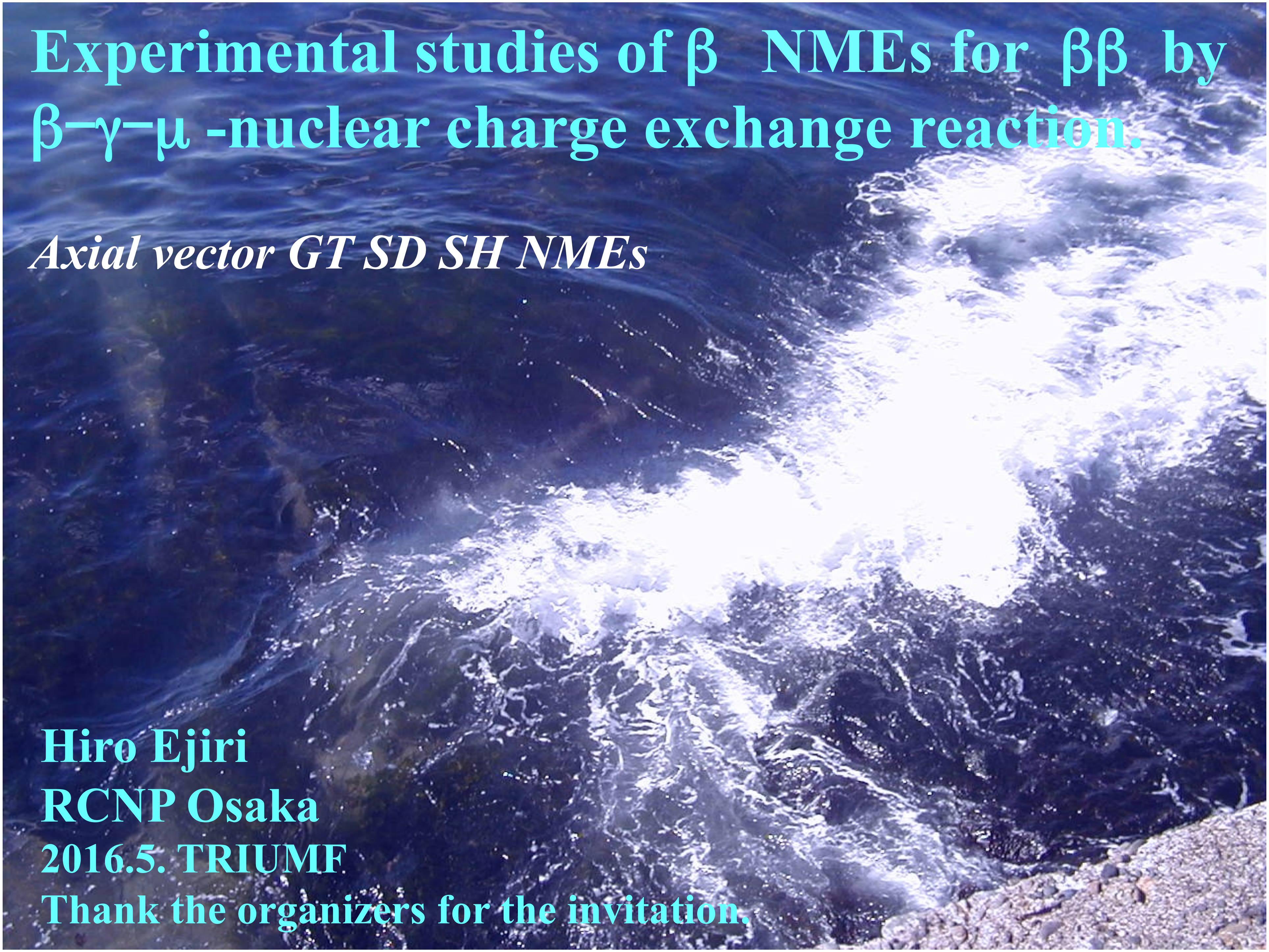
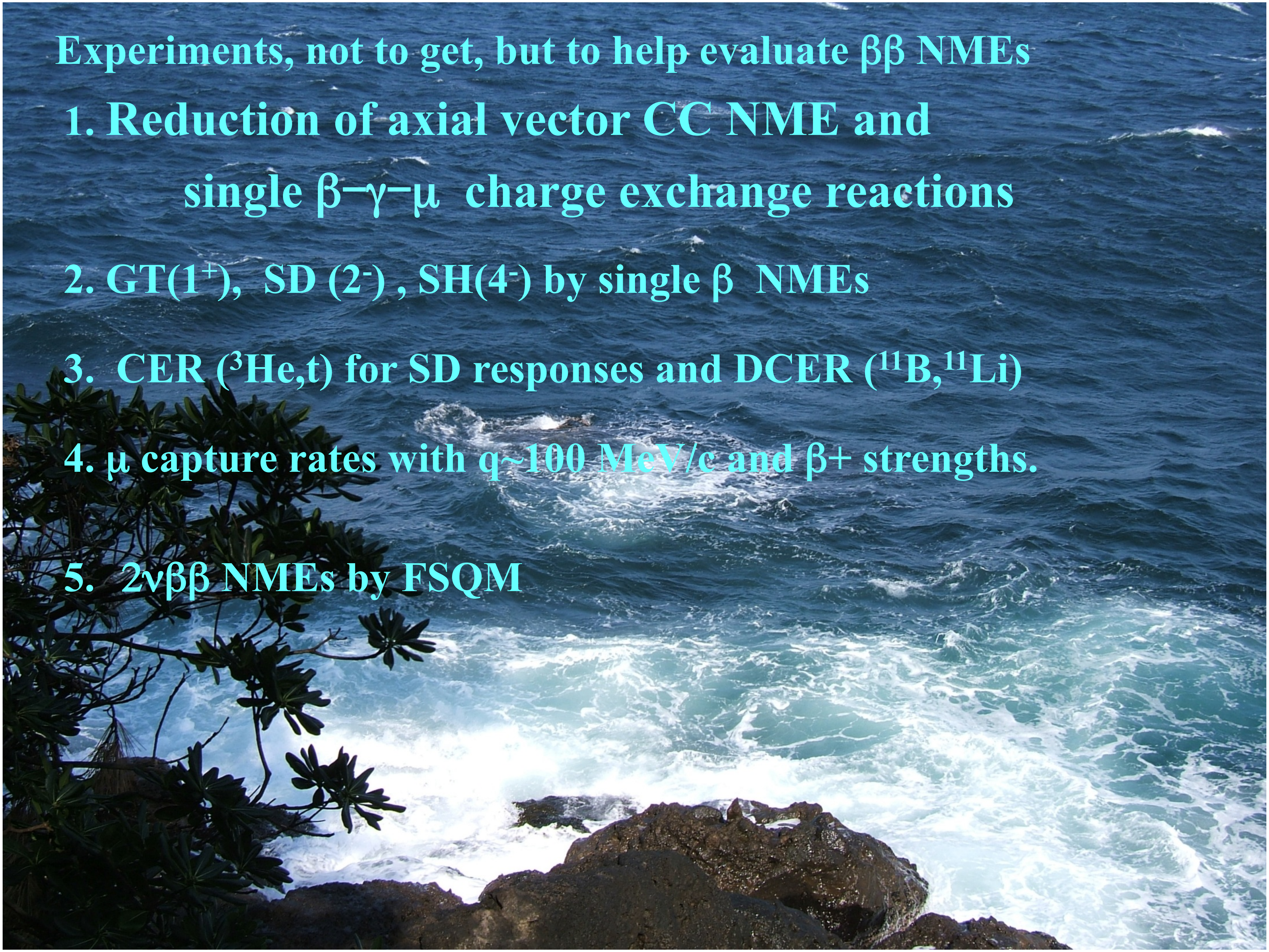


Experimental studies of β NMEs for ββ by β−γ−μ -nuclear charge exchange reaction.

Axial vector ***GT SD SH NMEs***

Hiro Ejiri
RCNP Osaka
2016.5. TRIUMF
Thank the organizers for the invitation.



Experiments, not to get, but to help evaluate ββ NMEs

1. Reduction of axial vector CC NME and single β−γ−μ charge exchange reactions
2. GT(1^+), SD (2^-) , SH(4^-) by single β NMEs
3. CER (^{3}He,t) for SD responses and DCER (^{11}B,^{11}Li)
4. μ capture rates with q~100 MeV/c and β+ strengths.
5. 2νββ NMEs by FSQM

DBD NMEs (light ν-mass exchange)

A: Exp. approach via single β M_{SB} (present report)

Single β exp. transition rate = $G\ g_A^2\ B(J)$ with g_A=1.267

Exp. strength $B(J) = 1/(2j_i+1)\ [M_{SB}]^2$

M_{SB} (EXP)=k M_{SB}(MODEL)

$k = (g_A^{eff}/g_A)$ Renormalization/reduction
due to nucler medium, Δ, meson effects etc
which are not explicitly in the model.

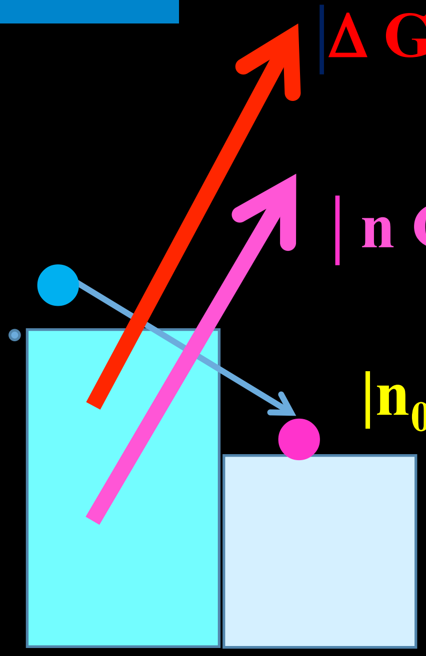
M_{SB} (EXP) /M_{SB}(MODEL) $\Rightarrow$ k (exp)= g_A^{eff} (exp),
to help/evaluate M_{DB} and k = g_A^{eff} for DBD

B: Theoretical approach: use models that include
all crucial effects >5%, and $k = (g_A^{eff}/g_A) = 1\pm5\%$

C: Exp. of DCE ??? or DBD if ν-mass known ???

Schematic view of ββ and GR

Ejiri Fujita PR 34 85 1978



$|\Delta\ GR> = \Sigma\ |n\ \Delta^+>$

$|\ n\ GR> = \Sigma\ |n\ p>$

$|n_0\ p_0>$

1. n_0 and p_0 are parts of
   the ground 0^+ state
   on the Fermi surface

2. τσ GR : coherent sum of
   many (N~30) $\Sigma\ |n^{-1}p>$

3. Δ GR: coherent sum of
   many (N=100) quark spin flip $\Sigma\ |n^{-1}\Delta^+>$

They mix destructively via repulsive interaction as

$$|np> = |n_0\ p_0> - \varepsilon\ |\ n\tau\sigma\ GR> - \delta\ |\Delta\ GR>$$

GR and other effects are uniform, and are given by
experimental renormalization of $k^{eff} = k^{eff}\ (\tau\sigma) \times k^{eff}\ (\Delta)$

Nuclear matrix element NMEs for 0νββ

Detector ν-mass sensitivities $\langle m_\nu \rangle = k\,[M^{0\nu}]^{-1}\,G^{-1/2}\,(NT)^{-1/4}\,(BG)^{1/4}$

$M = g^2_A M_{DA} + g^2_F M_{DF}$ $M_A = \langle h\sigma\sigma \rangle$ $M_F = -\langle h \rangle$ $h \sim a/(r_1 - r_2)$

$T = Gm^2M^2$, $g^2_A M_{DA} \sim \Sigma\ g_A M_{SB}\ g_A M_{SB}$

If $g_A M_{SB}$ is reduced to 0.7, T to 1/4, N 1 → 16 tons for 4 years

Axial vector $M_A(J)$

Momentum transfer

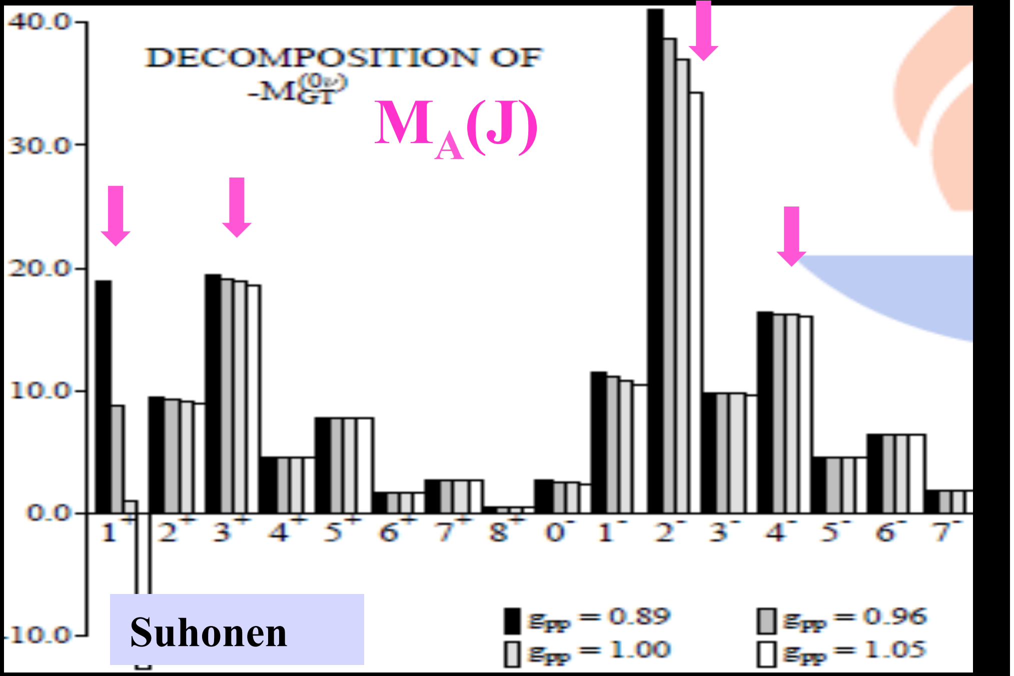
0νββ ν exchange

$q \sim 1/\Delta r = 1\text{-}0.3\ \mathrm{fm}^{-1}$

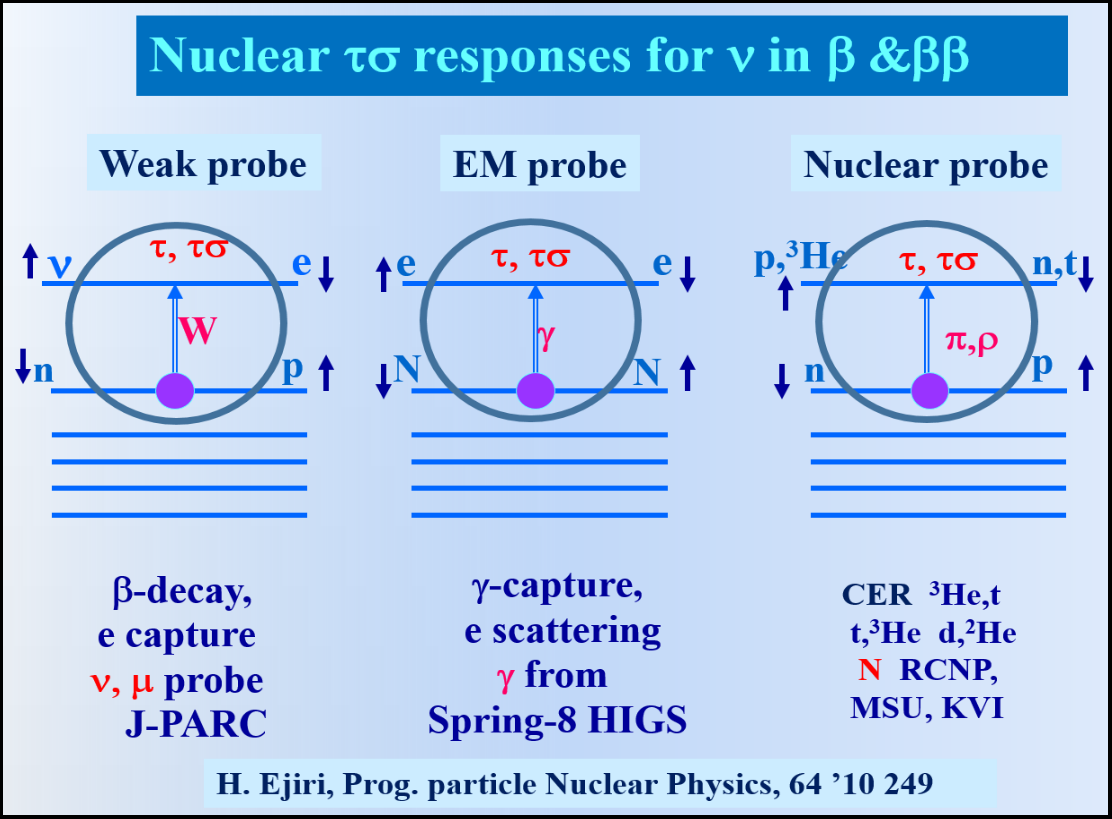
$\Delta l = qR = 1\text{-}2$

$J^\pi = 1+, 2-, 3+, 4-$

$M_A(J) = g_A\,\tau\,[\sigma \times f(r)\,Y_l]_J$



CER. Probs for ν-responses



Nuclear τσ responses for ν in β &ββ

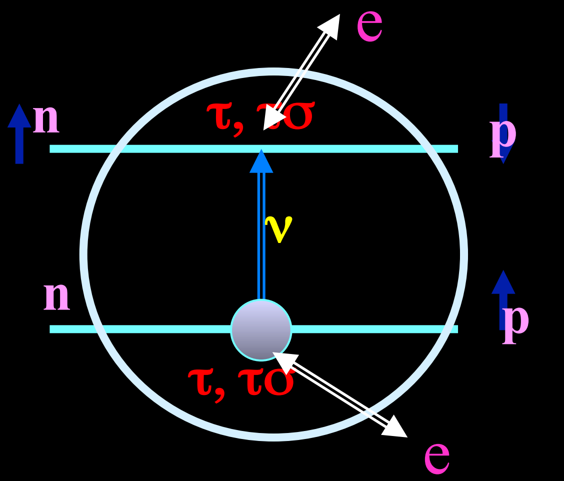
Weak probe **EM probe** **Nuclear probe**

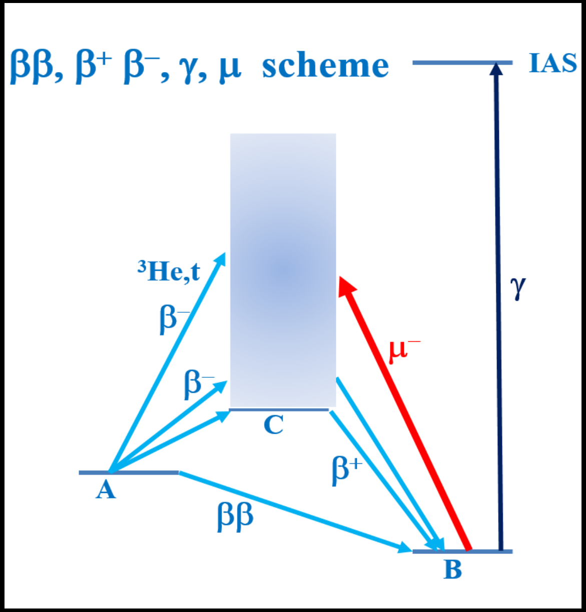
β-decay,
e capture
ν, μ probe
J-PARC

γ-capture,
e scattering
γ from
Spring-8 HIGS

CER ^{3}He,t
t,^{3}He d,^{2}He
N RCNP,
MSU, KVI

H. Ejiri, Prog. particle Nuclear Physics, 64 '10 249



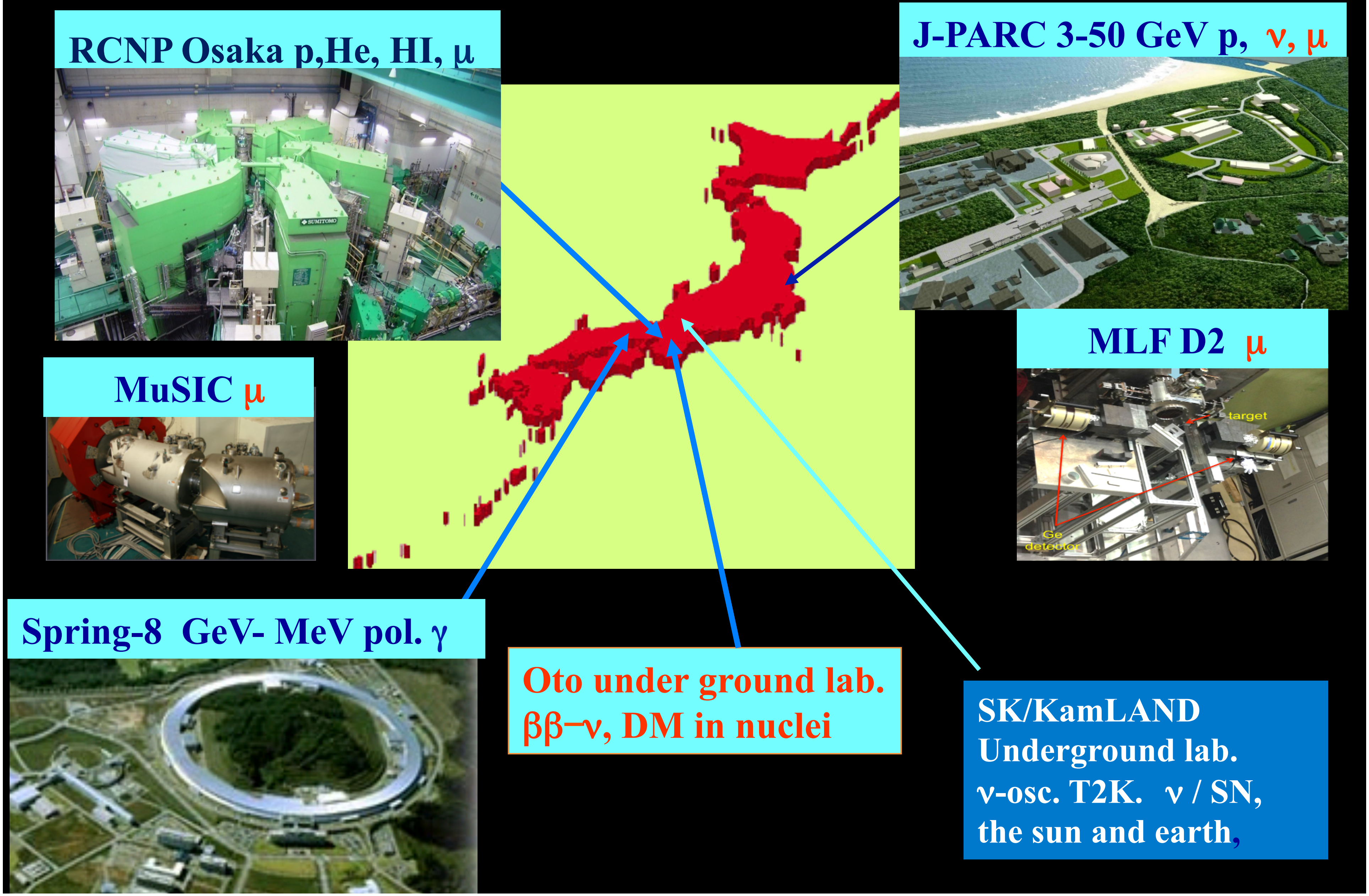


0νββ:two body operator, but single β NMEs are useful for 0νββ

Experimental probes for ν responses H. Ejiri PR 338 265 2000

DBD review Vergados Ejir Simkovic .Rep.Prog. Phys. 2012 65 106301

Neutrino response studies by RCNP/Osaka



RCNP Osaka p,He, HI, μ

J-PARC 3-50 GeV p, ν, μ

MuSIC μ

MLF D2 μ

Spring-8 GeV- MeV pol. γ

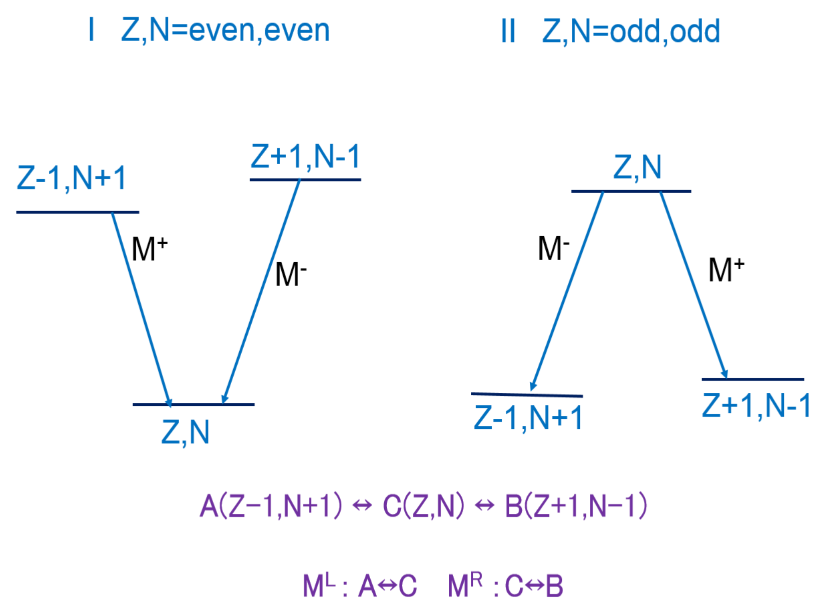
Oto under ground lab.
ββ−ν, DM in nuclei

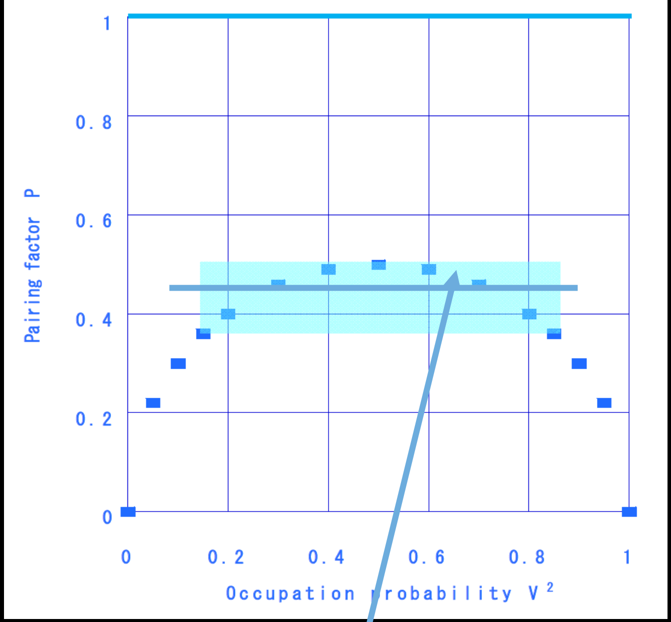
SK/KamLAND
Underground lab.
ν-osc. T2K. ν / SN,
the sun and earth,

2. Axial vector single β decay NMEs

GT 1^+, SD 2^-, SH 4^-

M(GT)= <$\tau^{\pm}$ (σ)>   M(SD)= <$\tau^{\pm}$ (σY_1)>





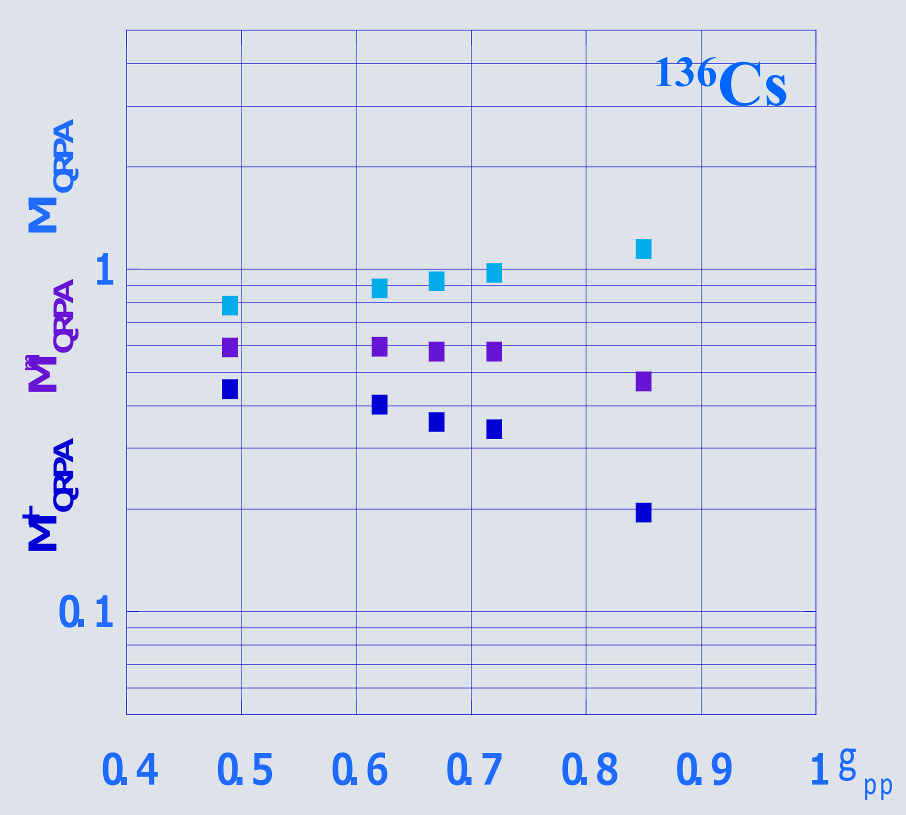
Geometrical mean $M^m = (M^+ \times M^-)^{1/2}$

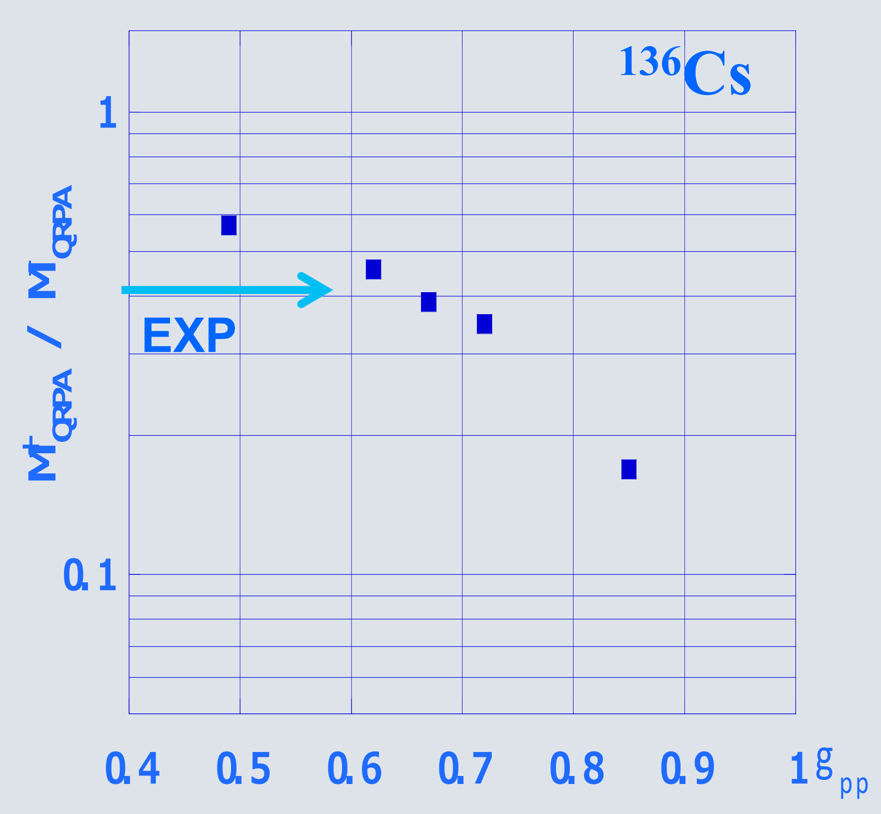
1.$M^m(QP) = M^m(SP)\ [U_p V_n\ U_n V_p\ ]^{1/2} \sim 0.43\ M^m(SP)$

Insensitive to U &V nuclear surface effects and g_{pp}

2. NMEs in ββ are $(M^m)^2 = (M^+ \times M^-)$

QRPA M(GT) dependence on g_{pp} p-p interaction





M^m (violet) is independent of g_{pp} since the effects on M^+ & M^- cancel.

M^+ / M^- is sensitive to g_{pp} . Exp. ratio gives g_{pp} = 0.6-0.7

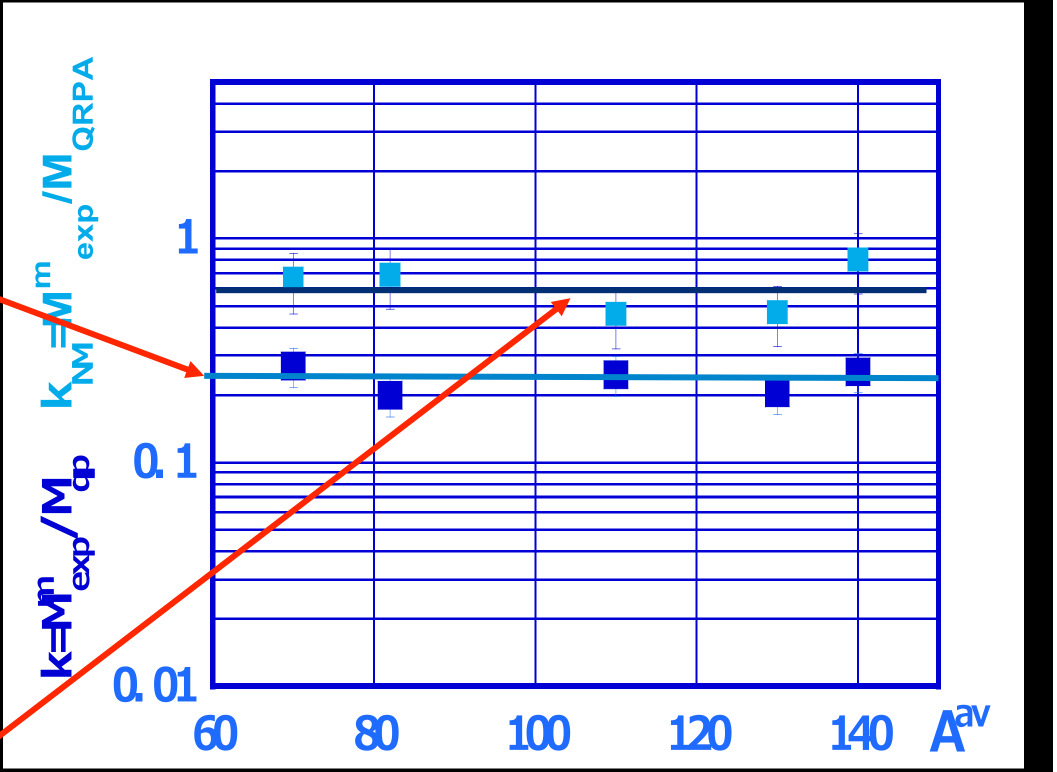
NMEs GT H. Ejiri J Suhonen J. Phys. G. 2015 42 055201

GT 1^+ $\tau\sigma$ NN & nuclear medium g_A

$M^m_{exp} < M^m_{QRPA} < M_{qp}$

$M^m_{exp} = k\, M_{qp}$

$k = k_{\tau\sigma}\, k_{NM} \sim 0.24$



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

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

$M^m_{exp} = k_{NM}\, M_{QRPA}$

$k_{NM} \sim 0.6 = g_A^{eff} / g_A$ NΔ NM

H, Ejiri J. Suhonen
J. Phys. G. 42 2015 055201

SD 2^- $\tau\sigma$ NN & nuclear medium g_A

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

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

$$M(QRPA) = k_{\tau\sigma}\, M(QP)$$

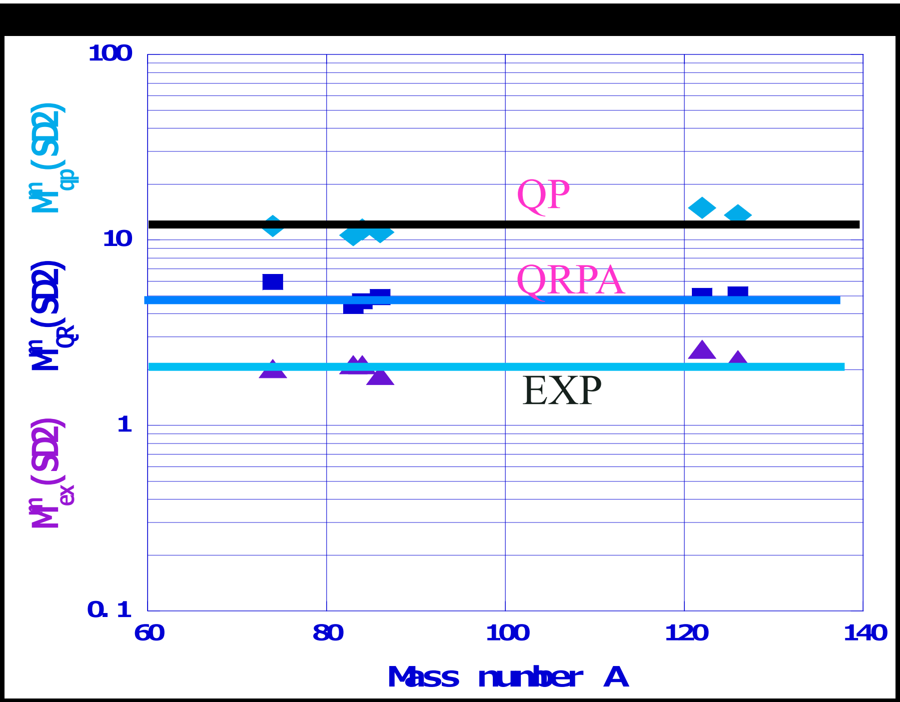
$k_{\tau\sigma} \sim 0.4$ $\tau\sigma$ correlation

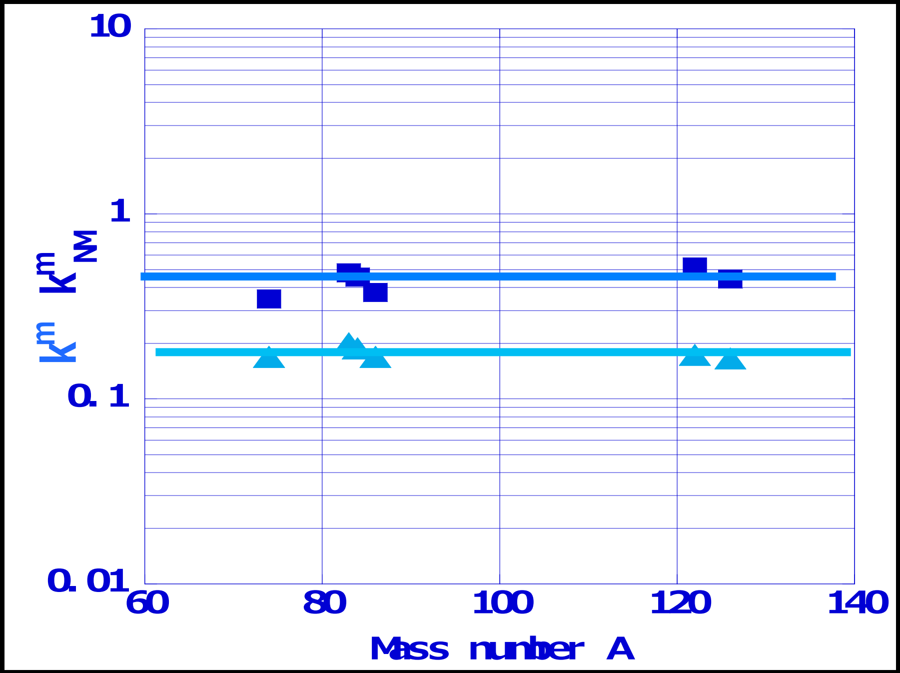
$$M(EXP) = k_{NM} M(QRPA)$$

$k_{NM}/{\sim}0.5 = g_A^{eff}\ /g_A$ NM

H. Ejiri, N Soucouti, J. Suhonen,
PL B729, 27 2014 .

Similar g_A in J. Suhonen O. Civitarese
PLB 725 (2013) 153



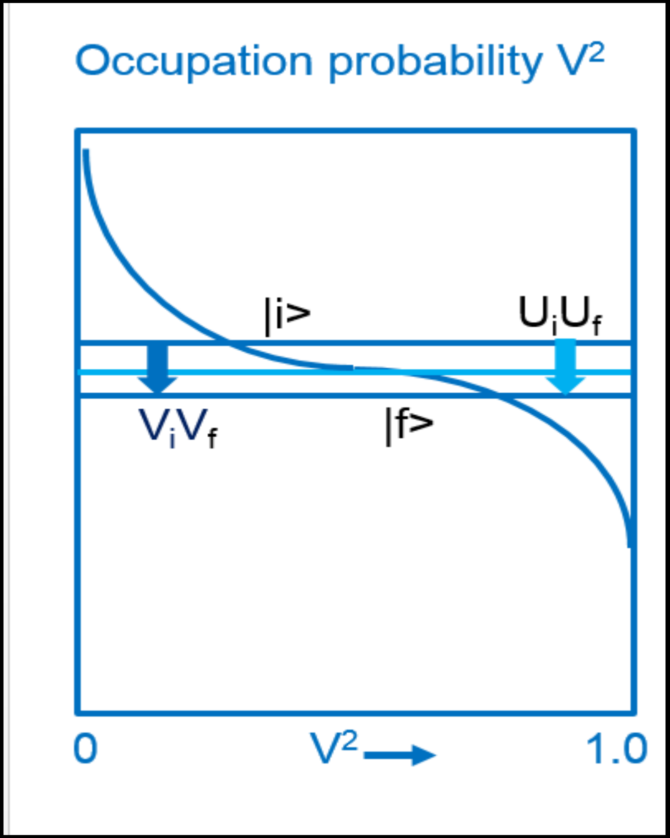


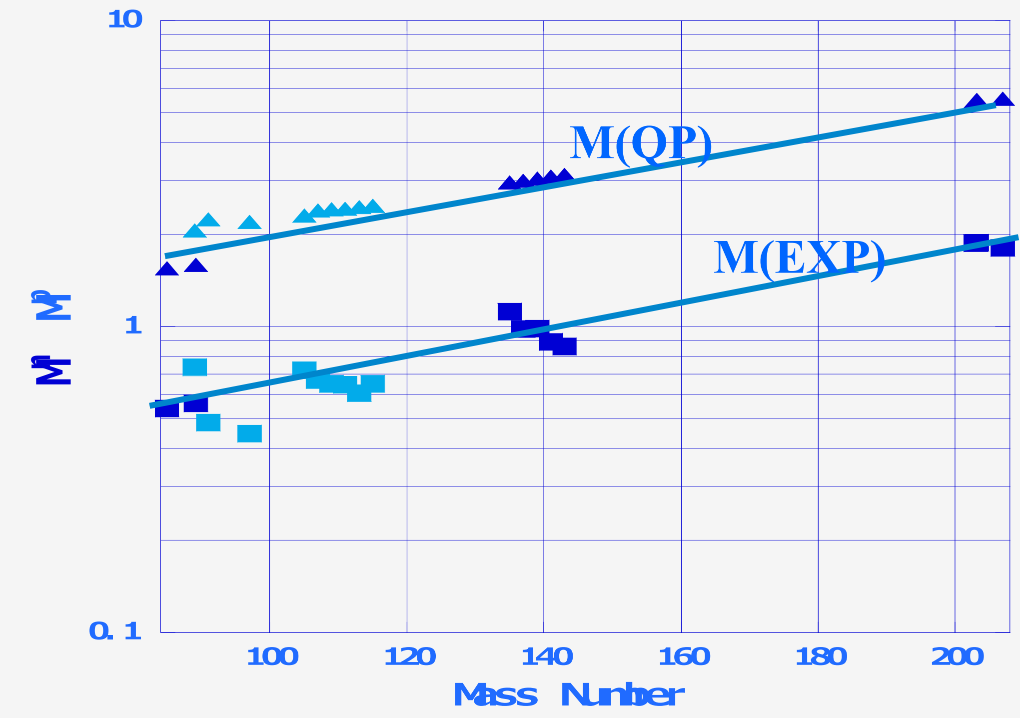
SH (Spin Hexadecapole 4^-) ν-responses

$M(SH)= <\tau^{\pm} (\sigma \times r^3 Y_3> \ \gamma$

$M(M4)=M_{sp}\ P$

$P=V_i V_f + U_i U_f \sim 1$

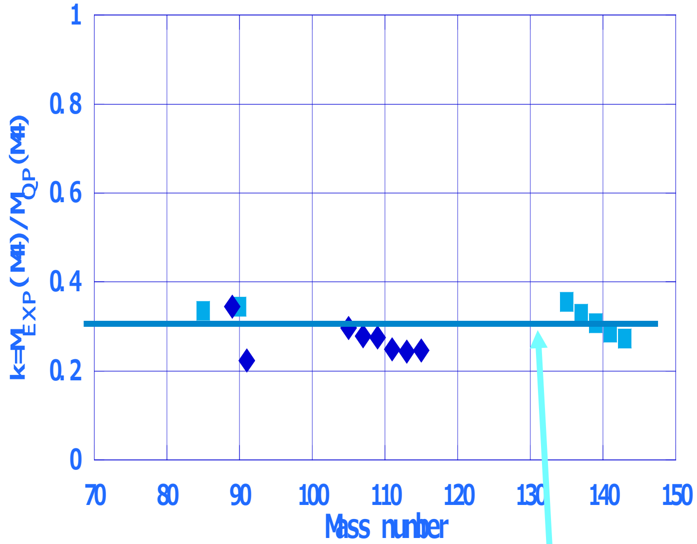


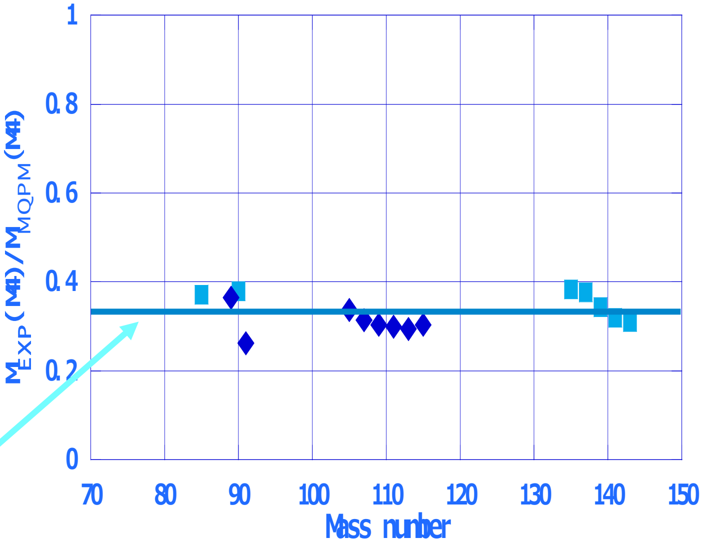


$M4\ \gamma\ M(EXP) = kM(QP)$

k~0.3 for proton and neutron

Jokiniemi, Suhonen, Ejiri AHEP2016



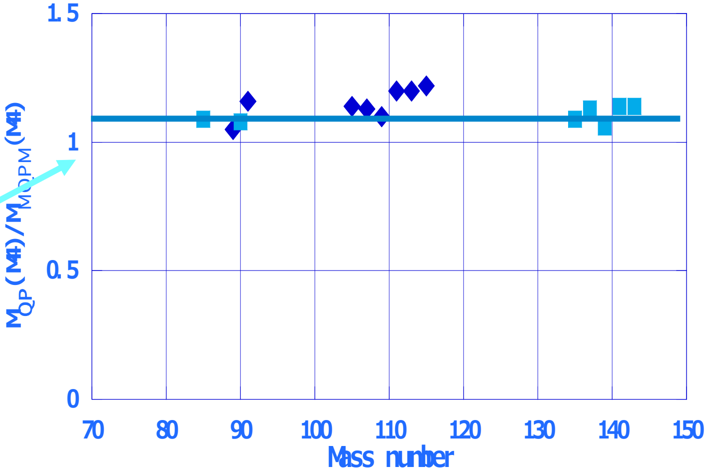


M_{EXP} / M_{QP} ~0.29

M_{EXP} / M_{MQPM} ~0.33

Microscopic quasiparticle phonon model

M_{QP} / M_{MQPM} ~1.2



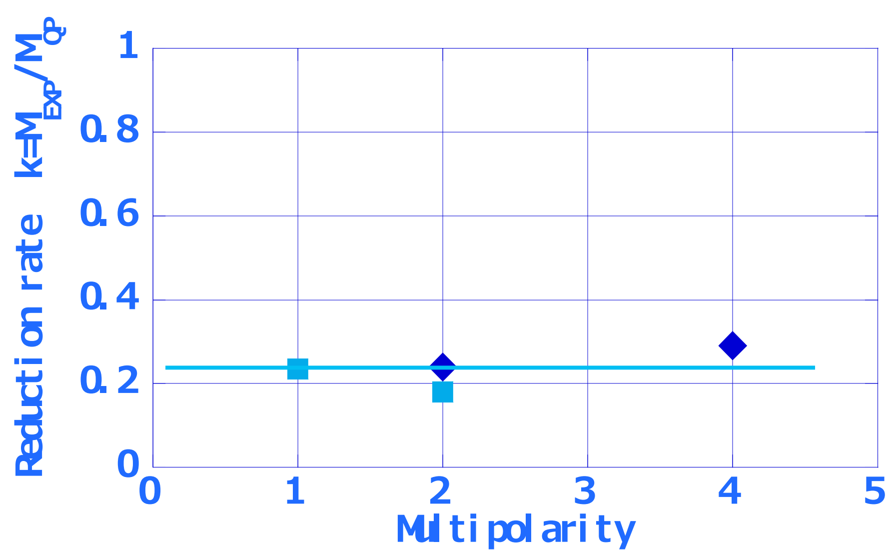
EXP $k_p \sim k_n \sim 0.3$, $k_p - k_n \sim 0$ $k_{-} \sim 0.3$ CC β NME $(g^{eff}_A/g_A \sim 0.3)$

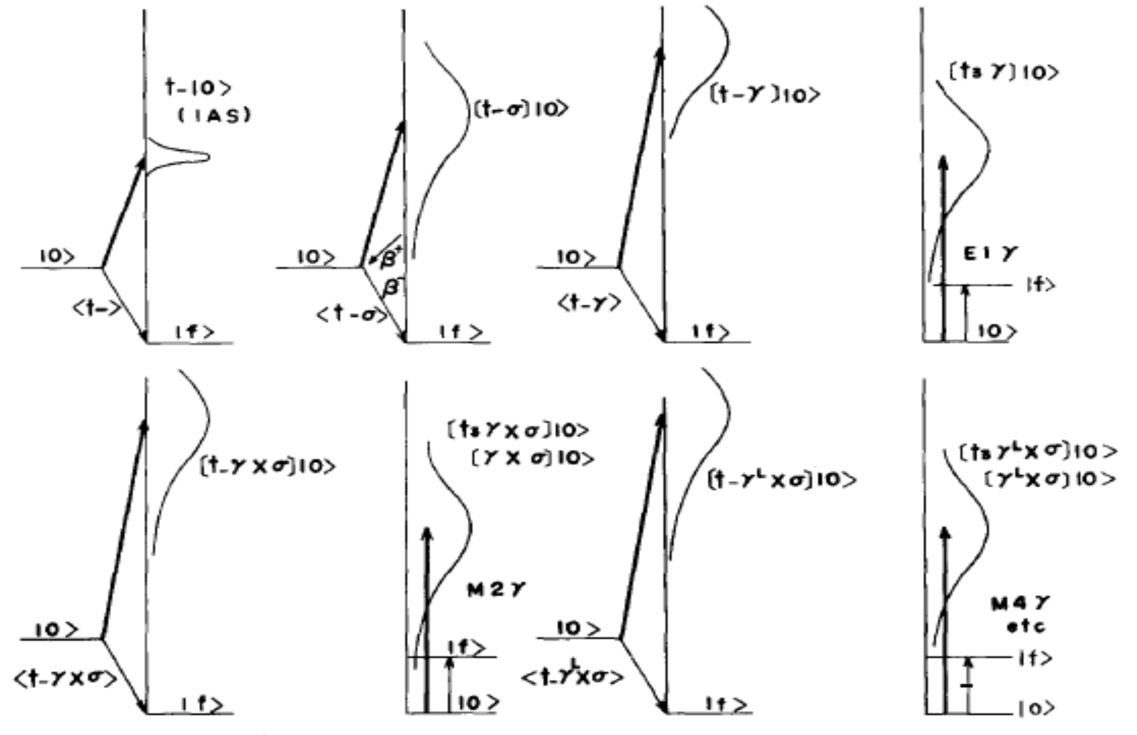
Universal reductions

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

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

k~0.25-0.30 for J=1,2,4





Ejiri Fujita PR 34 85 1978

$k = k(\tau\sigma)\ k(NM) \sim 0.3$

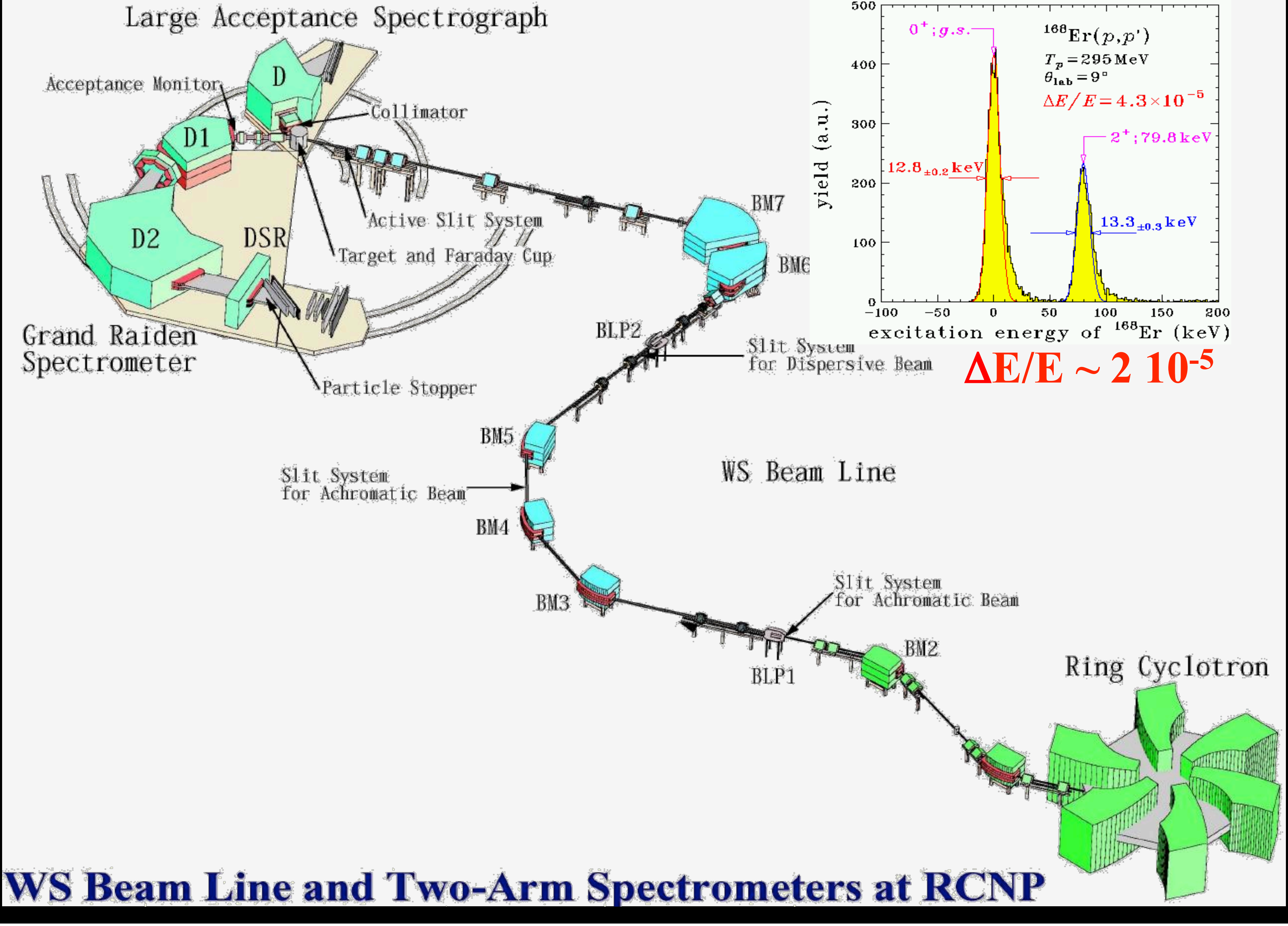
$k = k(\tau\sigma) \sim 0.5$ τσ GR

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

Δ isobar GR

3. Charge exchange (^{3}He,t) reactions

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



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

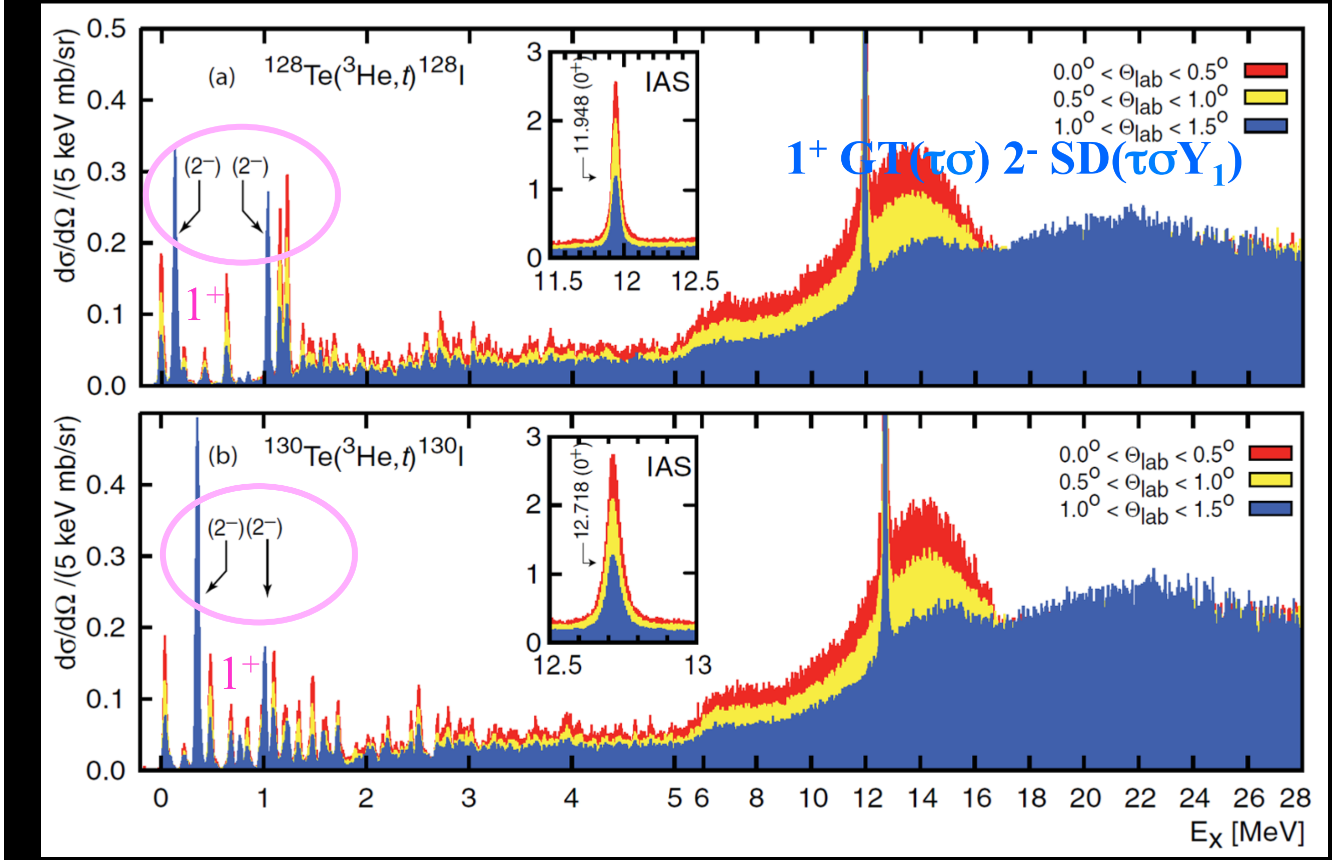
WS Beam Line and Two-Arm Spectrometers at RCNP

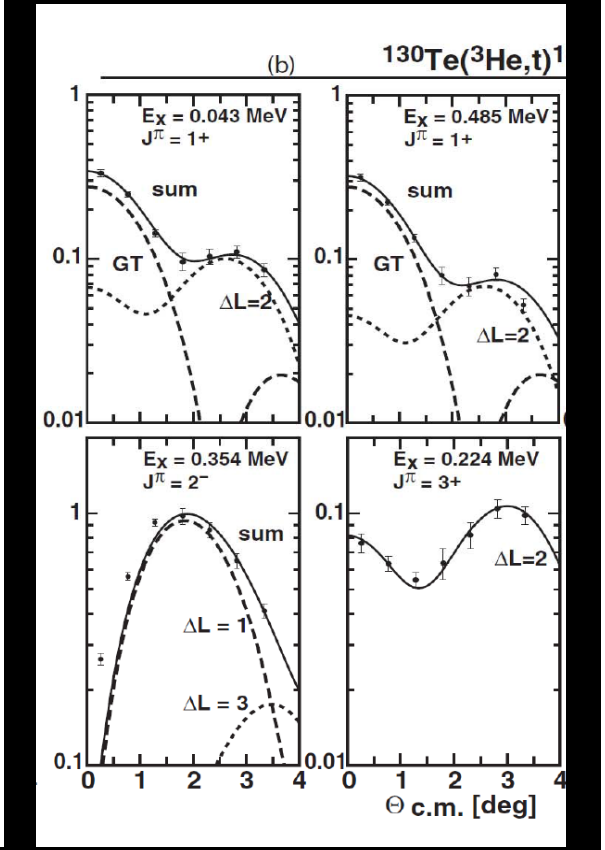
DBD ^{76}Ge, ^{82}Se, ^{100}Mo, ^{128}Te, ^{130}Te ^{150}Nd show GT SD SQ states.

$$\frac{d\sigma_\alpha(0^o)}{d\Omega}\frac{1}{K(E_i,0)N_\alpha^D} = |J_\alpha|^2 B(\alpha),$$

$B(\alpha)=M^2$, $M(1+) = \sigma\tau + [\sigma\tau\times r^2Y_2]_{J=1.2}$

$M(2-)= [\sigma\tau\times rY_1]_2$





Te data by Puppe et al. PRC 86 044603 2012

CER DBD NME P. EXP at RCNP Akimune, H.Ejiri, D.Frekers et al 1994- 2014.

Reviews Ejiri PR 338 ‘00, Vergados Ejiri Simkovic Rev.Prog. Phys. 75 ‘12.

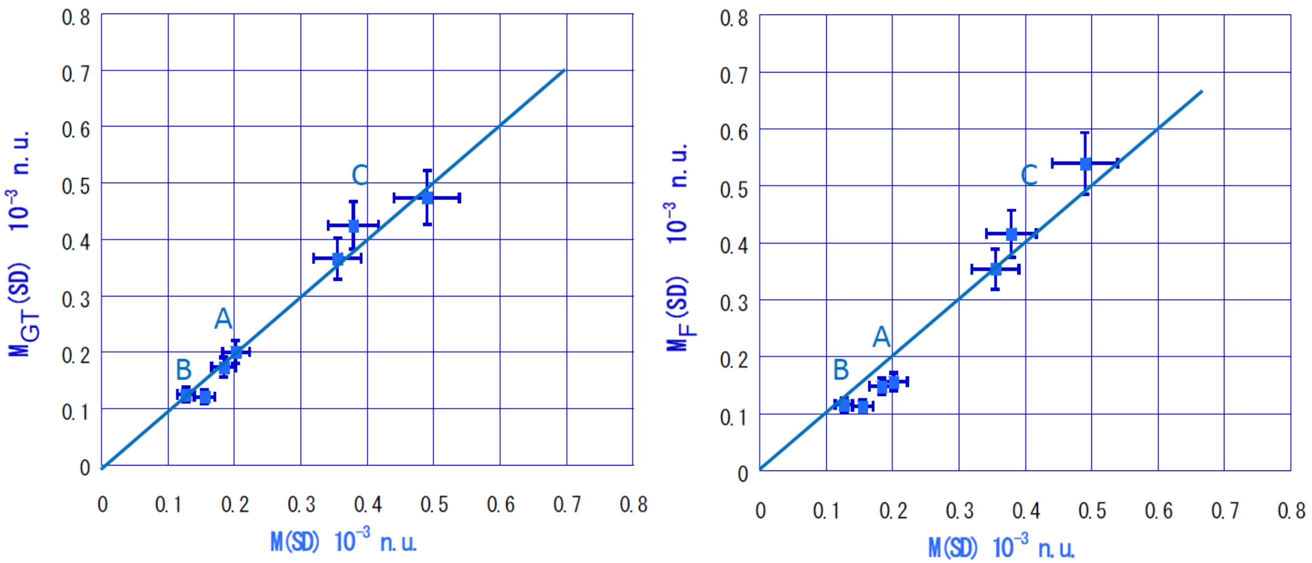
$$\frac{\sigma_\alpha(q,\omega)}{d\Omega} = K(E_i,\omega) f_\alpha(q) N_\alpha^D(q,\omega) J_\alpha^2 B(\alpha),$$

α denotes the Fermi, GT and SD mode excita

$$B_\alpha(SD) = R_\alpha B_{R\alpha}(SD), \quad M_\alpha(SD) = B_\alpha(SD)^{1/2}$$

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

Figure 3. The CER SD NMEs $M_{GT}(SD)$ (left hand side) and $M_F(SD)$ (right hand side) for the DBD nuclei are plotted against the SD NMEs $M(SD)$. A : $(1g9/2)_n \leftrightarrow (1f5/2)_p$ for $A = 76$ and 82, B: $(2d5/2)_n \leftrightarrow (2p1/2)_p$ for $A = 96$ and 100, and C: $(1h11/2)_n \leftrightarrow (1g7/2)_p$ for $A = 128$, 130 and 136.

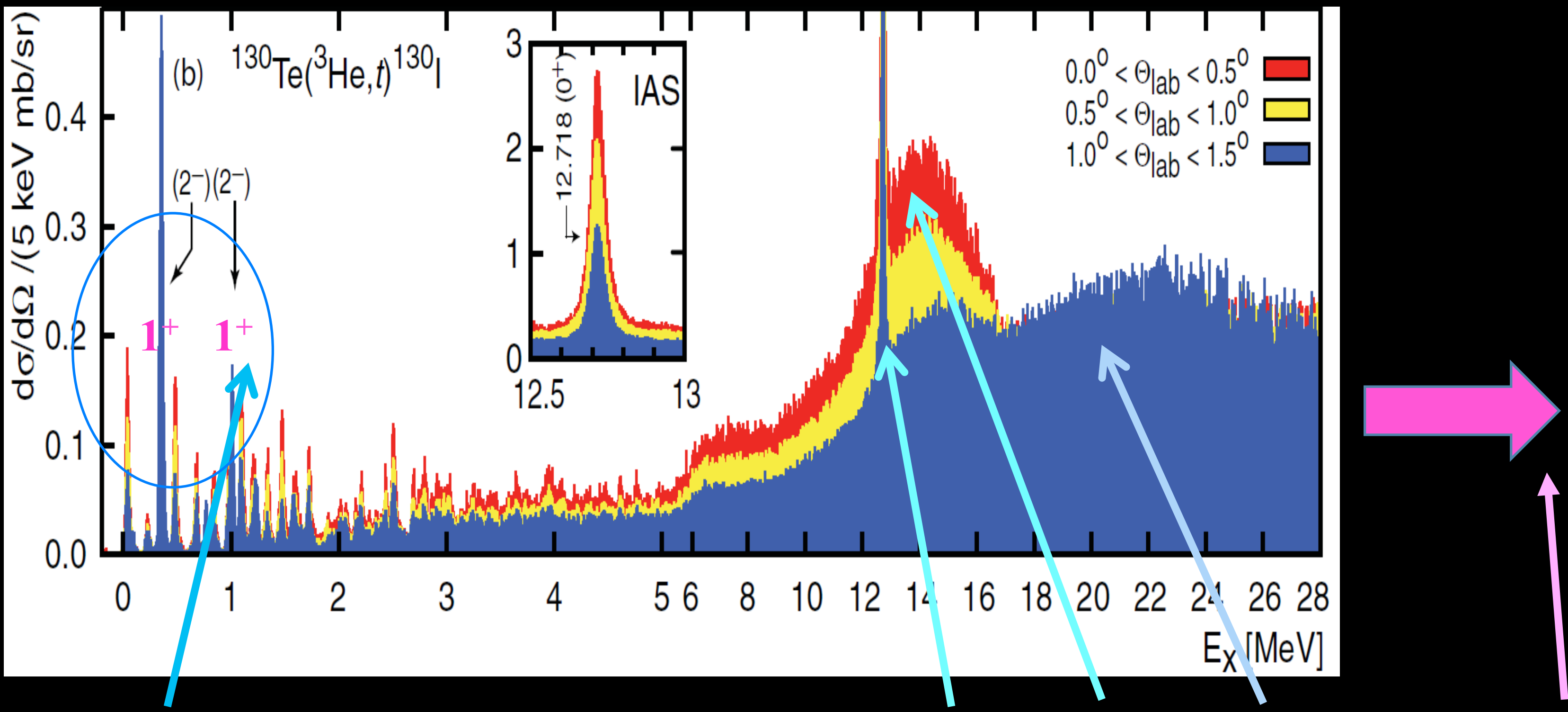


SD NMEs with g^{eff}_A ~0.25 g_A from ft data in neighboring nuclei.

Exps –May 9 on SD with Akimune, Ejiri, Frekers, Harakeh et al.

Single CER β (τσ) strengths on DBD Ge,Se, Zr,Mo,(Cd),Te,Xe RCNP Osaka

Konan, KVI, MSU, Munster, RCNP/Osaka, and others.



Weak GT(1^+), 2^- 3^+at low E.

ΣB(GT) 3Mev ~ 0.01 B(GTGR)

Strong IAS (0^+), GT(1^+), SD(2^-)

GR : ΣB(GT) ~ 0.5 B(SUM)

Higher (Isobar)

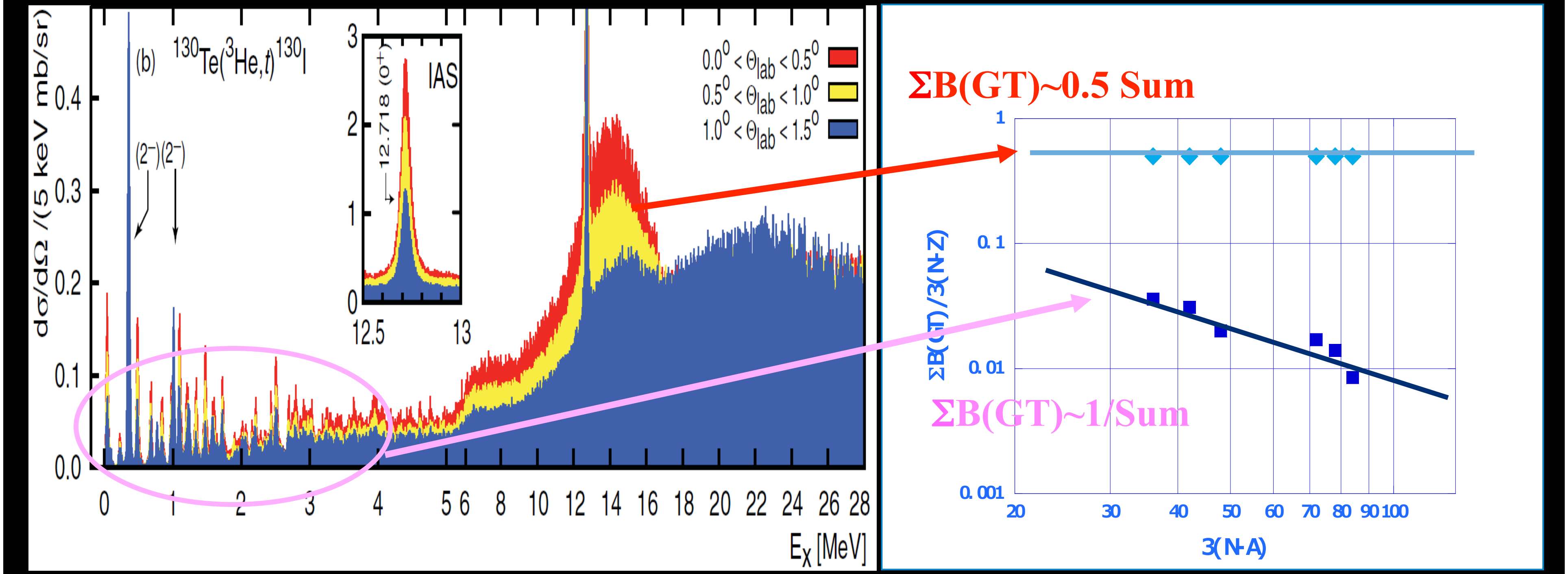
0.4 B(SUM)

…

P.Puppe et al PRC86 044603

H.Ejiri et al. PR 176 (1968) 1277
First 2^- GR based on reduced B(SD)

Single B(GT) Sum=3(N-Z)



ΣB(GT)~0.5 Sum

ΣB(GT)~1/Sum

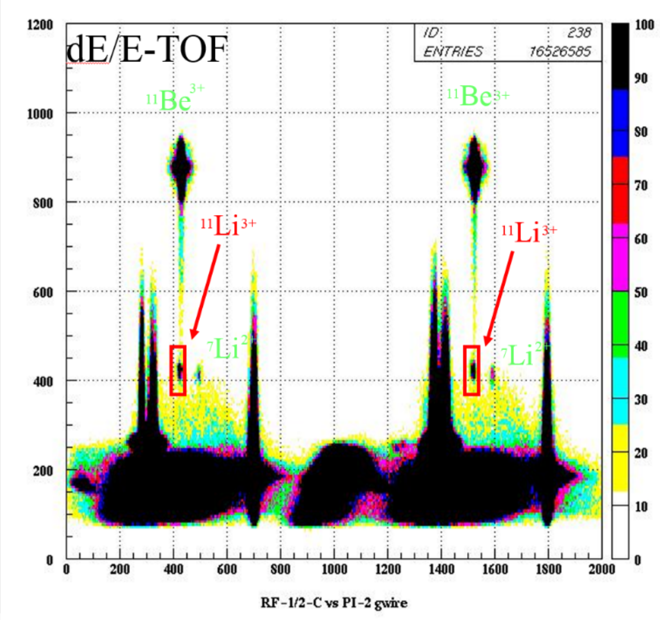
Double B(GTGT) Sum=$[3(N-Z)]^2$

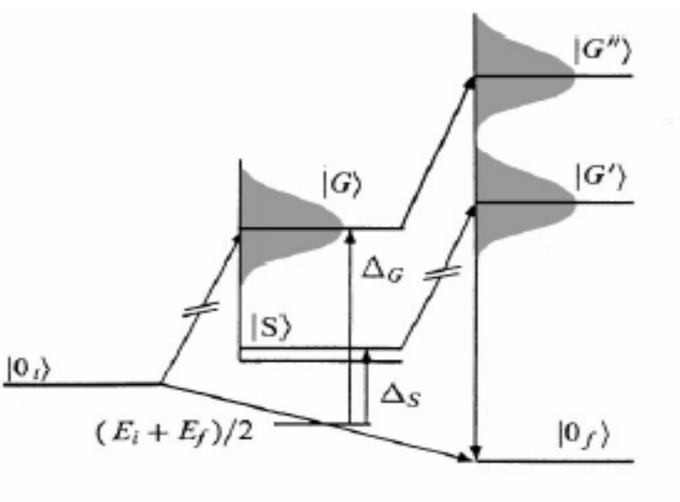
Fe56 3(N-Z)=12 Low GTGT /GR GTGT ~ less than 0.01~1/Sum

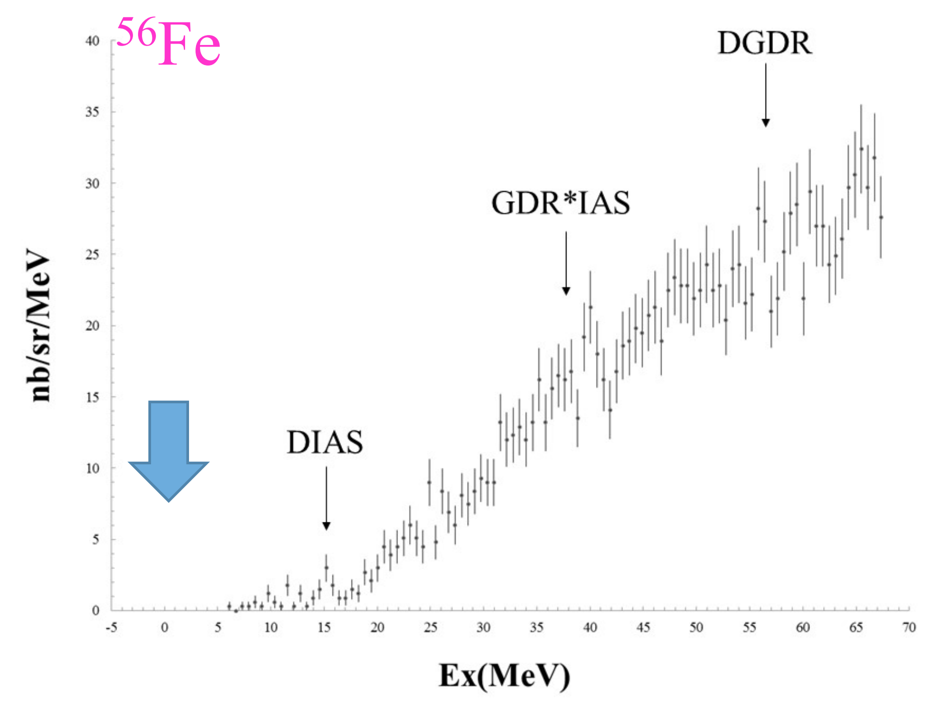
Low GT/GR GT ~0.1

Double charge exchange reaction ∗

RCNP 0.9 GeV ^{11}B, ^{11}Li







^{13}C strengths at low high states

^{56}Fe no low states, mostly GRs

ΣB(GT) low < 0.1 B(GT) GR

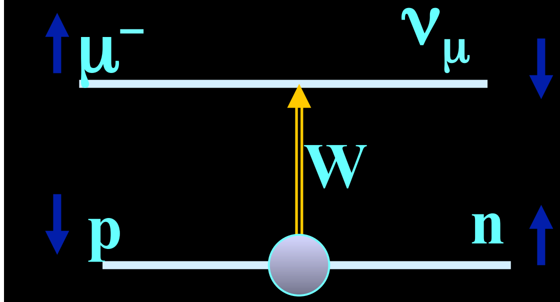
ΣB(GTGT) low < 0.01 B(GTGT) GR

Takahisa Ejiri et al 2010

4. Neutrino nuclear responses by muon CERs

A view from the Ejiri-weekend house

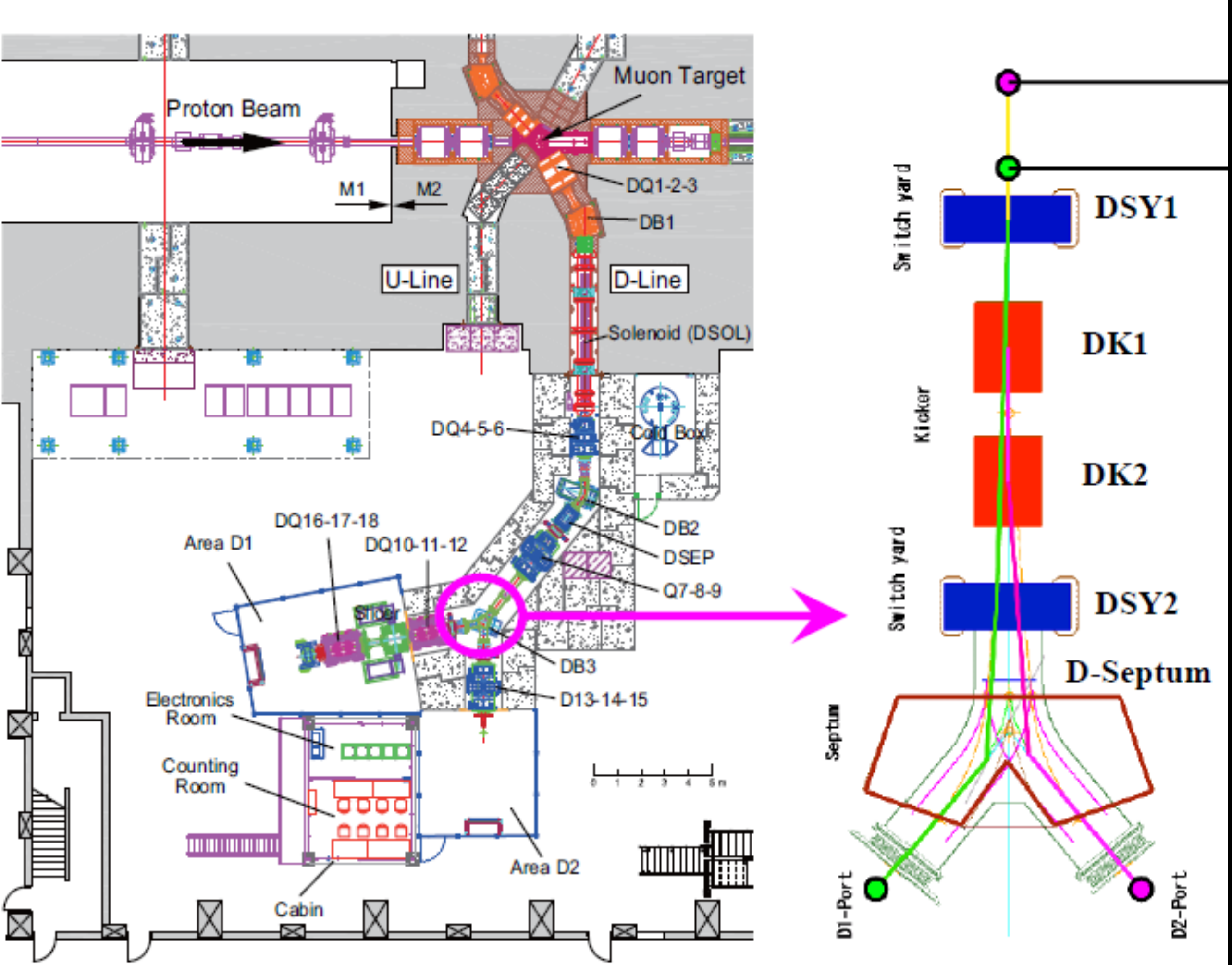
MLF μ probe



MLF (pulsed)

Enriched

^{100}Mo(μ,ν_μ xn $\beta\gamma$)

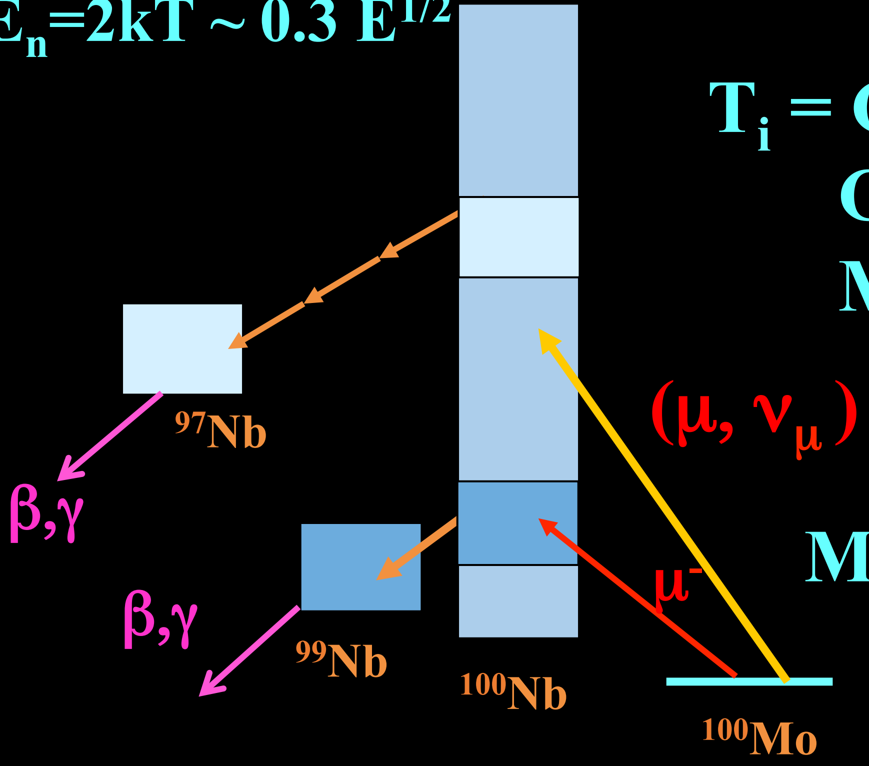


Present CER $^{100}\mathrm{Mo}(\mu,\nu_\mu,\ xn\ \gamma)^{100-x}\mathrm{Nb}\ \nu-\tau(\beta)+$ responses

$F(E_n) = E\ \exp(-E_n/kT)$

$E_n = 2kT \sim 0.3\ E^{1/2}$

$T = \Sigma\ T_i$ transition at ith excited state



$T_i = G_iM_i^2$ with

$G_i = k(Q-E_0)^2$ phase space

M_i : NME

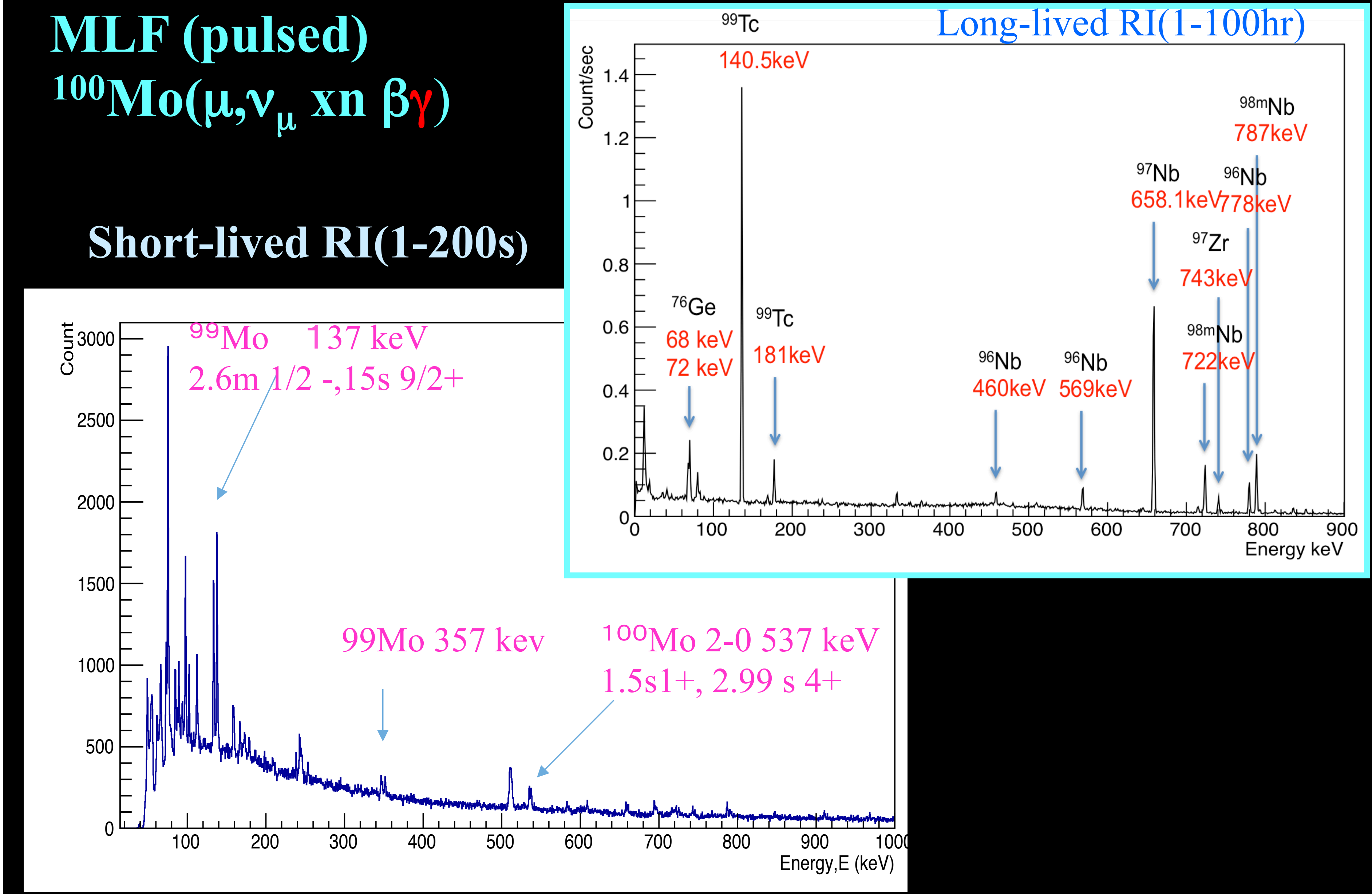
$M_i = g_AM_A + g_VM_V$ for i =0,1,2,..

Effective g_A for i =0,1,2,.

γ_i from $^{100\text{-}i}$Nb gives the isotope i distribution, relative strength in the whole excitation region. Life time gives the absolute strength

H. Ejiri Proc. e-γ conference Sendai 1972

MLF (pulsed)
^{100}Mo(μ,ν_μ xn $\beta\gamma$)



Short-lived RI(1-200s)

Long-lived RI(1-100hr)

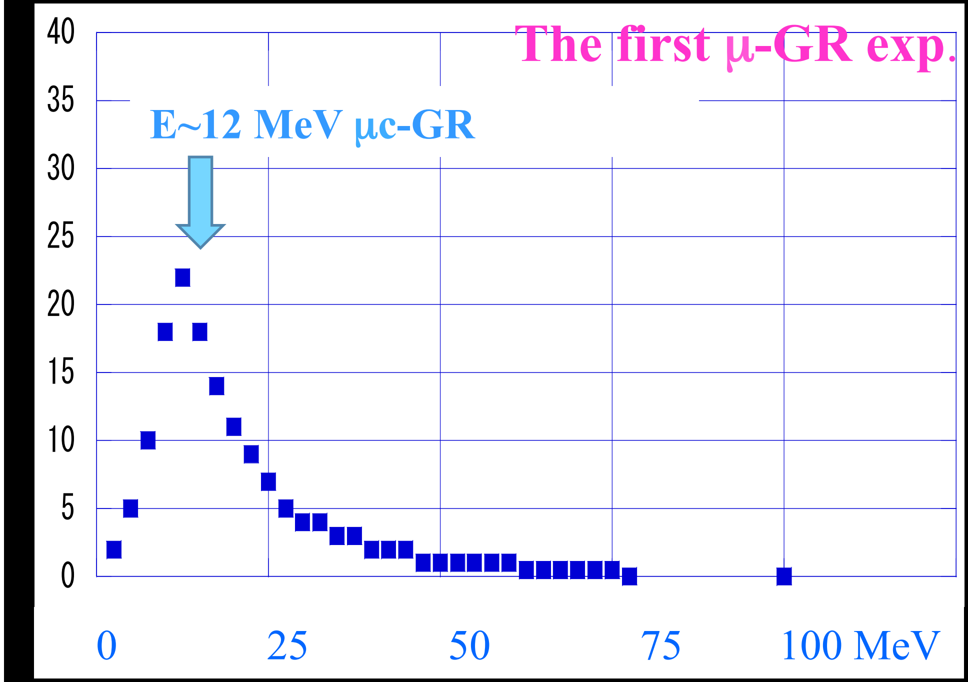
Izyan Hashim PhD Thesis, NNR14 Proc.

Observed isotope population agrees with calculation with μ- GR as given below.

J-PARC MLF

H. Ejiri et al. JPSJ 84 044202 2013

I. Hashim PhD Thesis 2015



The first μ-GR exp.

E~12 MeV μc-GR

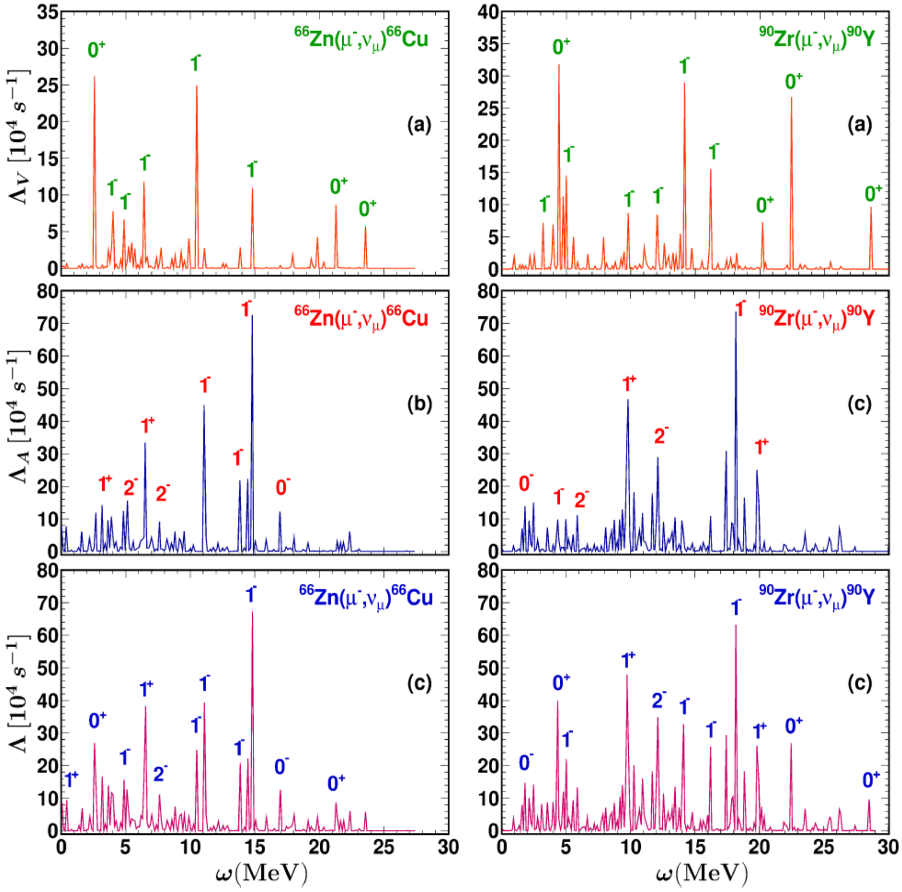
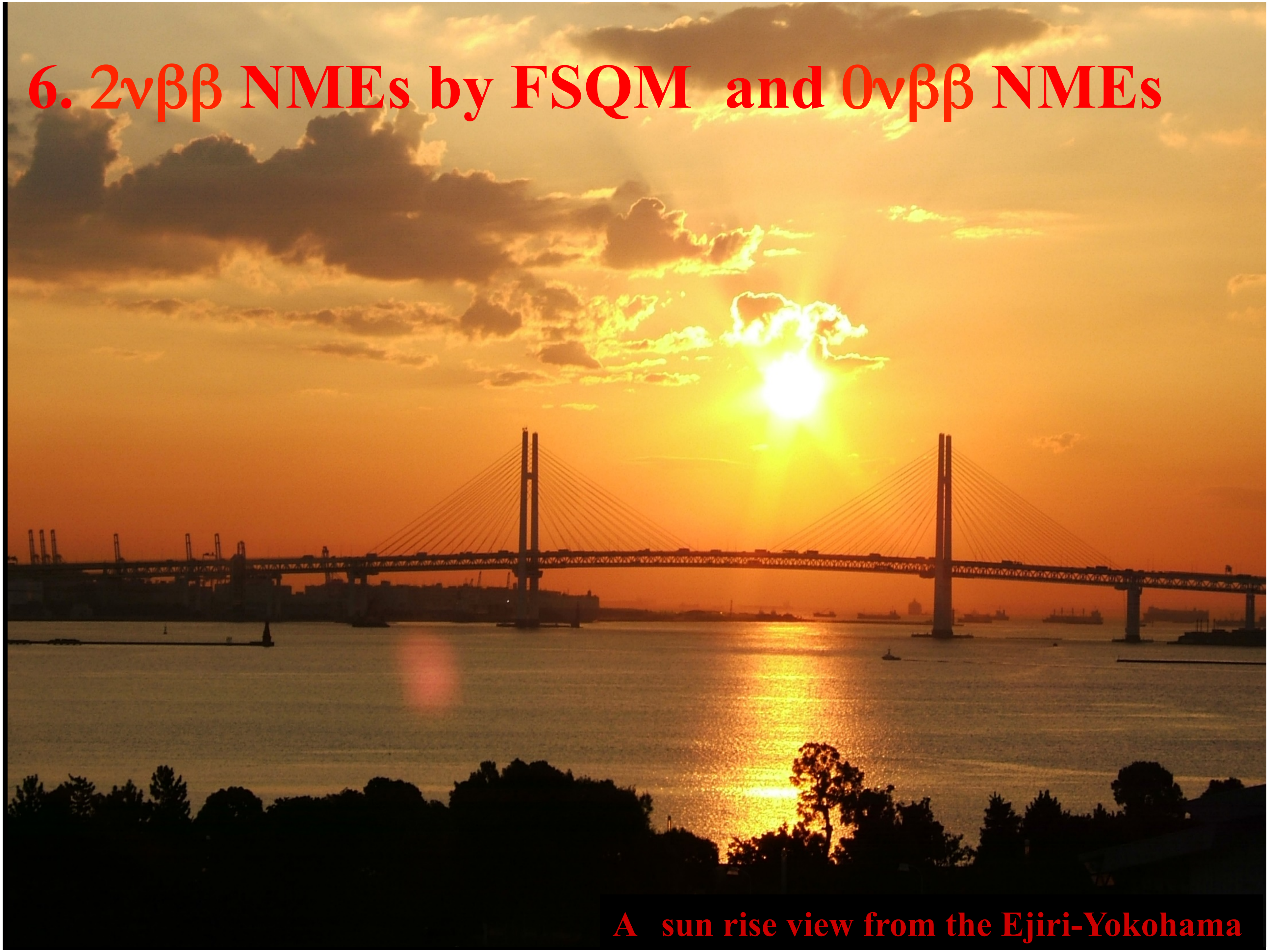


FIG. 4: The same as Fig. 2 but for the nuclei ^{66}Zn and ^{90}Zr.

Haris Kosmas

6. 2νββ NMEs by FSQM and 0νββ NMEs



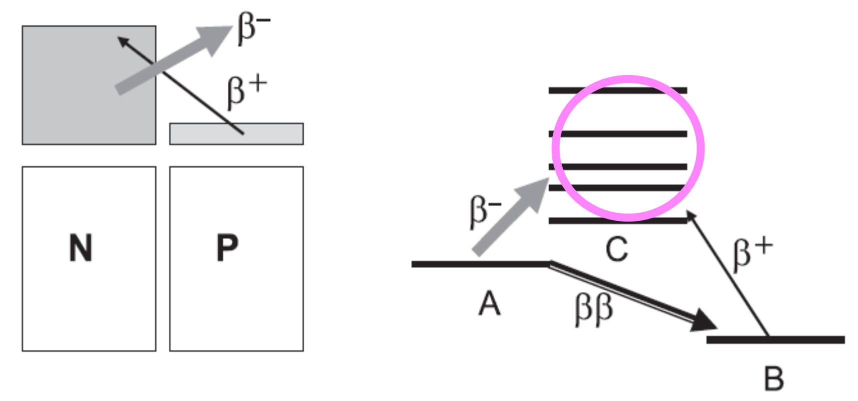
A sun rise view from the Ejiri-Yokohama

FSQP: Fermi Surface Quasi Particle Model

Ground state ββ

Fermi surface QP

0^+ (nn) → 0^+ (pp)



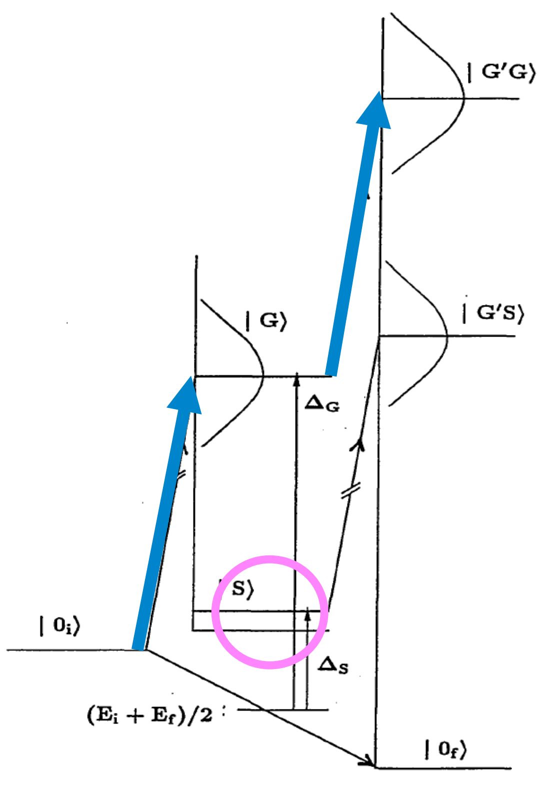
$$M^{2\nu\beta\beta} = \Sigma_k\, M^-_k M^+_k / \Delta_k$$

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

M^-_k and M^+_k are same sign

k^{eff}_A : τσ & medium/isobar effects, derived from exp. β, EC, CER,

$(k^{eff}_A)^2 \sim (0.23)^2 = 0.05$



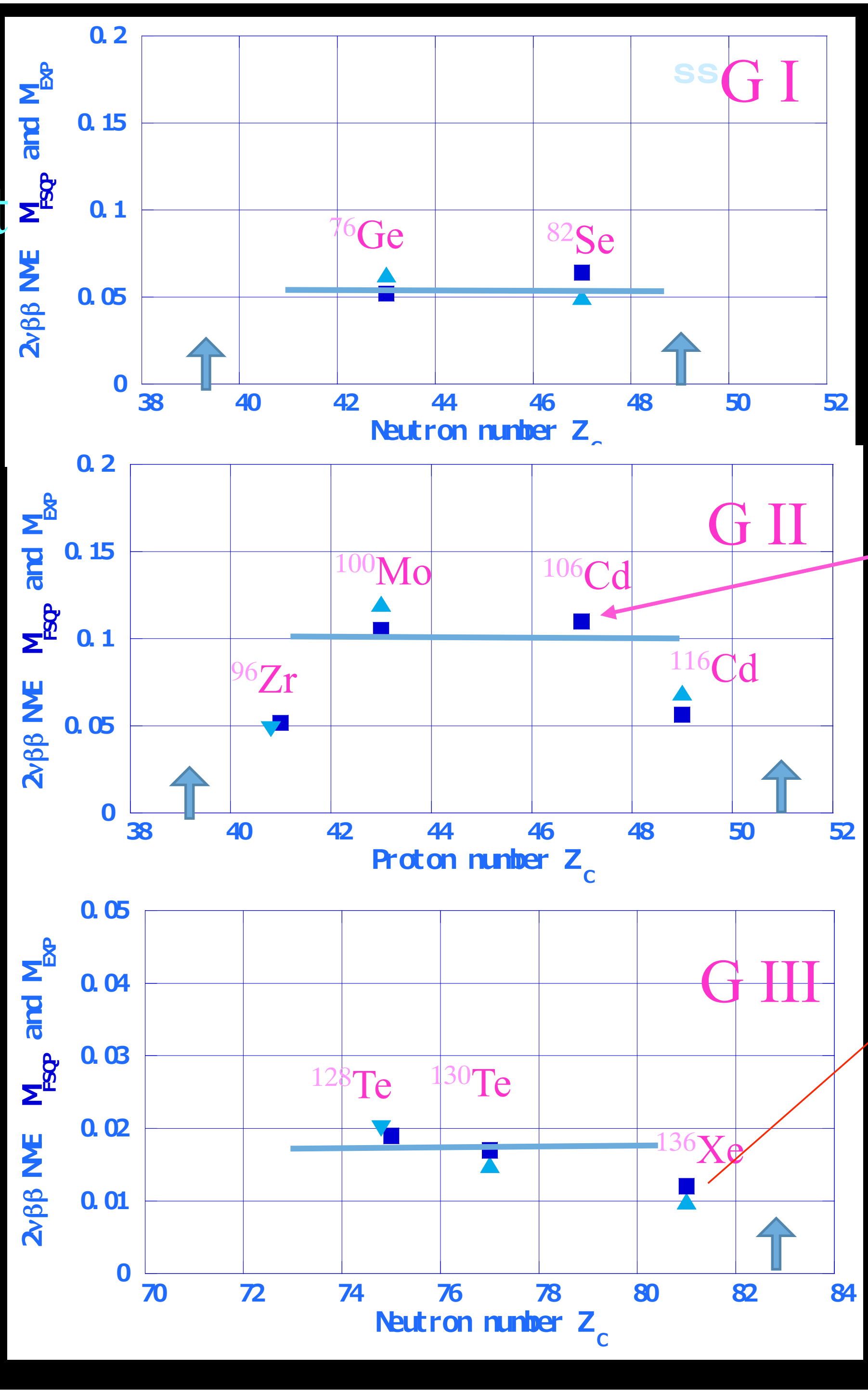
M(GR) < 0.05 M(FSQP)

H. Ejiri et al. J. Phys. Soc. Japan Lett. 65 (1996) 7; JPSJ 78 (2009) No 7.

$2\nu\beta\beta$
matrix element

M(FSQP)

M(EXP)



76 Ge is not small.

2p1/2-2p3/2

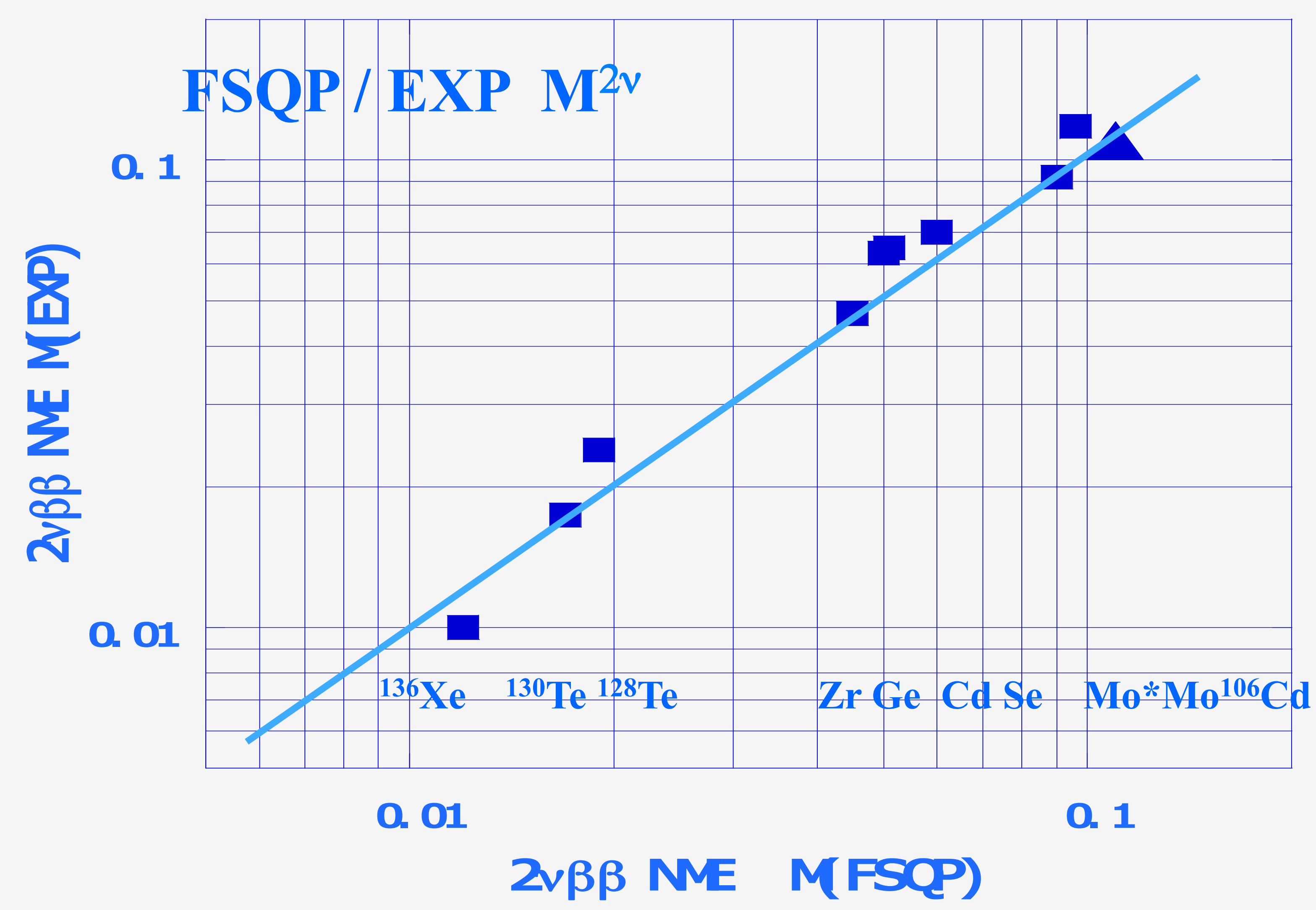
^{106}Cd predicted

$T_{1/2}$(ECEC)=5.2 10^{22}

1g7/2-1g9/2

N=82, p $\xrightarrow{X}$ n

2d3/2-2d5/2



$M^{2\nu}$: small by $(k^{eff})^2$ ~0.05, depend on VU, E(1^+) , not by g_{pp}

$M^{0\nu}$, likewise, small by k^{eff} for 2^- etc, depend on V,U (N=82)

Concluding remarks

1. Single β^- NMEs by (^{3}He,t) CERs, and β^+ by μ CER ($\mu,\nu_\mu xn\ \beta\gamma$) are used to help/confirm theories for $g_A{}^2M_{\beta\beta}$. if DBD theories reproduce the exp. single β absolute and relative strengths.

2. Exp. single $M^\beta(1^+)$ for low states reproduce exp. $M^{2\nu\beta\beta}$
   Exp. single $M^\beta(2^-)$ for low states may be used for $M^{0\nu\beta\beta}$
   Shell closure reduces UV factors and thus $M^{2\nu\beta\beta}$, and also $M^{0\nu\beta\beta}$?.

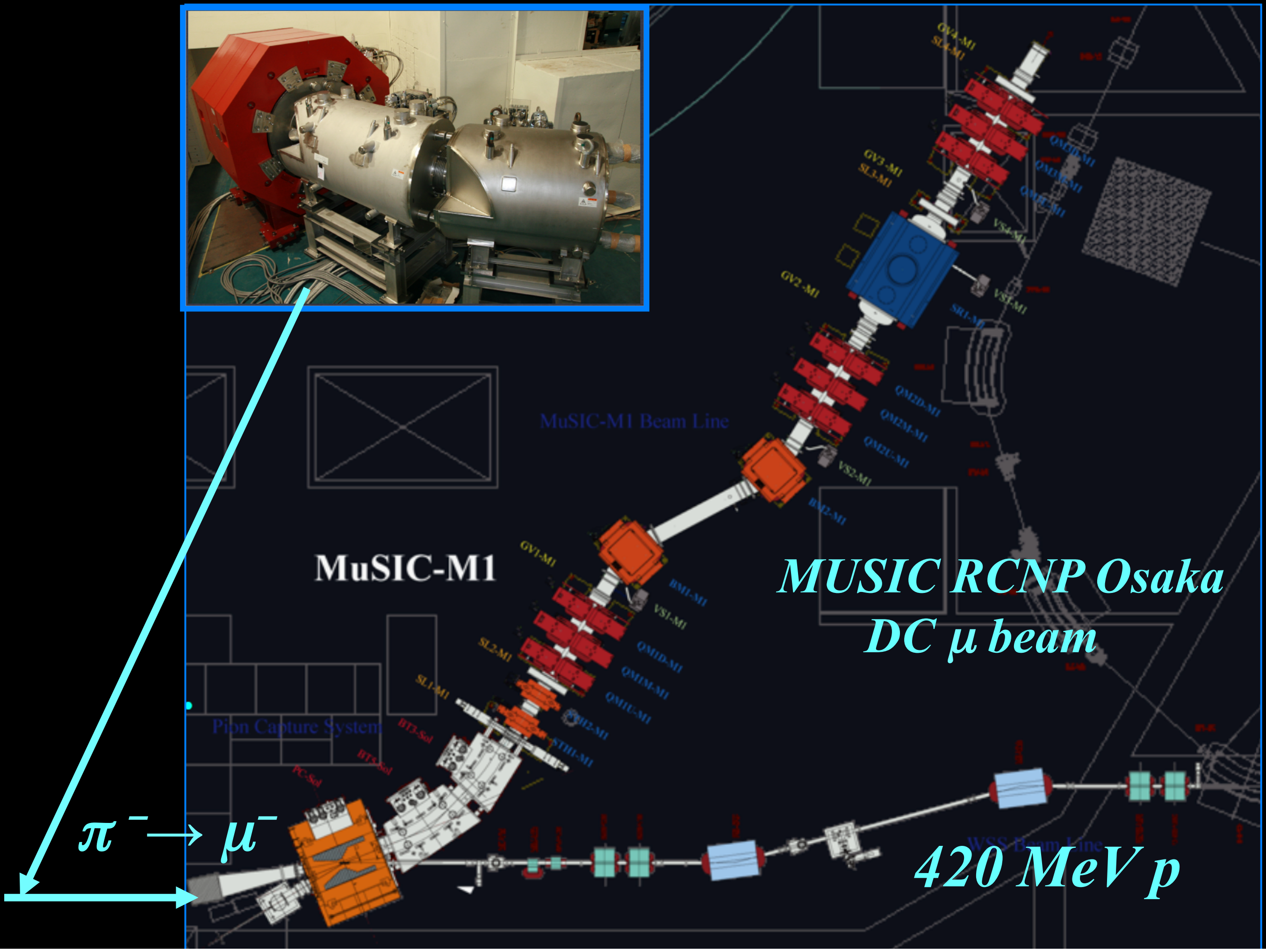
3. Exp. M^β(1+, 2-, 4-) are reduced from QP by k^{eff}~ 0.2-0.25, $k_{\tau\sigma}$ ~ 0.4-0.5 due to nuclear τσ, and k_m ~ 0.5-0.6 (=$g_A{}^{eff}/g_A$) due to nucl. medium & isobar effects. which are not explicitly included in pnQRPA. QRPA with $g_A{}^{eff}/g_A$ ~0.5-0.6 is used ? for M_A in $M^{0\nu\beta\beta}$.

4.GT1$^+$, SD2$^-$ strengths (M^2) at low states are pushed up to GR and even higher region, resulting in the reduction of k~-0.2~0.25.
DCER shows little strength at low states, and mostly at DGR.

Workshop at RCNP Osaka Sep. 26-30, 2016

1.Muon Xγ16 β + NMEs

2. NNR16 (Neutrino Nuclear Responses for DBD &Astro νs)



$\pi^- \rightarrow \mu^-$

MUSIC RCNP Osaka
DC μ beam

420 MeV p

Thank you for your attention

Ejiri-weekend house at Shounan