Low-energy Gamow-Teller state and T=0 pairing

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第十五届全国核结构大会

2014年10月 广西师范大学

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outline

- Introduction
- HFB+QRPA theory for open-shell nuclei
- Effects of T=0 pairing
- Constraint on T=0 pairing strength
- Collectivity of the low energy GT state
- Summary and outlook

Velocity-independent moments for Spin-Isospin excitation

$M^{\pm}_{\lambda\mu}(\rho V) = g_V \tau^{\pm} f(r) Y_{\lambda,\mu}\,,$ $\qquad$ $M^{\pm}_{\lambda\mu}(j_A, \kappa) = g_A \tau^{\pm} f(r) (Y_{\kappa}\sigma)_{\lambda\mu}$

Lowest allowed

$M^{\pm}_{0}(\rho_V) = g_V \tau^{\pm}$ → **Fermi 0+**

$M^{\pm}_{1\mu}(j_A, 0) = g_A \tau^{\pm} \sigma_{\mu}$ → **GT 1+**

First Forbidden

$M^{\pm}_{o}(j_A, 1) = g_A \tau^{\pm} r (Y_1 \sigma)_0$ → **SD 0-**

$M^{\pm}_{1\mu}(j_A, 1) = g_A \tau^{\pm} r (Y_1 \sigma)_{1\mu}$ → **SD 1-**

$M^{\pm}_{1\mu}(\rho_V) = g_V \tau^{\pm} Y_{1\mu}$ → **Dipole 1-**

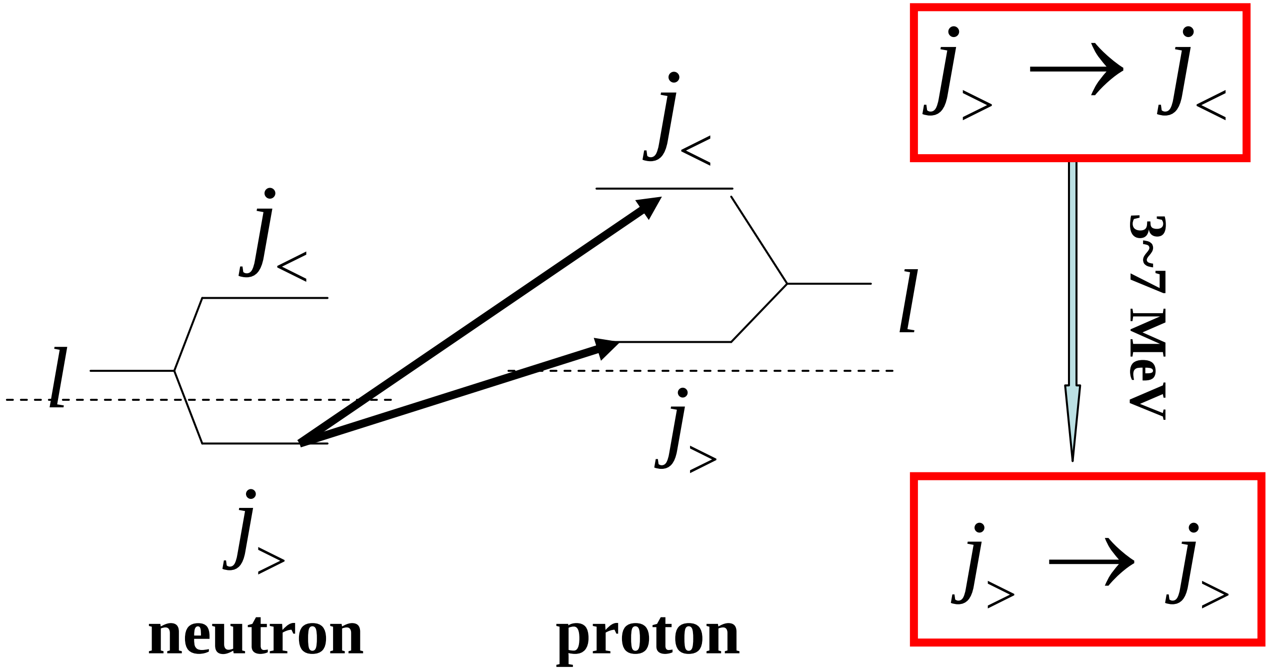
$M^{\pm}_{2\mu}(j_A, 1) = g_A \tau^{\pm} r (Y_1 \sigma)_{2\mu}$ → **SD 2-**

Simple figure for GT transition

$$O^{+}_{GT-} = \sum_{i=1}^{A} \vec{\sigma}_i t^{+}_{-}$$

(p,n) and (^{3}He,t)

$$\Delta S = 0, \Delta T = 1$$



$$O^{\nu +} = \sum_{np} X^{\nu}_{np} a^{+}_{p} a_{n} - \sum_{np} Y^{\nu}_{np} a^{+}_{n} a_{p}$$

Closed-shell RPA

$$O^{+}_{\nu} = \sum_{np} X^{\nu}_{np} \alpha^{+}_{p} \alpha^{+}_{n} - \sum_{np} Y^{\nu}_{np} \alpha_{n} \alpha_{p}$$

Open-shell QRPA

$$a^{+}_{k} = u_{k} \alpha^{+}_{k} + v_{k} \alpha_{\bar{k}}$$

Bogolyubov transformation

HFB+QRPA theory for open-shell nuclei I

HFB+pnQRPA in canonical basis

$$\begin{pmatrix} A & B \\ -B & -A \end{pmatrix}\begin{pmatrix} X \\ Y \end{pmatrix} = \Omega_{QRPA}\begin{pmatrix} X \\ Y \end{pmatrix}$$

Receive p-h contribution

$$A_{pn,pn} = E_{pp'}\delta_{nn'} + E_{nn'}\delta_{pp'} + V^{ph}_{pn,p'n'}(u_p v_n u_{p'} v_{n'} + v_p u_n v_{p'} u_{n'})$$
$$+ V^{pp}_{pn,p'n'}(u_p u_n u_{p'} u_{n'} + v_p v_n v_{p'} v_{n'})$$

$$B_{pn,p'n'} = V^{ph}_{pn,p'n'}(v_p u_n u_{p'} v_{n'} + u_p v_n v_{p'} u_{n'})$$
$$- V^{pp}_{pn,p'n'}\left(u_p u_n v_{p'} v_{n'} + v_p u_n u_{p'} u_{n'}\right)$$

Reveive p-p contribution

Transition strength:

$$B_\nu = \left|\sum_{pn}\left(X^\nu_{pn} u_p v_n + Y^\nu_{pn} v_p u_n\right)\left\langle p \left\| O^{+}_{-} \right\| n \right\rangle\right|^2$$

HFB+QRPA theory for open-shell nuclei I

HFB+pnQRPA in canonical basis

$$\begin{pmatrix} A & B \\ -B & -A \end{pmatrix}\begin{pmatrix} X \\ Y \end{pmatrix} = \Omega_{QRPA}\begin{pmatrix} X \\ Y \end{pmatrix}$$

$$A_{pn,pn} = E_{pp'}\delta_{nn'} + E_{nn'}\delta_{pp'} \;+ V^{ph}_{pn,p'n'}(u_p v_n u_{p'} v_{n'} + v_p u_n v_{p'} u_{n'})$$

$$+ V^{pp}_{pn,p'n'}(u_p u_n u_{p'} u_{n'} + v_p v_n v_{p'} v_{n'})$$

$$B_{pn,p'n'} = V^{ph}_{pn,p'n'}(v_p u_n u_{p'} v_{n'} + u_p v_n v_{p'} u_{n'})$$

$$- V^{pp}_{pn,p'n'}\left(u_p u_n v_{p'} v_{n'} + v_p v_n u_{p'} u_{n'}\right)$$

The single-particle states are obtained by HFB

J. Dobaczewski, et.al, NPA 422, 103(1984)

For more details of the theory one may refer to:

D.J.Rowe, nuclear collective motion

J. Terasaki. et. al, Phys. Rev. C 71, 034310(2005)

HFB+QRPA theory for open-shell nuclei II

Skyrme effective interactions

$$v_{Skyrme} = v_{central} + v_{LS} + v_{Tensor} + v_{Coulomb} + v_{pair}$$

The surface pairing interaction:

$$V_{T=1}(\mathbf{r}_1, \mathbf{r}_2) = V_0 \frac{1 - P_\sigma}{2} \left(1 - \frac{\rho(\mathbf{r})}{\rho_o}\right) \delta(\mathbf{r}_1 - \mathbf{r}_2),$$

$$V_{T=0}(\mathbf{r}_1, \mathbf{r}_2) = f V_0 \frac{1 + P_\sigma}{2} \left(1 - \frac{\rho(\mathbf{r})}{\rho_o}\right) \delta(\mathbf{r}_1 - \mathbf{r}_2)$$

The strength of T=1 pairing is determined to fit the pairing gap.

The strength of the T=0 pairing is not yet determined, so f is treated as a free Parameter at present.

Effect of T=0 pairing (as I know)

ground state Binding energy

p-n scattering

G.F. Bertsch, et al., Ann. Phy. 209, 327(1991)

H. Esbensen, et al., PRC 56, 3054(1997)

E. Garrido, et al., PRC 60, 064312(1999)

E. Garrido, et al., PRC 63, 037304(2003)

Excited state

β and 2 β decay

Neutron rich case

J. Engel, et. al. PRC 60, 014320(1999)

T. Niksic, et. al. PRC 71, 014308(2005)

F. Minato, et al., PRC 80, 047301(2009)

Niu, et al, PLB(2013)

Y.J. Ren, and Z.Z.Ren, 89, 064603(2014)

Song, Yao, et al

J. suhonen, et al., Phys. Rep 300, 123(1998)

Calculation of GT type β –decay half-life

$$\frac{1}{t_{1/2}} = \frac{g_A^2}{D} \int dE_e \sum_m \left| \langle 1_m^+ | \sum_i^A \boldsymbol{\sigma}_i \tau_i^- | 0^+ \rangle \right|^2 \frac{dn_m}{dE_e},$$

$$\frac{dn_m}{dE_e} = \frac{E_e \sqrt{E_e^2 - m_e^2}}{2\pi^3} (E_i - E_{1_m^+} - E_e)^2 F(Z, E_e),$$

$$F_0(Z, \epsilon) = 4(2p_l R)^{2(\gamma-1)} \left| \frac{\Gamma(\gamma+iy)}{\Gamma(2\gamma+1)} \right|^2 e^{\pi \cdot y}$$

with $\gamma = \sqrt{1 - (\alpha Z)^2}$, $y = \alpha Z \frac{\epsilon}{p_l}$

Calculation of GT type β –decay half-life

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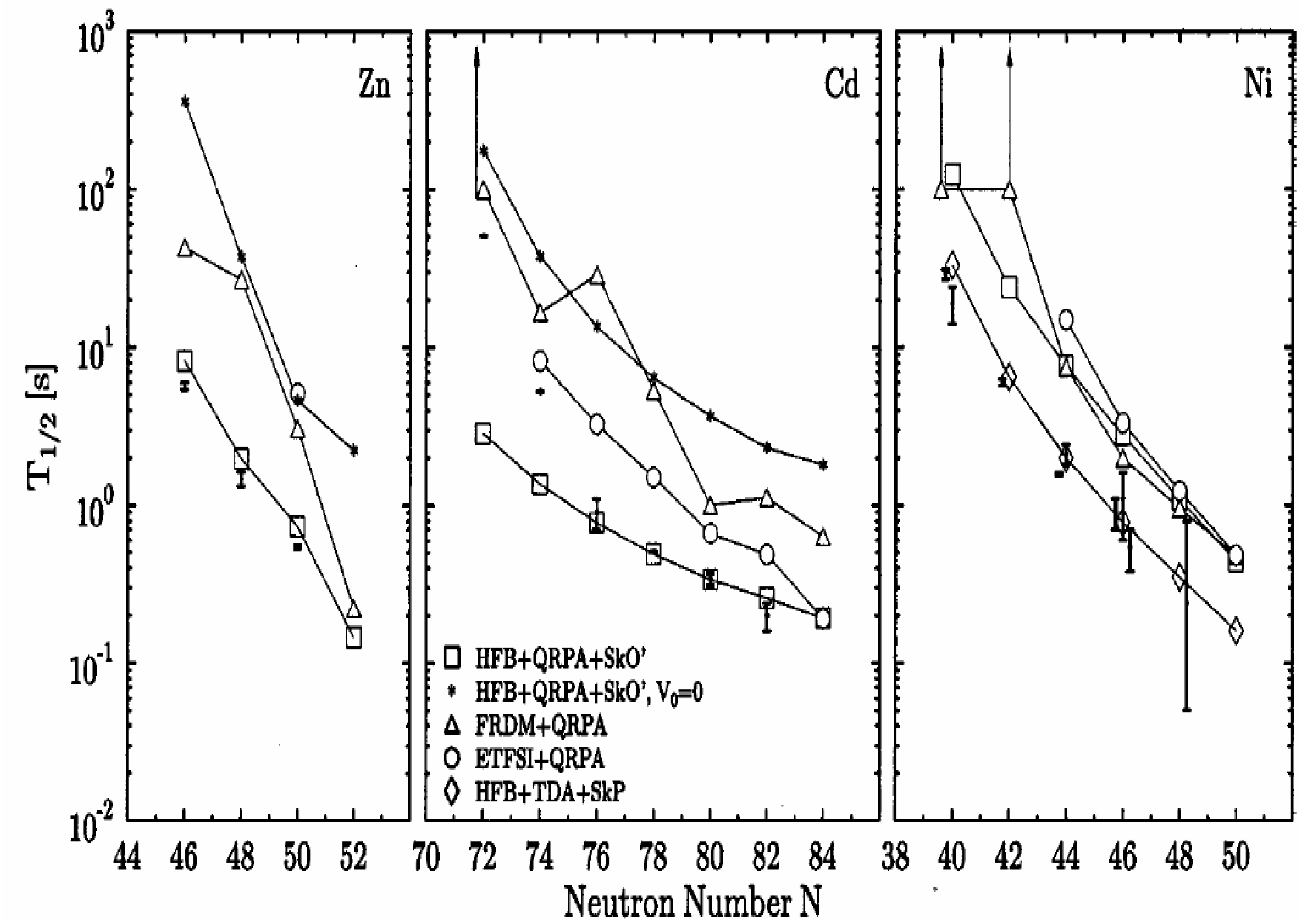
with $\gamma = \sqrt{1-(\alpha Z)^2}, y = \alpha Z \frac{\epsilon}{p_l}$

$$\boxed{T_{1/2}^{-1} \sim E^5}$$

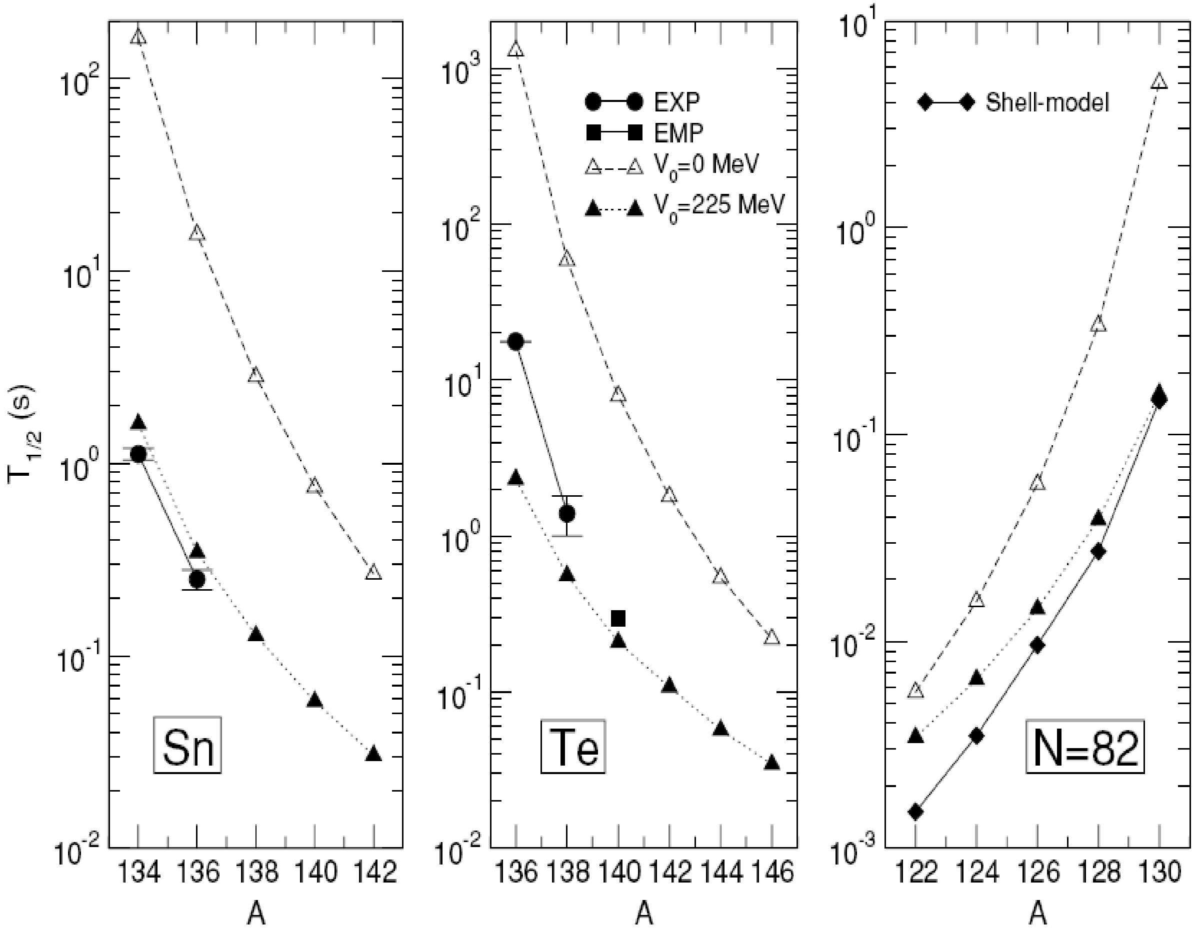
Role of T=0 pairing on β -decay of open-shell nuclei



J. Engel, et. Al. Phys. Rev. C 60, 014320(1999)

T=0 pairing is used
in QRPA Calculation with
Skyrme force.

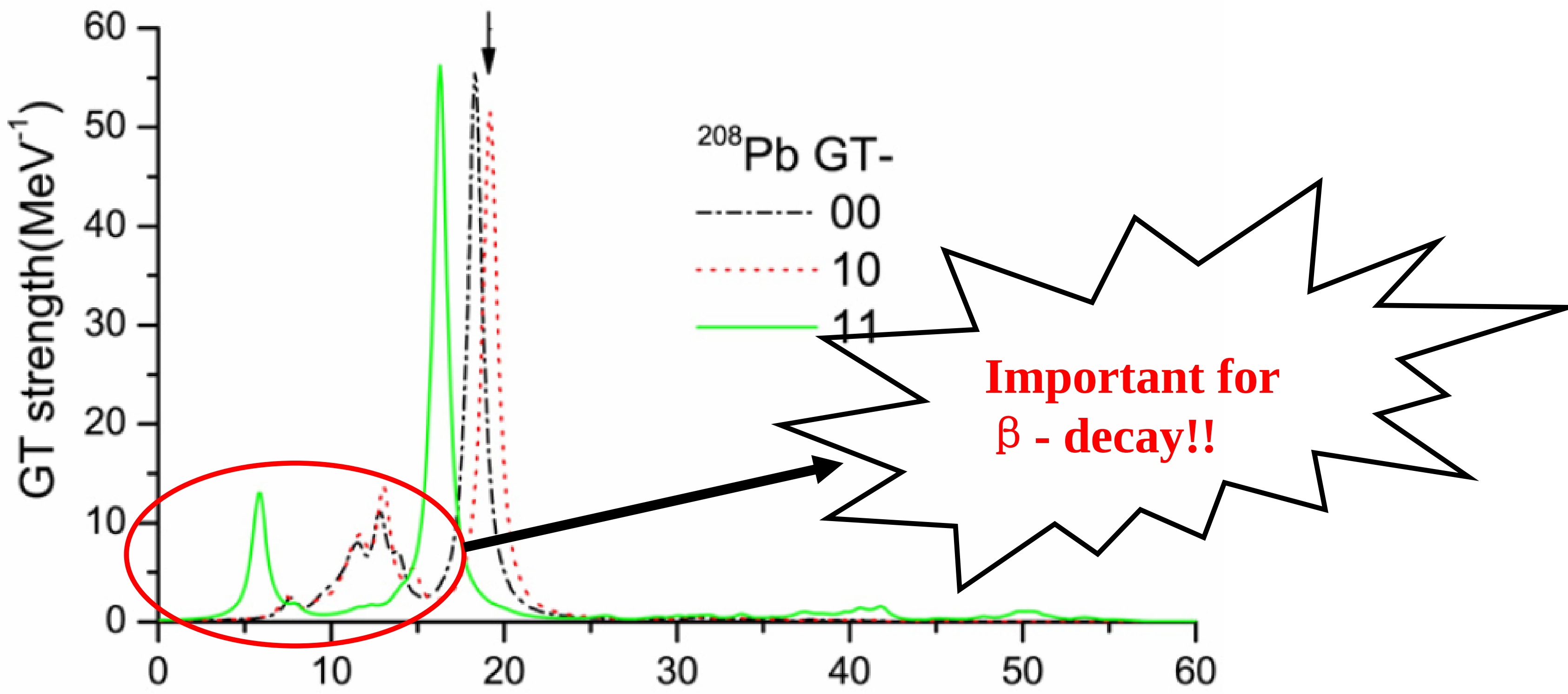
Role of T=0 pairing on β -decay of open-shell nuclei



T=0 pairing is used In relativistic QRPA Calculations.

T. Niksic, et. al. Phys. Rev. C 71, 014308(2005)

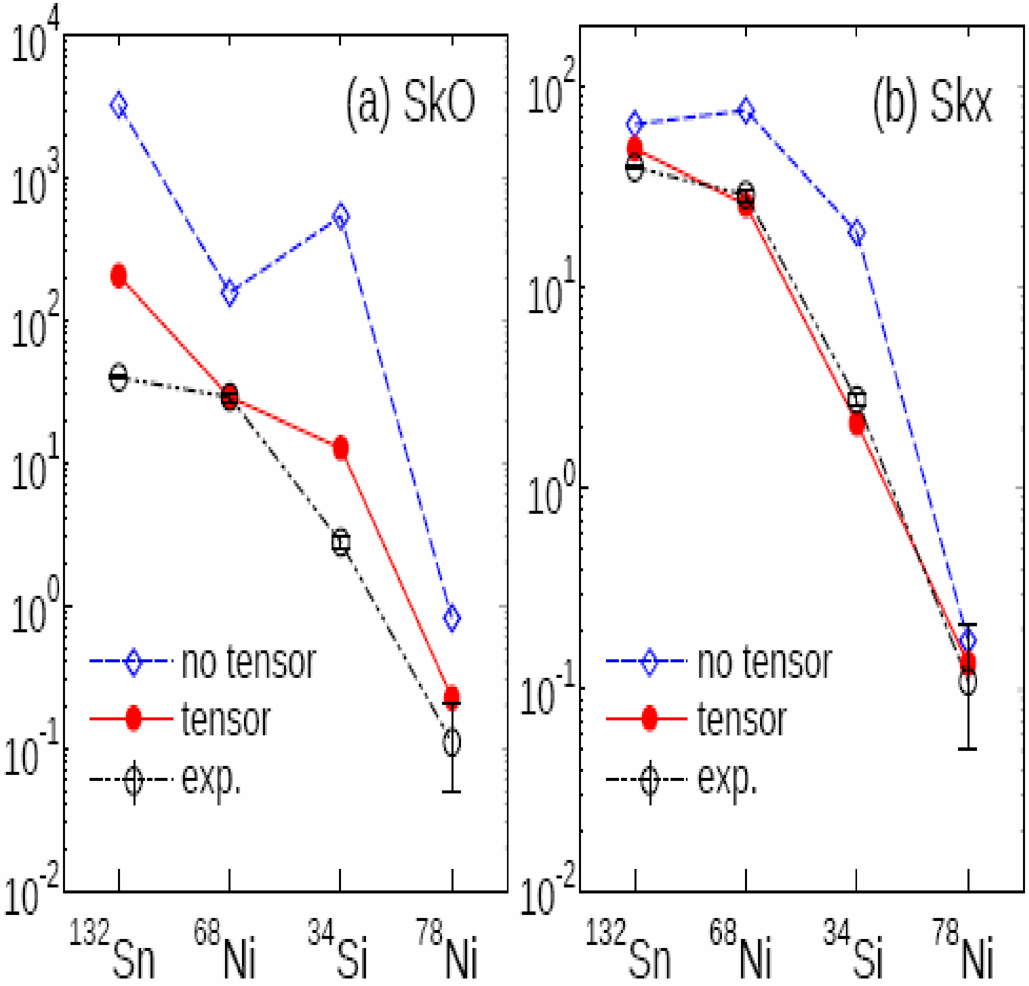
Tensor effects on low energy GT states in nuclei with neutron excess



Important for β - decay!!

Bai , Sagawa, Zhang, Zhang, Colò, Xu, Phys. Lett. B675, 28(2009)

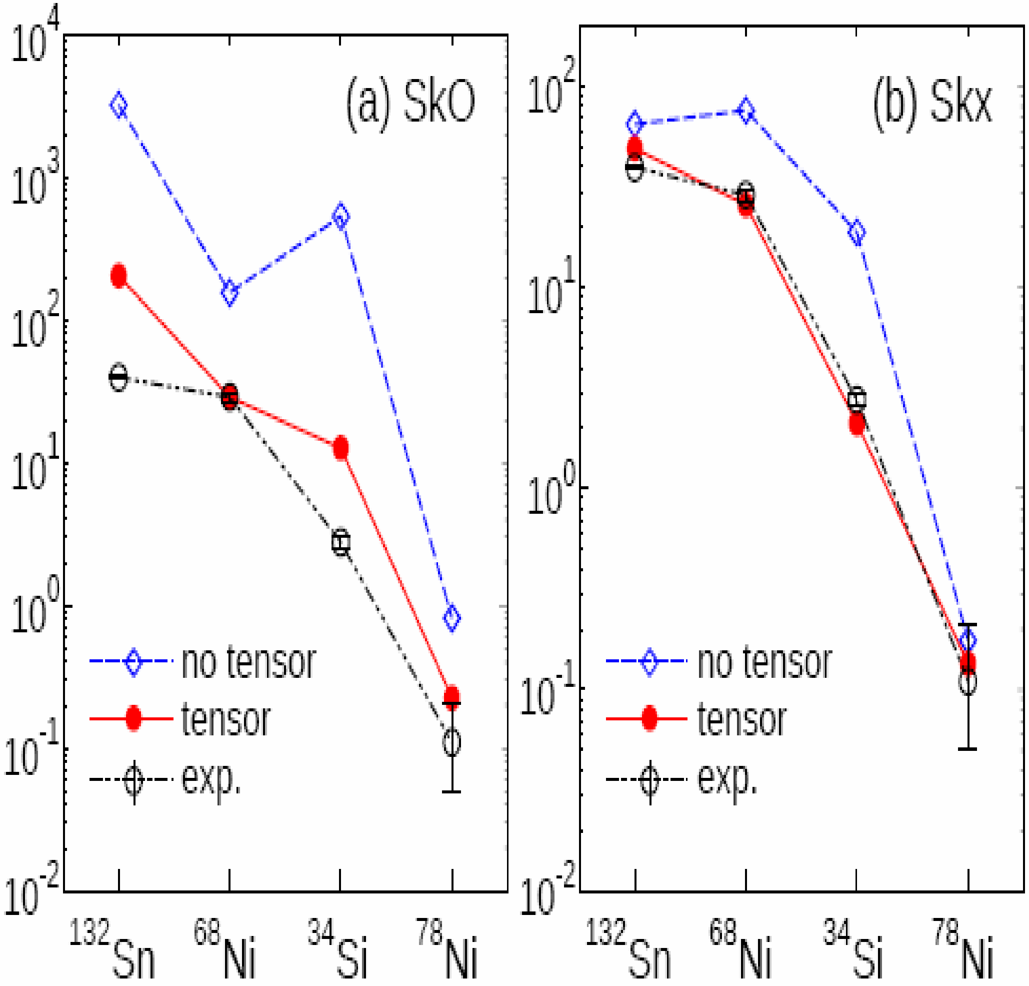
β -decay half-life in closed-shell nuclei



Tensor RPA correlations improve the β -decay half-life calculations in closed-shell nuclei.

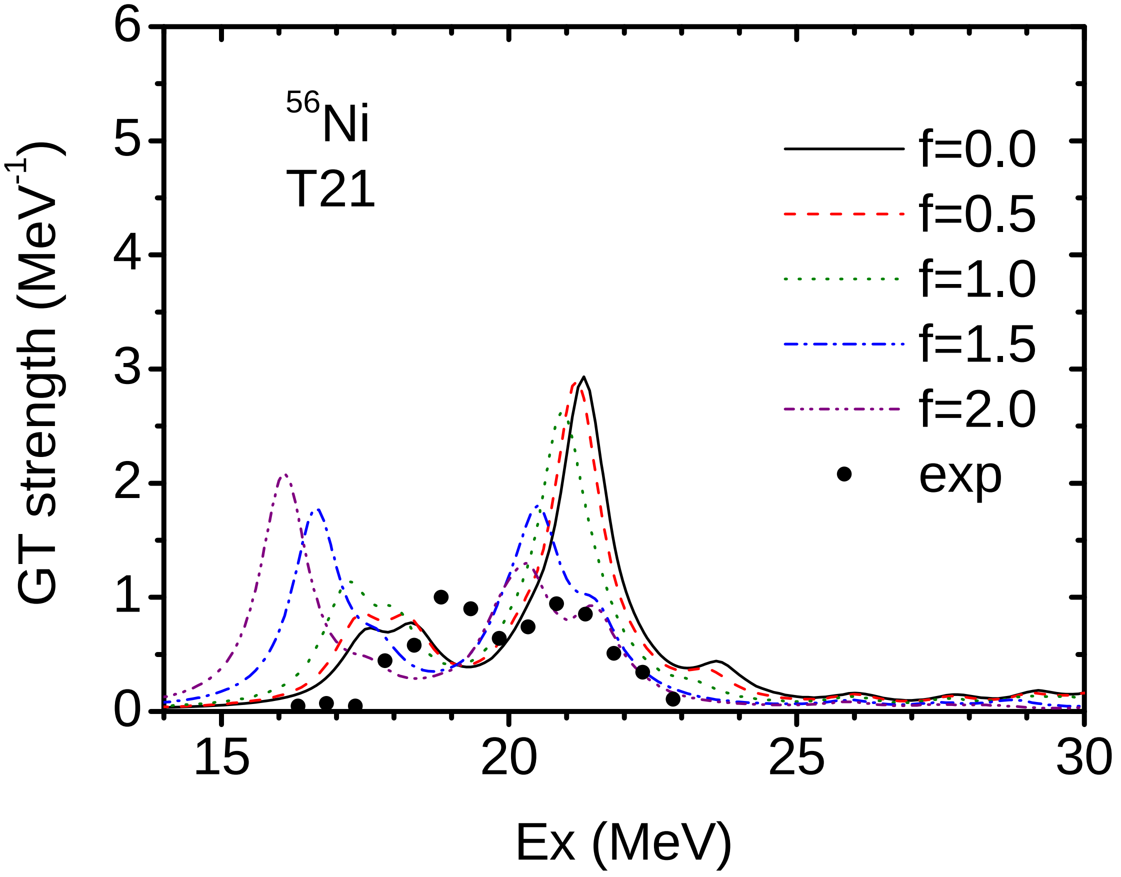
F. Minato and C. L. Bai, Phys. Rev. Lett 110, 122501(2013)

β -decay half-life in closed-shell nuclei



If it is proper to constrain T=0 pairing strength indirectly through β-decay half-life when tensor force is not fixed?

Isoscalar pairing in GT excitations of N=Z nuclei



Bai, Sagawa, Sasano, Uesaka, Hagino, Zhang, Zhang, Xu, PLB 719, 116(2013)

Exp. Data from: M. Sasano, et al., Phys. Rev. Lett. 107, 202501 (2011)

- **When T=0 pairing is small, the strength is almost concentrated in one peak;**
- **When T=0 pairing increased, the strength in low energy peak enhanced dramatically.**

PRL 112, 112502 (2014) PHYSICAL REVIEW LETTERS week ending 21 MARCH 2014

Observation of Low- and High-Energy Gamow-Teller Phonon Excitations in Nuclei

Y. Fujita,[1,2,†] H. Fujita,[1] T. Adachi,[1] C. L. Bai,[3] A. Algora,[4,5] G. P. A. Berg,[6] P. von Brentano,[7] G. Colò,[8] M. Csatlós,[5]
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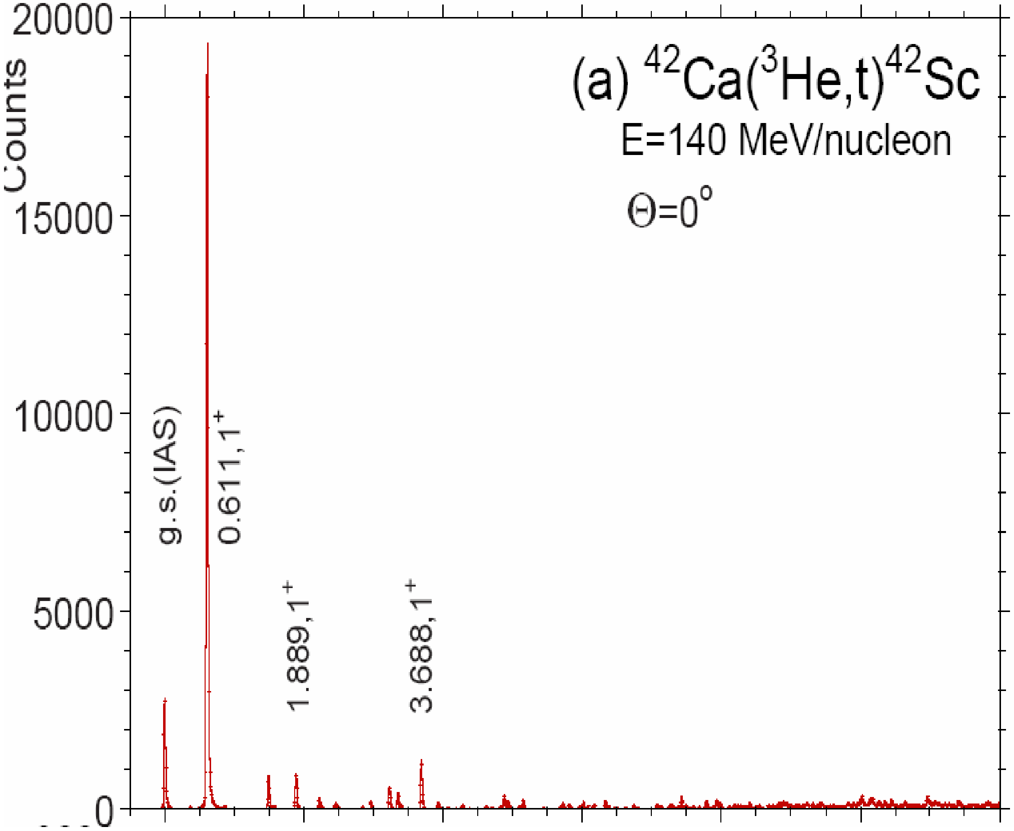
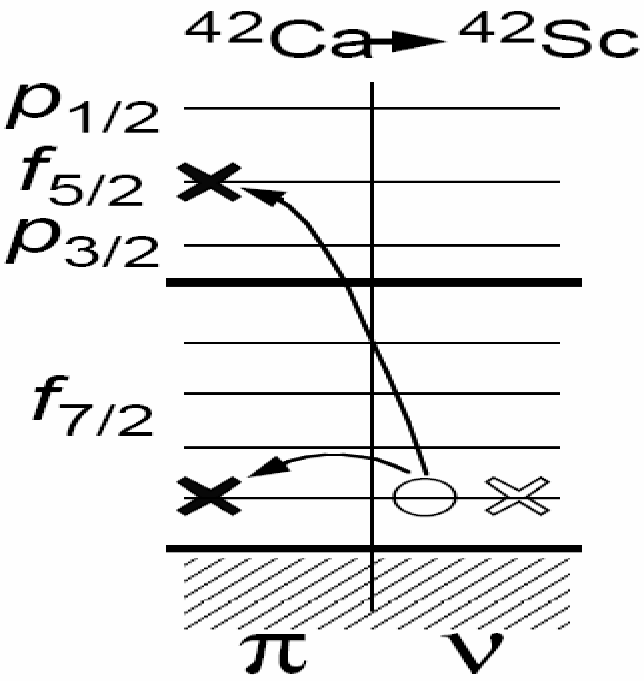
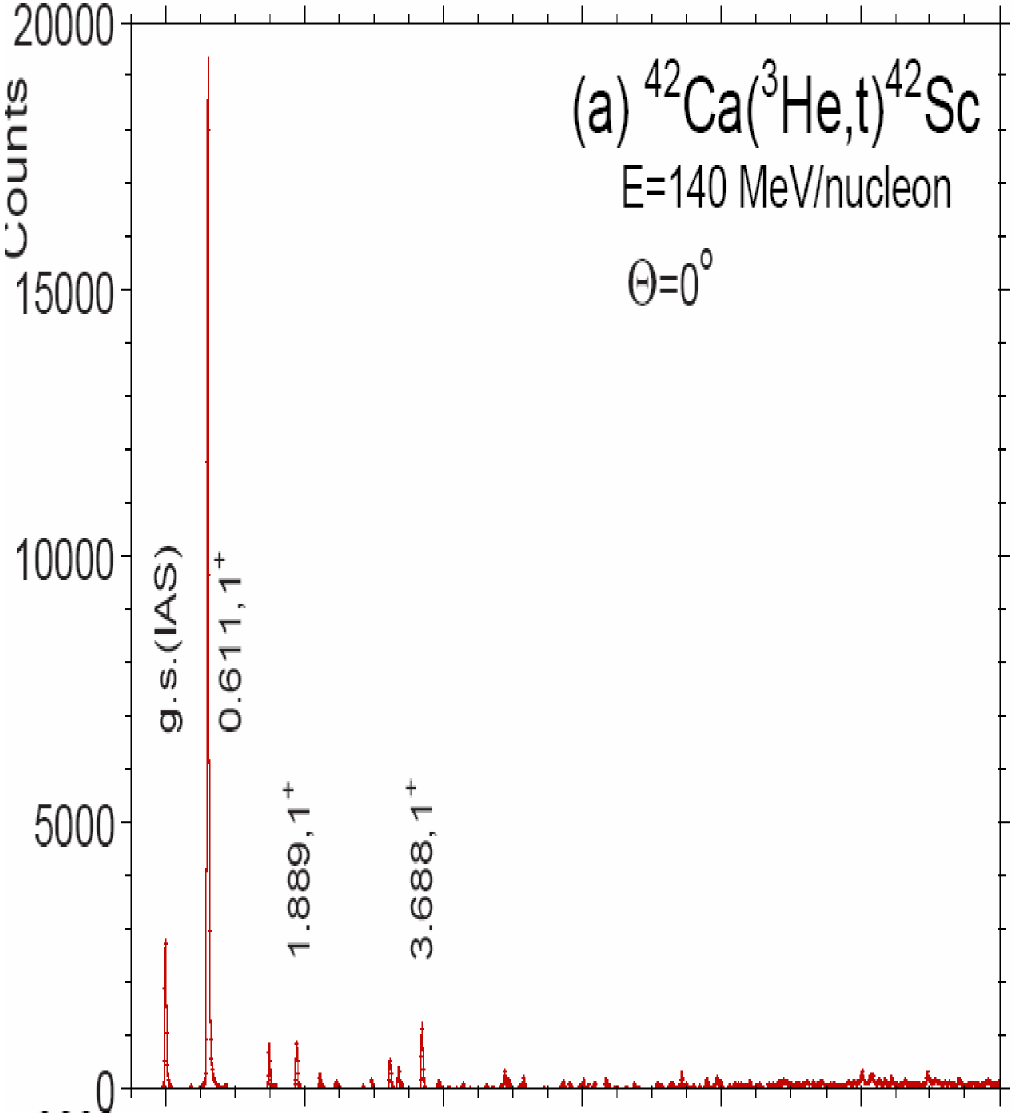
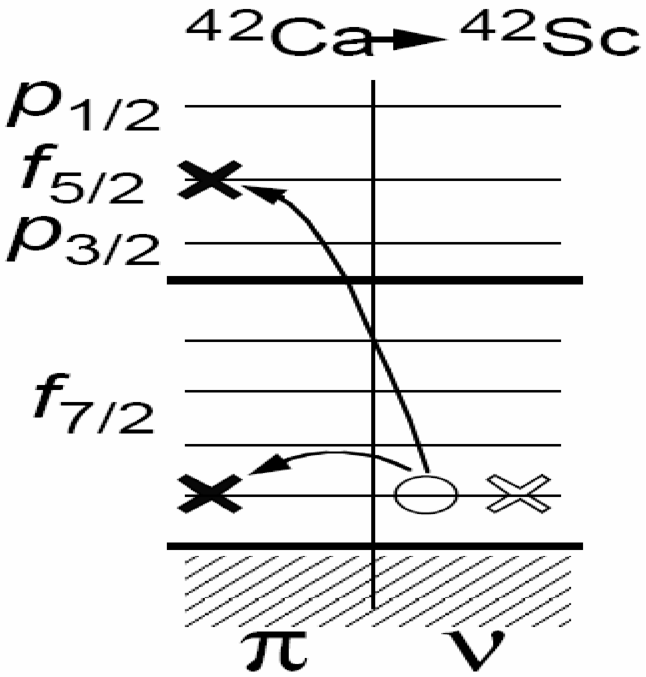
K. Hatanaka,[1] K. Hirota,[1] M. Honma,[12] D. Ishikawa,[1] E. Jacobs,[10] A. Krasznahorkay,[5] H. Matsubara,[1,§]
K. Matsuyanagi,[13,14] R. Meharchand,[9,∥] F. Molina,[4,¶] K. Muto,[15] K. Nakanishi,[1,**] A. Negret,[16] H. Okamura,[1,*] H. J. Ong,[1]
T. Otsuka,[17] N. Pietralla,[7,††] G. Perdikakis,[9,18] L. Popescu,[19] B. Rubio,[4] H. Sagawa,[12,13] P. Sarriguren,[20] C. Scholl,[7,‡‡]
Y. Shimbara,[21,§§] Y. Shimizu,[1,∥∥] G. Susoy,[11] T. Suzuki,[1] Y. Tameshige,[1] A. Tamii,[1] J. H. Thies,[22] M. Uchida,[1] T. Wakasa,[1,¶¶]
M. Yosoi,[1] R. G. T. Zegers,[9] K. O. Zell,[7] and J. Zenihiro[1,∥∥]





Low-energy Super GT states in N=Z+2 nuclei





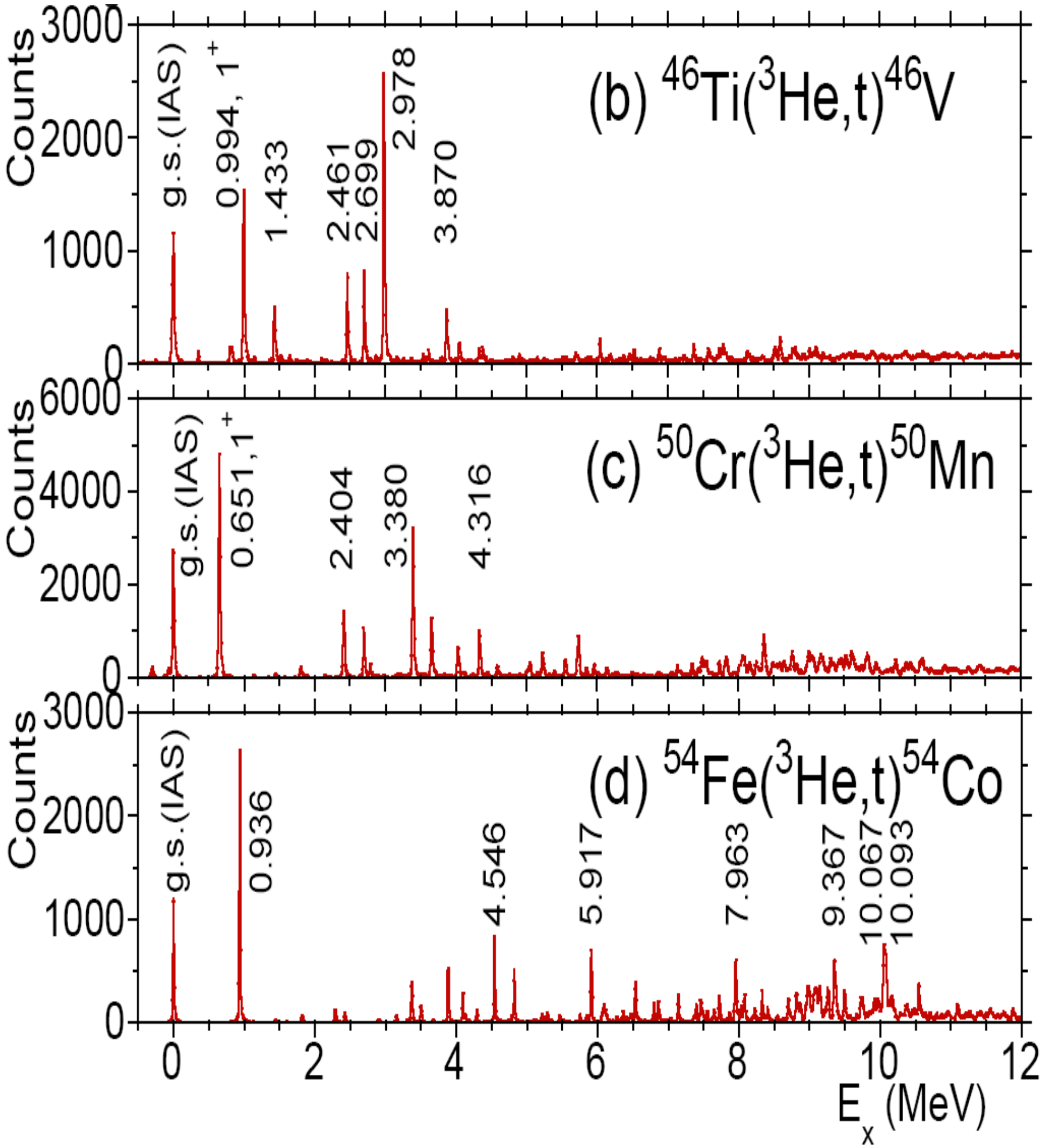
p-h channel:

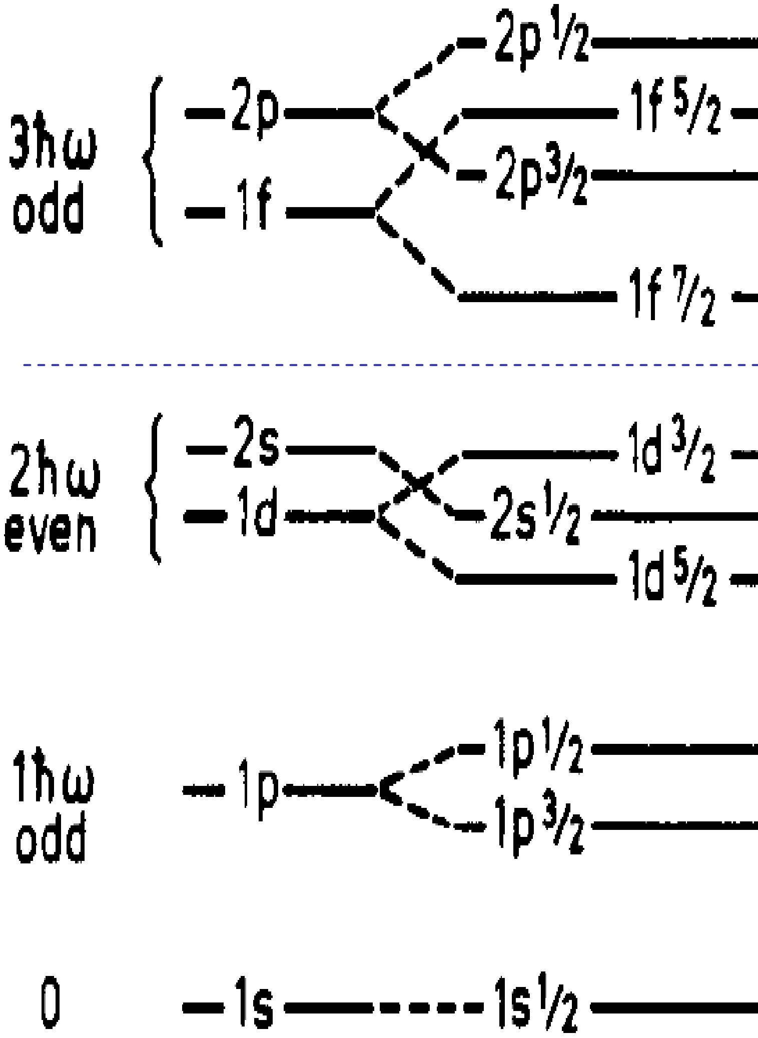
$$u_p^2\left(j_<\right)\times v_n^2\left(j_>\right)\simeq 1\times 0.25$$

p-p channel:

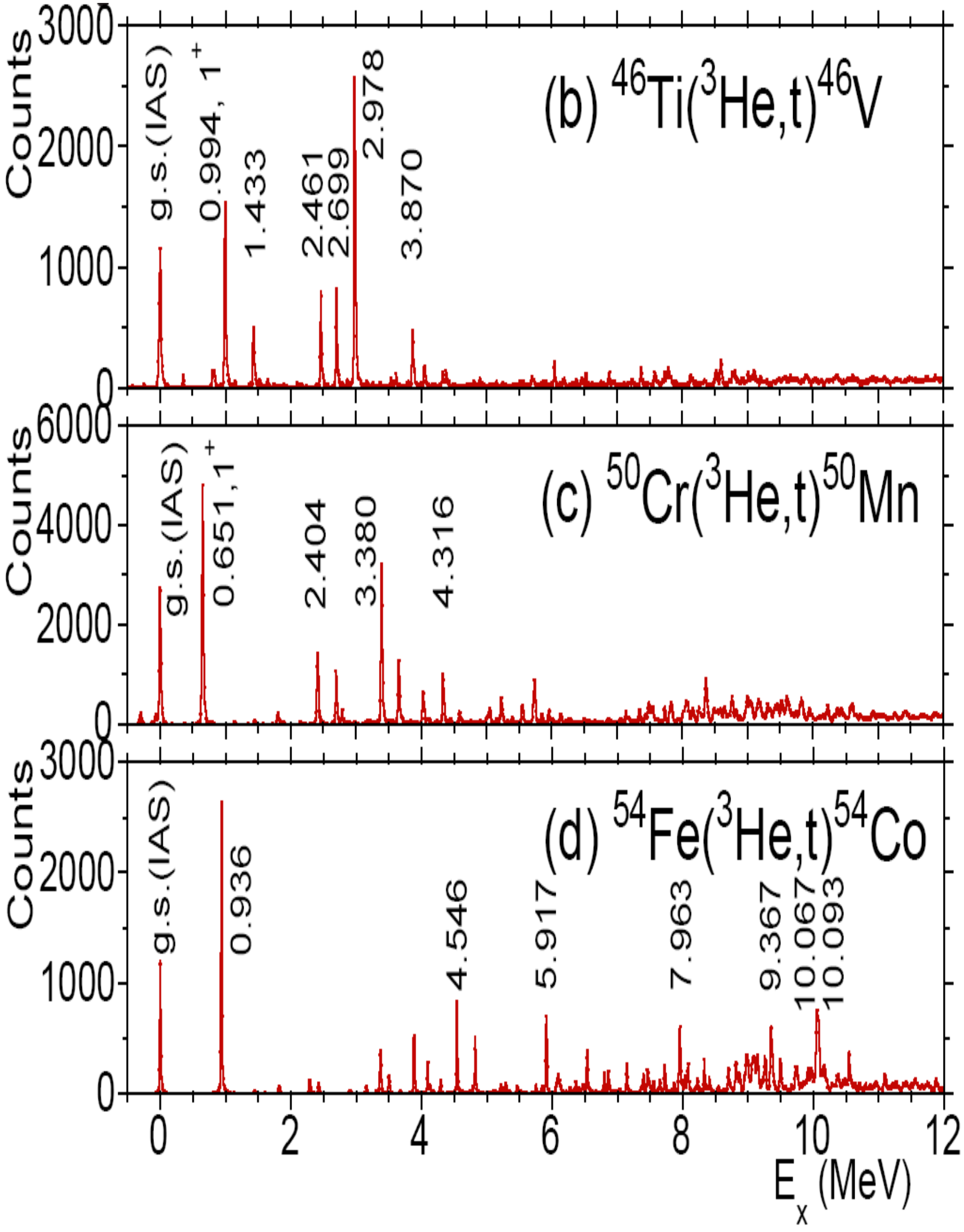
$$u_p^2\left(j_>\right)\times u_n^2\left(j_>\right)\simeq 1\times 0.75$$

Y. Fujita, et.al, PRL Y. Fujita et al., Phys. Rev. Lett. 112, 112502 (2014).





Y. Fujita, et.al, PRL Y. Fujita et al., Phys. Rev. Lett. 112, 112502 (2014).



$$u_{p<}^2 \times v_{n>}^2 \approx 1 \times 0.5$$

$$u_{p>}^2 \times u_{n>}^2 + v_{p>}^2 \times v_{n>}^2$$
$$\approx 0.75 \times 0.5 + 0.25 \times 0.5 = 0.5$$

$$u_{p<}^2 \times v_{n>}^2 \approx 1 \times 0.75$$

$$u_{p>}^2 \times u_{n>}^2 + v_{p>}^2 \times v_{n>}^2$$
$$\approx 0.5 \times 0.25 + 0.5 \times 0.75 = 0.5$$

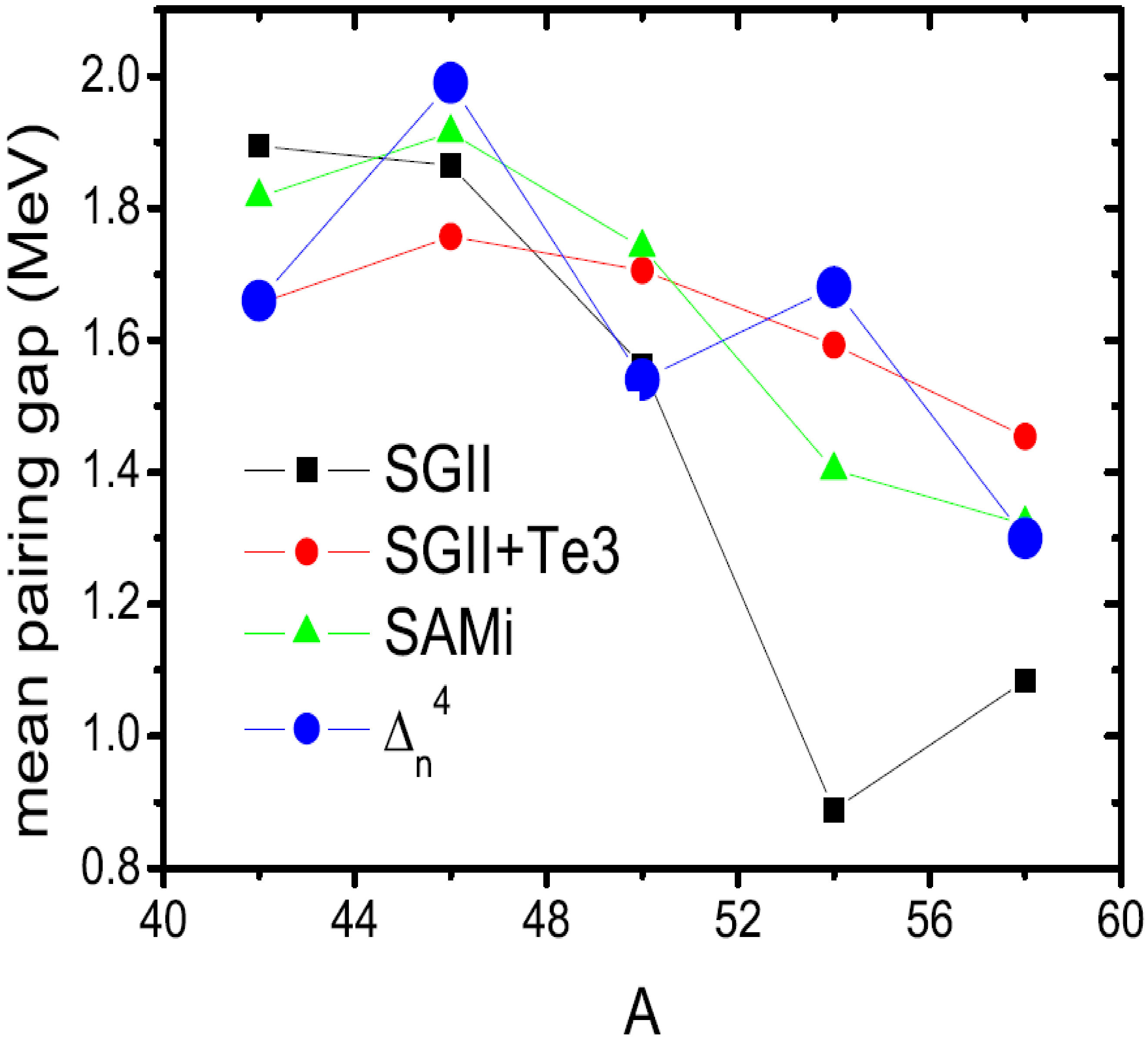
$$u_{p<}^2 \times v_{n>}^2 \approx 1 \times 1$$

$$v_{p>}^2 \times v_{n>}^2 \approx 0.75 \times 1 = 0.75$$

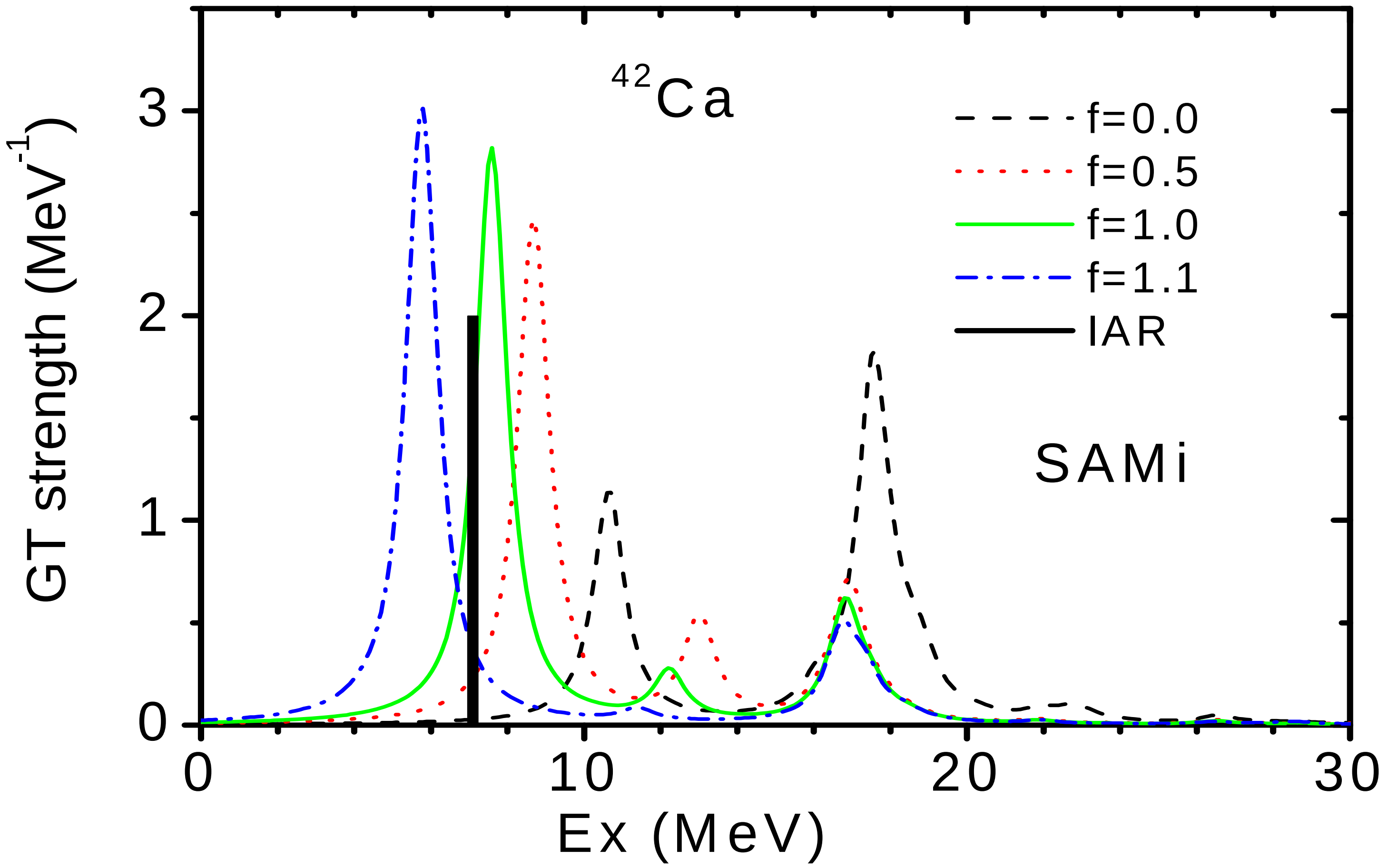
Approximation that nucleons Occupy from the lowest level.

Y. Fujita, et.al, PRL Y. Fujita et al., Phys. Rev. Lett. 112, 112502 (2014).

T=1 pairing strength

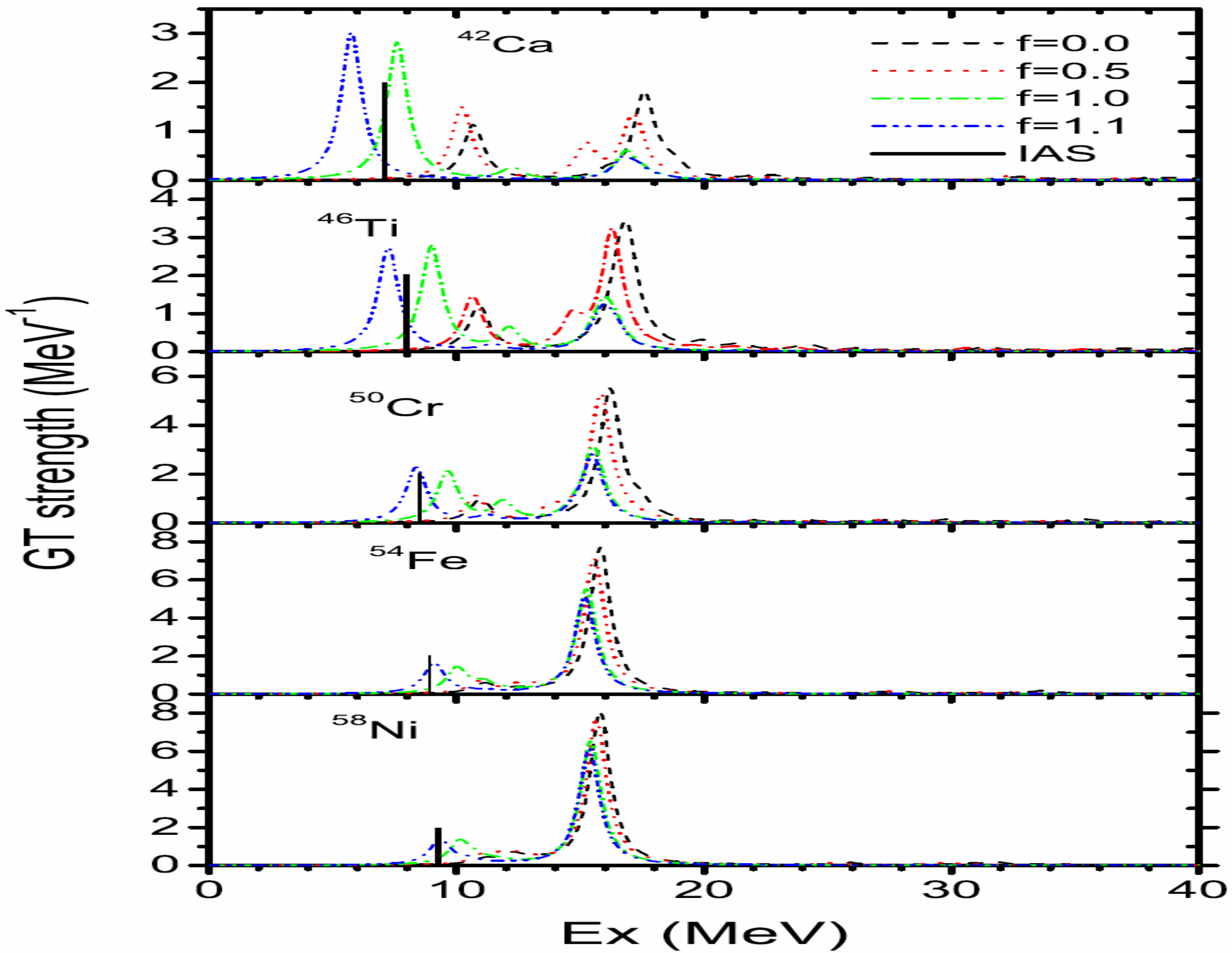


Strong GT states in low energy of N=Z+2 nuclei

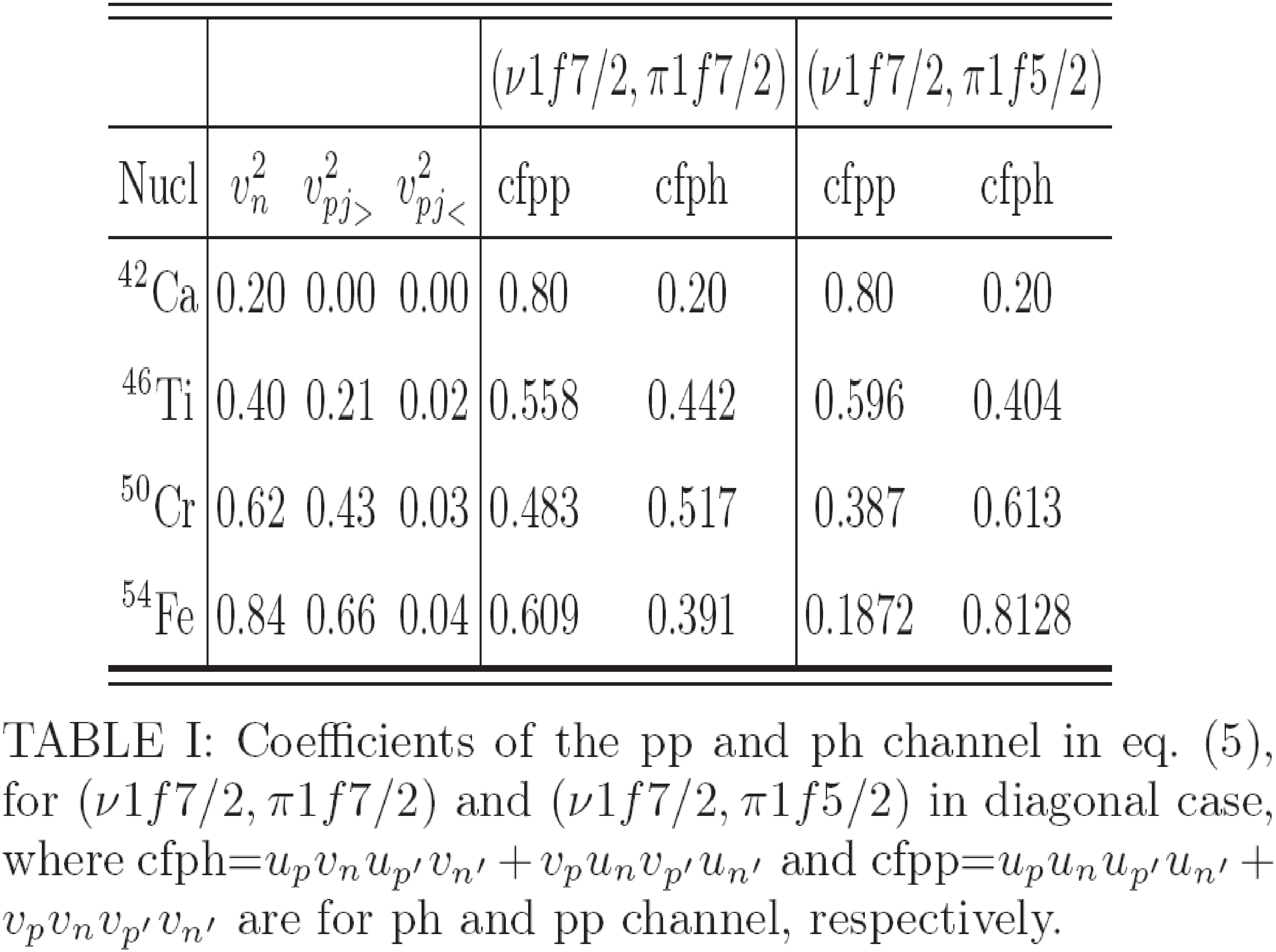


C.L.Bai, H. Sagawa, G. Colo, H. Fujita, H. Q. Zhang, X.Z. Zhang, F.R. Xu, Phys. Rev. C. in press

Evolution of the low-energy GT states



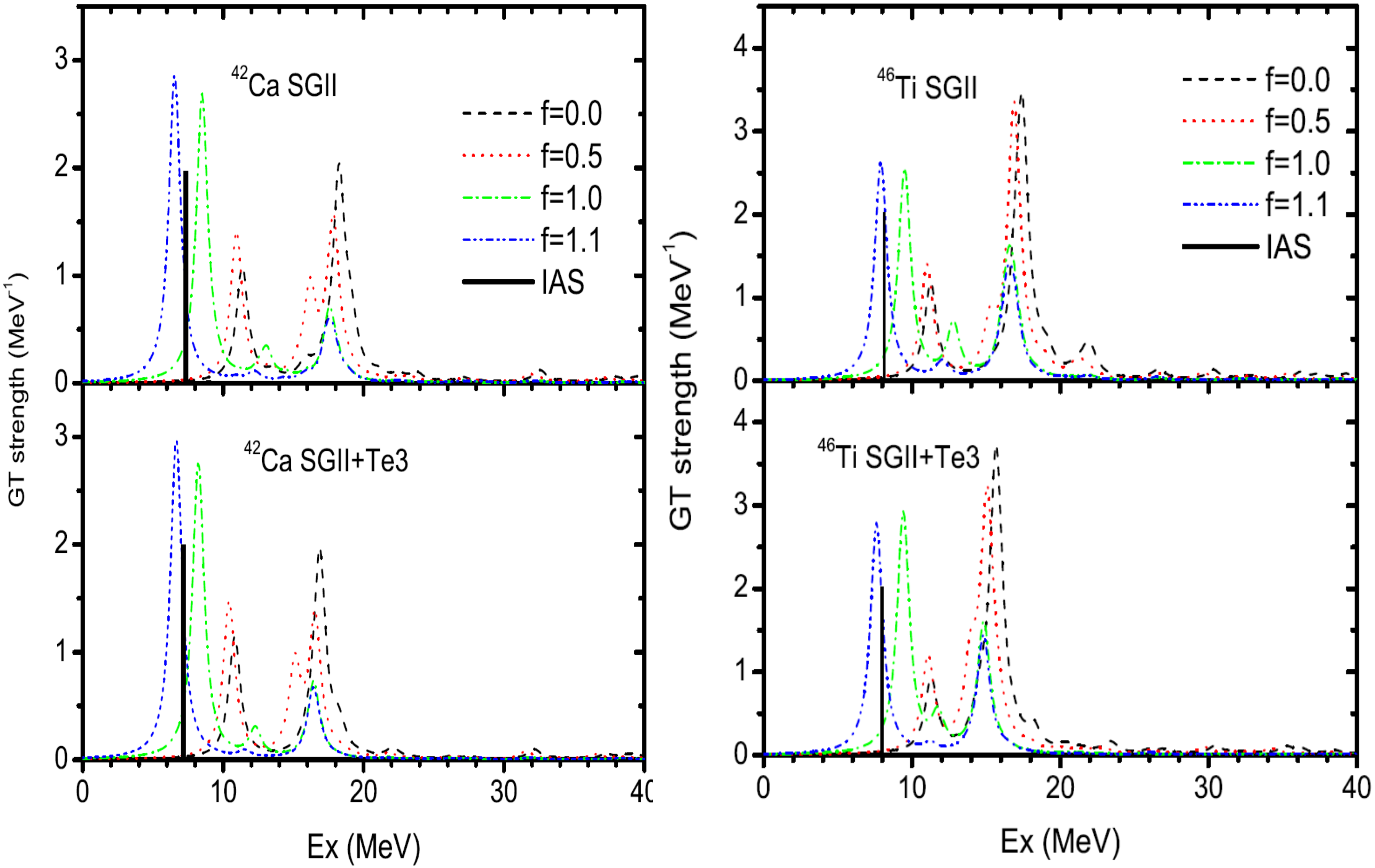
Ph and pp channel competition



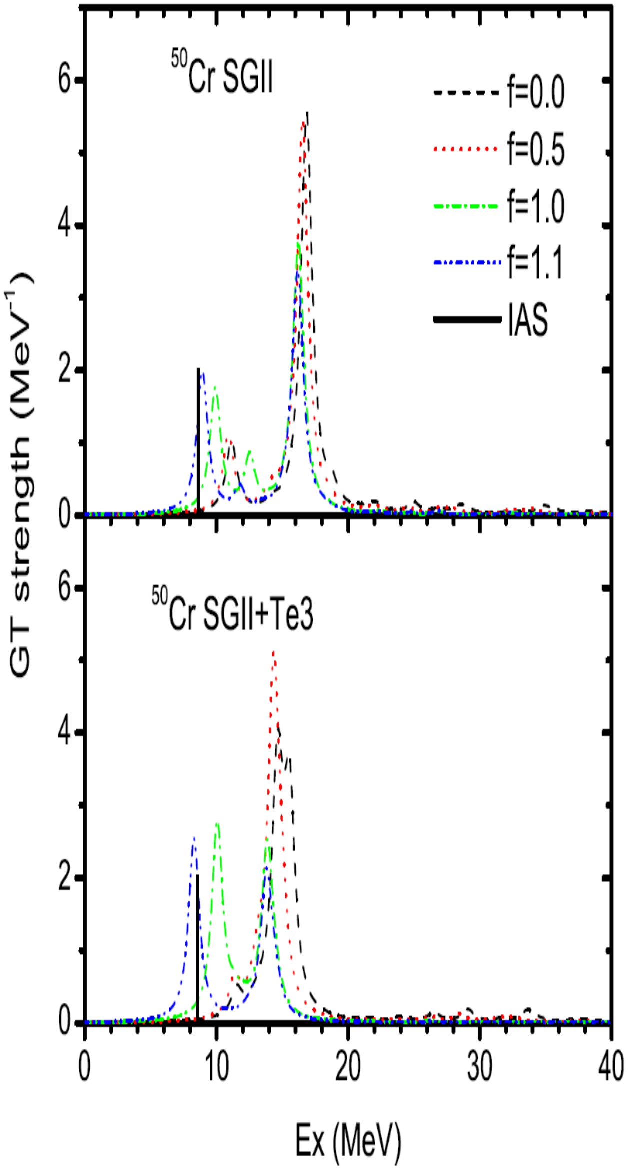
				$(\nu 1f7/2, \pi 1f7/2)$		$(\nu 1f7/2, \pi 1f5/2)$	
Nucl	v_n^2	$v_{pj_>}^2$	$v_{pj_<}^2$	cfpp	cfph	cfpp	cfph
^{42}Ca	0.20	0.00	0.00	0.80	0.20	0.80	0.20
^{46}Ti	0.40	0.21	0.02	0.558	0.442	0.596	0.404
^{50}Cr	0.62	0.43	0.03	0.483	0.517	0.387	0.613
^{54}Fe	0.84	0.66	0.04	0.609	0.391	0.1872	0.8128

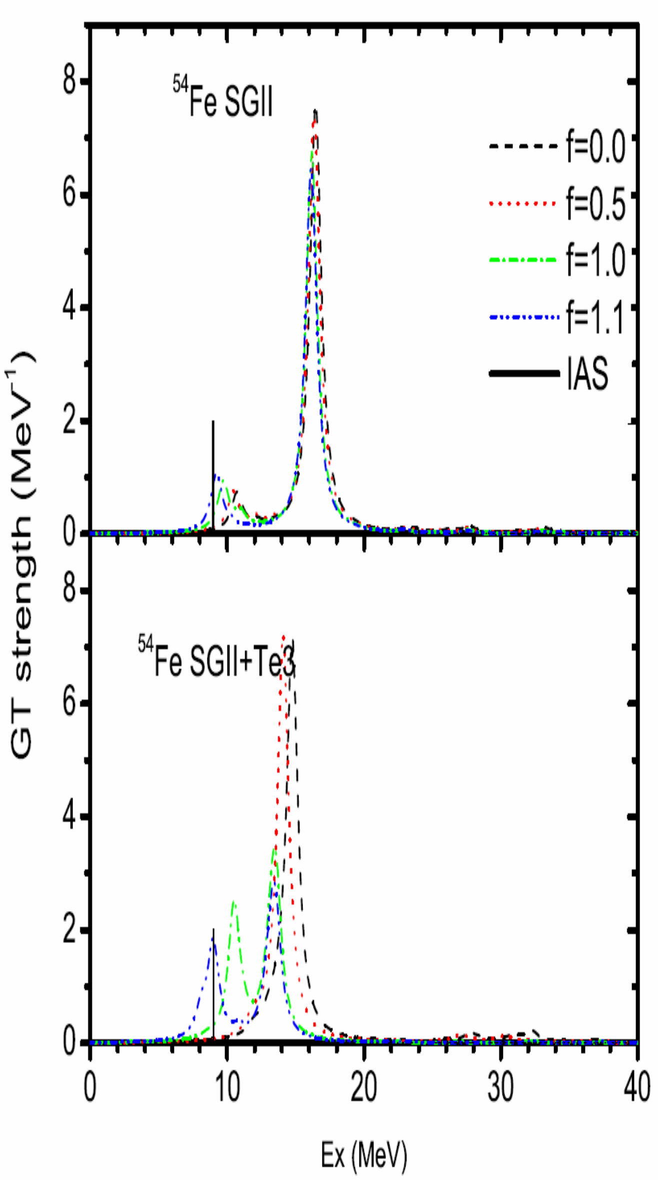
TABLE I: Coefficients of the pp and ph channel in eq. (5), for $(\nu 1f7/2, \pi 1f7/2)$ and $(\nu 1f7/2, \pi 1f5/2)$ in diagonal case, where cfph$=u_p v_n u_{p'} v_{n'} + v_p u_n v_{p'} u_{n'}$ and cfpp$=u_p u_n u_{p'} u_{n'} + v_p v_n v_{p'} v_{n'}$ are for ph and pp channel, respectively.

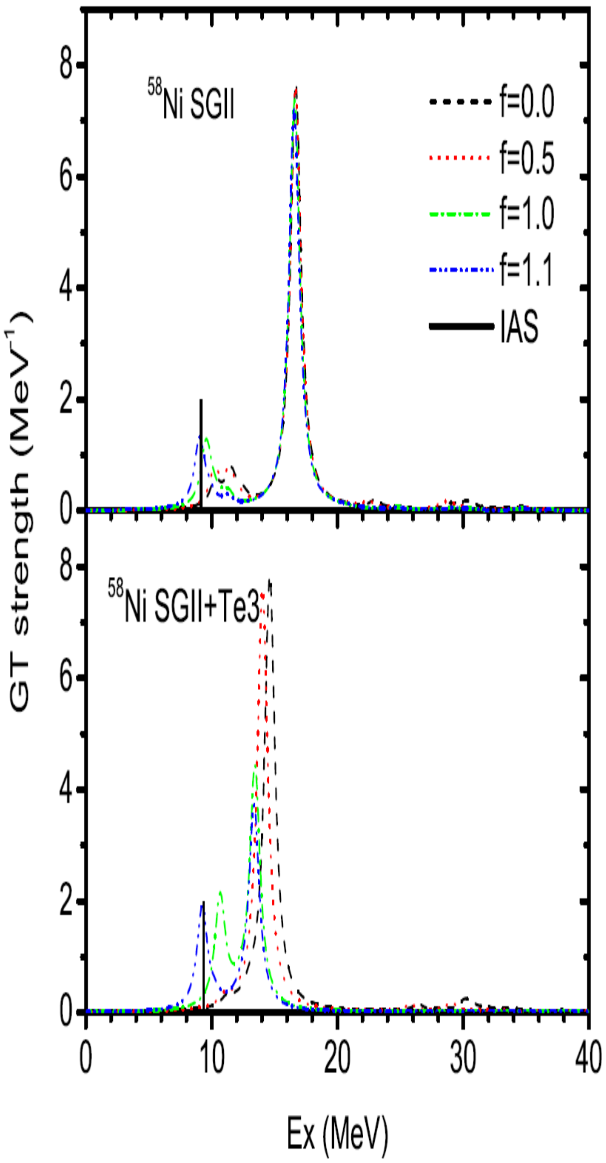
Competition between tensor and T=0 pairing



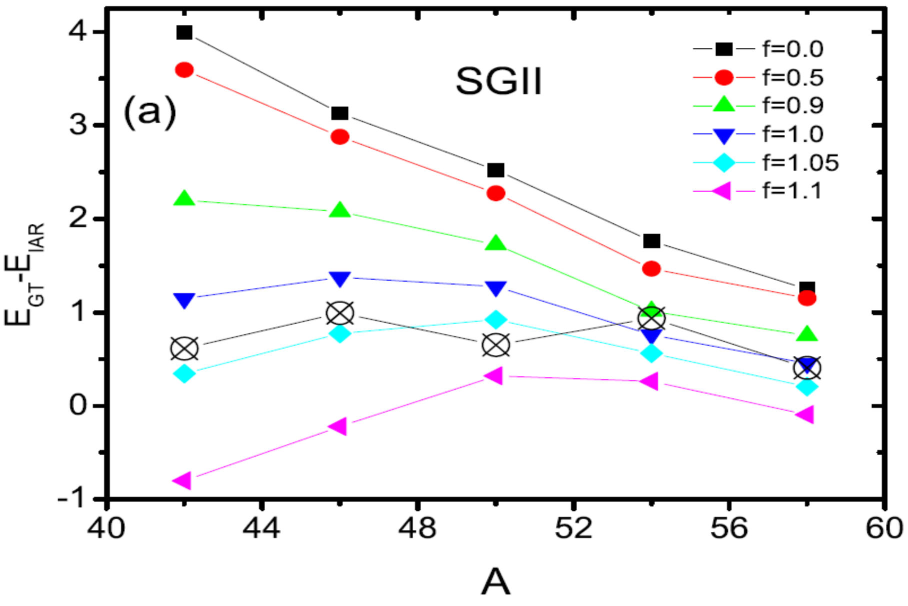
Competition between tensor and T=0 pairing

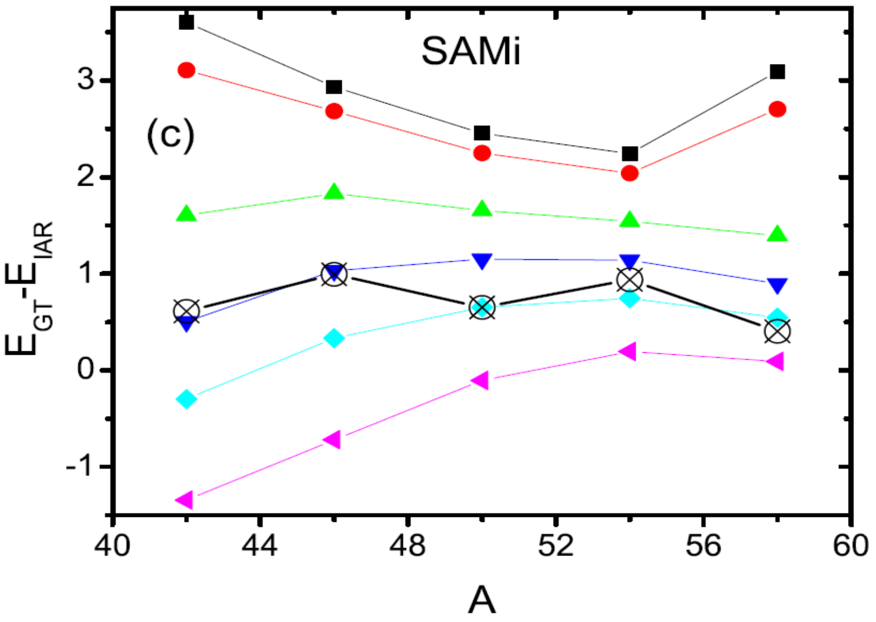


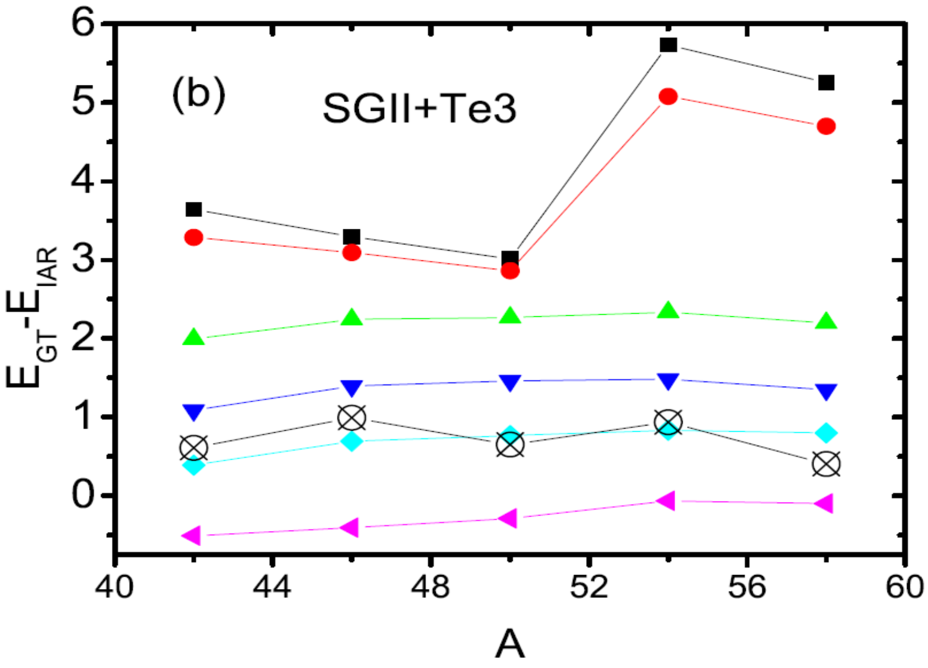




Isoscalar pairing in GT excitations of N=Z+2 nuclei

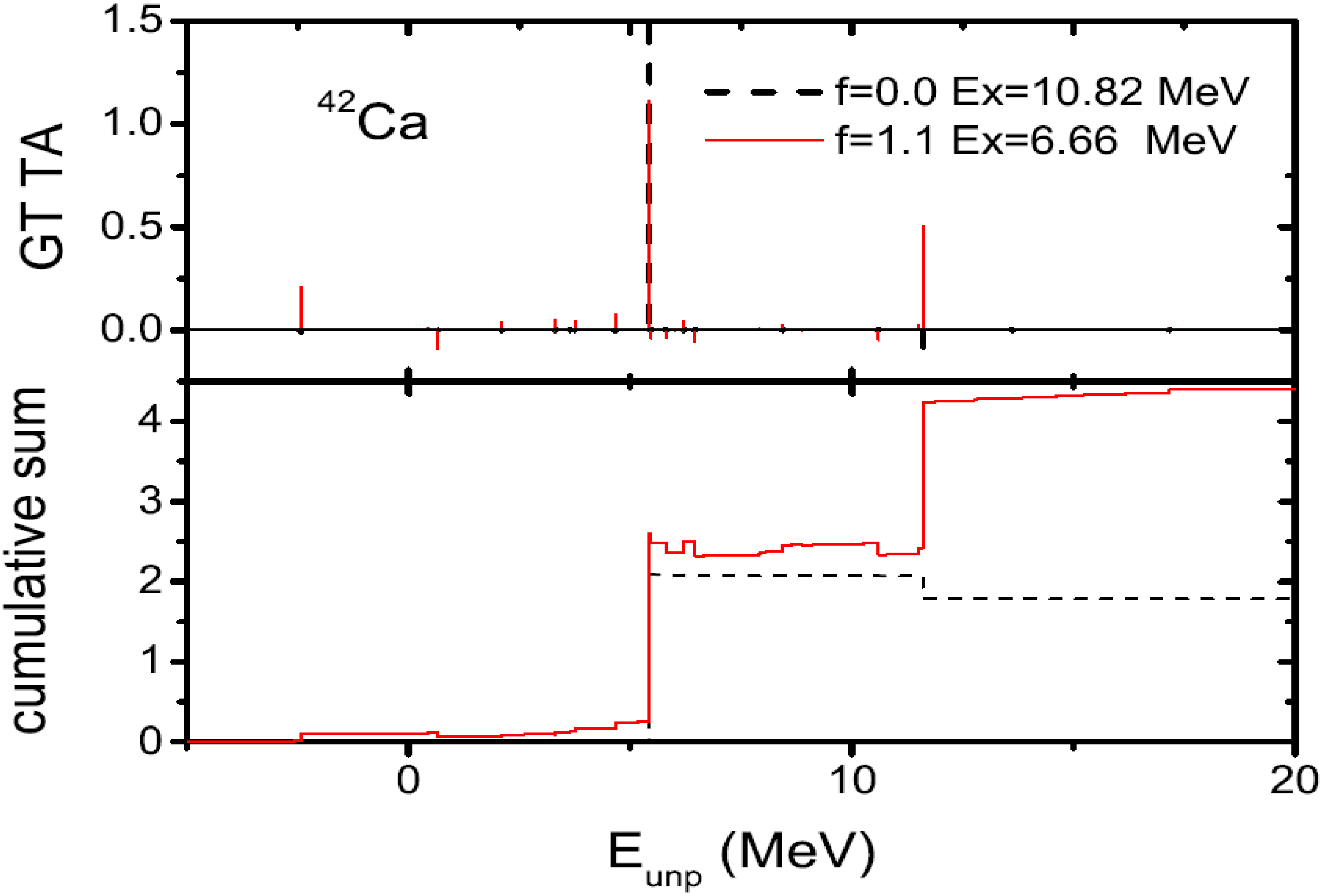






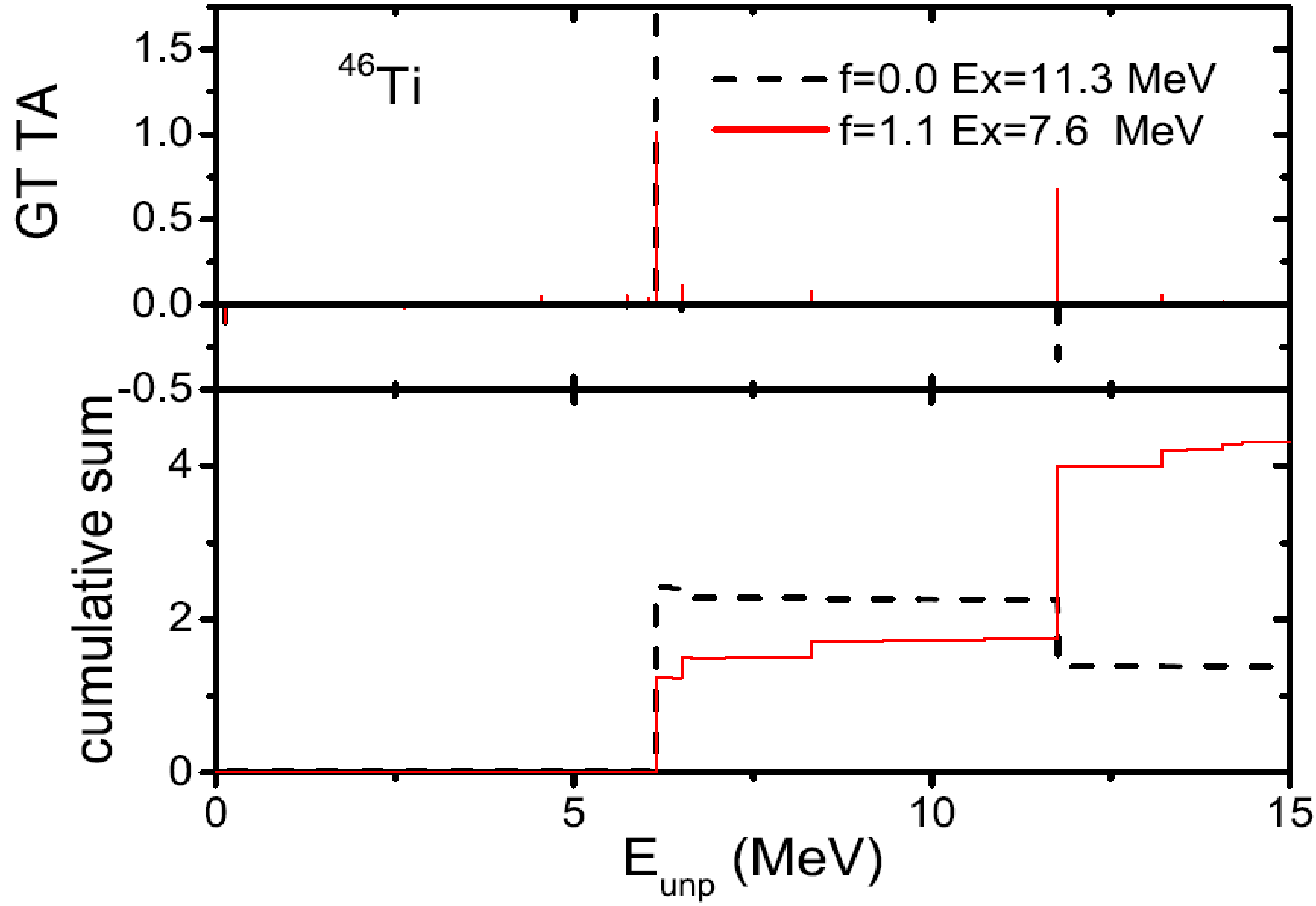
We suggest the value of f =1.0~1.05

Collectivity of the GT states

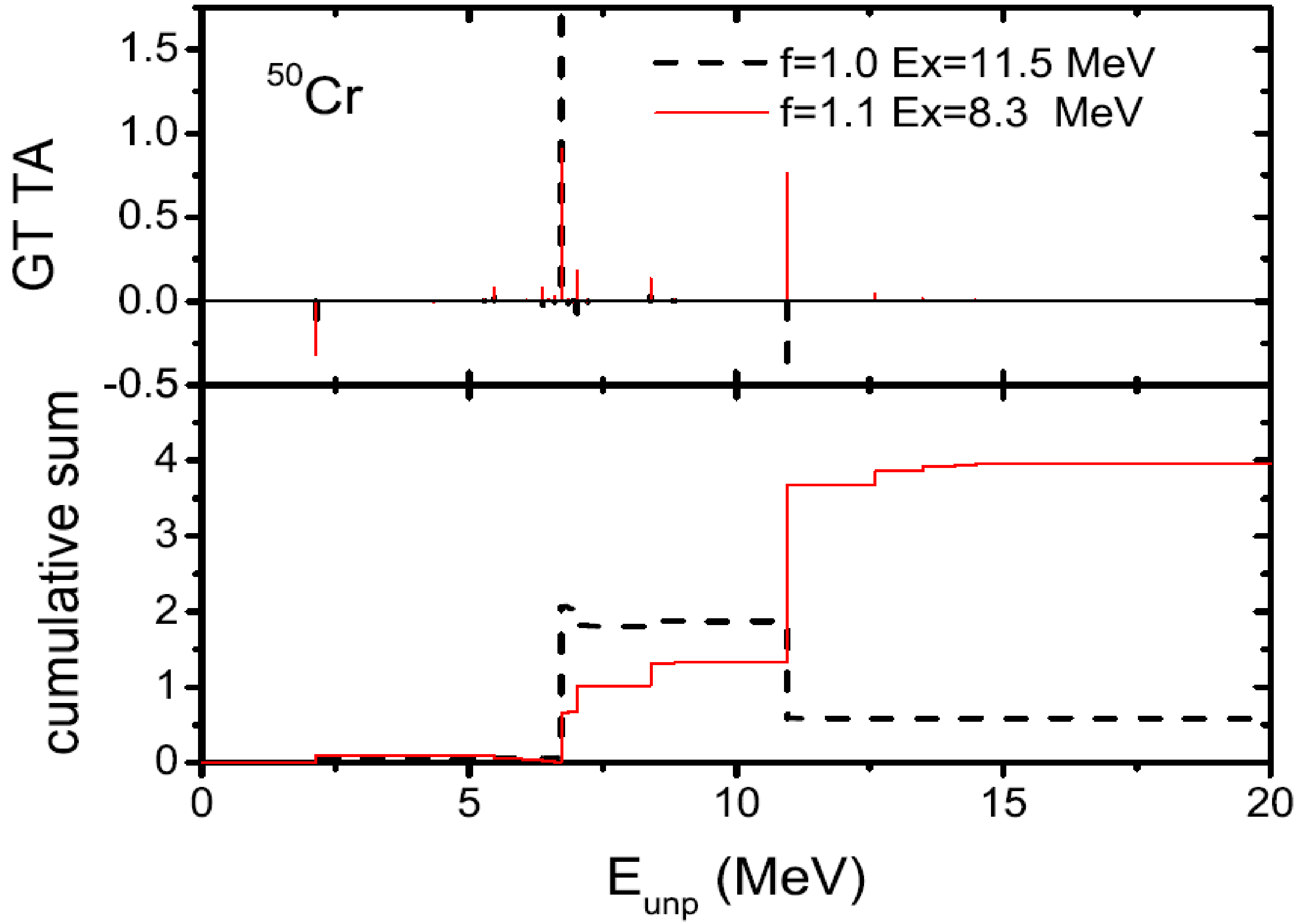


$$TA = (Xu_p v_n + Yv_p u_n) < p \| GT \| n >$$

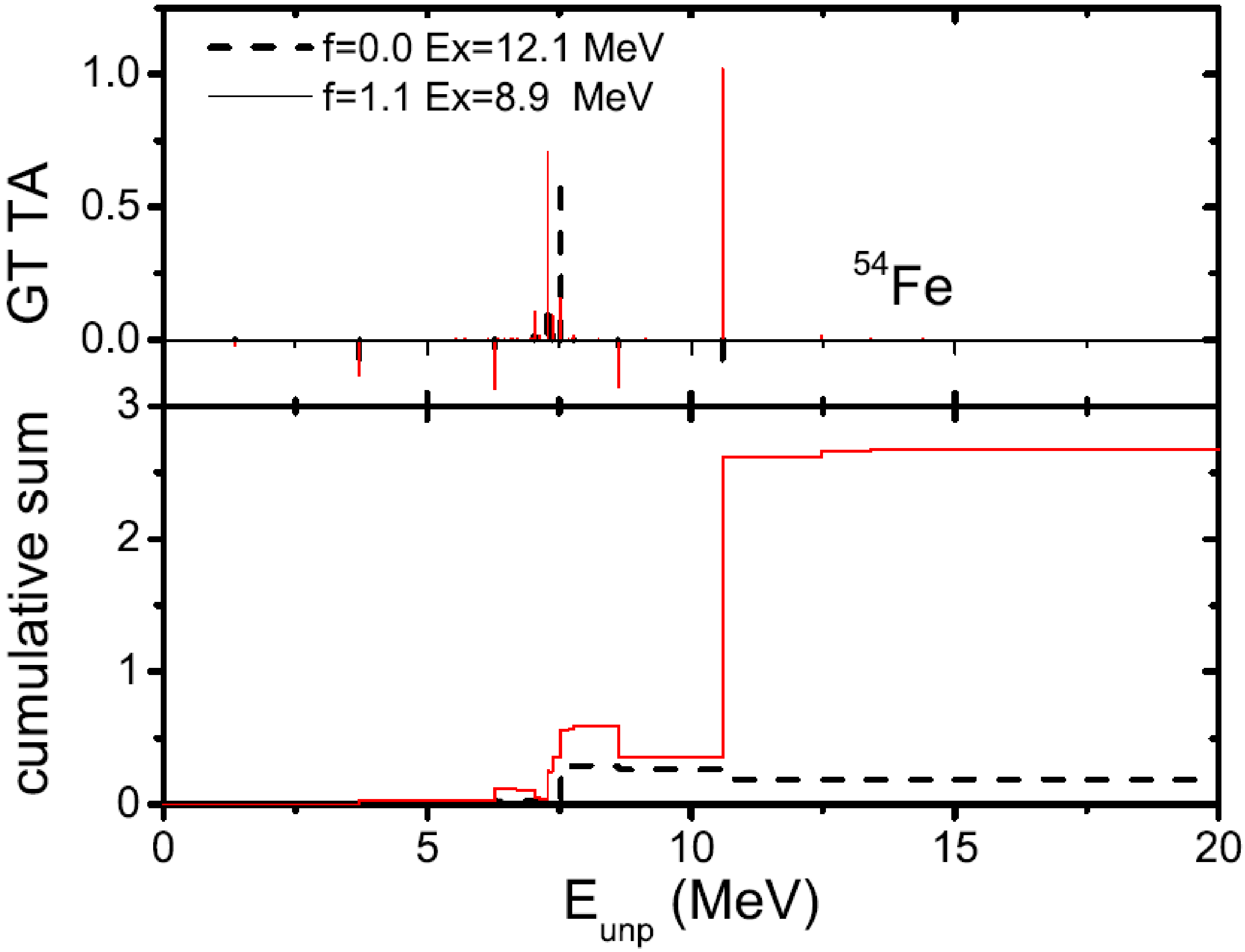
Collectivity of the GT states



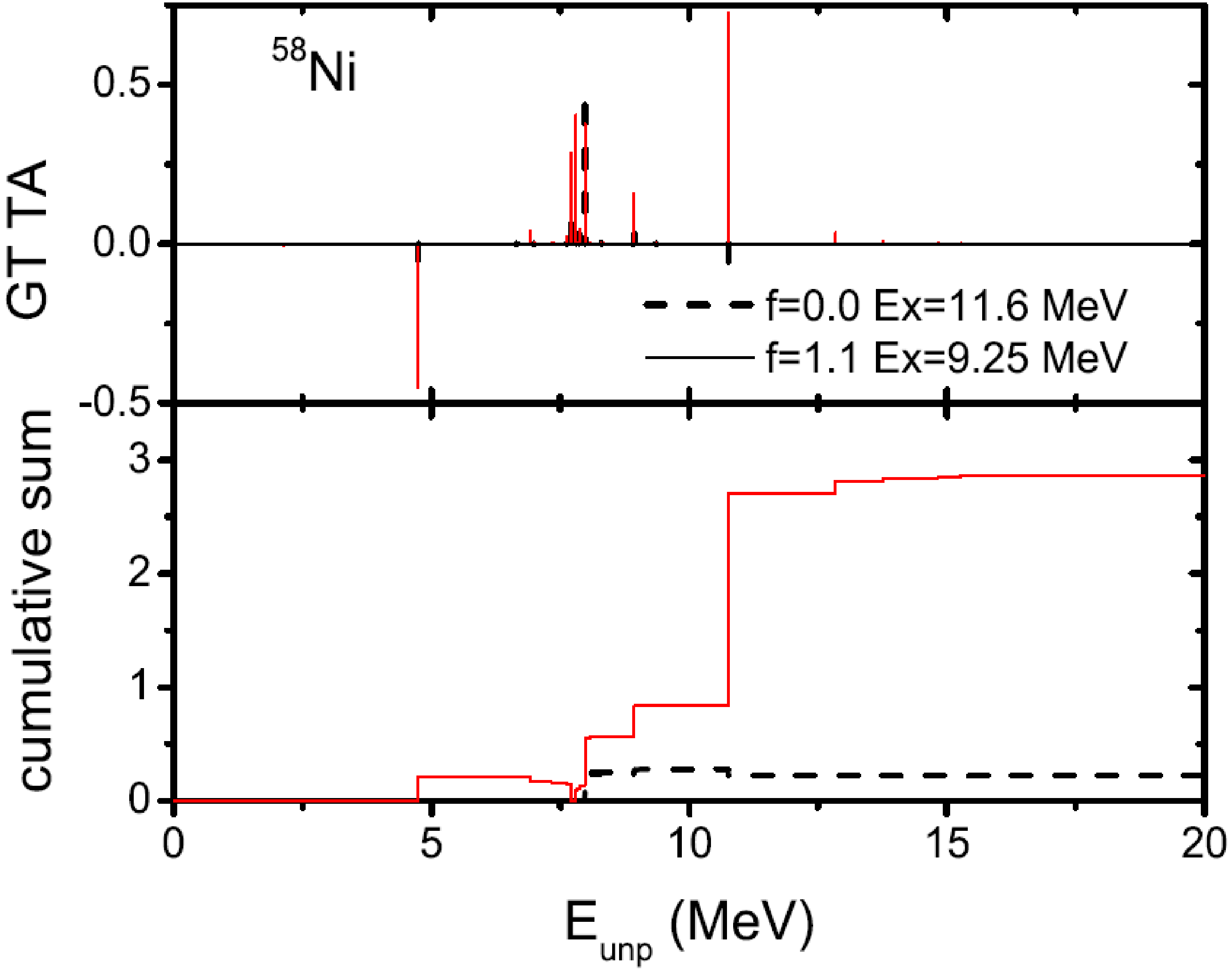
Collectivity of the GT states



Collectivity of the GT states



Collectivity of the GT states



Conclusion and outlook

- T=0 pairing is dominant to form the low energy super GT state in N~Z nuclei especially with A=42~50.

- Low energy GT states in these N=Z+2 nuclei are good candidate to constrain the strength of T=0 pairing to be about 1.0~1.05 times of T=1 pairing strength which can be constrained by the pairing gap.

- The collectivity of these low energy GT states are studied.

- We may suffer from the instability of zero-range pairing force.

Many Thanks for your attention