Experimental nuclear structure studies for neutrino physics

Hiro Ejiri RCNP Osaka

Key Questions

1. Why & how do we study experimentally ν-nucl. responses /structures ?

2. How do single β–γ exps. help study ν responses ?

3. How are charge exchange reactions used?

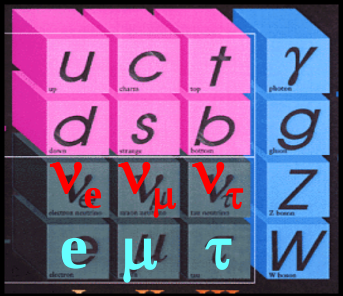
4. How are lepton(μ & ν) and photons are useful ?

5. How are axial/vector couplings renormalized ?.

Summary and remarks

Q1. Why & how do we study experimentally ν nuclear responses (nuclear structures) ?

Fundamental questions of neutrinos



Neutrinos, KEYs for astro nucl. particle physics

1. Dirac ν ≠ anti ν, Majorana particle ν = anti ν ?

2. Absolute mass & mass hierarchy ?

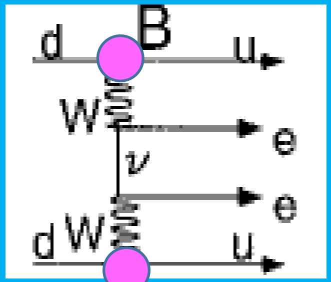
3. Lepton sector CP phases ? Leptogenesis for B asymmetry?

4. Astro neutrino nuclear interactions ?

5. Neutrino nucleosynthesis ?

These fundamental questions of ν s are studied by nuclear β/ββ decays and astro-ν interactions in nuclei, where ν-nuclear responses (structures) are crucial.

Nuclear Response = M^2 : M=NMEs



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

Nuclear phys Particle/astro phys.

A. DBD Neutrino-less ββ M

$M = g^2_A M_{DA} - g^2_F M_{DF} + g^2_A M_T$ g_i in unit of bare g_A for free N.

$M_{DA} = <\sigma\tau h\sigma\tau>$ $M_{DF} = -<\tau h\tau>$ $h \sim k/(r_1 - r_2)$

q~ 1/(1-5)fm ~ 40-150 MeV/c, $l\hbar \sim 0\text{-}5\hbar$

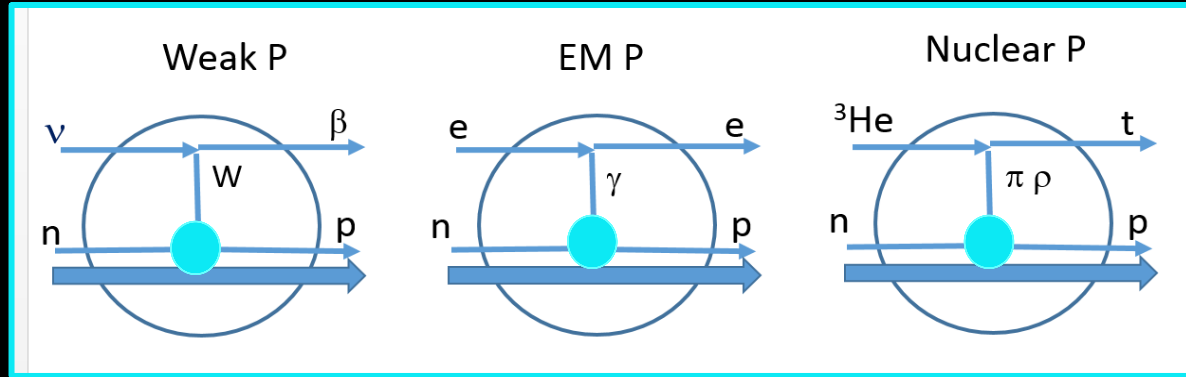
$g^2_A M_{DA} \sim \Sigma\ g_A M_B \cdot g_A M_B$ $J^{\pm} = 0\text{-}5^{\pm}$ 2νββ q=3 MeV/c, GT 1^+

B. Astro ν and anti-ν response

Super nova ν: E~5-50 MeV, q~ 5~ 50 MeV/c, $J^{\pm} = 0\text{-}3^{\pm}$

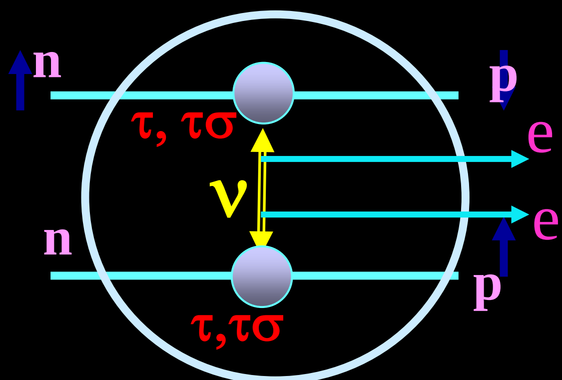
DBD ν and Astro ν responses are q=5-150 MeV/c, $J^{\pm}$ with J=0-4

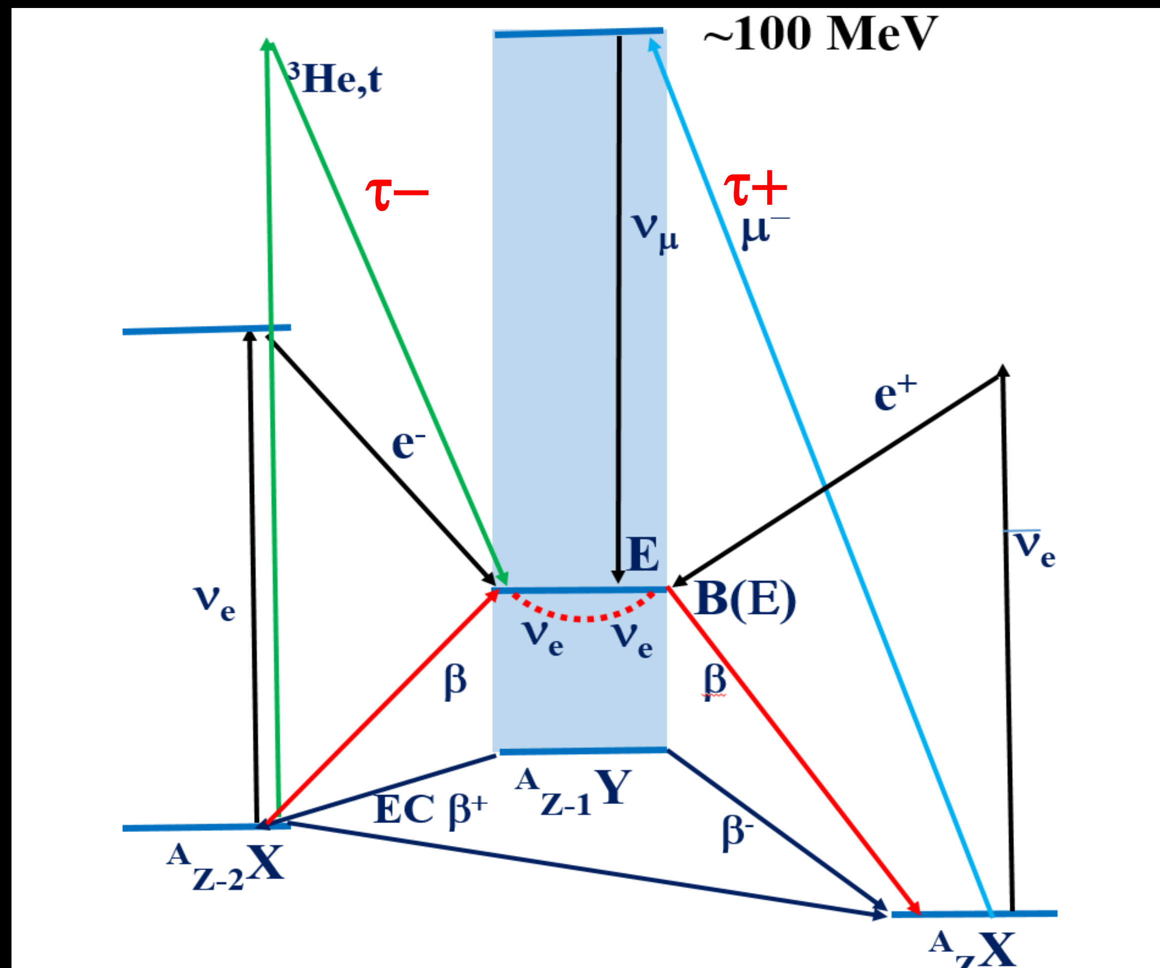
CERs for CC



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

Sensitive to NN, NΔ/π nuclear medium effects





$$M(EXP) = g_A M$$
$$M(EXP) = g_F M$$

to help calculations

Q2. How do single β–γ NMEs help study neutrino nuclear responses (NMEs)

GT 1^+ 2^-, 4^- $\tau\sigma$ axial vecor NMEs reductions

$$M^{m}_{exp} = k\, M_{QP}$$

$$k = 0.2 – 0.3 = k_{\tau\sigma}\, k_{NM}$$

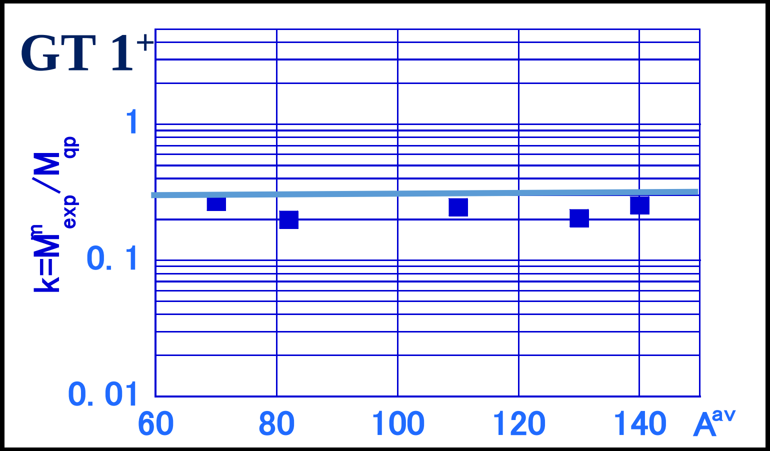
$$M_{QRPA} = k_{\tau\sigma}\, M_{QP}$$

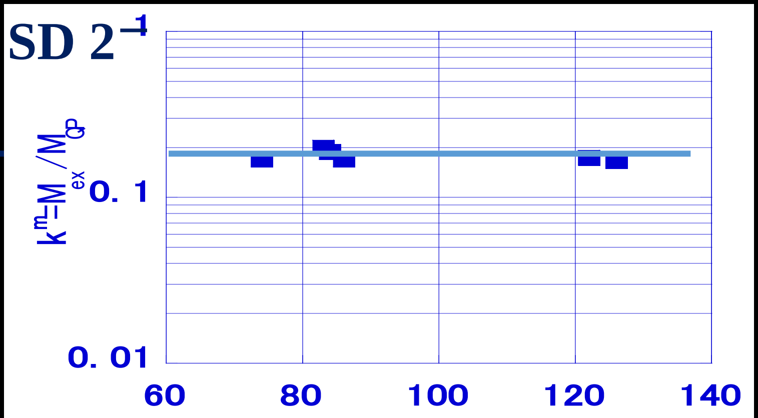
$k_{\tau\sigma} \sim 0.4$ due to NN $\tau\sigma$

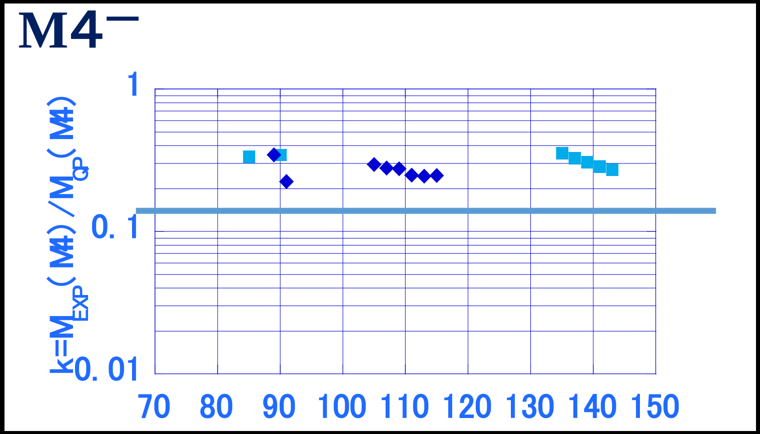
$$M_{exp} = k_{NM}\, M_{QRPA}$$

$k_{NM} \sim 0.6$ (g_A^{eff}/g_A)

NΔ π short range

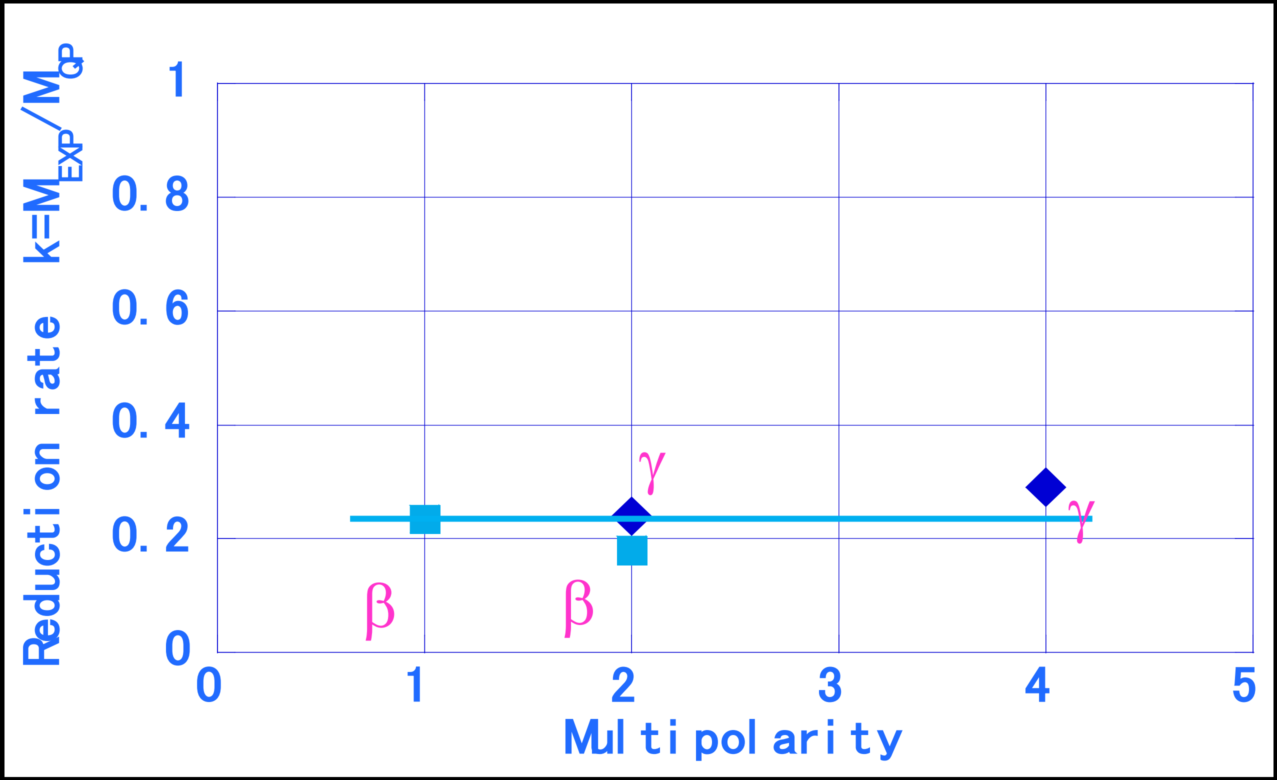






H, Ejiri J. Suhonen J. Phys. G. 42 2015 055201
H. Ejiri N. Soucouti, J. Suhonen PL B 729 27
L. Jokiniemi J. Suhonen H. Ejiri
AHEP2016 ID8417598

Universal reductions of axial vector β & γ



Ejiri Fujita PR 34 85 1978

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

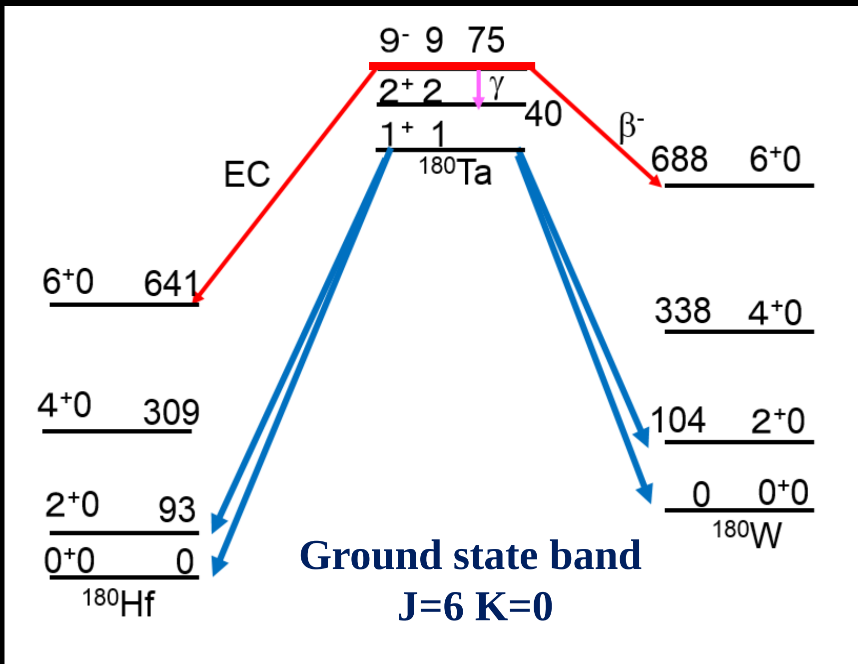
$k=k(\tau\sigma) \sim 0.5$: Nucleonic long range $\tau\sigma$ GR

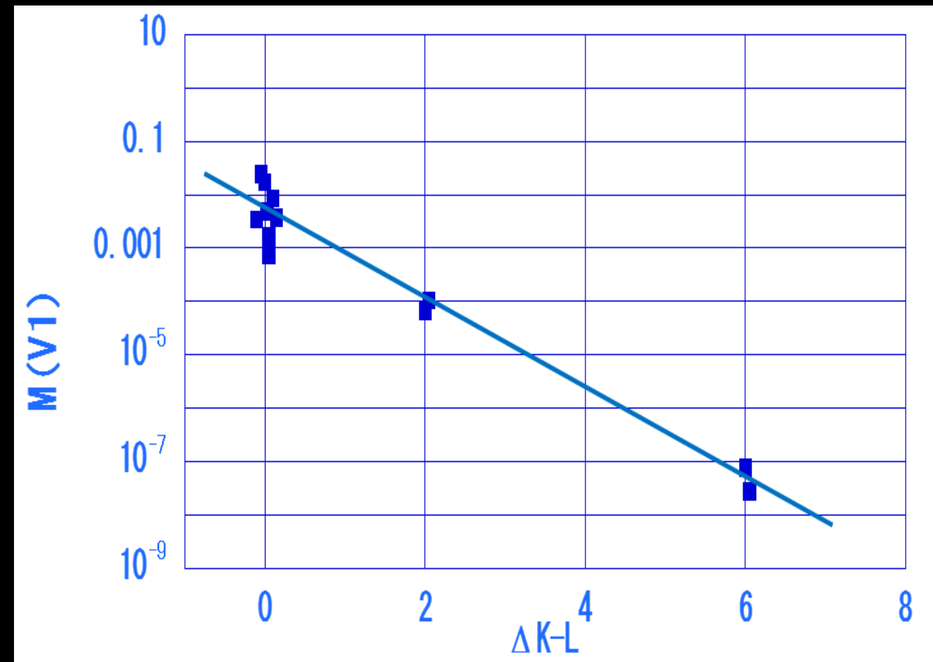
$k(NM) \sim g^{eff}_A/g_A \sim 0.6$: Short range nucl. medium $\Delta\ \pi$

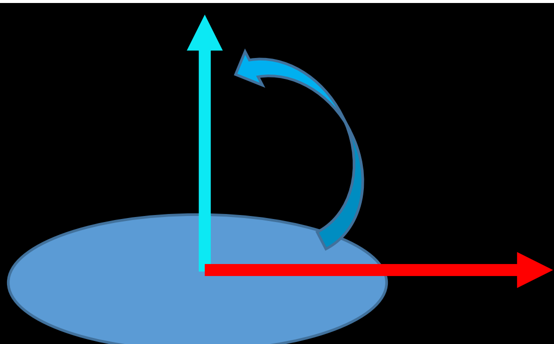
Neutrino nucleosynthesis ^{180}Ta, 2.4 10^{-12} per 1 Si

Synthesis ~ M^2 for 5-40 MeV

H. Ejiri T. Shima J. Phys. G. 44 2017 065101







$M=kF^{\Delta K\text{-}L}$, F=0.15 by every ΔK-L

EC $T_{1/2}$=1.4 10^{20} y Exp 2 10^{17} y

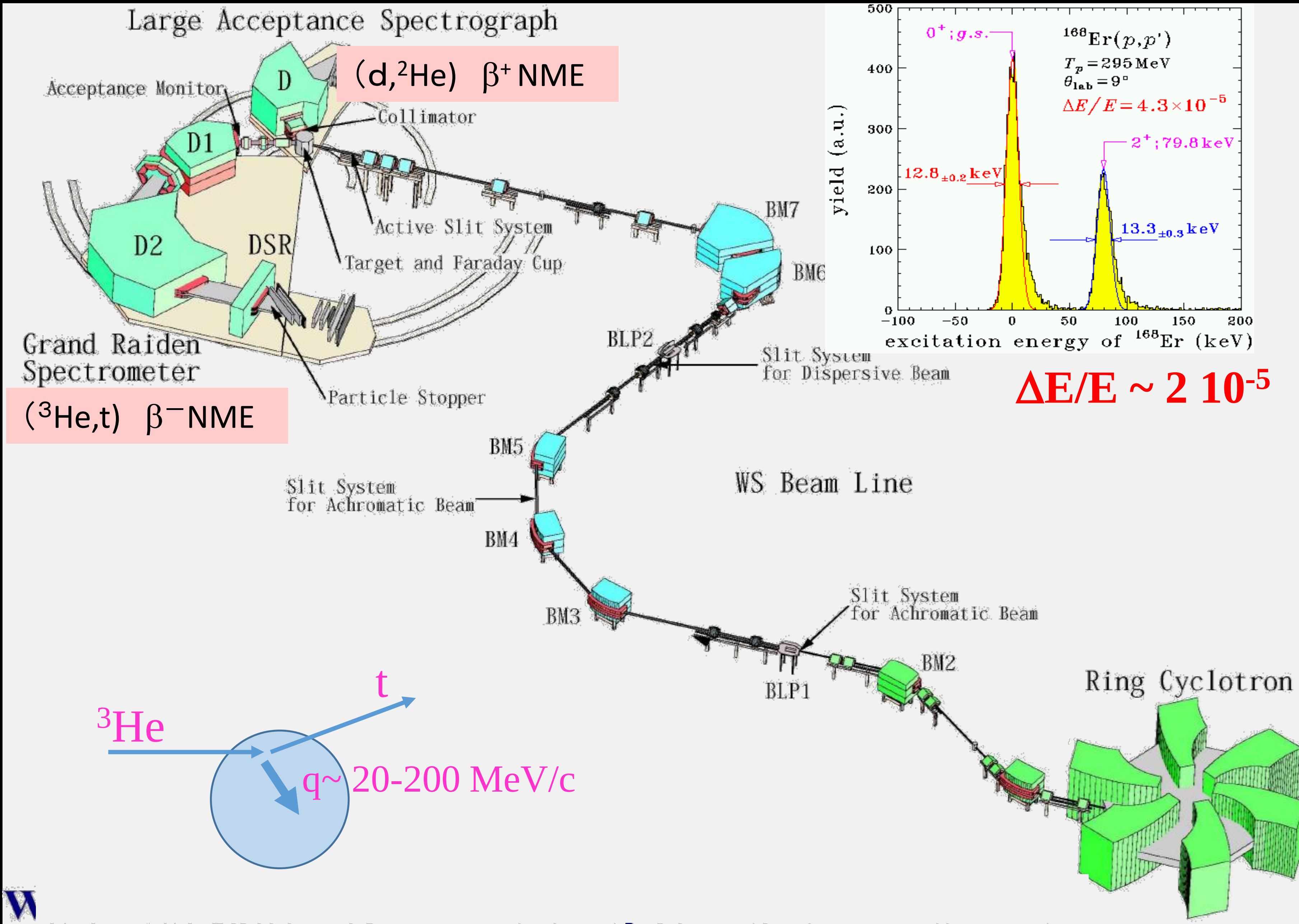
β^- $T_{1/2}$=5.4 10^{23} y Exp 1 10^{16} y

^{181}Ta isomer J=9 K=9

Exp Lehnert et al Dresden 2016

Q3. What do we learn from nuclear charge exchange reactions CERs ?

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



(d,^{2}He) β^+ NME

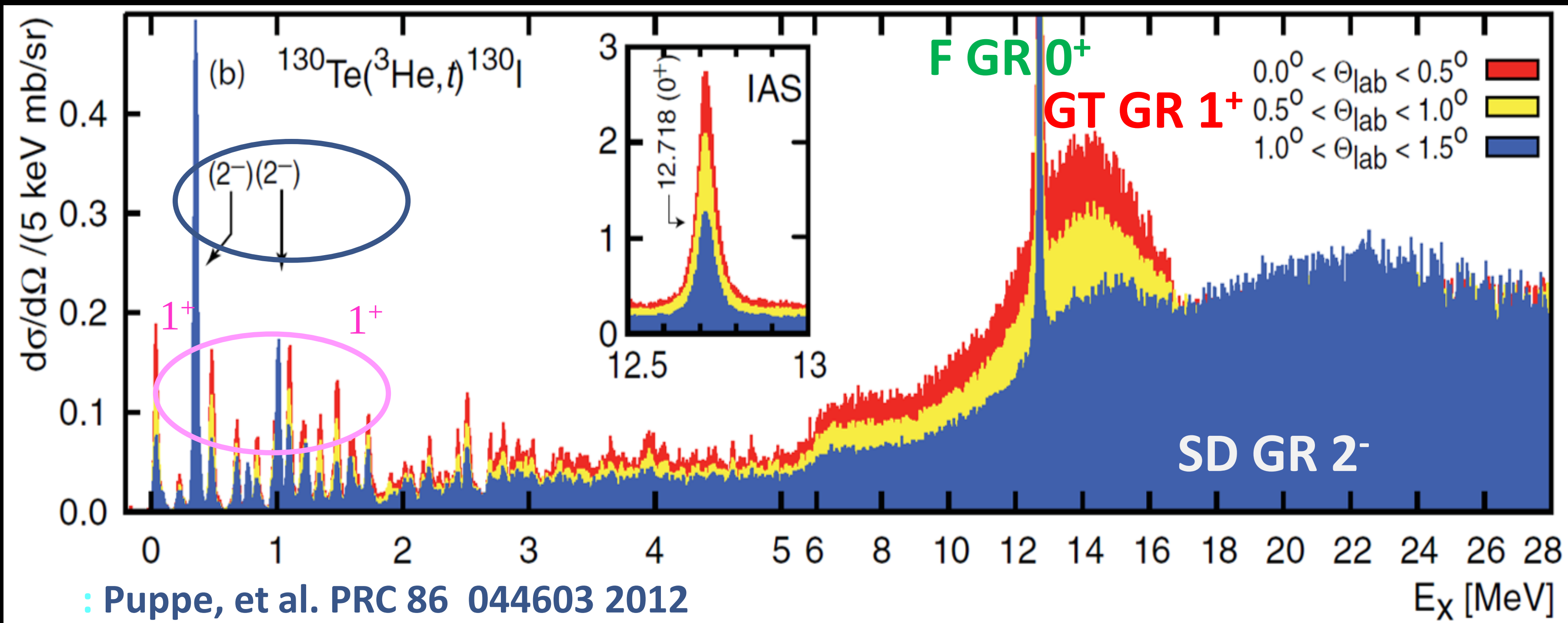
(^{3}He,t) β^-NME

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

RCNP CERs for DBD ^{76}Ge, ^{82}Se, ^{100}Mo, ^{128}Te, ^{130}Te ^{150}Nd

At E/A~0.2 GeV, V(τσ) dominates, thus

$M(J)= [\sigma\tau \times rY_l]_J$ θ=0~4 deg., q~ 20-150MeV/c



CER EXP at RCNP Akimune, H.Ejiri, D.Frekers M.Harakeh et al 1994- 2016.

No/weak F 0^+, GT 1^+ SD at low region and strong F GT SD GR

HI CER Lenske CNNP17

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

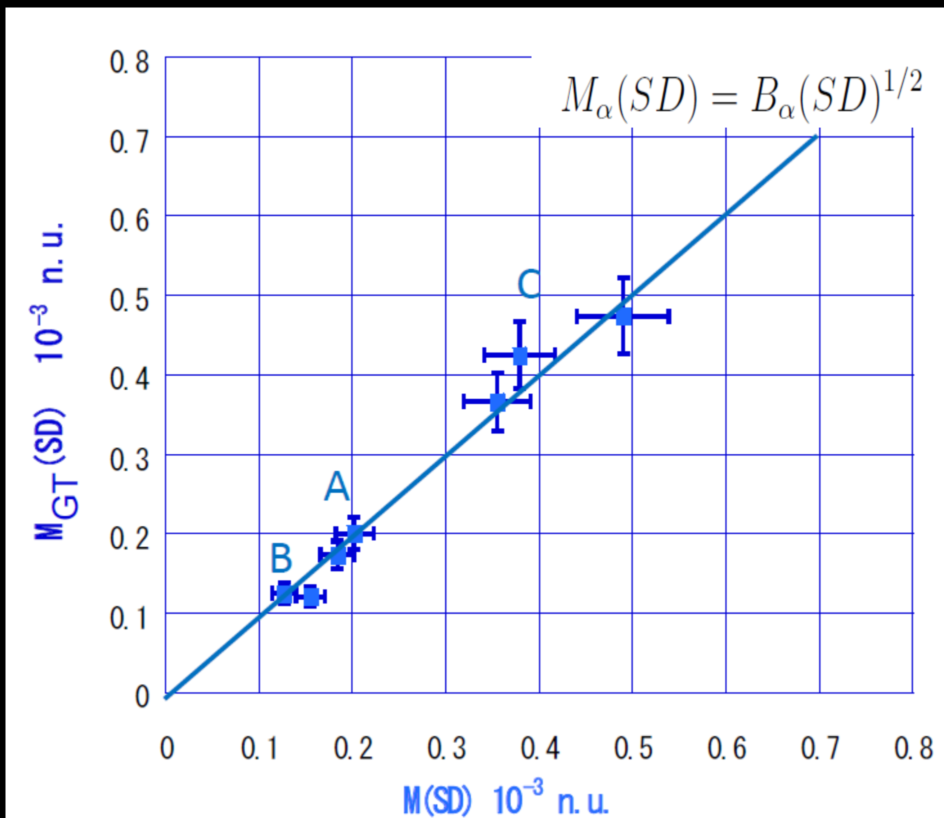
Ejiri D. Frekers
J. Physics G. 43 11L01

$$\frac{\sigma_\alpha(q,\omega)}{d\Omega} = K(E_i,\omega) f_\alpha(q) N_\alpha^D(q,\omega) J_\alpha^2 B(\alpha),$$

α denotes the Fermi, GT and SD mode excita

$$B_\alpha(SD) = R_\alpha B_{R\alpha}(SD),$$

$$B_{R\alpha}(SD) = [\frac{d\sigma_{SD}(\theta_1)}{d\Omega}][\frac{d\sigma_\alpha(\theta_0)}{d\Omega}]^{-1} B(\alpha),$$



	M(CER)	M (FSQP)
^{76}Ge (SD)	2.0	2.1
^{128}Te (SD)	3.55	3.4
^{130}Te (SD)	4.05	3.7

SD NMEs with k~0.25 from ft data in neighboring nuclei.

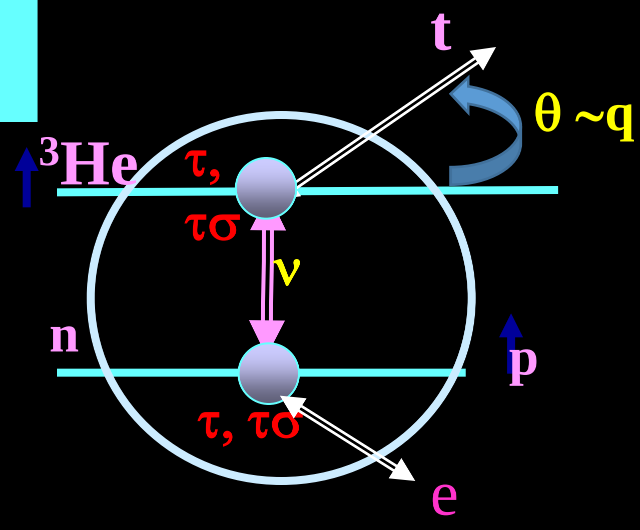
k=M/M(QP) = QRPA ~0.5

cs G. Letters Sept.

and medium(g_A) effect 0.5

SD RCNP Akimune, Ejiri, RCNP Catania, Munster KVI with

CER. F, GT &SD q-dependence

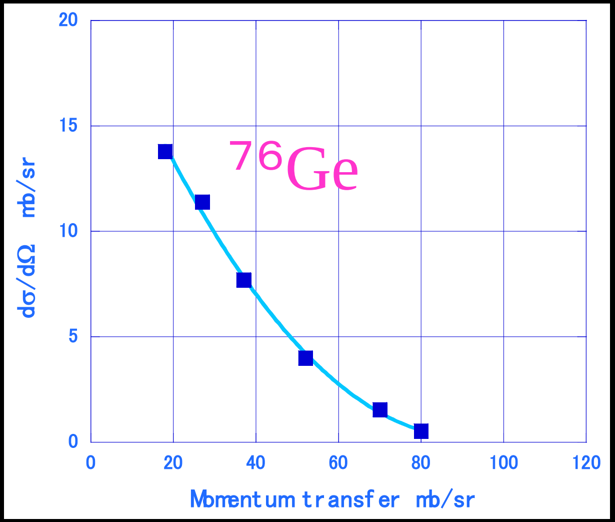


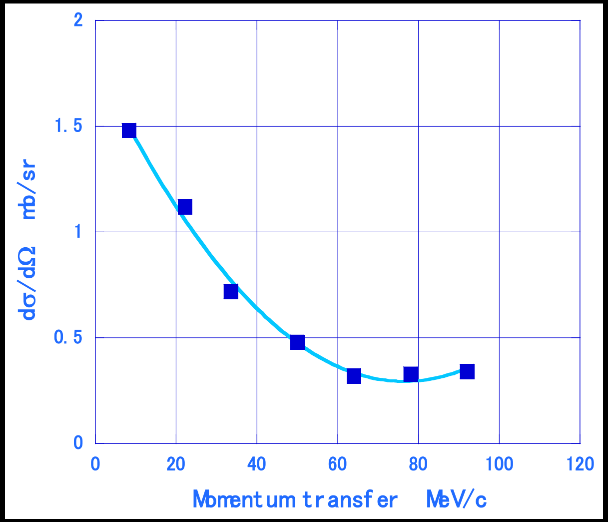
$$d\sigma(q) = C\,|j_a(qr)|^2\, M_\alpha(q)^{\,2}$$

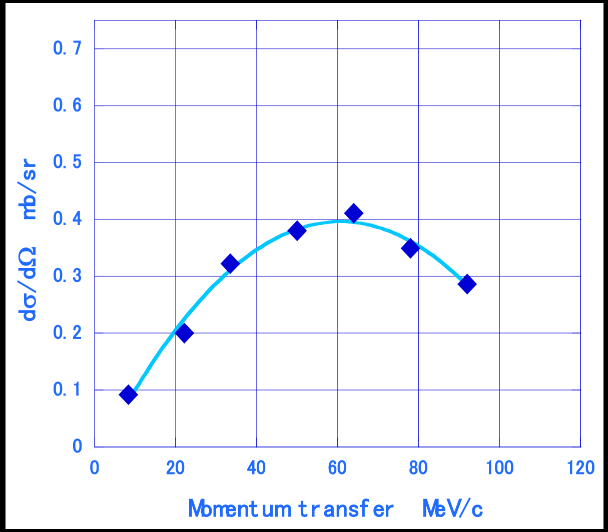
$$M_\alpha(q)=k^{eff}(q)\, M_\alpha(QP)$$

j_0 for IAS, GT, j_1 for SD

$k^{eff}(q)= g_A{}^{eff}(q)$~ constant q=20 – 100 MeV/c

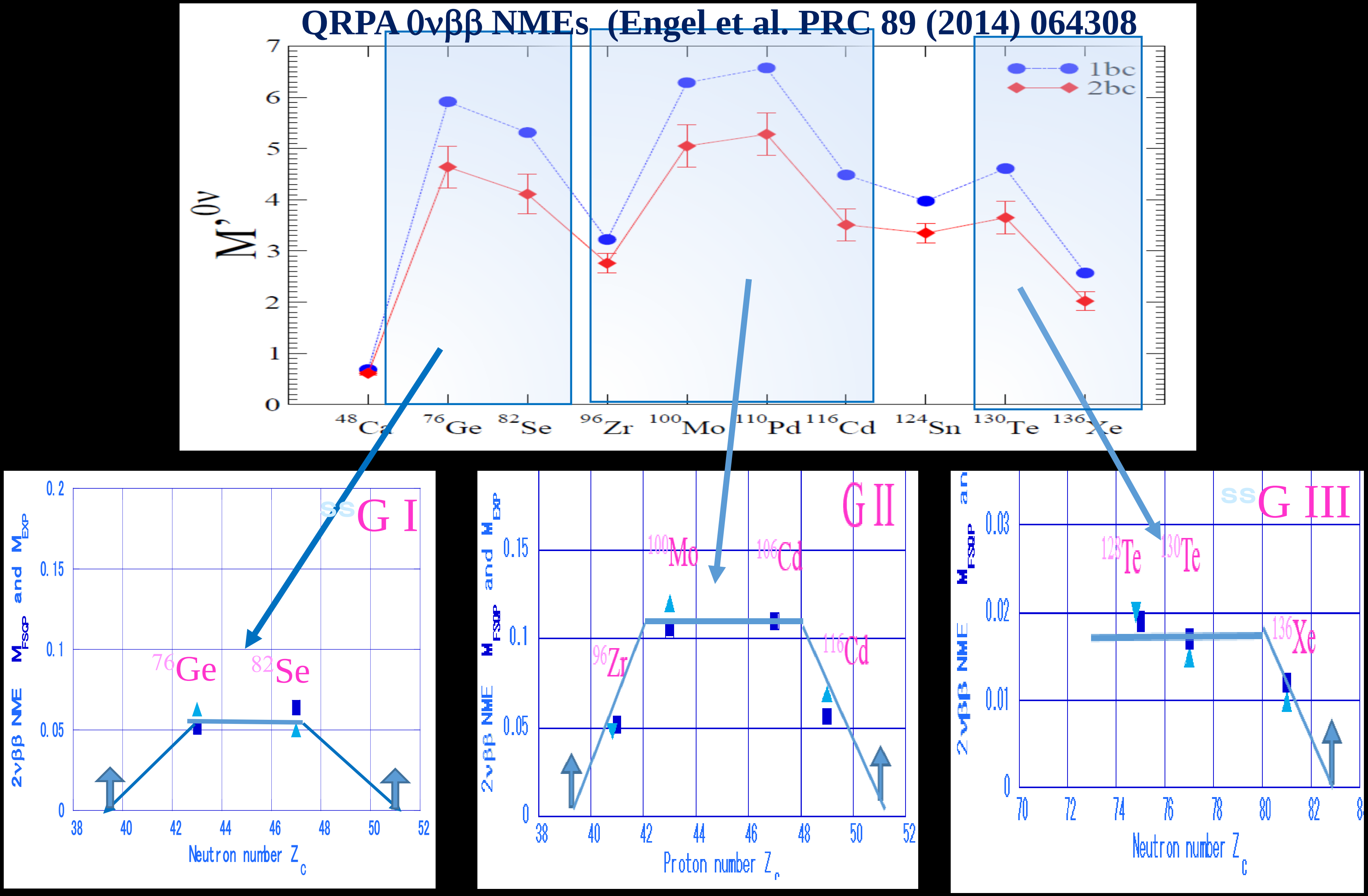






g_A~const over q=0-100 MeV/c

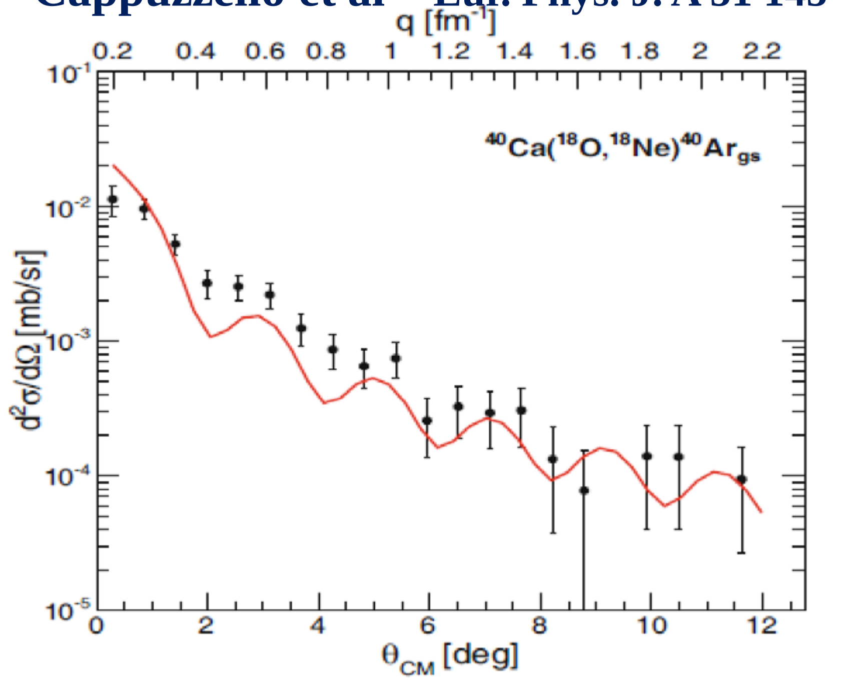
Nuclear structures on 2νββ NMEs



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

Double charge exchange reaction

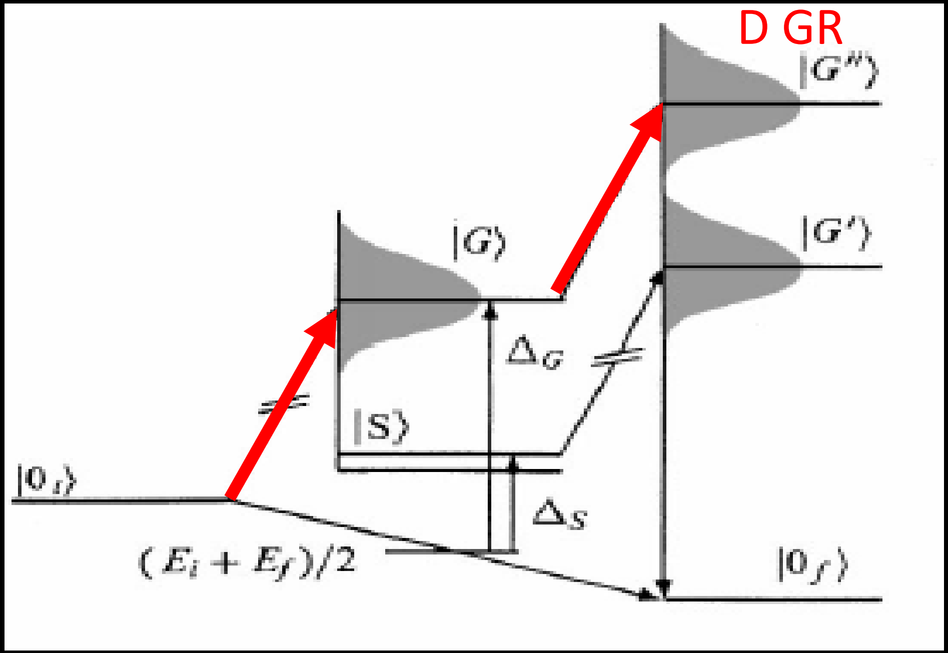
Cappuzzello et al Eur. Phys. J. A 51 145



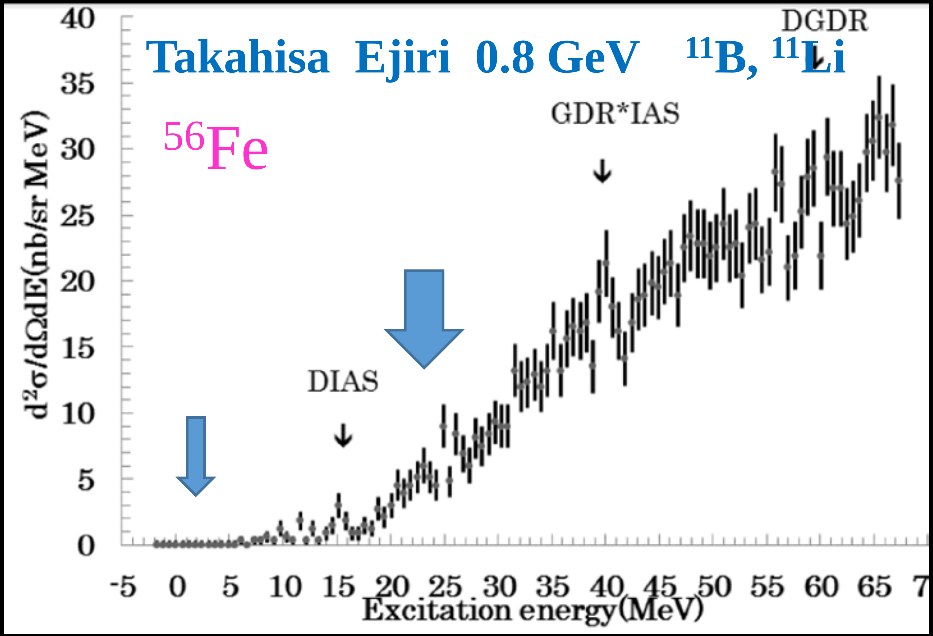
E/A=15 MeV Various kinds of V(τσ q)

N. Auerbach Annals 77 1989 DGT
H.Ejiri et al JPSJ 65 (1996), No GT GR
T. Uesaka GTGT

Yako DCE CNNP17
Menedez DGT CNNP17



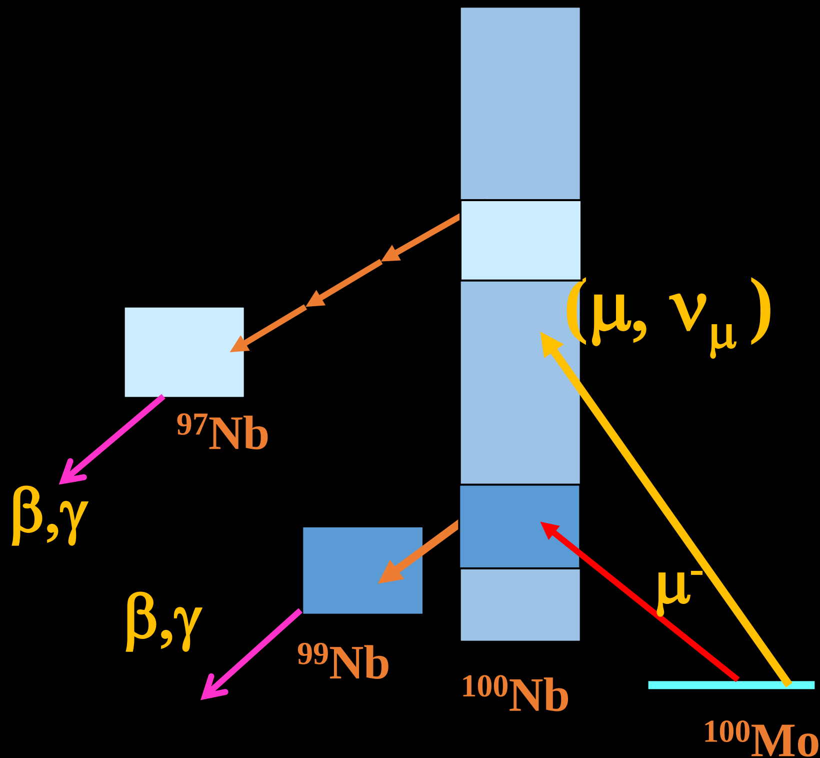
Takahisa Ejiri 0.8 GeV ^{11}B, ^{11}Li

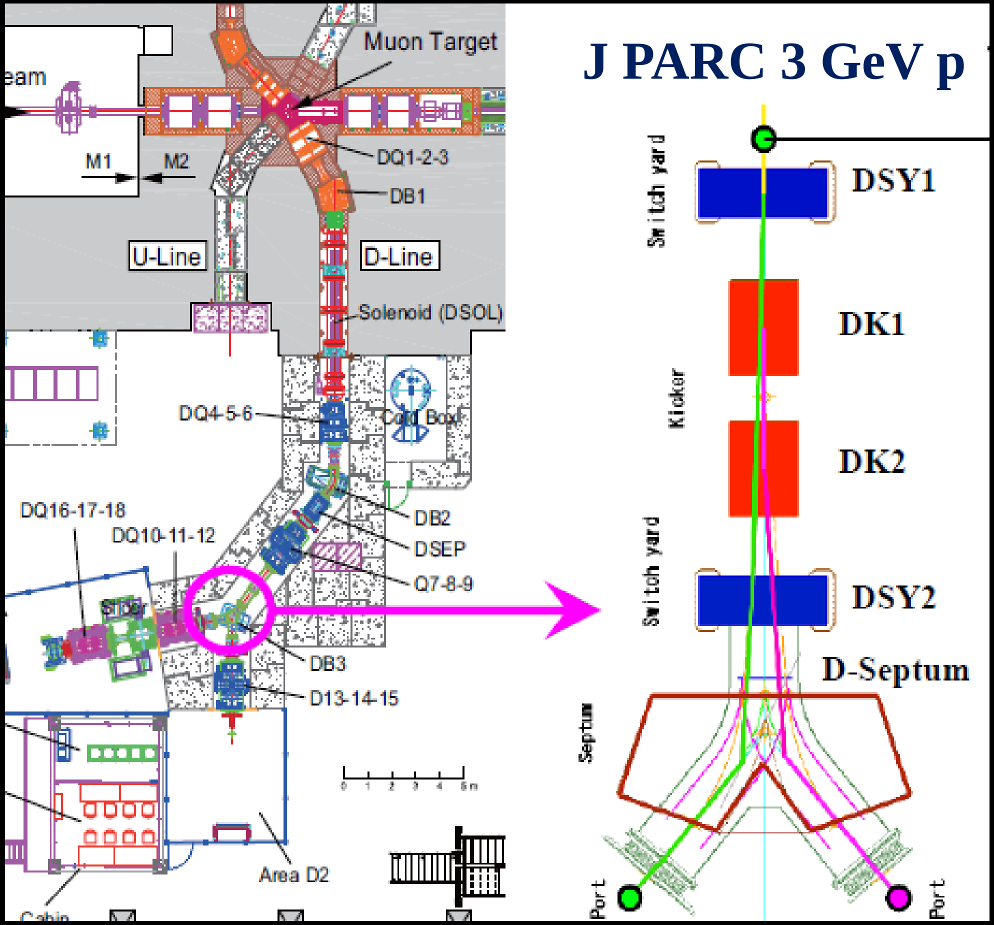


Y(0-10MeV) /Y(20-30 MeV)=0.03

Q5. How are lepton photon CERs used for neutrino nuclear responses ?

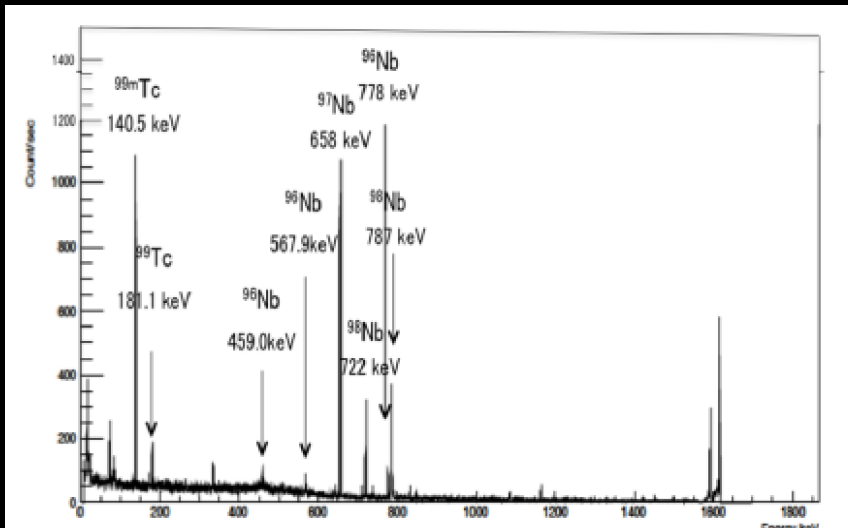
CER (μ,ν_μ, xn γ) ν–β^+ Responses q~50 MeV/c

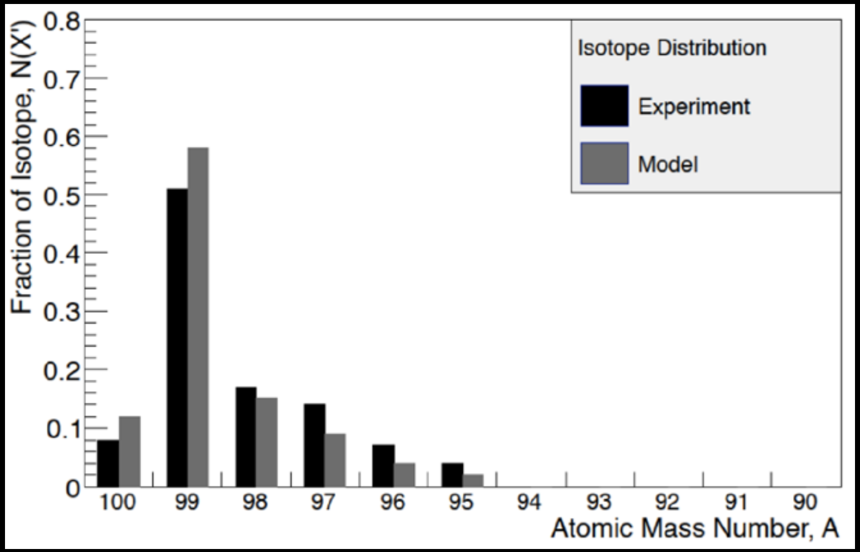


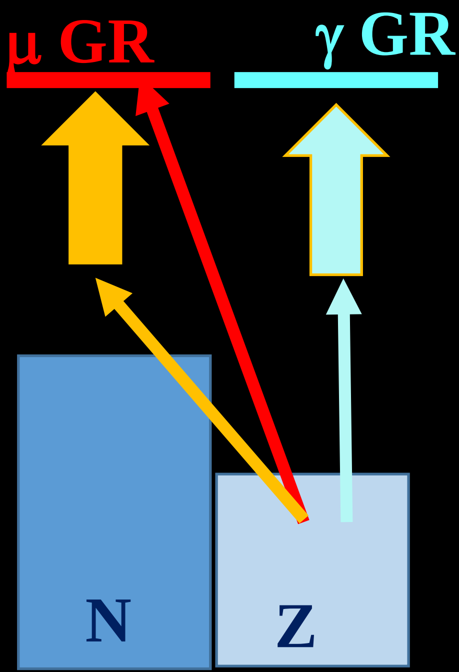


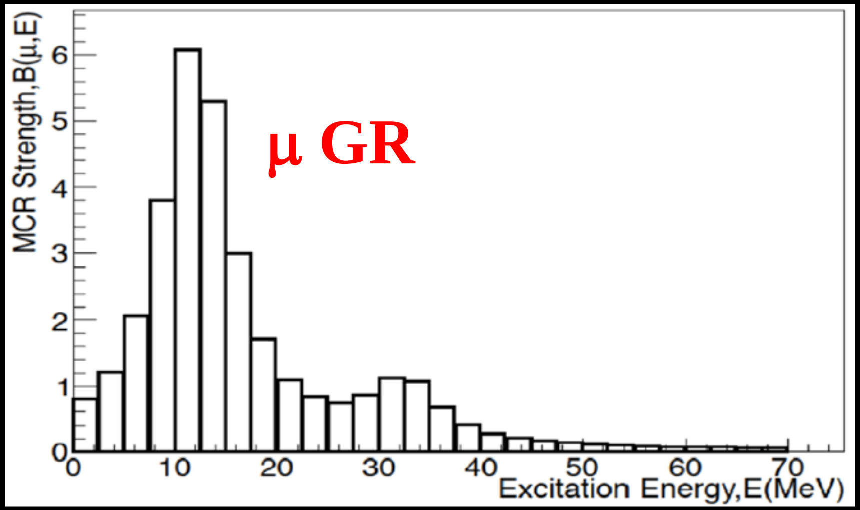
γ_i from $^{100-i}$Nb: relative strength   Life time : the absolute strength

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









I. Hashim PhD Thesis Osaka 2015I.

I. Hashim H. Ejiri , 2015. MXG16

Muon capture nuclear γ at SIN

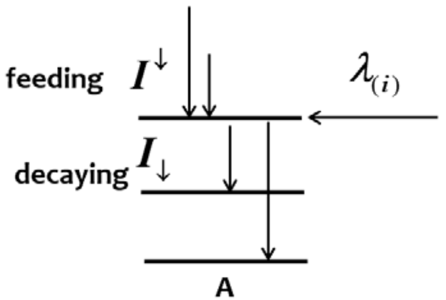
Ordinary muon capture (OMC) studies for the matrix elements in ββ decay.

What do we gain from μ-capture for the ββ decay?

Experiment: PSI, beamline μ-E4

K.Ya. Gromov, **D.R. Zinatulina**, **D. Frekers**, C. Briançon, V. Egorov, R. Vasiliev, M. Shirchenko, I. Yutlandov, C. Petitjean, J. Deutsch.

Extraction of the partial rates



$$\lambda_{(i)} = \frac{\sum I_{\downarrow} - \sum I^{\downarrow}}{\varepsilon \sum I(nK)}$$

detailed balance

$$\lambda_{cap} = \lambda_{total} - Q\lambda_{decay} \quad Q \rightarrow \text{Huff-factor}$$

$$\lambda_{(i)}[\%] = \frac{\lambda_{(i)}}{\lambda_{cap}}$$

(μ, ν_{μ}) low states,

Many γ from and the state .

Daniya in MXG16

J. Suhonen, M. Kortelainen Czech. J. Phy. 56 2006 519, EXP 453.
V. Egorov (μ, γ , n γ, p γ) on ^{48}Ti, ^{76}Se 2004 γ –exp.

Neutrinos reaction

SNS ORNL , J-PARC

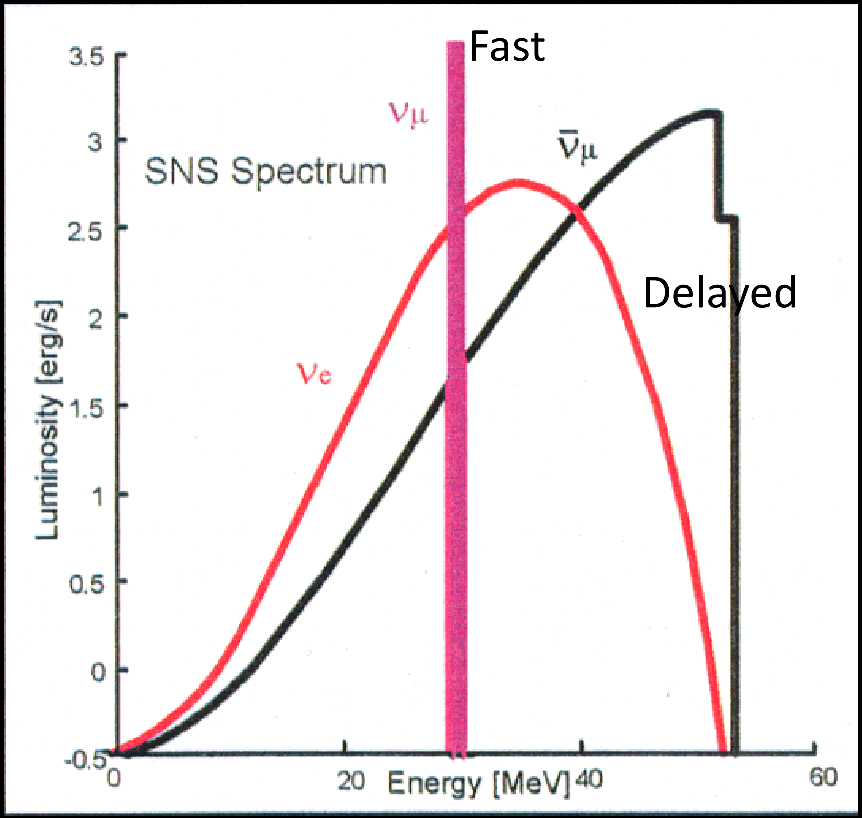
$p + Hg \rightarrow n\, \pi^+$

$\pi^+ \rightarrow \mu^+ + \nu_\mu$

$\mu^+ \rightarrow e^+ + \nu_e + \text{anti-}\nu_\mu$

SNS 1 GeV p 10^{15} ν/s,

J-PARC 3 Gev p 5 10^{14}* ν/s



Astro nuclear responses of

$\sigma \sim 10^{-41-42}$ cm^2 with large detectors(10 tons)

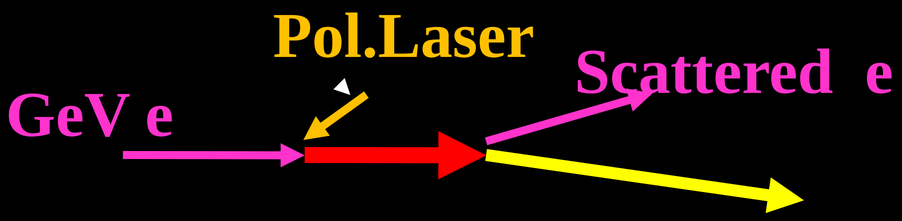
* H. Ejiri NIM. 503 (2003) 276 – 278.

SNS HFIR ORNL ν, anti-ν Galindo Uribarri CNNP17

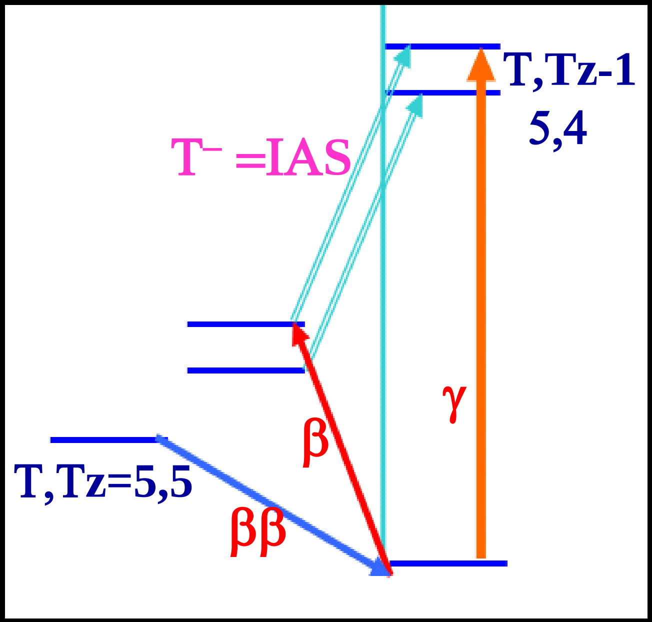
LEPS Photon probe

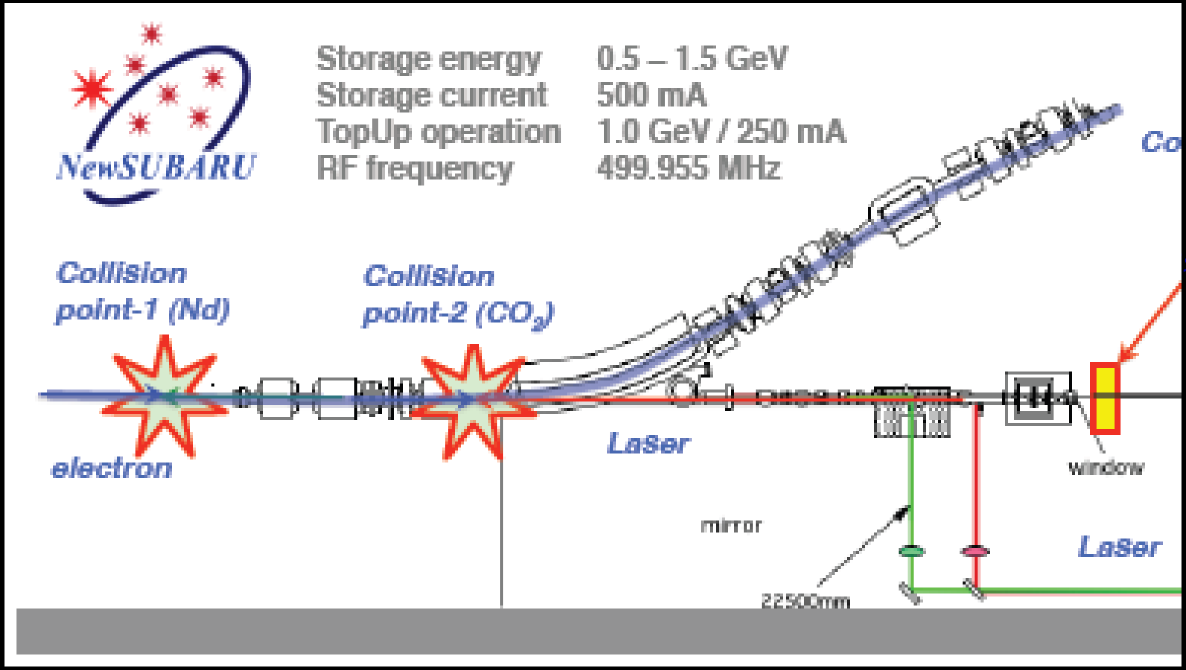
H. Ejiri PRL 21 '68, PR 38 '78
H. Ejiri, A. Titov PR C 88 054610 2013

Laser electron photon sources



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





β^+ NME via IAS γ

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

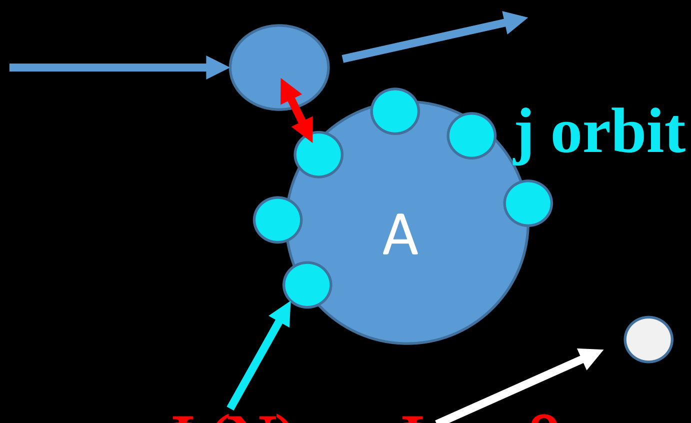
Particle γ for good resolution CNNP17 Brandao de Oliveira

Nucleon transfer reaction

To A σ=No holes=U_j^2 (2j+1)

From A : σ=No of particle $V_j^2/(2j+1)$

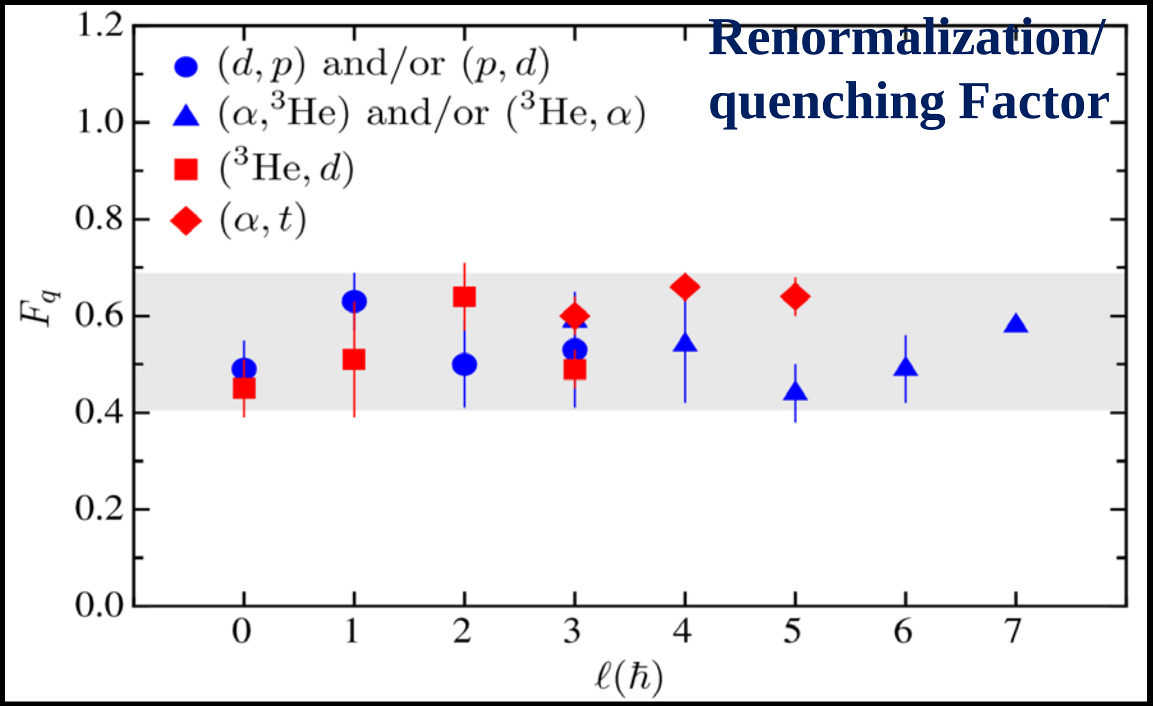
Verify U & V in DBD models.



$\Phi(N)=\alpha\ \Phi_0 + \beta$

Single n in nucleus is α^2=0.55 free nucleon.

Sum = 0.55 (2j+1)



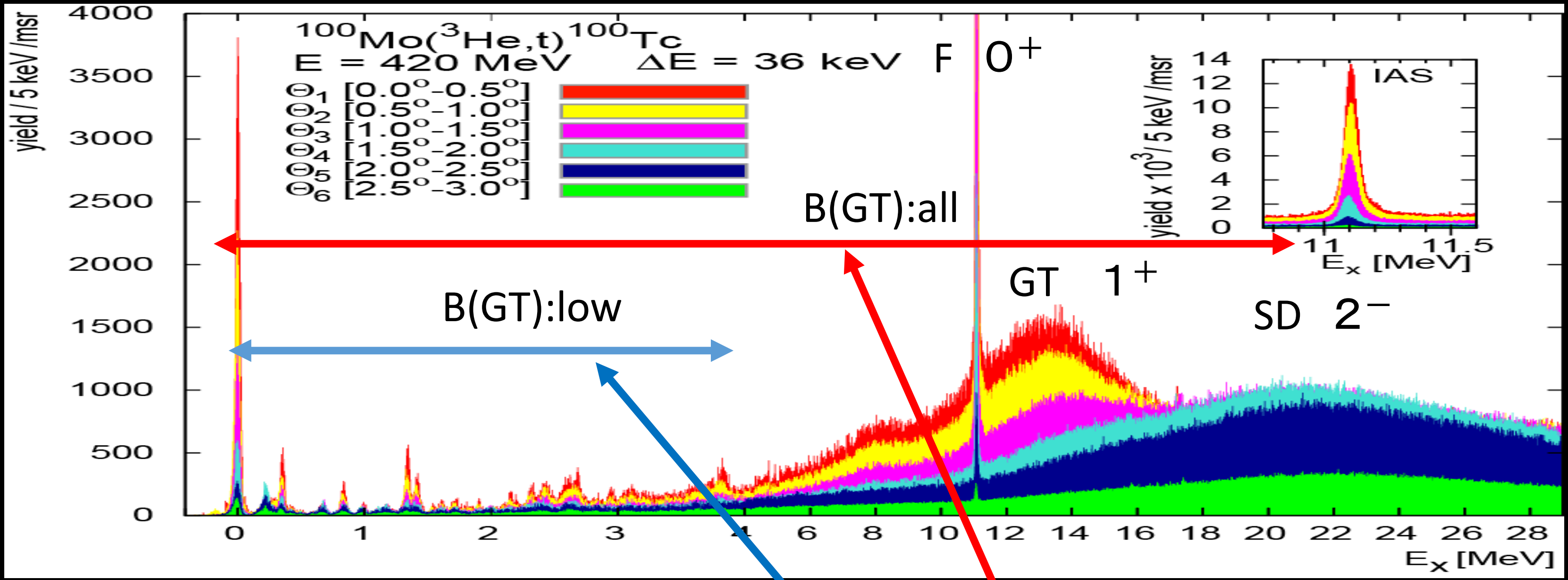
J.Freeman and J.P.Schiffer, J. Phys. G. 39 (2012) 124004.

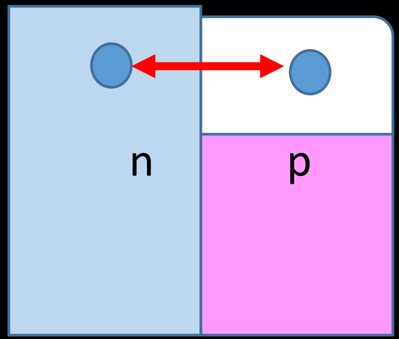
B.P.Kay, J.P. Schiffer and S.J. Freeman, PR L 111 (2013) 042502.

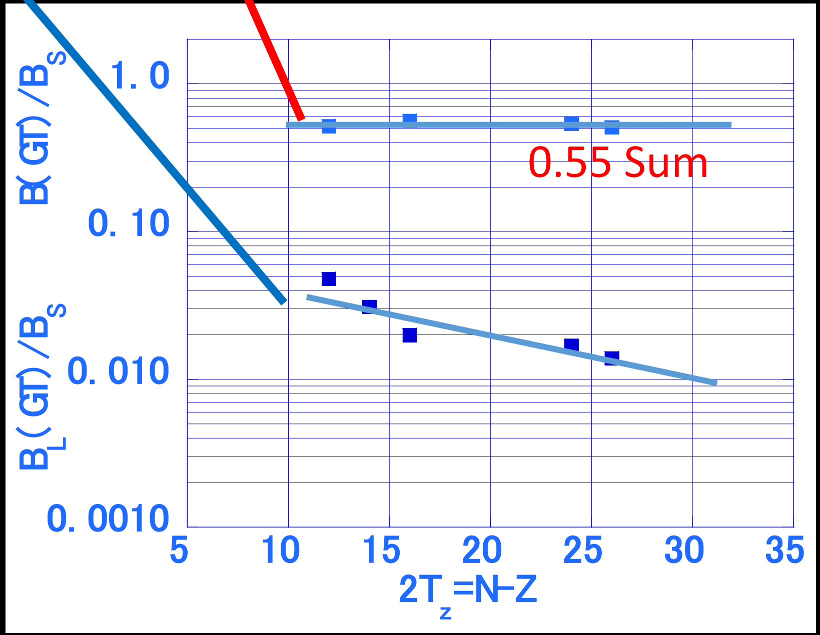
(p,t) :Noveling pt, dα Reveiro CNNP17

Q5. How are axial vector coupling g_A renormalized in nuclei ?

B(GT) sum strength







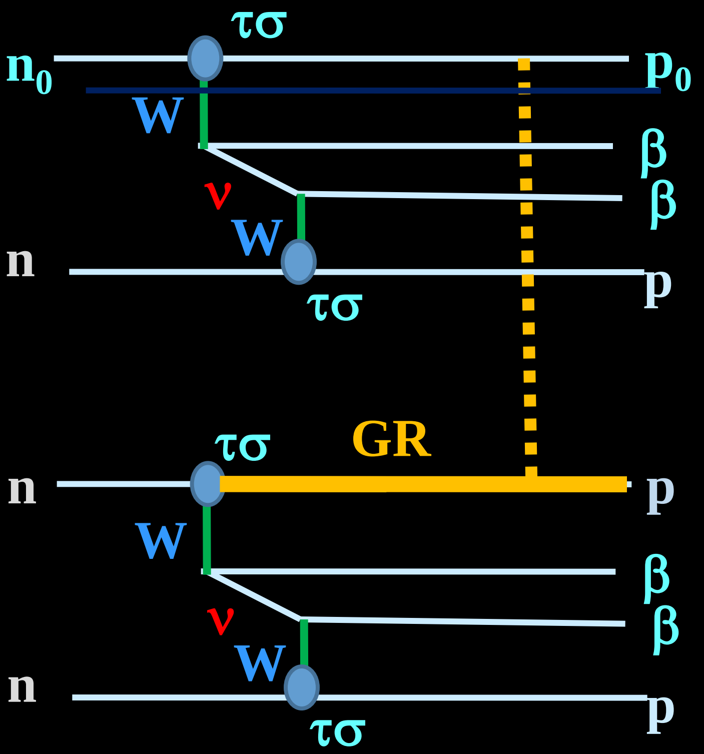
Σ B(GT)/B(σ) = 0.55 (N-Z)

Nucleon in nucleus

is 0.55 free nucleon

Schematic view of ν/β response

1. n_0 and p_0 at the gr. 0^+ state
   on the diffused Fermi surface



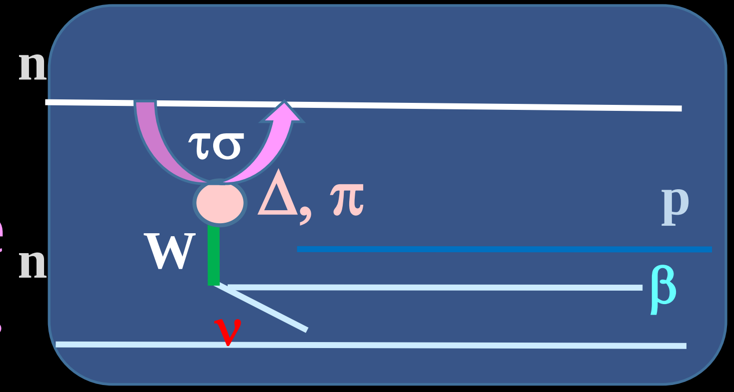
2. Coupling with GR= Σ |$n^{-1}p$>

$M= \kappa_{\tau\sigma} M \quad \kappa_{\tau\sigma} = 1/(1+\chi_{\tau\sigma})$

$\kappa_{\tau\sigma}$: renormalization

$\chi_{\tau\sigma}$: susceptibility=E(GR)/E

3. Non nucleonic medium and
   short range effects
   π, Δ fields modified, no more
   free nucleon. k_M~0.6 amplitude
   Effecive g_A and g_V give Δ origin.



Q5. Summary and remarks

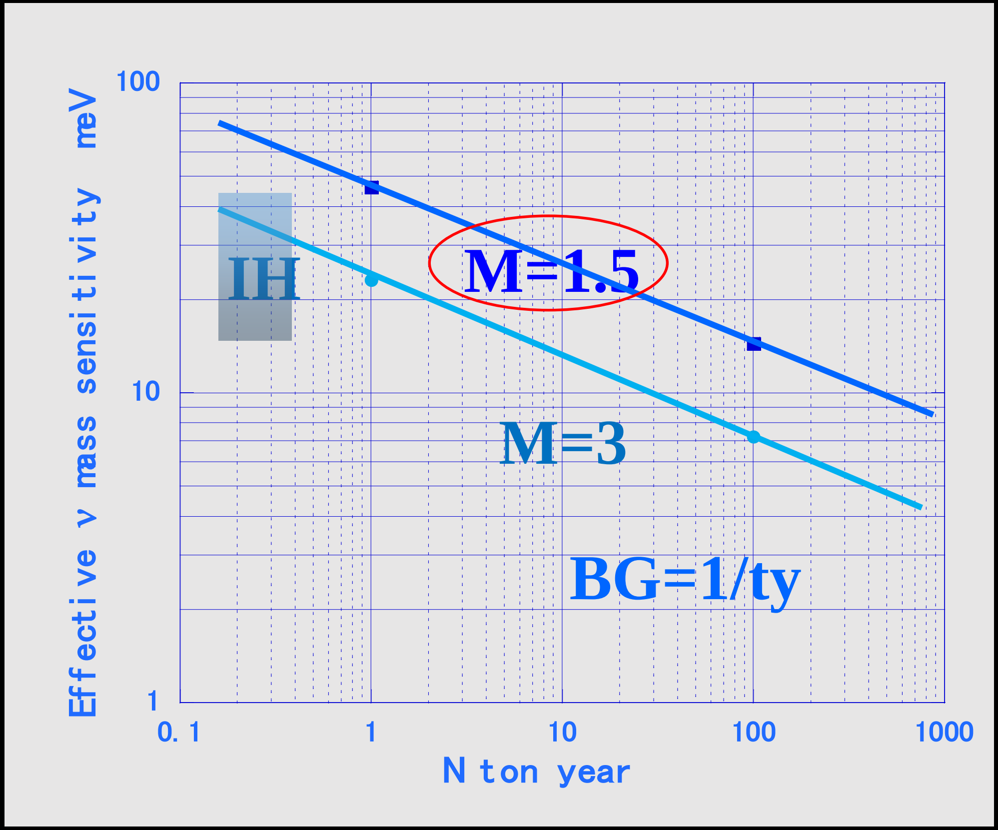
1. NMEs(ν-response) are sensitive to nucl. correlations, nuclear medium, Δ π effect. Experimental studies of single β, nuclear CERs, & μ–ν CER reactions help evaluate weak NMEs.

2. Fermi, GT, SD, higher multipole NMEs are re- normalized with respect to QP NMEs k~0.25, for momentum q=5-100 MeV, 0.4 by nucleonic correlation in QRPA, and 0.6 by nuclear medium/short range/ Δ π effects.

3. It is timely to discuss realistic and coordinated efforts for IH-DBD EXPs and SB/DBD NMEs.

1. IH DBD Exp. NT ty = $k(m_\nu)^4$ $[M^{0\nu}]^{-4}$ (BG) G^{-2}

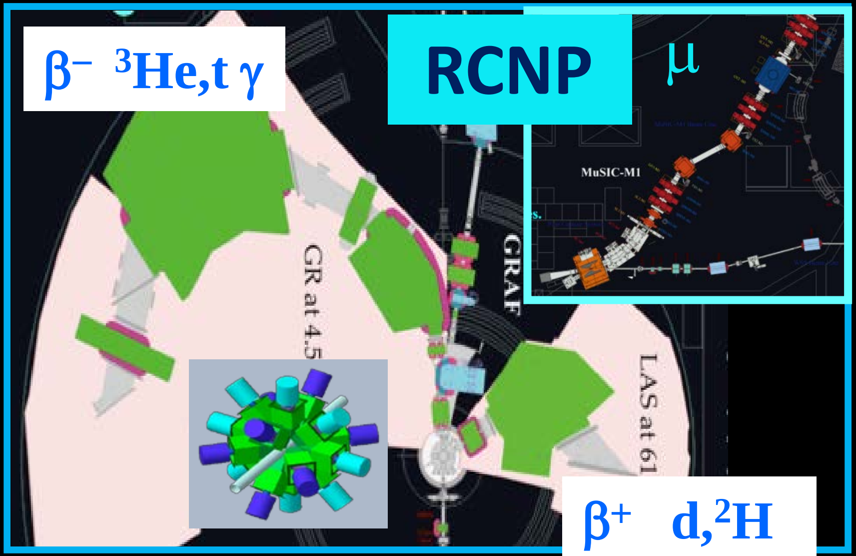
$M^{0n} \sim (g^{eff})^2 M = 3 \rightarrow 1.5$,
G ~ 4 10^{-14}/y
NT ~ 1 →15 ty for IH



A. N~5-10 ton enriched N with large NMEs.

B. E-resolution ΔE/E < 0.01 Particle ID (β/γ/α) to reduce intrinsic 2νββ & solar ν BG< 0.3 /t y (Ejiri Elliott PRC 89 2014, 95 2017).

2. Coordinated experiments for ν nuclear responses



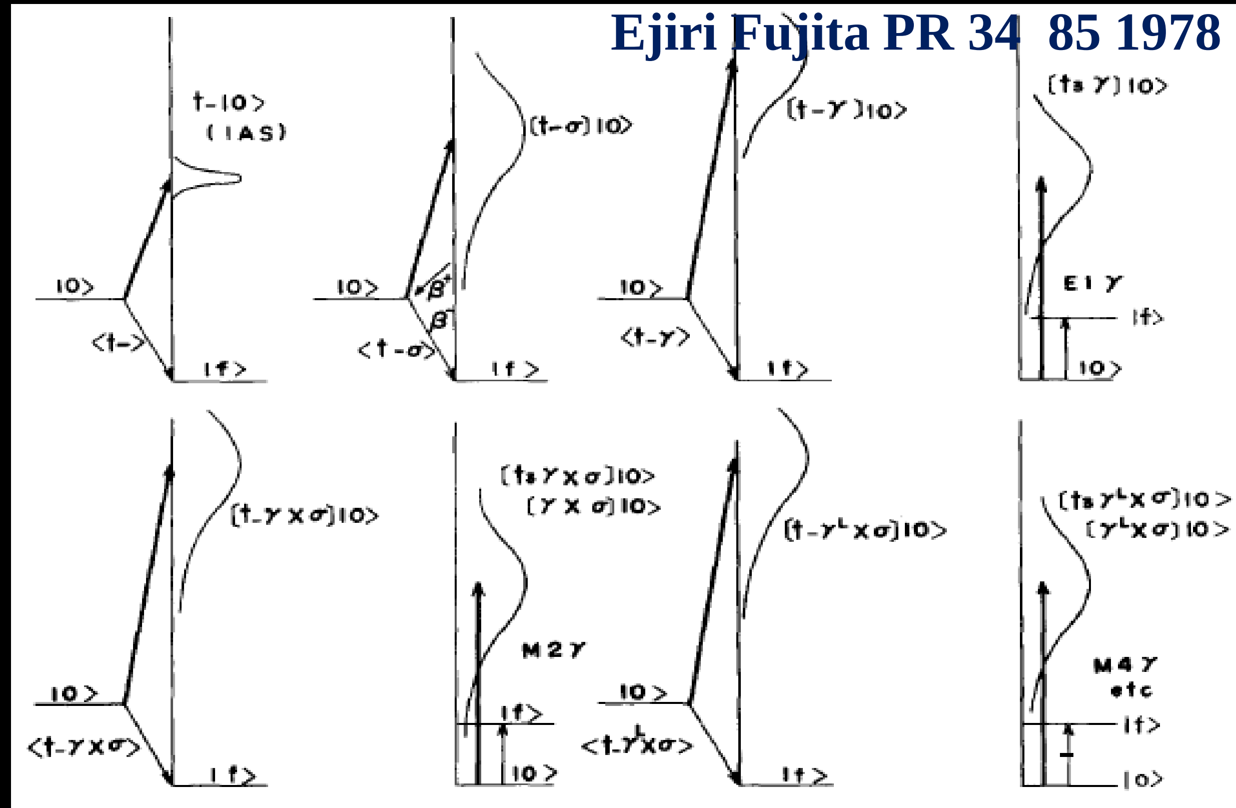

Grazie per la
Vostra attenzione

Universal reductions Axial vector β

$M(SL) = \langle \tau^{\pm} (\sigma \times r^l Y_l \rangle_J$

$M(EXP) = k\, M(QP)$

$k \sim 0.25$ for $J=1,2,4$

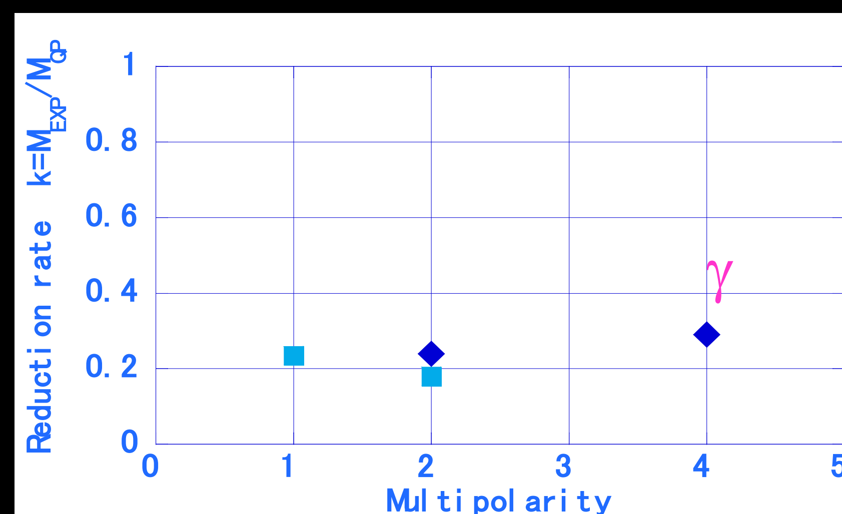


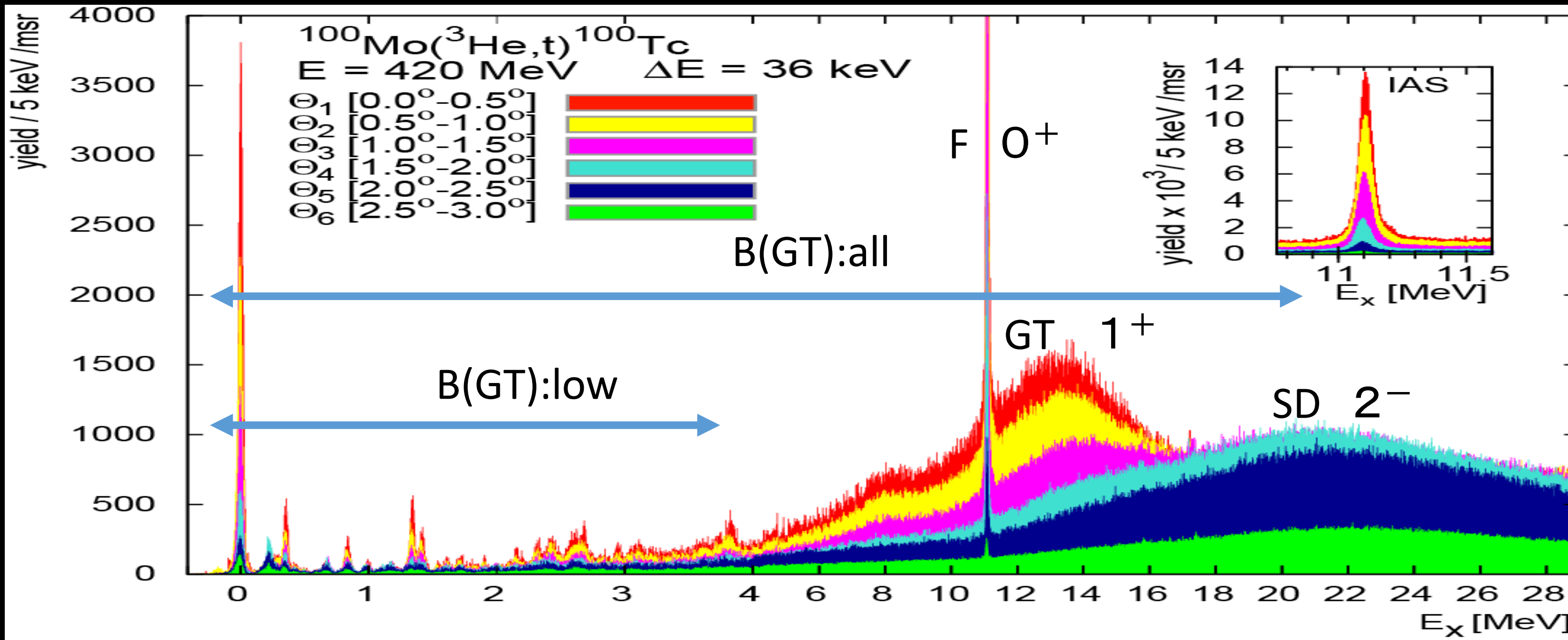
$k = k(\tau\sigma)\, k(NM) \sim 0.25$

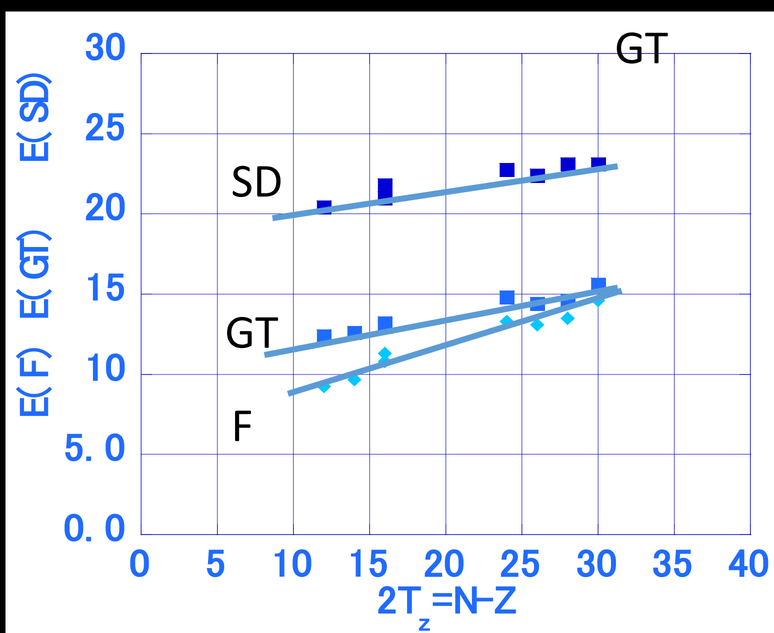
$k = k(\tau\sigma) \sim 0.5$ τσ GR

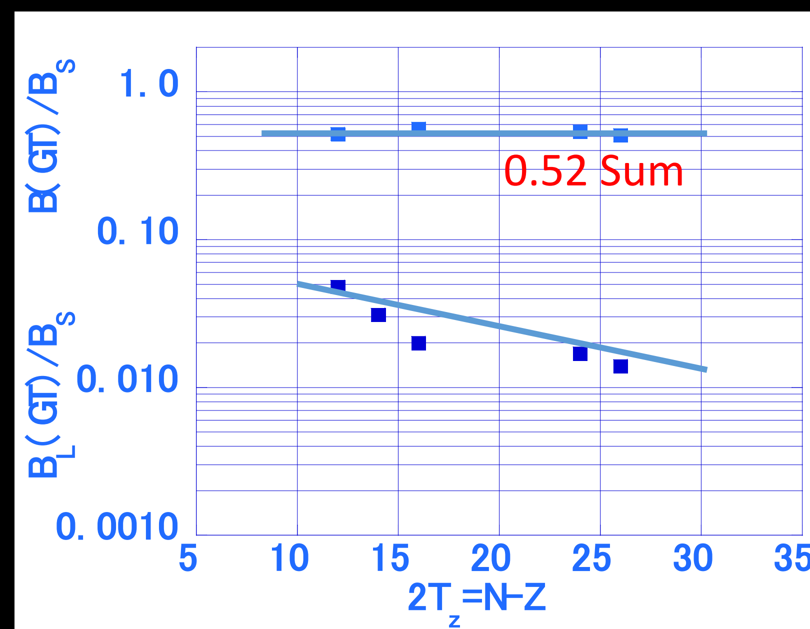
$K(NM) \sim g^{eff}_A / g_A \sim 0.6$

Nucl. Medium Δ isobar GR




100Mo(3He,t)100Tc
E = 420 MeV ΔE = 36 keV
Θ1 [0.0°-0.5°]
Θ2 [0.5°-1.0°]
Θ3 [1.0°-1.5°]
Θ4 [1.5°-2.0°]
Θ5 [2.0°-2.5°]
Θ6 [2.5°-3.0°]
yield / 5 keV /msr
F 0+
B(GT):all
GT 1+
B(GT):low
SD 2−
IAS
yield x 10^3/ 5 keV /msr
Ex [MeV]

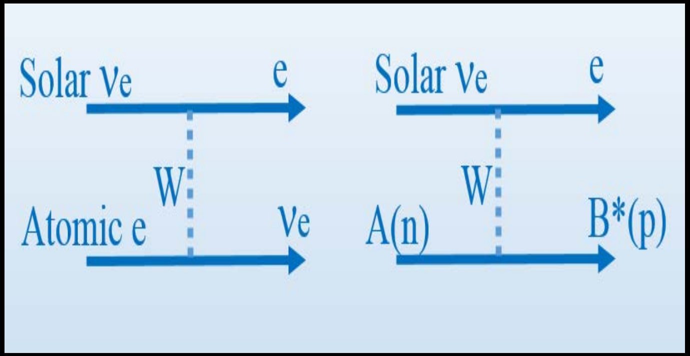

E(SD)
E(GT)
E(F)
GT
SD
GT
F
2Tz=N-Z

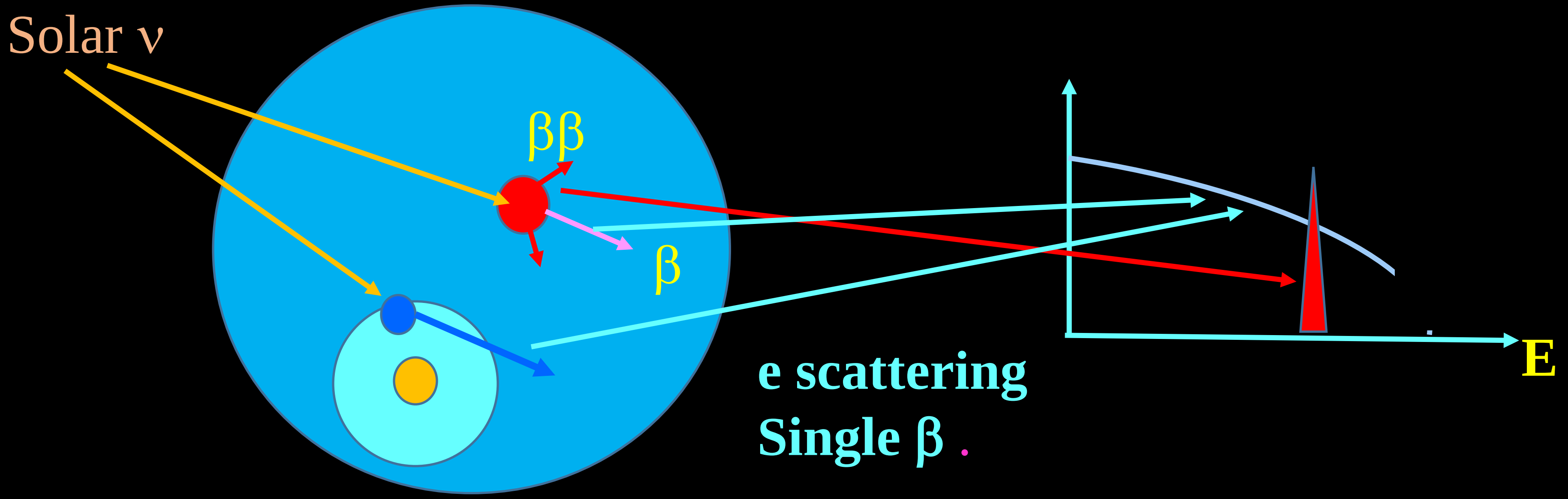

B(GT)/Bs
BL(GT)/Bs
0.52 Sum
2Tz=N-Z

Solar-ν interactions with nuclei and atomic electrons in DBD detectors are serious BGs

- Solar ν unavoidable.
- ν response on DBD nucleus is crucial

DBD rates for IH 0.5-0.9 / t y
Solar ν BG ~0.2-0.3 /t y if ΔE/E =1 %

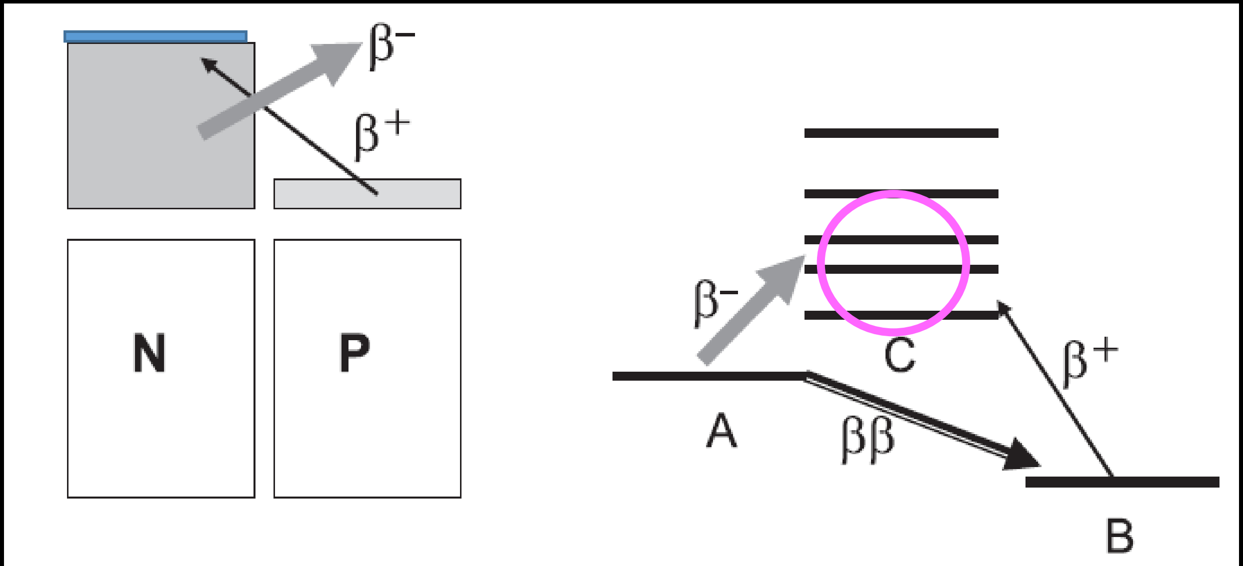




H. Ejiri and S. Elliott PR C 89 055501 2014, 95 055501 2017

FSQP: Fermi Surface Quasi Particle Model

Ground state 0^+ (nn) $\rightarrow$ 0^+ (pp), n and p are Fermi surface QP



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

$$M^-_k = (k^{eff}_i)\ m_{ij} V_n U_p,\quad M^+_k = (k^{eff}_f)\ m_{ij} U_n V_p,\quad (k^{eff}_A)^2 \sim (0.23)^2 = 0.05$$

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

H. Ejiri et al. J. Phys. Soc. Japan Lett. 65 (1996) 7; JPSJ 78 (2009)

CER $d\sigma/d\Omega = K\,N\,M^2$ $V = V_0 \tau\tau\sigma\sigma\,\delta(r_1 - r_2)$ N distortion

$M^* = \int V\ j_l(qr)\ \phi_i\ \phi_f\ r^2\,dr$ Surface interaction at r ~R with ΔR

$= V\ j_l(qR)\ M^*$ $M^* = \int \phi_i\ \phi_f\ r^2\,dr\ \sim \Delta R$ ϕ_f =radial w.f.
for interaction integral from R to R+ ΔR

$M(\beta) = \int r\ \phi_i\ \phi_f\ r^2\,dr \sim R^{eff}$ for l to $(l+1)$ transition .

Assuming $\Delta R \sim k\ R^{eff}$, and thus $h\ M^* = M(\beta)$,
M(β) is obtained from CER M* by using h.

	M(β)	M (FSQP)	k= M(β)/M(QP
^{76}Ge (SD)	2.0	2.1	0.22
^{128}Te (SD)	3.55	3.4	0.22
^{130}Te (SD)	4.05	3.7	0.22

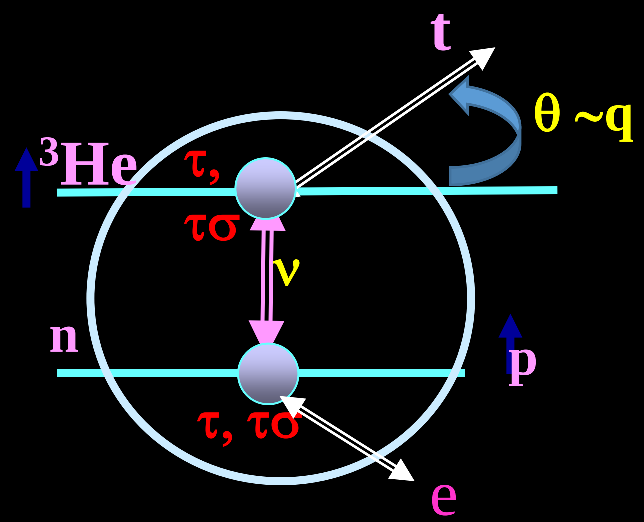
with k=M/M(QP) =QRPA effect ~0.5 and medium(g_A) effect 0.5

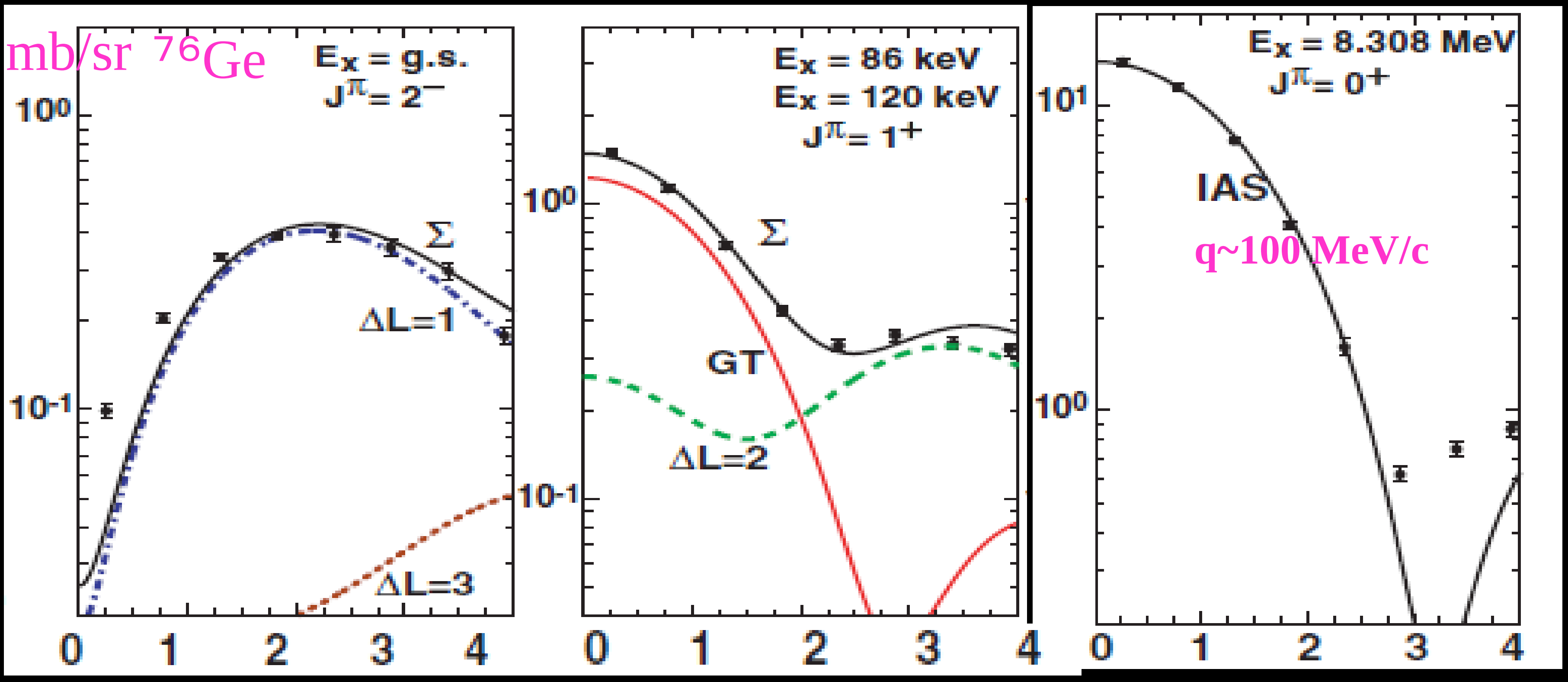
CER. F, GT &SD

$\sigma=[(g_A(q)\,(j_l(qr)]^2 \sim k\,(j_l(qr)]^2$

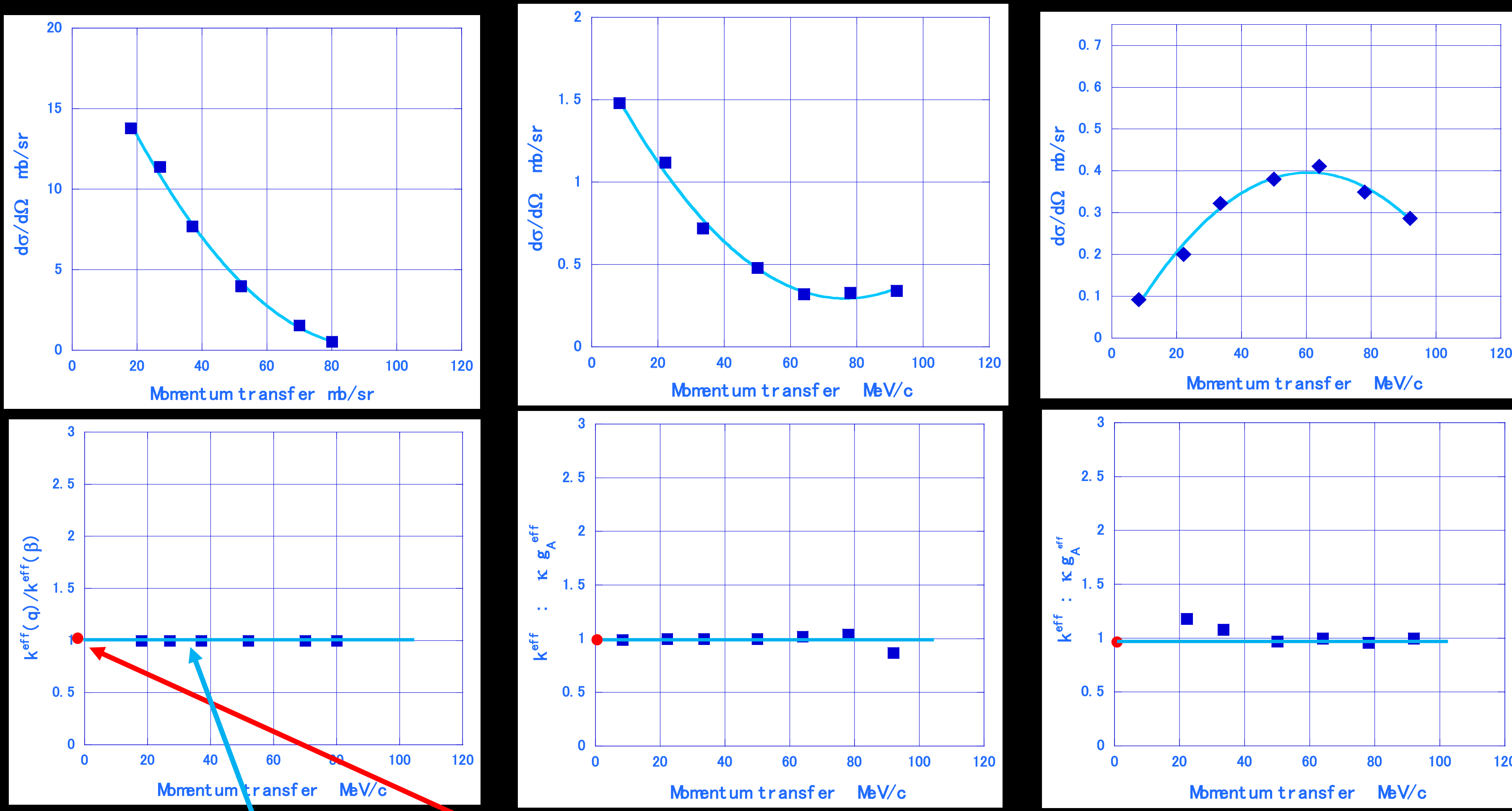
j_0 for IAS, GT, j_1 for SD

g_A~const over q=0-100 MeV/c





IAS F 0^+ GT 1^+ SD 2^-



$d\sigma(q) = K\,|j_a(qr)|^2\, M_\alpha(q)^{\,2}$ $\quad M_\alpha(q)=k^{eff}(q)\, M_\alpha(QP)$

$k^{eff}(q)= \kappa^{eff}\, g_A^{eff}(q)$ $\sim k^{eff}(q=0\,)= \kappa^{eff}\, g_A^{eff}(q=0)$ for β

$\sim$ constant $q=20 – 100$ MeV/c : $r=5 – 2$ fm (DBD, SN)