Single and double charge exchange reactions for astro-ν and DBD-ν NMES.

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NEWS 2023-5

Subjects to be discussed

- 1. Experimental approaches to
- NMEs for DBD and Astro- ν
- 2. Nuclear single and double CERs for weak NMEs.
- 3. Recent RCNP SCERs and DCERs,

H. Ejiri, Universe 8, 457 (2022)

H. Ejiri, L. Jokiniemi and J. Suhonen, Phys. Rev. C Letters 105, L02250 (2022).

H. Ejiri, Frontiers, 9, 650421 (2021).

H. Ejiri, J. Suhonen and K. Zuber, Phys. Rep. 797, 1 (2019).

- **1. Experimental approaches to**
- **NMEs for DBD and Astro- ν**
- **2. Nuclear Single and double CERs for weak NMEs**
- **3. Recent RCNP CERs and DCERs**

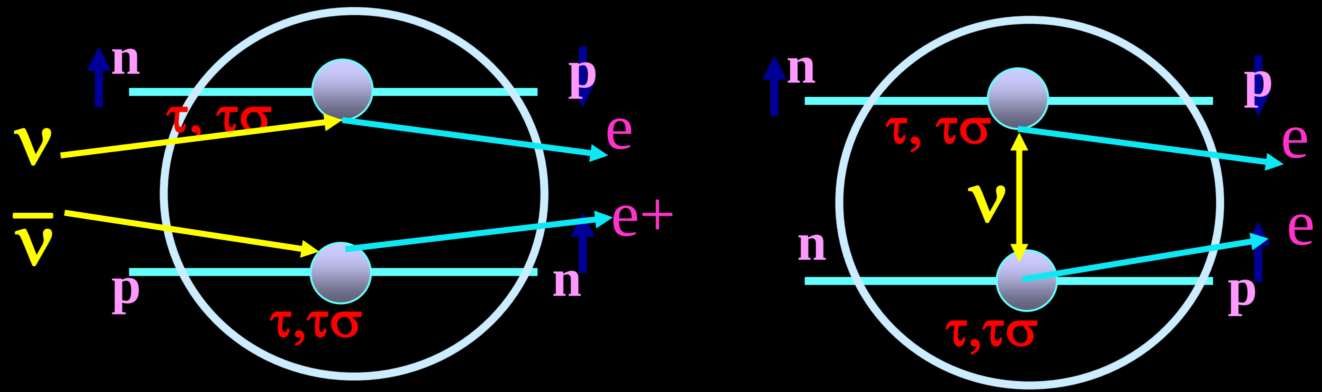
A. Nuclear models and experimental observables

- Nuclear models (theories) to understand basic static /dynamic properties as observed, and to predict (evaluate) nuclear quantities, which are not known experimentally but are valuable and interesting.
- Nuclear experiments to measure basic static/dynamic nuclear properties, and to provide key data to help nuclear (models) theories evaluate nuclear quantities of current interest.

The present talk : How can SCER /DCER provide key data for astro–ν and DBD nuclear theories to evaluate their NMEs.

Not to measure the NMEs, nor approximate values for them.

Astro-ν :real DBD ν: virtual



Boson	W	W W
Operators	τ, τσ F, GT…	ττ τστσ FF, GTGT…
Momentum L	10-50 MeV/c L=0-3	50-150 MeV L=0-6

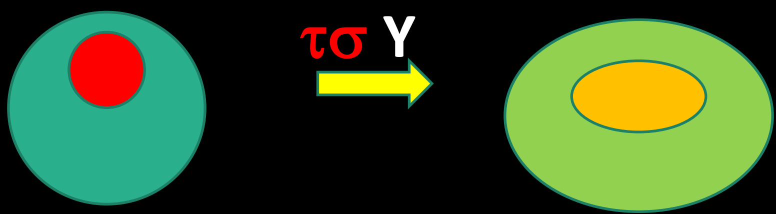
***NMEs are very sensitive to all kinds of τ, τσ nucleonic and non-nucleonic correlations, i.e. τ, τσ polarization (giant resonances). The NME models are such that include well these correlations. (Note 2νββ NE is also sensitive to energies of GT states)**

***Experimental τ, τσ NMEs and τ, τσ giant resonances help theories to build models and parameters (g_{ph} g_{pp} g_A^{eff}) to be used and to verify them if they reproduce the experimental τ σ data.**

Effective τ (vector)and $\tau\sigma$ (axial-vector) couplings

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

Such renormalization effects that are not explicitly included in the model, deviation of model NME from Exp. NME

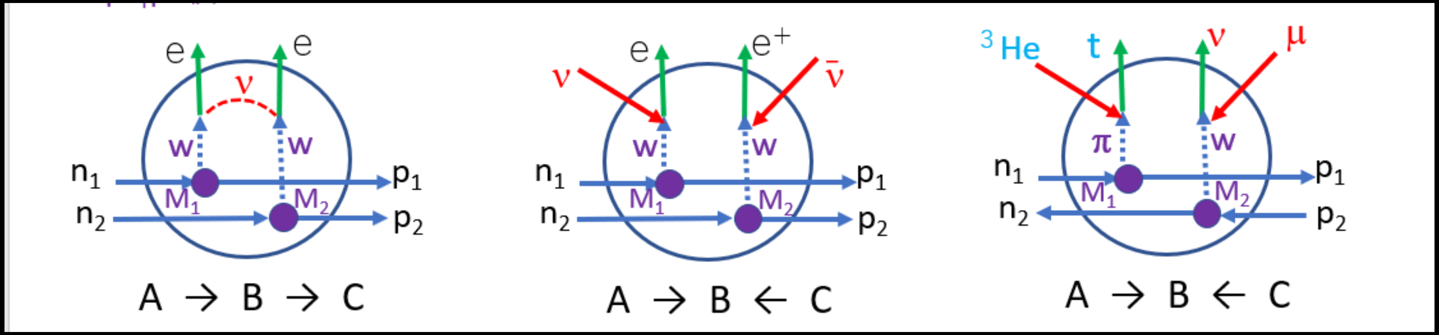


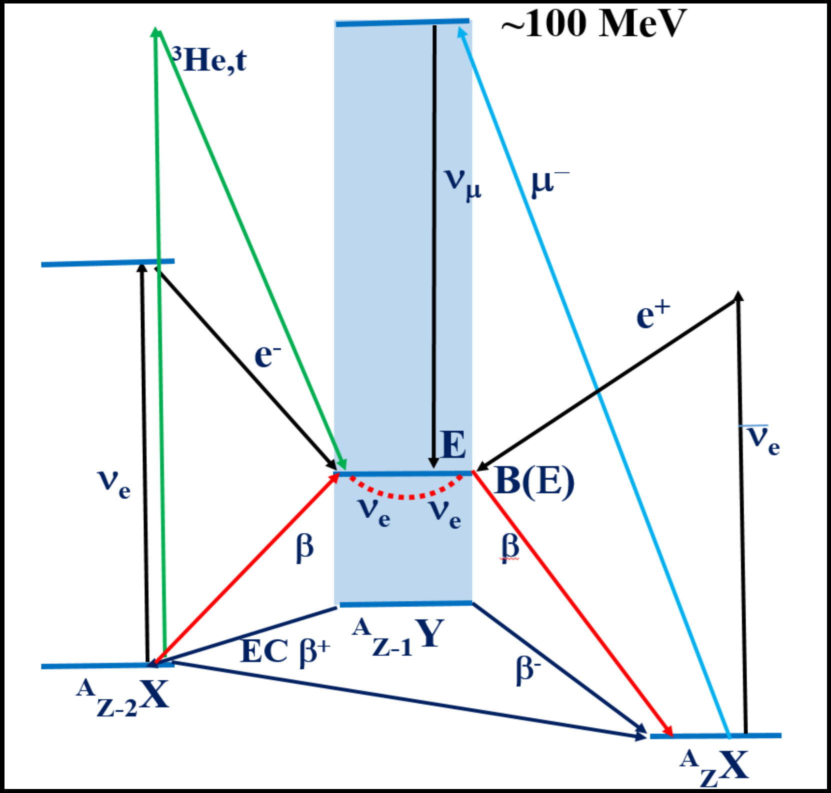
Models based on "nucleon" . The nucleon and the nuclei changes. Since 1960, effective μ , GT e^{eff}/e , moment of inertia, etc.

A : Theoretical way gM with g_A=1.27 and g_V=1 for n-p NME, and calculate M with all the effects of nucleonic and non-nucleonic correlations in the nucleus. To be checked by comparing the model τ ,,τσ multipole NMEs and others with experimental ones.

B: Experimental way. Provide theoretical models with useful τ and τσ and other data such as g^{eff}/g for initial, intermediate and final nuclei. The present talk on how SCER /DCER can do them

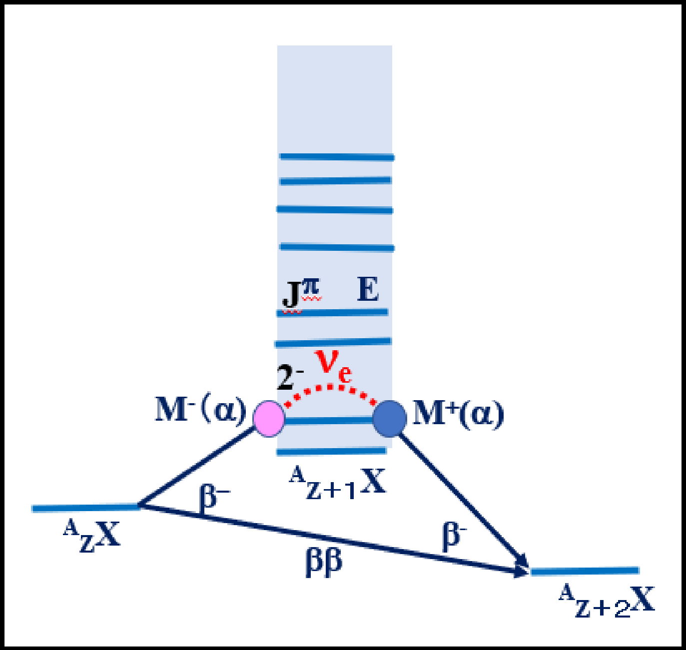
Double β decay, astro- νs and CERs at RCNP





1. DBD 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

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

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

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

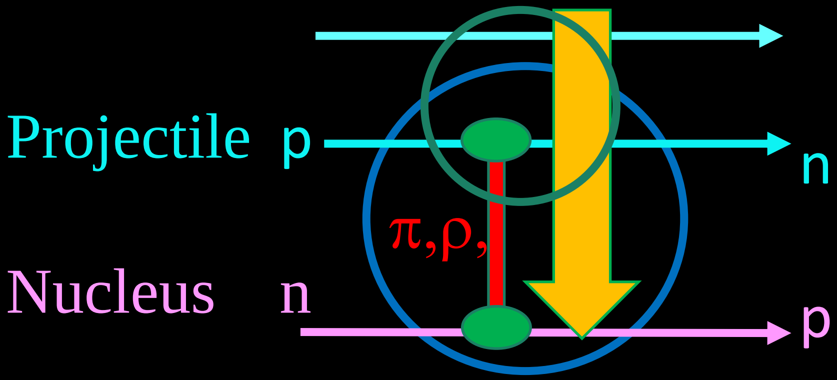
$H(r_{12}) \sim 1/r_{12}$ ν potential for ν-exchange , multipoles up to $R/r_{12} \sim 6$,

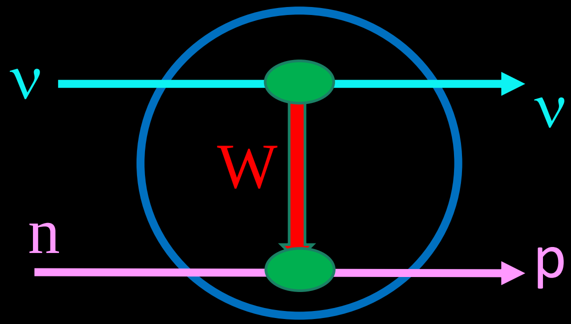
$M^{0\nu} = \Sigma_J\ M(J)$ J= Multipole sum

$M(J) = \Sigma_k\ M_k(J)$, Sum over all intermediate state k

Spin (σ) isospin (τ) multipole correlations

Nuclear interaction　　Weak interaction





Boson	π,ρ,...	W	
Boson mass	0.1 GeV	100 GeV	$(m/M)^4$:10^{12}
Momentum	0.1-0.001 GeV/c	0.1-0.001 GeV/c	
Cross-section	1 0^{-3} b (b=10^{-24} cm^2)	10^{-14}—10^{-18} b	Ratio:10^{12}
Type	τ, τσ, Tensor etc	τ(F), τσ(GT) , T	
Steps	Single and Multi-steps	Single step No distortion	
Distortion	Absorption	No absorption	

Cross sections for nuclear and neutrino CERs

(^{3}He,t) with E=0.45 GeV >> 0.03 GeV excitation of the target.

σ_N~0.6 mb (exp) for all GT and SD strengths up to 30 MeV

$\sigma_N \sim \sigma_n N_D$ for nucleus.

Using experimental N_D ~0.04 for the projectile flux attenuation, we get

σ_n=1.5 10^{-2} b for nucleon, i.e k=0.01 of the total σ_n=1.5 b

$\sigma_\nu \sim 10^{-14}$ b at E_ν=0.1 GeV

The ratio

$\sigma_n/\sigma_\nu \sim 1.5\ 10^{-2}$ b $/10^{-14}$ b $\sim (M_\pi/M_W)^{-4}$

2. σ_N(i) =0.5 mb/sr for a low-state

= σ B(GT)/B(GT sum) for SCER,

using B(GT)/B(GT sum) = 5 10^{-3}

get σ=0.1 b /sr

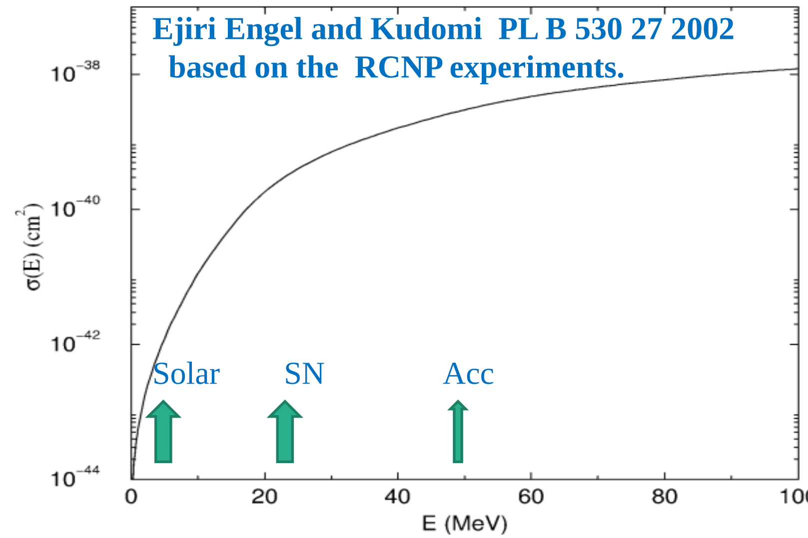


Fig. 1. The calculated cross section for ν_e charged-current scattering on ^{100}Mo, as a function of neutrino energy.

$\sigma_{N\,N}$(j)= σ k B(GT)/B(GT sum)^2 for DCE

= σ x0.01x25 10^{-6} =25 nb/sr

Accelerator ν: reactions H. Ejiri , NIM A503, 276 2003.

- **1. Experimental approaches to**
- **NMEs for DBD and Astro- ν**
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- **3. Recent RCNP CERs and DCERs,**

Nuclear Interactions

1 Central interactions
with τ, τσ, and Y_L as weak
F and GT multipole ones.

2. Tensor LS as well at
q=0.5-2 GeV/c.

3. Major τσ and τ also at
E/A~0.1-0.2 GeV.

4. Distortion and multi-step
process get minimum at
E/A=0.2 - 0.4 GeV.

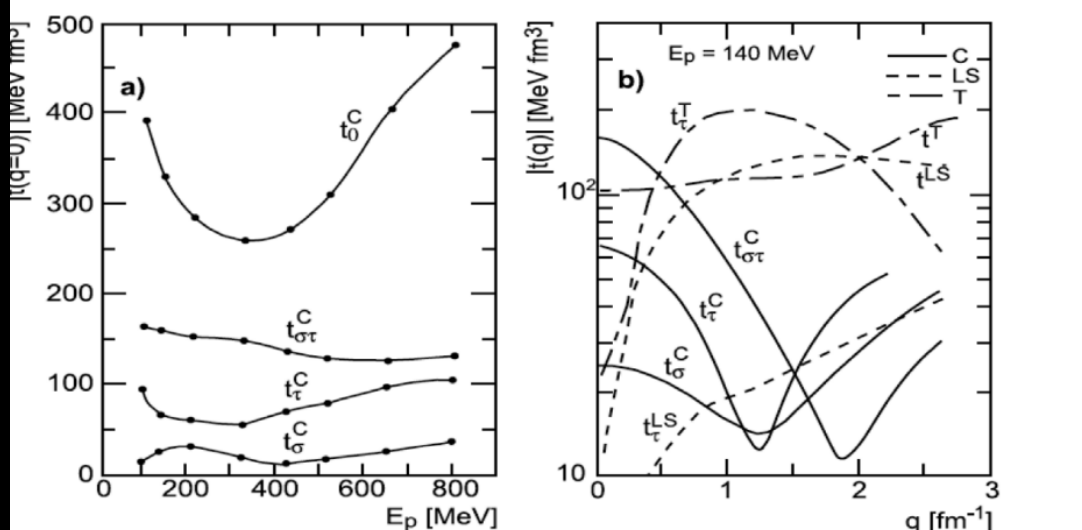
$$V^{\mathrm{eff}} = V^{\mathrm{C}} + V^{\mathrm{LS}} + V^{\mathrm{T}},$$

$$V^{\mathrm{C}} = V^{\mathrm{C}}(r_{ij}) + V^{\mathrm{C}}_{\sigma}(r_{ij})\boldsymbol{\sigma}_i \cdot \boldsymbol{\sigma}_j + V^{\mathrm{C}}_{\tau}(r_{ij})\tau_i\tau_j + V^{\mathrm{C}}_{\sigma\tau}(r_{ij})\boldsymbol{\sigma}_i \cdot \boldsymbol{\sigma}_j\tau_i\tau_j\,,$$

$$V^{\mathrm{LS}} = \left[V^{\mathrm{LS}}(r_{ij}) + V^{\mathrm{LS}}_{\tau}(r_{ij})\tau_i\tau_j\right]\mathbf{L}\cdot\mathbf{S}\,,$$

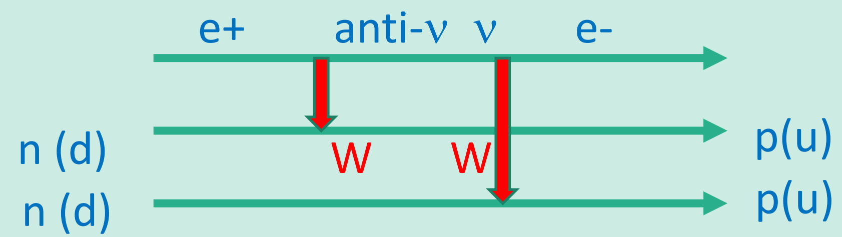
$$V^{\mathrm{T}} = \left[V^{\mathrm{LS}}(r_{ij}) + V^{\mathrm{LS}}_{\tau}(r_{ij})\tau_i\tau_j\right]S^{T}_{ij}\,.$$

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

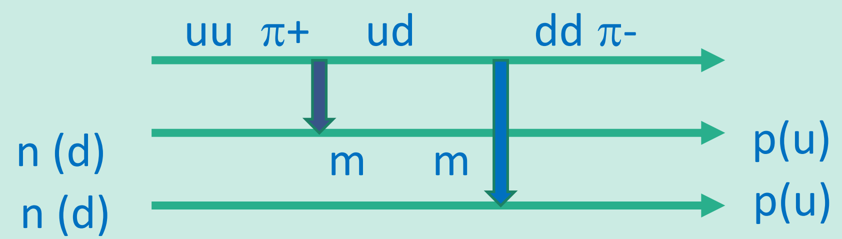


Double charge exchange (2n-2p) in a nucleus via lepton, hadron and nuclear probes

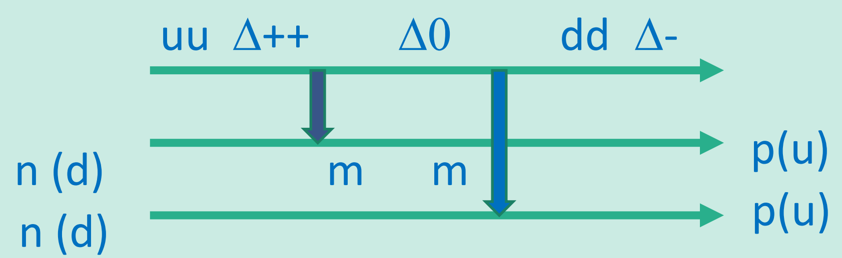
Lepton:
Weak 0νDBD



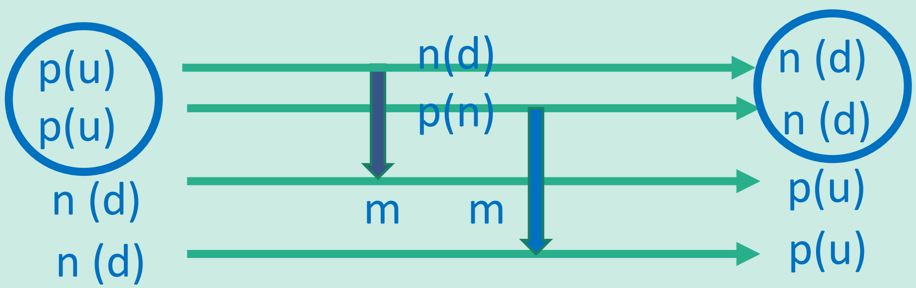
Hadron meson
uu-dd quarks



Baryon Δ, Σ,
uu-dd quarks

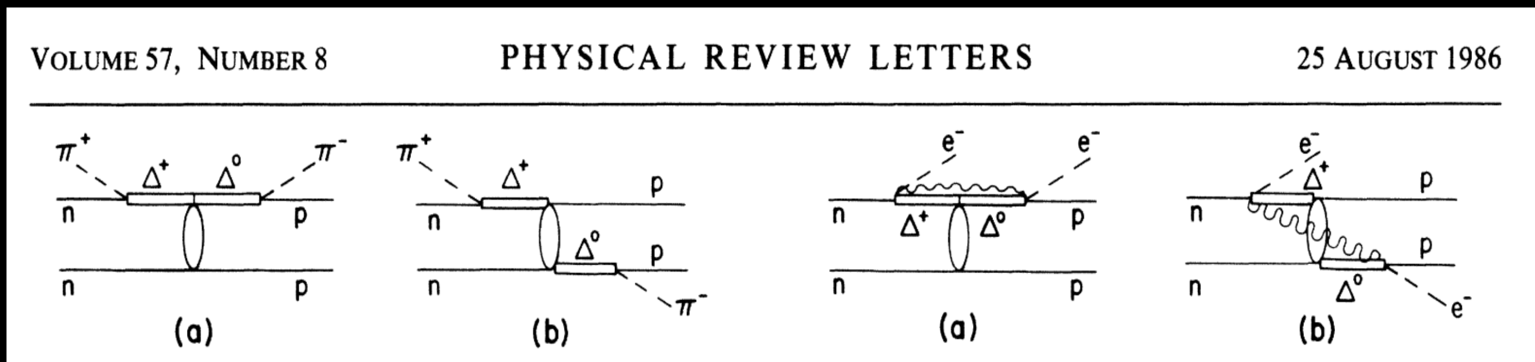


2 nucleons in
Light ion (He)
Heavy ion (B, C, O)



DCE-π

- **The Δ contribution by DCE-π experiments.**
- **1. Major DBD is $\Delta\Delta$ mode** **A Fazely and L. C.Liu PRL 57 968 1986**



- **Exp. 164 MeV π low momentum transfer to the final nucleus.**
- **σ=60-30 nb /sr D(Distortion)=0.01 -0.005 for A=76-130.**
- **T. Tomoda $\Delta\Delta$ is not major, but 30- 1 % for η and mass NMEs.**
- **Using the exp. σ=60 nb /sr for A=^{76}Ge,**
- **M(η)=0.23 – 0.070=0.16 , where $\Delta\Delta$ is -0.07 and g_A^{eff}/g_A=0.6.**
- **M(m)=1.5-0.012= 1.49 , where $\Delta\Delta$ is -0.012 and g_A^{eff}/g_A=0.6.**

Kinematics of RCNP SCER (^{3}He,t)

Lightest ion

Low Q~a few MeV

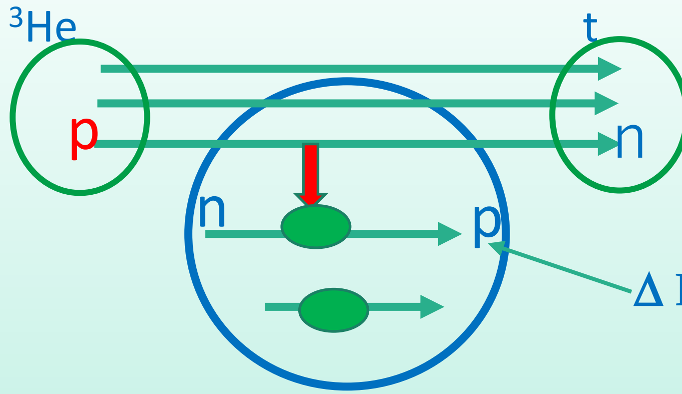
E/A=0.14-0.15 GeV

Projectile nucleon, go out,

$P_f >> 200$ MeV/c

Target nucleon stays in the target

$\Delta P_f << 200$ MeV/c

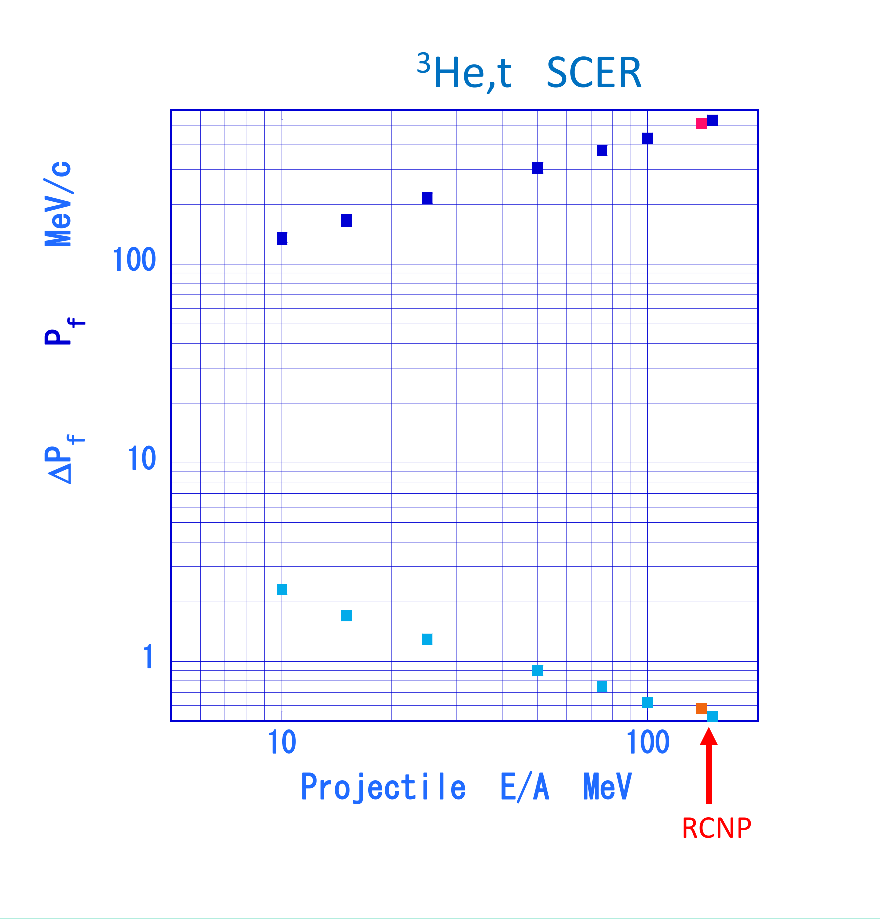


Momentum P transfer ,

depending on the t angle,

Δp~0-200 MeV/c, Δl=0-3

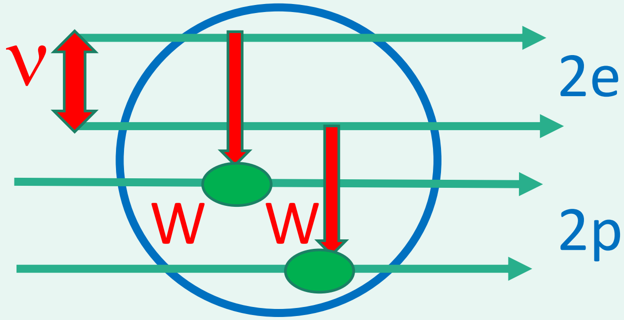
Major $\tau\sigma$ axial-vector excitation at E/A~0.1-0.2 GeV.



GS

DBD

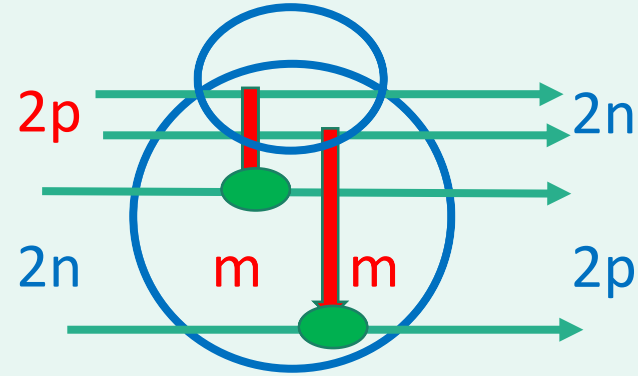
Each W $\Delta P<200$ MeV/c to keep n in the nucleus, the summed $\Delta P= 2\text{-}3$ MeV/c



CE τστσ ττ NME

Medium E/A~0.1 GeV CER

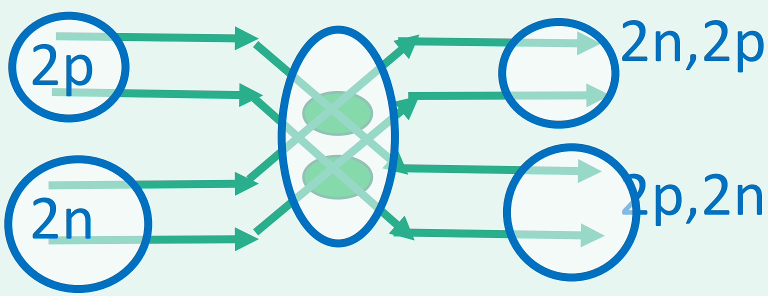
In projectile, each m transfer <200 MeV /c to keep n in the nucleus



CE τστσ, ττ NME

Medium-Low E/A=30MeV

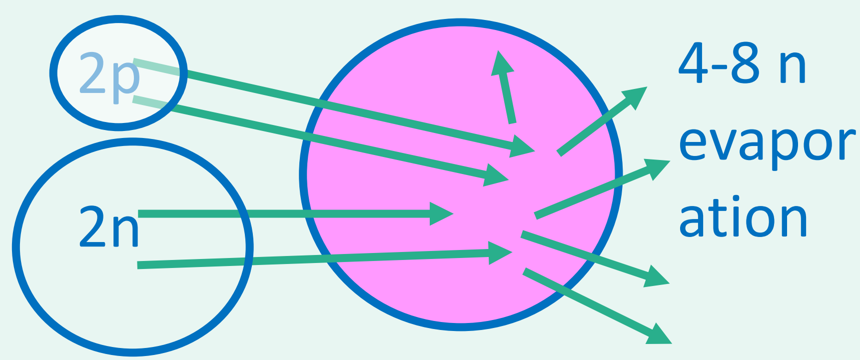
Projectile & target np are mixed up to CE or NCE. Multistep/distortion.



CER &Non CER τ&σ

Low E <15 MeV

Projectile n and p multi-interact with all n



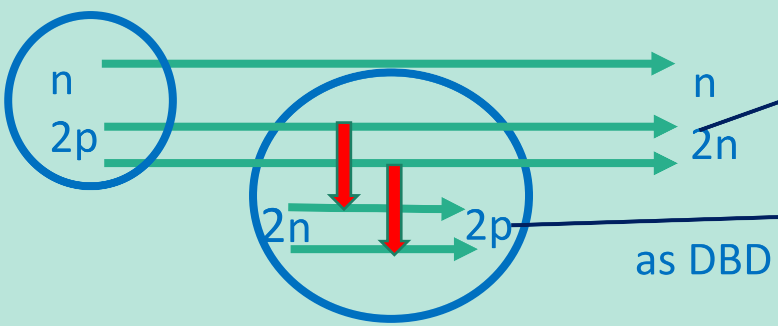
Non CER Non τσ

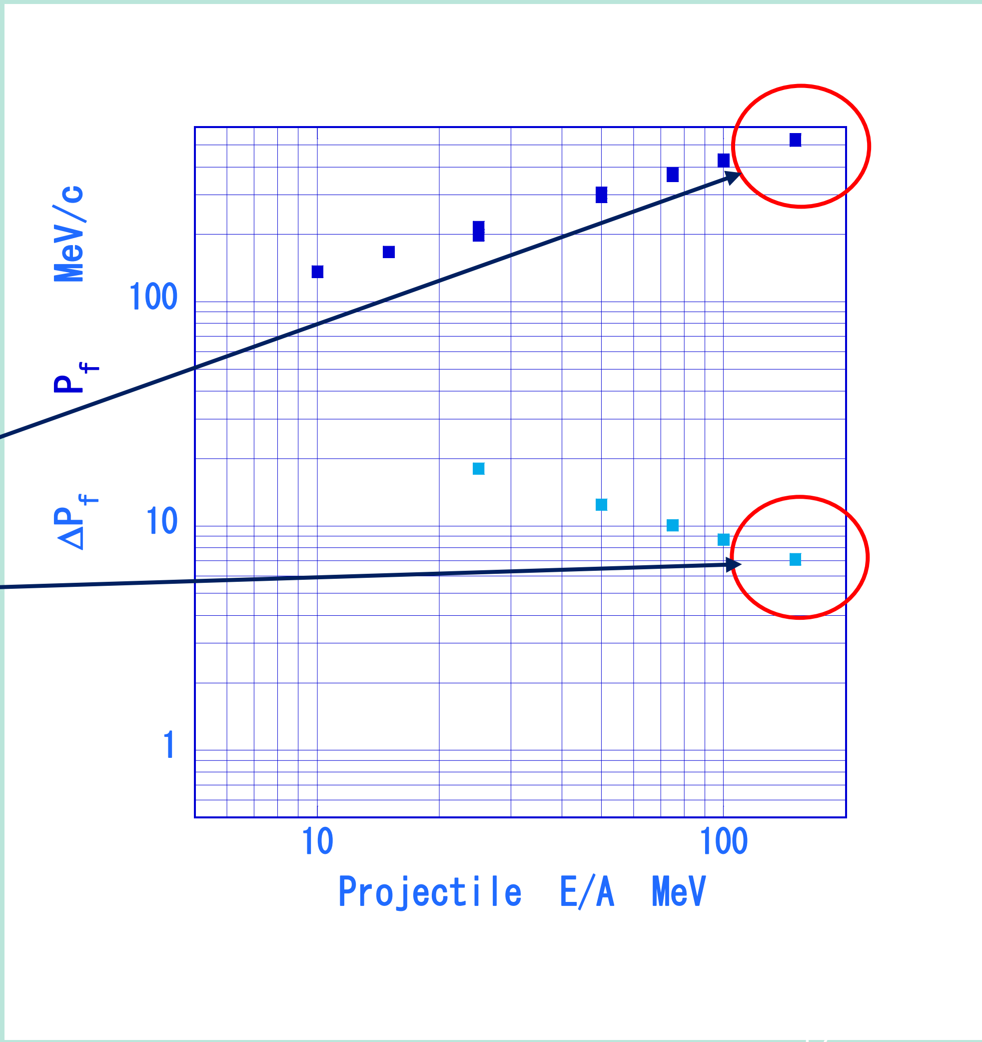
Momentum transfer

^{3}He, 3n
Lightest charged projectile
except (π^{+}, π^{-})

Total p transfer small,
but relative = P_F=100 MeV/c

DBD nuclei: Q value=-7 MeV by 2 n





Heavy Ion DCERs for DBD

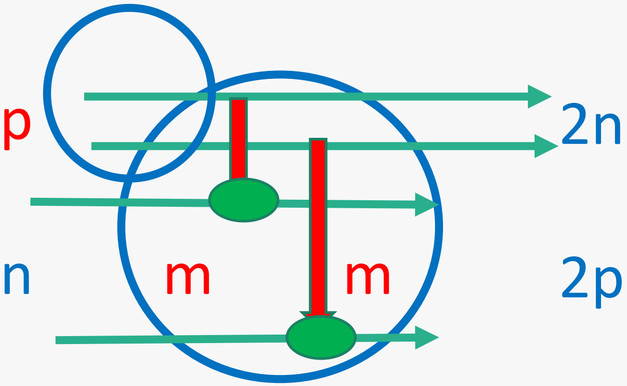
RCNP Lightest HI ions ^{11}B,^{11}Li at E/A=0.08 GeV

Extensive program at Catania , 3 talks at NEWS.

- F. Cappuzzello, et al., Prog. Part. Nucl. Phys. 128, 103999 (2023). Universe 2020 6 217.
- NEWS: Cappuzzello, Agodi, Menendez, Lenske
- F. Cappuzzello et al Eur. Phys. J. A 51 2015 145. NEUMEN
- C. Agodi et al., NEWS , Catania HI CER Project
- N. Shimizu, J. Menendez, K. Yako Phys. Rev. Lett. 120 142502 2018
- H. Lenske et al, Universe 7 98 2021. NEWS

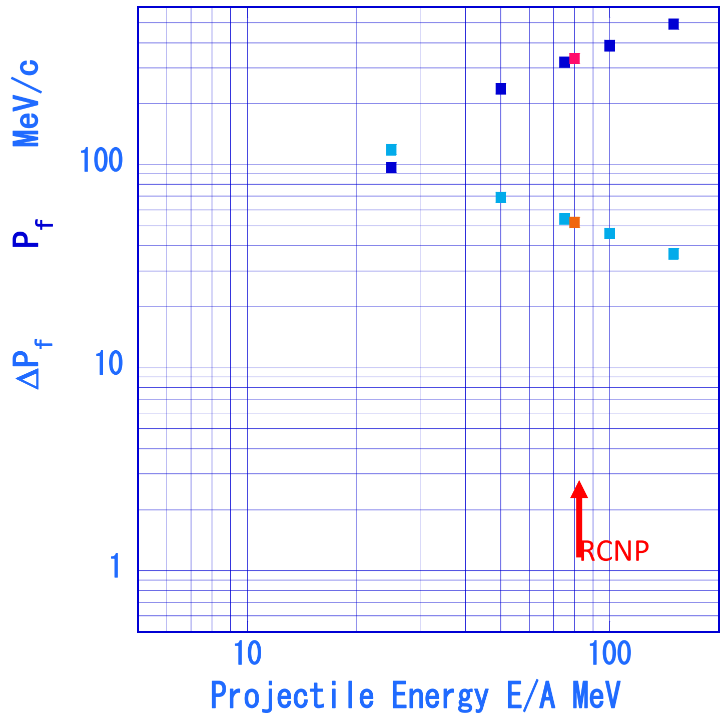
Momentum P_f and transfer momentum ΔP_f at θ=0 deg.

Conditions $P_f >> 200$ MeV/c
$\Delta P_f << 200$ MeV/c

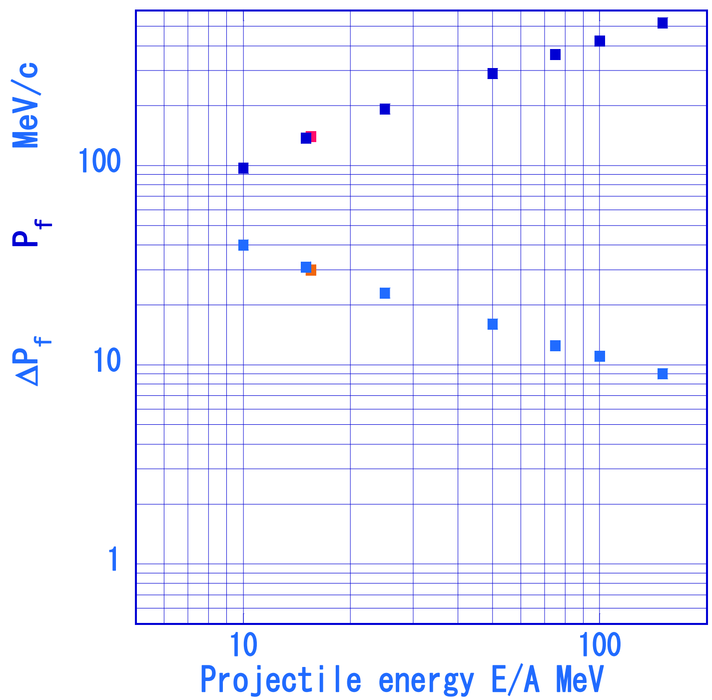


Lightest charged projectile and ejectile

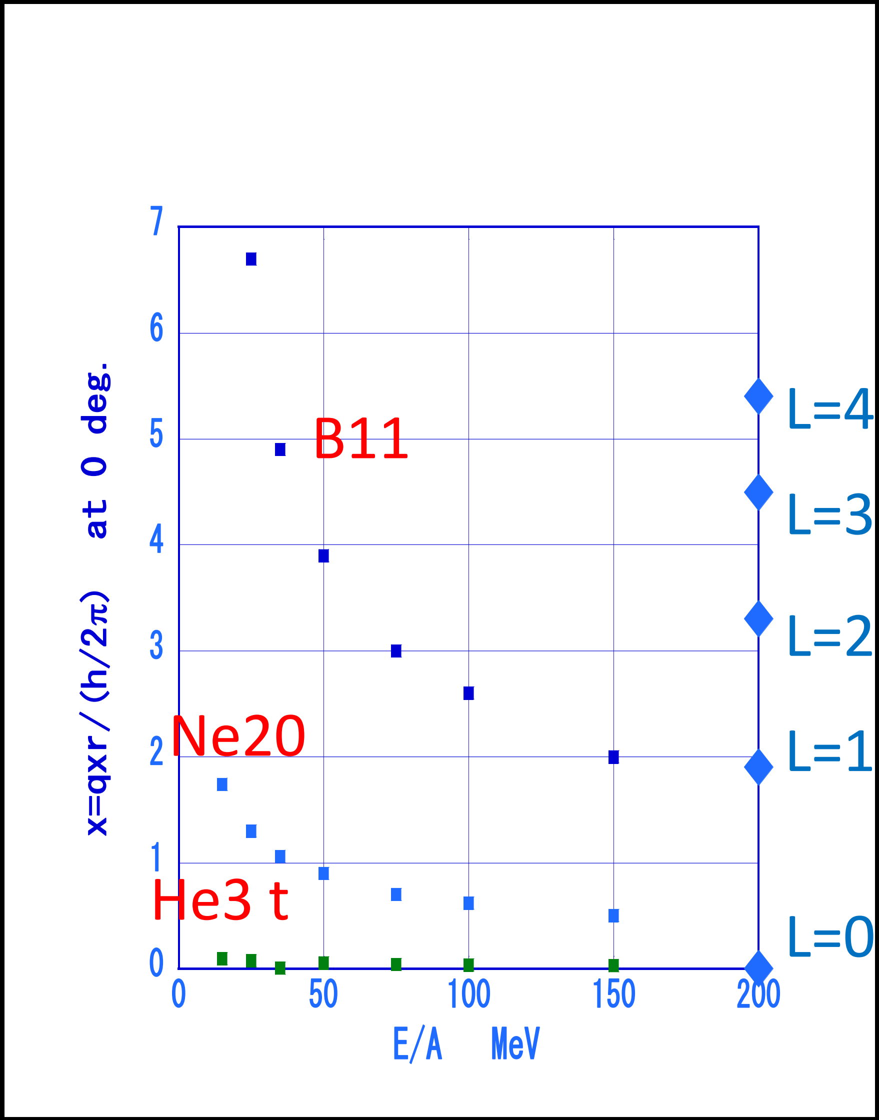
^{11}B,^{11}Li Q/2=-20

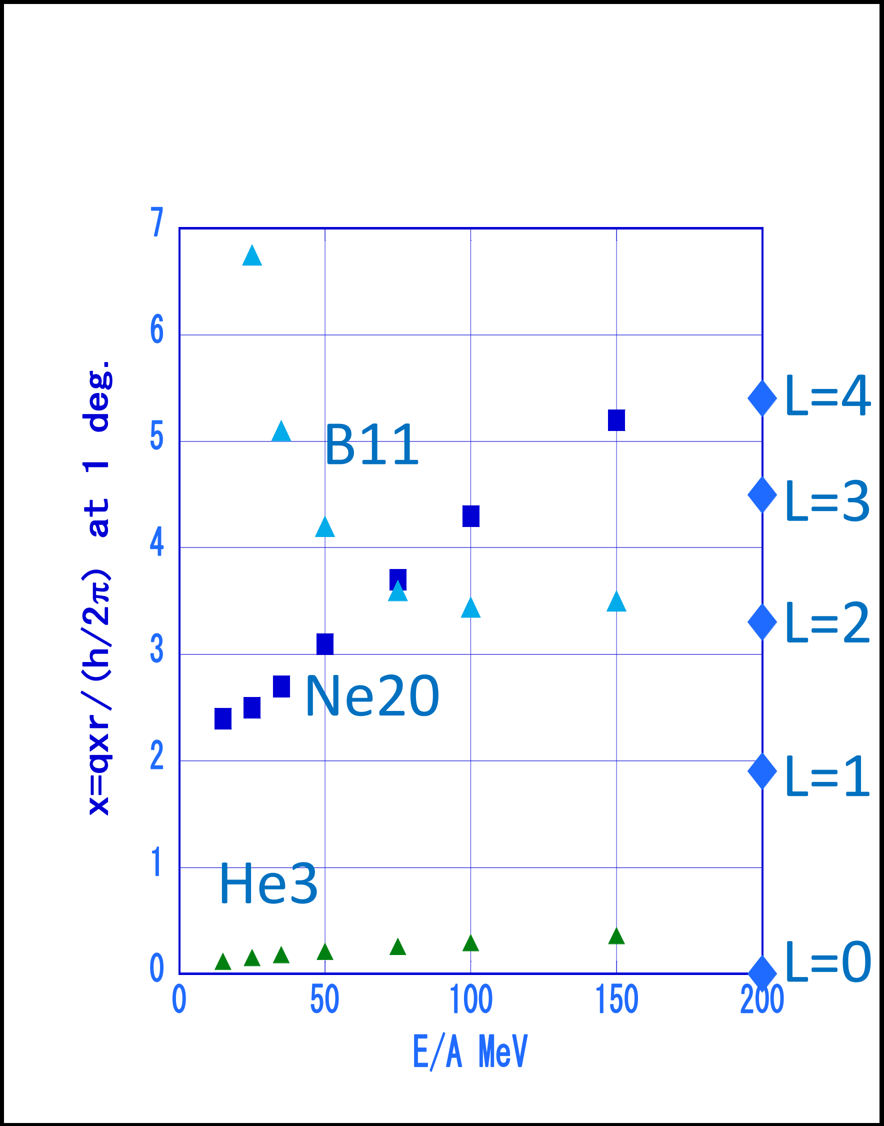


^{20}Ne ,^{20}O Ex=5 MeV E/A=15 MeV.
Results Phys. 28 104691 2021 Te

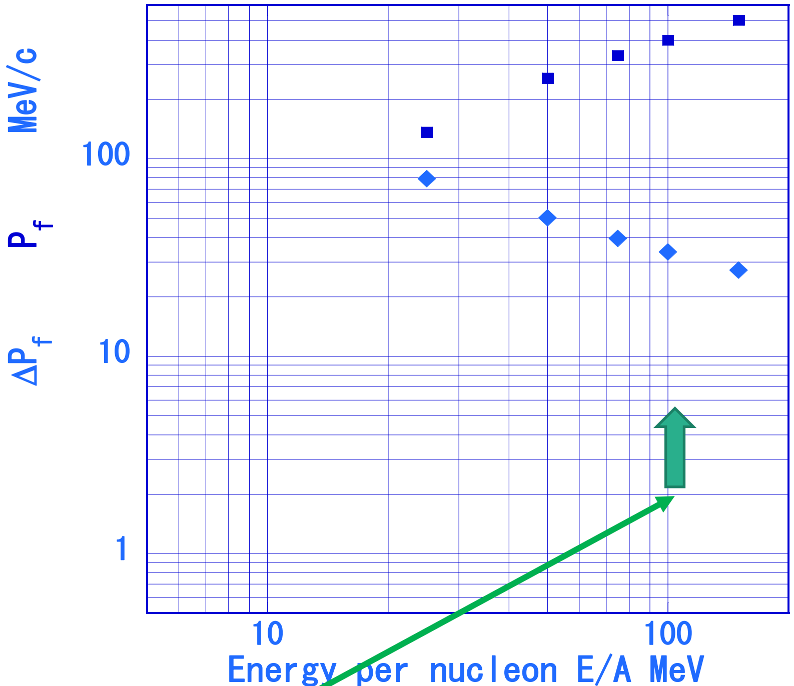


It is a challenge to get data relevant to DBD GT/F NMEs from low-E HI exps.

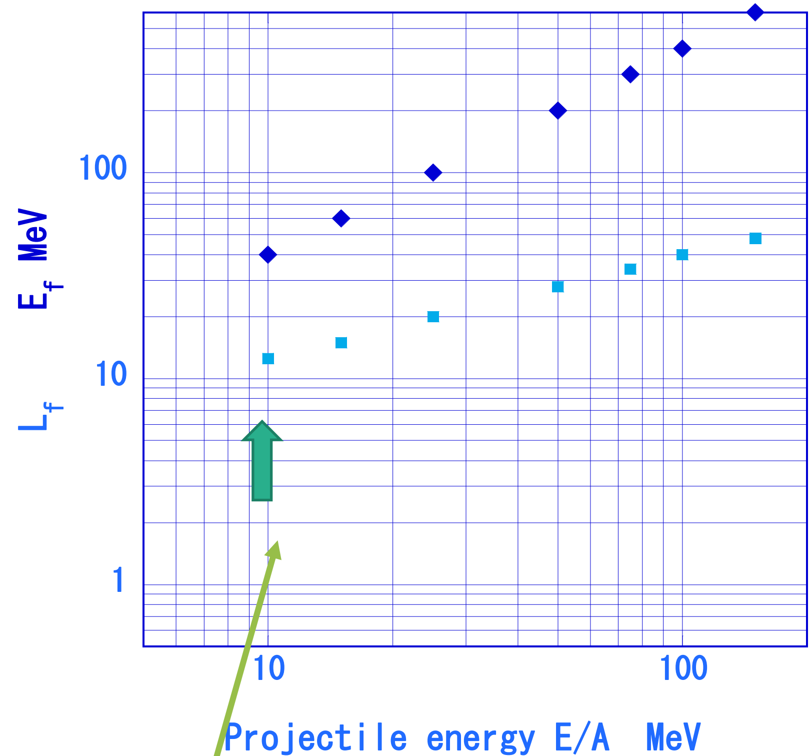

7
6
5
4
3
2
1
0
0
50
100
150
200
E/A MeV
x=qxr/(h/2π) at 0 deg.
B11
Ne20
He3 t
L=4
L=3
L=2
L=1
L=0


7
6
5
4
3
2
1
0
0
50
100
150
200
E/A MeV
x=qxr/(h/2π) at 1 deg.
B11
Ne20
He3
L=4
L=3
L=2
L=1
L=0

He4, 4n Reaction Q=-30 MeV

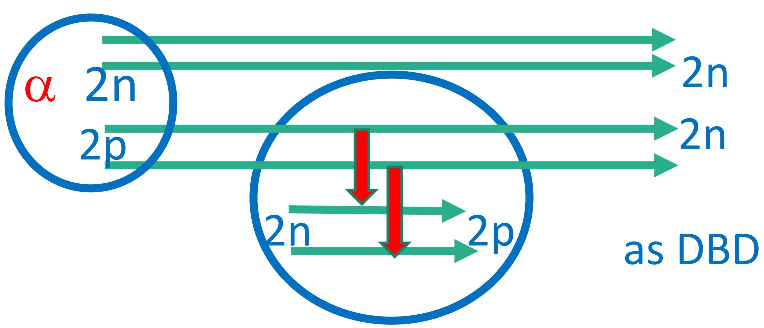


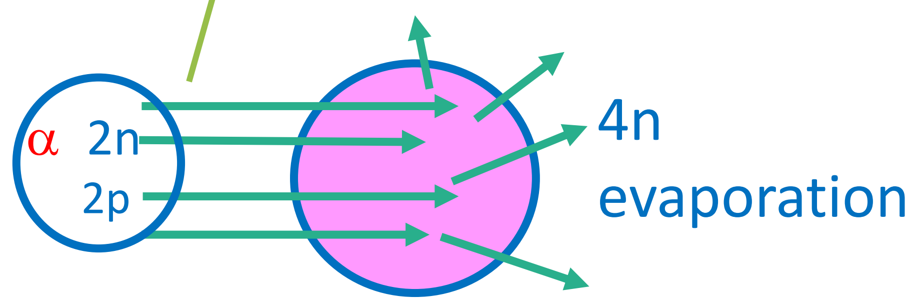
He4, 4n Reaction Q=-30 MeV



Medium E/A=100MeV α interact with 2n, CER to 2p , 30-MeV/c each P transfer like DBD

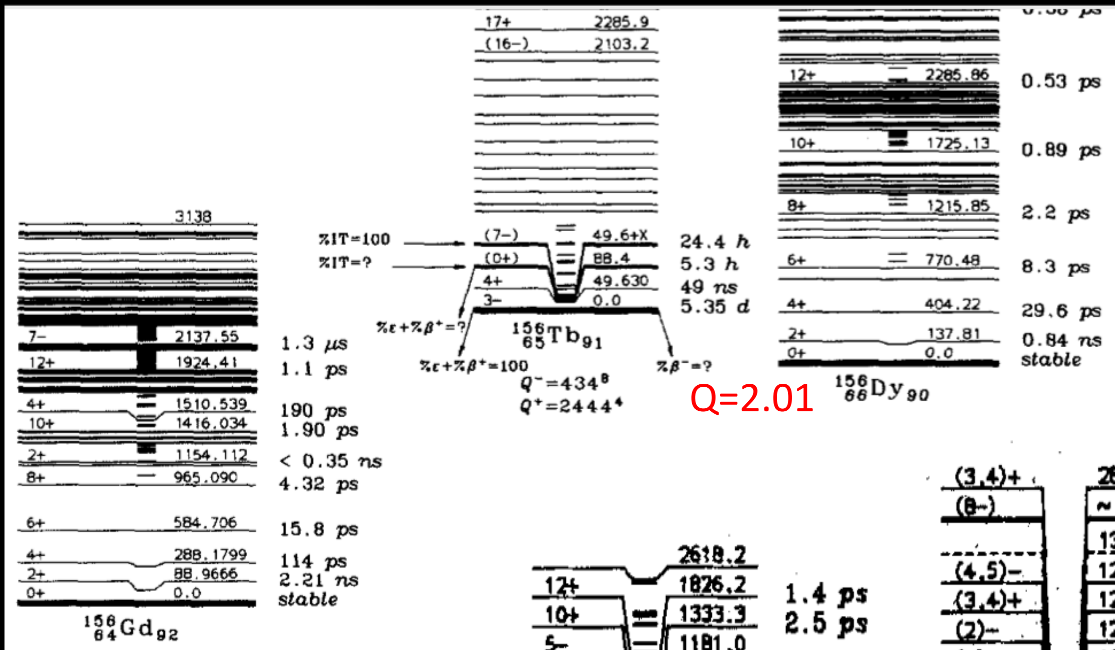
Low E/A=10 MeV α interact with all n, heat up to a few MeV, and 4 n evaporation, L~15 rotation

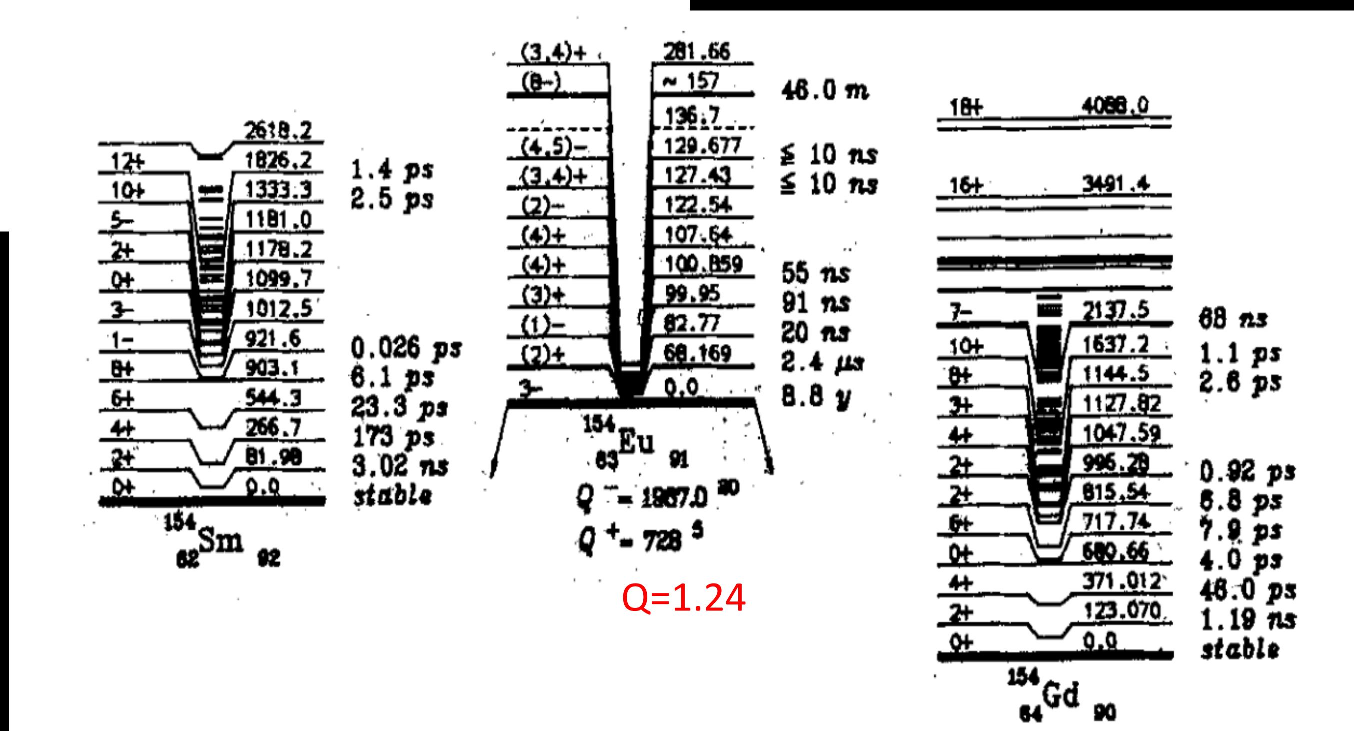




Deformed DBD nuclei with A=150 Nd and 152, 154 Sm.

Low energy (E/A=10-20 MeV) INS Univ. Tokyo





JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN, Vol. 24, No. 6, JUNE, 1968

Conversion Electrons from (α, xn) Reactions on Sm Isotopes and Nuclear Structures of Gd Nuclei

Hiroyasu EJIRI, Masayasu ISHIHARA, Mitsuo SAKAI

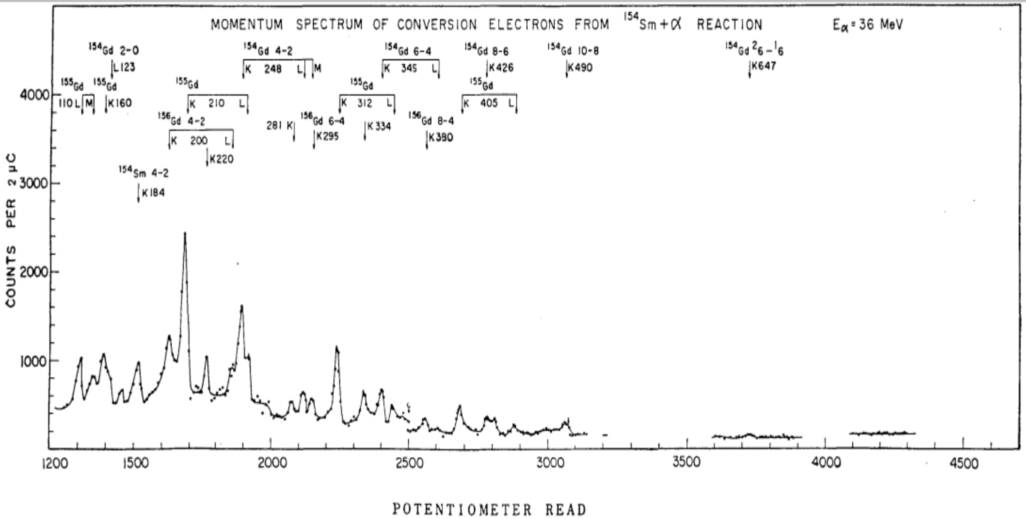
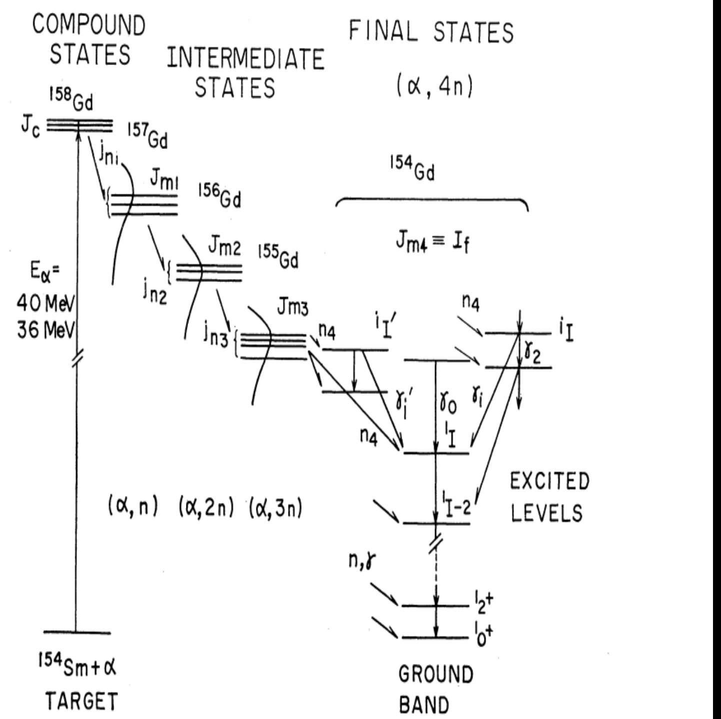


Fig. 4. Momentum spectrum of conversion electrons from the ^{154}Sm+α reaction with 36 MeV incident alphas. The discriminator level is risen at the position C↑.

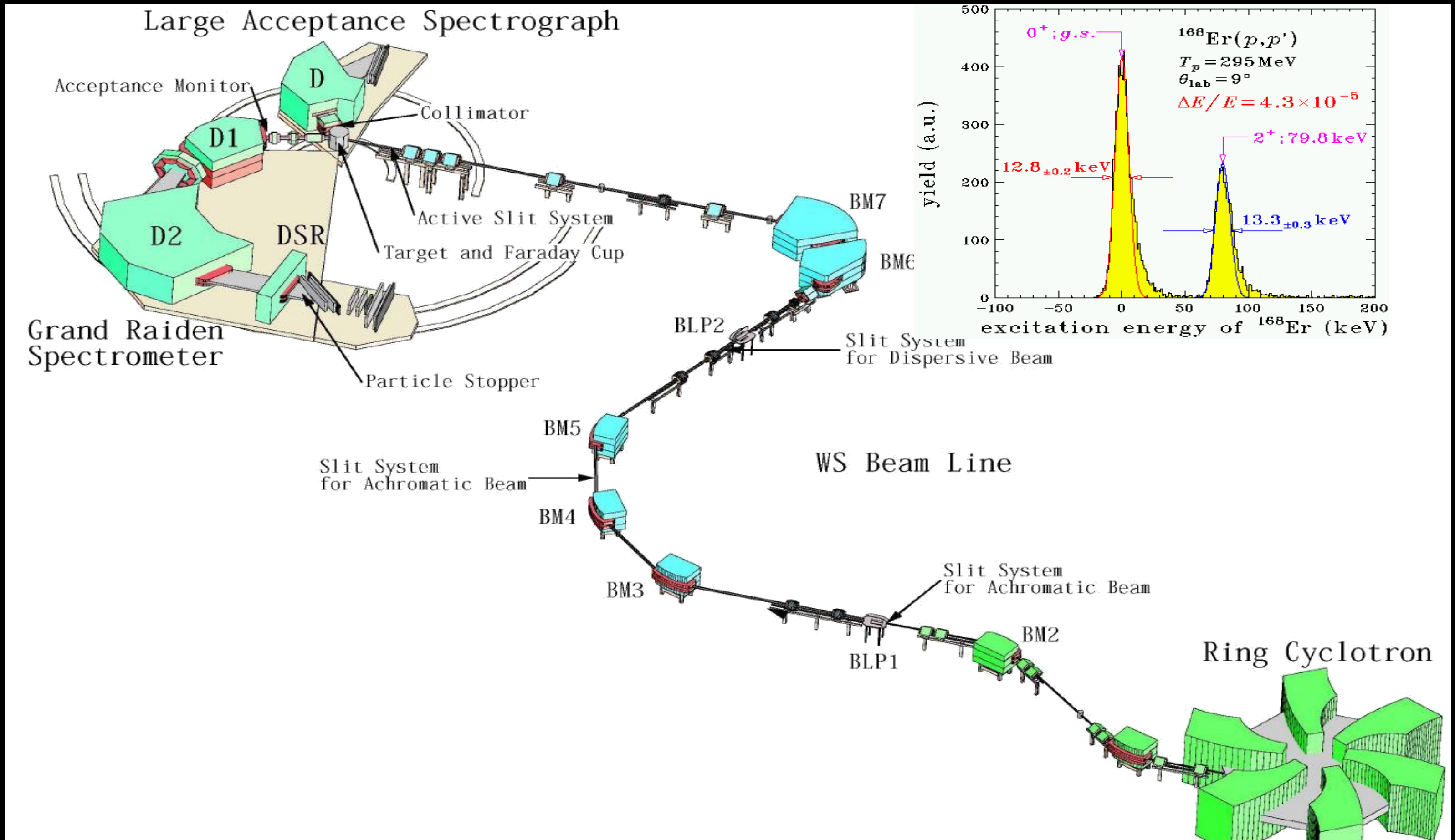


1. Low energy (E/A=10 MeV) reaction (Q~30 MeV) is used to heat up nucleus. Most E (40 MeV), P (0.5 GeV/c) and L (~20) are transferred to nucleus.
2. Cool down by neutron evaporation, leaving rotational motion. Charge exchange because of the Coulomb barrier.
3. Gamma spectroscopy elucidates such nuclear structures of the final nucleus as the deformation/moment of inertia and the pairing energy and so on.
4. In A=154 case, the large (1.5 factor) change of the moment of inertia from initial to final nuclei. The DBD NME calculation should consider the change .

Subjects to be discussed

- 1. Experimental approaches to
- NMEs for DBD and Astro-n
- 2. Nuclear Single and double CERs
- 3. Recent RCNP CERs and DCERs,

RCNP cyclotron E/A= 0.1 GeV warrants one step CER. Spectrometer with energy resolution 30 keV is used to select individual states up to 30 MeV of current interest. Momentum transfer 0-200 MeV/c at θ=0-3 deg.,for L=0.1.2. These are powerful for studies of astro-ν and DBD NMEs



WS Beam Line and Two-Arm Spectrometers at RCNP

2. Exp. GT & SD GRs and quenching for single- β

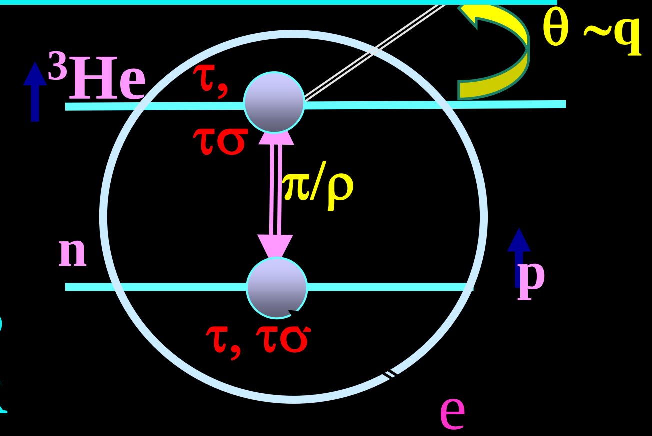
CERs at RCNP

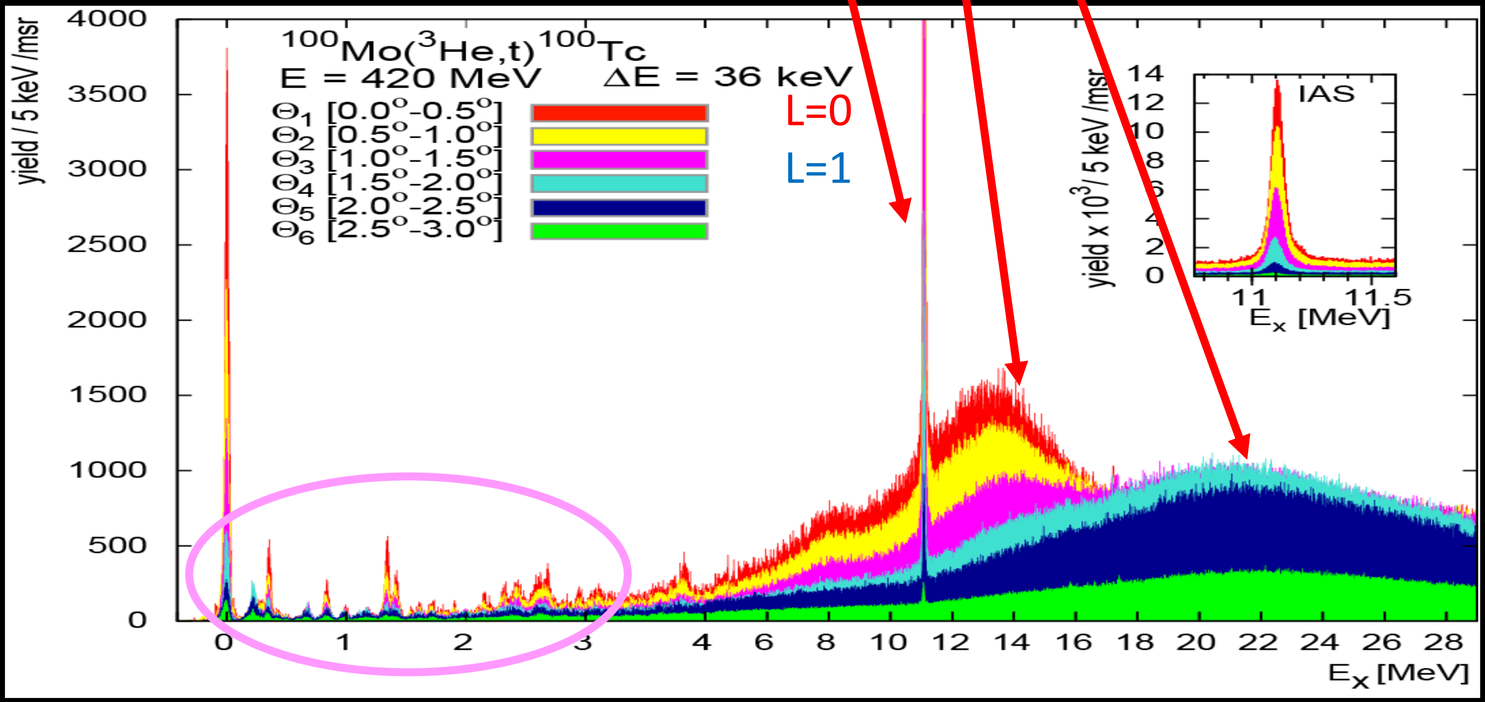
Most τσ strengths are pushed up into GRs (Giant resonances)

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





Ejiri, Suhonen, Zuber PR 797 1 2019 Thies et al PR C 2012 86 14303

Most axial vector states (L=0,1,2) are excited, but no separation of $M(J=1+) = M(\tau\sigma)_1 + \delta M(\tau(\sigma Y_2)_1$ s-wave t at forward angle, and $M(J=2-) = M(\tau\sigma Y)_2 + \delta M(\tau(\sigma Y_3)_2$ p-wave t .
Absolute NMEs calibration by β or γ decays
Momentum dependence of g_A^{eff}/g_A=constant

J. H. THIES *et al.* PHYSICAL REVIEW C **86**, 014304 (2012)

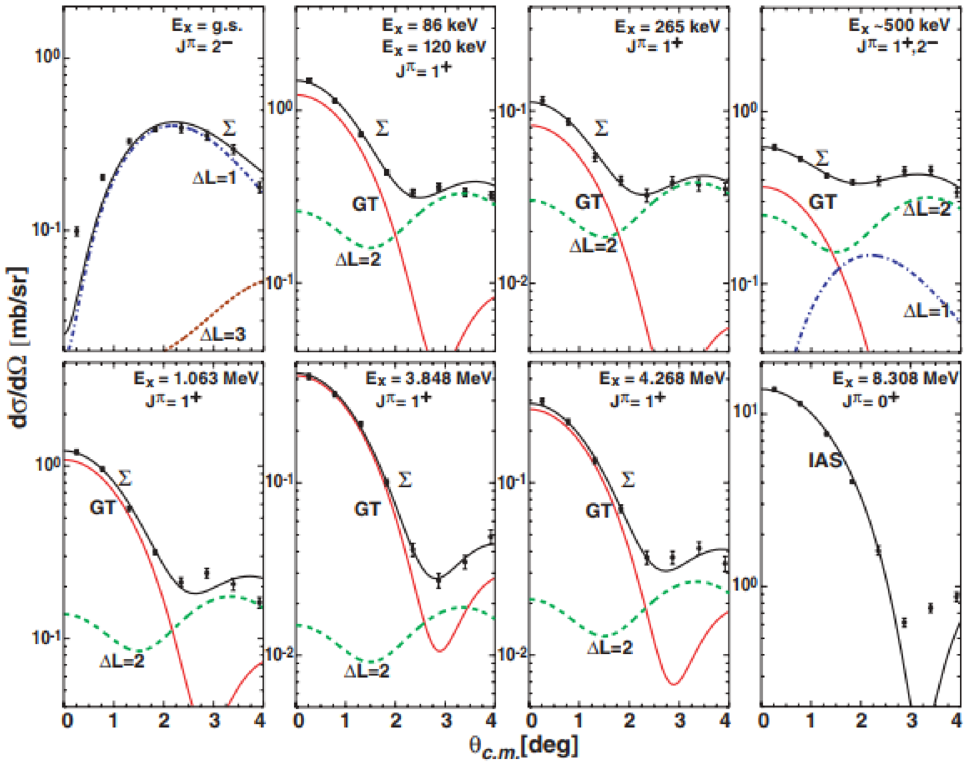
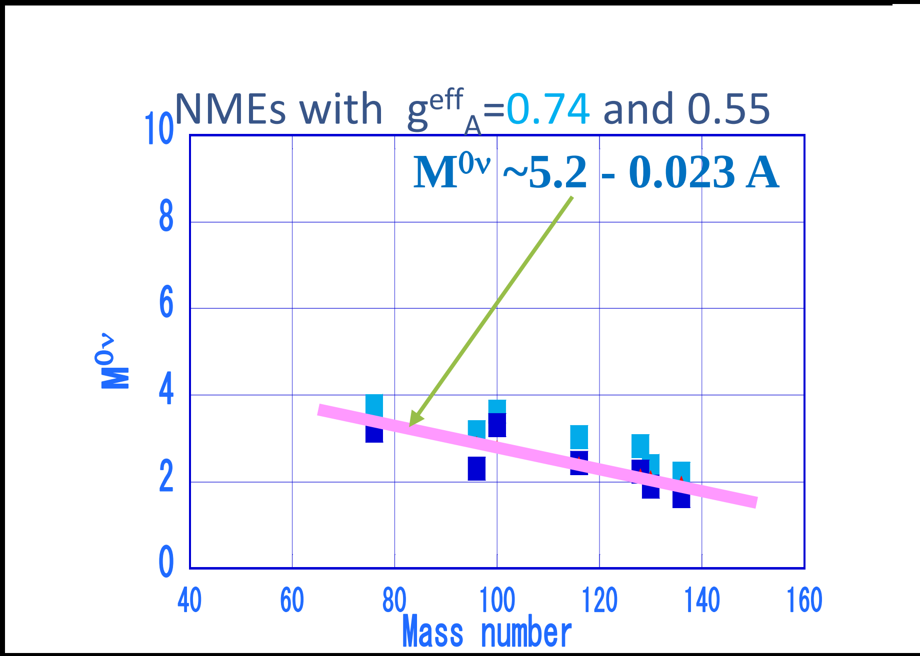
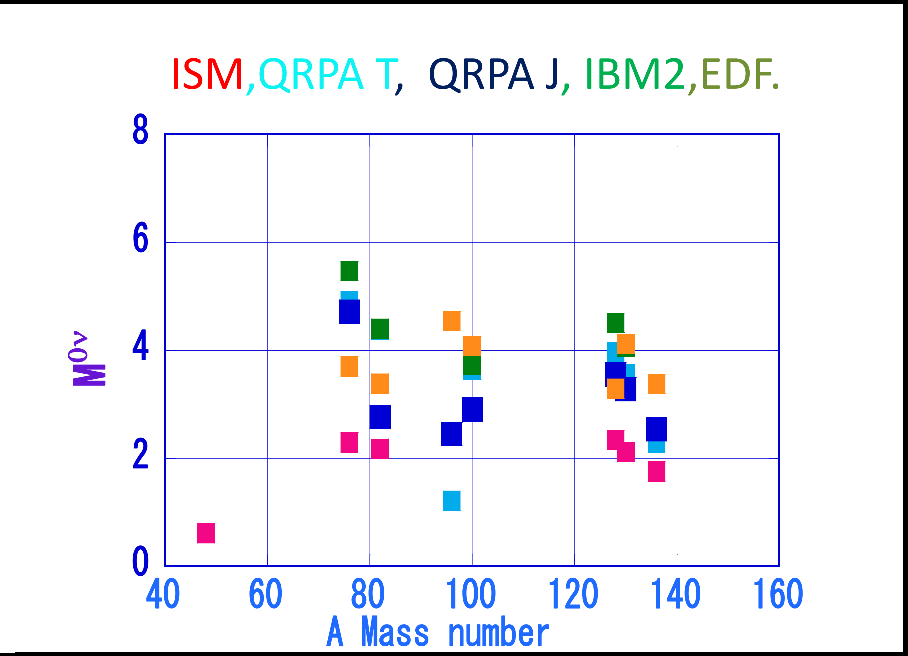


FIG. 3. (Color) Cross-section angular distributions for selected states of the ^{76}Ge(^{3}He,t)^{76}As reaction as discussed in the text. Note that the states around 100 keV and 500 keV could not be separated. The data points represent their sum.

$M^{0\nu}$ (pnQRPA) Ejiri Jokiniemi Suhonen PRC L 104 2022

with exp. $g_A^{eff}/g_V = 0.65 \pm 0.1$ from GT and SD exps , g_{ph} from SD GR exps and g_{pp} from $2\nu\beta\beta$ exps.





$M^{0\nu}$~ pnQRPA with $g_A^{eff}/g_A = 0.65 \pm 0.1$

$M^{0\nu}$ =3-2 ~ 5.2 - 0.023 A ± 10%

$(0.55/0.74)^2 = 0.55$, while NMEs ratio=0.8

$M^{0\nu}$~ depends on models ($g_A^{eff}/g_V=1$)

ROPP 2014 Vergados Ejiri Simkovic

2. RCNP DCER $^{11}B,^{11}Li$ at E/A=0.08 GeV

Unique features

1. Lightest projectile for both charged projectile and ejectile reactions.

2. Medium energy E/A~0.1 GeV for one-step DCER like DBD.

3. P transfer of 100 MeV, L=1-3

4. ^{11}Li no bound excited state. Only ground state of the ejectile to study the target excitation.

Double charge exchange ($^{11}B,^{11}Li$) reaction for double beta decay response

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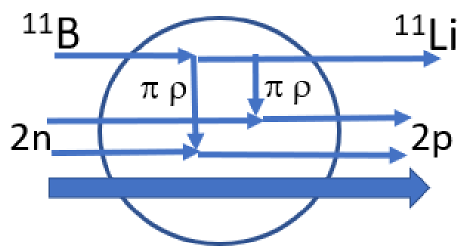
arXiv 1703.08265

Nuclear DCER



$$^{A}_{Z}X + ^{11}B \rightarrow ^{A}_{Z+2}X + ^{11}Li$$

$$^{A}_{Z}X \rightarrow ^{A}_{Z+2}X + 2e$$

RCNP Ring cyclotron provided ^{11}B with E/A=0.08 GeV.
Grand RAIDEN high resolution spectrometer for ^{11}Li momentum analysis, and identification by TOF and energy loss.

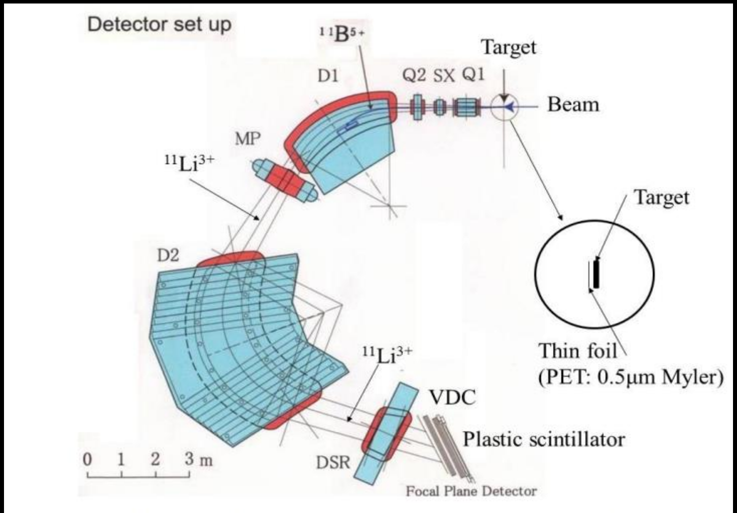


Figure 1. The Grand Raiden spectrometer. Q1, Q2: quadrupole D1: DSR: for DCER(^{11}B,^{11}Li)

$^{13}C(^{11}B,^{11}Li)^{13}O$ ground state is well identified.

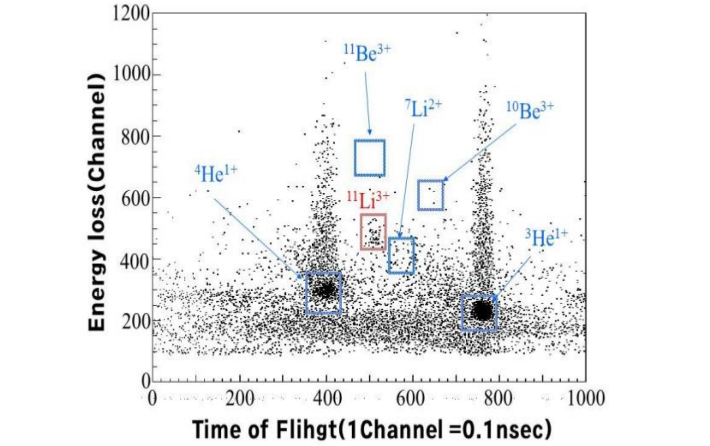
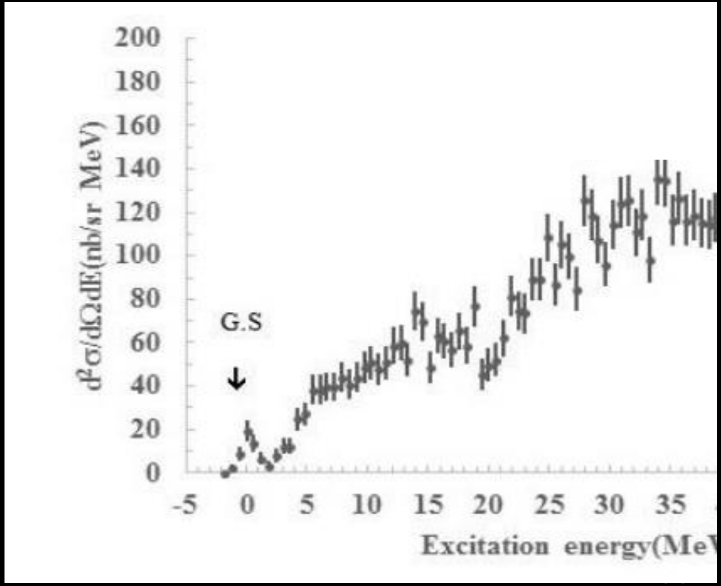


Figure 2. Particle identification of the scattered ^{11}Li particle by using TOF and the energy loss at plastic scintillator (thickness:3mm). The start signal of the TOF is RF signal from the Ring cyclotron.



How one can learn double axial-vector coupling, $(g_A^{eff}/g_A)^2$, double quenching coefficient, being crucial for DBD NMEs, from DCER

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Article

Single and Double Charge-Exchange Reactions and Nuclear Matrix Element for Double Beta Decay

τσ, τ

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Abstract: Neutrino properties such as the Majorana nature and the masses, which are beyond the standard model, are derived from the experimental double beta decay (DBD) rate by using the DBD nuclear matrix element (NME). Theoretical evaluations for the NME, however, are very hard. Single charge-exchange reactions (SCERs) and double charge-exchange reactions (DCERs) are used to study nuclear isospin (τ) and spin (σ) correlations involved in the DBD NME and to help the theoretical calculation of the DBD NME. Single and double $\tau\sigma$ NMEs for quasi-particle states are studied by SCERs and DCER. They are reduced uniformly with respect to the quasi-particle model NMEs due to the $\tau\sigma$ correlations. Impact of the SCER- and DCER-NMEs on the DBD NME is discussed.

Schematic diagrams of SCER, DCER, and DBD

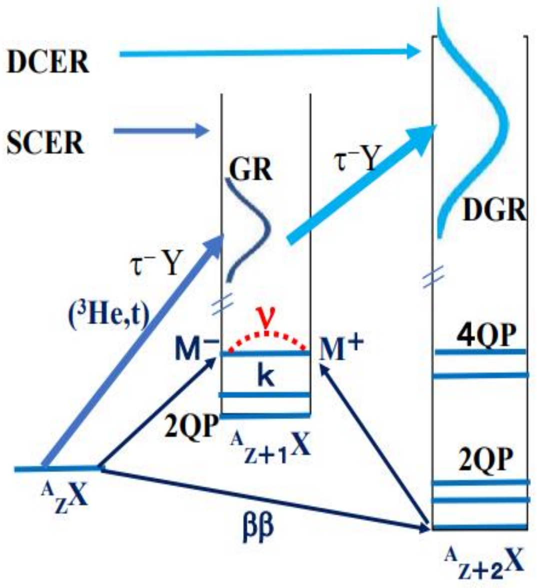


Figure 1. Schematic diagram for the $0\nu\beta\beta$ DBD transition of ${}^{A}_{Z}X \rightarrow {}^{A}_{Z+2}X$ with a neutrino exchange. SCER: ${}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}X$. DCER: ${}^{A}_{Z}X \rightarrow {}^{A}_{Z+2}X$.. QP: Quasi particle-hole state. GR: Giant resonance. DGR: Double giant resonance. M^{-} (M^{+}): τ^{-} (τ^{+}) single-β response associate with DBD.

Axial-vector τσ NMEs for low-lying (Q) states are reduced by nucleonic and non-nucleonic τσ correlations, some of them are in model, others are incorporated by axial-vector coupling, (g_A^{eff}/g_A)

Double τσ τσ NMEs for low-lying (Q) states are doubly reduced by nucleonic and non-nucleonic τσ τσ correlations, some of them are in model, others are incorporated by axial-vector coupling, $(g_A^{eff}/g_A)^2$

SCER and DCER for low-lying SD states and IAS

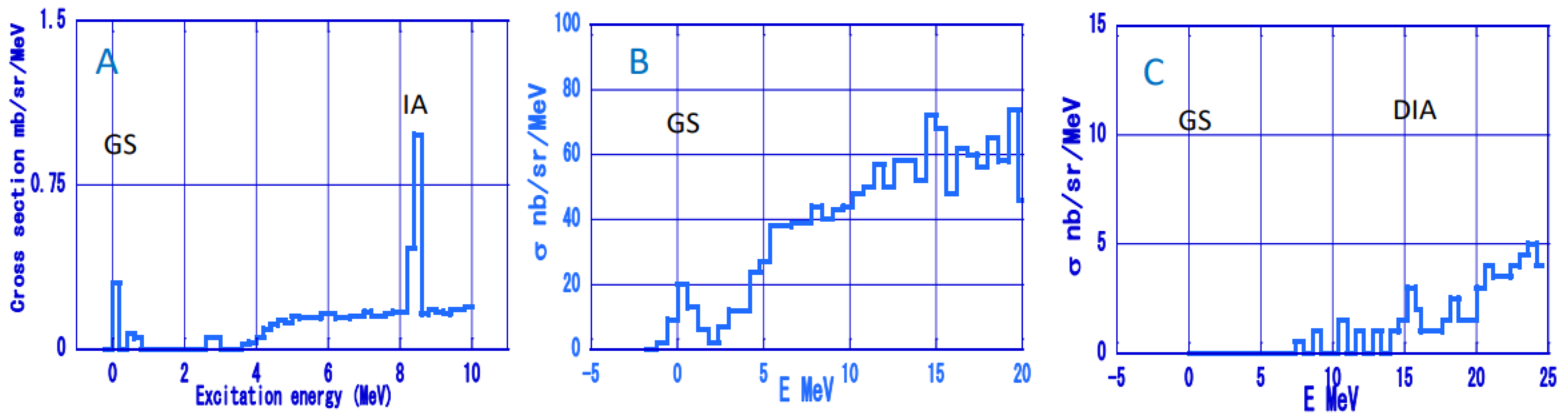


Figure 4. Energy spectra of the SCER and the DCERs: A: SCER of (^{3}He,t) on ^{76}Ge at θ=2 - 2.5 deg., where the SD (L=1) excitation gets maximum [17]. B: DCER of (^{11}B,^{11}Li) on ^{13}C at θ=0 - 2.5 deg., where GTSQ (L=2) excitation gets maximum [24]. C: DCER of (^{11}B,^{11}Li) on ^{56}Fe at θ=0 - 2.5 deg., where GTSD (L=1) excitation gets maximum [24]. GS: Ground state. IA: Isobaric analogue state. DIA: Double isobaric analogue state.

The ground state is well excited in ^{13}O .
The low states and IAS are little excited in SCER on^{76}Ge ,
The low states and double IAS are very little excited in ^{56}Fe.

SCER $\tau\sigma$ SD interaction is large and τ interaction for IAS is small.
in SCER with E/A=0.14 GeV and DCER with E/A=0.08 GeV

Analysis: key is extraction of absolute value for specific (τσ) NME. Use the ratio of the cross section to the IAS with known NME=N-Z.

Distortion factors (loss of the incoming and outgoing particle flux: 0.05) are major uncertainties in SCE and DCER. They are common for low and IAS since E(IAS)=0.01 GeV << E(^{11}B)=1 GeV.

$$d\sigma(\mathrm{SD,QP}_i)/d\Omega = (2L+1)K(\mathrm{SD,QP}_i)N(\mathrm{SD,QP}_i)|j_1(q_iR)|^2|J_{\tau\sigma}|^2 B(\mathrm{SD,QP}_i),$$

$$\frac{d\sigma(\mathrm{SD,QP}_i)/d\Omega}{d\sigma(\mathrm{F,IA})/d\Omega} = 3\frac{|j_1(q_iR)|^2}{|j_0(q_{\mathrm{IA}}R)|^2}\frac{|J_{\tau\sigma}|^2}{|J_\tau|^2}\frac{B(\mathrm{SD,QP}_i)}{B(\mathrm{F,IA})},$$

9.8 N-Z

$$d\sigma(\mathrm{GTSD,QP}_k)/d\Omega = (2L+1)K(\mathrm{GTSD,QP}_k)N(\mathrm{GTSD,QP}_k)|j_1(q_kR)|^2|J_{\tau\sigma}|^4 B(\mathrm{GTSD,QP}_k),$$

$$\frac{d\sigma(\mathrm{GTSD,QP}_k)/d\Omega}{d\sigma(\mathrm{FF,DIA})/d\Omega} = \frac{3|j_1(q_kR)|^2}{|j_0(q_{DI}R)|^2}\frac{|J_{\tau\sigma}|^4}{|J_\tau|^4}\frac{B(\mathrm{GTSD,QP}_k)}{B(\mathrm{FF,DIA})},$$

GT SD p-p and f-g, p-d : 0-2 MeVfor 15MeV

11.5 6

Quenching (g^{eff}/g) coefficients

M(EXP)=$k_{\tau\sigma}$(QP)M(QP) $k_{\tau\sigma}$(QP)~ 0.25 – 0.3 , QP: only U V factors without $\tau\sigma$.

$k_{\tau\sigma}$(QP)~ $k_{\tau\sigma}$(QR) k(NQR) = 0.5 × 0.5 -0.6 g_A^{eff}/g_A QP: 0-2 MeV, k' for low 0-12 MeV

Table 1. Top: The SD strengths and the reduction coefficients for the QP and low-lying states by SCERs on DBD nuclei. Shown are the SD strength B(SD,QP), the F strength B(F,IA), the reduction coefficient $k_{\tau\sigma}$ for the QP states, and the reduction coefficient $k'_{\tau\sigma}$(SD) for the low-lying states. See text. Bottom: The GT-SD strength and the reduction coefficient for the QP states by DCER on ^{56}Fe. Shown are the GT-SD strength B(GTSD,QP), the F strength B(FF,DIA), the reduction coefficient $k_{\tau\sigma}$(GTSD).

Nuclide	B(SD,QP)	B(F,IA)	$k_{\tau\sigma}$(SD)	$k'_{\tau\sigma}$(SD)
^{76}Ge	0.080±0.016	12	0.30 ±0.05	0.26±0.05
^{82}Se	0.091±0.018	14	0.29±0.04	-
^{96}Zr	0.024±0.005	16	0.27±0.04	0.31±0.06
^{100}Mo	0.053±0.011	16	0.35±0.05	0.33±0.06
^{128}Te	0.452±0.090	24	0.32±0.05	0.29±0.05
^{130}Te	0.456±0.090	26	0.31±0.05	0.29±0.05
^{136}Xe	0.457±0.091	28	0.34±0.05	0.26±0.05
Nuclide	**B(GTSD, QP)**	**B(FF, DIA)**	**$k_{\tau\sigma}$(GTSD)**	**-**
^{56}Fe	0.61 ±0.12	8	0.092±0.014	-

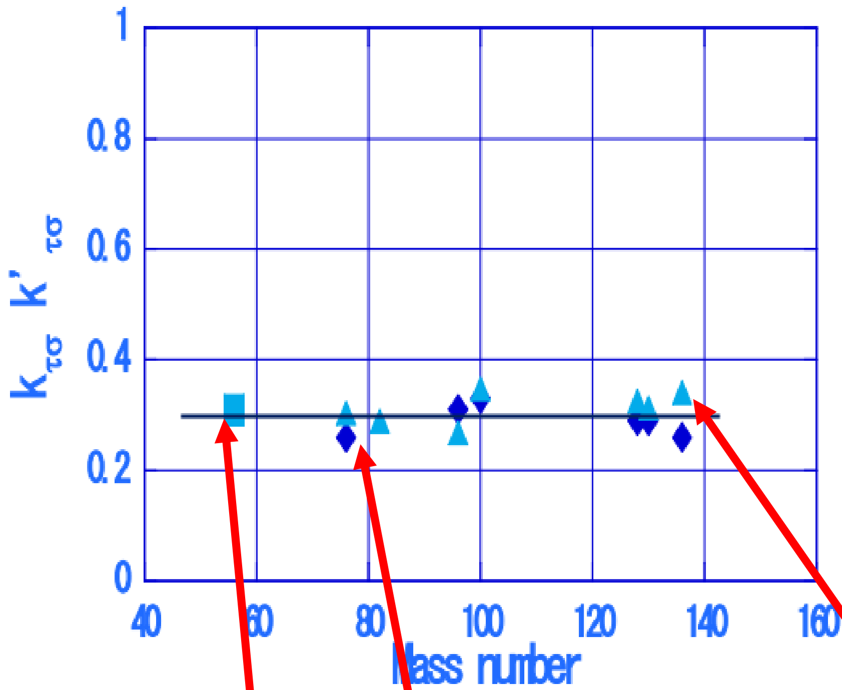


Figure 3. Reduction coefficients for axial-vextor NMEs. Light blue triangles: $k_{\tau\sigma}$(SD,QP) for the QP SD states by SCERs on DBD nuclei. Blue diamonds: $k'_{\tau\sigma}$(SD,L) for low-ling SD states by SCERs on DBD nuclei. Light blue square: $(k_{\tau\sigma}(\text{GTSD,QP}))^{1/2}$ for the QP GT-SD states by DCER on ^{56}Fe. Solid line: the reduction coefficient of 0.3 to guide eye

Lepton ($e\ \nu\ \mu$) CERs

μ-ν_μ CER used at RCNP

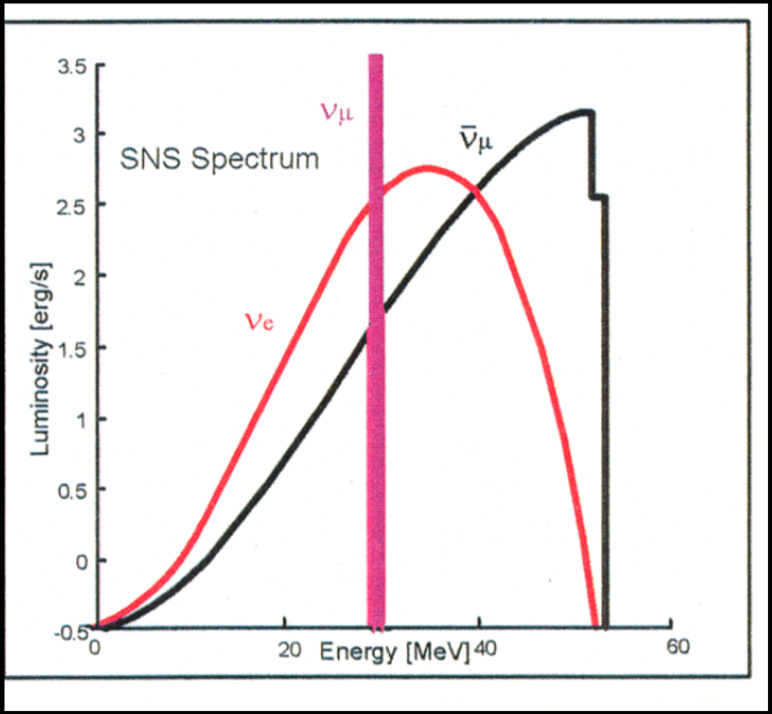
Lepton (e ,ν) CERs

A: ν from intense p

SNS (Spallation N) ORNL JPARC

$\pi^+ = \mu^+ + \nu_\mu$

$\mu^+ = e^+ + \nu_e$ + anti–ν_μ



N~10^{15}/sec. 10% is used to irradiate 1 ton target

Yield = 0.6 10^{-1}/sec for 10^{-41}cm^2 for a low GT state.

B: e from intense e linac 10^{16}/sec

e^- + X=ν_e +Y* (γ β decays)

30 MeV linac pulsed 0.5 A N~2 10^{15} /sec. 5 gr/cm^2 target

Target 5 gr/cm^2, Yield =0.6 10^{-3}/ sec for 10^{-41}cm^2 for a low GT.

Concluding remarks

1. Single and double charge-exchange nuclear reactions (SCER, DCER) via charged mesons are used to study the charged current NMEs (nuclear sector) via charged W boson.

2. The nuclear cross sections are $10^{15\text{-}12}$ larger than the weak ones, reflecting the much lighter mass of the mesons.

3. SCER-DCER NMEs with similar isospin spin ($\tau\sigma$, τ) and multipole (Y_L) operators are used to help evaluate the IBD and DBD $\tau\sigma$, τ NMEs and the $\tau\sigma$ τ correlations.

4. Nuclear reactions with E/A~0.1 GeV are useful to study IBD and DBD $\tau\sigma$, τ NMEs with p~0.1 GeV/c.

5. Absolute NMEs are derived from the ratio of the cross section to the cross section for the IAS/DIAS with known NME.

6. Axial vector single-β NMEs for low-lying QP states are reduced by a factor 0.3 from QP model and axial-vector DDB NMEs by $(0.3)^2$ due to nucleonic and non-nucleonic $\tau\sigma$ correlations.

Thank you for your attention