Neutrino nuclear responses ,NMEs, for ββ and astro physics by nuclear charge exchange reaction.

Axial vector GT SD SO NMEs

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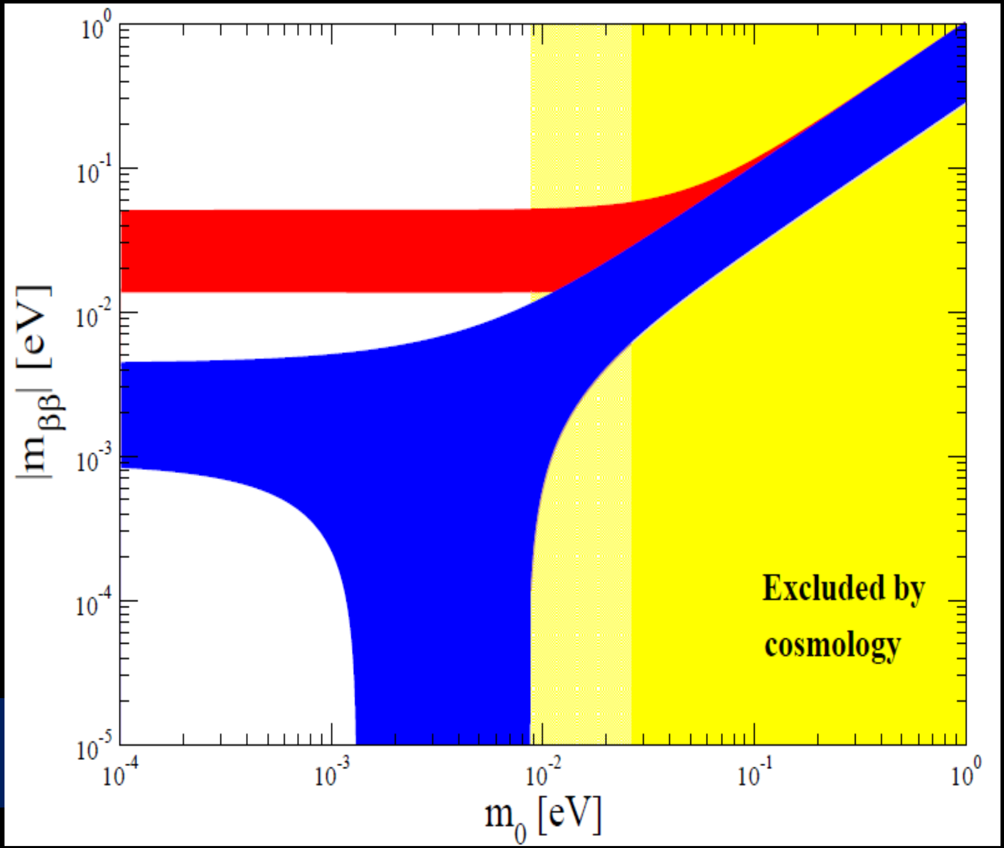
2016.9. NNR16 RCNP Osaka

Neutrino-less ββ in Nuclear Femto (fm) Lab

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

Lepton number ΔL=2

beyond SM.



Particle physics

Majorana ν, m_ν CP

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

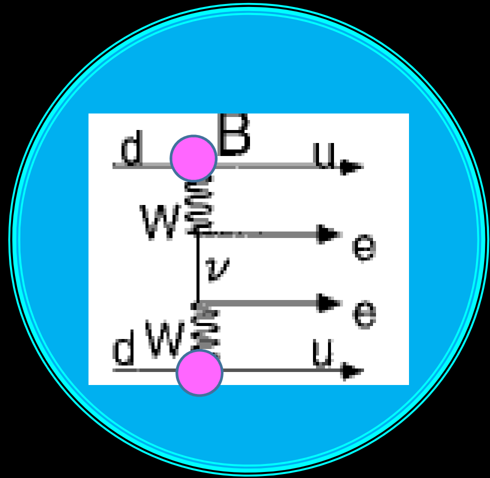
Nucl. physics. g_A
nuclear medium &
τ σ correlations

Cosmology
DM
Leptogenesis

NH $m_3 >> m_2, m_1$

IH $m_3 << m_2, m_1$

Nuclear matrix element NMEs



Detector ν-mass sensitivities

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

$$M = g^2_A M_{DA} + g^2_F M_{DF}$$

$$M_A = \langle \sigma\tau h \sigma\tau \rangle \quad M_F = -\langle \tau h \tau \rangle$$

$$h \sim k/(r_1 - r_2)$$

$$T = G m^2 M^2,$$

$$g^2_A M_{DA} \sim \Sigma\; g_A M_B\; h\; g_A M_B$$

If $g_A M_{SB}$ is reduced to 0.7,

T to 1/3, N 1 ⇨ 10 tons

Momentum transfer

$0\nu\beta\beta$ ν exchange

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

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

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

Axial vector $M_A(J)$

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

Crucial questions on NMEs for 0νββ exps.

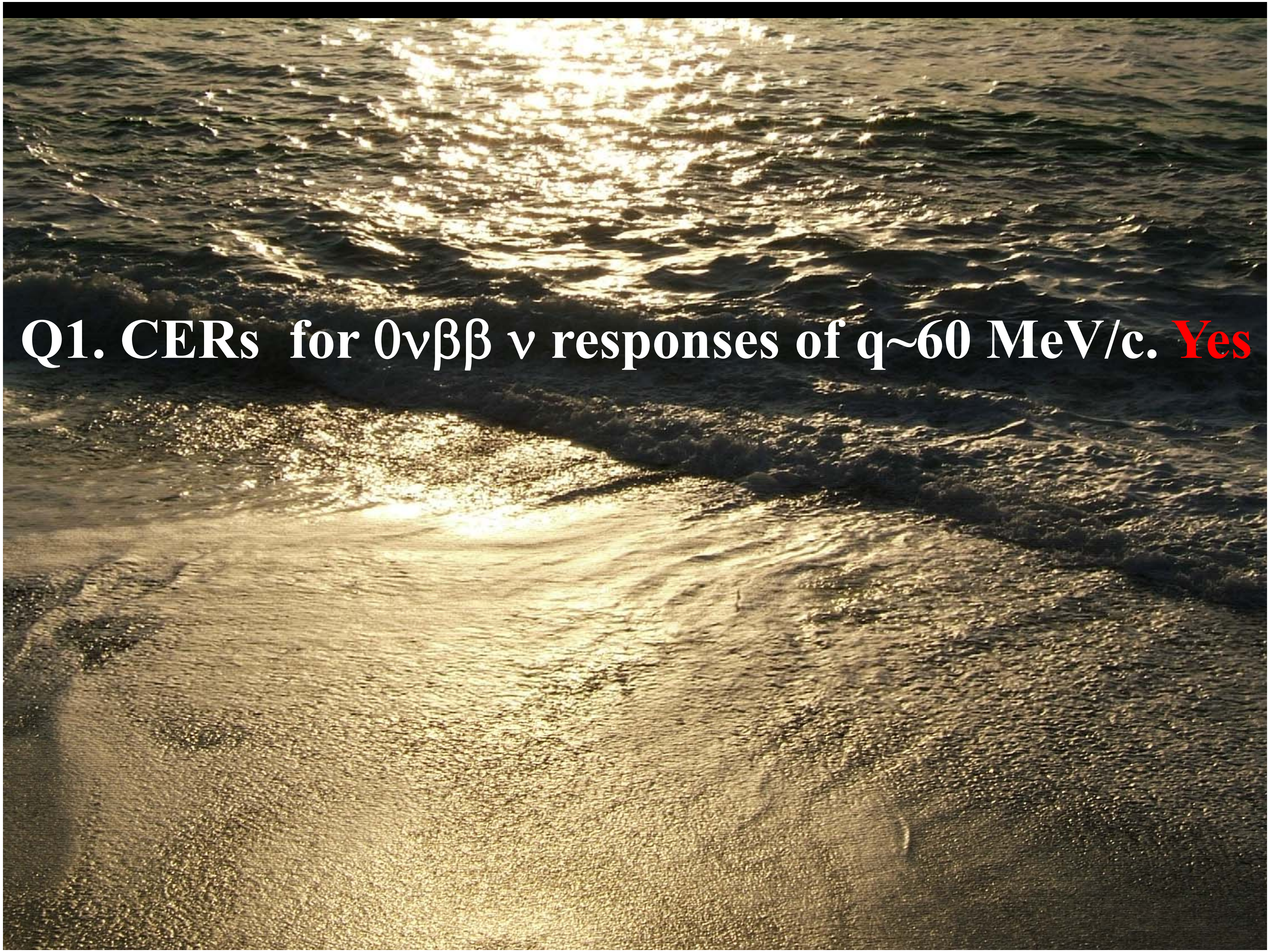
	2νββ	0νββ
CER is possible ?	q=0 GT 1+ Yes	q≠0 SD 2- ,3+ No ?
NME is reduced ?	GT g_{pp} cancell Yes	Many J, not g_{pp} No ?
NMEs reflect nucl. structure ?	Sensitive to nuclear. structures as it is. Yes	No sensitive, universal because of many J. No?
Solar ν BGs ?	Rate is very small No	Solar ν serious. No ?

If all NO, NMEs would be all large and same, no worry about NMEs

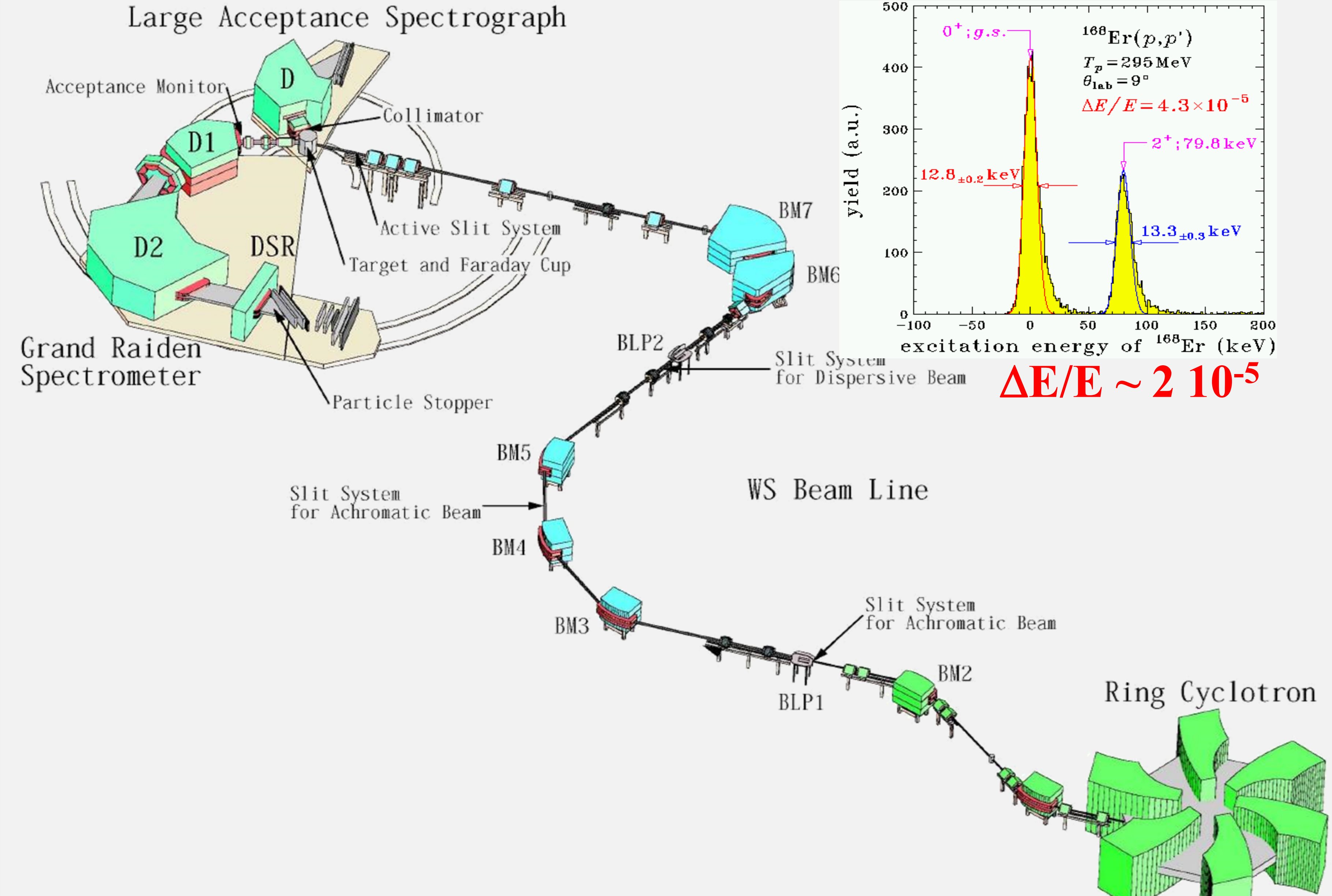
Just detectors with large N(enriched isotopes) and small BG(2νββ)

We show all YES, and thus need CERs and theories to study NMEs.

Q1. CERs for 0νββ ν responses of q~60 MeV/c. Yes



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



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

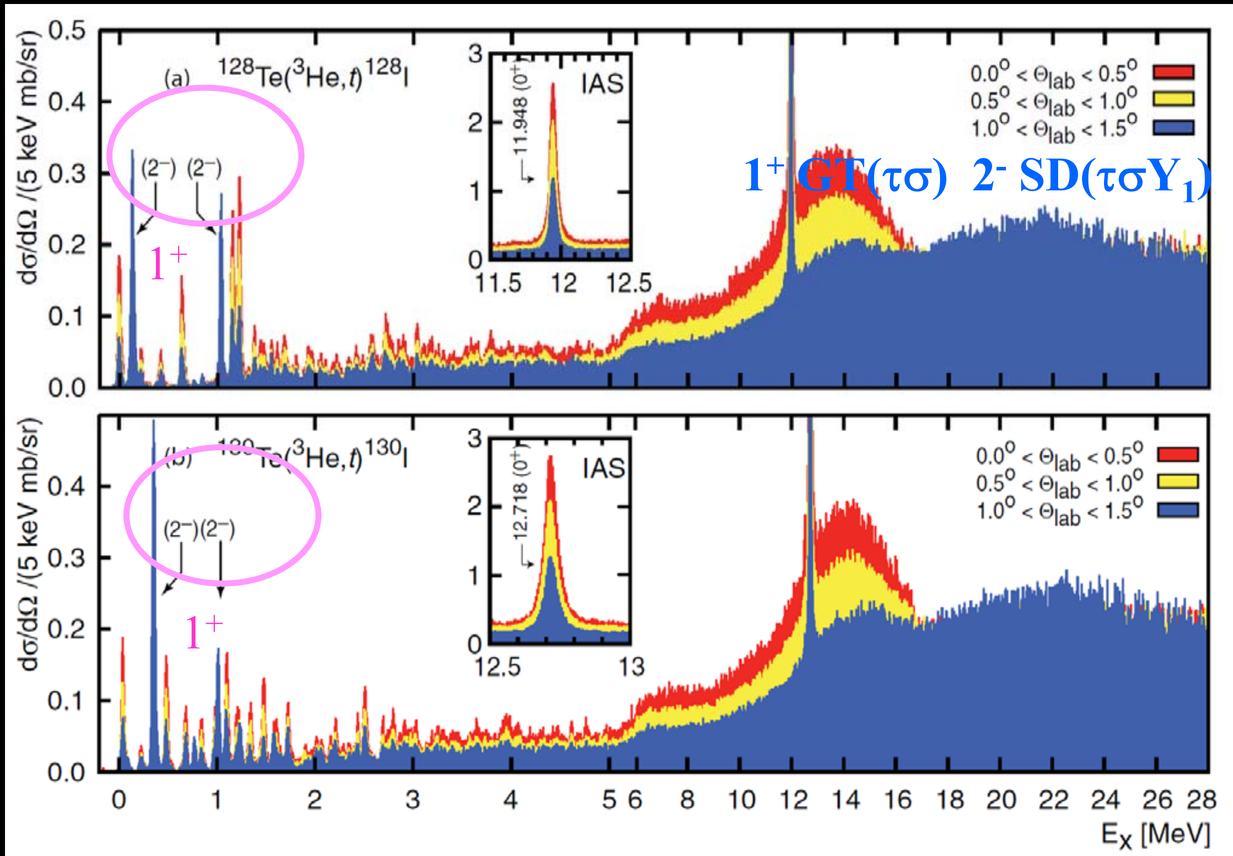
WS Beam Line and Two-Arm Spectrometers at RCNP

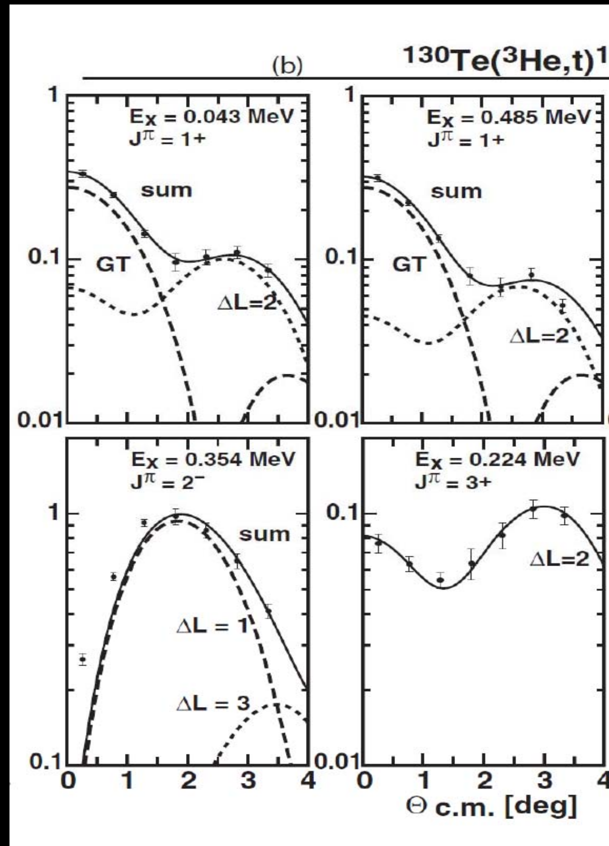
DBD ^{76}Ge, ^{82}Se, ^{100}Mo, ^{128}Te, ^{130}Te ^{150}Nd show GT SD SQ states.

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

B(α)=M^2, M(1+) = στ θ=0 deg., p~0

M(2-)= $[\sigma\tau \times rY_1]_2$ θ=2 deg., p~60MeV/c





Te: Puppe, Akimune, Frekers, Ejiri, et al. PRC 86 044603 2012

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

SD NMEs M(FSQP) = k M(EXP).

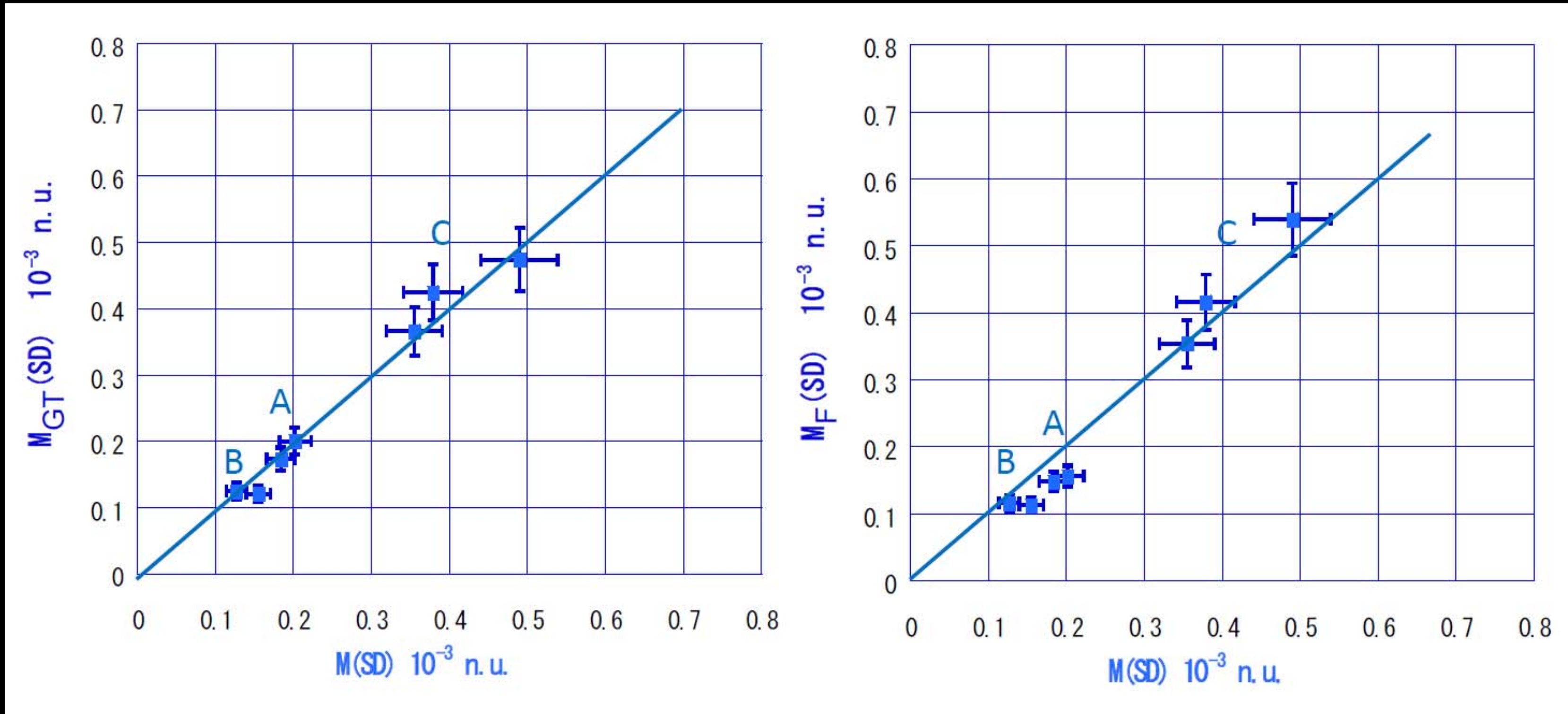
H. Ejiri D. Frekers
J. Physics G. Lett. 43 2016 11LT01

$$\frac{\sigma_\alpha(q,\omega)}{d\Omega} = K(E_i,\omega) f_\alpha(q) N^D_\alpha(q,\omega) J^2_\alpha B(\alpha),$$

α denotes the Fermi, GT and SD mode excita

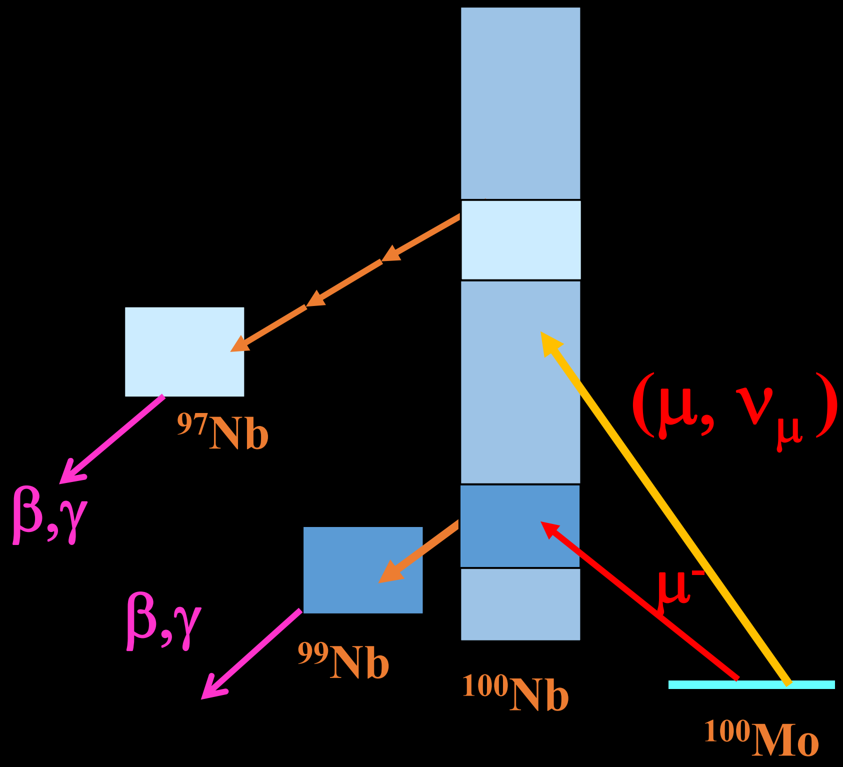
$$B_\alpha(SD) = R_\alpha B_{R\alpha}(SD) \quad M_\alpha(SD) = B_\alpha(SD)^{1/2}$$

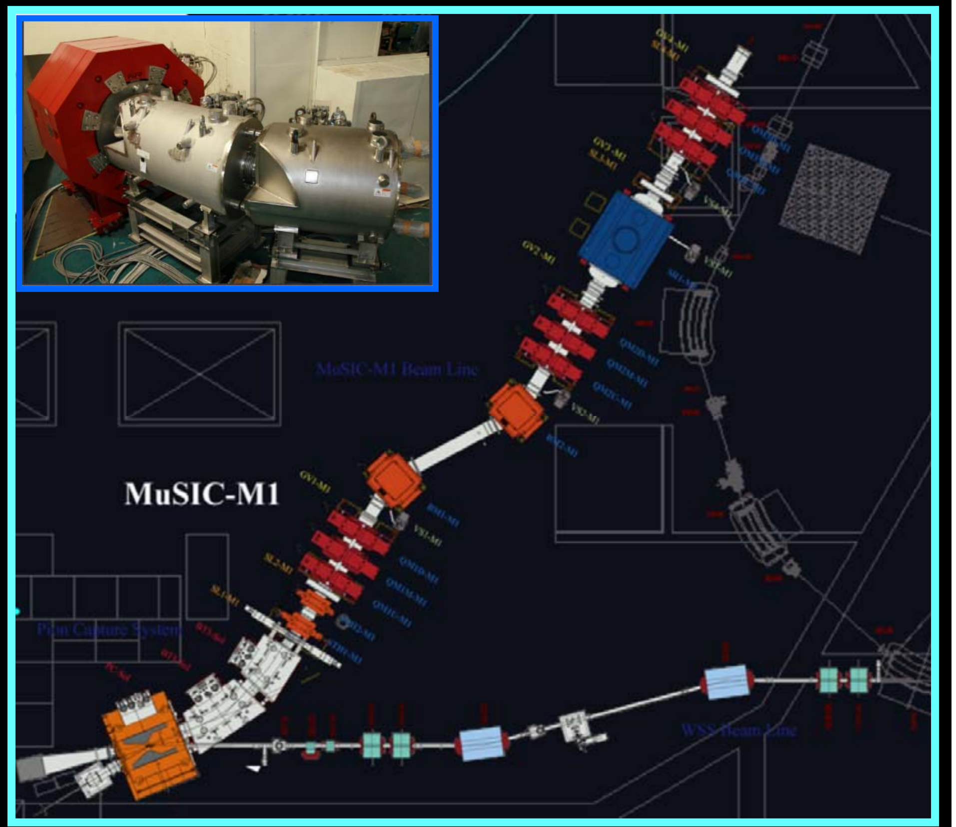
$$B_{R\alpha}(SD) = [\frac{d\sigma_{SD}(\theta_1)}{d\Omega}][\frac{d\sigma_\alpha(\theta_0)}{d\Omega}]^{-1} B(\alpha),$$



SD NMEs with k~0.25 g_A from ft data in neighboring nuclei.
Exps in May on SD with Akimune Ejiri, Frekers et al. Sept 30th

CER (μ,ν_μ, xn γ) $\nu-\tau(\beta)+$ responses with q~50-60 MeV/c





γ_i from $^{100-i}$Nb gives relative strength &life tlme the absolute strength

H. Ejiri Proc. e-γ conference Sendai 1972

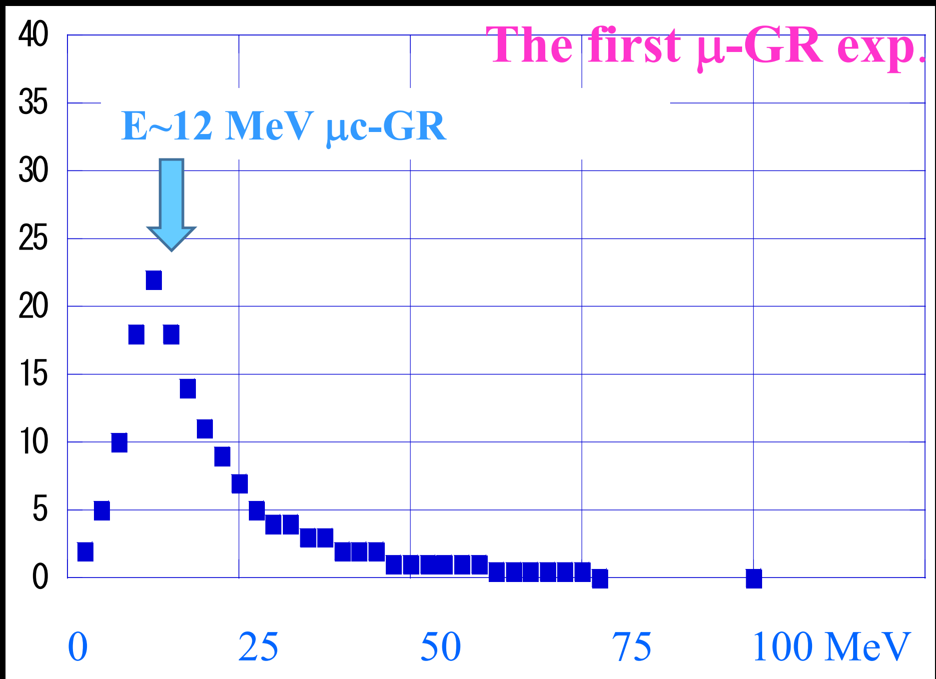
I. Hashim PhD Thesis 2015; I. Hashim H. Ejiri , NNR14, MXG16

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



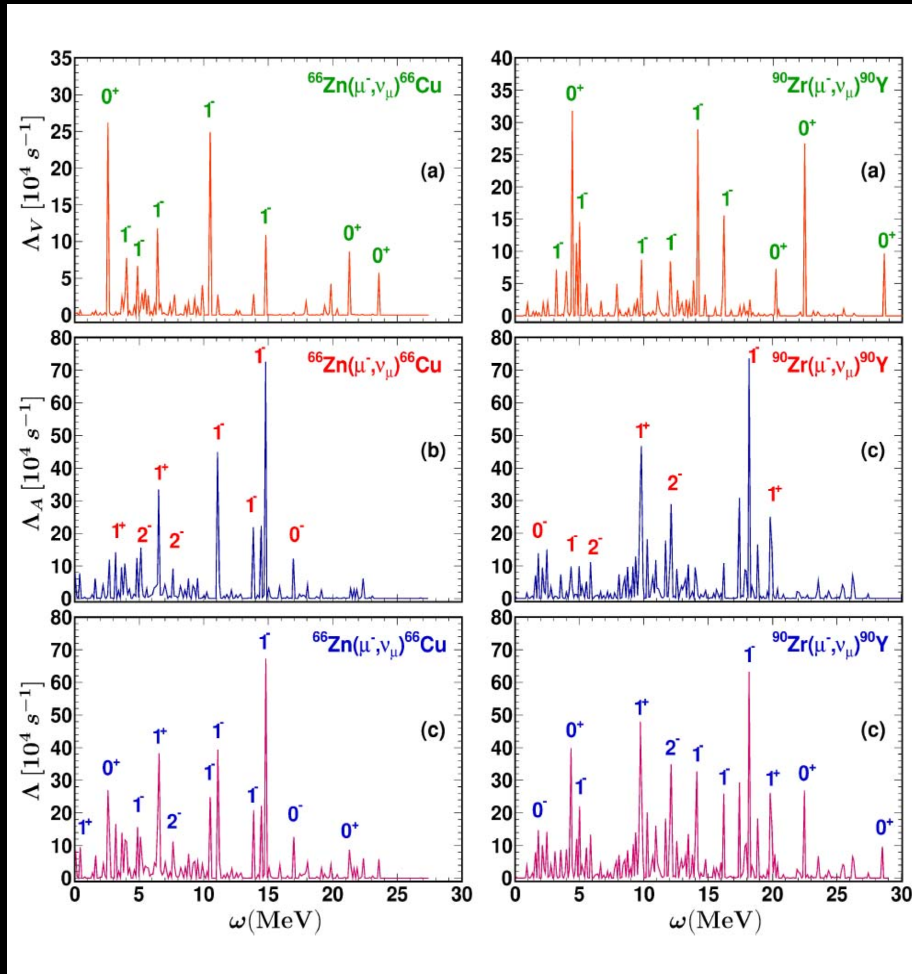


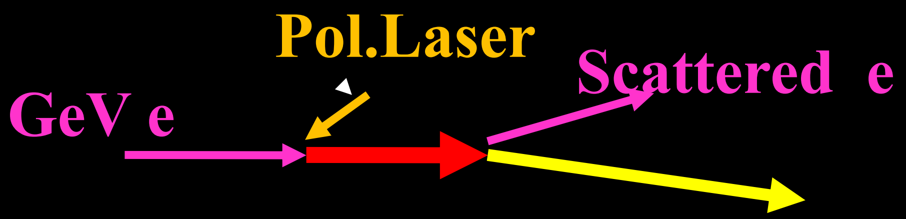
FIG. 4: The same as Fig. 2 but for the nuclei ^{66}Zn and ^{90}Zr.

Haris Kosmas

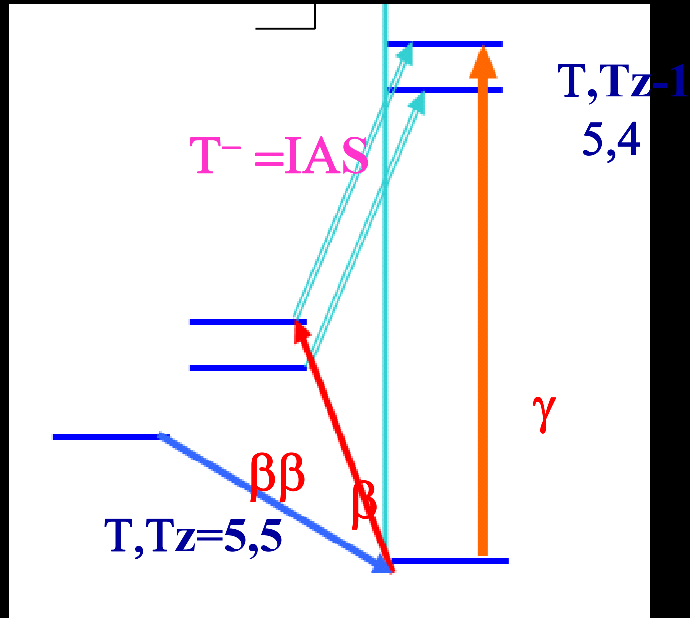
LEPS Photon probe

H. Ejiri PRL 21 '68
H. Ejiri, A. Titov PR C 88 '13

Laser electron photon Sources

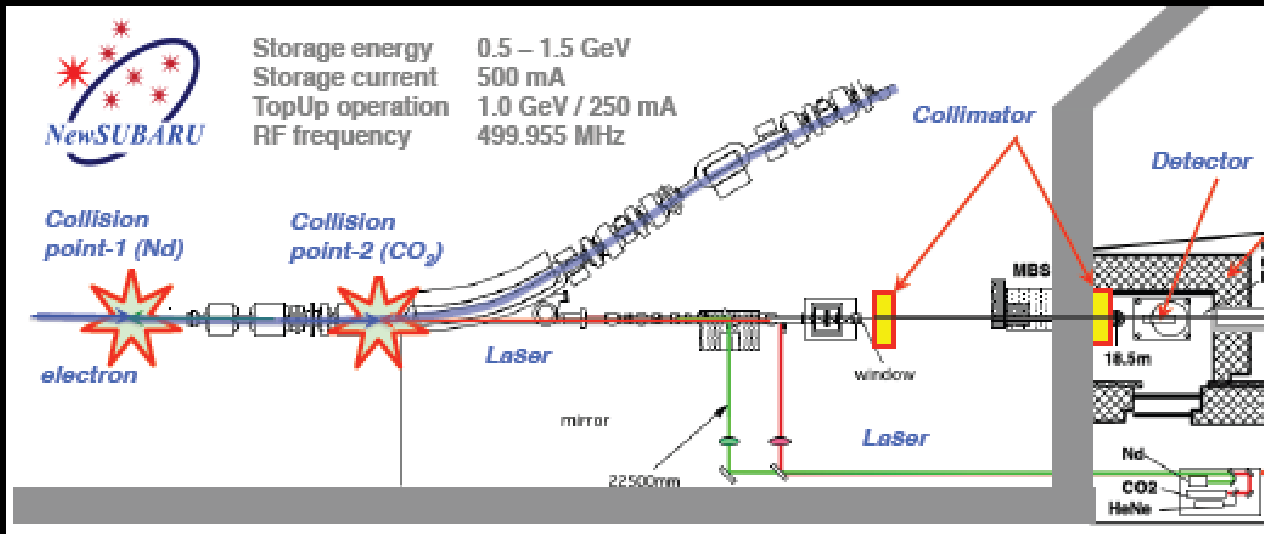


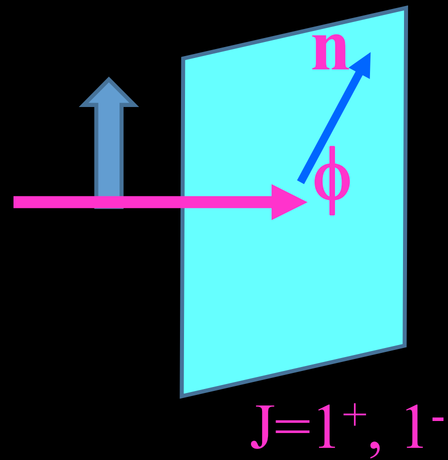
$E_\gamma \sim 4\,\gamma^2 E_l = 2\;10^8 E_l \sim 20$ MeV,



β+ responses via IAS γ

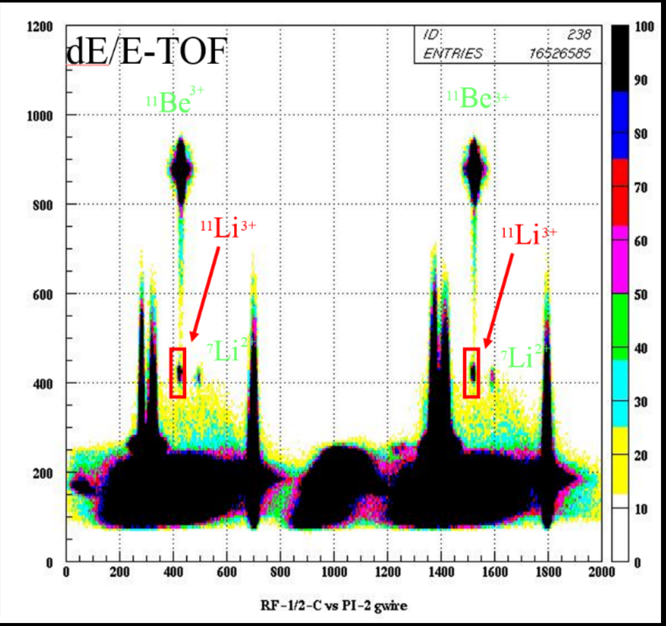
$\langle f\,|g\,M_\beta|\,i\rangle = g/e\,(2T)^{1/2} \langle f\,|\,em_\gamma\,|\,I\rangle$

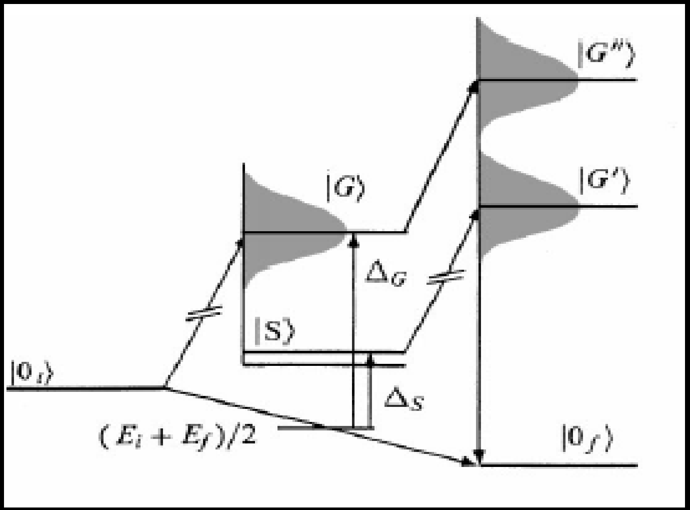


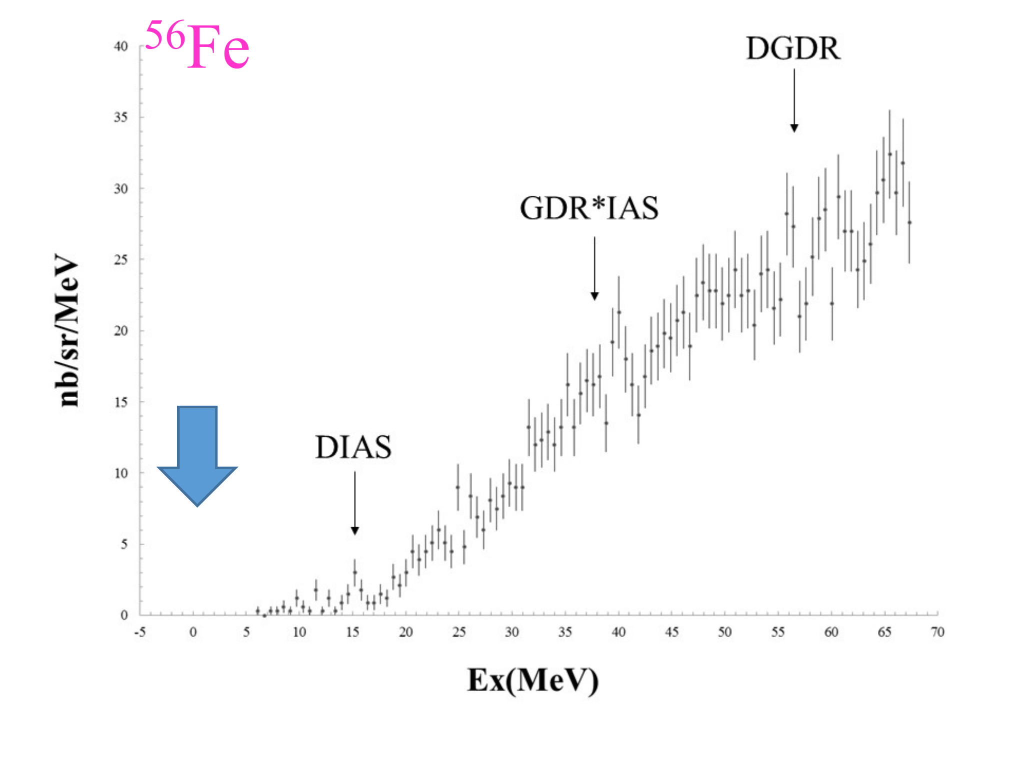


Double charge exchange reaction *

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

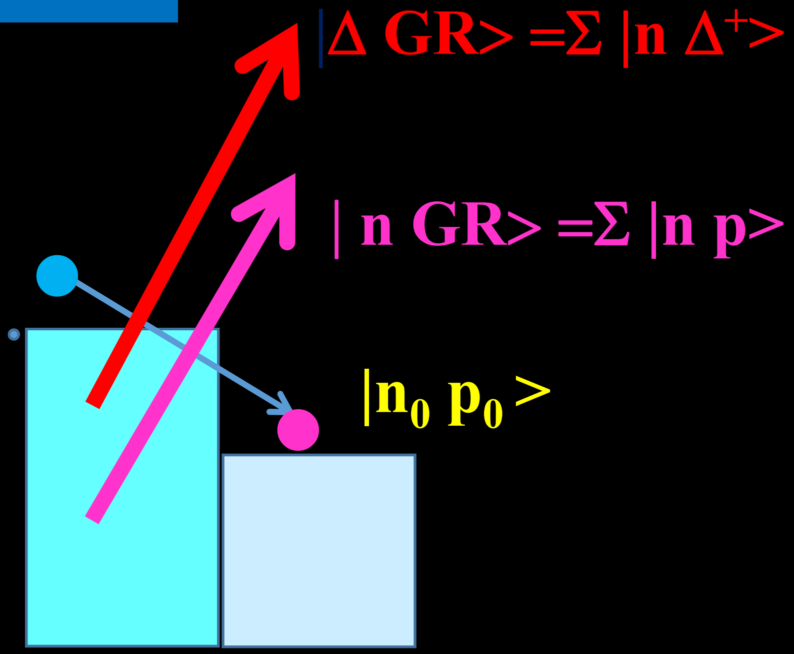
Q2. Axial vector single β decay NMEs

GT 1^+, SD 2^-, SH 4^- are reduced Yes

Schematic view of ββ and GR

Ejiri Fujita PR 34 85 1978

1. n_0 and p_0 are on the ground 0^+ at Fermi surface.



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

   Δ GR: coherent sum of many (N=100) $\Sigma\ |n^{-1}\Delta^+\rangle$

4. They mix destructively via repulsive interaction as

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

GR and other effects are uniform, and are given by experimental renormalization of $M = k^{eff}\ M^0$ (QP)

$$k^{eff} = k^{eff}\ (\tau\sigma) \times k^{eff}\ (\Delta) = [1/(1+\chi_{\tau\sigma})][1/(1+\chi_M)]$$

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

$$M_{exp} < M_{qp}$$

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

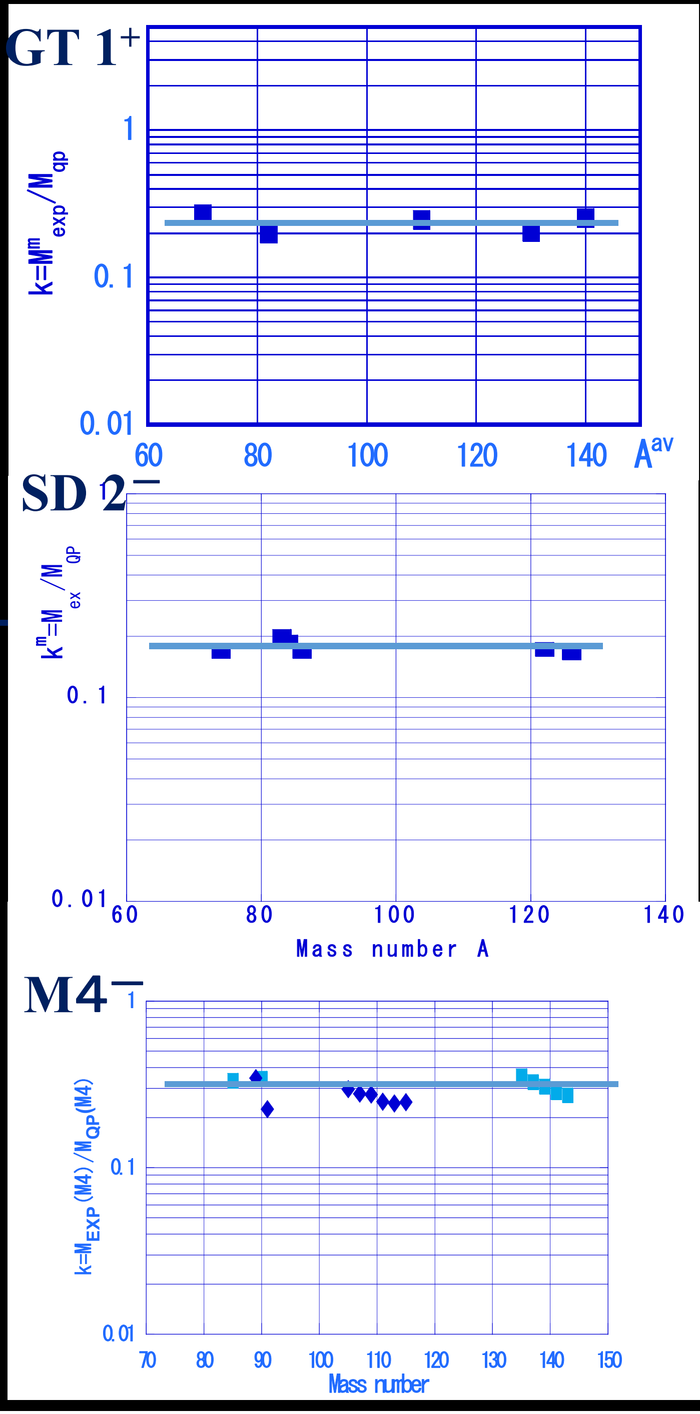
$$k = 0.2 - 0.3 = k_{\tau\sigma}\, k_{NM}$$

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

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

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

$$k_{NM} \sim 0.6 = g_A^{eff} / g_A \quad N\Delta\ NM$$

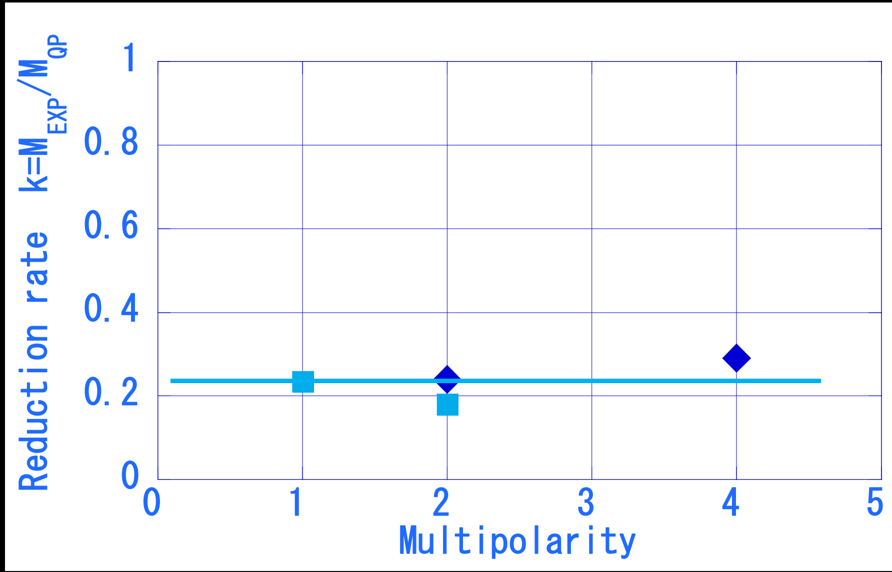


H, Ejiri J. Suhonen J. Phys. G. 42 2015 055201

H. Ejiri N. Soucouti, J. Suhonen PL B 729 27

L. Jokiniemi J. Suhonen H. Ejiri (Sept.29th)
arXiv 1604.04399v1

Universal reductions

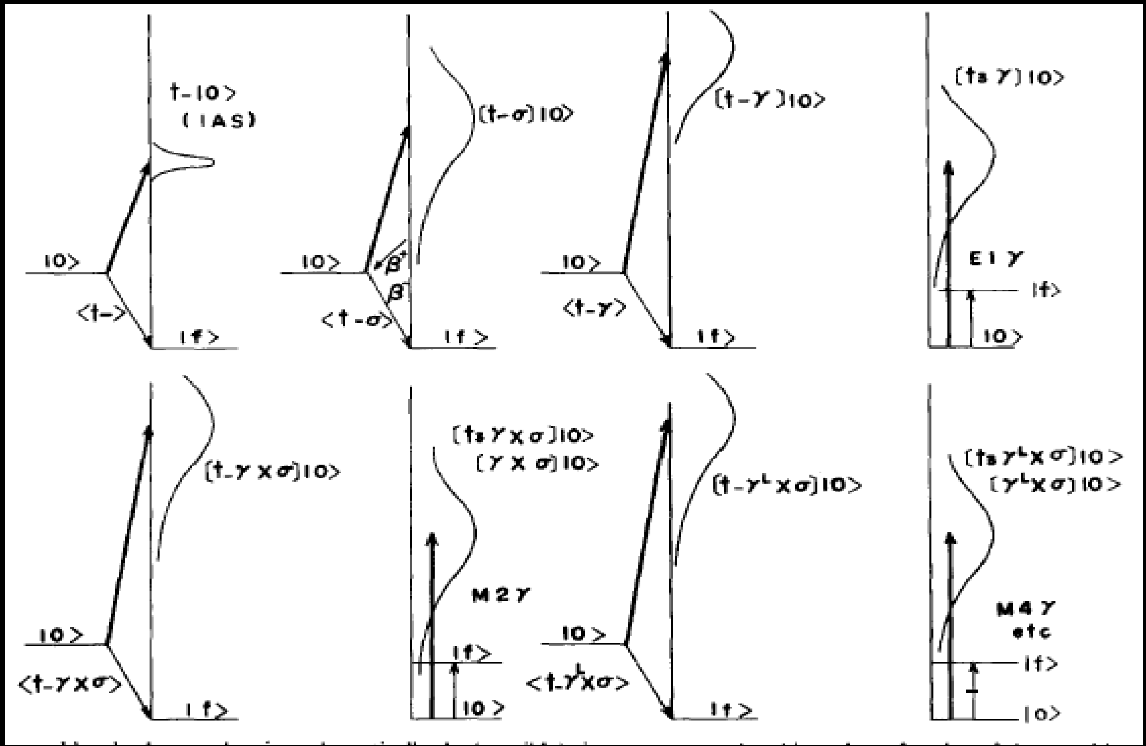


$M(SL)=\langle\tau^{\pm}(\sigma \times r^{l}Y_{l}\rangle_{J}$

Use M(EXP)=k M(QP)

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

Exp. NME, NO Quenching.



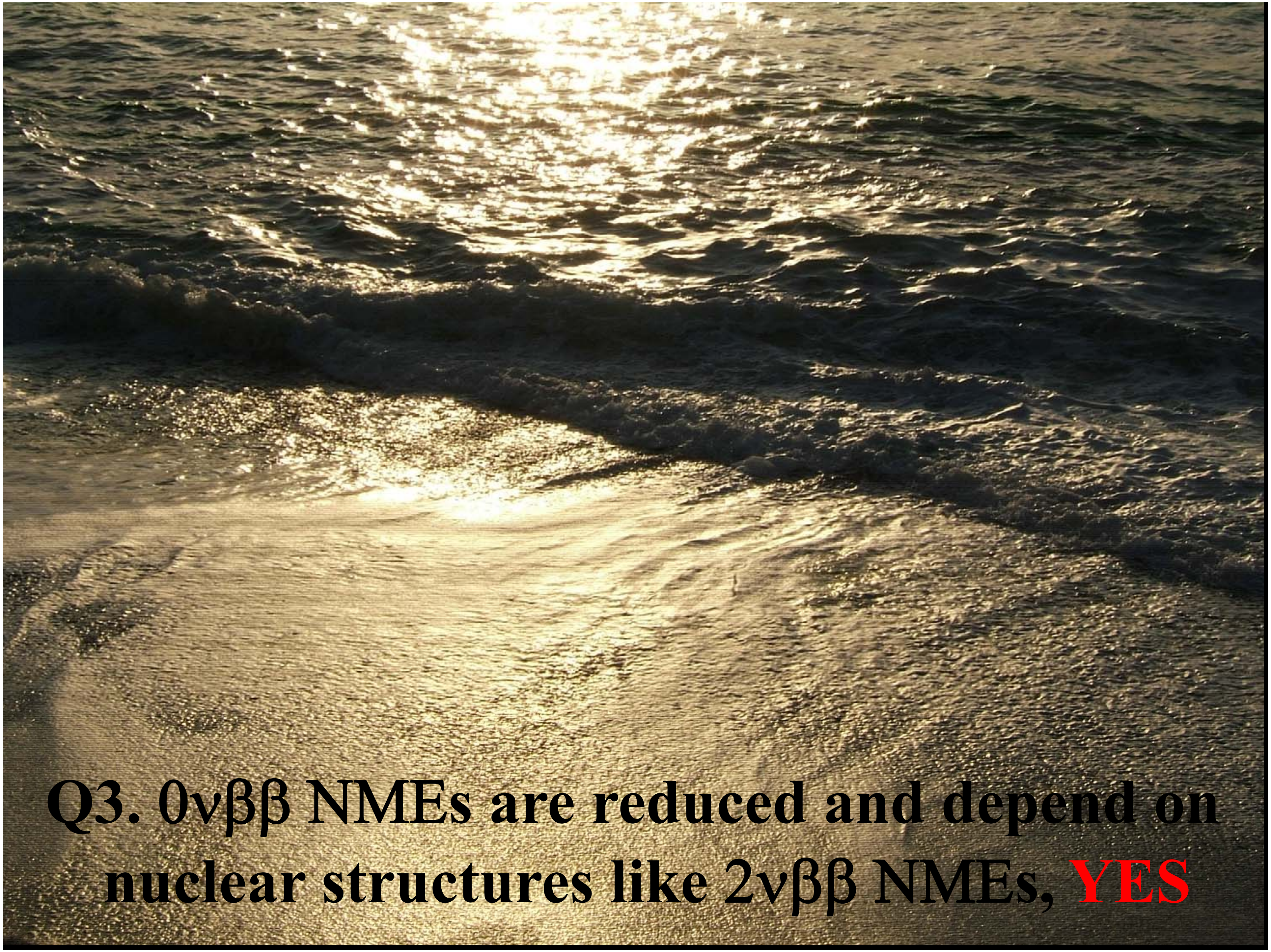
Ejiri Fujita PR 34 85 1978

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

$k=k(\tau\sigma)\sim 0.5$ τσ GR

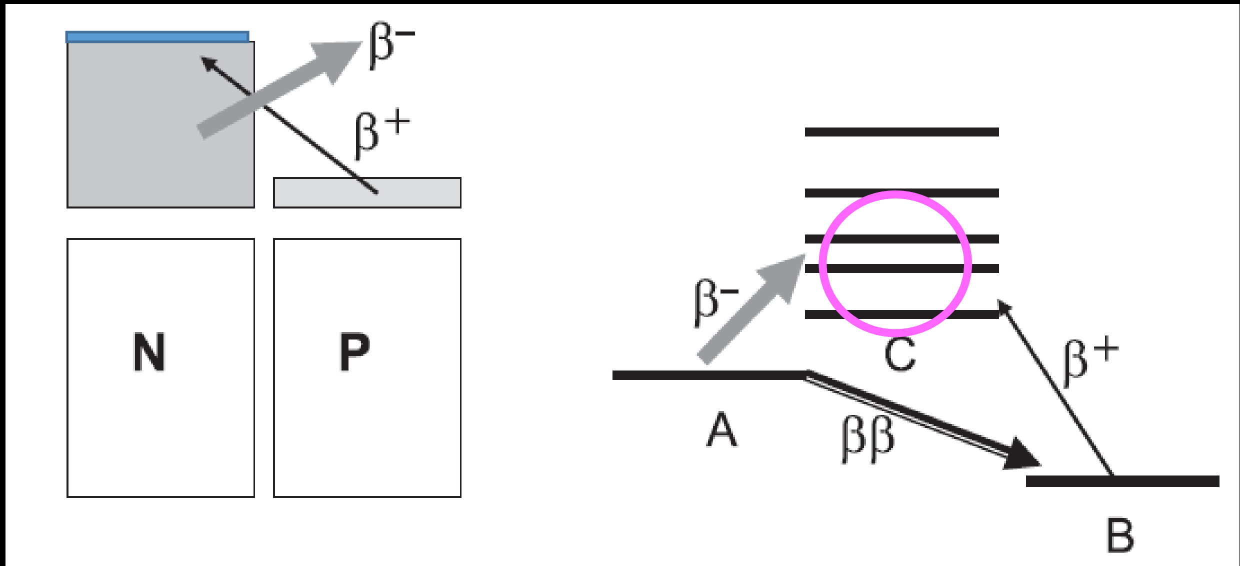
$K(NM)\sim g^{eff}_{A}/g_{A}\sim 0.6$

Δ isobar GR


Q3. 0νββ NMEs are reduced and depend on
nuclear structures like 2νββ NMEs, YES

FSQP: Fermi Surface Quasi Particle Model *

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



$M^{2\nu\beta\beta} = \Sigma_k M^-_k M^+_k / \Delta_k$ FSQP No GT GR *

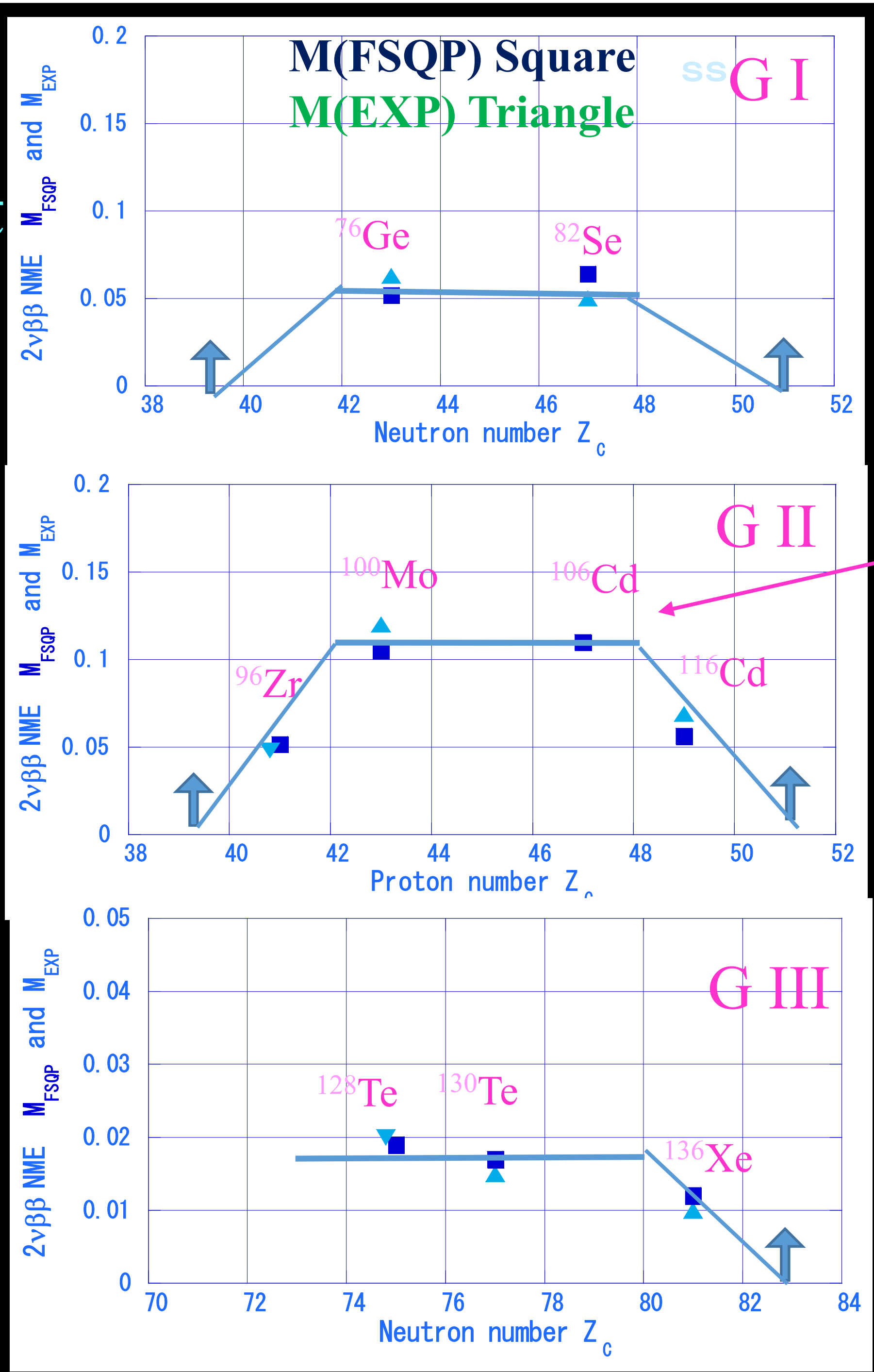
$M^-_k = (k^{eff}_i)\ m_{ij} V_n U_p$, $M^+_k = (k^{eff}_f)\ m_{ij} U_n V_p$, $(k^{eff}_A)^2 \sim (0.23)^2 = 0.05$

Both vacancy &occupancy in non-closed shell nuclei

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

2νββ matrix element

Shell closure effect at N~82,50
No room for β decay proton to neutron



76 Ge is not small.

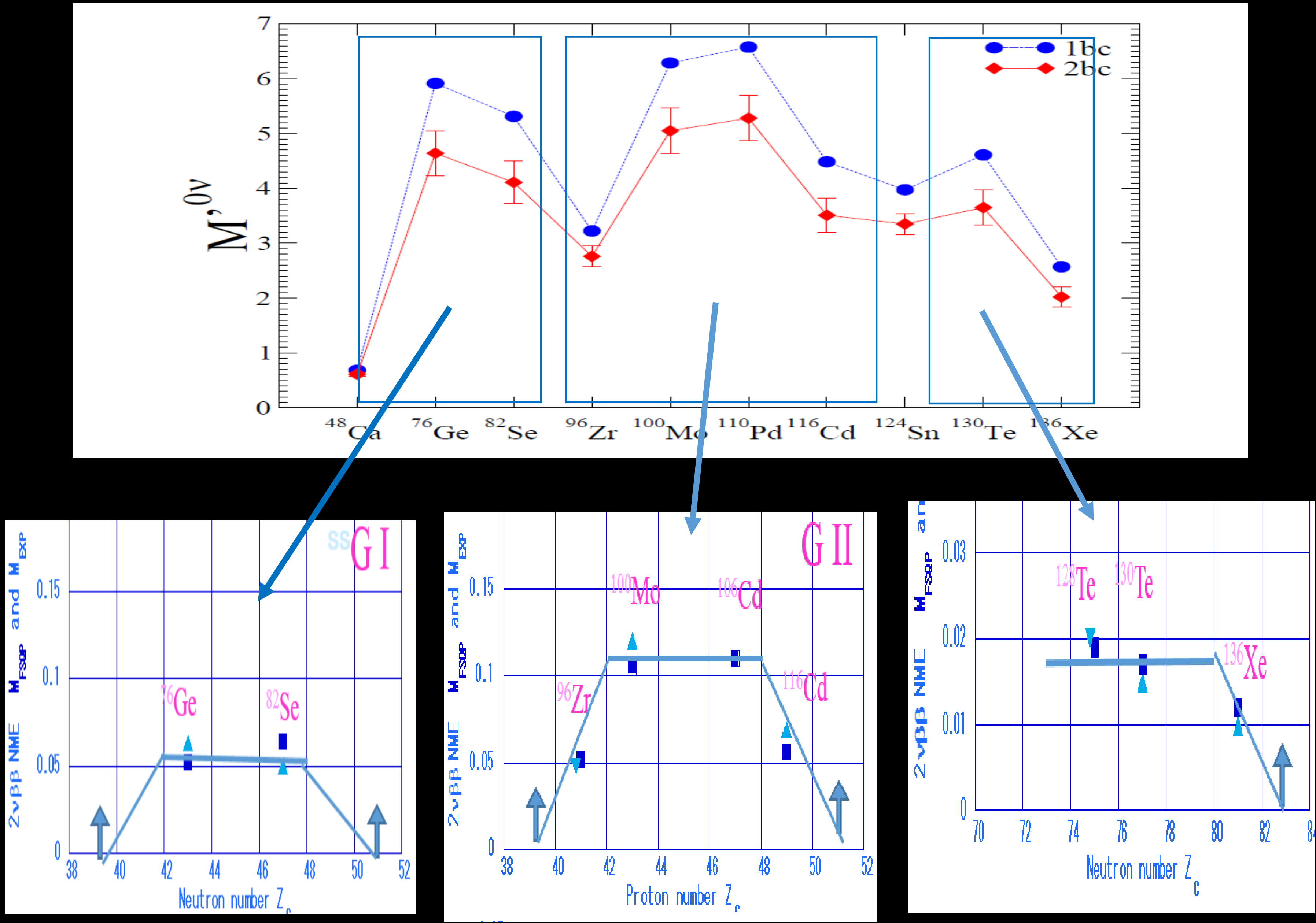
2p1/2-2p3/2

^{106}Cd predicted $T_{1/2}$(ECEC)=5.2 10^{22}

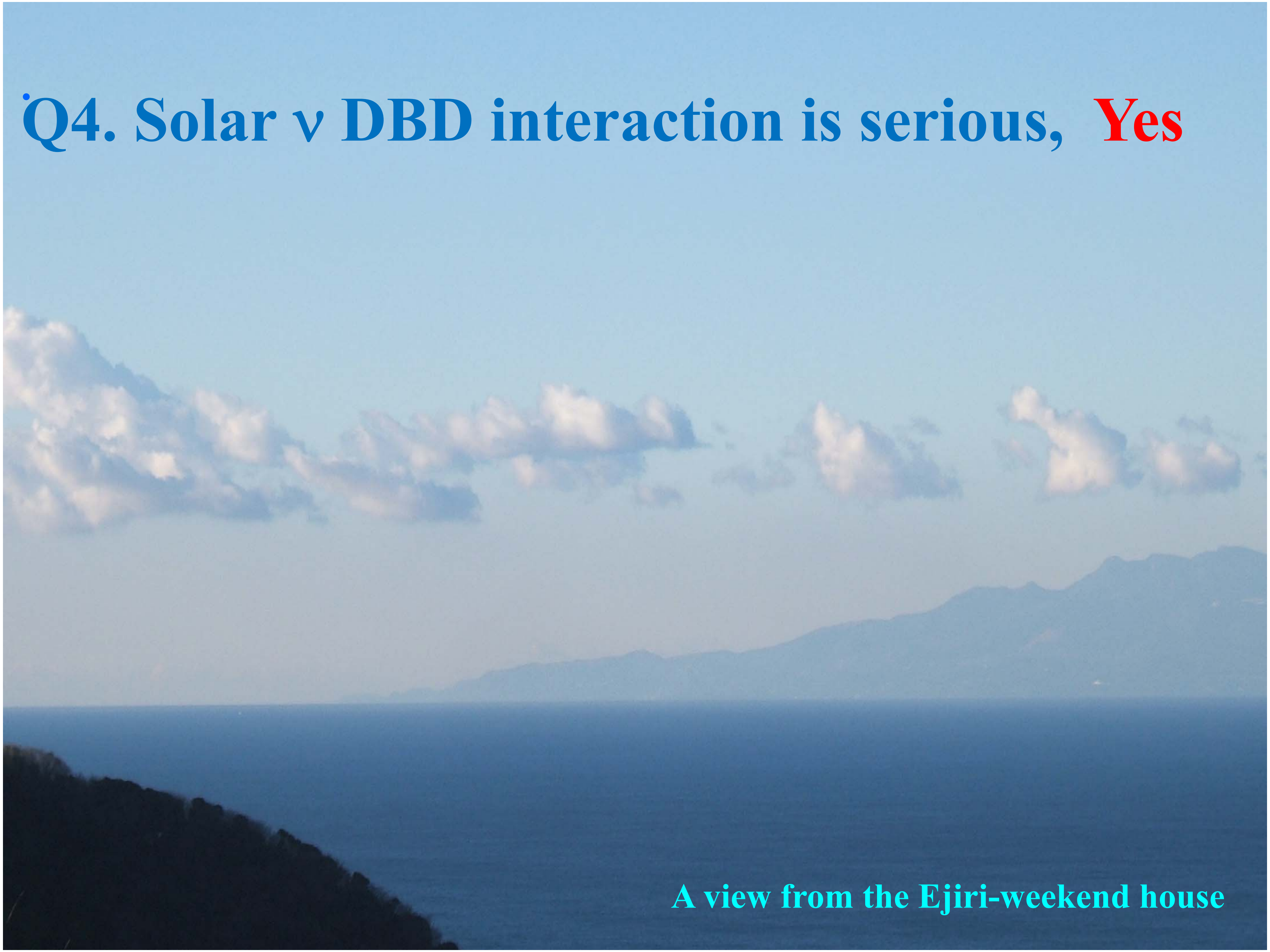
1g7/2-1g9/2

2d3/2-2d5/2

QRPA 0νββ NMEs show the shell-closure effects as 2νββ NMEs



Q4. Solar ν DBD interaction is serious, Yes

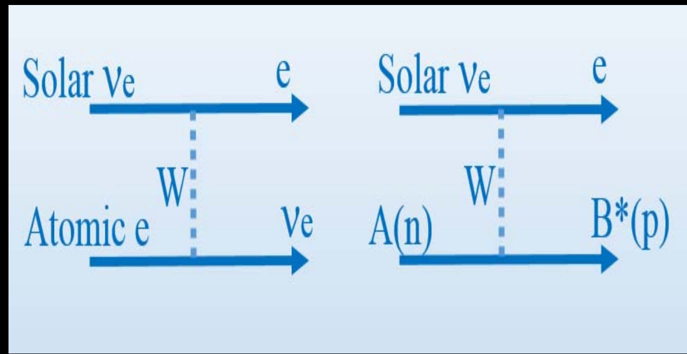


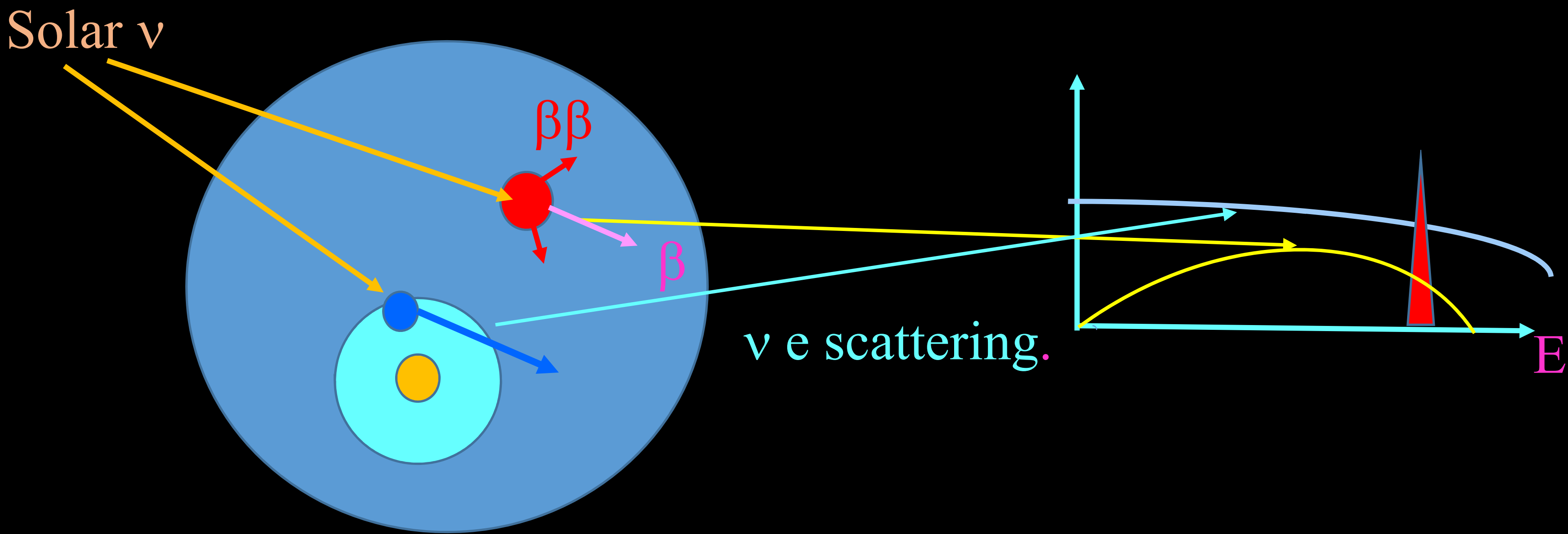
A view from the Ejiri-weekend house

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

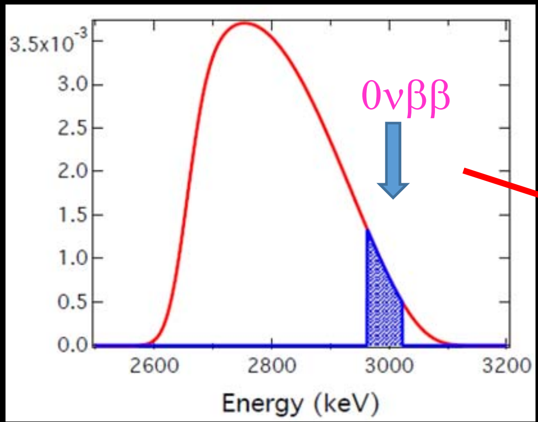
- **Solar ν unavoidable.**
- **BG rate need to be < ββ signal rate**
- **E-resolution is a key element**

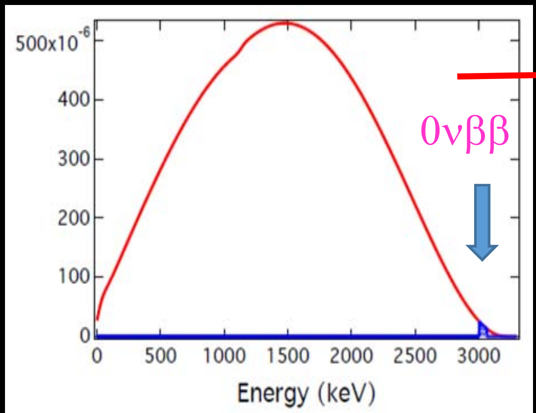
Solar ν response by CERs

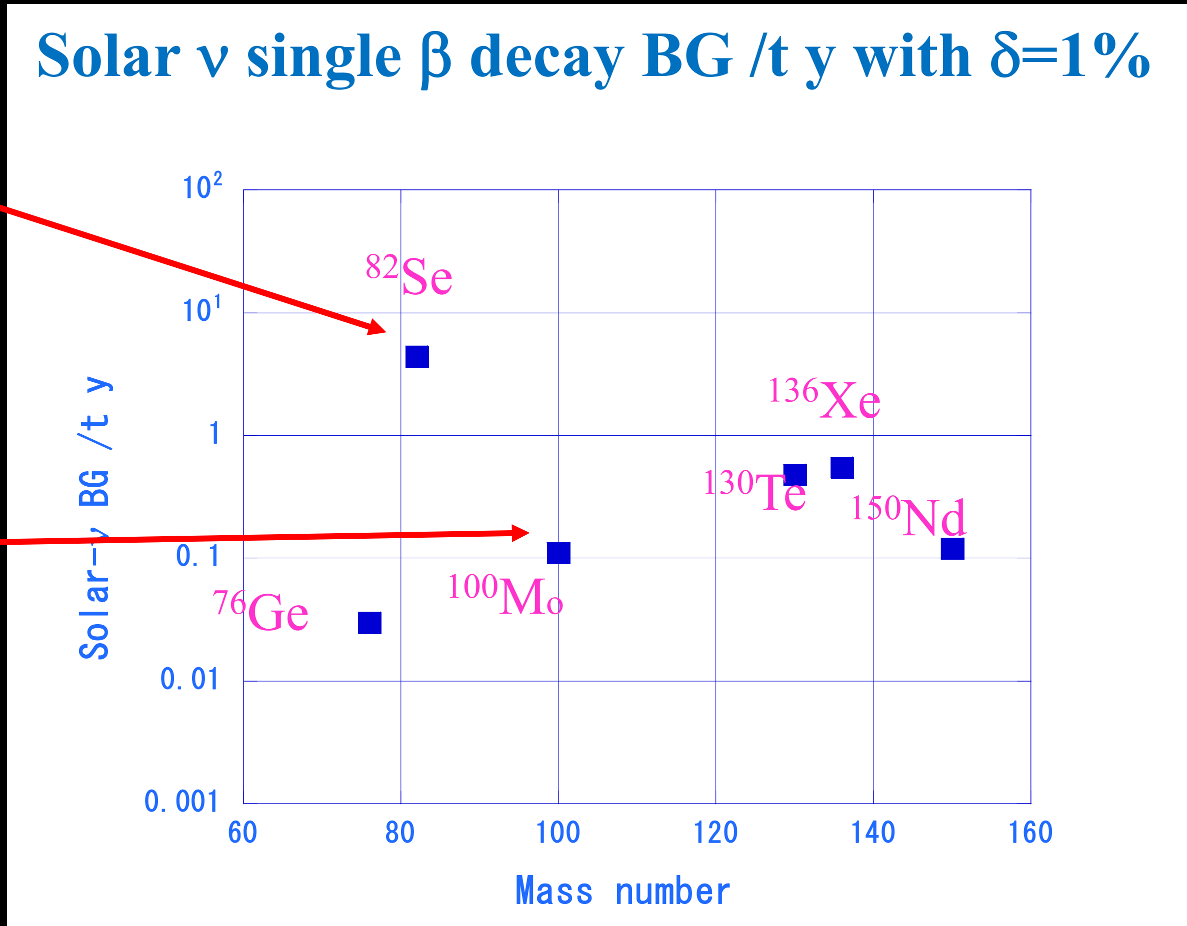




DBD rates for IH mass are 0.5-0.9 / t y except 0.2 for ^{76}Ge
Thus solar ν BG should be <0.2-0.3 /ty except <0.1 for ^{76}Ge

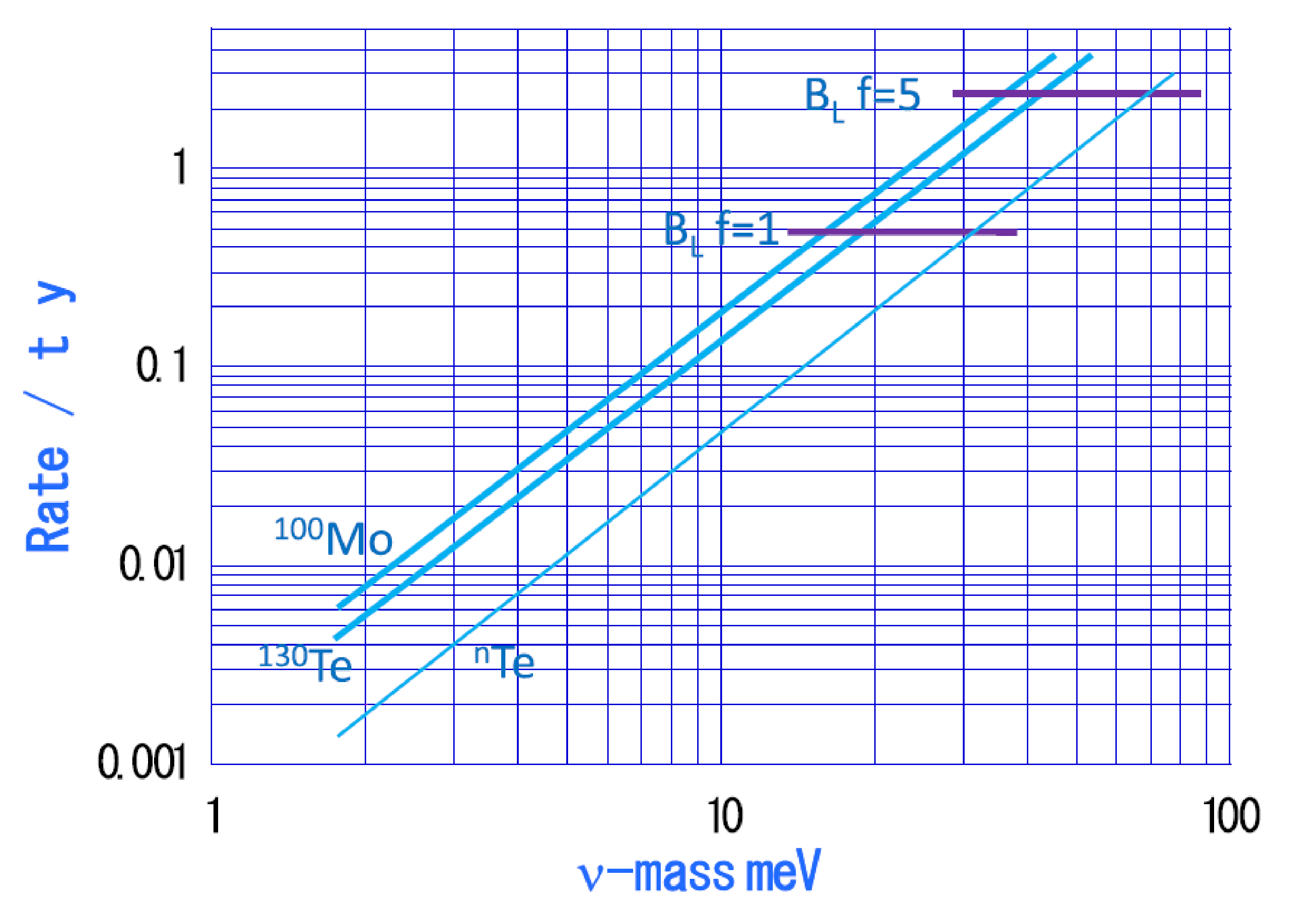






^{82}Se detector δ <0.1 % , and ^{130}Te ^{136}Xe δ <1% bolometers.
No plastic , liquid , ionization chambers.

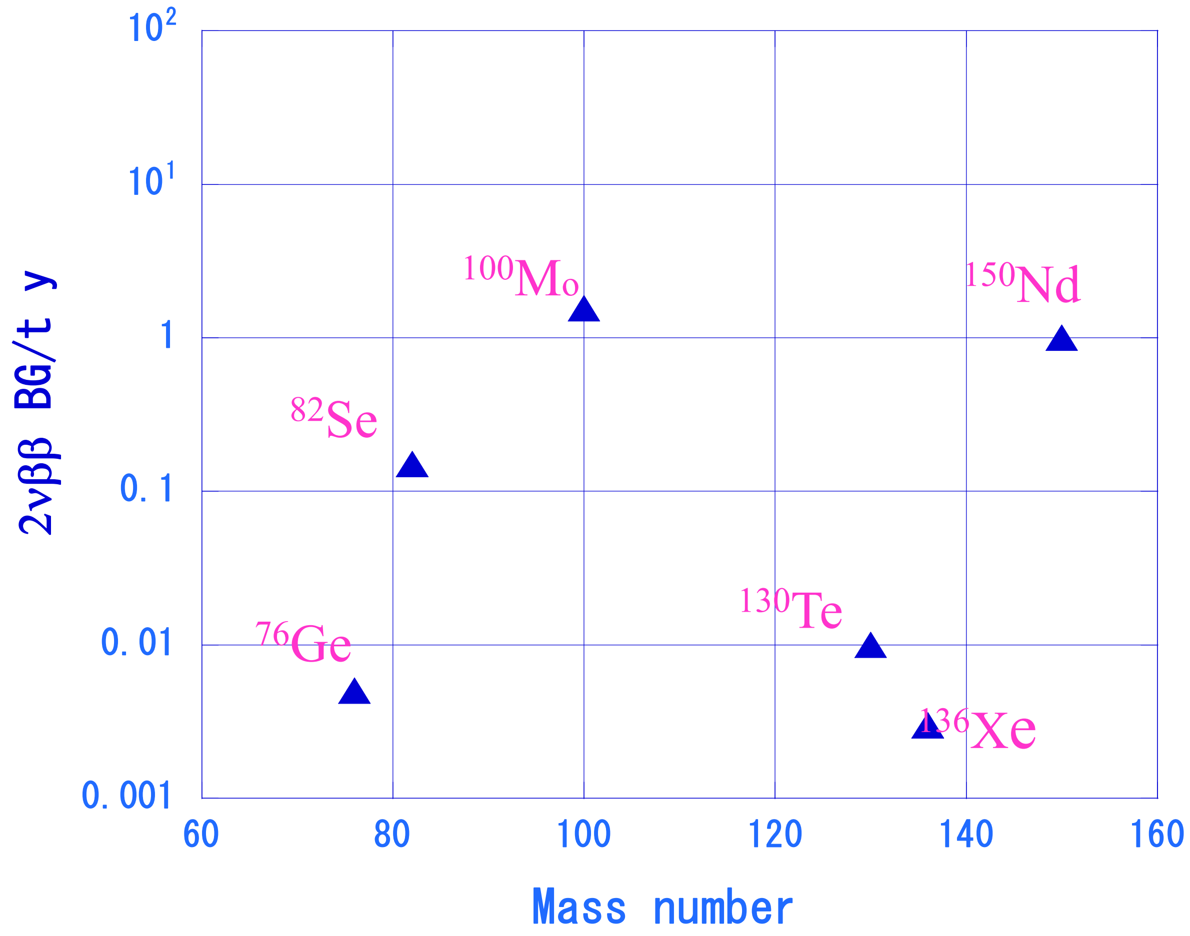
Solar-ν on atomic electrons in liquid scintillators



f=δ/R with δ energy resolution and R DBD isotope concentration,
In case of f=5, R=1%, δ =5%, BG ~2.5. Need f=1 , R=1% δ=1%

H. Ejiri K. Zuber J. Phys. 43 045201 2016

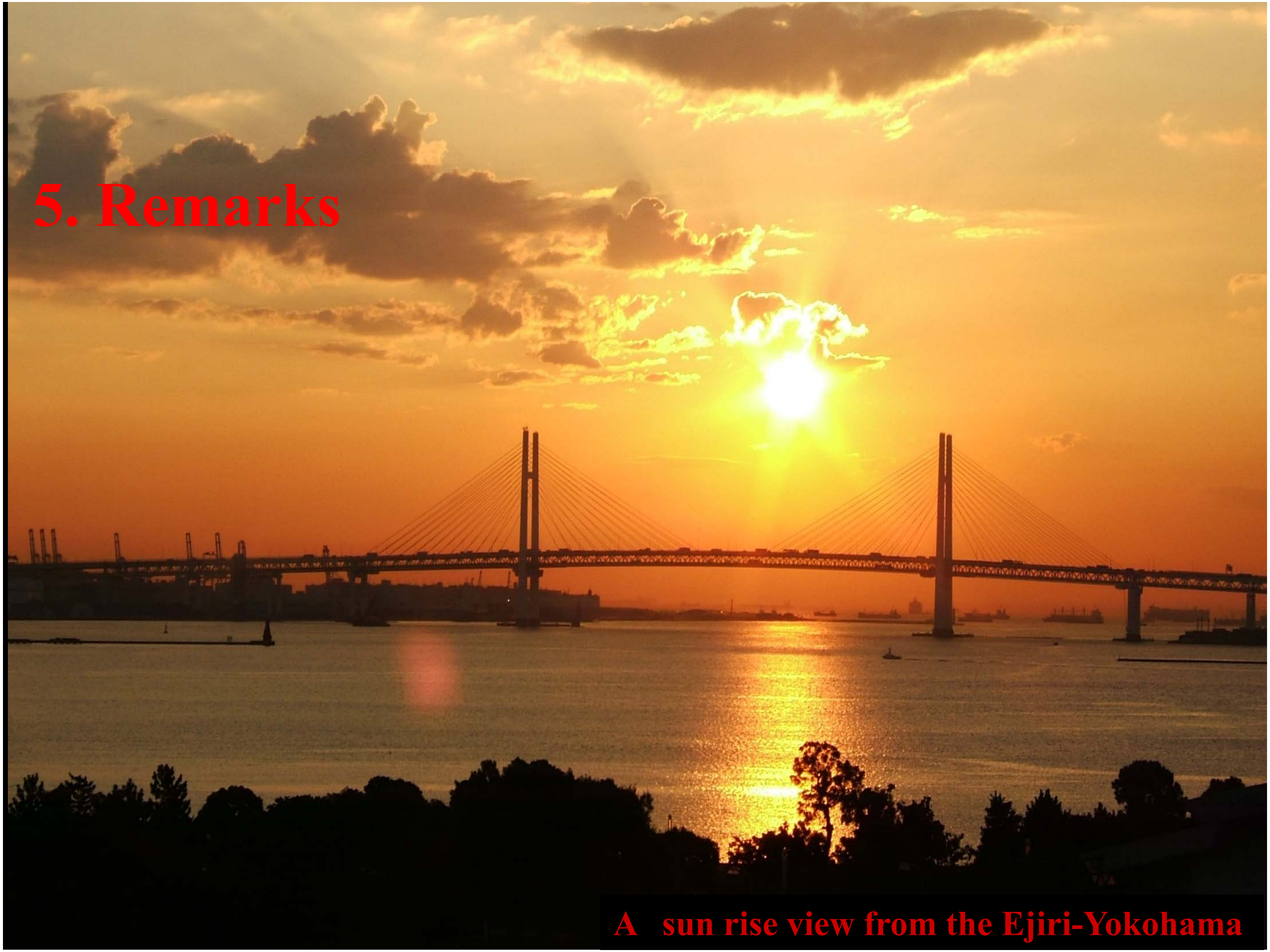
$2\nu\beta\beta$ BG rate with δ=2 %



^{100}Mo, ^{150}Nd δ<1.5 % , ^{82}Se δ< 3 %

for $2\nu\beta\beta$ BG < DBD rates. No scintillators

5. Remarks



A sun rise view from the Ejiri-Yokohama

Crucial questions for ν mass studies by 0νββ .

	2νββ	0νββ
CER possible ?	q=0 GT 1+ Yes	q≠0 SD 2- ,3+ Yes
Reduced NME	GT g_{pp} accident. Yes	Many J, not g_{pp} Yes
NME reflects Nucl. structure	NMEs depend on nucl.structure Yes	All J states involved. No dep. Yes
Solar ν BG	Rate is too small No	Solar ν serious. Yes

So far, all are No, and no worry about NMEs and nuclear physics.

Now, all are Yes, we needs exp/theory works for NMEs,

Effect of 30% of NMEs (works) ~ 10 tons of DBD isotopes, 300 M $.

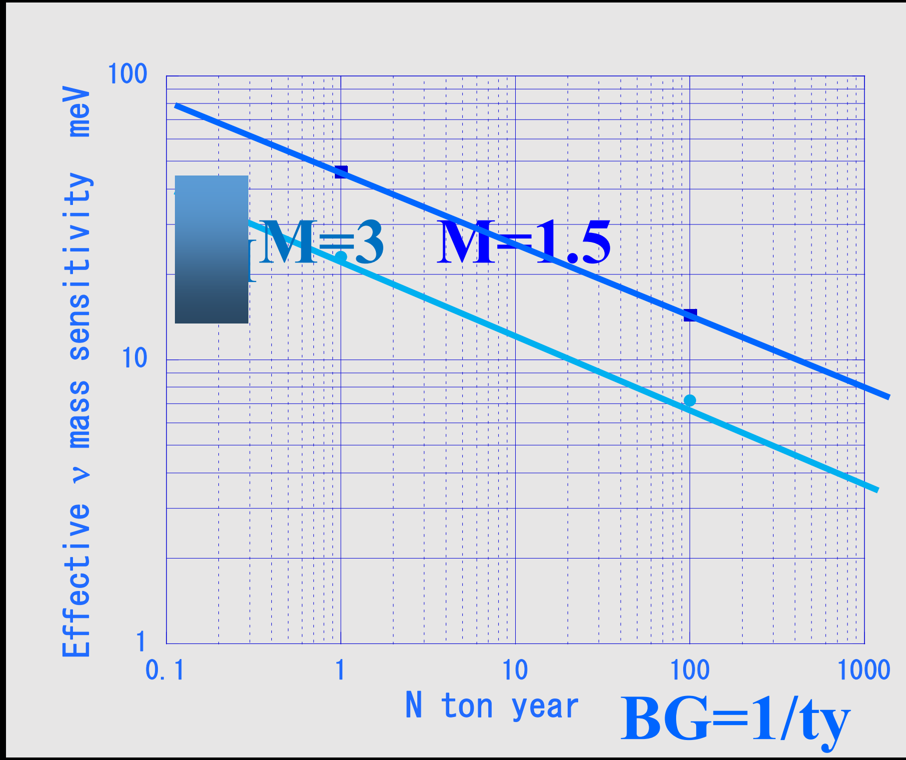
Isotope	A (%)	$Q_{\beta\beta}$ (MeV)	$G^{0\nu}$ (10^{-14} y)	$T_{1/2}^{0\nu-\mathrm{exp}}$ (10^{24} y)	NME	$\lvert\langle m_\nu\rangle\rvert$ eV (eV)	Future experiments
^{48}Ca	0.19	4.276	7.15	0.014 [237]	ISM EDF	19.1 7.0	CANDLES
^{76}Ge	7.8	2.039	0.71	19 [36, 227, 228]	ISM, EDF (R)QRPA EDF	0.51, 0.31 (0.20, 0.32) (0.26, 0.35)	GERDA
	7.8	2.039	0.71	22 [42]	ISM, EDF (R)QRPA EDF	0.47, 0.29 (0.18, 0.30) (0.24, 0.32)	—
	7.8	2.039	0.71	16 [229, 230]	ISM, EDF (R)QRPA EDF	0.55, 0.34 (0.22, 0.35) (0.28, 0.38)	MAJORANA
^{82}Se	9.2	2.992	3.11	0.36 [38, 234, 235]	ISM, EDF (R)QRPA EDF	1.88, 1.17 (0.76, 1.28) (1.12, 1.49)	SuperNEMO MOON
^{100}Mo	9.6	3.034	5.03	1.0 [38, 234]	EDF (R)QRPA EDF	0.46 (0.38, 0.73) (0.62, 1.06)	MOON AMoRE
^{116}Cd	7.5	2.804	5.44	0.17 [238]	EDF (R)QRPA	1.15 (1.20, 2.16)	COBRA $CdWO_4$
^{130}Te	34.5	2.529	4.89	3.0 [231, 232, 239]	ISM, EDF (R)QRPA EDF	0.52, 0.27 (0.25, 0.43) (0.33, 0.46)	CUORE
^{136}Xe	8.9	2.467	5.13	5.7 [40]	ISM, EDF (R)QRPA	0.44, 0.23 (0.17, 0.30)	EXO, NEXT KamLAND-Zen
^{150}Nd	5.6	3.368	23.2	0.018 [38, 240]	EDF (R)QRPA	4.68 (2.13, 2.88)	SuperNEMO SNO+ DCBA

LUMUNEU CUPID Li_2MoO_4

Exp.requirements to reach the IH 45-15

$<m_\nu> = k\,[M^{0\nu}]^{-1}\,G^{-1/2}\,(NT)^{-1/4}\,(BG)^{1/4}$

1. $g_A M^{0\nu}$~3 →1.5, G ~ 4,
   NT ~ 1 →15 ty for IH



2. N~1-10 ton enriched N
   Not close to magic nuclei.

3. δ < 0.01 to reduce
   2νββ & solar ν BG

4. Particle ID (β /γ/α) τo reach BG <<1/t y

^{76}Ge SSD, CUPID, ^{100}Mo scintillation bolometers,


Thank you for your attention
Ejiri-weekend house at Shounan