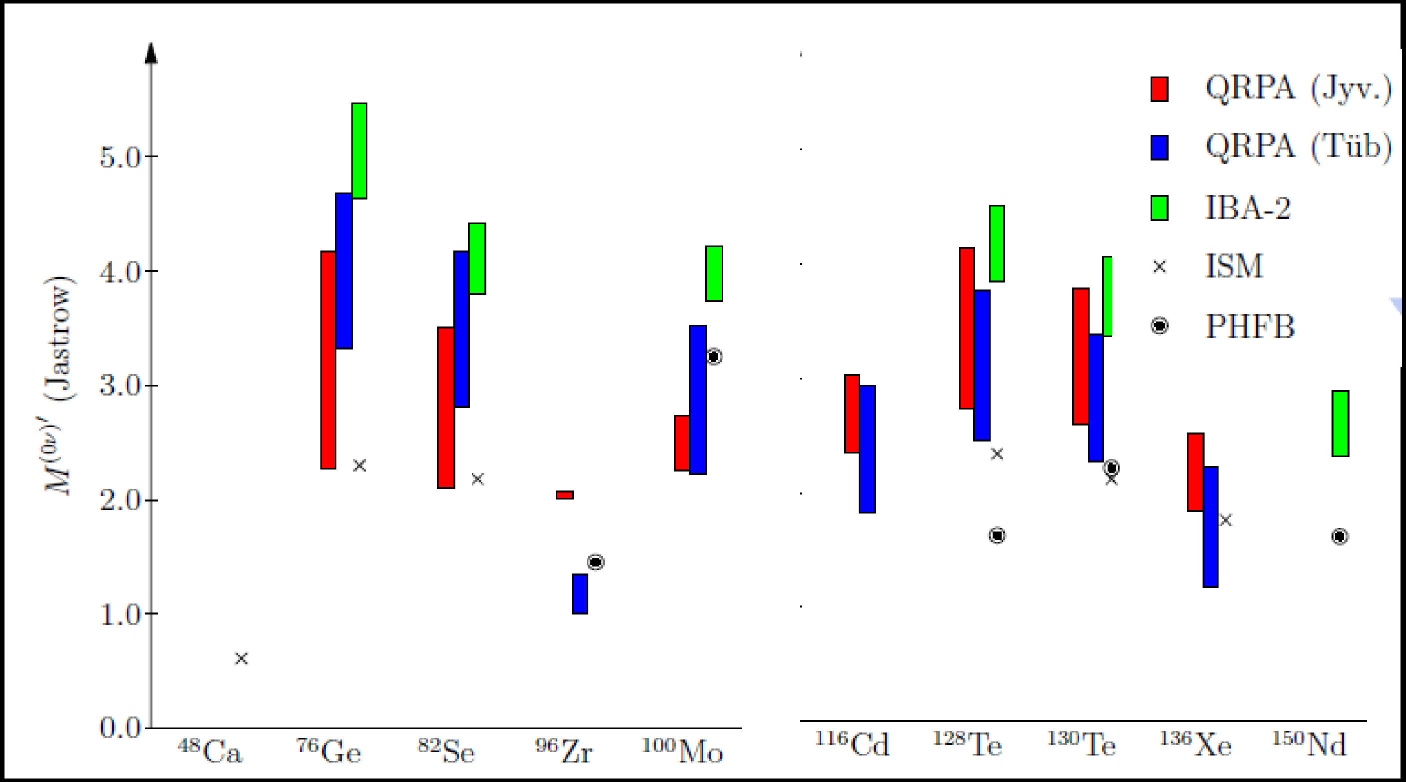


Coherent
Nucleon τ σ flip
$\chi=\kappa(N\text{-}Z\sim 10)$

Coherent
Quark τ σ flip
$\chi=\kappa(N+Z\sim 100)$

Nucleonic and Δ $\tau\sigma$ polarization and susceptivility may be tested in FB. March APFB by Prof. Hiyama

C: Real NME M (Nuclei) ≠ model NME M(nucleons)
Strongly interacting many hadron system , not like model

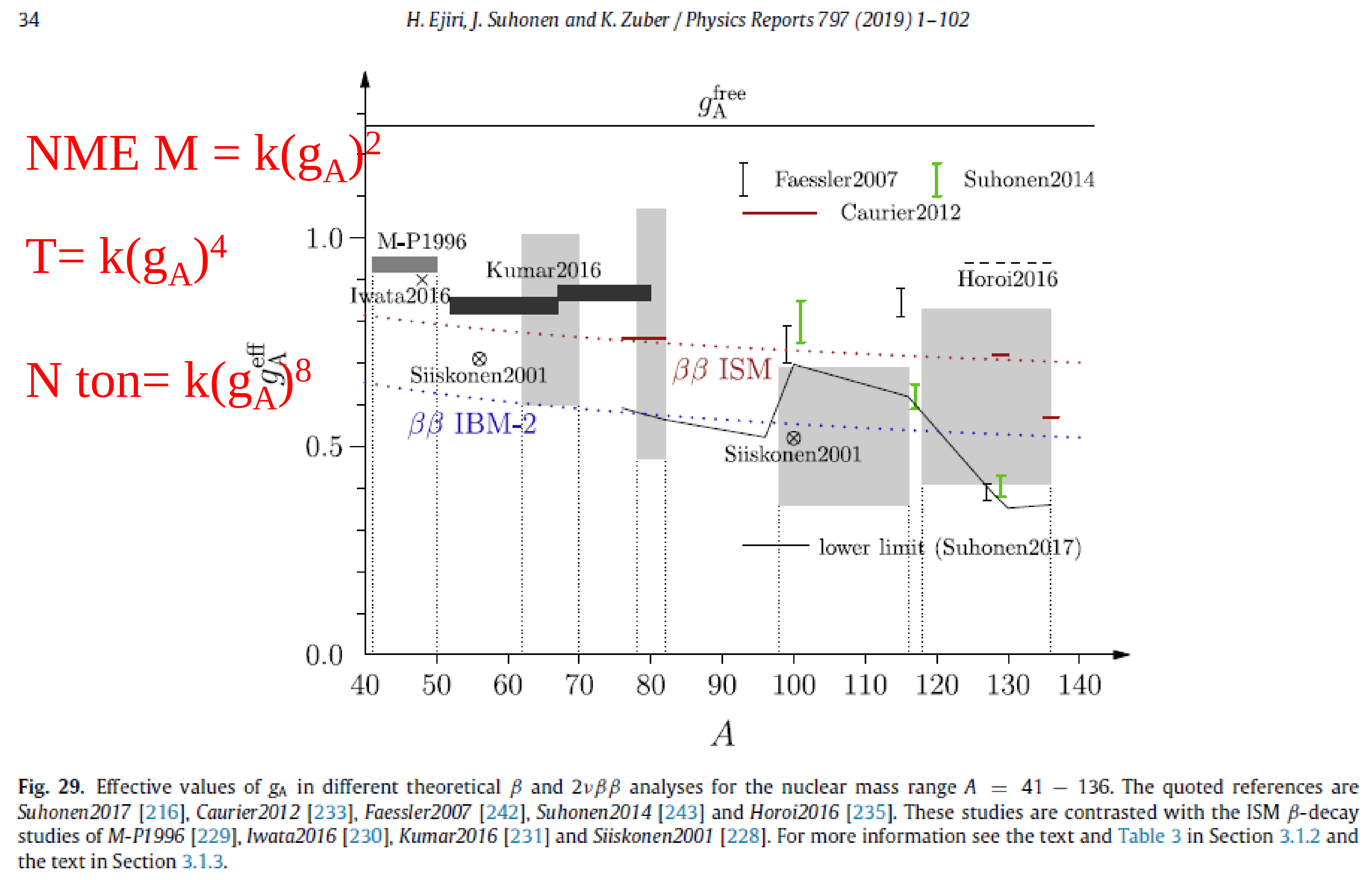


Suhonen

$$M^{0\nu} = (g_A)^2 M(\text{model}).$$

A factor ~ 10, depending on models and parameters

Experimental inputs are indispensable



34 H. Ejiri, J. Suhonen and K. Zuber / Physics Reports 797 (2019) 1–102

NME M = k$(g_A)^2$

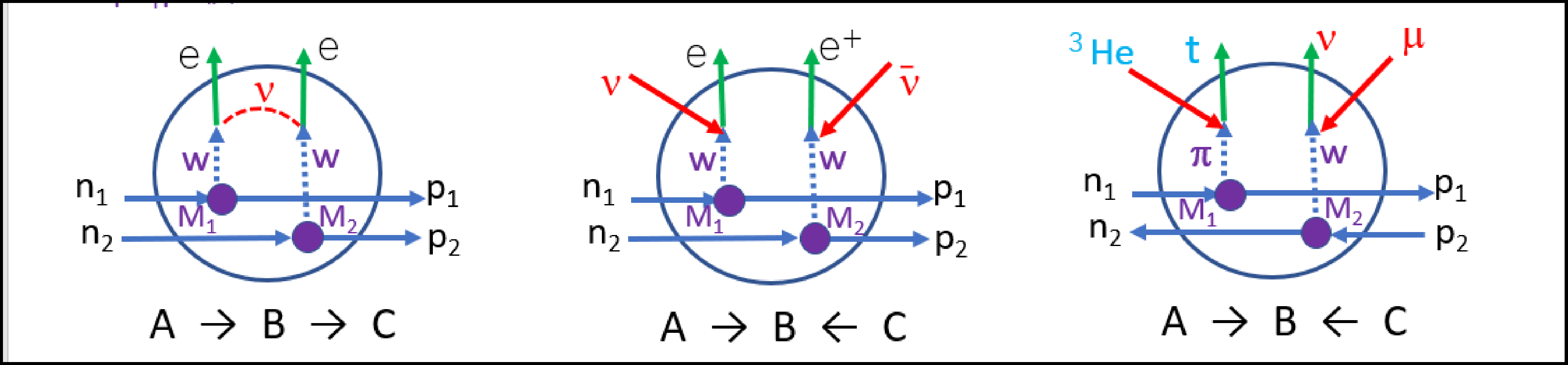
T= k$(g_A)^4$

N ton= k$(g_A)^8$

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

4. Experimental approaches to DBD NMEs



DBD M_1 and M_2 via neutrino potential by single β NMEs

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

(g_A^{eff}) for renormalization effects due to non-nucleonic and nuclear medium effects which are not in pnQRPA.

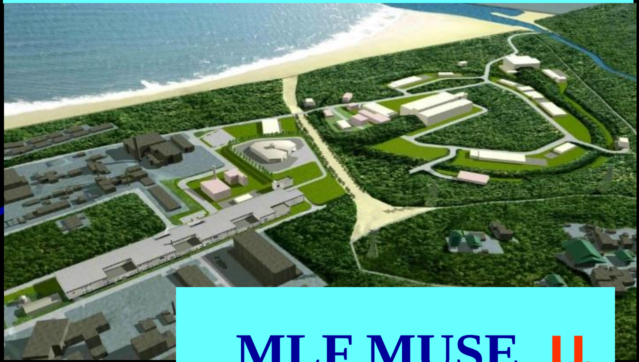
$(g_A^{\text{eff}})^{-} \sim (g_A^{\text{eff}})^{+}$ for β = (g_A^{eff}) for ββ

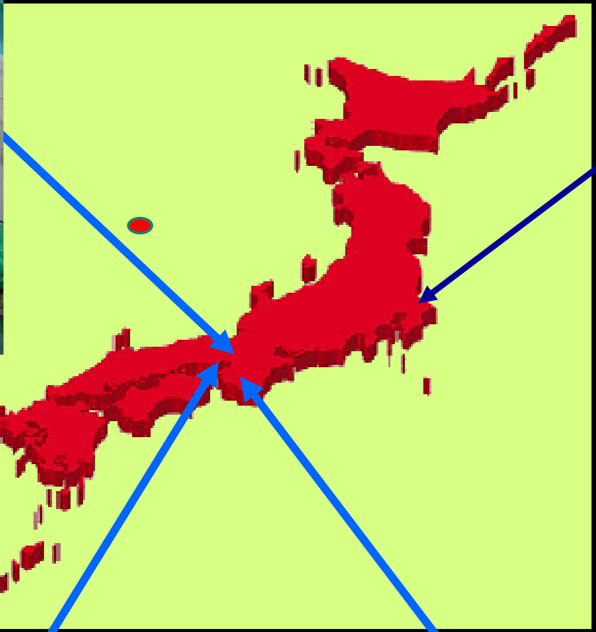
$M(\alpha, \beta\beta) = (g_A^{\text{eff}})^2\, M(\text{QRPA}\ \beta\beta)$

Response experiments by RCNP/Osaka

RCNP Osaka p,He,

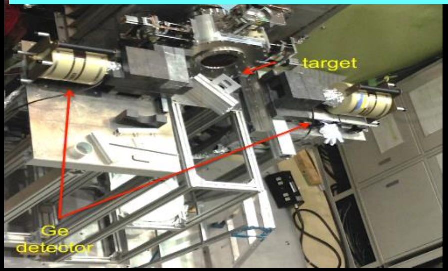
J-PARC 3-50 GeV p, ν, μ





MuSIC μ

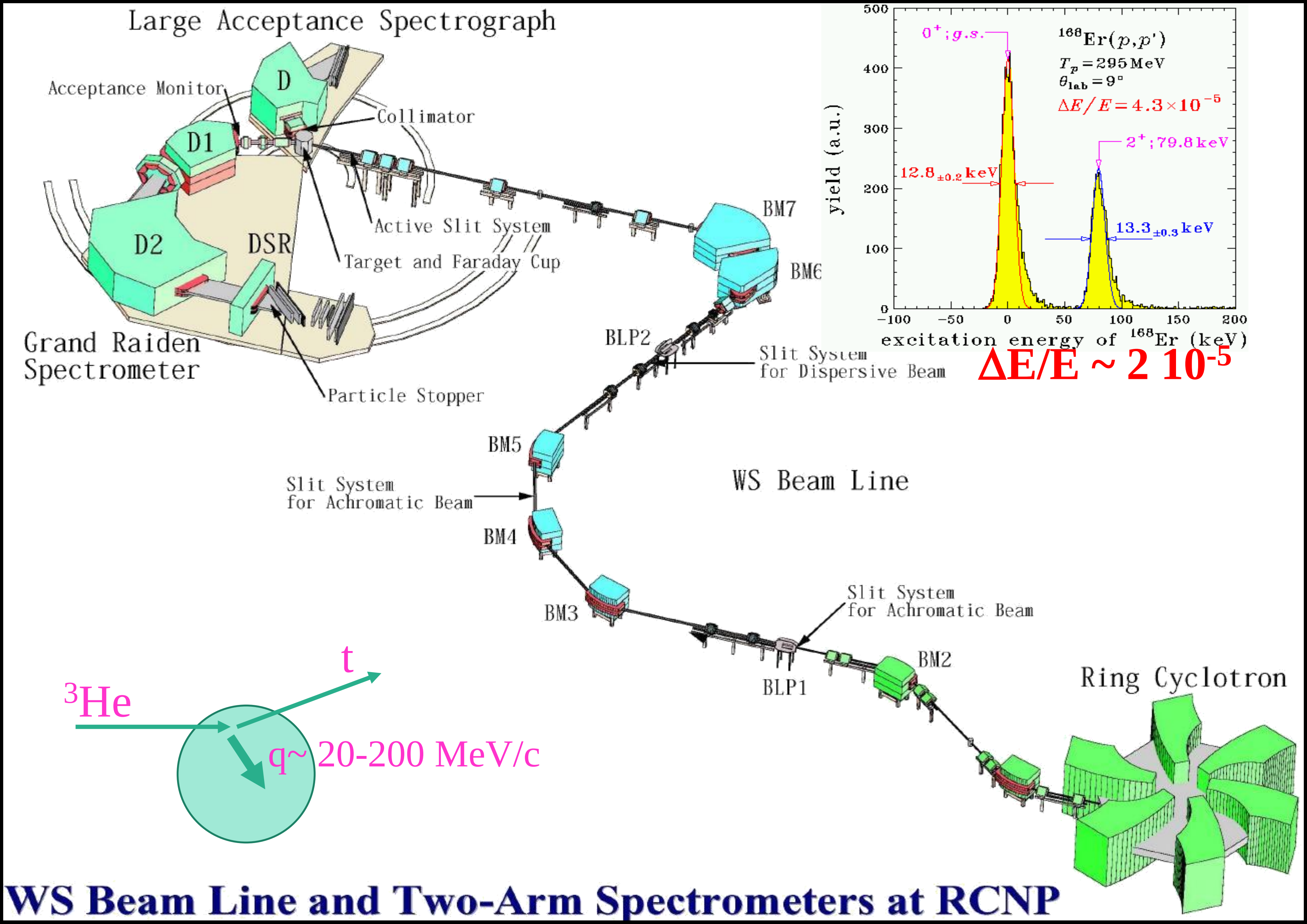
MLF MUSE μ



Spring-8 GeV- MeV pol. γ

Oto under gr. $\beta\beta$–ν,

High E resolution (^{3}He,t) CERs at RCNP Osaka



$\Delta E/E \sim 2\ 10^{-5}$

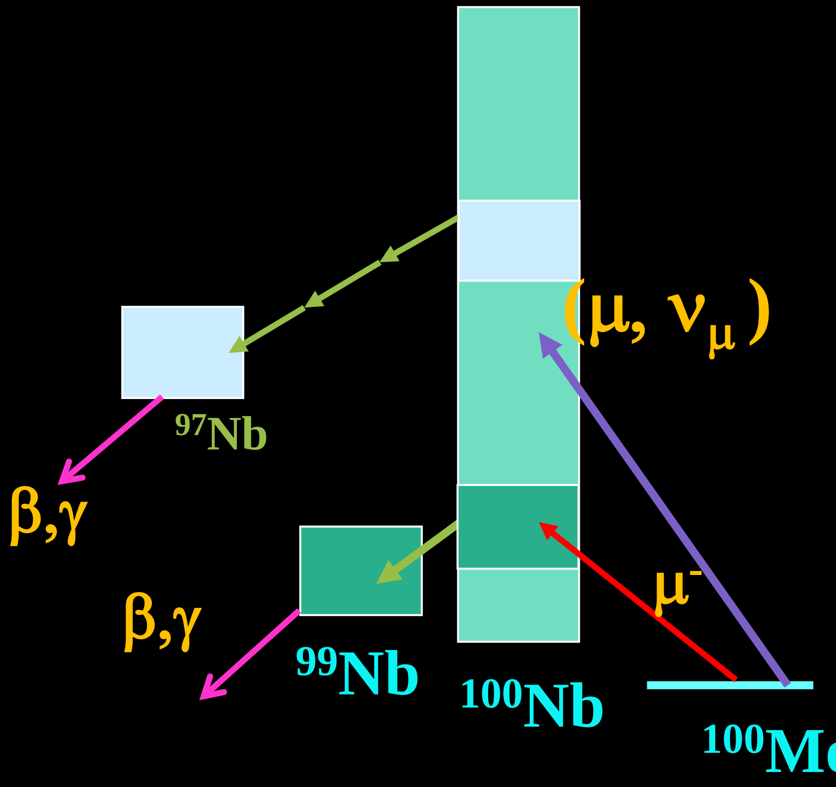
q~ 20-200 MeV/c

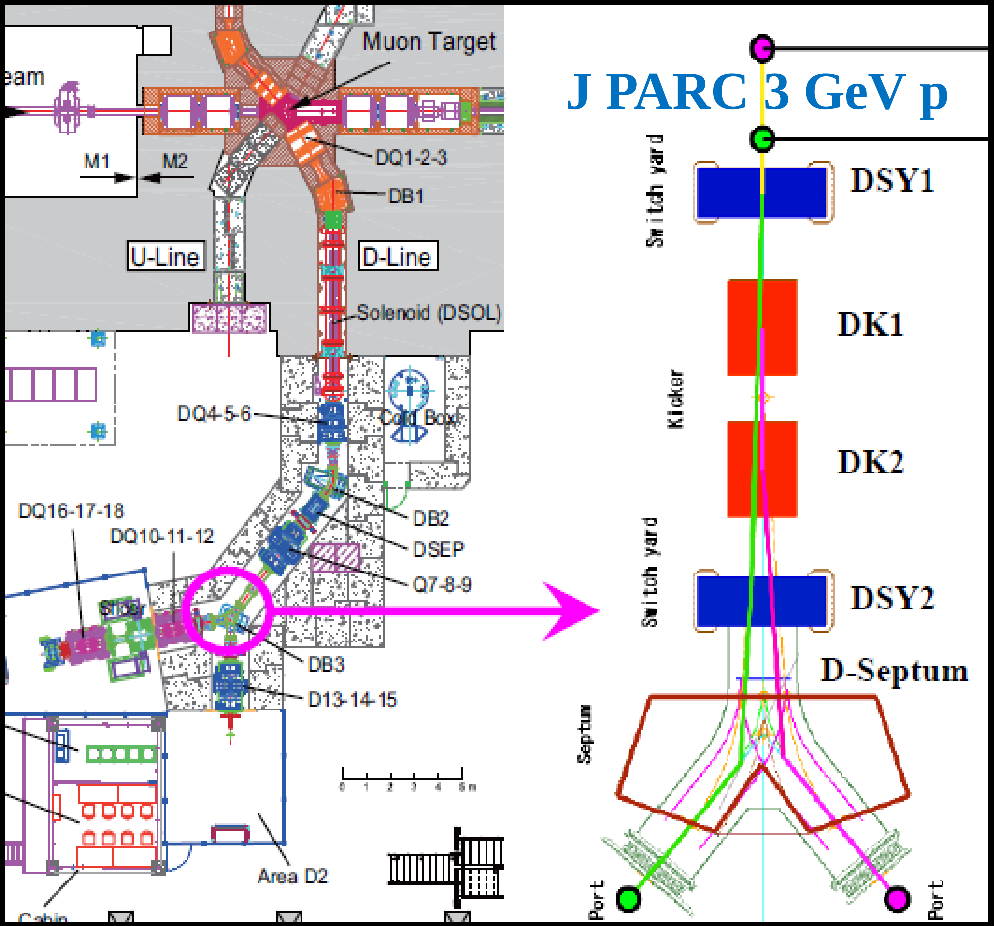
WS Beam Line and Two-Arm Spectrometers at RCNP

CER $(\mu,\nu_\mu, xn\ \gamma)\ \bar{\nu}\text{–}\beta^+$

E~ 5-30 MeV

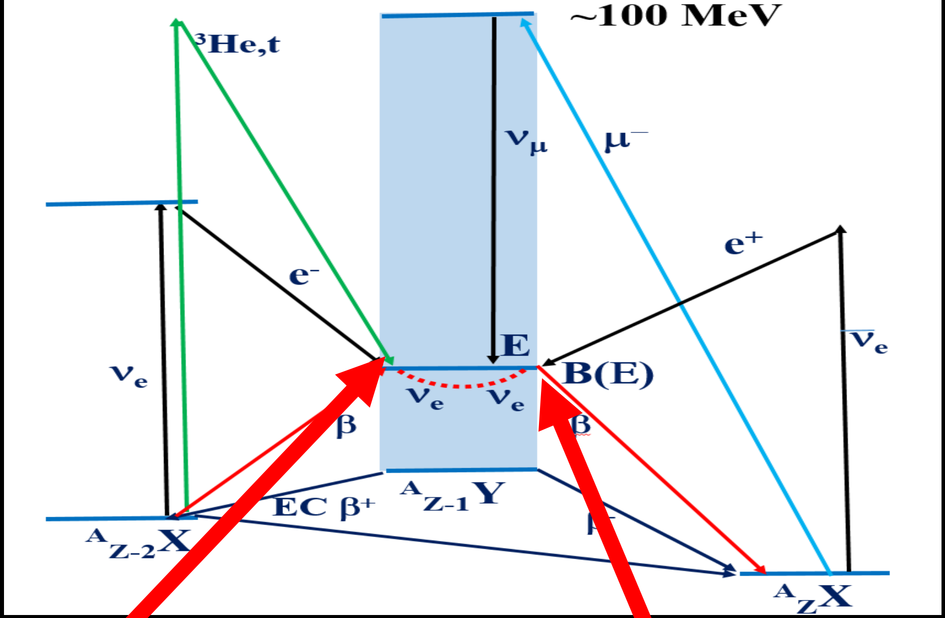
q~100~50 MeV/c 2^- 3^+





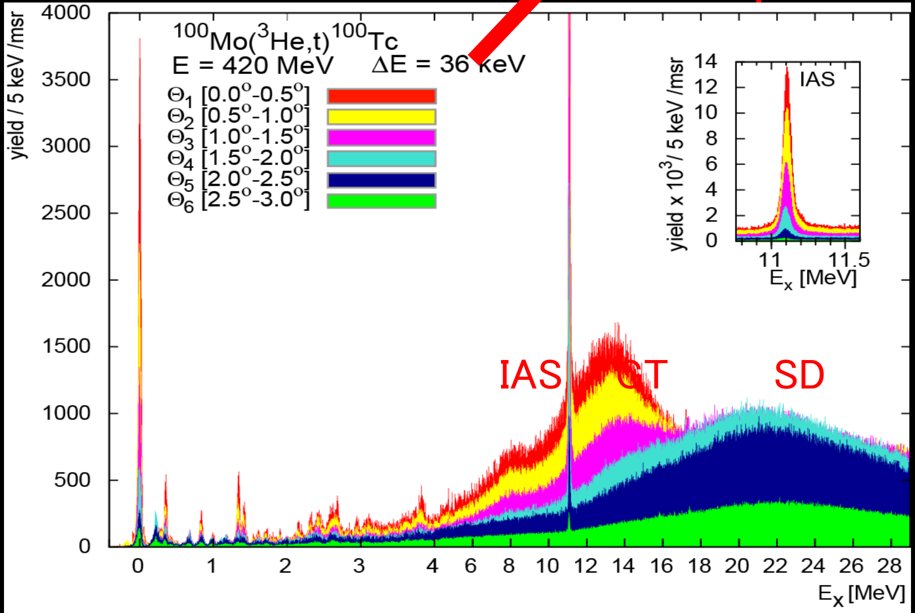
γ_i from $^{100\text{-}i}$Nb: relative strength Life time : the absolute strength

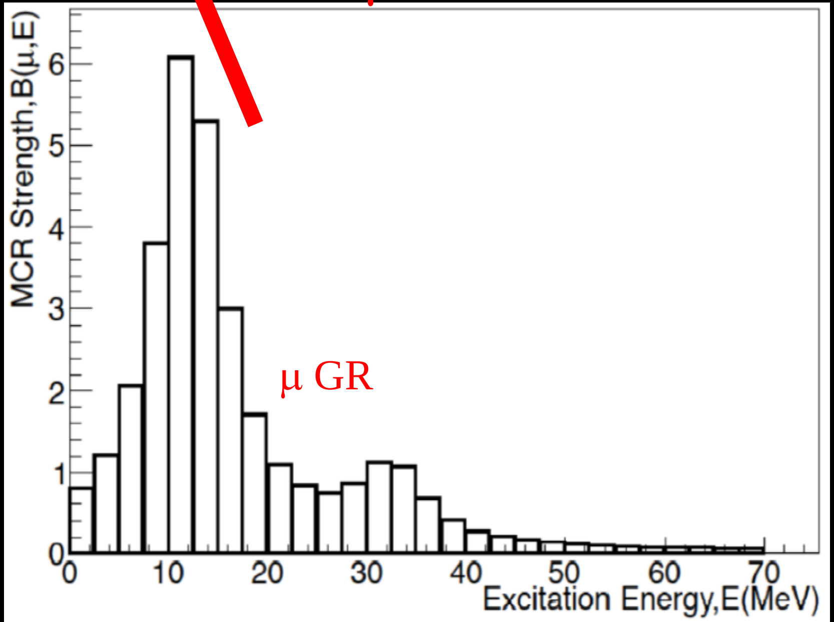
H. Ejiri Proc. e-γ conference Sendai 1972, H. Ejiri et al., JPSJ 2014
NNR19:I. Hashim , Hashim H. Ejiri et al., PRC 97 (2018) 014617



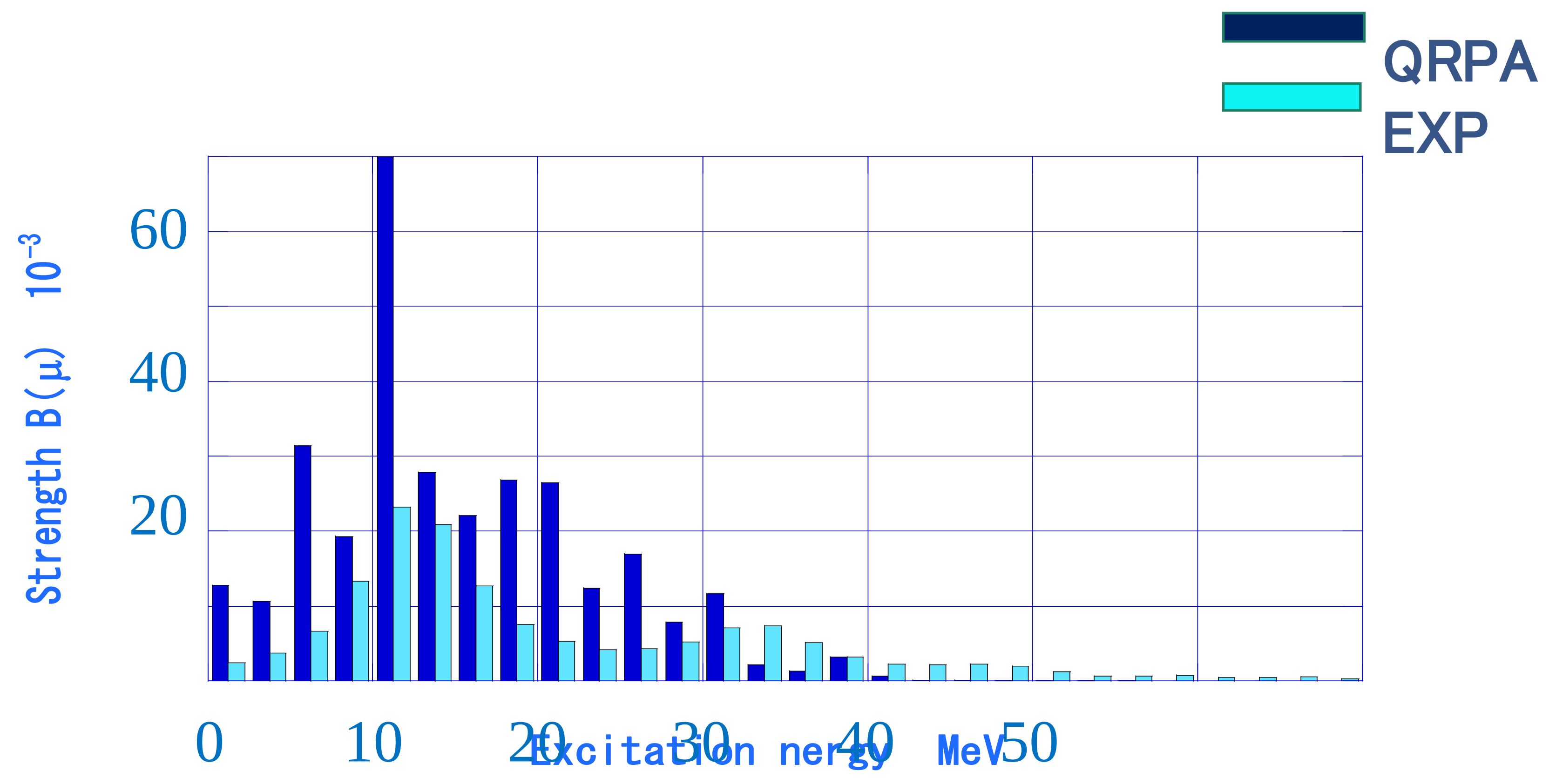
Nuclear π ρ

μ W





$B(\mu)= [g_A M_A + g_V M_V + g_p M_p]^2$



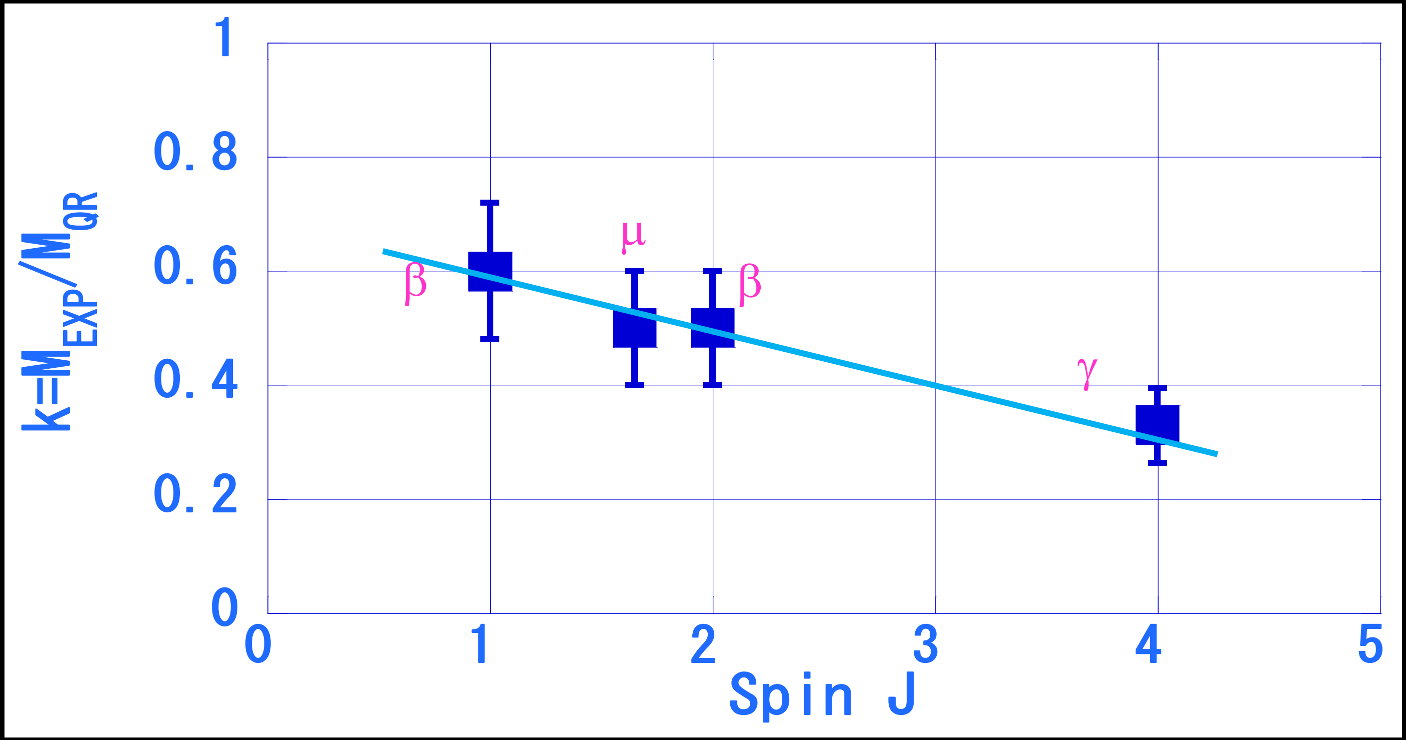
Jokiniemi L, Suhonen J, Ejiri H, Hashim I, PL B 2019 795 143.

$g^{eff}_A = 0.8$ $g_p = 7.3$ Pseudscalar

Exp/QRPA suggests $g^{eff}_A \sim 0.5$ $g^{eff}_A/g_A \sim 0.4$

Universal reductions of axial vector β & γ i

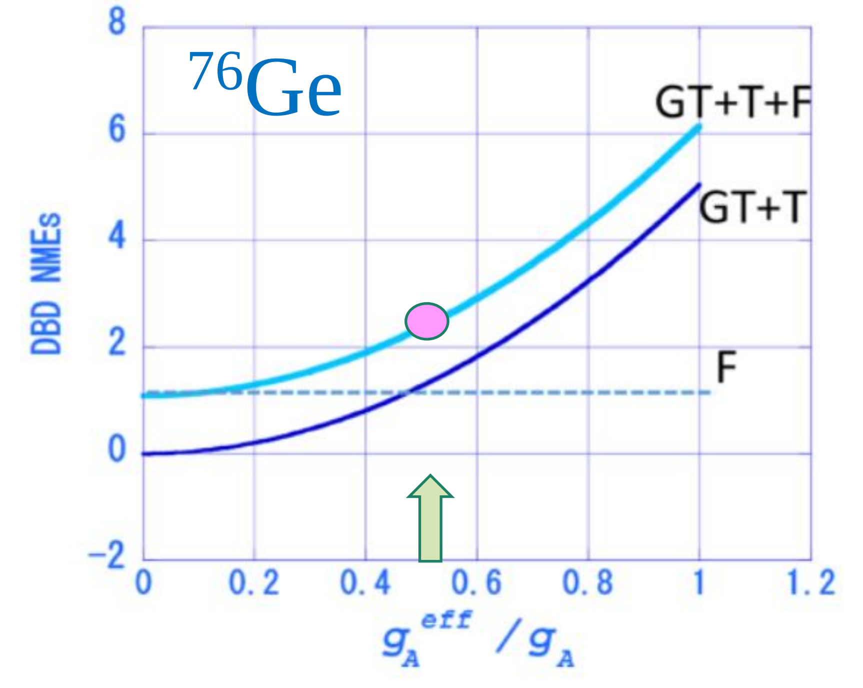
Ejiri Fujita PR 176 1968,
PR 34 85 1978

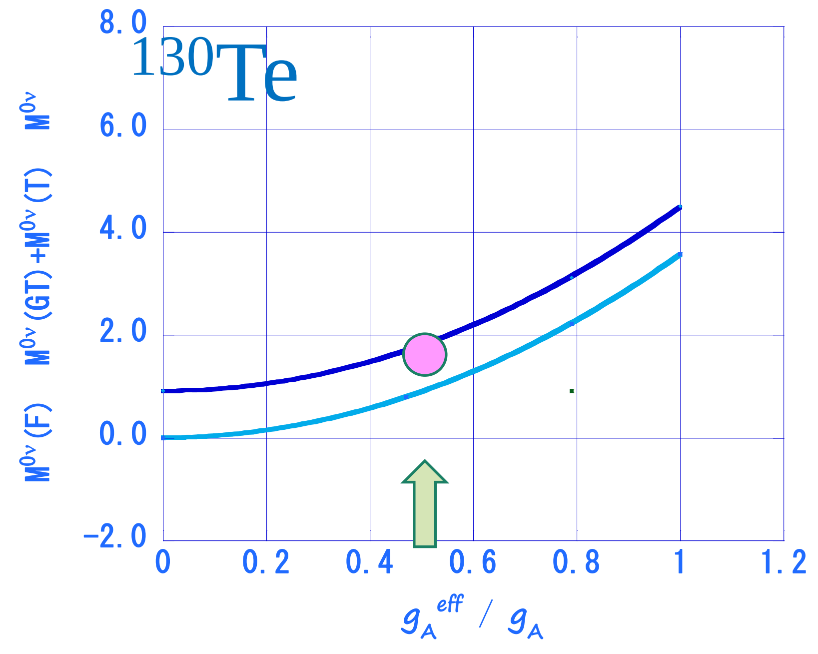


H, Ejiri J. Suhonen J. Phys. G. 42 2015
H. Ejiri N. Soucouti, J. Suhonen PL B 729 2014 .
L. Jokiniemi J. Suhonen H. Ejiri AHEP2016 ID8417598
L. Jokiniemi, J. Suhonen, H. Ejiri, I. Hashim PL B 794 143 2019

^{76}Ge ^{130}Te DBD NMEs with exp. $k=g_A^{eff}/g_A= 0.5$

$$M^{0v} = [\frac{g_A^{eff}}{g_A}]^2[M_M^{0v}(GT) + M_M^{0v}(T)] + [\frac{g_V}{g_A}]^2 M_M^{0v}(F),$$

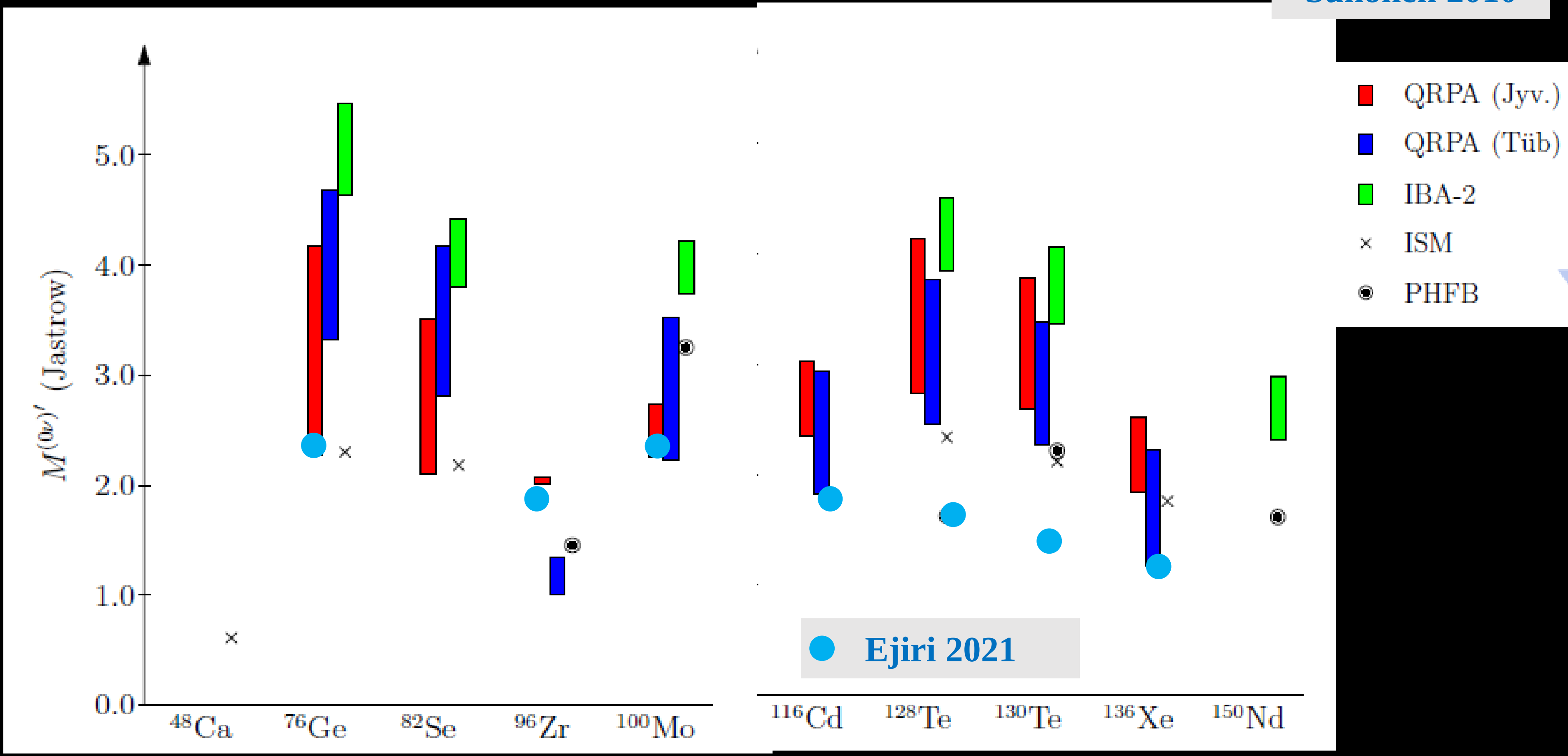




QRPA Jokinieni, Ejiri, Frekers, Suhonen Phys. Rev. C 98 2018 024608

NMEas are very sensitive to nuclear models and parameters

Suhonen 2010



● Exp. NMEs Present with $g_A^{eff}/g_A=0.5$

QRPA Jokinieni, Ejiri, Frekers, Suhonen Phys. Rev. C 98 2018 024608

5. Perspectives and Remarks

A: Possible DBD detector with IH mass 20 meV

ν-mass from 200 to 20 meV by 10^4 in (N/B)

1. Multi-ton enriched isotopes
2. BG 1ton year , E-resolution =0.1-2 %

m_0	M	BG/t y	N ton	Isotope A
40	2	0.1	3	Ge 76 Semiconductor
20	2	1	2	Se/82Mo 100 Bolometer
20	1	1	30	Xe 136 TPC/Scintillator

Coordinated collaboration works on
3 possible detectors are highly promoted.

B. Nuclear matrix elements

1. CER: nuclear (^{3}He,t) and leptonic (μ,ν_μ) provide single-β NMEs with J= 0-2, p=5-100 MeV/c, associated with DBD NMEs.

2. NMEs (EXP)/NME(QRPA)= quenching /renormalization

   $k_{NM}=g_A^{eff}/g_A\sim0.5$ for GT, SD, μ 30-80 MeV/c

3. Using the experimental g_A^{eff}/g_A and QRPA, DBD NMES ~2

4. Extensive experimental works on (^{3}He,t), (d,^{2}He) and μ-CERs to study $k=g^{eff}_A$ multipole and nuclear dependences.

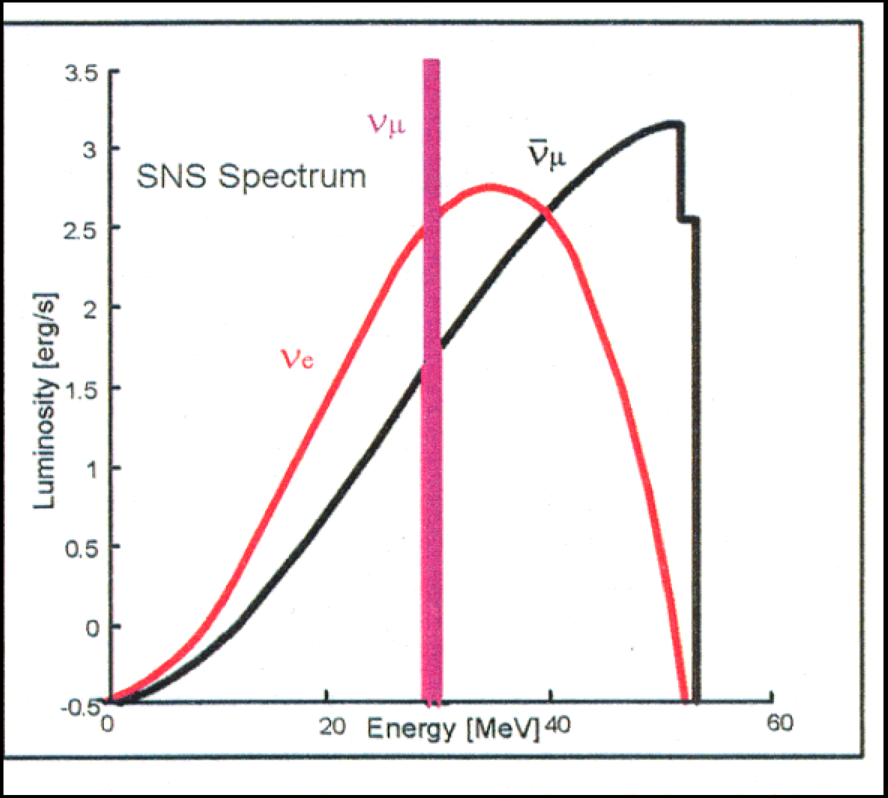
5. Extensive theoretical works on Δ & non-nucleonic effects and nuclear medium effects.

C: New experimental ways for NMES

1 Neutrino beam experiments

$p+A=n\pi^+ \quad \pi^+ \rightarrow \mu^+ + \nu_\mu \qquad \mu^+ \rightarrow e^+ + \nu_e + \overline{\nu}_\mu$

Source	E GeV	Np	Nν /s
SNS	1	$6\ 10^{15}$	$1\ 10^{15}$
J−PARC	3	$1.2\ 10^{15}$	$5\ 10^{14}$

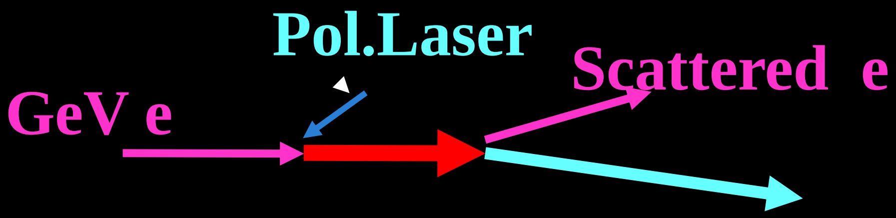


H. Ejiri NIM. 503 (2003) 276 – 278.

2. Photon LEPS

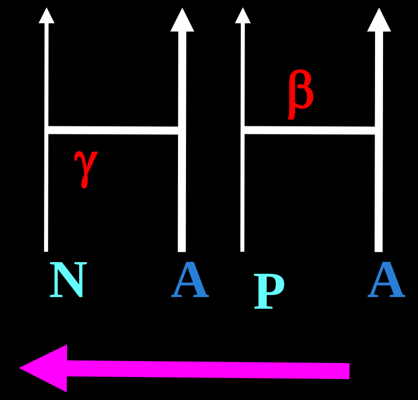
Laser electron photon Sources

H. Ejiri PRL 21 1968, PR 38 '78

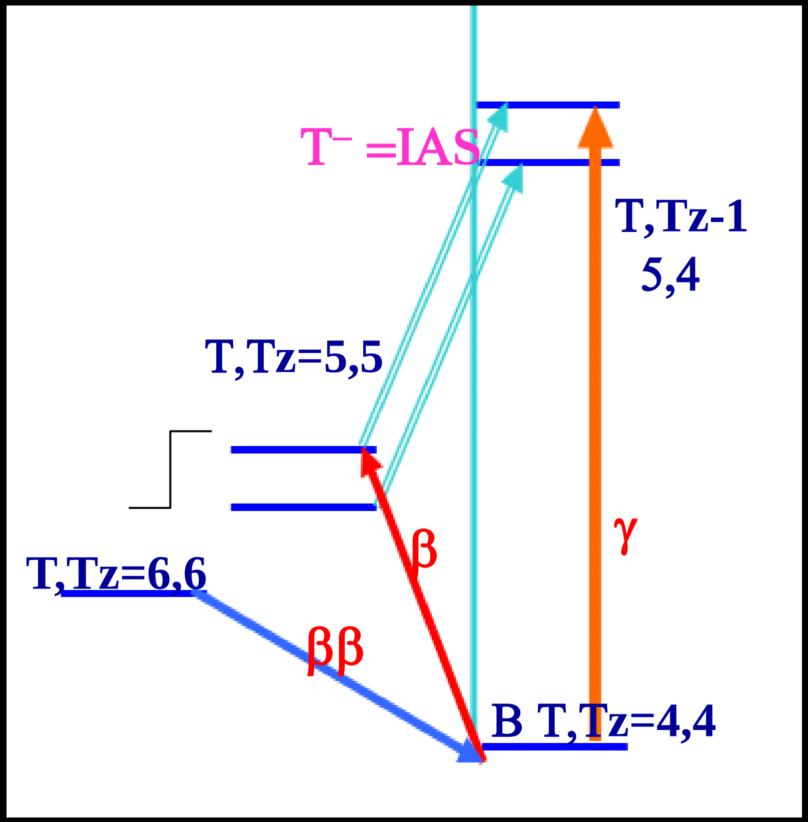


Pol. Laser electron photon

$E_\gamma \sim 4\,\gamma^2\, E_l = \; 2\; 10^8\, E_l \sim 20$ MeV,



T^- isospin rotation



β+ responses via IAS

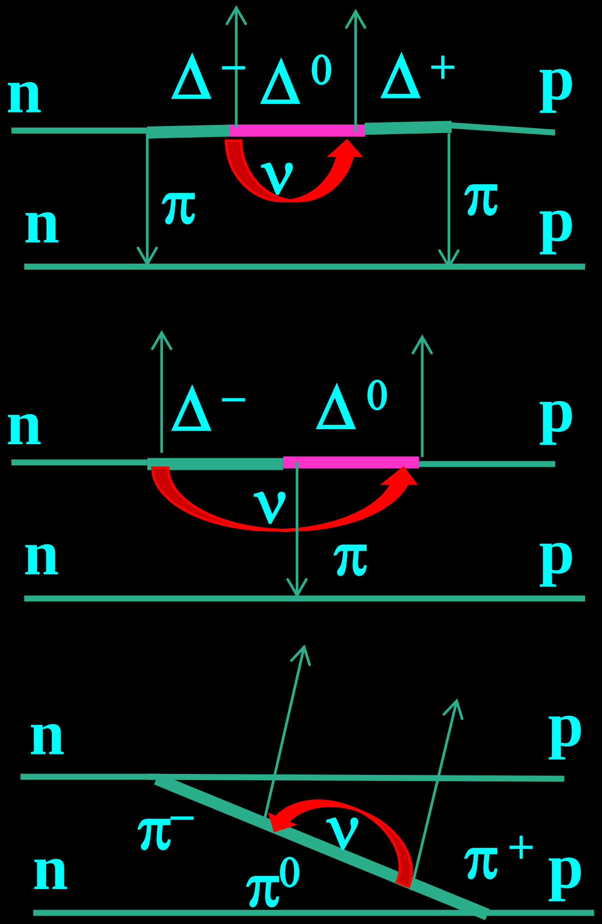
$\langle f \mid g\, M_\beta \mid i \rangle = g/e\, (2T)^{1/2} \langle f \mid em_\gamma \mid IAS \rangle$

Thanks for your attension

Hadronic (Δ, π) *

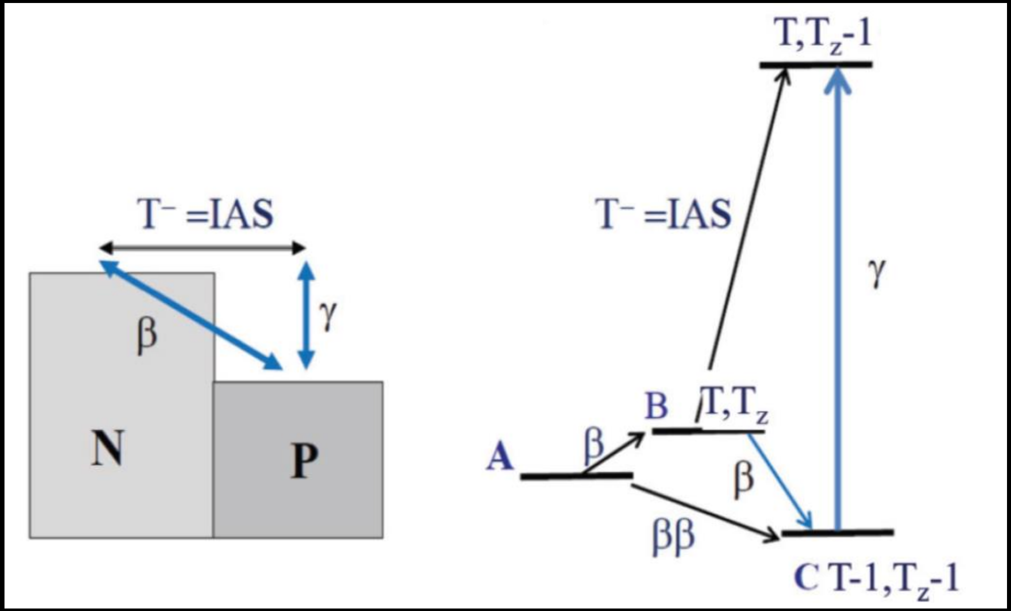
Effect on low ββ 0^+ - 0^+

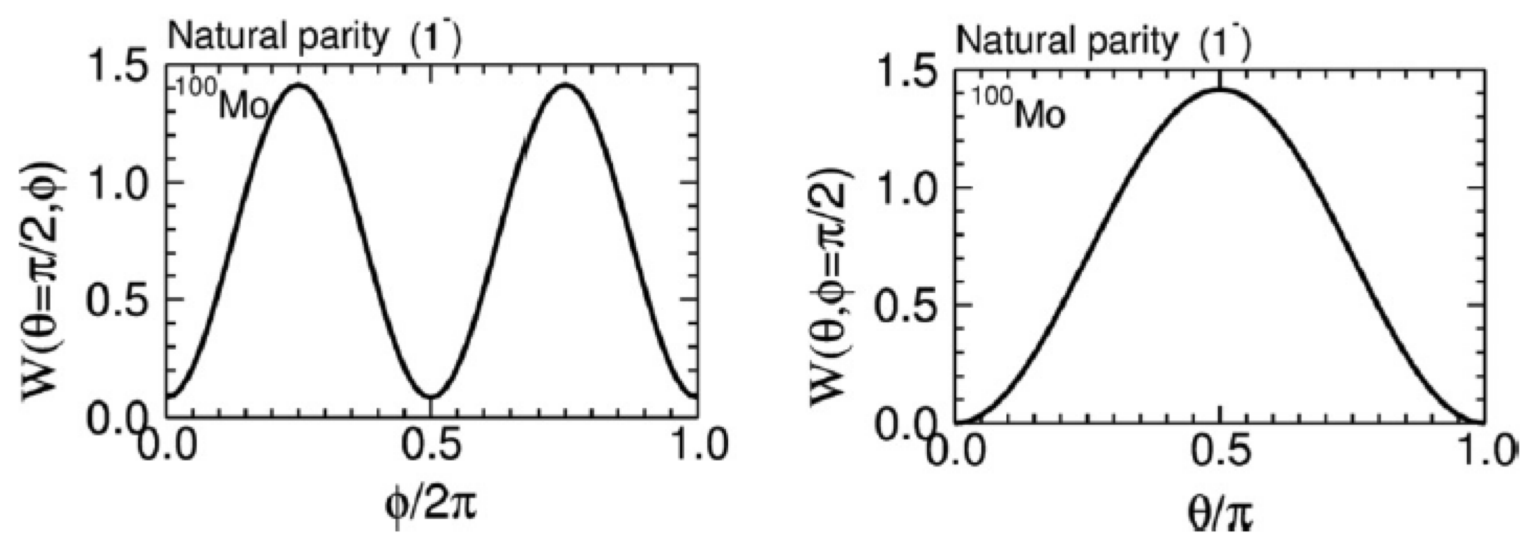
$P(\Delta)^2 \sim (10^{-2})^2 \sim 10^{-4}$



*Pontecorvo; Haxton, Stephenson, Kotani Doi .

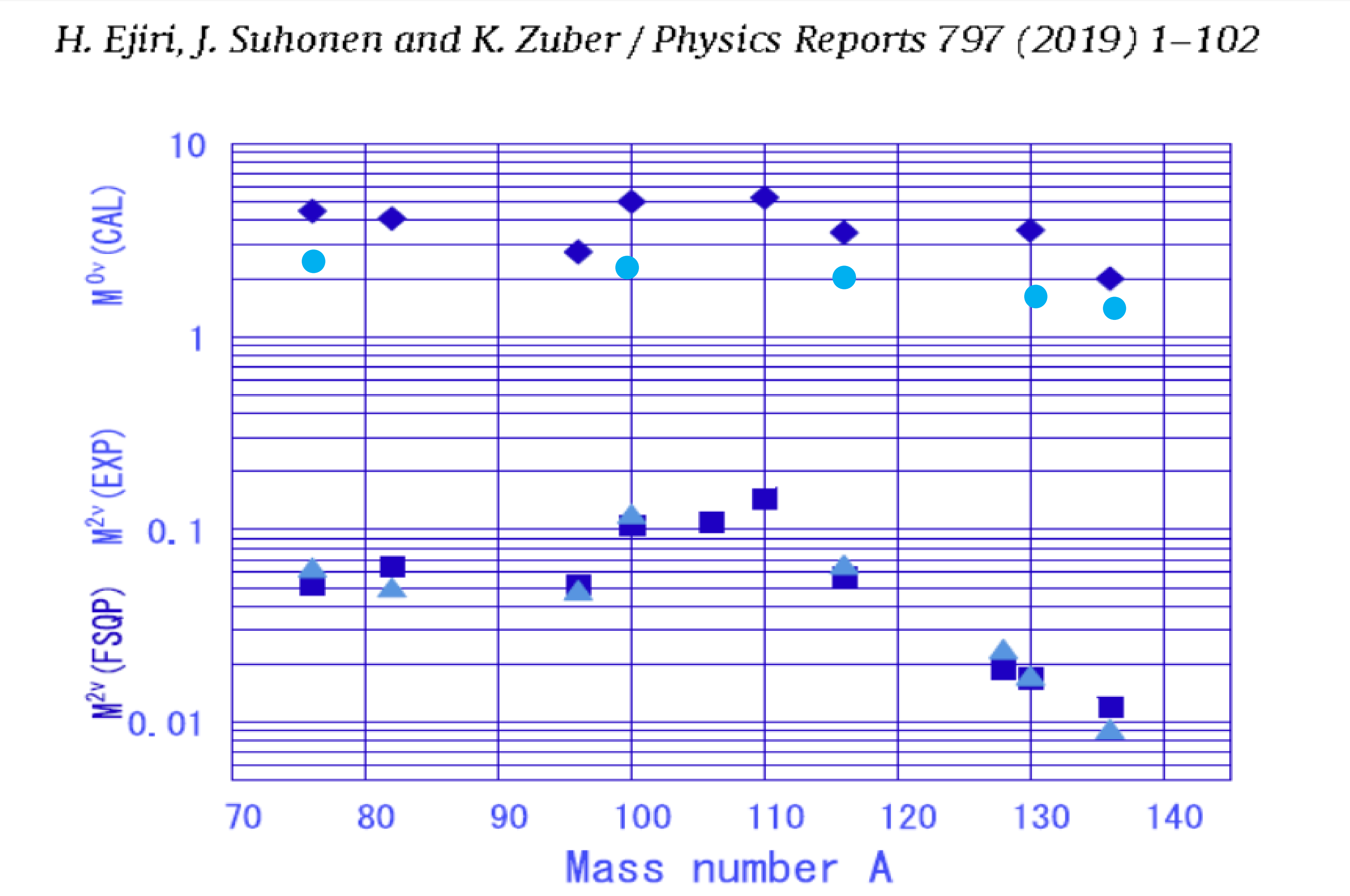
Isovector component by IAS isospin T from Ground state with T-1





Ejiri H, et al. Phys. Rev. Lett. 2119 1968 373
Ejiri H, Titov. A, et al., Phys. Rev, C 88 2013 054610

Nuclear structures on 2ν and 0νββ NMEs



H. Ejiri, J. Suhonen and K. Zuber / Physics Reports 797 (2019) 1–102

2νββ NMEs triangle exp, tsquare FSQP(Ejiri) J. Phys. 2017

Single nucleon in a nucleus is 0.5 probability, NMS ~ 0.7

1. Nucleon knock-out (e,e’p) Lipikas PR C 86 2012 047304
2. Nucleon transfer reactions