Experimental approaches to nuclear matrix elements and the quenching for double beta decays.

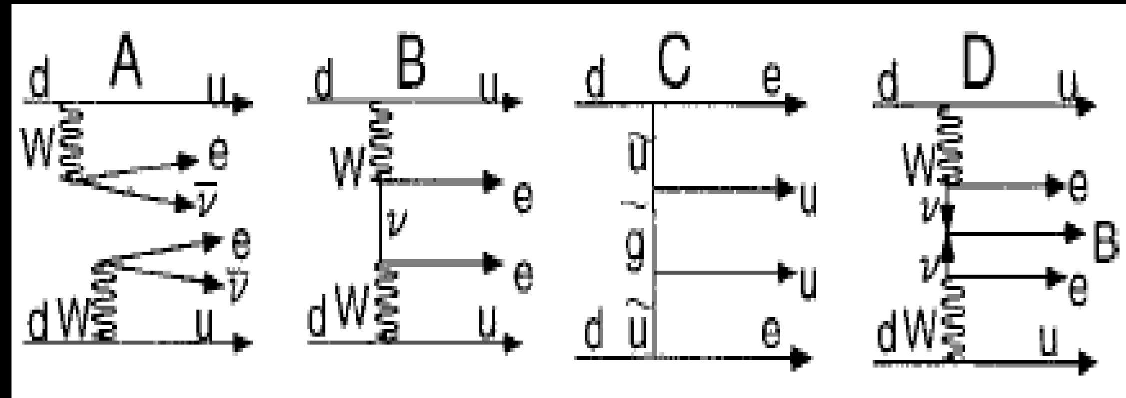
Hiro Ejiri
RCNP Osaka
2020-10-23

Double beta decay (DBD) nuclear matrix element (NME) is crucial. Accurate theories for $g_A M^{0\nu}$ are hard . Experimental approaches !!

1. DBD and neutrinos beyond the standard model.
2. DBD NME for neutrino mass studies.
3. Experimental approaches to DBD NMEs
4. DBD NME, quenching, and remarks

1. Ejiri H 2019 Frontiers in Physics 10.3389/fphys. 00030
2. Ejiri H, 2019 J. Phys. G. Nucl. Part. Phys. 46 125202
3. Ejiri H , CER collaboration . 2020 J. Phys. 47 LT 01.
4. Ejiri H, Suhonen J and Zuber Z 2019 Phys. Rep. 797 1

A. 2νββ
B. 0νββ,
C. SUSY
D. Majoron



0νββ

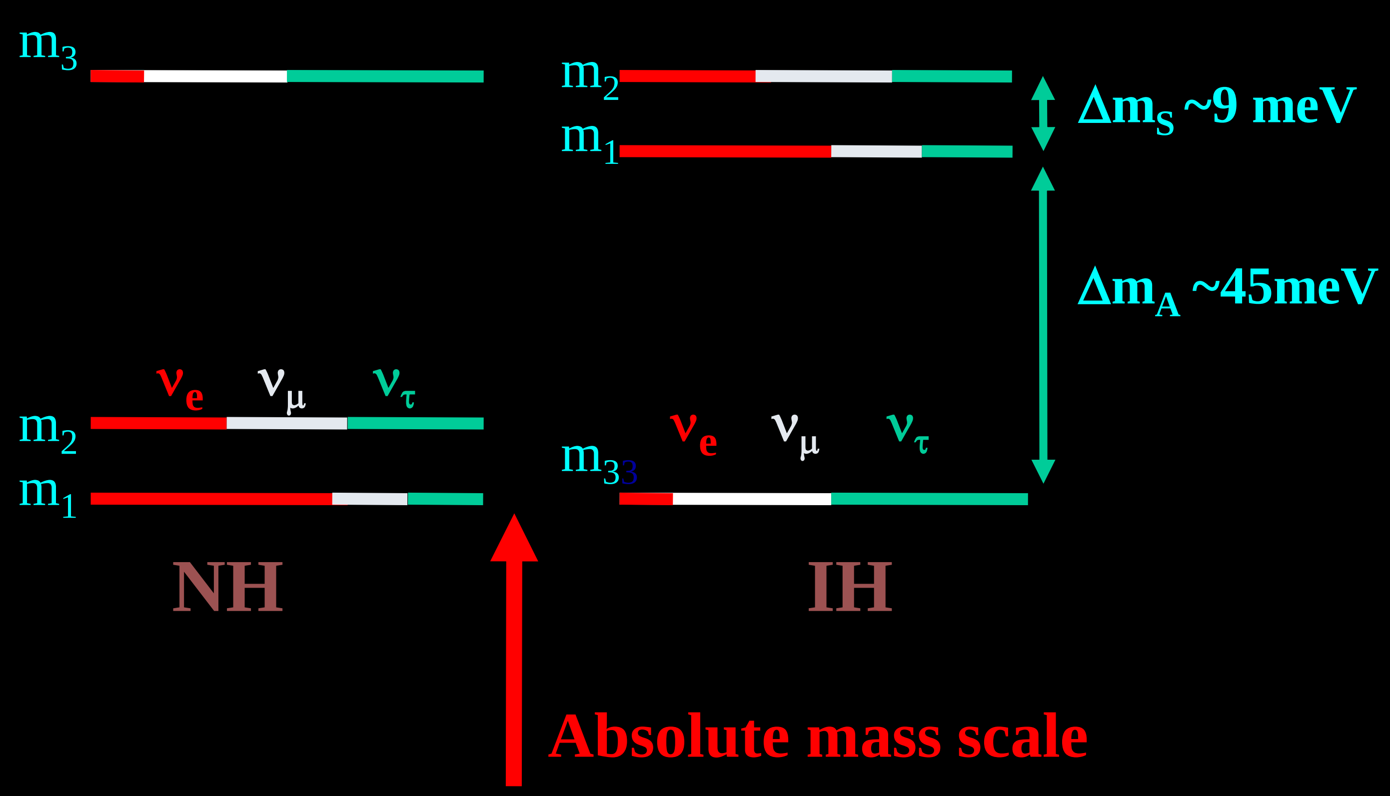
1. **Light (2-20 meV) Majorana ν exchange**
2. **Right-handed current**
3. **Susy exchange**
4. **Majoron emission**

Kinematics Energy and angular correlation to select 2νββ, 0νββ, LHC/RHC, Majoron.

NME Nucleus dependence to select light ν, heavy ν, SUSY and others.

ν–mass spectrum

n



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

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

Mass hierarchy

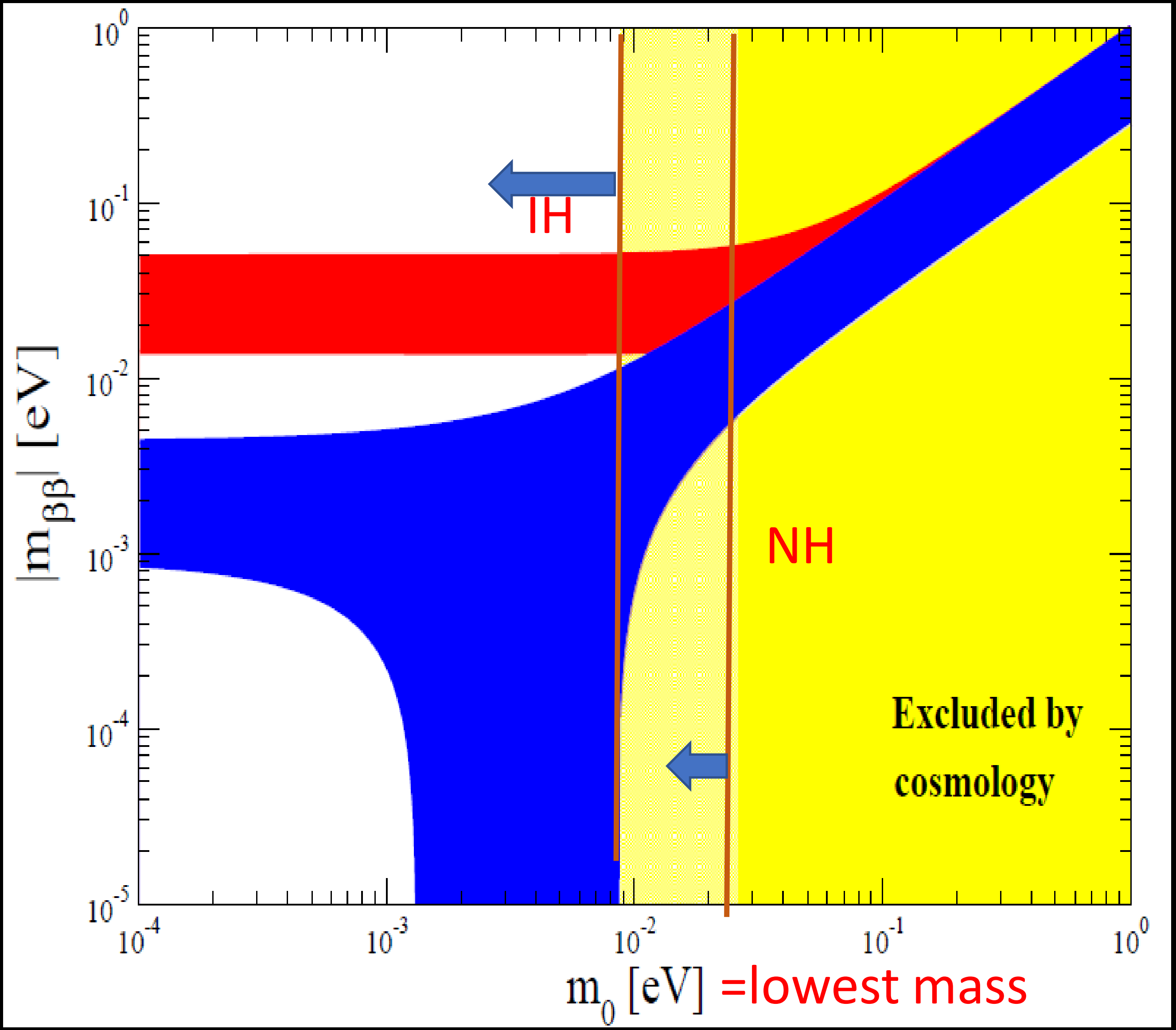
If m^{eff} is

<15 meV IH

< 12 meV NH

➢

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

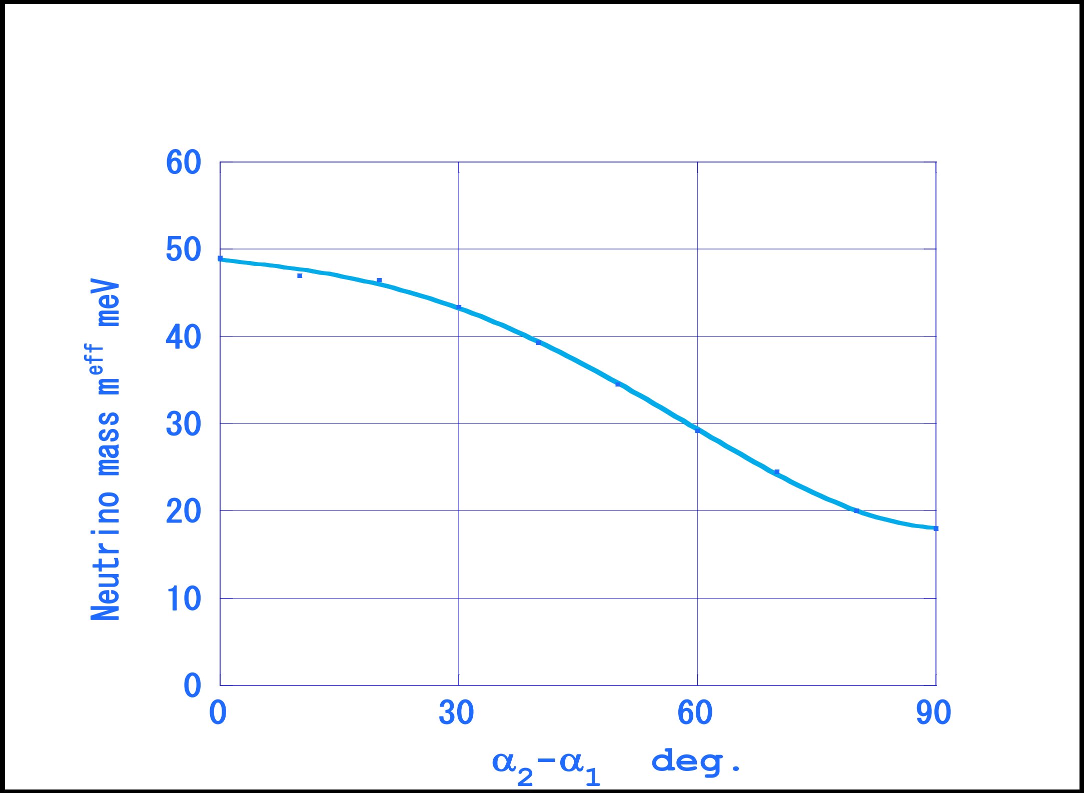


J. Vergados, H. Ejiri, F. Simkovic, Rep. Prog. Phys. 75 (2012) 106301.

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

IH mass $m_3 << m_1 < m_2$

$\langle m \rangle \sim m(A)\,(1-\sin^2 2\theta_{12} \sin^2\alpha_{12})^{1/2}$



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

2. DBD NMES for neutrino studies in nuclei

Why Nuclear Matrix Element M

A. $T^{0\nu} = kMm_{\nu}^{eff}$ Extract m_{ν}, phase, mass hierarchy

B. ν- mass –sensitivity (m to be measured)

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

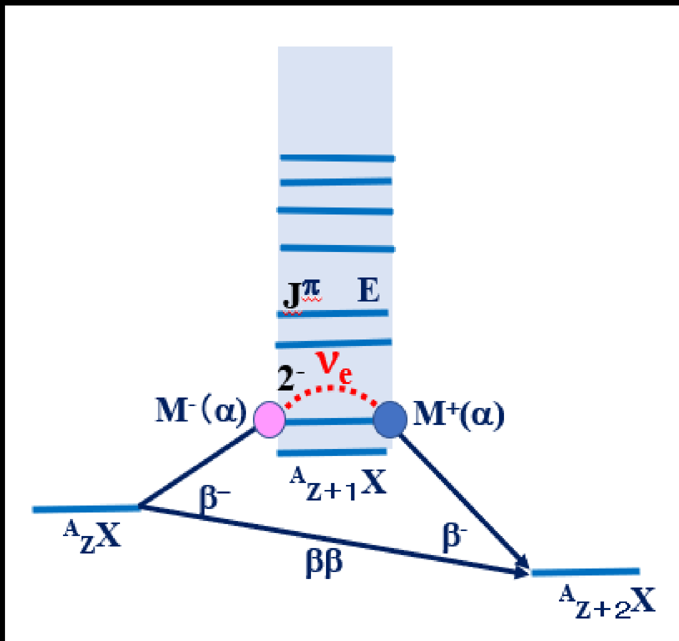
- M = NME, B=BG/ty N=Isotope mass ton
- Factor 0.7, 30% in M is equivalent to
- factors 10 less in BG or 10 more in N tons

. Theoretical M: factor 10 uncertainty

- Experimental data to help theory evaluate M

DBD 0νββ NME

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



Quenching due to effects not in model

Model NMEs

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

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

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

$H(r_{12}) \sim 1/r_{12}$ 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

Problems of DBD NME

A. $T^{o\nu}=k\,|M^{0\nu}\,m_\nu|^2$ $M^{0\nu}$ is NOT experimentally obtained unless $T^{o\nu}$ and m_ν are measured .

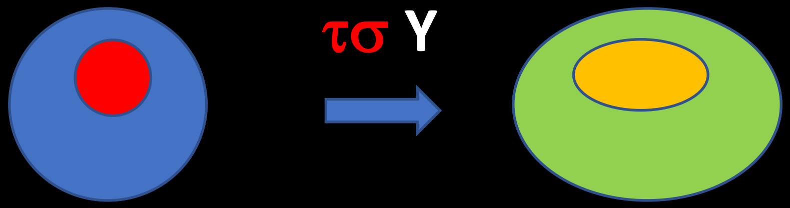
B. Thus we rely on theoretical model , but a typical DBD nucleus is a many-body strongly interactions system of more than 300 hadrons (nucleons, mesons, isobars)

C. Real NME M (Nuclei) $\neq$ model NME M(nucleons)

$M(N)=\langle F|T|I\rangle$ F, I. Nuclei : nucleon hadron complex

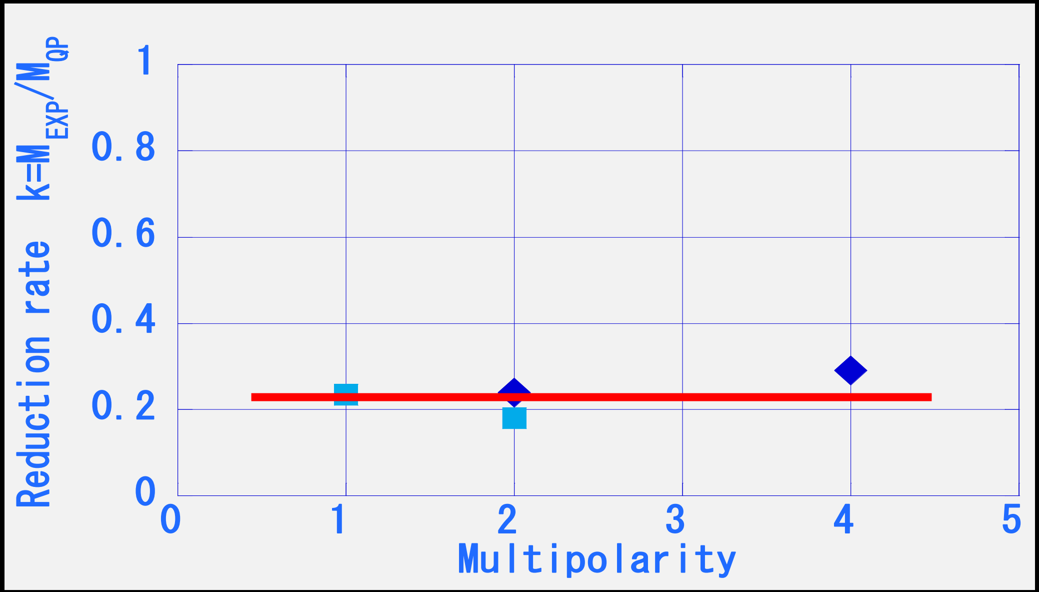
$M(n) = \langle f|T|i\rangle$ f, I, nucleons in a nuclear model

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



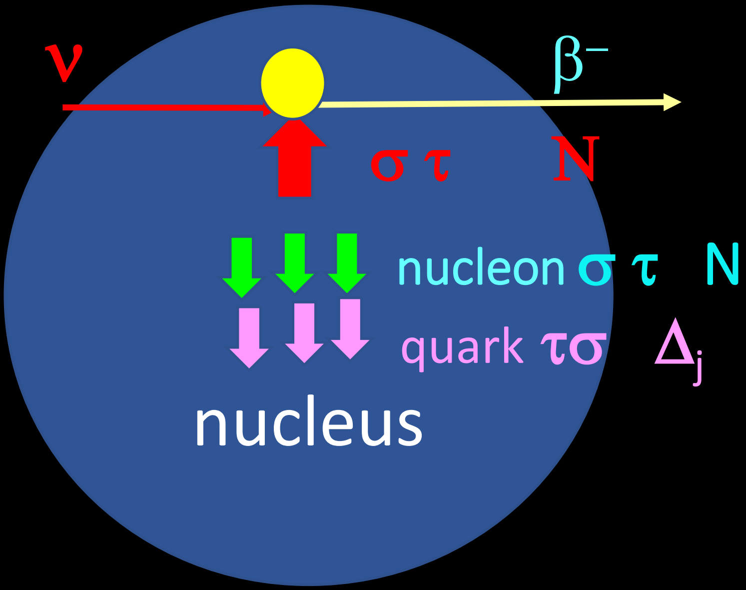
Dress / core change from i- to f

k=k(τσ) k(NM)~0.25 with respect to QP (Quasi-particle)



E. Spin isospin correlations/polarizations
Nucleonic $\tau\sigma$ $N^{-1}N$ GR , non-nucleonic $N^{-1}\Delta$ GR

Nuclear medium
$\tau\sigma$ polarization



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

$M^{\beta} \sim k^{eff} M_0$

k^{eff} $(\tau\sigma) \sim 1/(1+\chi_{\tau\sigma}) = 0.5$

$\chi_{\tau\sigma}$: susceptibility ~ 1

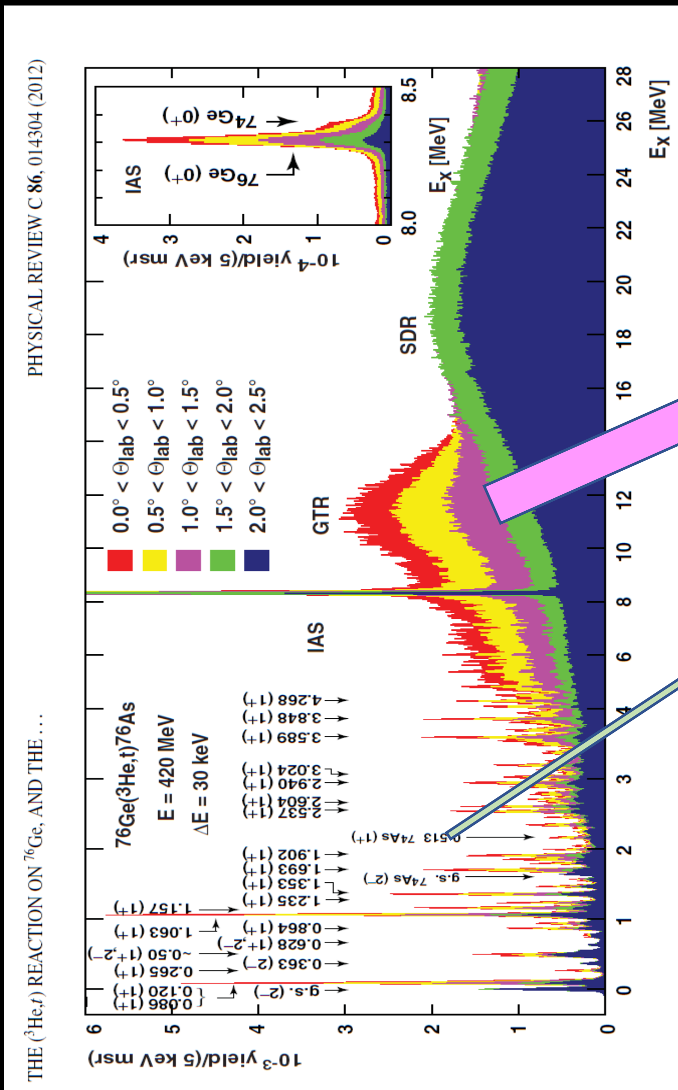
due to nuclear and isobar polarizations

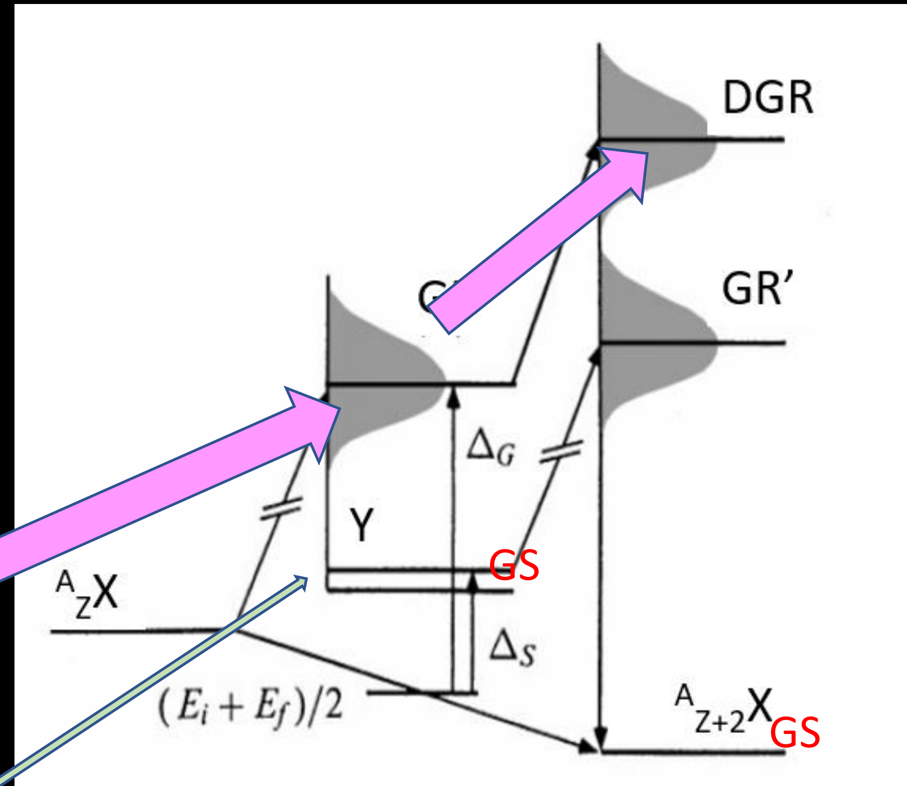
H. Ejiri PRC 26 '82 2628

Nuclear core change ,

Bohr Mottelson
PL B 10 '81 10 Isobar

F. Very small strength





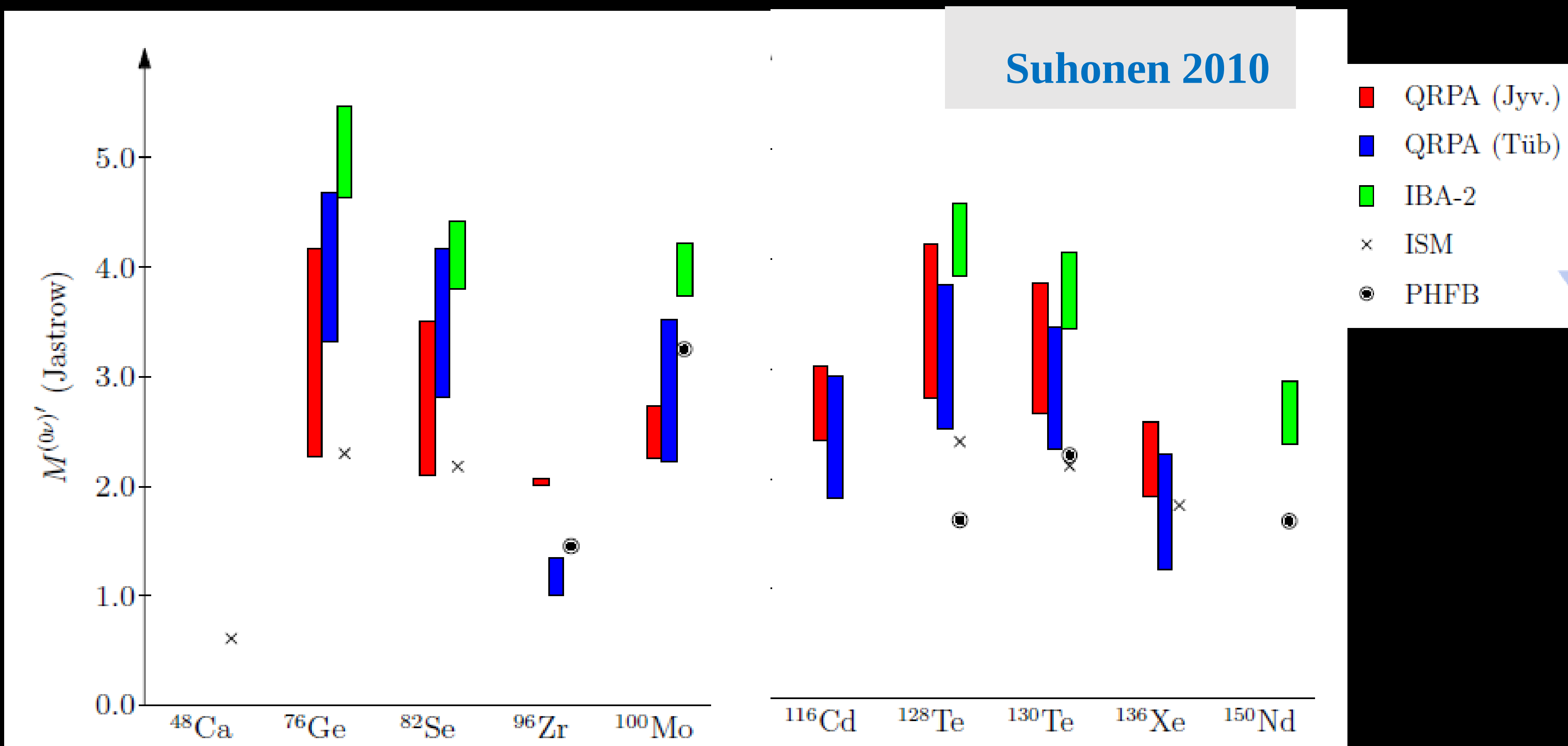
Single β M(GS) = 1 10^{-2} Sum

2DBD b M(GS) = 4 10^{-4} Sum

Closure approximation <i|T|GS>

GS should pick up 10^{-4} strength

NMEs are very sensitive to nuclear models and parameters



NME $M = k(g_A)^2$

$T = k(g_A)^4$

N ton= $k(g_A)^8$

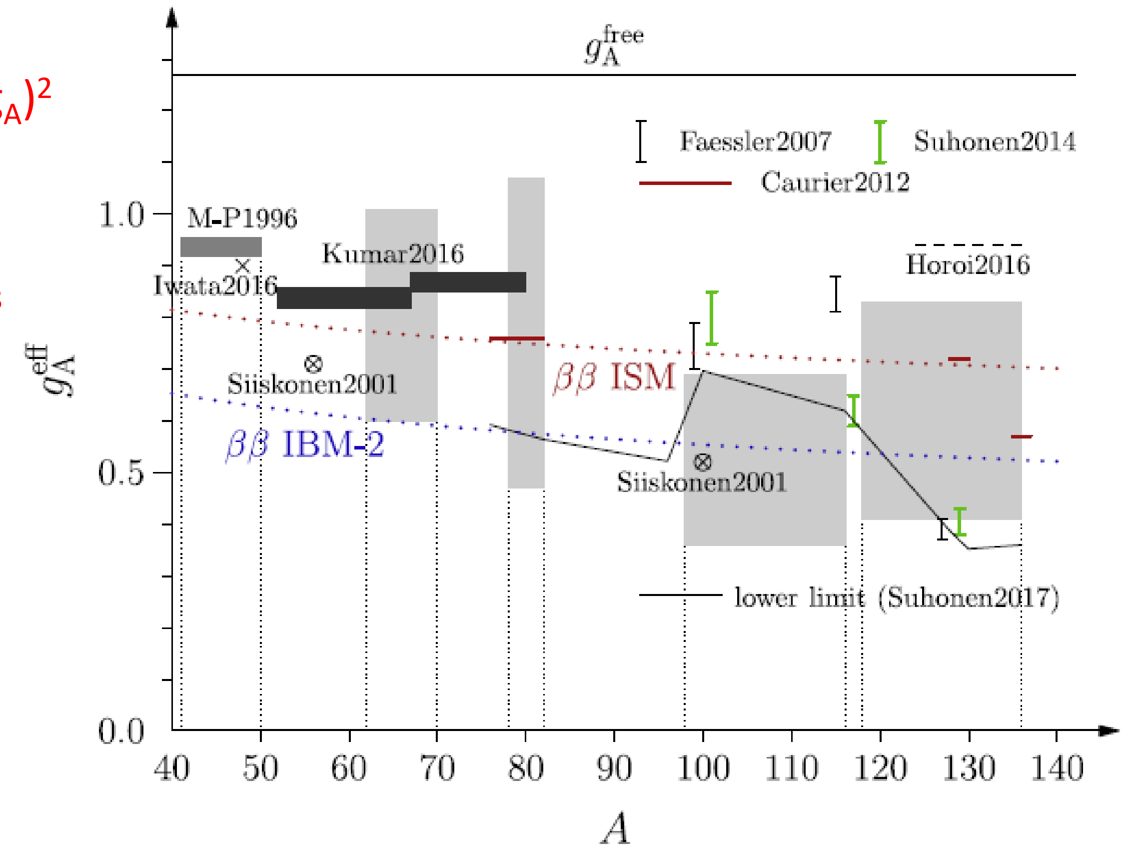
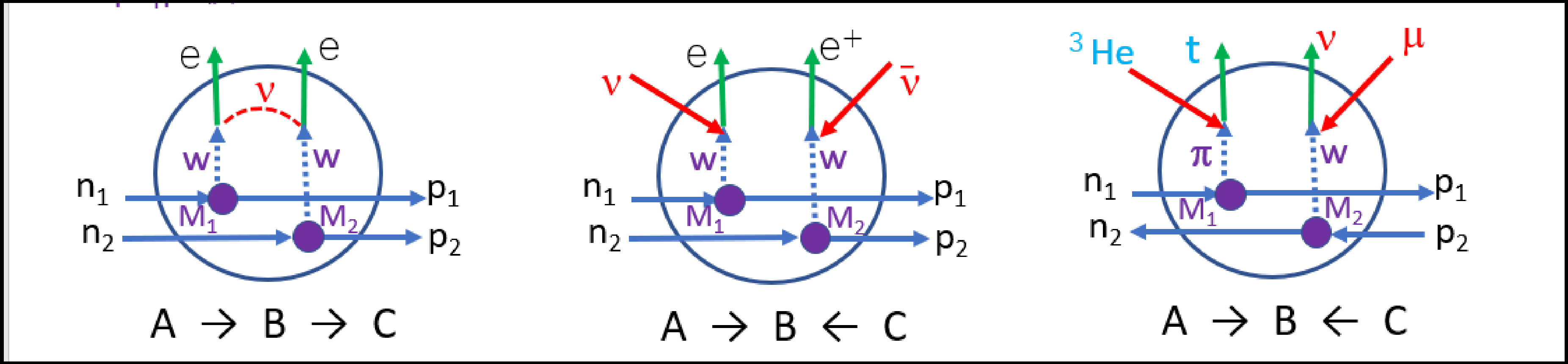


Fig. 29. Effective values of g_A in different theoretical β and $2\nu\beta\beta$ analyses for the nuclear mass range $A = 41 - 136$. The quoted references are *Suhonen2017* [216], *Caurier2012* [233], *Faessler2007* [242], *Suhonen2014* [243] and *Horoi2016* [235]. These studies are contrasted with the 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**

3. Experimental studies for ν nuclear responses for low and medium momentum transfers

Double β decay, single β&ν and CERs



DBD M_1 and M_2 via neutrino potential by single β NMEs

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

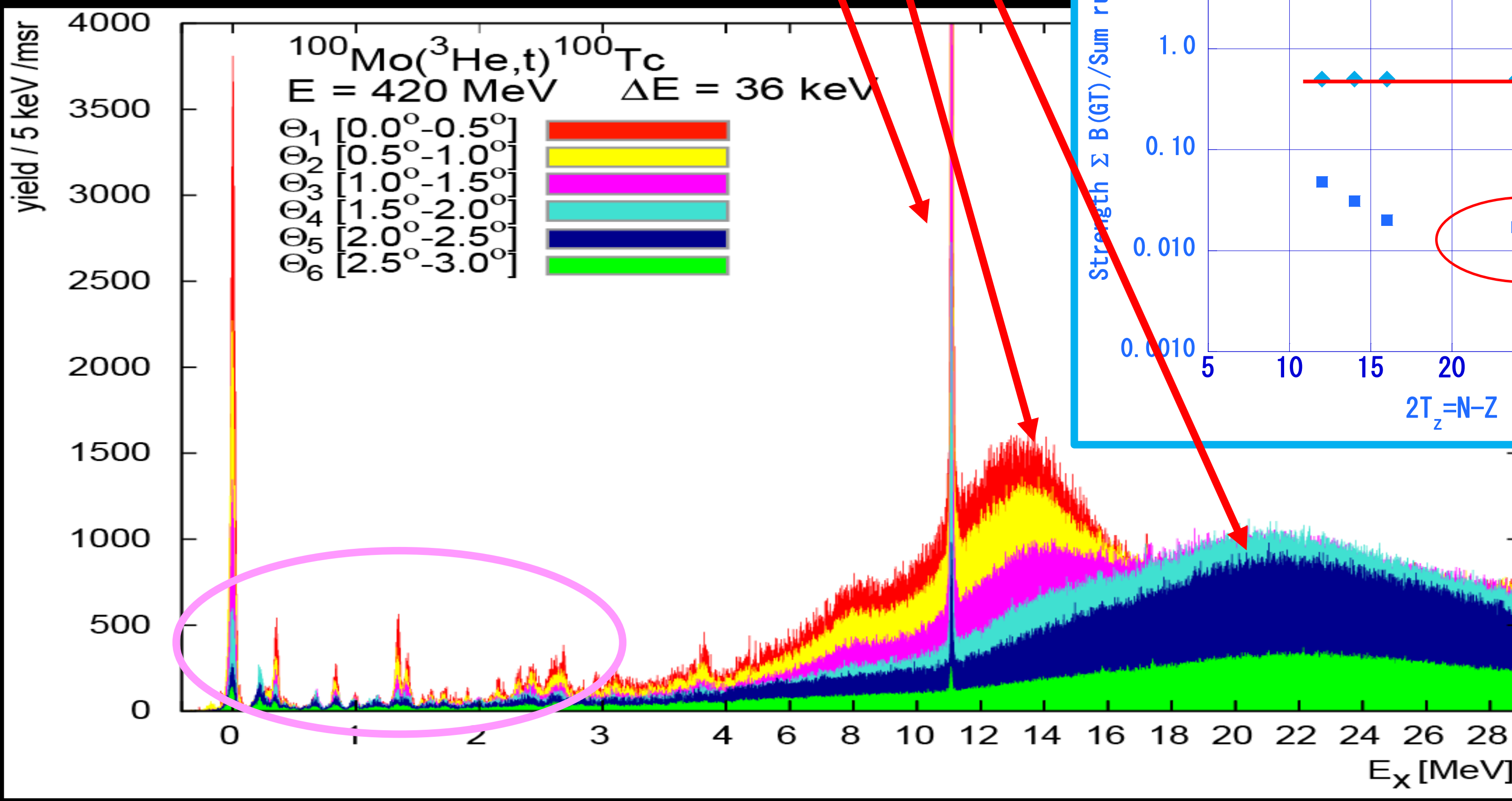
(g_A^{eff}) for renormalization effects due to non-nucleonic and nuclear medium effects which are not in pnQRPA.

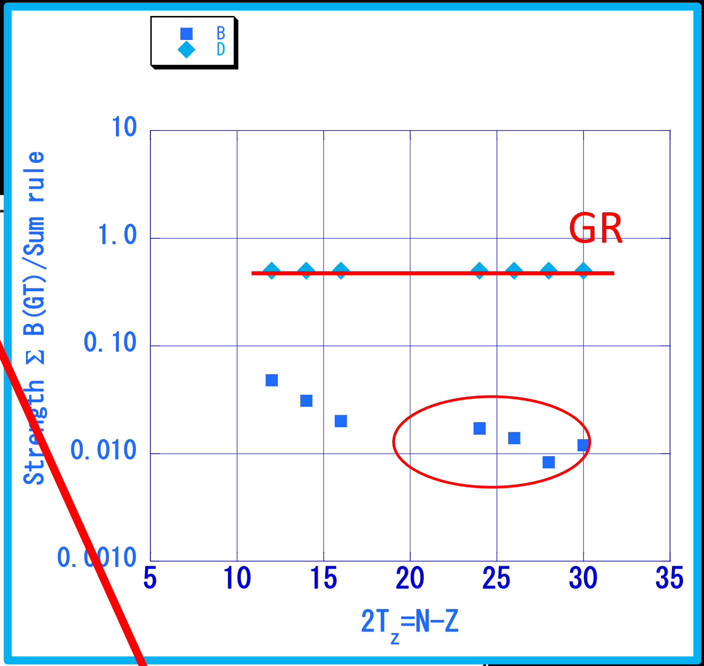
$(g_A^{eff})^- \sim (g_A^{eff})^+$ for β = (g_A^{eff}) for ββ

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

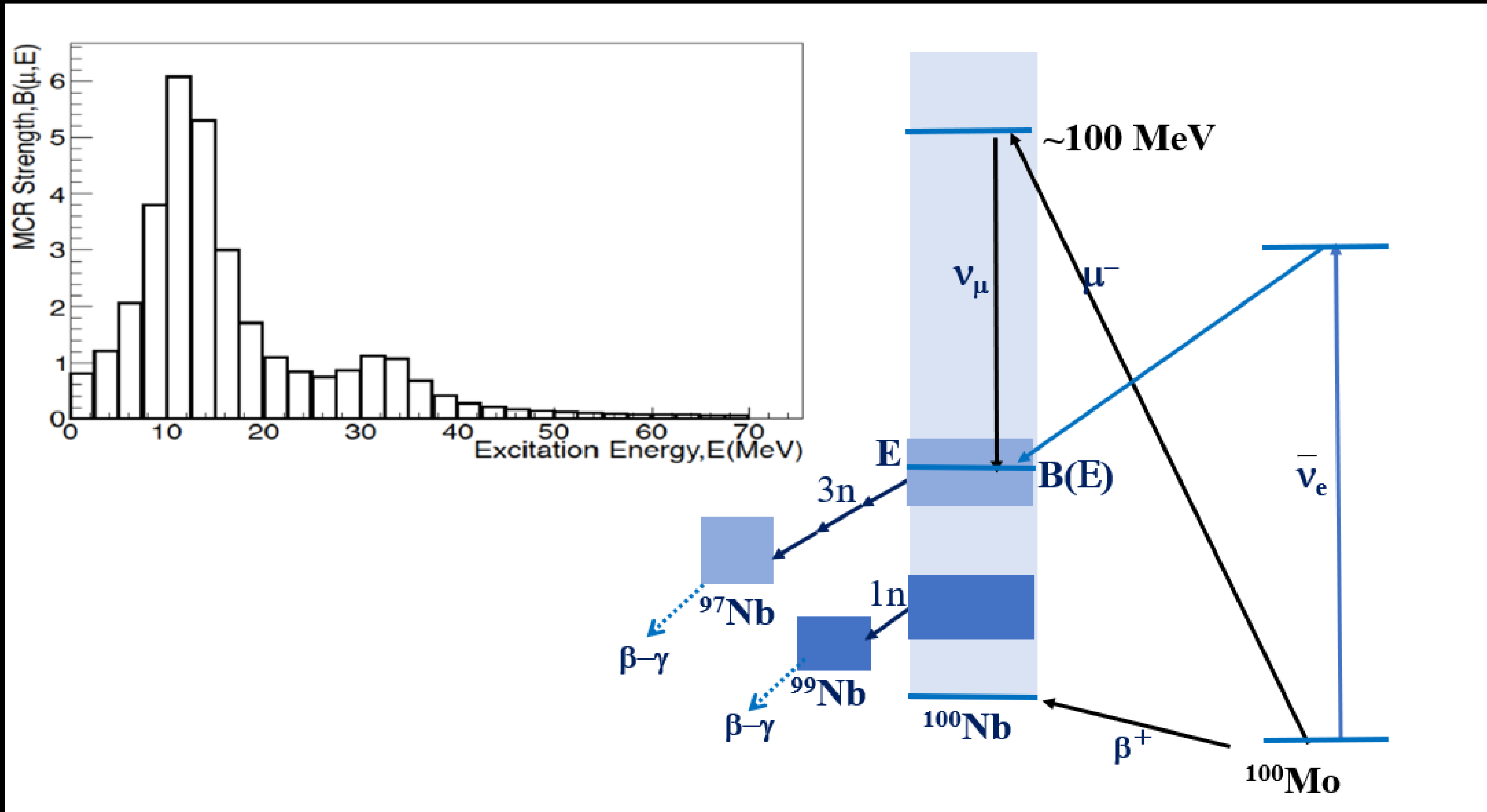
Most strengths are in GRs(Giant resonance)

Fermi No at low states, all in F-GR: IAS
GT A few % at low states, 50% GT-GR
SD A few % at low states, main SD-GR





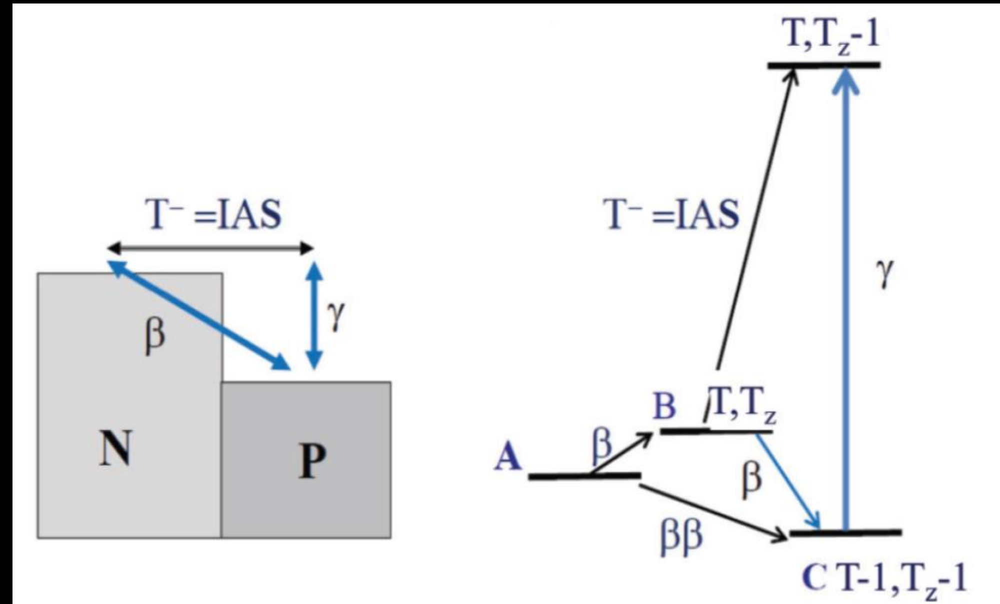
Leptonic (muon) CER μ+ (A,Z) = ν_μ + A(Z-1)

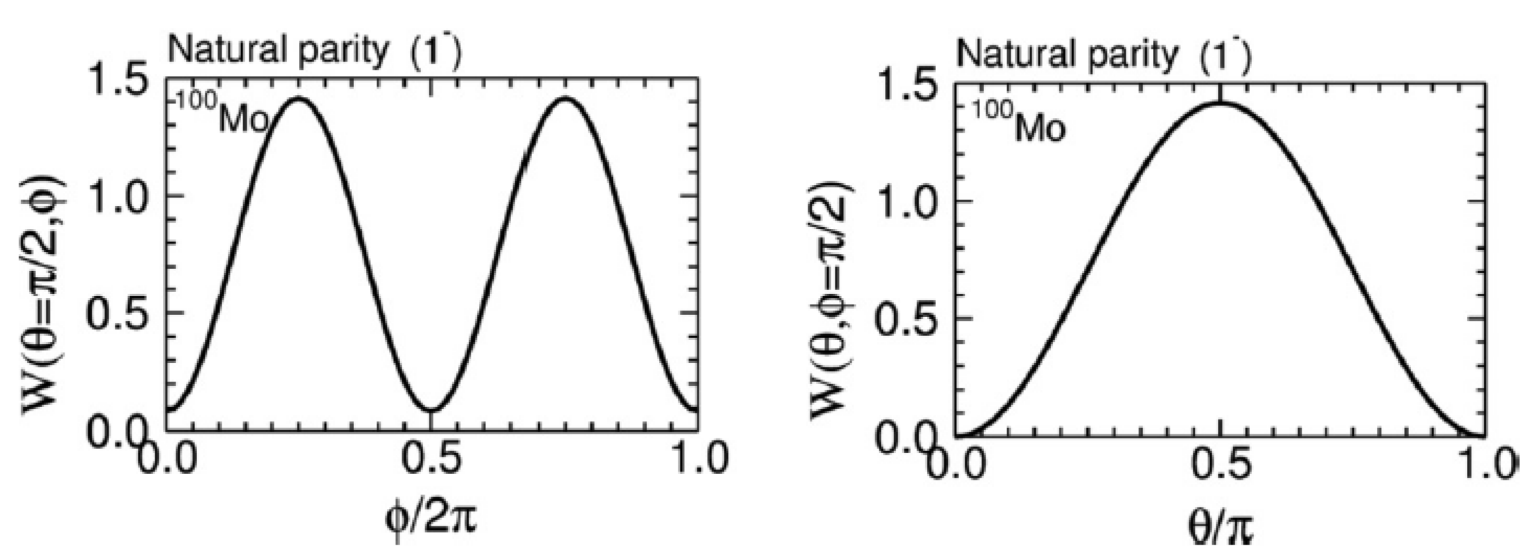


H. Ejiri Proc. e-γ conference Sendai 1972, H. Ejiri et al., JPSJ 2014
Hashim H. Ejiri Het al., PRC 97 (2018) 014617
Zinatulina D, et al., Phys. Rev. C 99 2019, 024327.
Jokoniemi L, Suhonen J, Ejiri H, Hashim I P.L. B 72019, 94, 143

Photo nuclear reaction

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

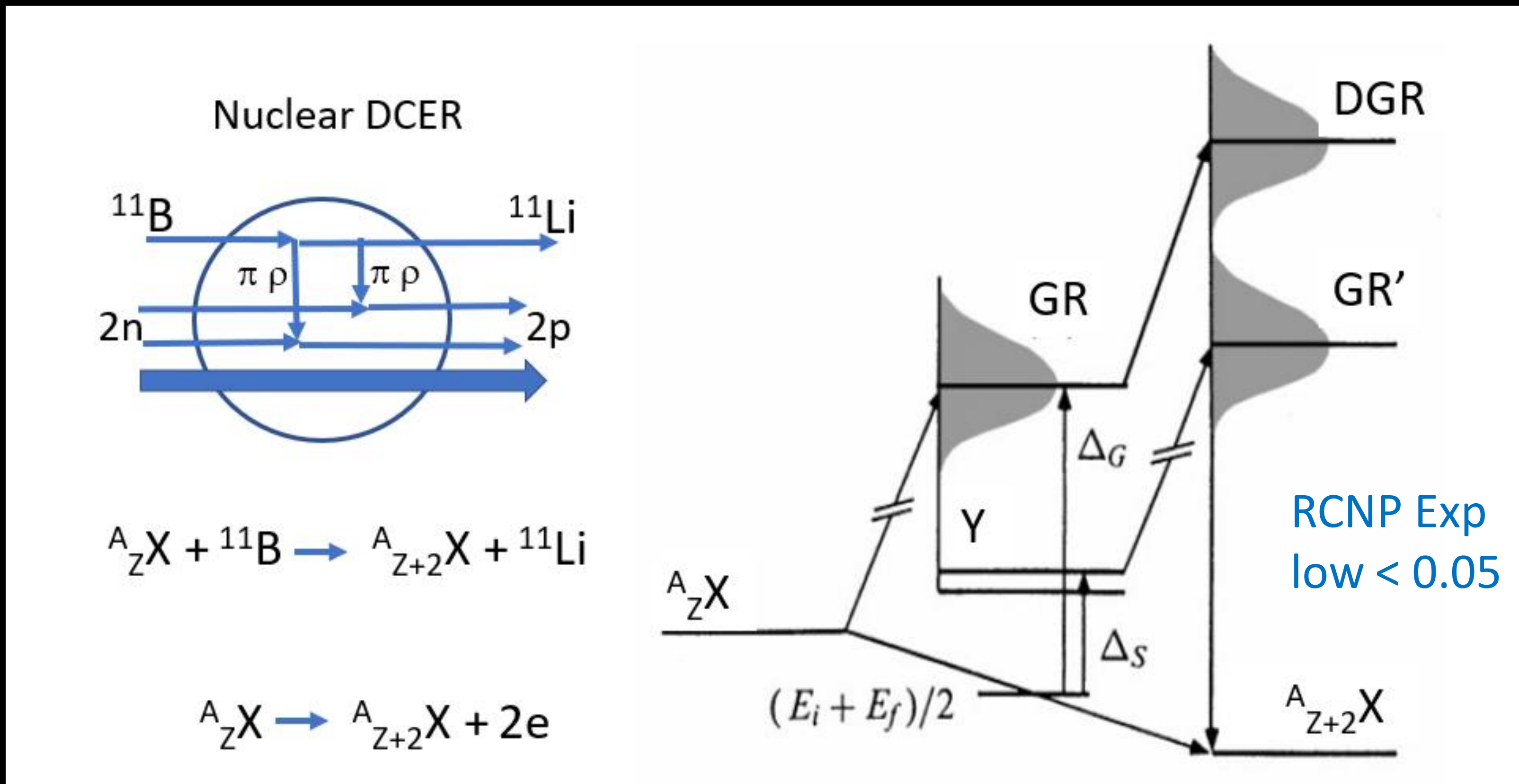
Double charge exchange reactions (DCERs)

Mainly double GRs (GT, SD).

Little strengths at low-states of the DBD interest

Comparison of exp. with theoretical cross-sections for g_A

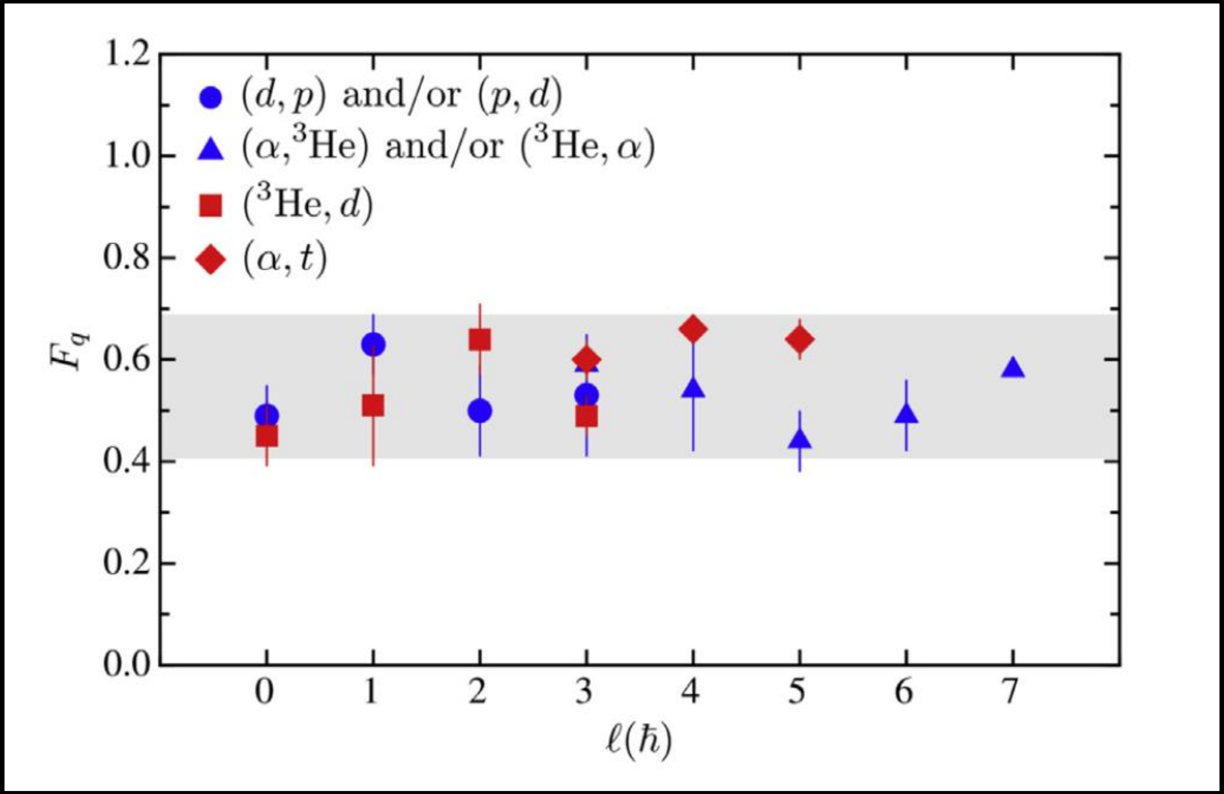
Ejiri H. Phys. Rep 338, 2000, 265



Cappuzzello et al Eur. Phys. J. A 51 2015 145. Catania HI CER Project

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

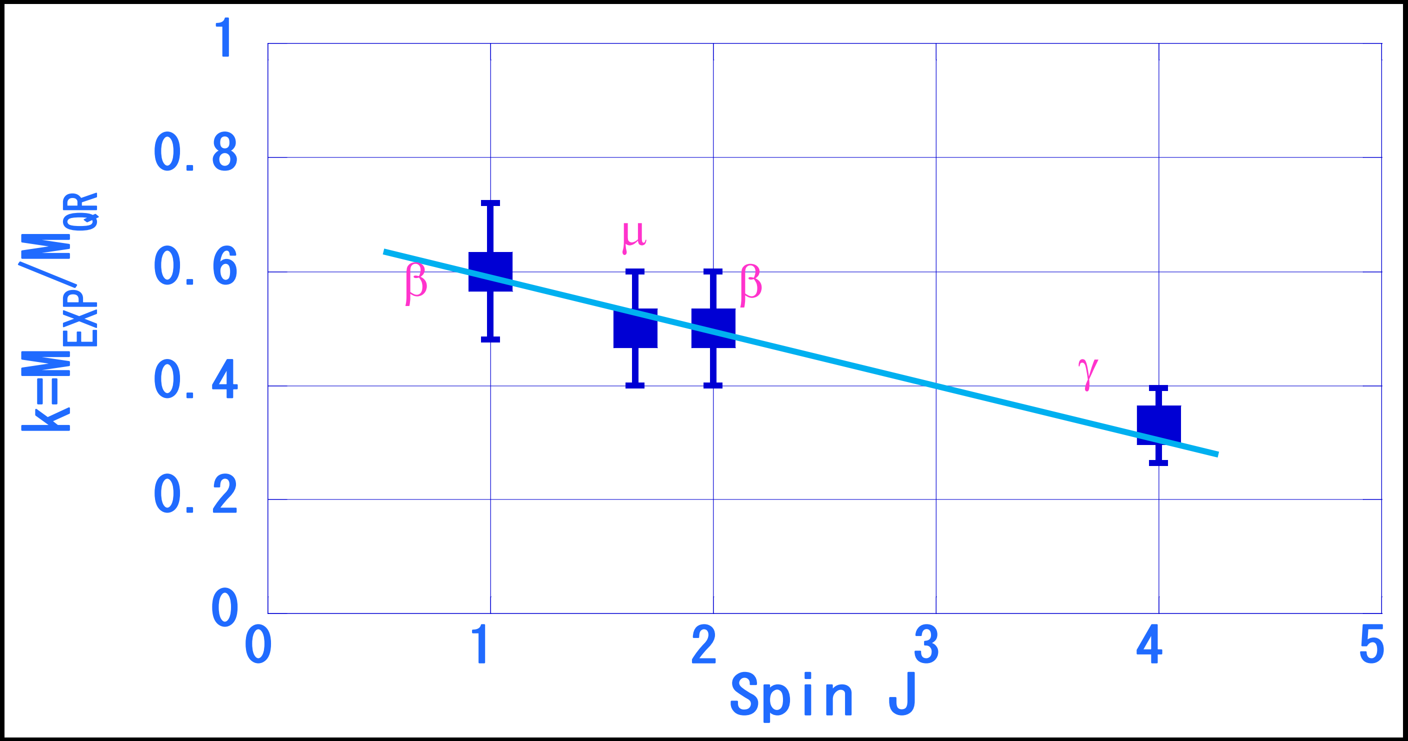


B.P. kay , J.P. Schiffer , S. J. Freeman Phys. Rev> Lett. 111 2013 042502

4. DBD NMES and Remarks

Universal reductions of axial vector β & γ i

Ejiri Fujita PR 34 85 1978



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

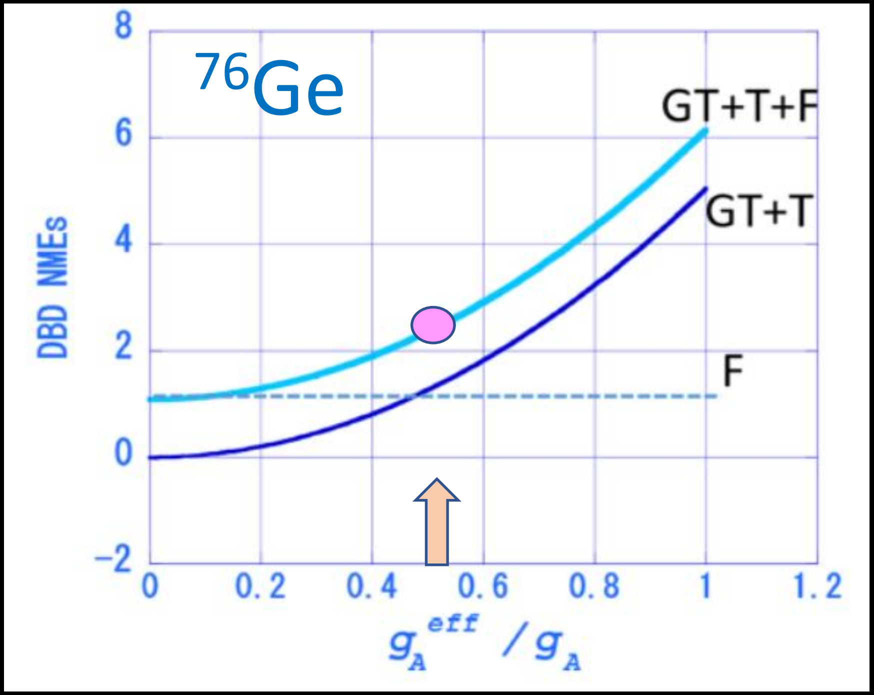
H. Ejiri N. Soucouti, J. Suhonen PL B 729 2014 .

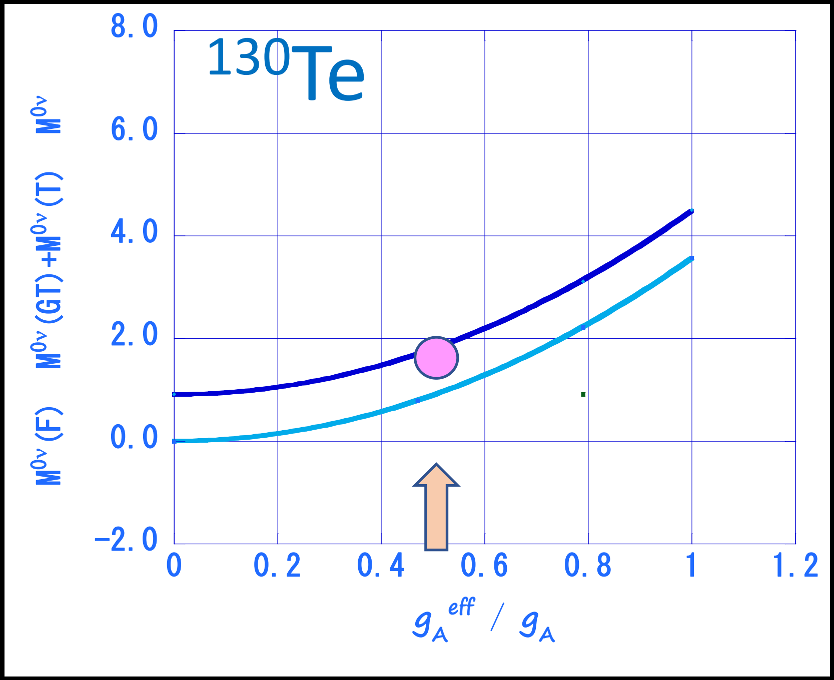
L. Jokiniemi J. Suhonen H. Ejiri AHEP2016 ID8417598

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

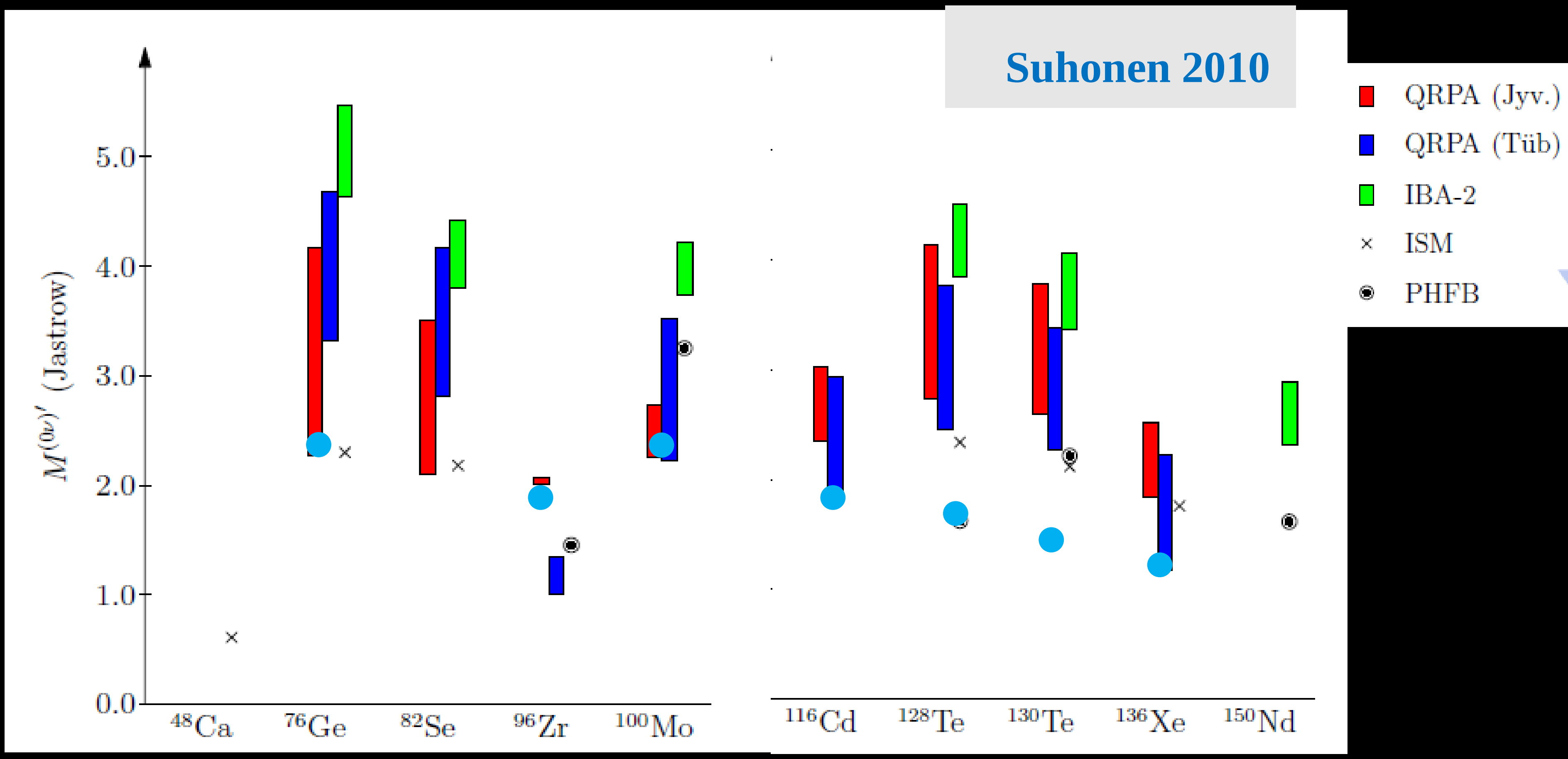
$$M^{0\nu} = [\frac{g_A^{eff}}{g_A}]^2[M_M^{0\nu}(GT) + M_M^{0\nu}(T)] + [\frac{g_V}{g_A}]^2 M_M^{0\nu}(F),$$





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

NMEas are very sensitive to nuclear models and parameters

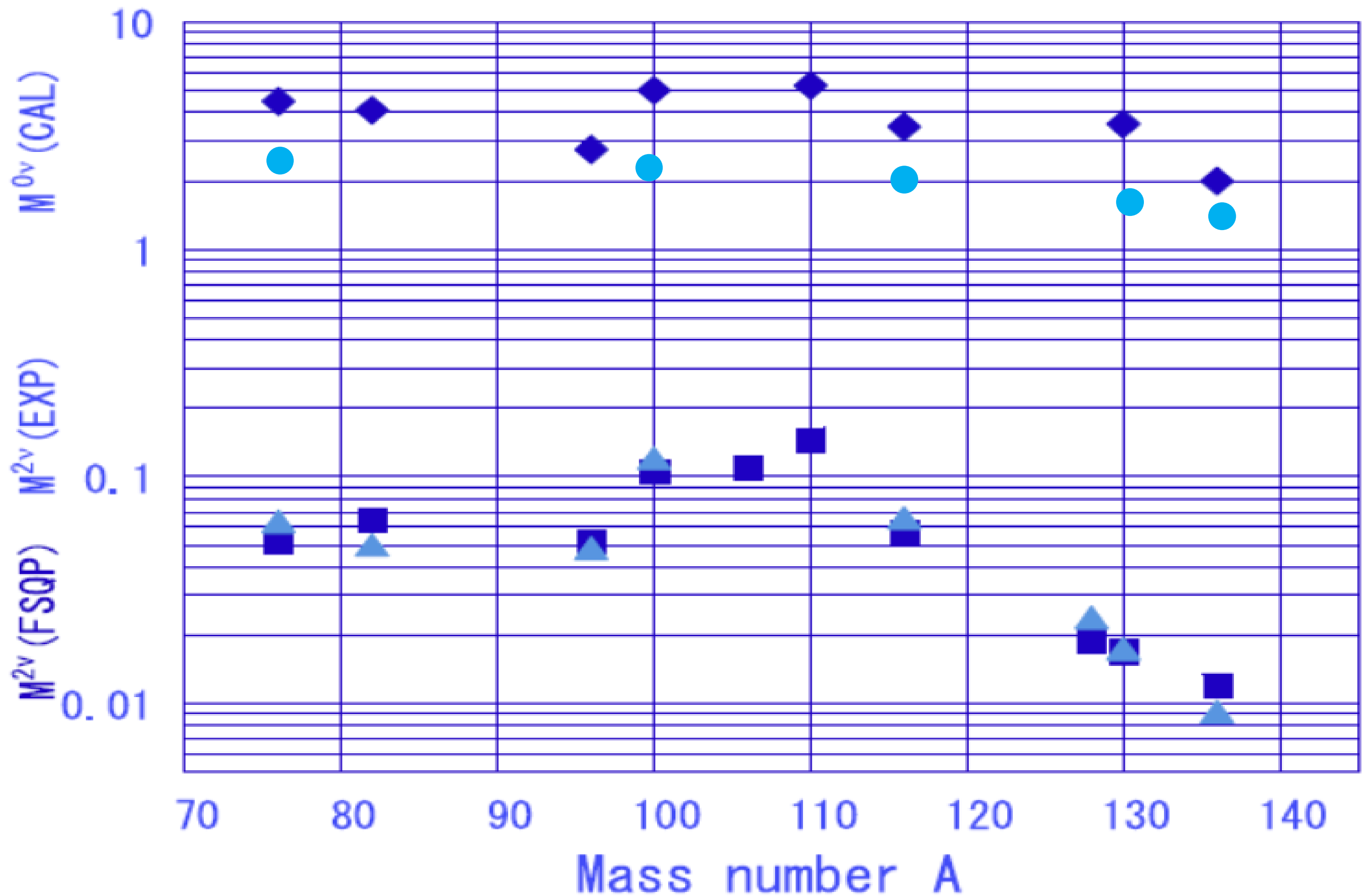


Exp. NMEs Present with g_A^{eff}/g_A=0.5

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

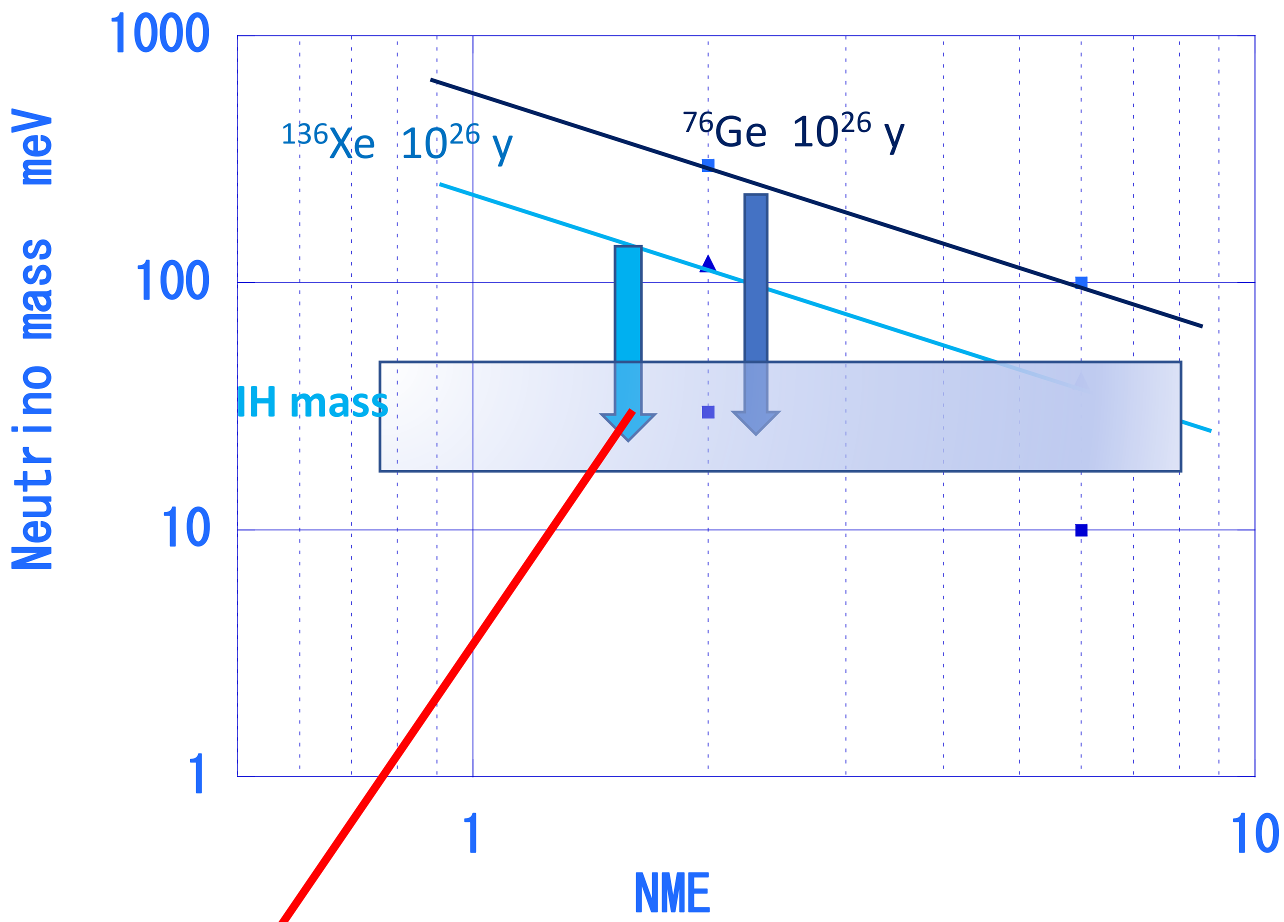
Nuclear structures on 2ν and 0νββ NMEs

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



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

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

Concluding remarks and perspectives.

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

   $k_{NM}=g_A^{eff}/g_A \sim 0.5$ for GT, SD, μ 30-80 MeV/c

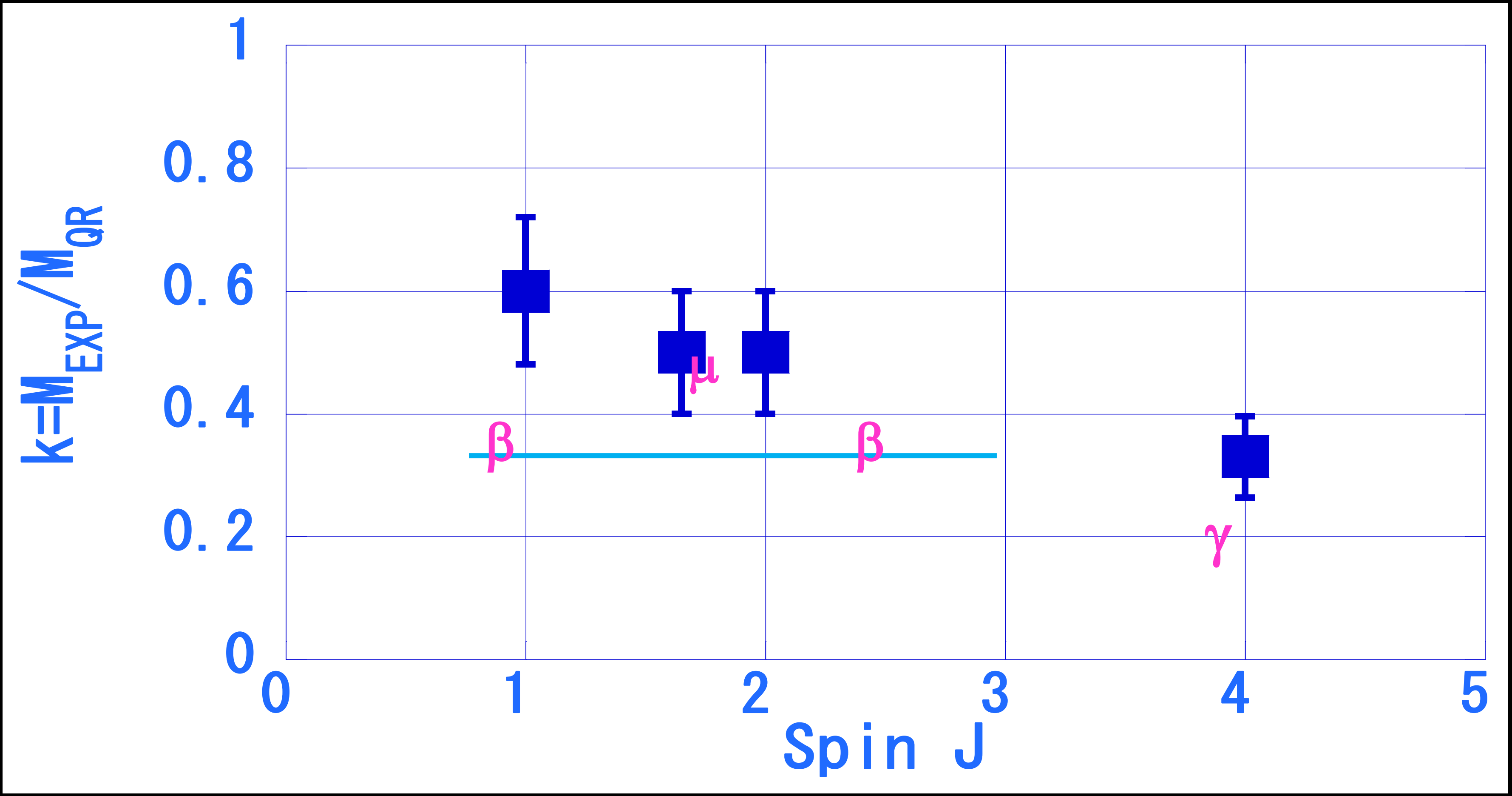
3. Using the experimental g_A^{eff}/g_A and QRPA, DBD NMES ~2

4. Polarized photon beam from New SUBARU and others are used to study charged and neutral current responses. Inelastic Coulomb scatterings are also interesting for these.

5. DCERs, which are extensively under progress at Catania and others, are new promising ways to study DBD.
6. Neutrino beam experiments at ORNL SNS (Exp. Coherent s. Theor. H. Kosmas) and J-PARC will be of potential interest.
7. Model refinements by using such data relevant to DBD as isovector 1+, 2-, 3+ transitions, and models including mesons and isobars, and ab-initio calculations are encouraged.


Thanks for your attention
Greenary Nimph 翠の精

3. Neutrino nuclear responses in medium momentum region

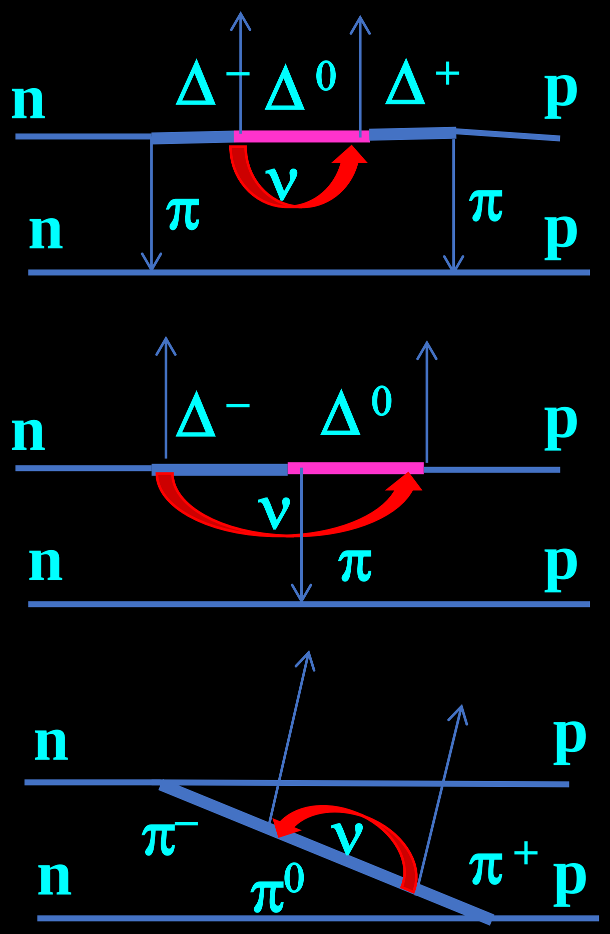


k=M_EXP/M_QR
Spin J
0
0.2
0.4
0.6
0.8
1
0
1
2
3
4
5
β
β
μ
γ

Hadronic (Δ, π) *

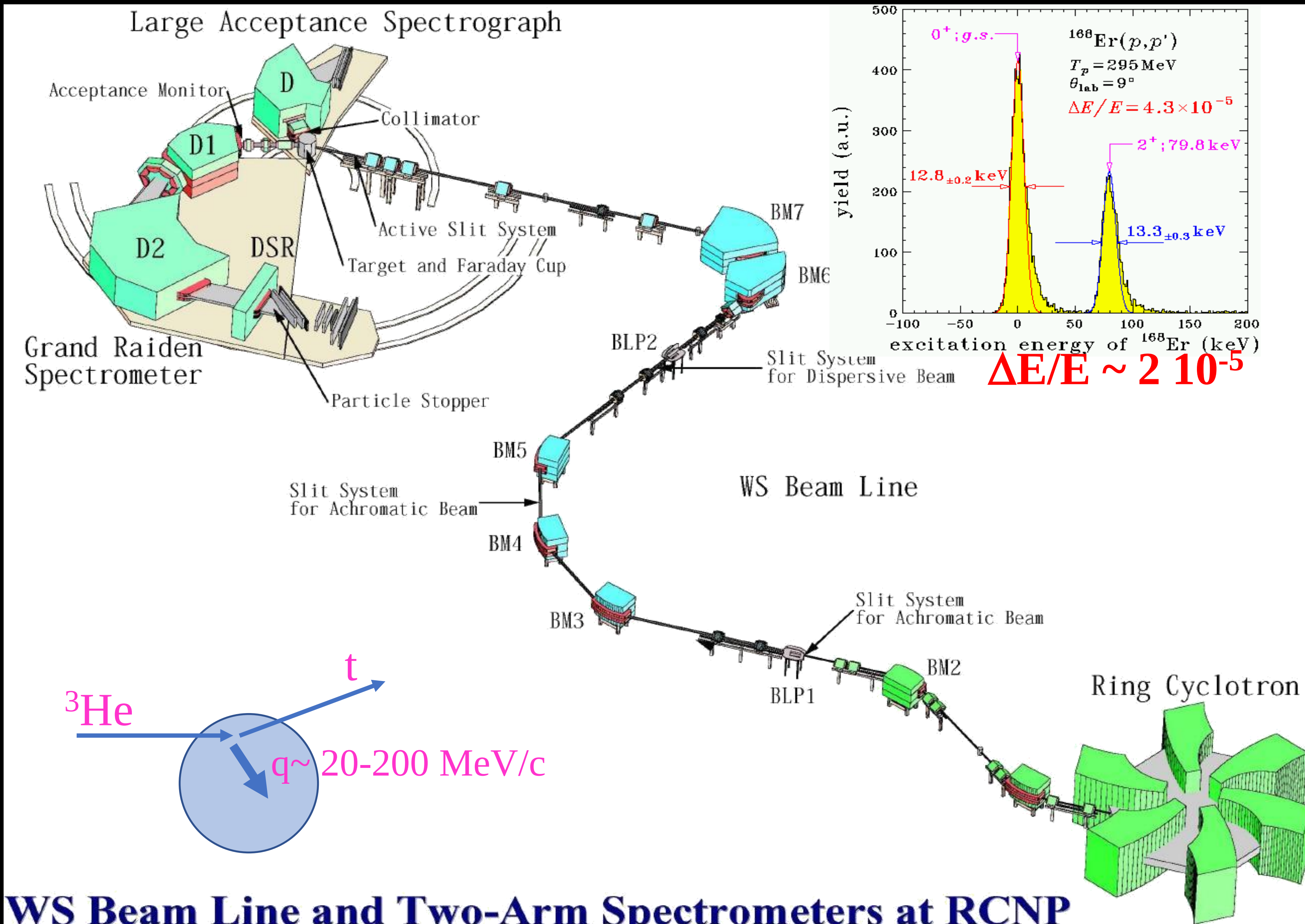
Effect on low $\beta\beta$ 0^+ - 0^+

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



*Pontecorvo; Haxton, Stephenson, Kotani Doi .

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

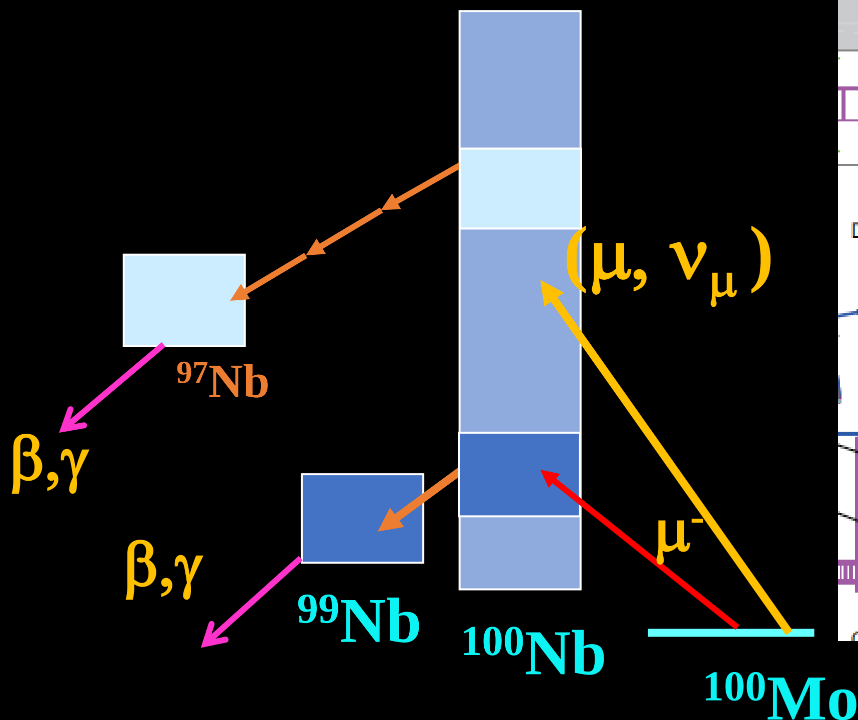


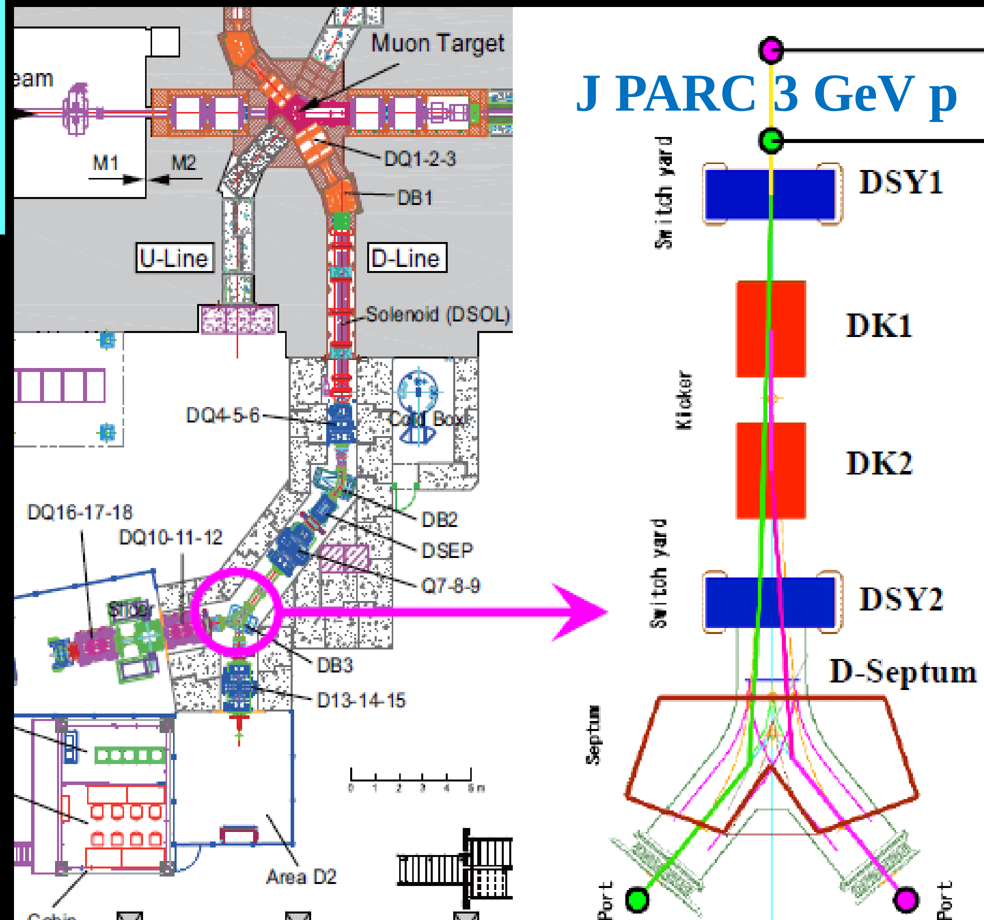
$\Delta E/E \sim 2\ 10^{-5}$

B2: Lepton CER

(μ,ν_μ, xn γ)

β^+ ant-ν q~50-100 MeV/c





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

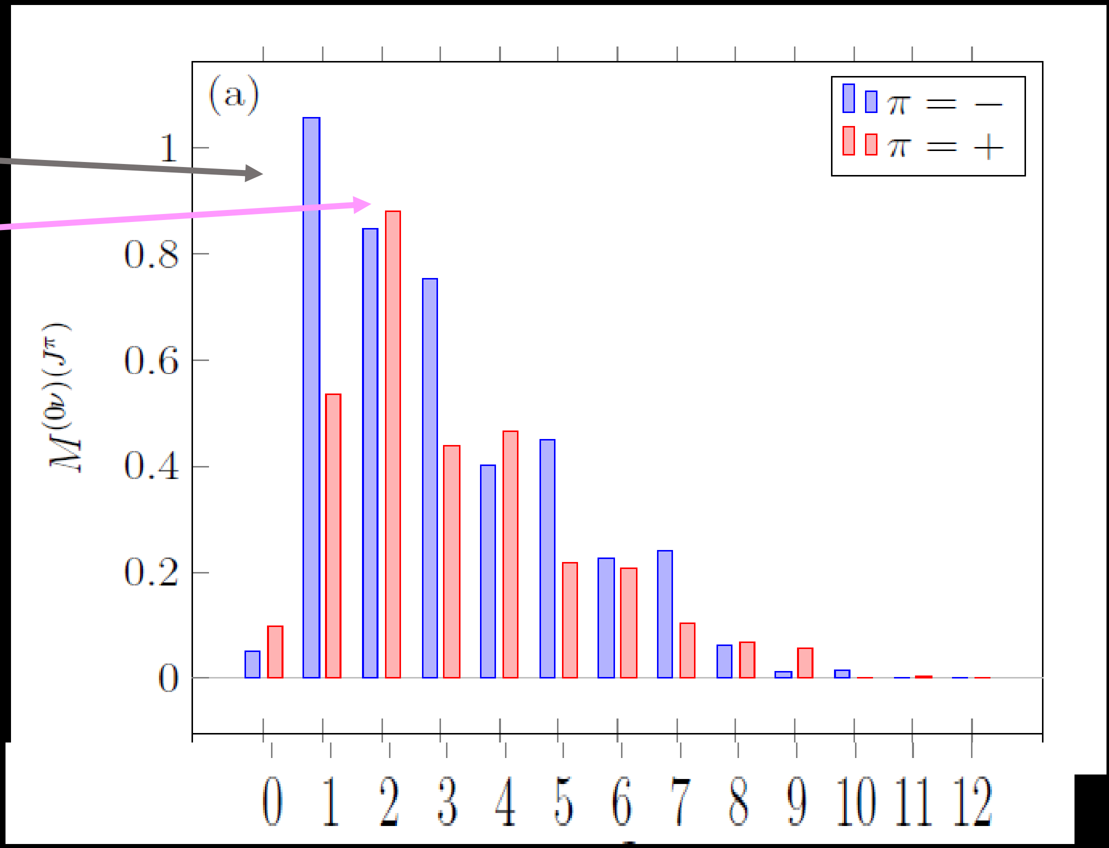
M Theory pnQRPA

Jokiniemi Ejiri Suhonen Frekers PR C 98 024608

L=1 p-wave 60 MeV/c

1^{-} (Y_1)

2^{-} SD ($\sigma \times Y_1$) g_A=1)



M Experiment

So far GT (L=0)

SD ^{76}Ge—^{76}As – ^{76}Se

Present CER β-decay

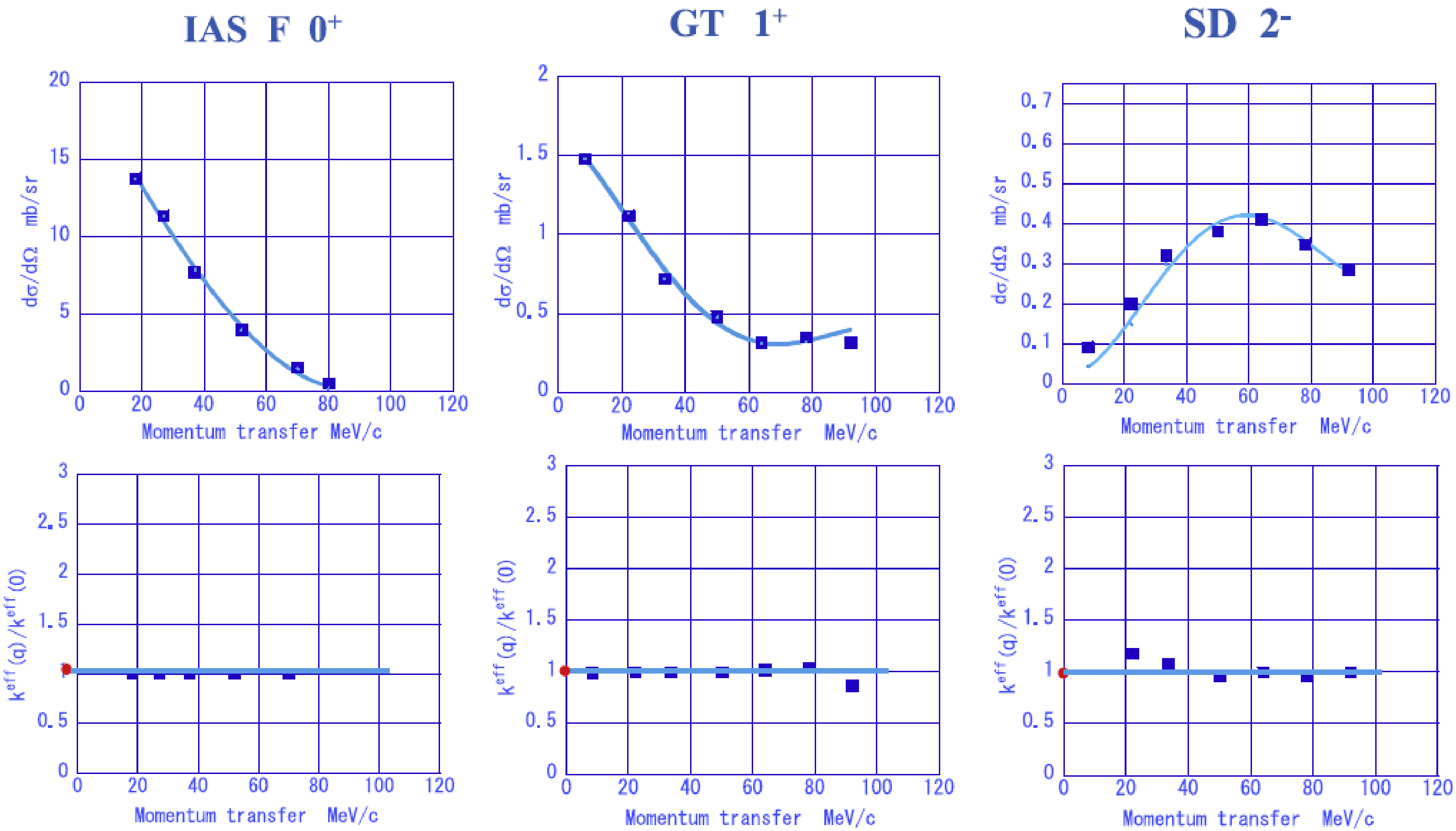


Fig. 15. Top: The ^{76}Ge(^{3}He,t) CER cross sections as functions of the momentum transfer q [95]. F 0^{+}: 8.31 MeV IAS, GT 1^{+}: the 0.12 MeV GT state, SD 2^{-} the ground SD state. The solid lines are the DWBA calculations. Bottom: The ratio $k^{eff}(q)/k^{eff}(q = 0)$ for α = F (IAS), GT (1st GT state), and SD (ground states. The red point is the normalization point at $q = 0$. See [103].

g_A^{eff}~const over q=0-100 MeV/c

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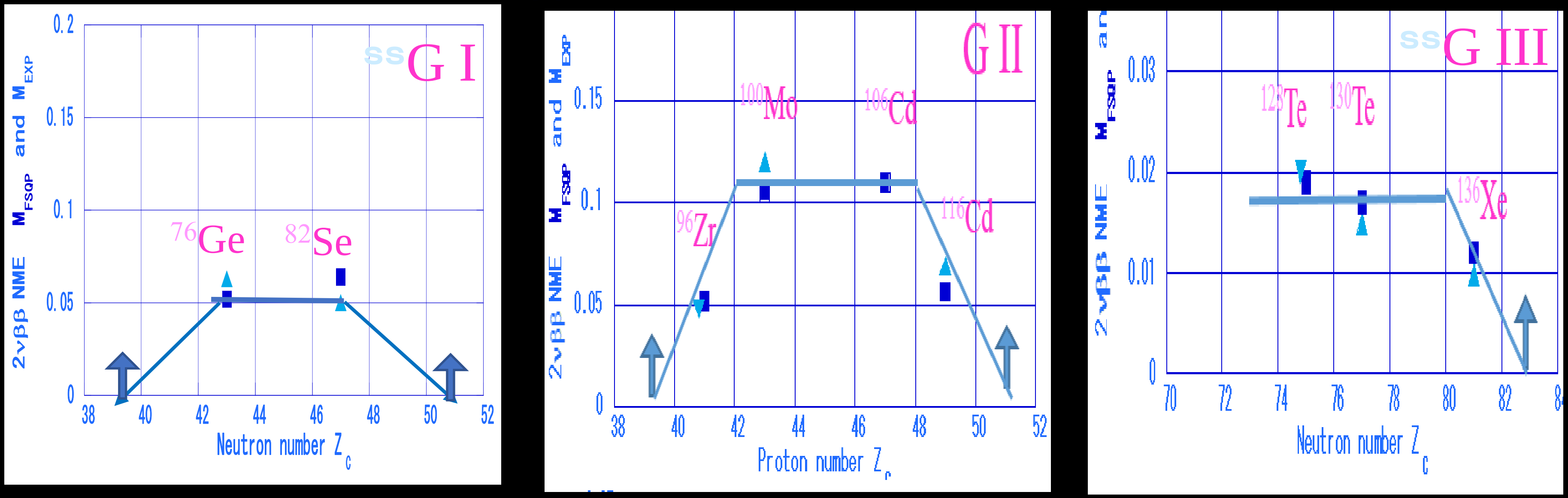
DBD 2νββ NME

QRPA 0νββ NMEs (Engel et al. PRC 89 (2014) 064308



Triangle =exp, Squares=FSQP(Ejiri) J. Phys. 2017

$$M^{2\nu\beta\beta} = \Sigma_k\, M^-{}_k M^+{}_k /\Delta_k$$

$$M^-{}_k = (k^{eff}{}_i)\;\; m_{ij} V_n U_p ,\;\; M^+{}_k = (k^{eff}{}_f)$$

$$m_{ij} U_n V_p ,\quad (k^{eff}{}_A)^2 \sim (0.23)^2 = 0.05$$

Shell closure makes U or V small, and thus UV small .