Experimental Aspects of Nuclear Matrix Elements for Double Beta Decays and Astro Neutrinos

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.

Why Nuclear Matrix element M

1. Get ν-mass $m = [1/M]\,[T_{1/2}\, G]^{-1/2}$
2. Detector design sensitivity

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

- M = NME, B=BG/ty N=Isotope mass ton
- M Factor 3 in M is equivalent to
- Factors 100 in BG/ton year or N tons

3. Theoretical M: factor 10 uncertainty

- Need experimental input to M

1. Neutrino nuclear responses and g_A quenching
2. Experimental studies for ν nuclear responses
3. Low multipole low momentum responses
4. Medium momentum responses for DBD and SN.
5. Neutrino responses for astro neutrinos and DBD

H.Ejiri J.I. Fujita Phys. Rep 38 1978 85

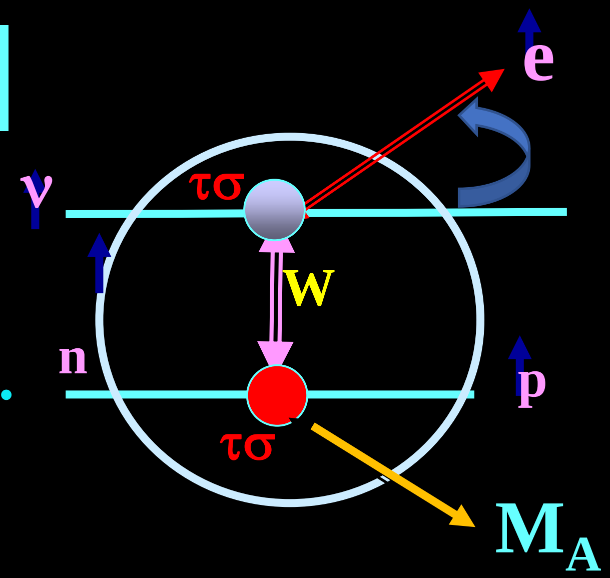
H. Ejiri Phys. Rep. 338 2000 265

H. Ejiri J. Suhonen K. Zuber Phys. Rep. 797 1 2019

H. Ejiri Frontiers 10.3389/fyhs. 2019. 00030

H. Ejiri NNR19 May 2019 Neutrino Response Workshop 2019

Nuclear Response = M : M=NMEs



$T = G\,[\,M\,(m_\nu)/A_\nu\,]^2$

Nuclear phys   Particle/astro phys.

A. DBD Neutrino-less ββ M

$M = g^2_A M_A - g^2_V M_V + g^2_A M_T$ with bare $g_{A,V}$ for free N.

$M_A = k_A^2\, M_A(\text{model})$, $M_V = k_V^2\, M_V(\text{model})$,

$k_A = g_A^{eff}/g_A$: Effects which are not in M_A(model)

B. Astro ν and anti-ν response

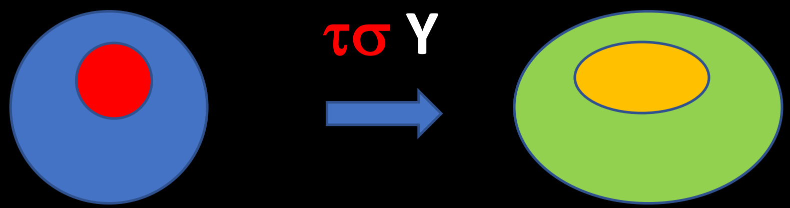
$M_A = k_A\, M_A(\text{model})$, $k_A = g_A^{eff}/g_A$:

DBD ν and Astro ν are q=5-150 MeV/c, $J^{\pm}$ with J=0-5

Effective couplings $k_A = g^{eff}/g$

$M_A = k_A\, M_A(\text{model})$ $k = g^{eff}/g$ Deviation of model NME

from Exp. = True MNE since Model is NOT perfect



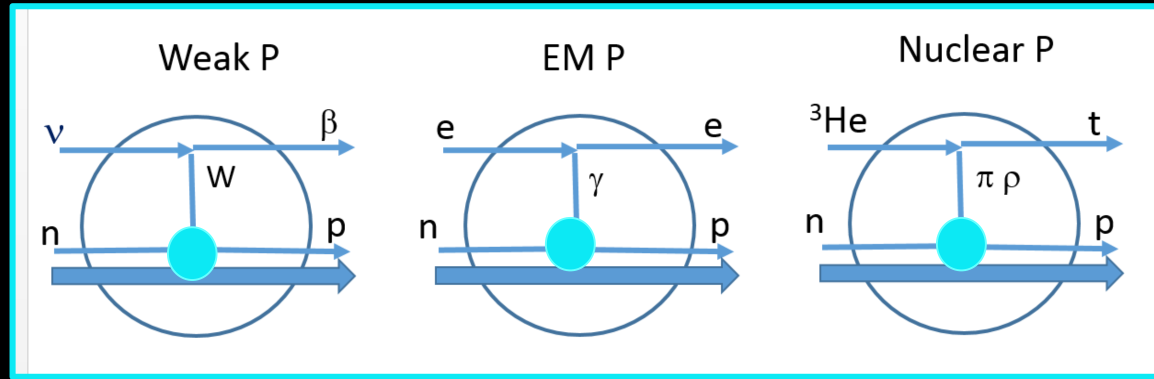
Dress / core
change i-f

Since 1960 for μ GT as e^{eff}/e .

A : Theoretical way ab initio NME $k_A = g^{eff}/g = 1$
Cal. for g^{eff}/g for meson isobar , many body, medium

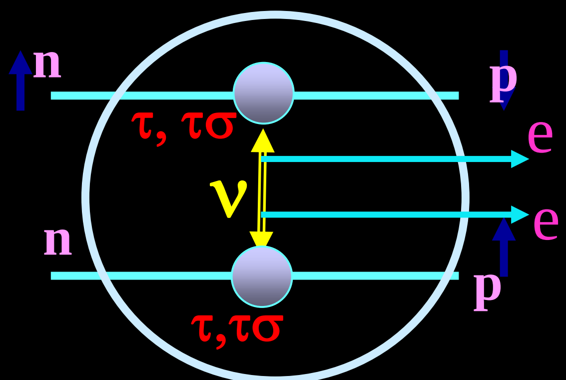
B: Experimental way : present
Exp g^{eff}/g = Exp NME/Model NME for single beta M,
Use Exp. g^{eff}/g and Model QP, QRPA to get NME

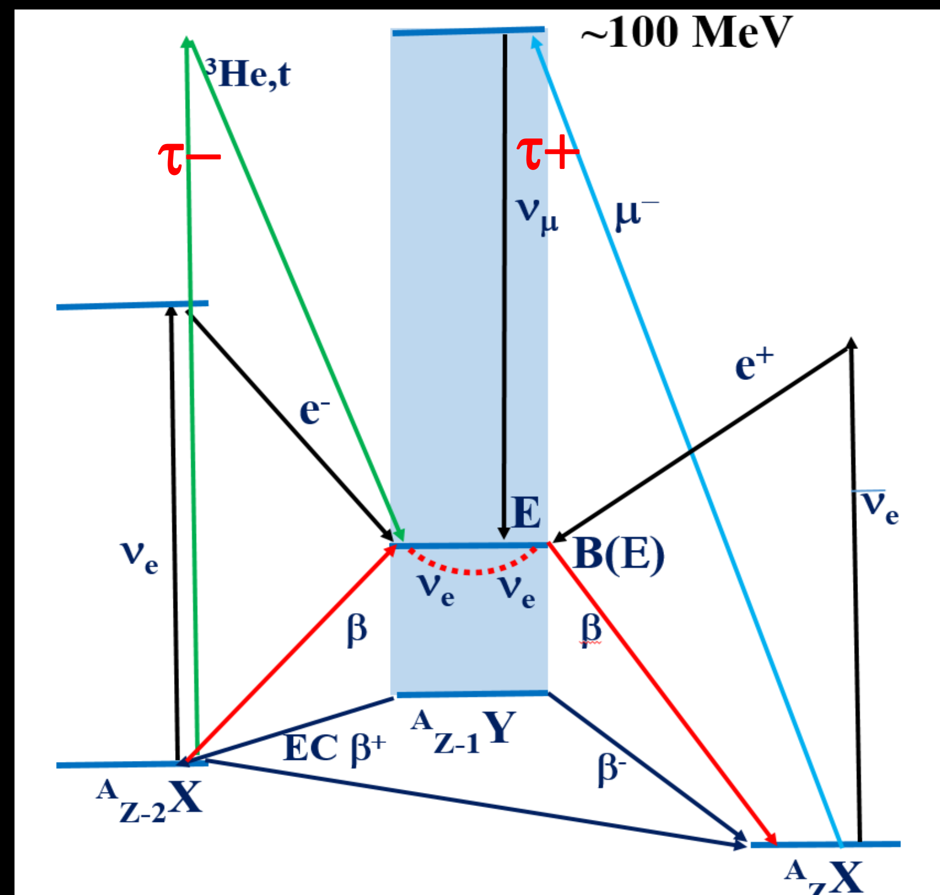
CERs for CC



$$M = g^2{}_A M_{DA} - g^2{}_F M_D$$

Sensitive to NN, NΔ/π nuclear medium effects





M(EXP) =$g_A M$, $g_F M$ by lepton and nuclear CERs to help calculations which are sensitive to nn & medium.

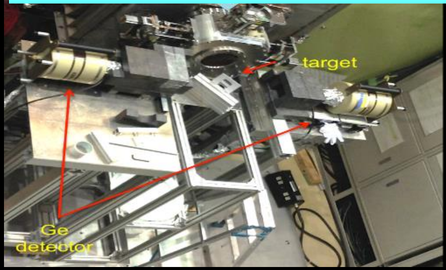
Response experiments by RCNP/Osaka

RCNP Osaka p,He,

MuSIC μ

J-PARC 3-50 GeV p, ν, μ

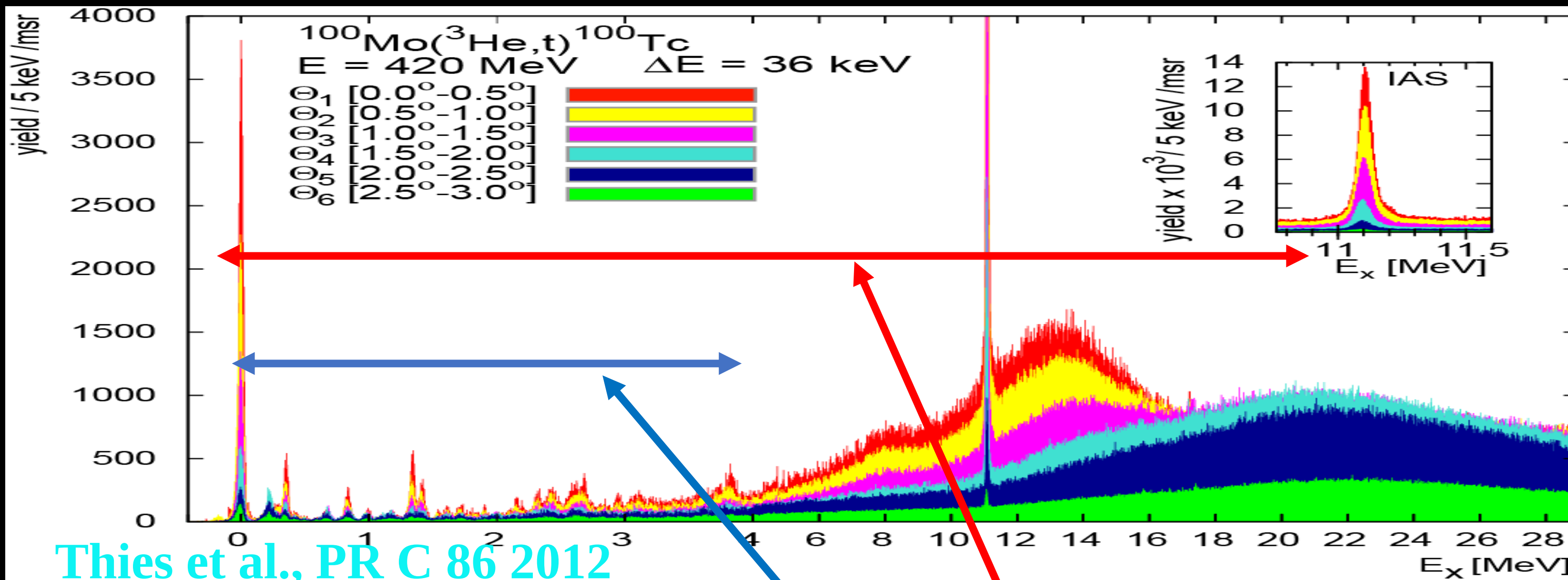
MLF MUSE μ



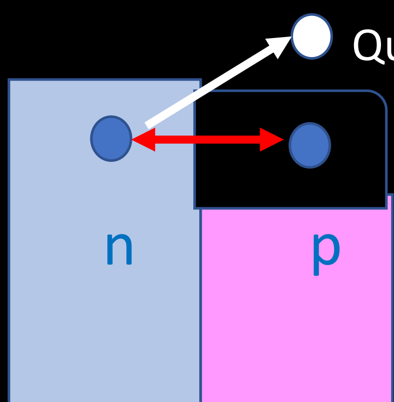
Spring-8 GeV- MeV pol. γ

Oto under gr. ββ–ν,

B(GT) sum strength



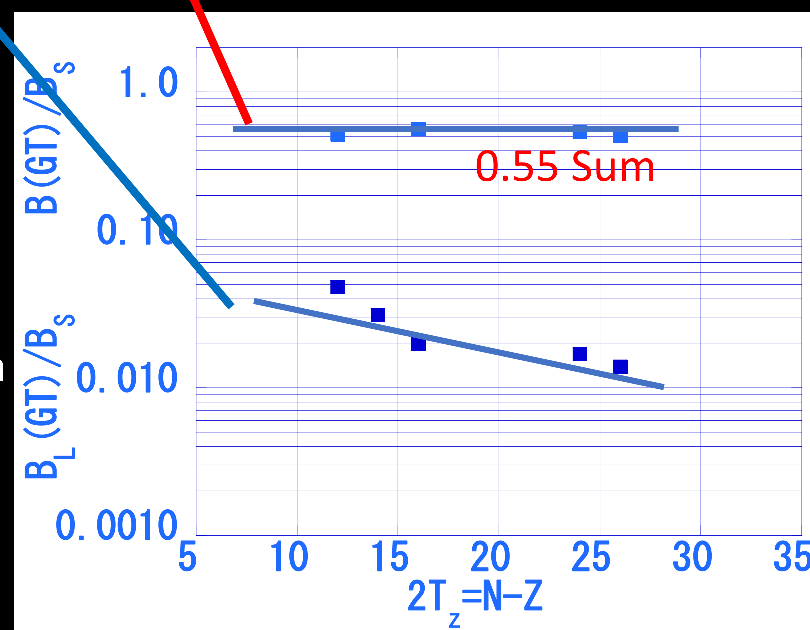
Thies et al., PR C 86 2012



Quasi-free = No GT

(N-Z) [B(σ)=3]

C. Douma 116 122 Sn

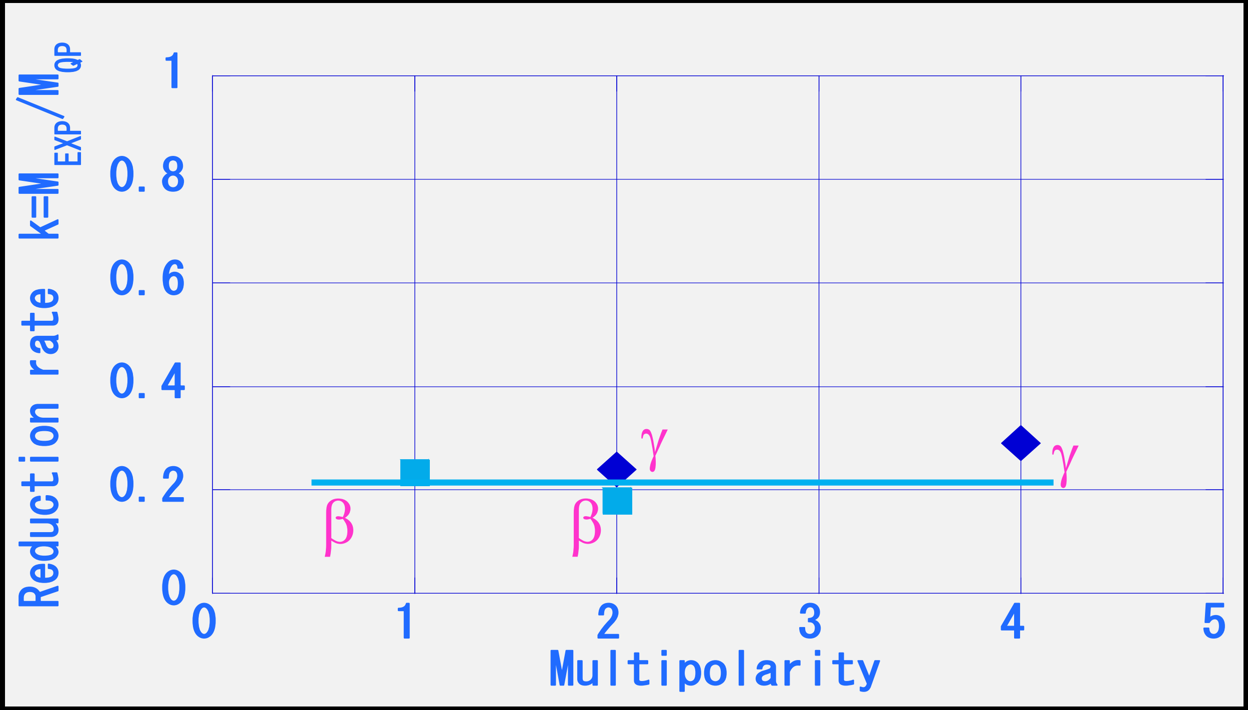


Σ B(GT)/B(σ) = 0.55 (N-Z)

Note : Nucleon in nucleus

is 0.55 free nucleon

Universal reductions of axial vector β & γ in low p



Ejiri Fujita
PR 34 85 1978

$k=k(\tau\sigma)\ k(NM) \sim 0.25$ with respect to QP

$k=k(\tau\sigma) \sim 0.5$: Nucleonic long range τσ GR

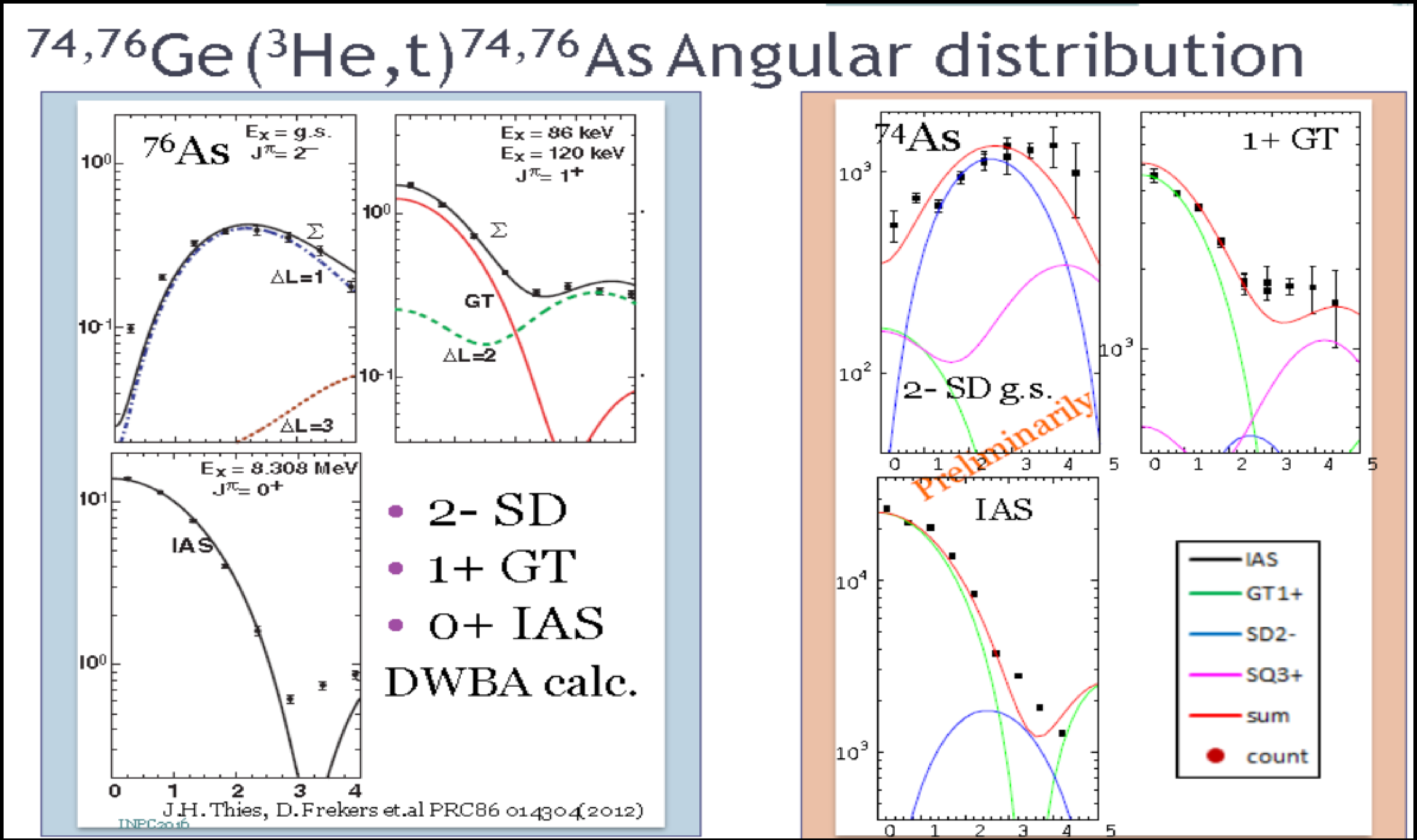
$k(NM) \sim g^{eff}_A/g_A \sim 0.6$: Short range nucl. medium Δ π

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

SD Spin dipole τ[σxrY1] 2⁻ Maior of DBD



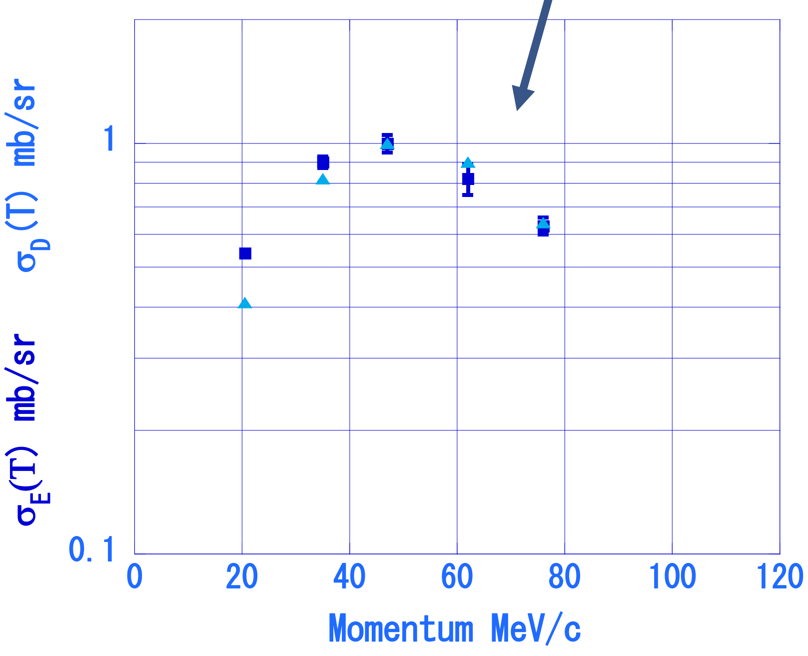
H. Akimune, H. Ejiri, RCNP Catania, KVI , Munster・・

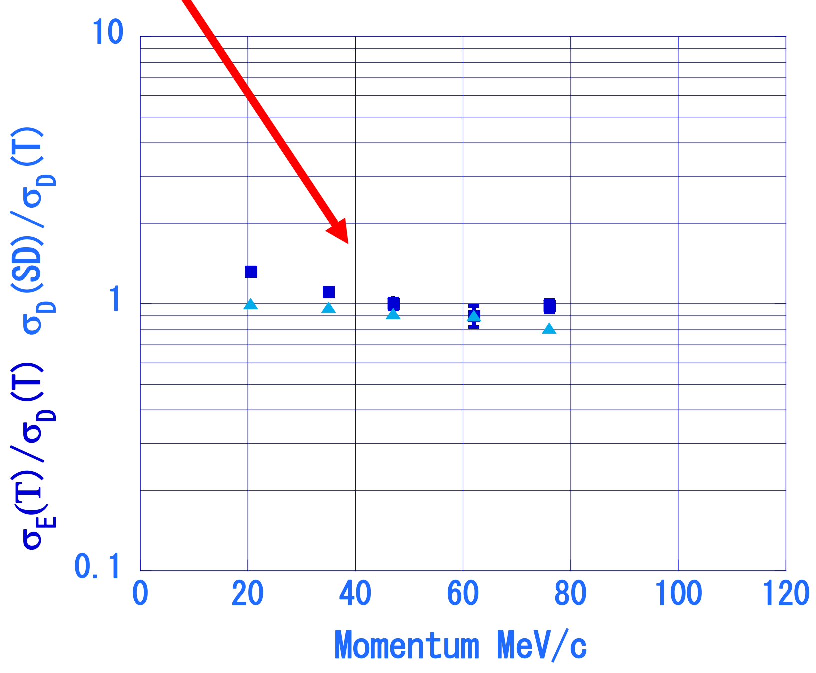
Kinematical q dependence and NME q dependence

$$\frac{d\sigma_i}{d\Omega} = K_i(\alpha)F_i(\alpha, q)J_i(\alpha)^2\kappa^{eff}(q)^2 B_i(\alpha), \quad (5)$$

where $K_i(\alpha)$ and $J_i(\alpha)$ with α=F, GT, and SD are the kinematic factors and the volume integrals of the interaction, respectively. The kinematic q-dependence is given

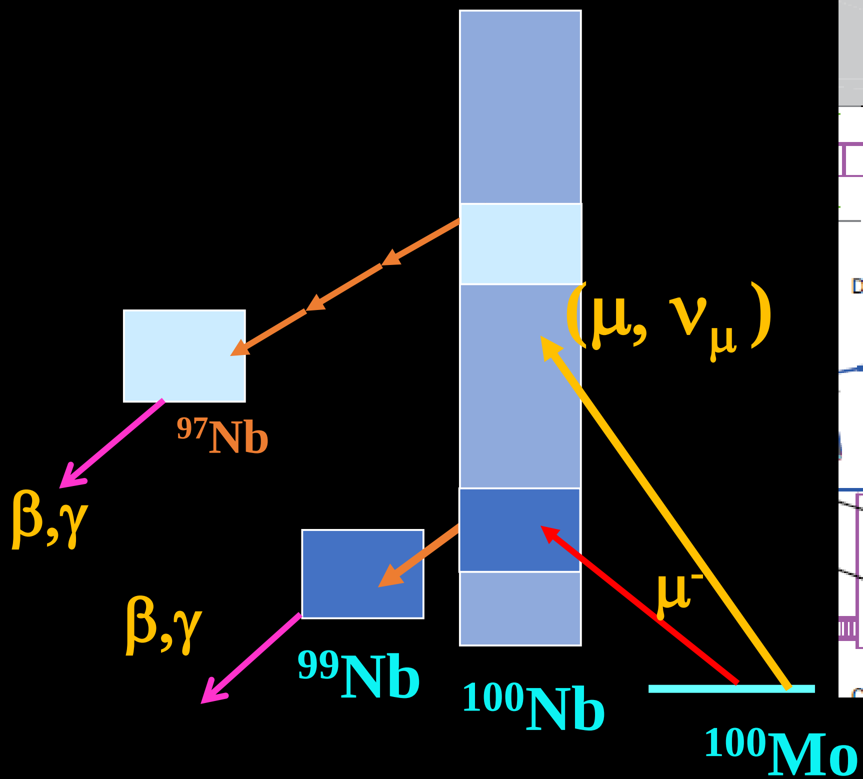
^{130}Te SD 2^-

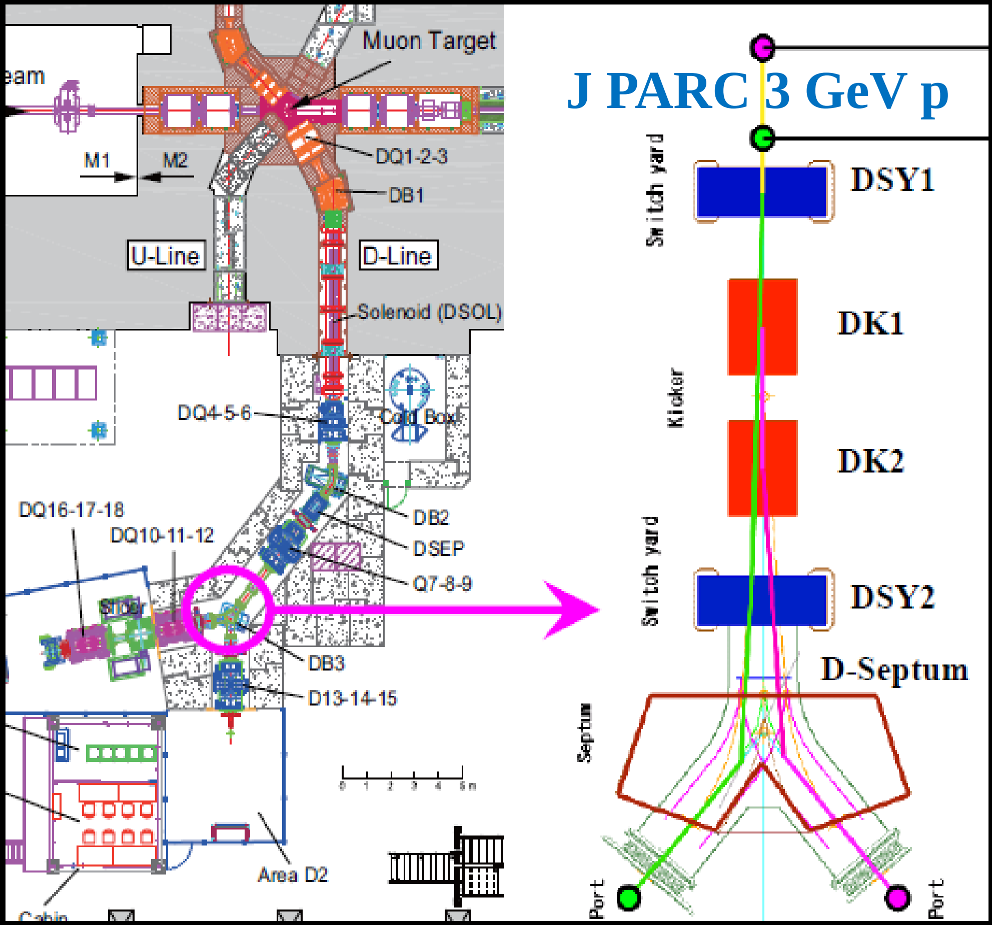




g_A^{eff}~const over q=0-100 MeV/c

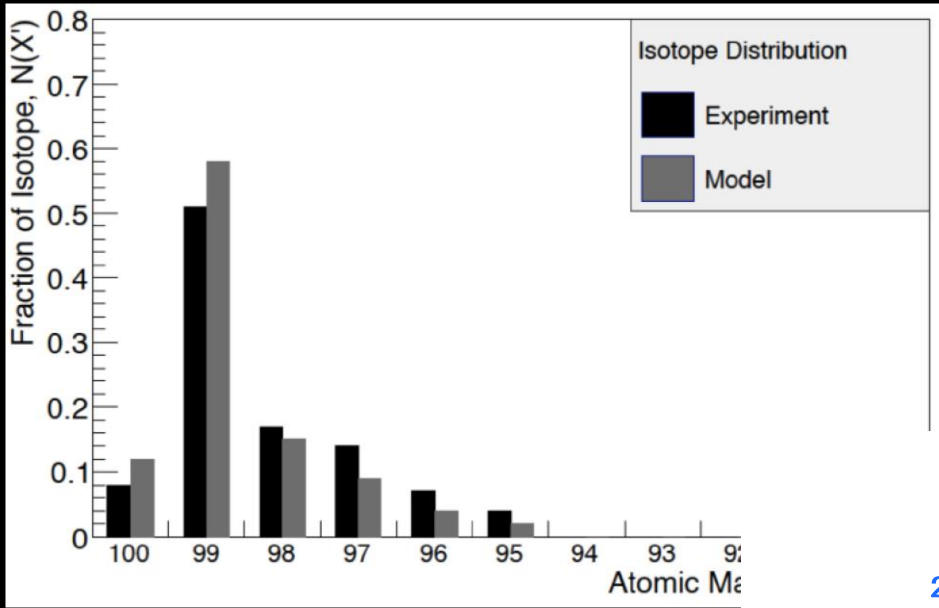
CER $(\mu,\nu_\mu$, xn $\gamma)$ $\overline{\nu}$–β^+ Responses q~80 MeV/c





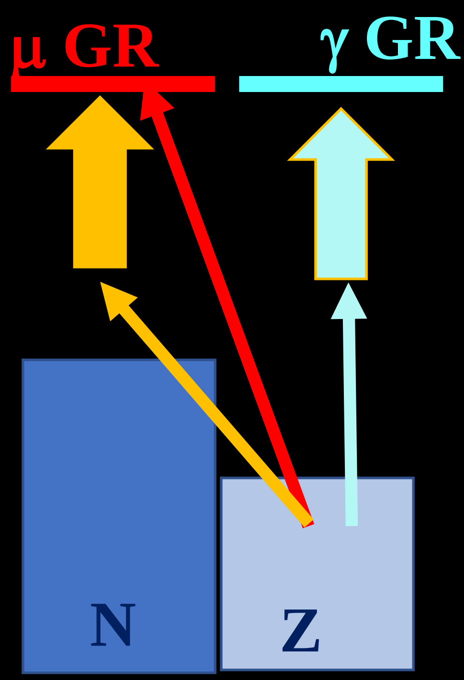
γ_i from $^{100-i}$Nb: relative strength   Life time : the absolute strength

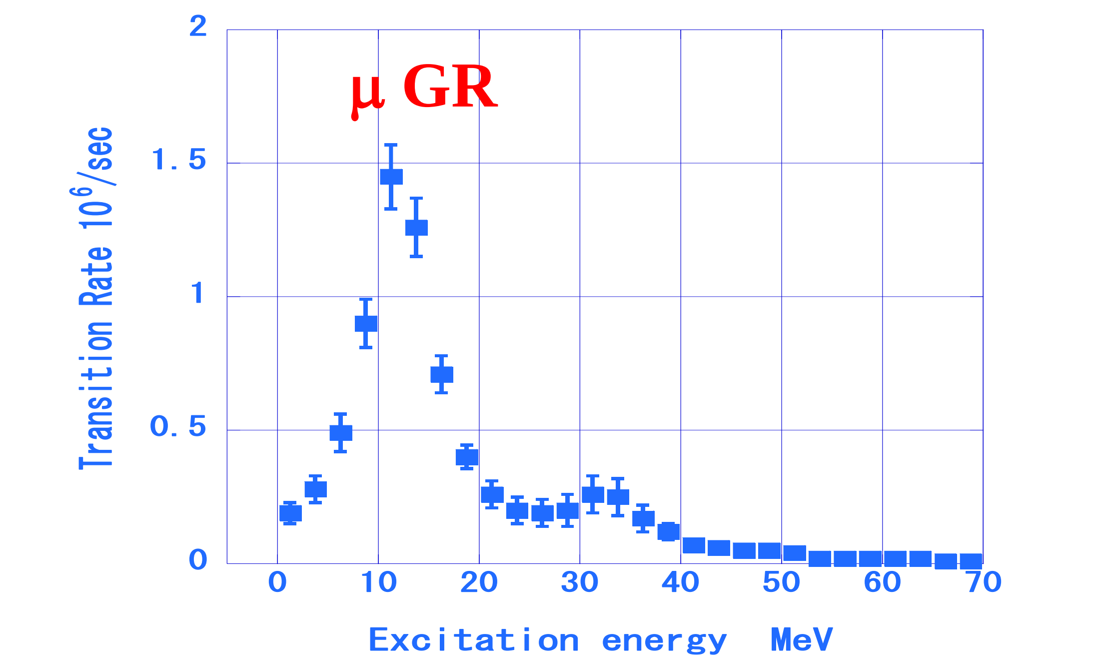
H. Ejiri Proc. e-γ conference Sendai 1972, H. Ejiri et al., JPSJ 2014
NNR19:I. Hashim , Hashim H. Ejiri et al., PRC 97 (2018) 014617



Jokiniemi L, Suhonen H, Ejiri H, and Hashim I.H. 2019 P L B 794 143.

k~0.4 for pnQRPA





I. Hashim H. Ejiri , MXG16, PR C 97 2018

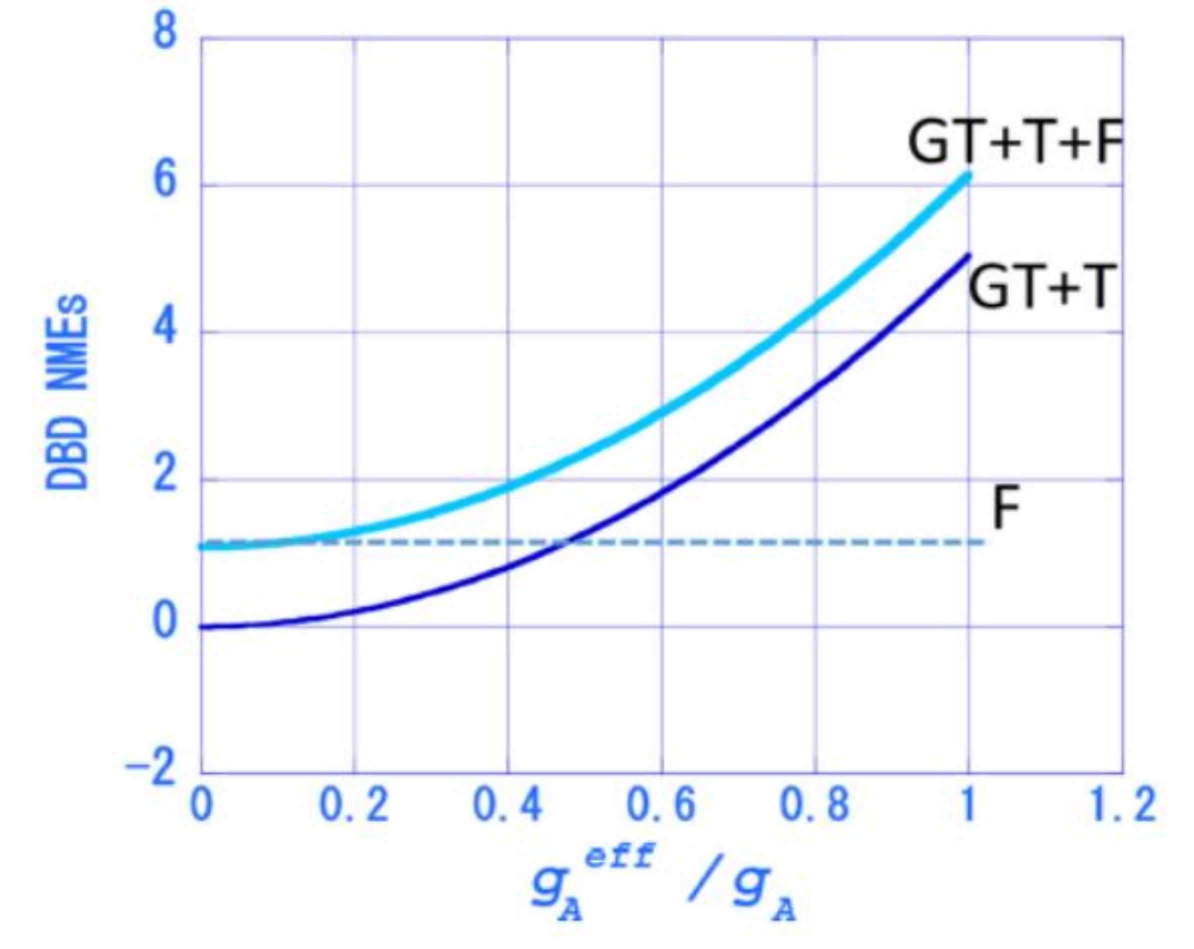
$$M^{0\nu} = [\frac{g_A^{eff}}{g_A}]^2[M_M^{0\nu}(GT) + M_M^{0\nu}(T)] + [\frac{g_V}{g_A}]^2 M_M^{0\nu}(F),$$

M(α) Model

pnQRPA

^{76}Ge

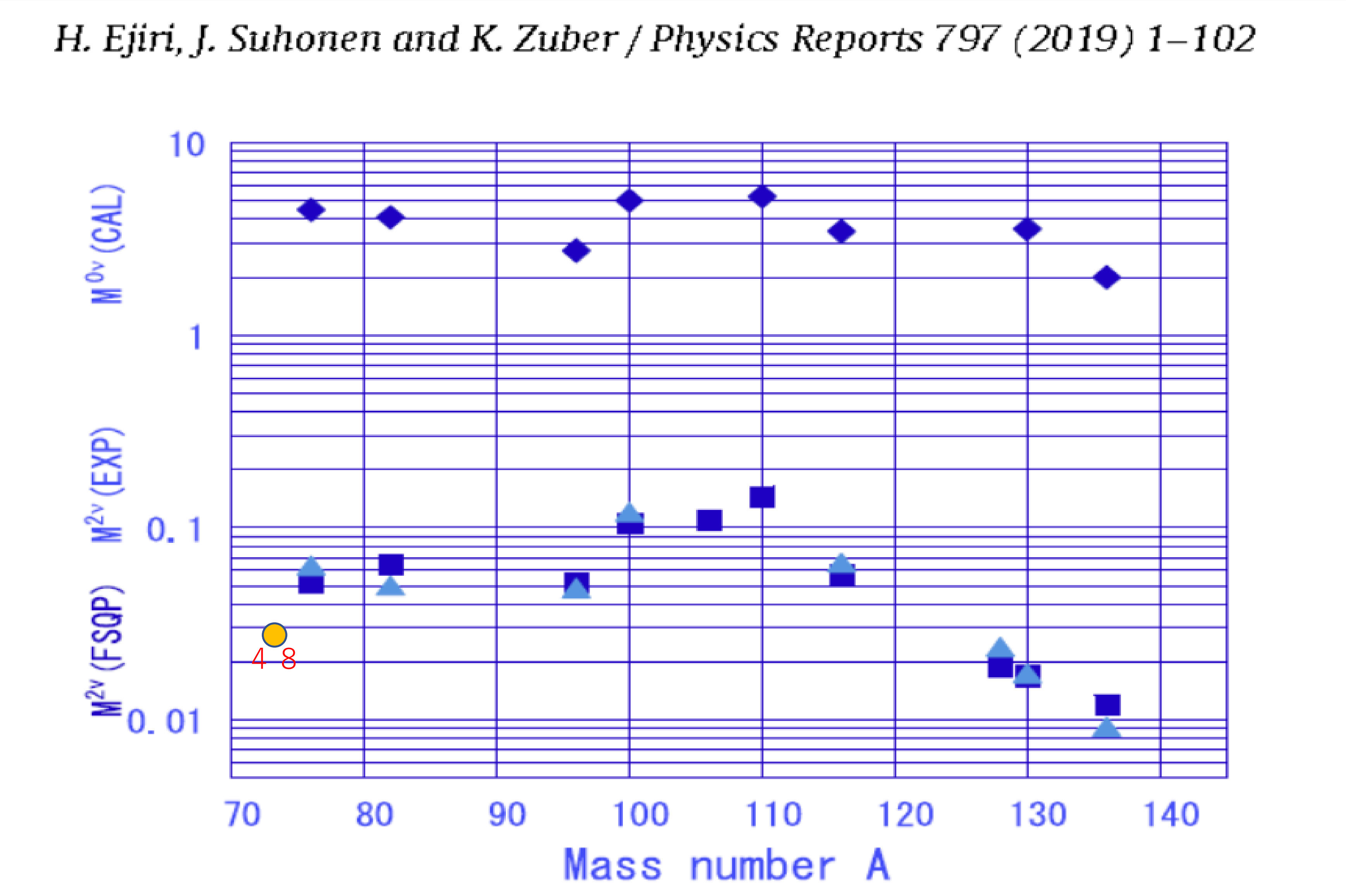
M(GT)=5.4,
M(T)=-0.36
M(F)=1.76
Jokiniemi, Ejir, Suhonen PR C 98 2018



g_A^{eff}/g_A= 0.5 leads to reductions 0.2 for M(GT),

0.4 for $M^{0\nu}$, 0.16 for DBD rate, ~ 40 for DBD detector

Nuclear structures on 2ν and 0νββ NMEs



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

DBD strategy Goal IH mass 20-15 meV

Yes Majorana and IH and mass , No Dirac or NH

- $m = k\, m_0 / M\, [B/N]^{1/4}$ m_0 for S=1/ty
- M = NME, B=BG/ty N=Isotope mass ton

ν-mass from 200 meV to 20 meV :

- BG by a factor 100 and N by 100.

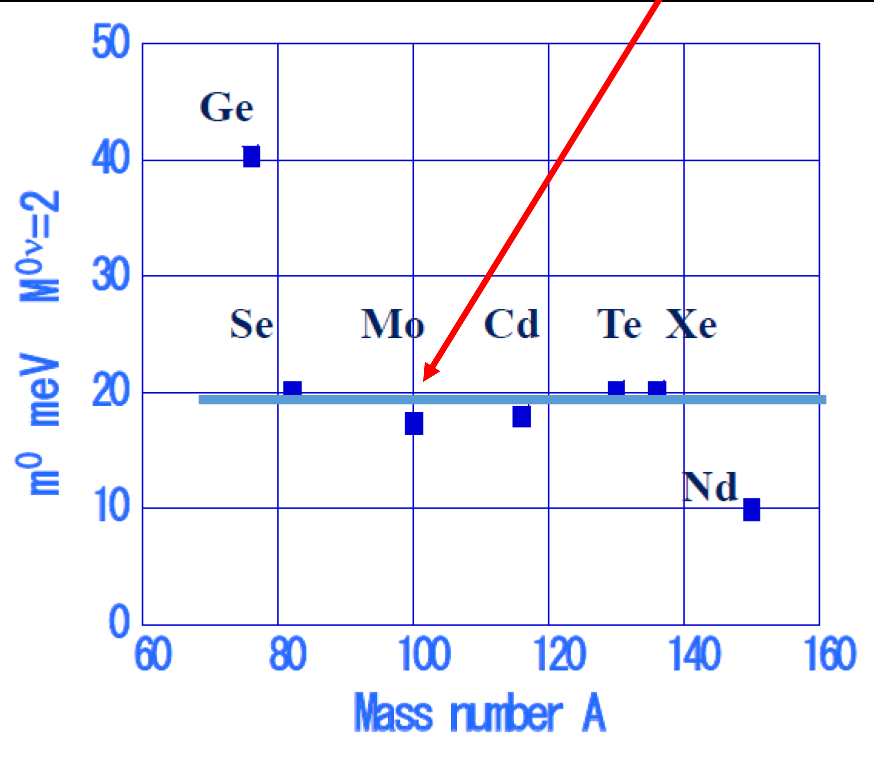
Exp. with Large M, large N, small BG

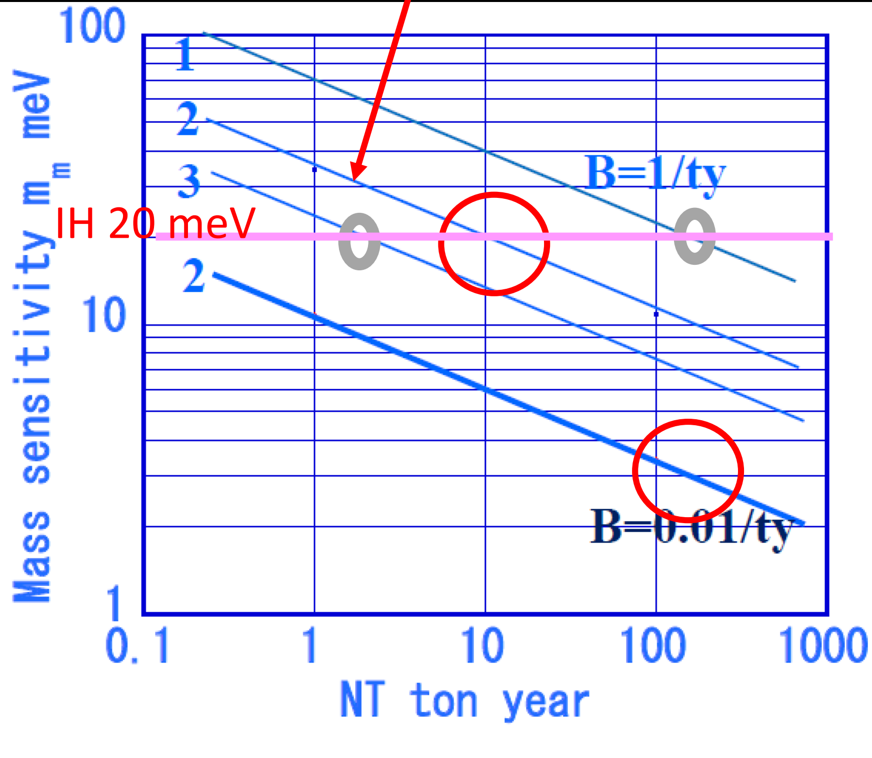
DBD $0\nu\beta\beta$ NMEs and DBD mass sensitivity

Nuclear sensitivity m^0= mass for 1/t y

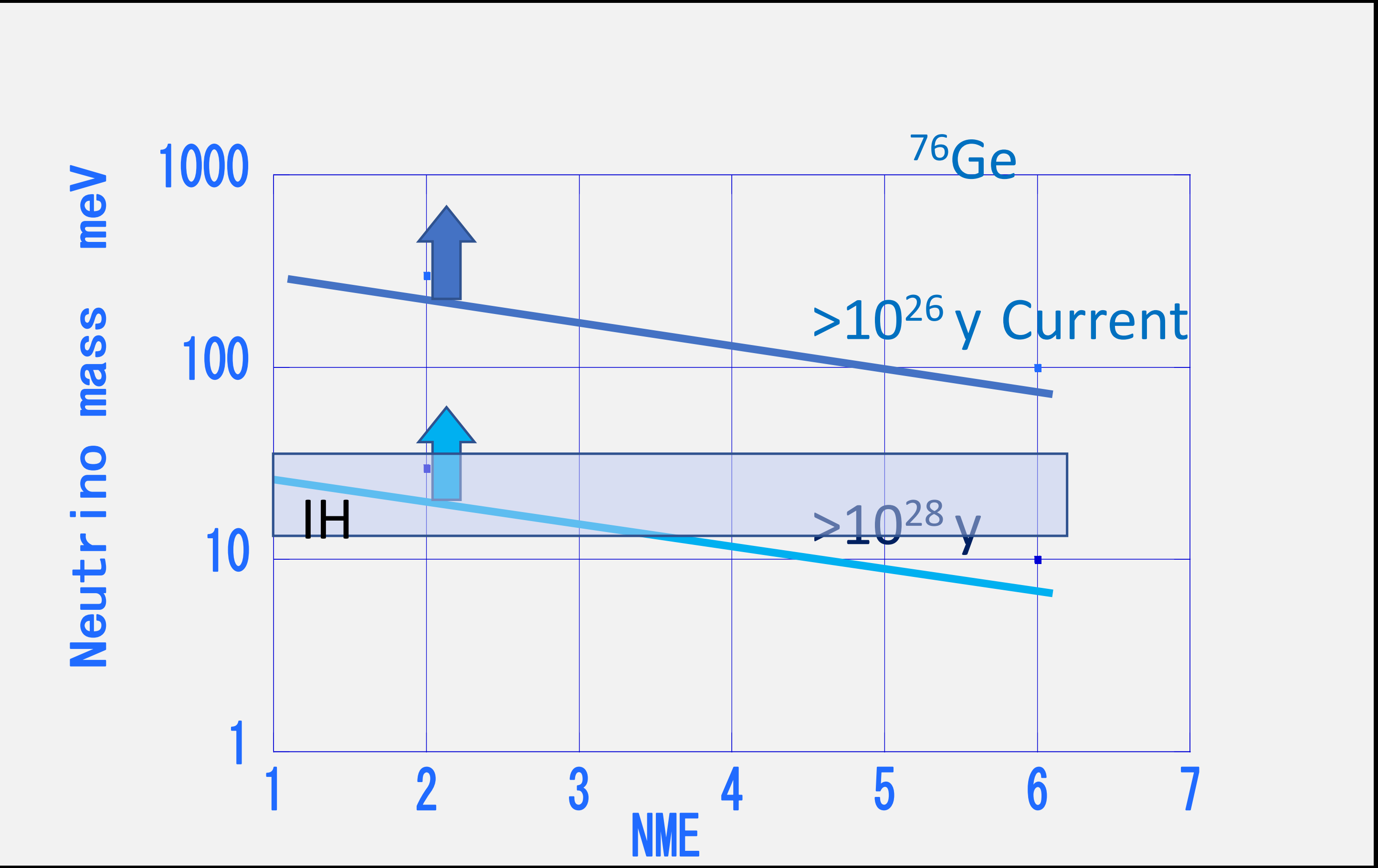
Ge requires a factor 20 less BG

Mass sensitivity mass to be detected $m_m = m^0 D$





$M^{0\nu}=k^2$ M(QRPA) ~ 2 , k=(g^{eff}/g)~0.6 - 0.7



Neutrino mass regions depend on NME

Possible DBD detector with IH mass 20 meV

Yes Majorana and IH and mass No Dirac or NH

- $m = k\, m_0 / M\, [B/N]^{1/4}$ m_0 for S=1/ty
- $M = NME = g_A{}^2 M(QRPA)$
- B=BG/ty N=Isotope mass ton

m_0	In case M	BG/t y	N ton /5y	Isotope A
40	2	0.1	3	Ge 76
20	1.5	1	6	Se 82
20	2	1	2	Mo 100
20	1-2	1	30-2	Xe 136


Thanks for your attention　Greenary Nimph 翠の精

Remarks

1. CER: (^{3}He,t) provides NMEs J= 0-2, p=5-100 MeV/c

   used for evaluating β^-, ν astro ν and DBD responses.

2. CER: (μ,ν_μ) shows MGR (giant resonance) at 12 MeV

   provides NMEs J= 0-3, p=50-100 MeV/c

   used for evaluating β^+, ν astro $\bar{\nu}$ and DBD responses.

3. M_{EXP}(GT,SD) are reduced from M_{QP} by $k^{eff}\sim$ 0.2-0.25,

   $k_{ts} \sim$ 0.4-0.5 by nucl. $\tau\sigma$, $k_m \sim 0.4\text{-}0.6 = (g_A^{eff}/g_A)$.

4. DBD NMEs ~ 0.5 NMEs(QRPA), and

   16 times less BG or more DBD isotopes than QRPA.

Estimation of M(SD) for ββ nuclei

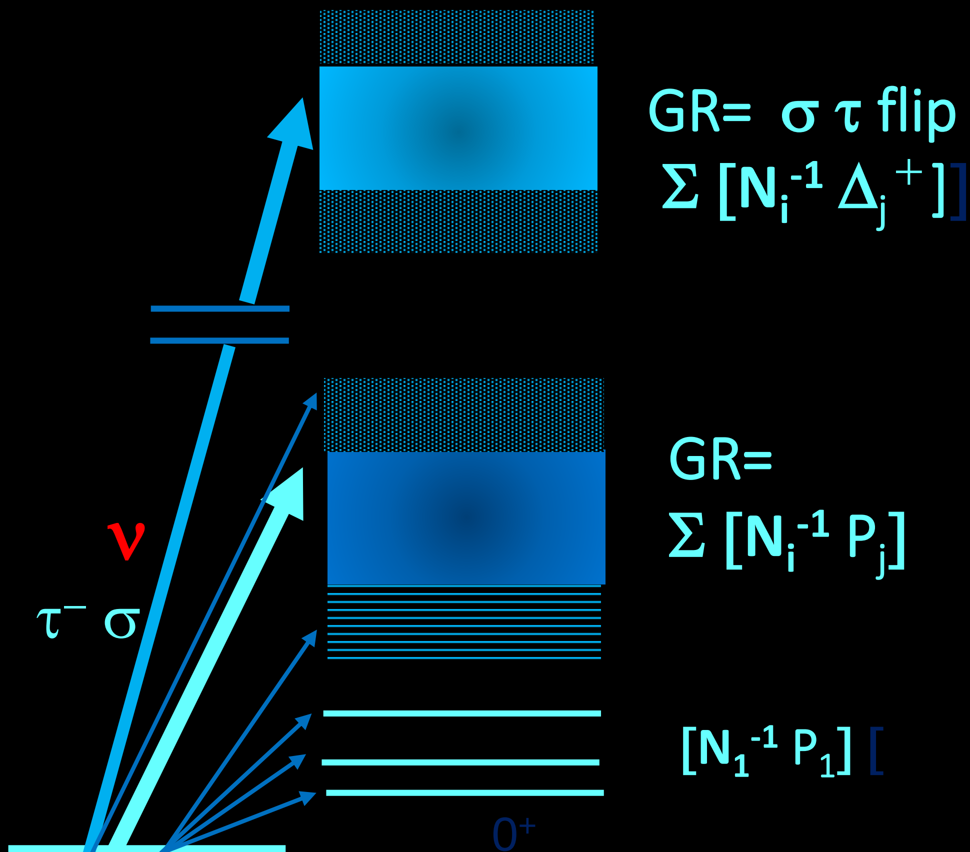
$$R = \frac{B(SD)}{B(F)} \Big/ \frac{\sigma_{SD}}{\sigma_{IAS}} = \frac{B'(SD)}{B'(F)} \Big/ \frac{\sigma'_{SD}}{\sigma'_{IAS}}$$

$$B(SD) = \frac{|M(SD)|^2}{2J_i + 1}$$

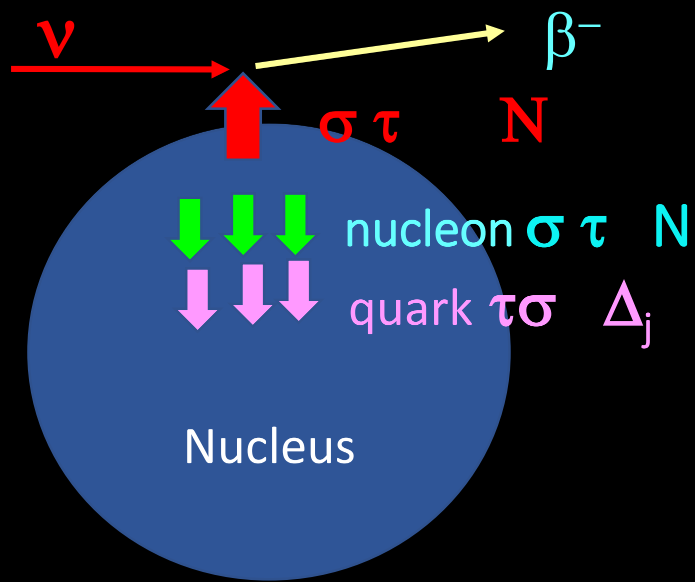
Benchmark Nuclei		M(SD)	σ(SD)/σ(IAS)	R
^{74}Ge <-> ^{74}As	2- g.s.	1.68	3.80±0.20 E-02	2.38±0.25
^{122}Sn <-> ^{122}Sb	2- g.s.	3.75	1.71±0.23 E-01	6.60±0.89
^{124}Te <-> ^{124}Te	2- g.s.	2.74	8.00±1.50E-02	5.30±0.74

ββ decay Nuclei		M(SD)		
^{76}Ge <-> ^{76}As	2- g.s.	1.57±0.24	2.71±0.13 E-02	2.38±0.66
^{128}Te <-> ^{128}I	2- 134 keV	2.82±0.48	7.75±0.50 E-02	5.95±0.60
^{130}Te <-> ^{130}I	2- 354 kev	3.33±0.59	9.90±1.47 E-02	5.95±0.60

Weak int.: spin isospin τσ $N^{-1}N$ GR and $N^{-1}\Delta$ GR



Nuclear medium
τσ polarization



H. Ejiri PRC 26 '82 2628

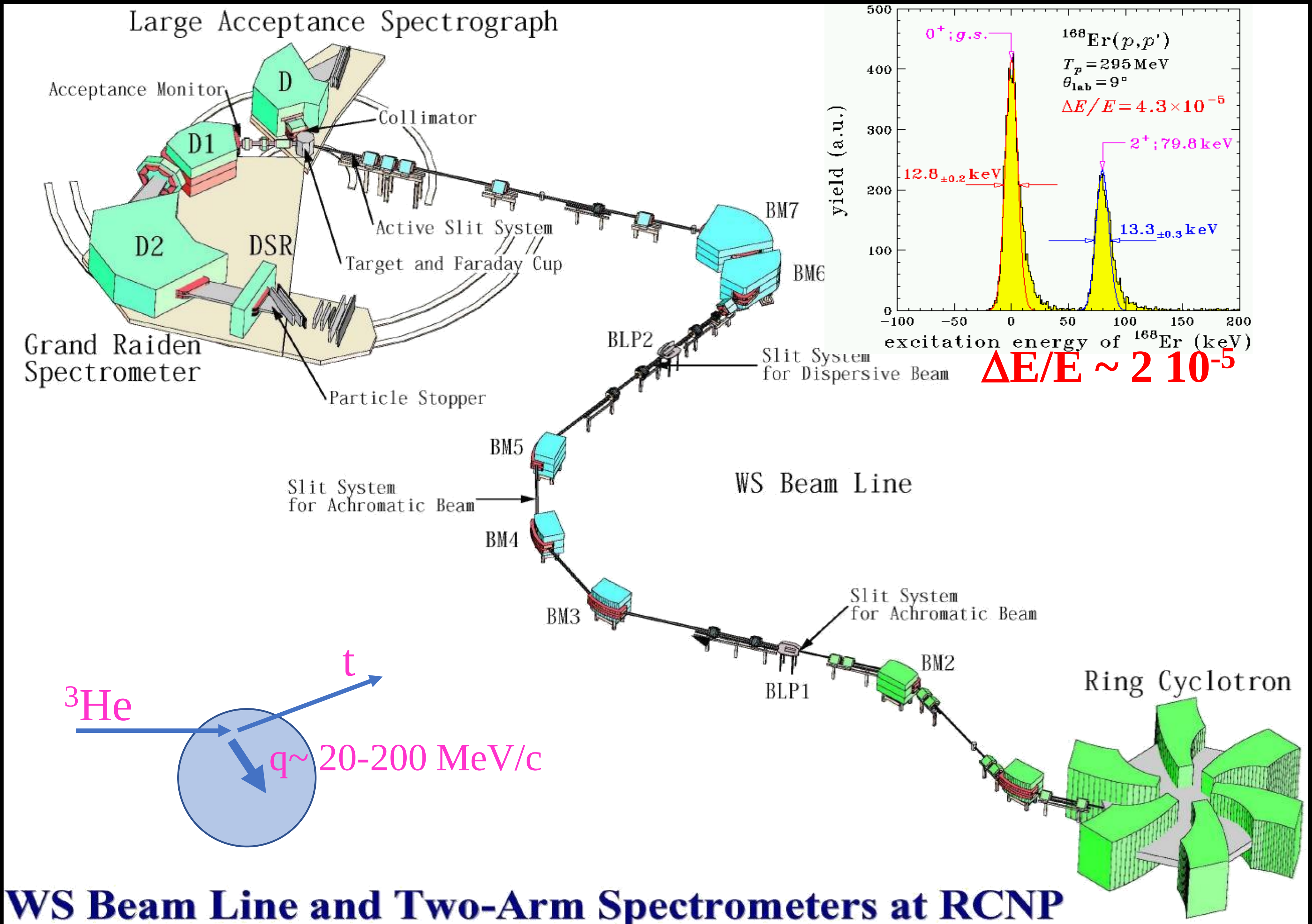
Nuclear core change ,
Bohr Mottelson
PL B 10 '81 10 Isobar

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

$$M^{\beta} \sim k^{eff} M_0 \quad k^{eff}\ (\tau\sigma) \sim 1/(1+\chi_{\tau\sigma}) = 0.4$$

$$k^{eff}\ (\Delta) \sim 0.6 \qquad \chi_{\tau\sigma}\text{: susceptibility}$$

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



$M(SD\ 2^-)EXP = k\ M(SD\ QP)$

$B(SD)=[\sigma(SD)/\sigma(IAS)]B(IAS)$ **K**, $B(SD)=M(SD)^2$

$\sigma(SD)/\sigma(IAS)$ for ^{76}Ge, B(IAS) =N- Z, and **K** is from the measured cross section ratio for ^{74}Ge with B(SD) from ft

	M(CER)	M (FSQP)
^{76}Ge (SD)	1.57 ± 0,24	2.1
^{128}Te (SD)	2.82 ± 0.48	3.4
^{130}Te (SD)	3,33 ± 0.59	3.7

M(ESQP) with k~0.25 from ft data in neighboring nuclei.

H. Ejiri D. Frekers J. Physics G. Letters Sept.

k~0.25, with 0.5 from $\tau\sigma$ and medium(g_A) effect 0.5

SD RCNP H. Akimune, H. Ejiri, RCNP Catania, Munster, KVI , ・ ・