The first University in Korea Soongsil University

Gamow-Teller States and Neutrino Reactions by QRPA and Deformed QRPA

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T. Kajino, K. Nakamura, T. Hayakawa, S. Chiba,
T. Maruyama …

Neutrinos and Dark Matter 2012, Nara, Japan, June 11-15

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3. Summary

Neutrino Spectra

$$E_{\nu e} \leq E_{\bar{\nu} e} \leq E_{\nu \mu}$$

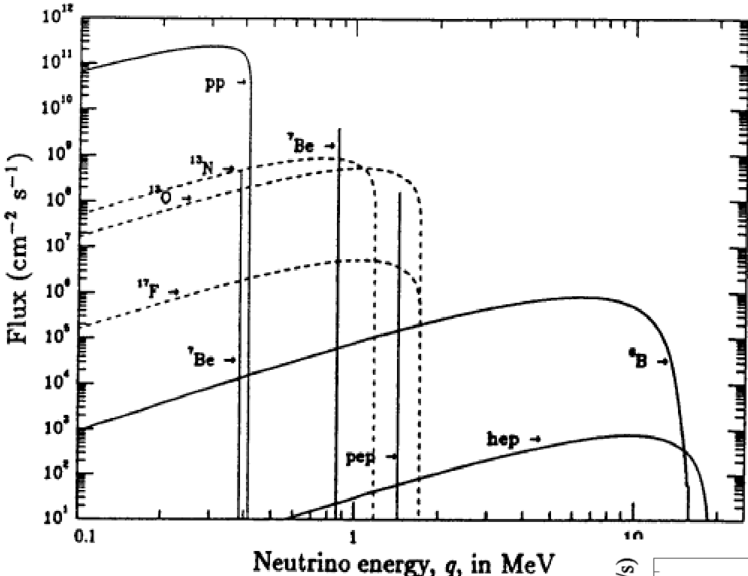
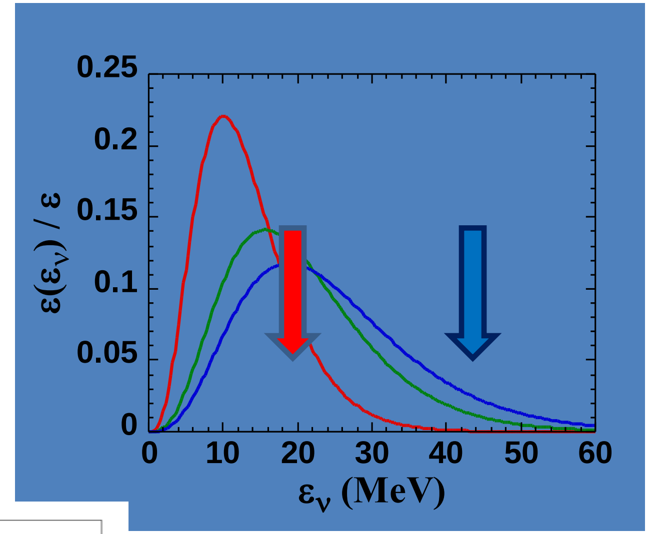
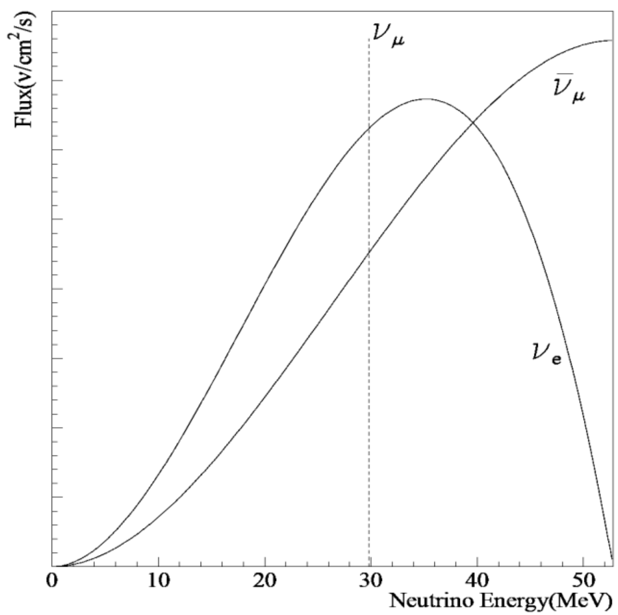


Fig. 4.4. **Solar neutrino spectrum.** Energy spectrum of solar neutrinos, as predicte
model. Solid and dashed curves distinguish between neutrinos produced in the pp-cha
respectively. (From 49.)

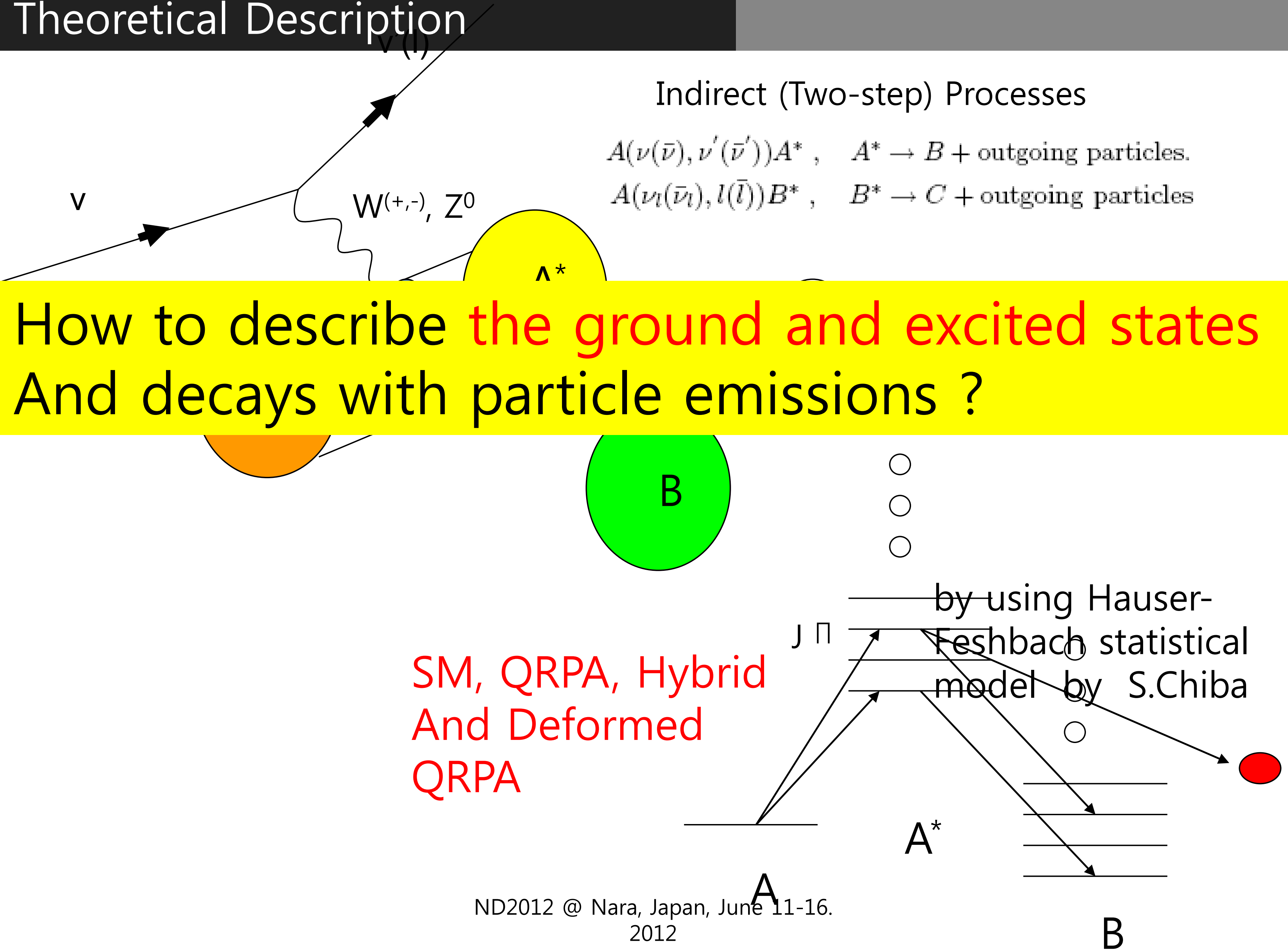




Theoretical Description

Indirect (Two-step) Processes

$$A(\nu(\bar{\nu}),\nu'(\bar{\nu}'))A^*\ , \quad A^* \to B + \text{outgoing particles.}$$
$$A(\nu_l(\bar{\nu}_l),l(\bar{l}))B^*\ , \quad B^* \to C + \text{outgoing particles}$$



How to describe the ground and excited states And decays with particle emissions ?

SM, QRPA, Hybrid And Deformed QRPA

by using Hauser-Feshbach statistical model by S.Chiba

Cross Sections

$$(\frac{d\sigma_\nu}{d\Omega})_{(\nu/\bar{\nu})} = \frac{G_F^2 \epsilon k}{\pi\ (2J_i+1)}\ [\ \sum_{J=0}(1+\vec{\nu}\cdot\vec{\beta})| < J_f||\hat{\mathcal{M}}_J||J_i > |^2$$

$$+(1-\vec{\nu}\cdot\vec{\beta}+2(\hat{\nu}\cdot\hat{q})(\hat{q}\cdot\vec{\beta}))| < J_f||\hat{\mathcal{L}}_J||J_i > |^2 -$$

$$\hat{q}\cdot(\hat{\nu}+\vec{\beta})2Re < J_f||\hat{\mathcal{L}}_J||J_i > < J_f||\hat{\mathcal{M}}_J||J_i >^*$$

$$+\sum_{J=1}(1-(\hat{\nu}\cdot\hat{q})(\hat{q}\cdot\vec{\beta}))(| < J_f||\hat{\mathcal{T}}_J^{el}||J_i > |^2 + | < J_f||\hat{\mathcal{T}}_J^{mag}||J_i > |^2)$$

$$\pm\sum\hat{q}\cdot(\hat{\nu}-\vec{\beta})2Re[< J_f||\hat{\mathcal{T}}_J^{mag}||J_i > < J_f||\hat{\mathcal{T}}_J^{el}||J_i >^*]]\ ,$$

$$\sigma(E_\nu) = \frac{G_F^2 cos^2\theta_c}{\pi\hbar^4 c^3}\sum_i k_i\epsilon_i F(Z,\epsilon_i)[B_i(GT)+B_i(F)]\ , \qquad (8)$$

where k_i and ϵ_i refer to the momentum and total energy of the outgoing electron and $F(Z,\epsilon_i)$

$$R_{CL}(\mathbf{q},\omega) = \Sigma_{J=0}| < J_f||\hat{\mathcal{M}}_J(\mathbf{q}) + \frac{}{\mathbf{q}}\hat{\mathcal{L}}_J(\mathbf{q})||J_i > |^2\ ,$$

$$R_T(\mathbf{q},\omega) = \Sigma_{J=0}| < J_f||\hat{\mathcal{T}}_J^{el}(\mathbf{q})||J_i > |^2 + | < J_f||\hat{\mathcal{T}}_J^{mag}(\mathbf{q})||J_i > |^2\ ,$$

$$R_I(\mathbf{q},\omega) = \Sigma_{J=0}2Re < J_f||\hat{\mathcal{T}}_J^{el}(\mathbf{q})||J_i >< J_f||\hat{\mathcal{T}}_J^{mag}(\mathbf{q})||J_i >\ \ ,$$

$$(\frac{d\sigma_\nu}{d\mathbf{q}^2})^{ERL}_{\nu/\bar{\nu}} = \frac{2G_F^2\epsilon cos^2(\frac{\theta}{2})}{\nu\ 2(J_i+1)}\ [\ R_{CL}(\mathbf{q},\omega)+C(\theta,\mathbf{q})R_T(\mathbf{q},\omega)\mp tan(\frac{\theta}{2})C(\theta,\mathbf{q})R_I(\mathbf{q},\omega)]$$

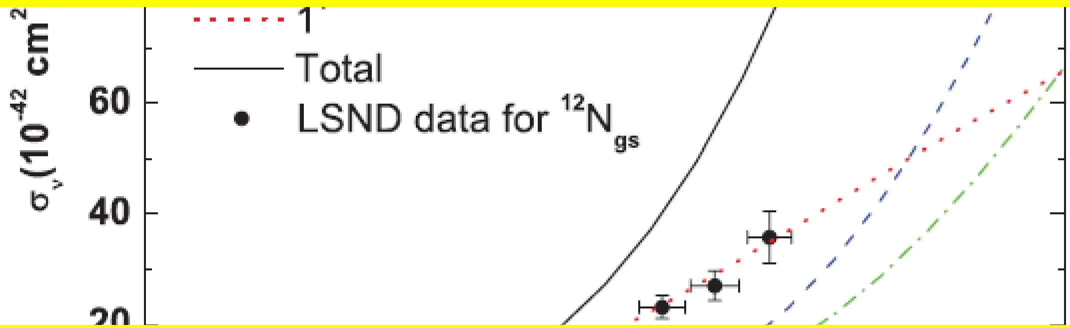
LSND : $\nu_e\,{}^{12}C \rightarrow e^- + {}^{12}N^*$

1. We need more data on nu reactions ! Neutrino beam from pion or

2. GT transitions by CEX are largely appreciated !

Roles of RIF for unstable nuclei are important for unstable nuclei !

4. Coulomb distortion beyond Fermi function for beta decay may work !

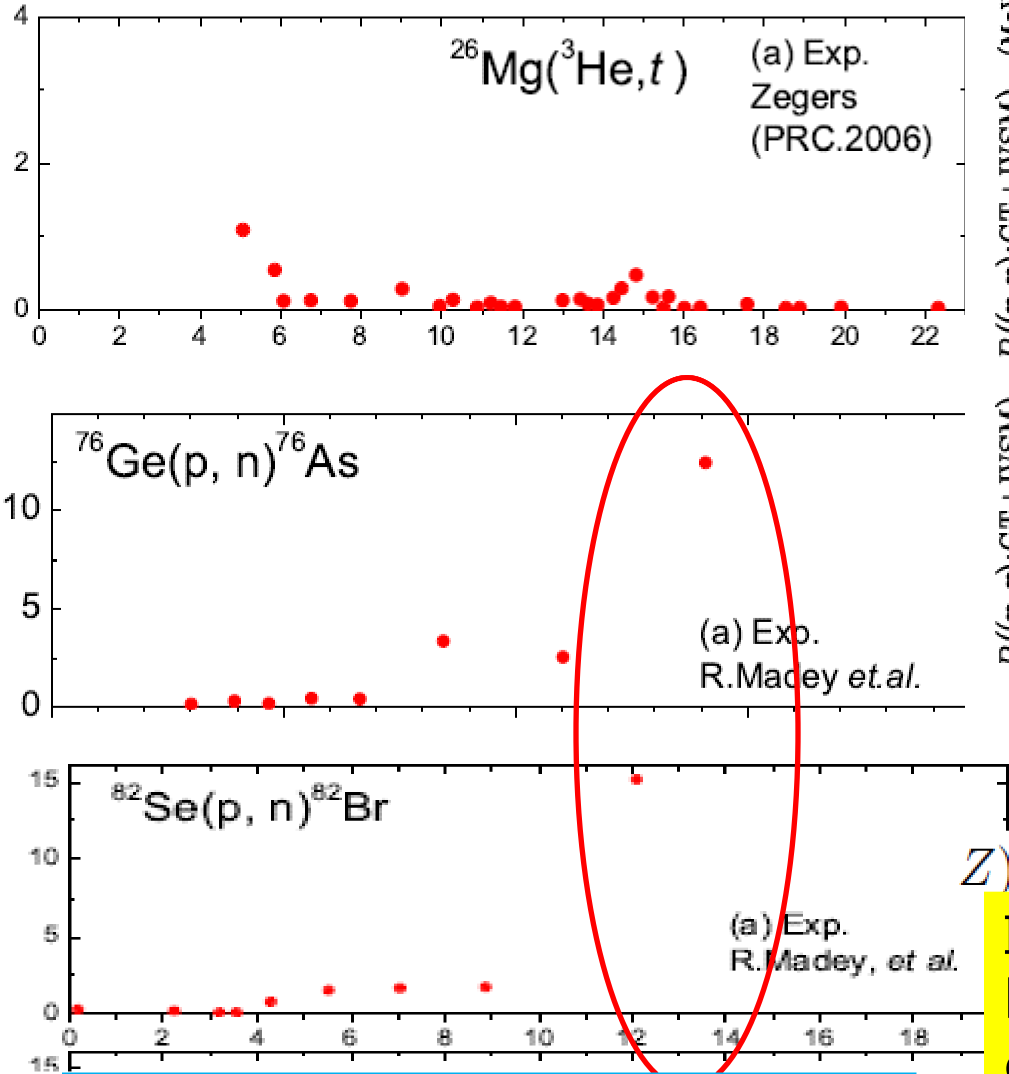


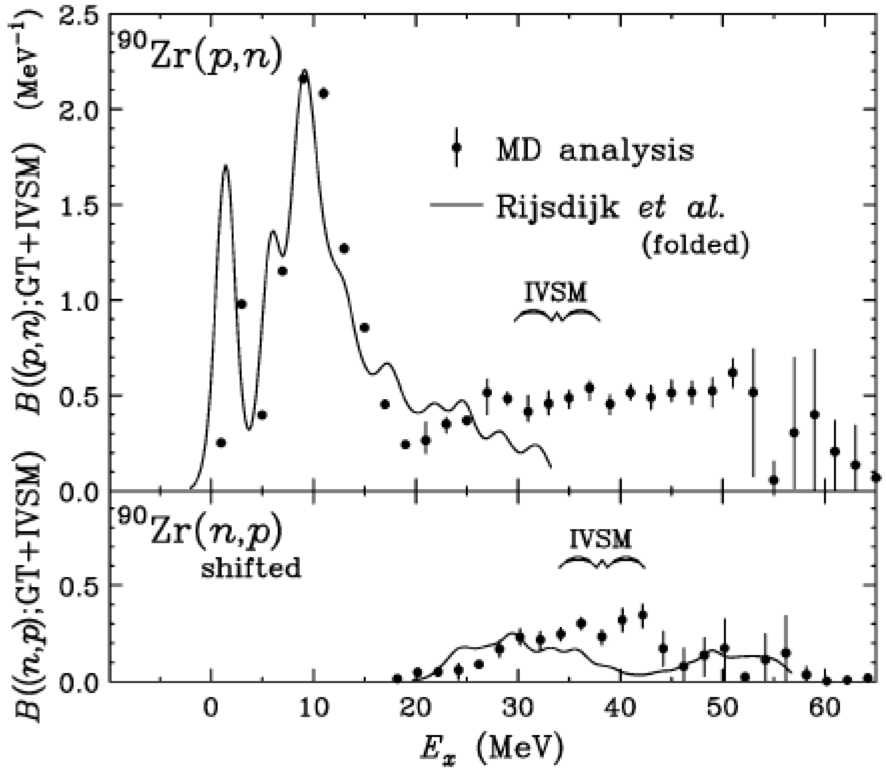
5. Contributions from higher energy tails,
high - lying (GT) excited states beyond 1 nucleon threshold ,
also contribute !

PHYSICAL REVIEW C **81**, 028501 (2010)

Myung-Ki Cheoun,[1,4,*] Eunja Ha,[1] Su Youn Lee,[1] K. S. Kim,[2] W. Y. So,[3] and Toshitaka Kajino[4,5]

High-lying GT states





$$Q = (S_- - S_+)/(3(N - Z)) = 0.90 \pm 0.05\ [17]\ \text{or}\ 0.88 \pm 0.06\ [18]$$

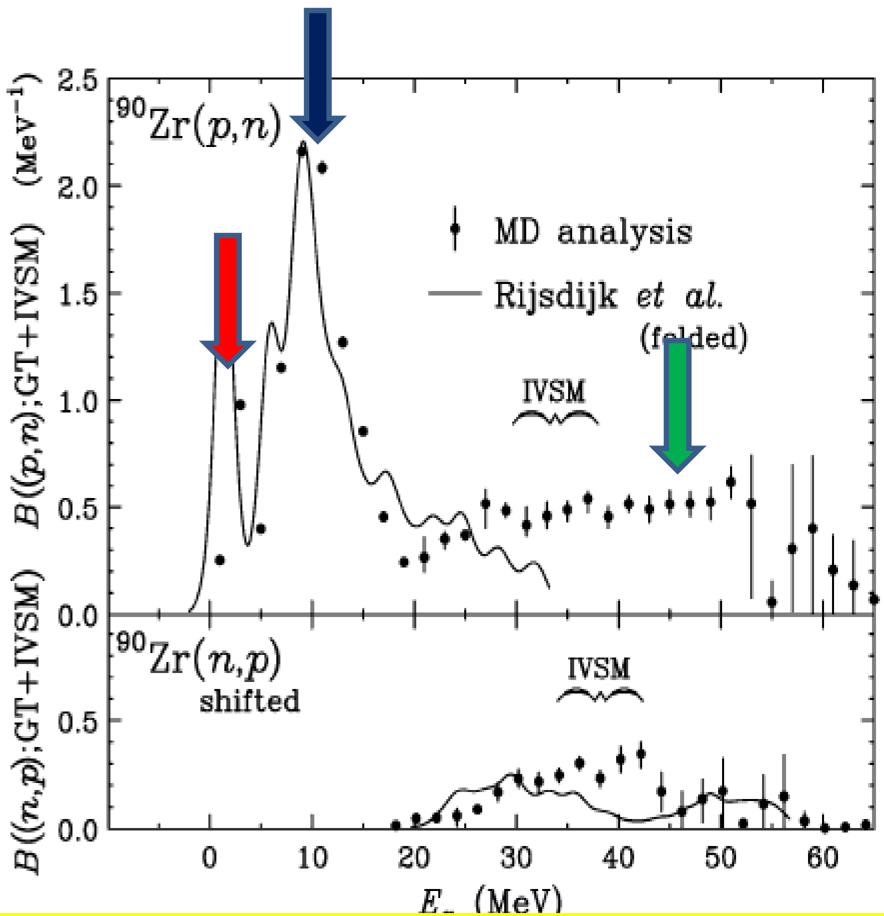
ISR is recovered
by high-lying GT excitation
coming from 2p-2h correlations.
Then, g_A quenching problem ??

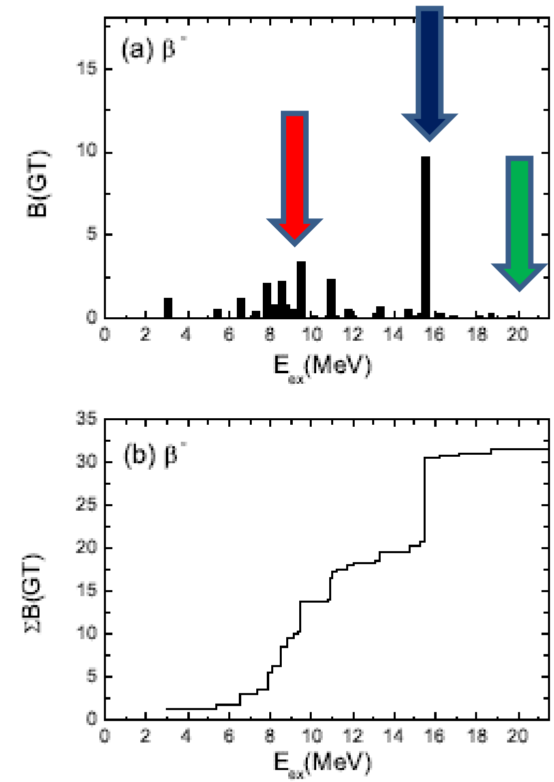
Contribute to nu-reaction ?
Deformation ? New Data ?

GT Results for 90Zr

Physics Letters B 615 (2005) 193–199 K. Yako[a], H. Sakai[a,b],

90Zr : beta- =6111KeV, beta+=2280 KeV

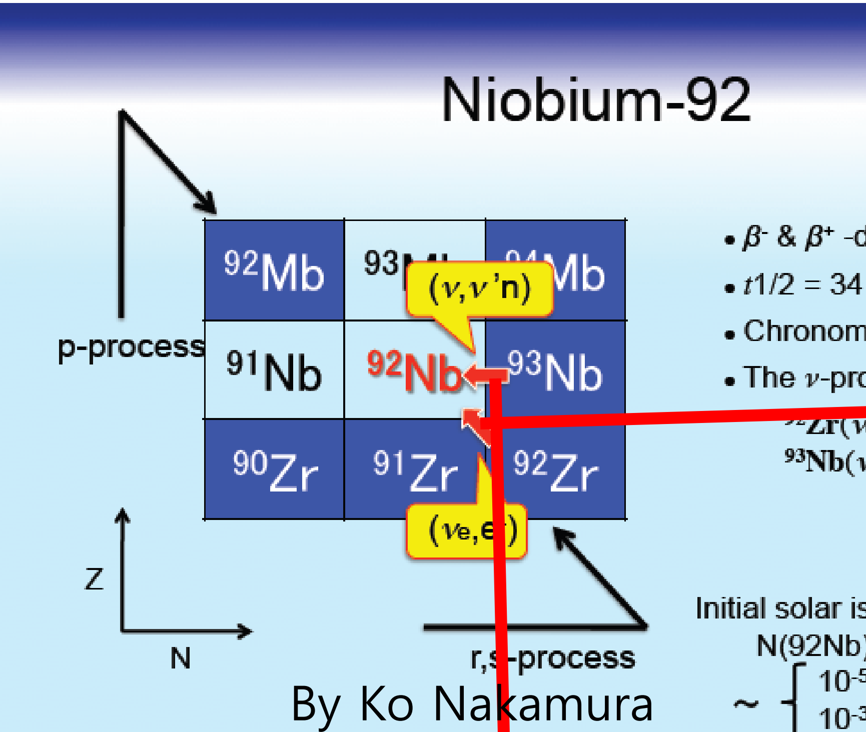


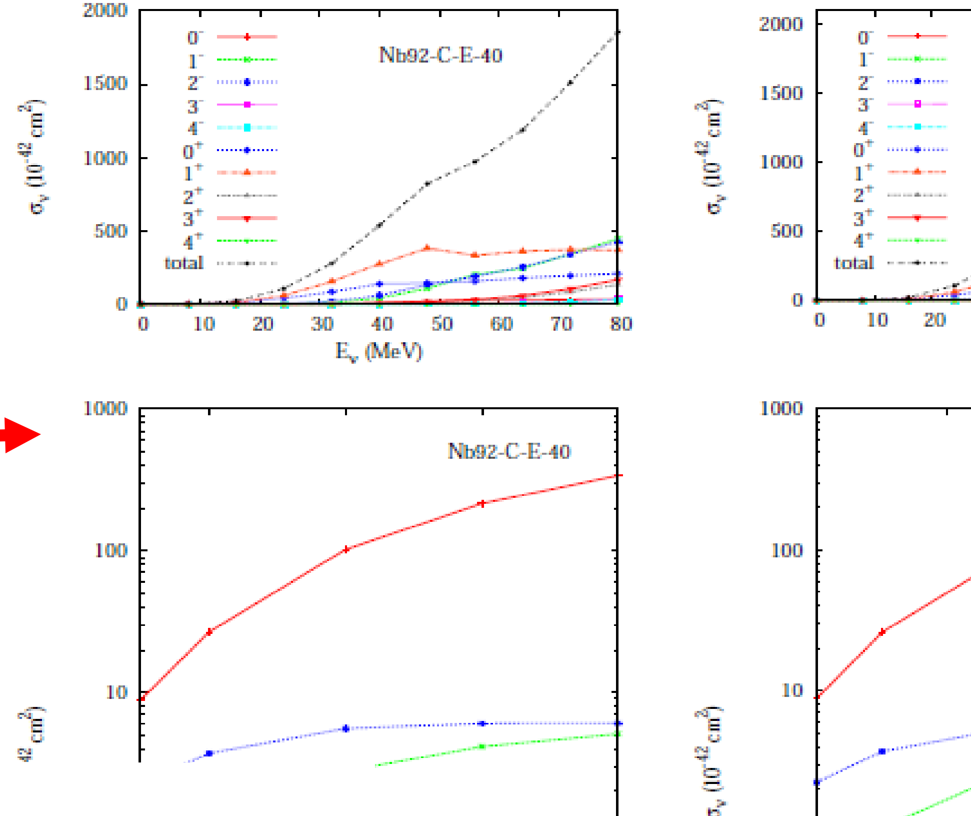


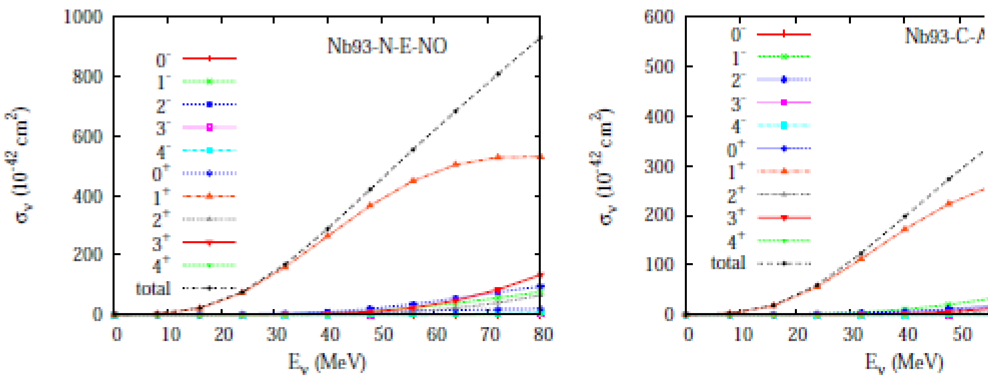
1. Peak positions on high-lying GT states are well pointed.
2. ISR is nicely reproduced .
3. 2p-2h mixings are vital for the high-lying GT states.

ation energy

E_{ex} in the daughter nucleus ^{60}Cu. Left panel (Right) is without (with) np pairing correlations.

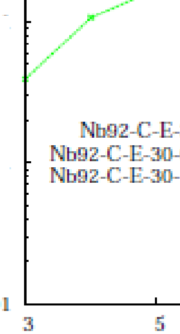






$$\langle \sigma_\nu \rangle = \frac{1}{N} \int dE_\nu \sigma_\nu(E_\nu) f(E_\nu) Br,$$

$$f(E_\nu) = \frac{E_\nu^2}{\exp[(E_\nu/T) - \alpha] + 1},$$



MKC et.al, in press, PRC (2012)

FIG. 7: Energy dependent cross sections of NC reactions for ^{92}Nb, ^{93}Nb($\nu(\bar{\nu}),\nu'(\bar{\nu}')n$)^{93}Nb. Left is for incident ν_e and right is for $\bar{\nu}_e$.

ture dependent cross sections of CC reac
ions for ^{92}Nb, ^{92}Zr(ν_e, e^-)^{92}Nb. Blue and
$(\nu_e, e^- p)^{91}$Zr and ^{92}Zr($\nu_e, e^- n$)^{91}Nb.

Results for 40Ar

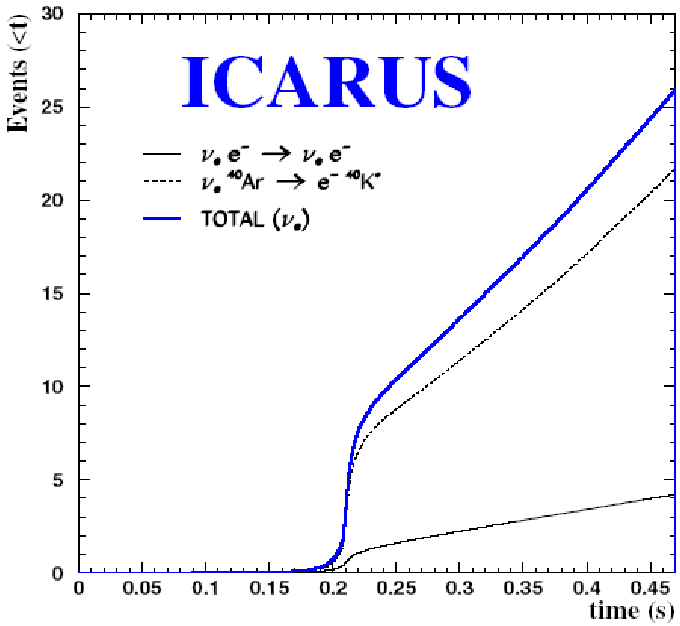
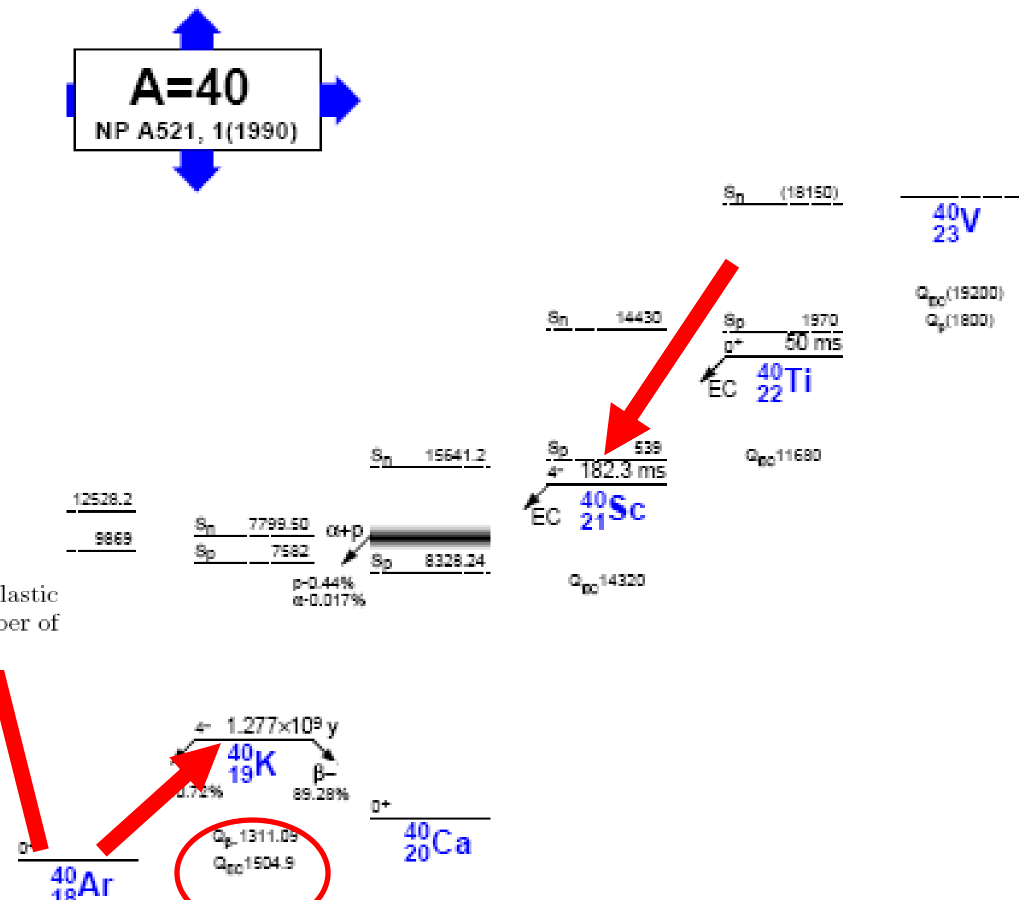
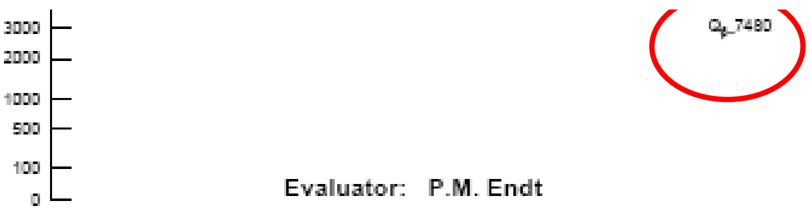


Figure 11. Integrated number of ν_e events as a function of time for the elastic and absorption channels. The thick solid line corresponds to the total number of events for a 3 kton detector. No oscillation effects are included.





Imaging of Cosmic and Rare Underground Signals (ICARUS) :

1. Liquid Argon time projection chamber (LArTPC)
2. For solar neutrino from ^8B
3. For SN neutrino and oscillations

Hybrid Model of Shell and QRPA Models for GT strengths

$$B(\mathrm{GT}) = \frac{1}{2J_i+1}(\langle J_m^\pi||\sigma t||J_i^\pi\rangle)^2 \qquad M_m(\mathrm{GT}) = \langle J_m^\pi||\sigma t||J_i^\pi\rangle$$

$$M_m(\mathrm{GT}) = \sum_{pn}\langle p||\sigma||n\rangle \mathrm{OBTD}(p,n,m,i)_{\mathrm{QRPA}}$$

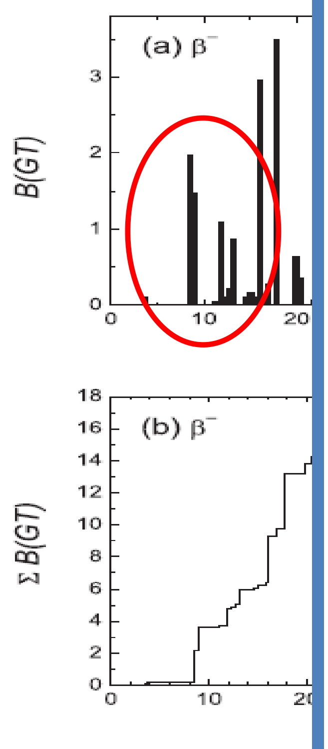
$$M_m(\mathrm{GT}) = \sum_{pn}\langle p||\sigma||n\rangle \mathrm{OBTD}(p,n,m,i)_{\mathrm{SM}},$$

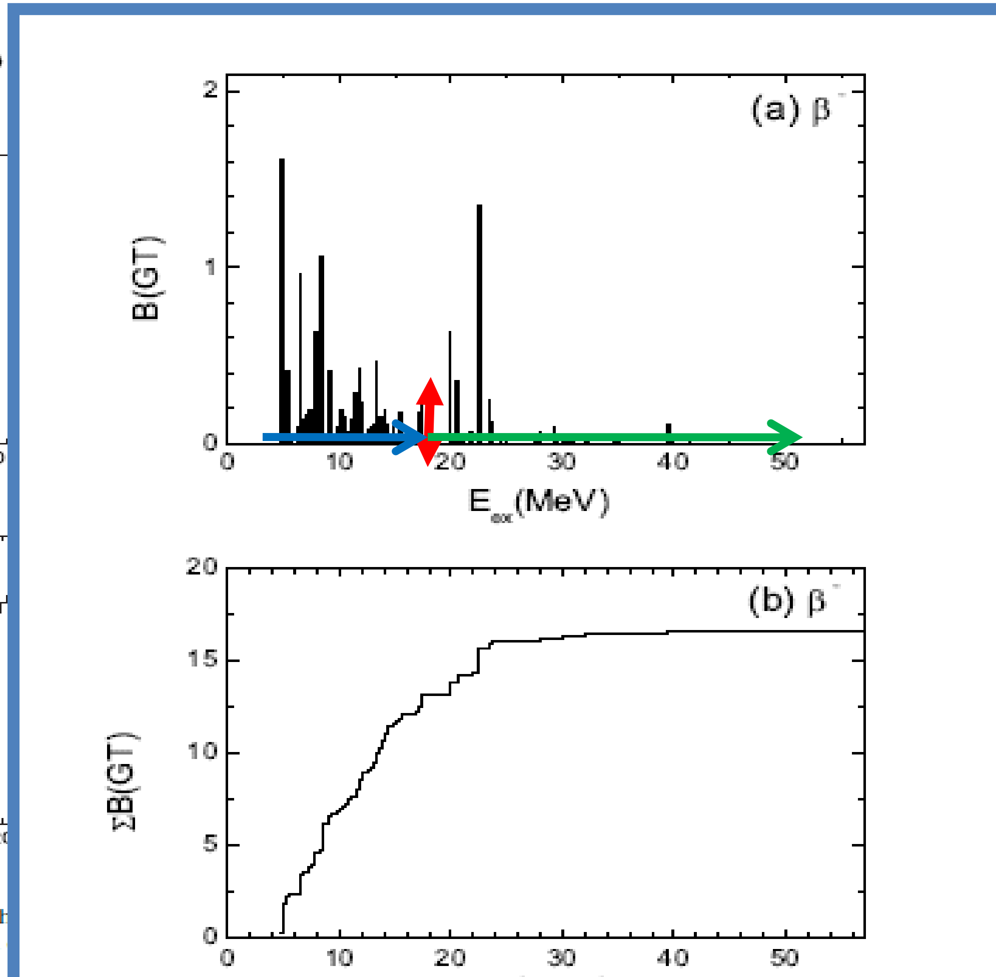
$$M_m(\mathrm{GT}^-) = \sum_{pn}\langle p||\sigma||n\rangle (X_m^{pn}u_p v_n + Y_m^{pn}v_p u_n),$$

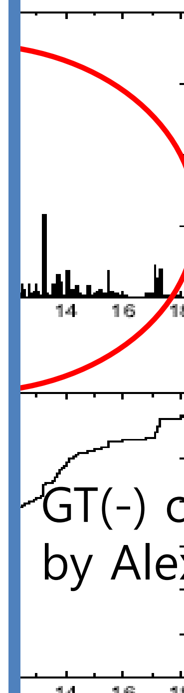
where

$$M_m(\mathrm{GT}^+) = -\sum_{pn}\langle p||\sigma||n\rangle \ldots$$

$$\ldots \tilde{a}_n]^{\Delta J} \ldots J+1 \ldots ||J_i^\pi\rangle.$$







GT(-) on Ar40
by Alex Brown

FIG. 2. The GT(−) strength
(b) as a function of the excited

Results for 40Ar

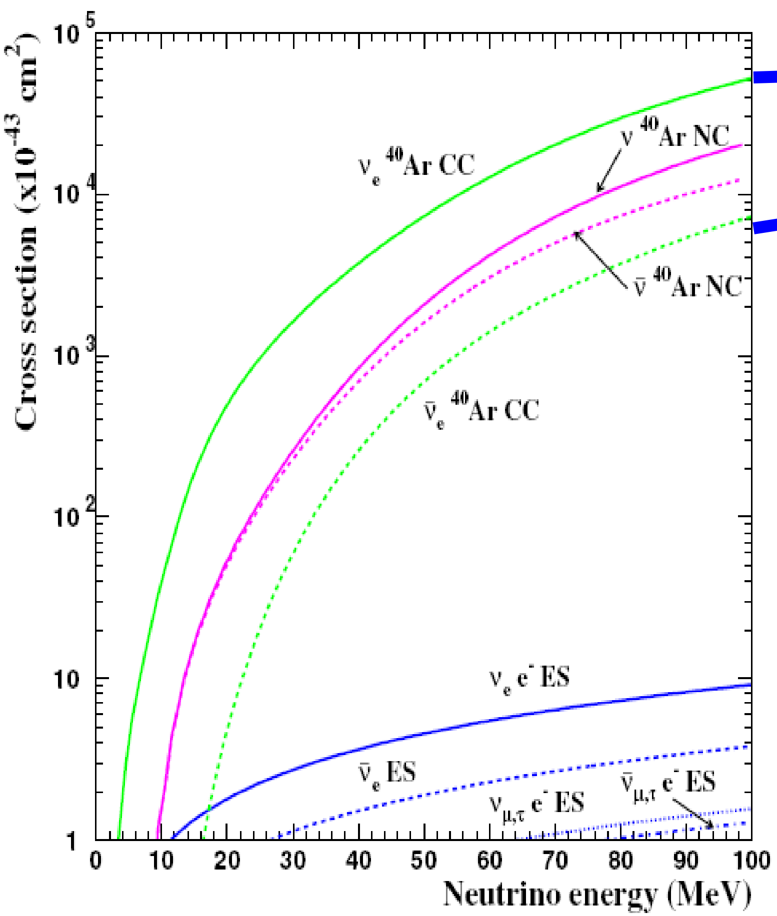
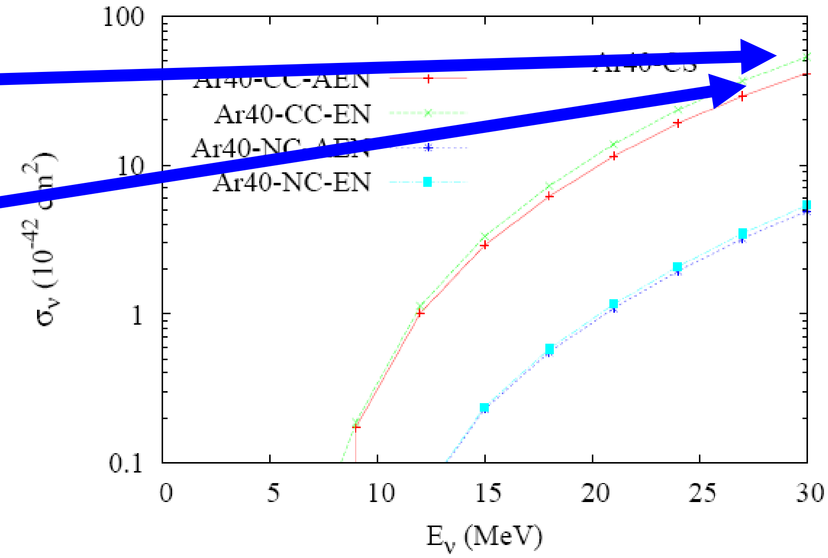
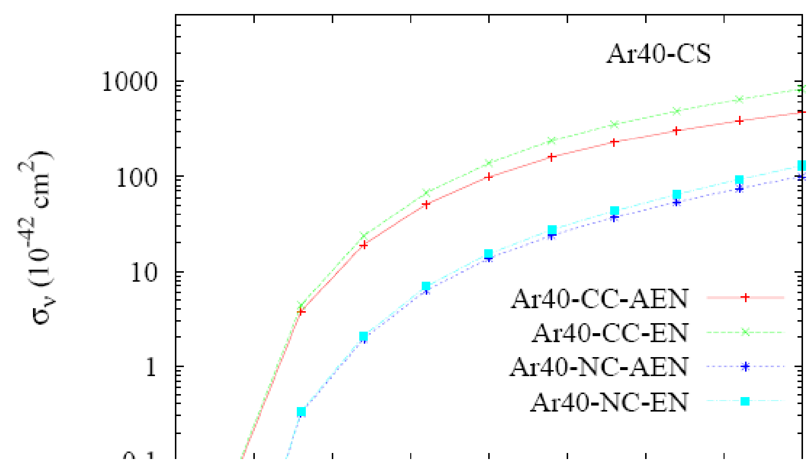


Figure 3. Neutrino cross sections relevant to the supernovae detection with a liquid argon TPC detector.





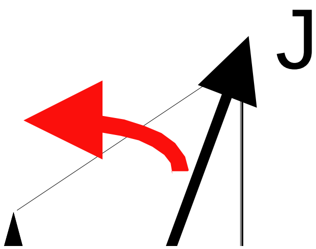
$$\sigma(E_\nu) = \frac{G_F^2 cos^2\theta_c}{\pi \hbar^4 c^3} \sum_i k_i \epsilon_i F(Z, \epsilon_i)[B_i(GT) + B_i(F)] \ , \qquad (8)$$

where k_i and ϵ_i refer to the momentum and total energy of the outgoing electron and $F(Z, \epsilon_i)$

Deformed QRPA From spherical basis to Nilsson basis

$$|\alpha\Omega_\alpha > = \sum B^\alpha_a |a\Omega_a > \qquad B^\alpha_a = \sum_{Nn_z\Sigma} C^{j\Omega_a}_{l\Lambda\frac{1}{2}\Sigma} A^{n_r l}_{Nn_z\Lambda}\, b_{Nn_z\Sigma}. \quad A^{n_r l}_{Nn_z\Lambda} =< n_r l\Lambda|Nn_z\Lambda >$$

$$|\alpha\bar{\beta} > = \sum_{abJ} F^{JK}_{\alpha a\beta b}|ab,\ JK > = \sum_J C^{JK}_{j_a\Omega_a j_b\Omega_b}|a\Omega_a > |b\Omega_b >, \text{ and } F^{JK}_{\alpha a\beta b} = B^\alpha_a\, B^\beta_b (-1)^{j_\beta-\Omega_\beta}\, C^{JK}_{j_a\Omega_a j_\beta-\Omega_\beta}$$

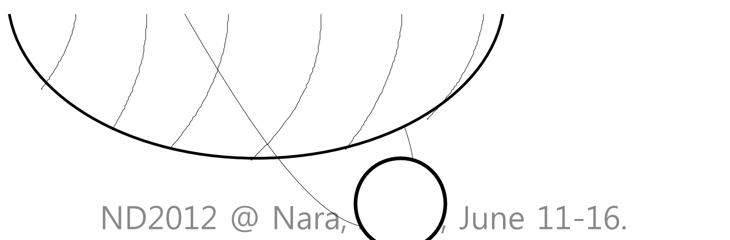


Normal-parity orbits;

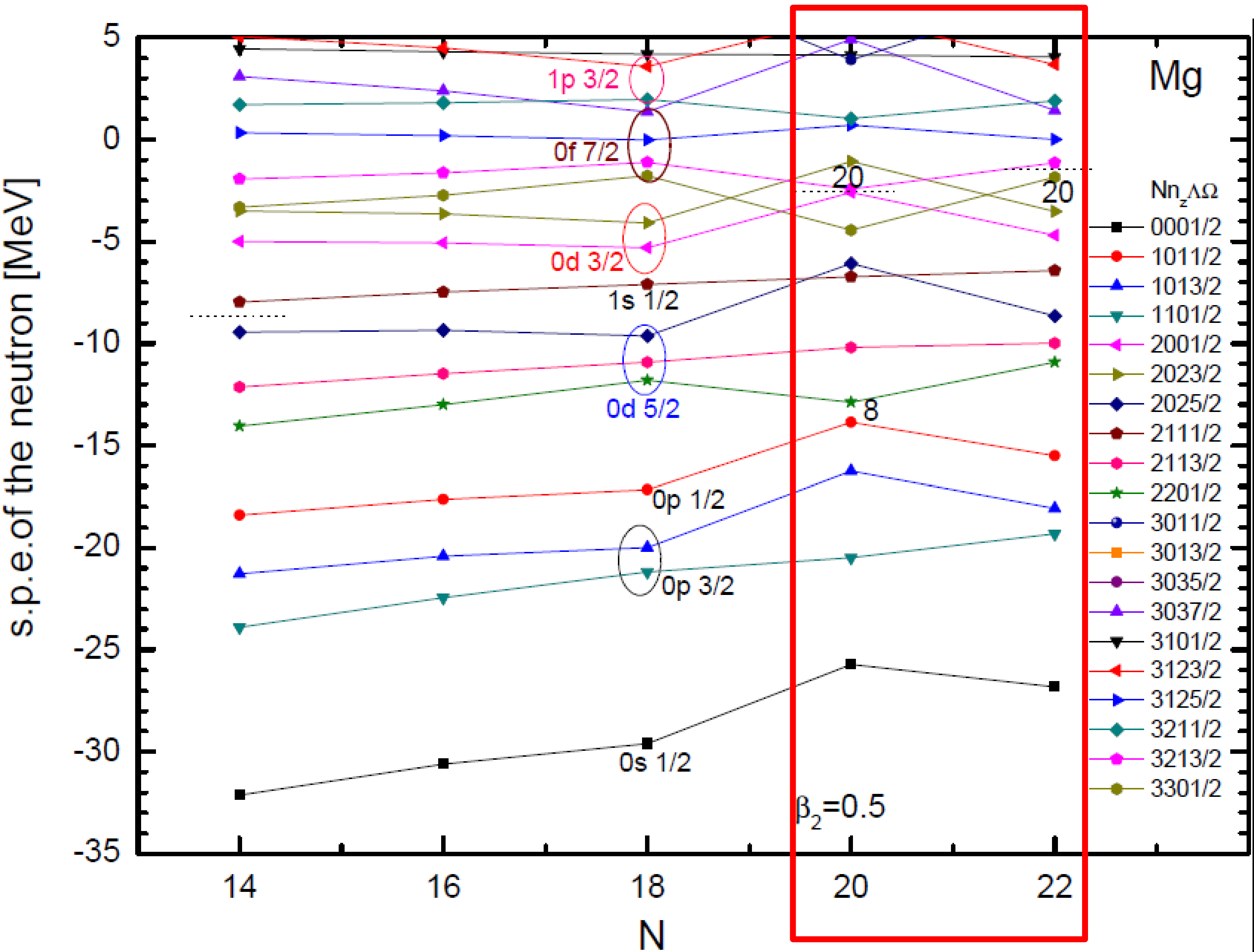
$|[411\ 3/2]> = 0.926\,|411\ 3/2> + \ldots$
$= 0.418\,|g_{9/2}> - 0.140\,|g_{7/2}> + 0.864\,|d_{5/2}> + 0.246\,|d_{3/2}>$

$|[411\ 1/2]> = 0.900\,|411\ 1/2> + \ldots$
$= -0.163\,|g_{9/2}> + 0.396\,|g_{7/2}> - 0.099\,|d_{5/2}> + 0.848\,|d_{3/2}> + 0.297|s_{1/2}>$

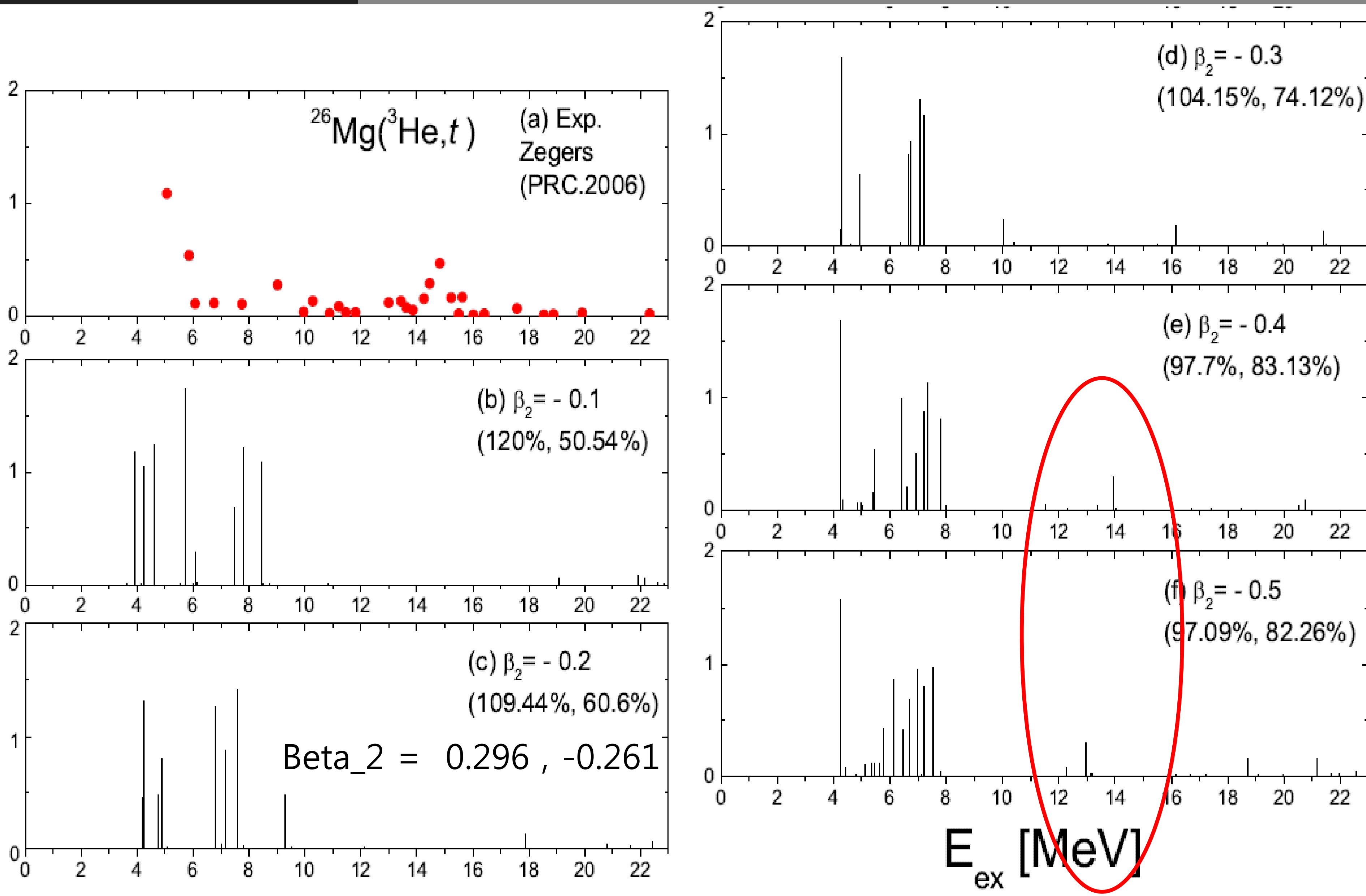
$|[400\ 1/2]> = 0.968\,|400\ 1/2> + \ldots$
$= 0.147\,|g_{9/2}> - 0.072\,|g_{7/2}> + 0.539\,|d_{5/2}> - 0.160\,|d_{3/2}> + 0.811\,|s_{1/2}>$



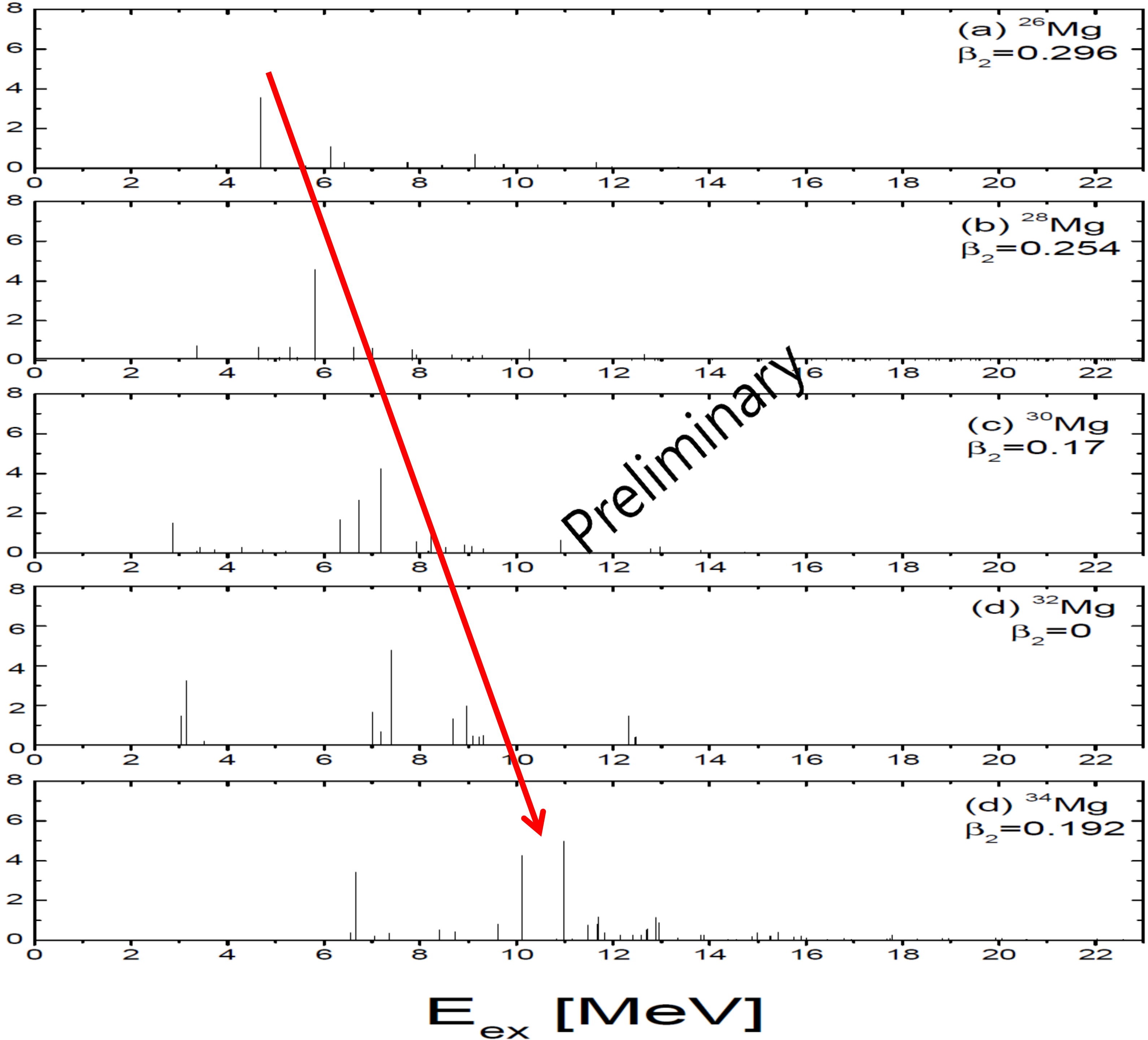
Deformed QRPA From spherical basis to Nilsson basis



Deformed QRPA GT strength distributions on 26 Mg

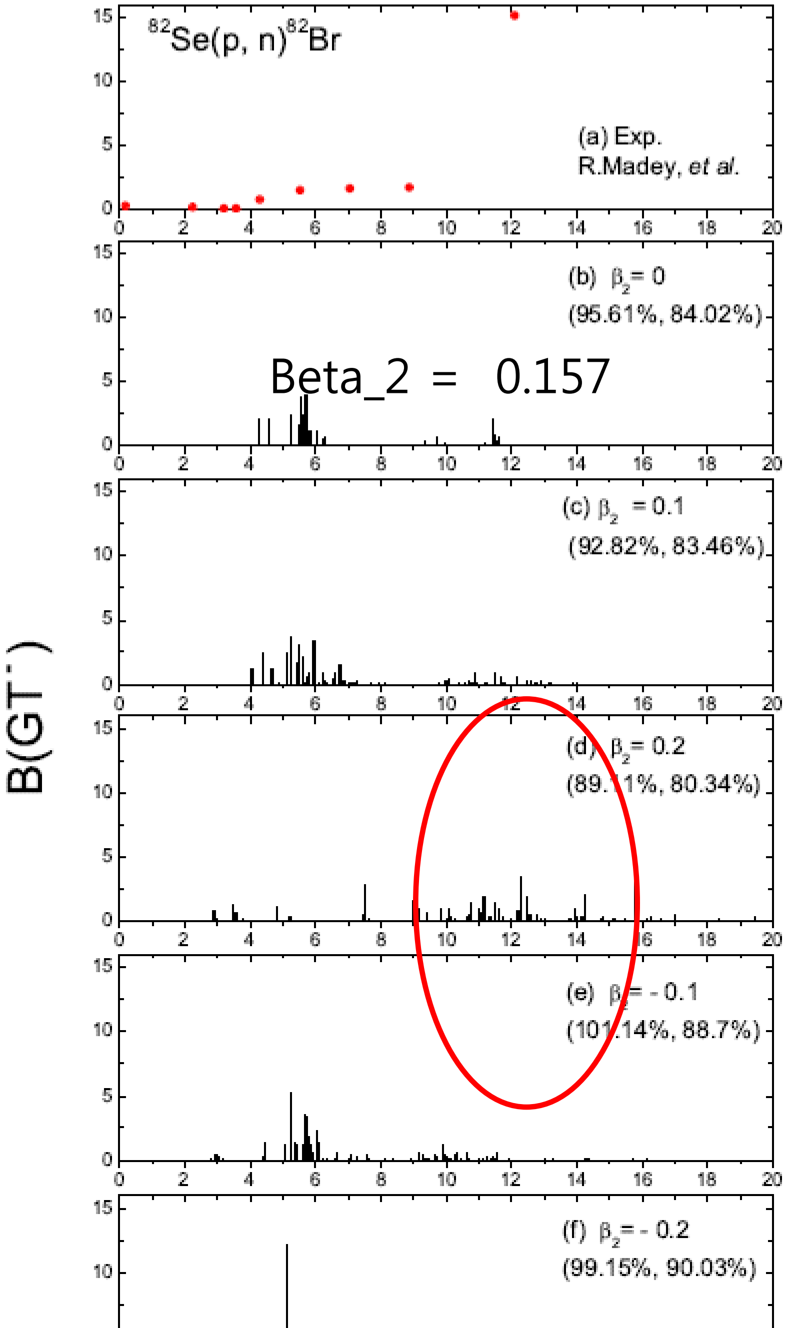


Beta_2 = 0.296 , -0.261

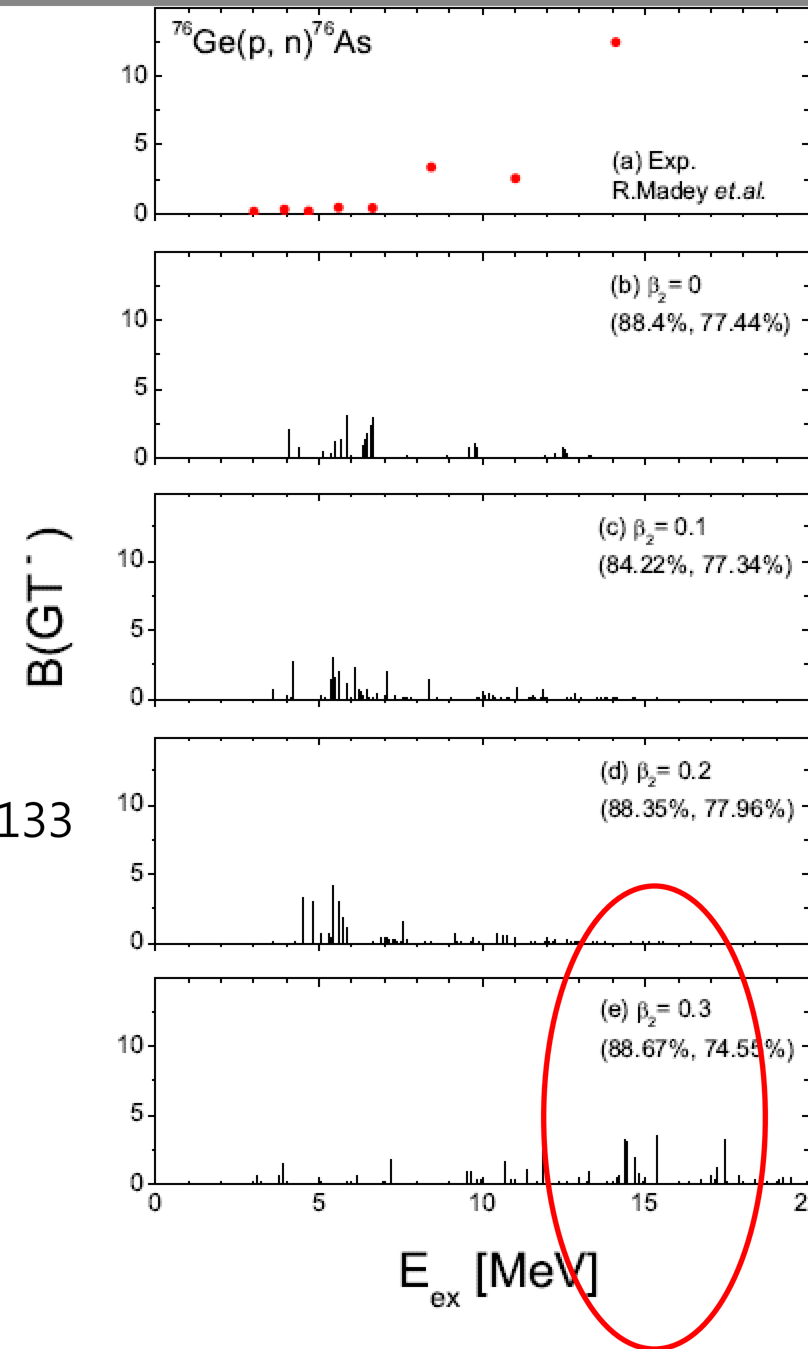


(a) 26Mg
β2=0.296
(b) 28Mg
β2=0.254
(c) 30Mg
β2=0.17
(d) 32Mg
β2=0
(d) 34Mg
β2=0.192
Preliminary
0 2 4 6 8 10 12 14 16 18 20 22
0 2 4 6 8
Eex [MeV]

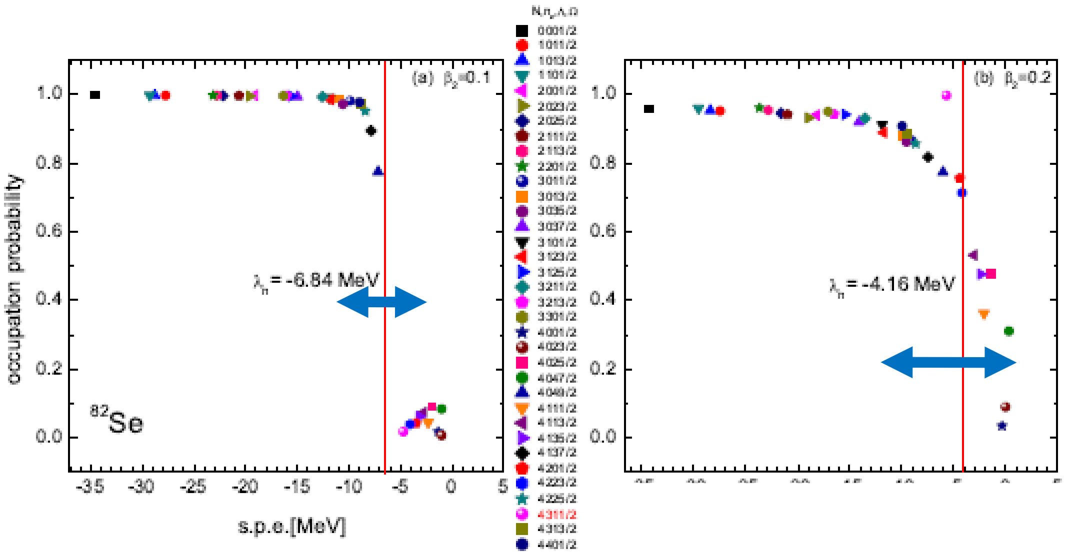
Deformed QRPA GT strength distributions on 76 Ge and 82 Se

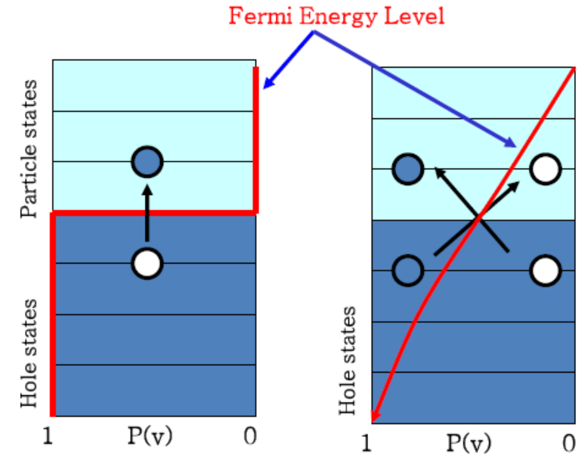


Beta_2 = 0.133

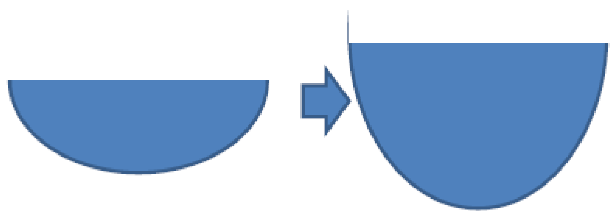


Deformed QRPA GT strength distributions on 76 Ge and 82 Se





Deformation ->



Fermi energy increase ->

Wide Fermi smearing ->

2p-2h mixing ->

High-lying GT excitation

FIG. 1: (Color online) Occupation probability of the neutron of ^{82}Se with two deformation parameters β_2 as a function of the single particle energy given as Nilsson basis.

High-lying excitations are intimately associated with the deformation !!

Summary

1. More data are necessary for understanding neutrino-induced reactions.
   DIF of pions or Beta beam neutrinos from RI are plausible sources of neutrinos on the lab. on Earth.

2. GT transitions are welcome because they dominate low energy X-section.
   In specific, RIB Facilities may greatly contribute to the CEX on the unstable nuclei.

3. Multi-pole transitions as well as GT should be considered !

4. Coulomb distortion beyond Fermi function for beta decay may work !

5. Contributions from higher energy tails, high-lying excited states beyond 1 nucleon threshold , also contribute .
   More CEX data beyond 1 nucleon threshold are necessary.

6. QRPA and DQRPA are quite useful for the nu-reaction description.