Tensor force effect on pairing correlations for the Gamow-Teller transition

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in collaboration with

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  E. Ha *et al.* Prog. Theor. Exp. Phys. (2022) 043D01

- **Effect of TF on GT transition for ^{48}Ca, ^{78}Ni, and ^{208}Pb, doubly magic nuclei.** **(on-going work)**

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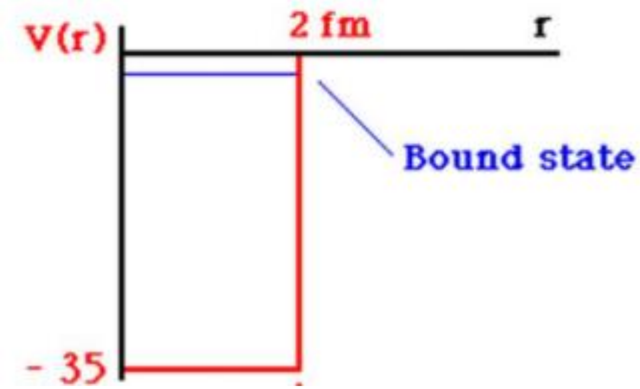
- Effect of TF on Gamow-Teller transition for ^{48}Ca and ^{78}Ni

(on-going work)

3. Summary

❖ Tensor force(TF) : first evidence from the deuteron

Binding energy	2.225 MeV
Spin, parity	1^+
Isospin	0
Magnetic moment	μ=0.857 μ_N
Electric quadrupole moment	Q=0.282 e fm^2 **Not spherical**

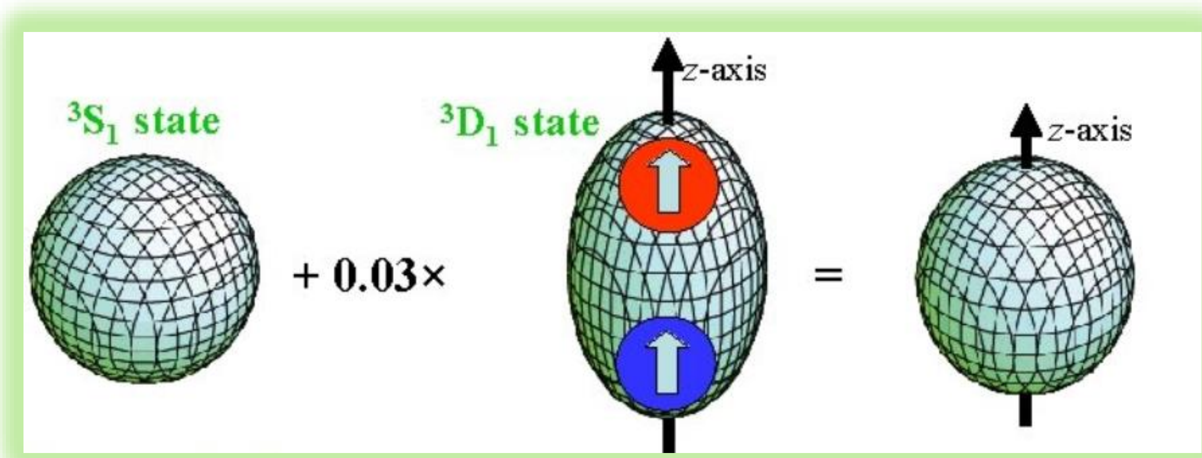


$\boxed{{}^{2S+1}L_J}$

$$|\psi_d\rangle = 0.98|{}^3S_1\rangle + 0.20|{}^3D_1\rangle$$

$(L = 0)$ $(L = 2)$

$S = 1$



Tensor force(**TF**) mixes two states.

✓ Deuteron is unbound without TF.

❖ Tensor force (TF)

In OBEP $\hat{V} = \hat{V}_c + \hat{V}_T$

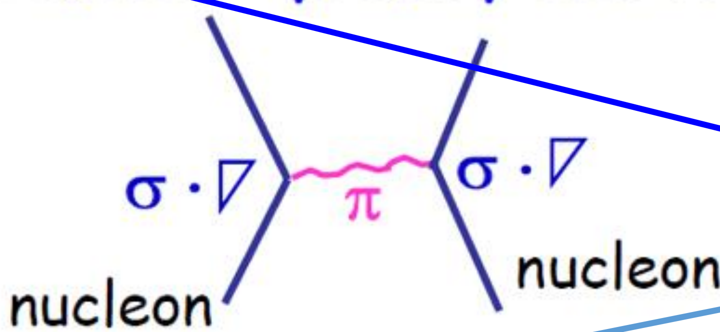
Tensor part $\hat{V}_T = V_T(r)\hat{S}_{12}$ non-central

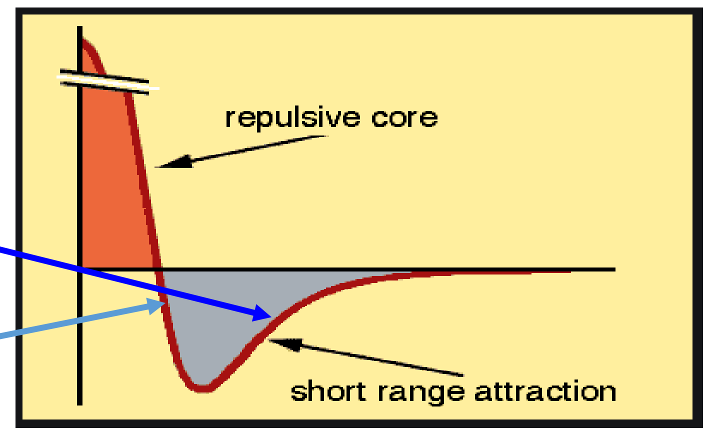
Tensor force operator $\hat{S}_{12} = 3\frac{(\boldsymbol{\sigma}_1 \cdot \boldsymbol{r})(\boldsymbol{\sigma}_2 \cdot \boldsymbol{r})}{r^2} - (\boldsymbol{\sigma}_1 \cdot \boldsymbol{\sigma}_2)$

Origin of TF :

Tensor attraction 80% of entire attraction.

π meson : primary source





ρ meson (~ π+π) : minor (~1/4) cancellation

Ref: Osterfeld, Rev. Mod. Phys. 64, 491 (92)

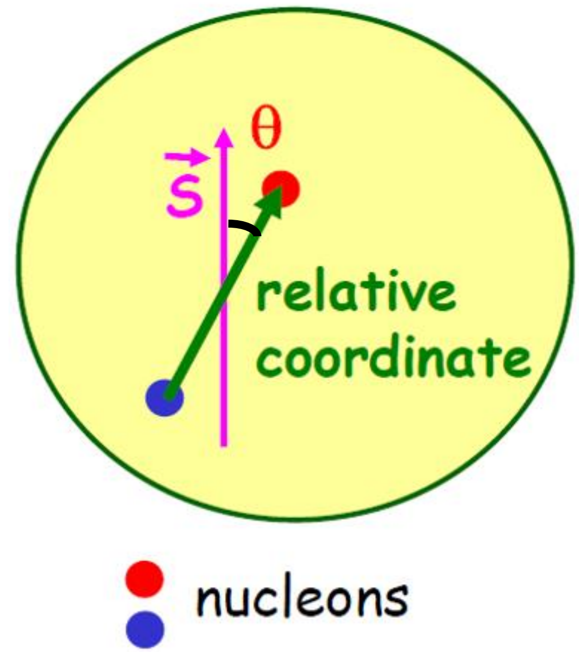
❖ How does the TF work ?

$$\hat{S}_{12} = 3\frac{(\boldsymbol{\sigma}_1 \cdot \boldsymbol{r})(\boldsymbol{\sigma}_2 \cdot \boldsymbol{r})}{r^2} - (\boldsymbol{\sigma}_1 \cdot \boldsymbol{\sigma}_2) = -2S^2(1 - 3cos^2\theta) \sim Y_{2,0}$$

$\hat{\boldsymbol{S}}_{12} = \mathbf{0}$ **for** $\boldsymbol{S} = \mathbf{0}$, **Only S=1 contribute to TF.**

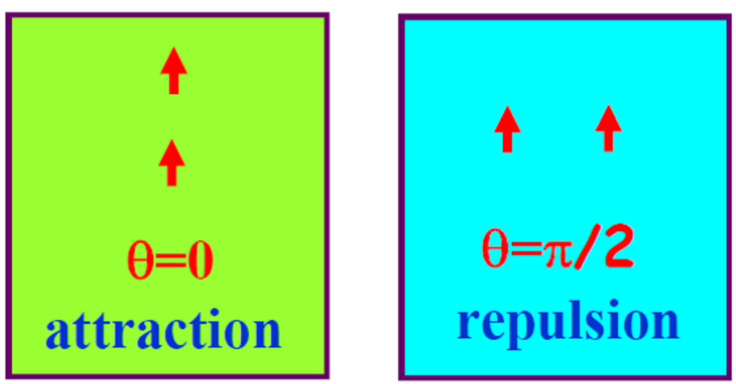
Spin of each nucleon ↑ is parallel, because the total spin must be S=1

The potential has the following dependence on the angle θ with respect to the total spin $\vec{S}$.



Tensor force $\hat{V}_T = V_T(r)\hat{S}_{12}$ $\qquad V_T(r) < 0$

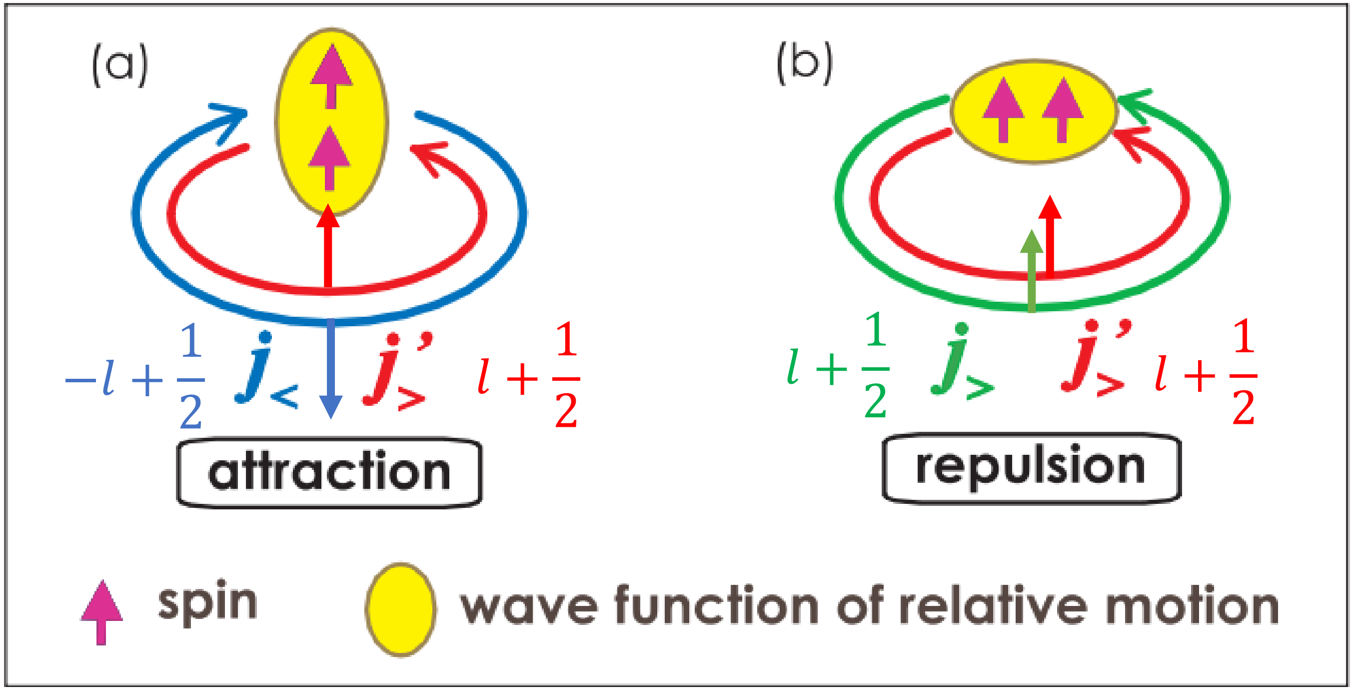
$\hat{V}_T \sim -\hat{S}_{12} \sim 1 - 3cos^2\theta$



From Otsuka’s talk

❖ TF acting two nucleons in shell models

Δp is large → Δr is small by the principle of uncertainty



$j_> = l + ½,\ \ j_< = l - ½$

TO et al., PRL 95, 232502(2005)

❖ TF in shell model

D. Steppenbeck *et al.*
Nature 502,207(2013)

From Otsuka's talk

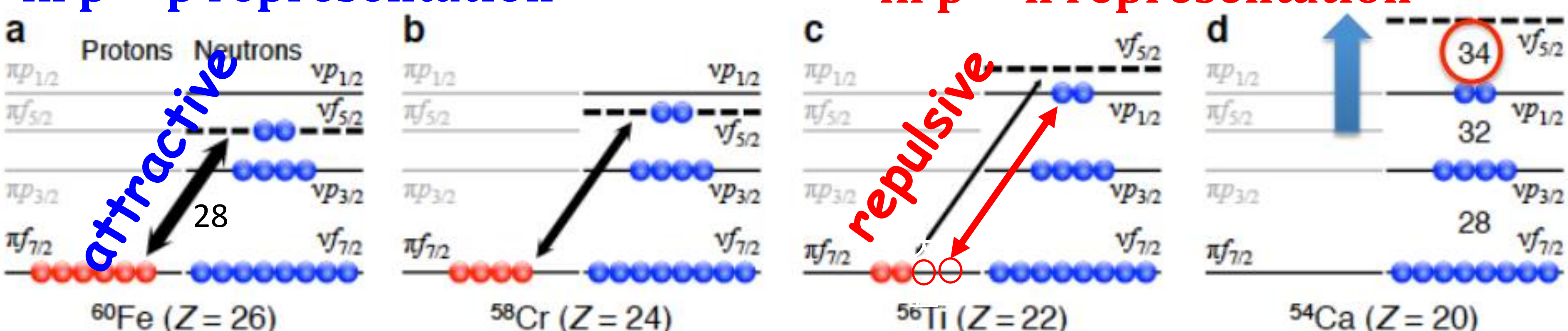
New magic number from ^{54}Ca (N=34)!

N=34 magic number
and the shell evolution due to proton-neutron interaction

neutron $f_{5/2}$ - $p_{1/2}$ spacing increases by ~0.5 MeV per one-proton removal from $f_{7/2}$, where tensor and central

As two-proton(hole) are removed(created) the attractive(repulsive) TF becomes weaker(stronger).

in p − p representation **in p − h representation**

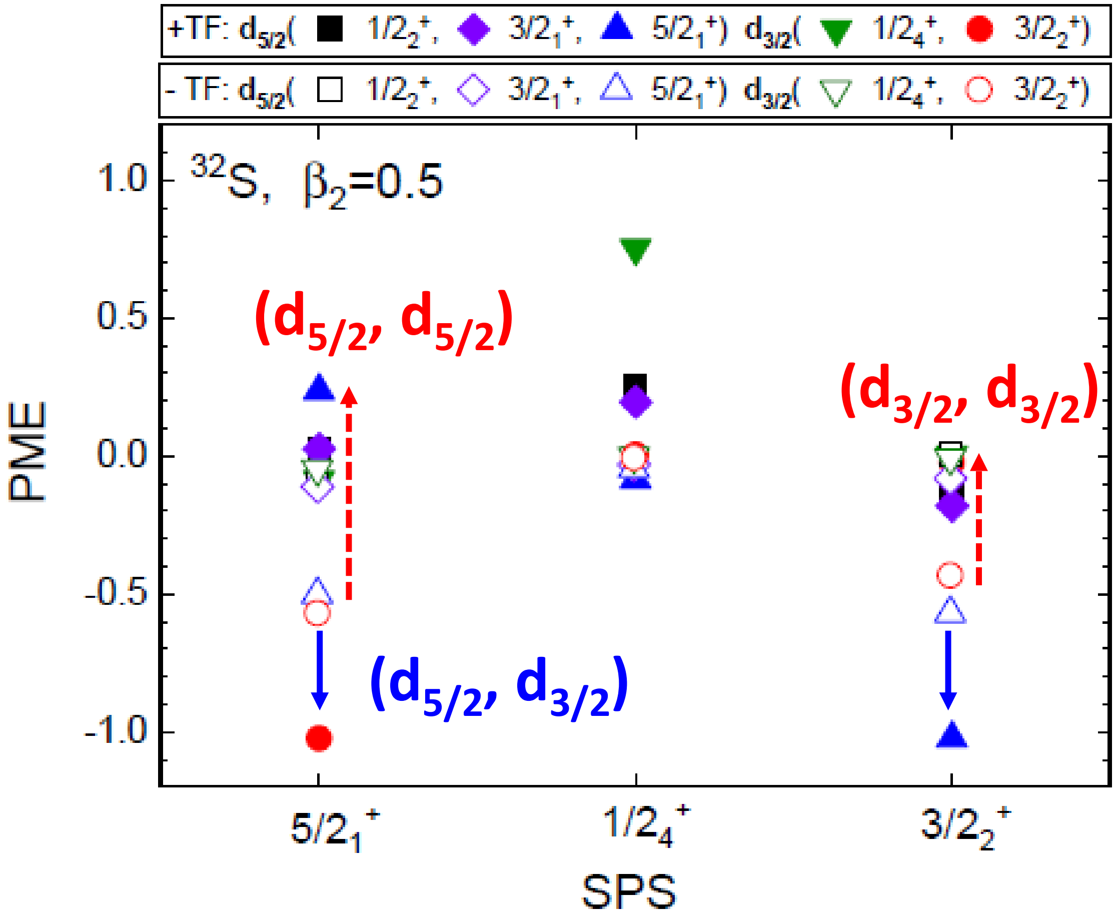


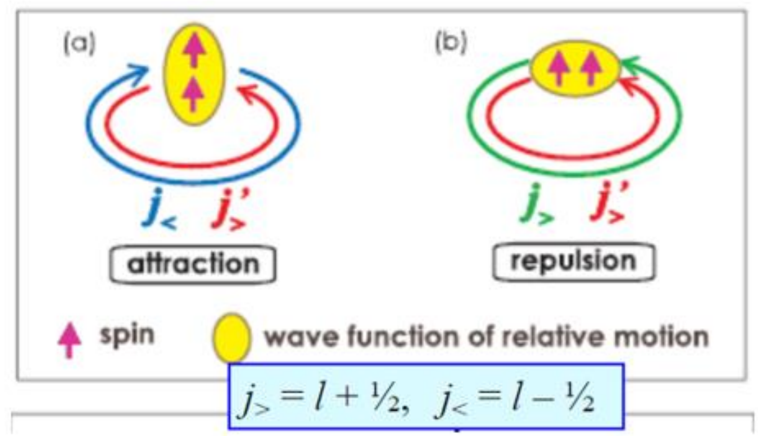
✓ **The attractive TF in p-p representation corresponds to the repulsive TF in p-h representation.**

❖ Effect of TF in G-matrix

How do the properties of TF work in the excited state?

E. Ha *et al.* *PRC 104*(2021)





✓ The properties of TF are maintained not only in the ground state but also in the excited state.

$$+ \left[\sum_{J,a,c} g_{\rm np}^{T=0} F^{J0}_{\alpha a \bar{\alpha} a} F^{J0}_{\gamma c \bar{\gamma} c} iG(aacc, J, T=0)\right] Im(u^*_{1n_\gamma} v_{1p_\gamma} + u^*_{2n_\gamma} v_{2p_\gamma})\Bigg] ,$$

- ✓ TF in the N-N interaction plays an important role in variation of the nuclear shell structure in nuclei.

- ✓ How does the TF affect the ground states and the excited states on GT transition?

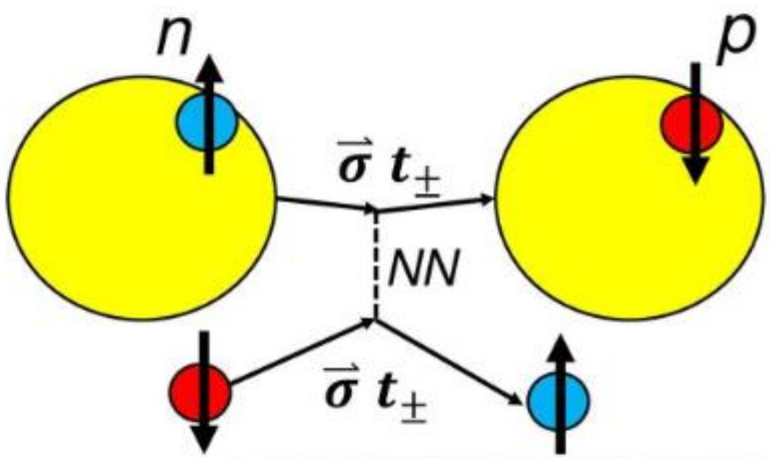
TF has non-central property.

- ✓ Could TF(microscopic) be closely associated with the nuclear deformation(macroscopic) ?

Gamow-Teller transition and Charge-Exchange (CE) reactions at 100-300 MeV

$\Delta T=1$, $\Delta S=1$, $\Delta L=0$ induced by $\vec{\sigma}\, t_{\pm}$

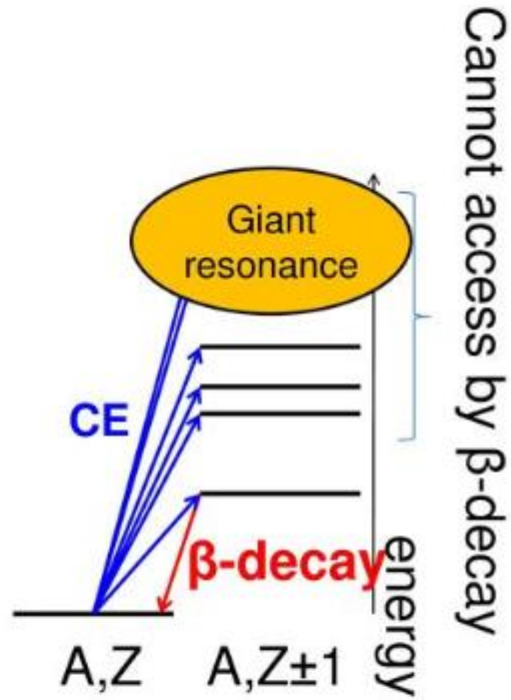
strength : **B(GT)**



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

100 – 300 MeV
→ Isovector spin-flip >> Isovector nonspin-flip
& DWIA good

$$\left(\frac{d\sigma}{d\Omega}(q=0)\right)_{(p,n)} = \hat{\sigma}\, B(GT)$$



Any (0-50 MeV) Ex!

From M. Sasano's talk

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- Effect of TF on GT transition for ^{48}Ca, ^{78}Ni, and ^{208}Pb, doubly magic nuclei. (on-going work)

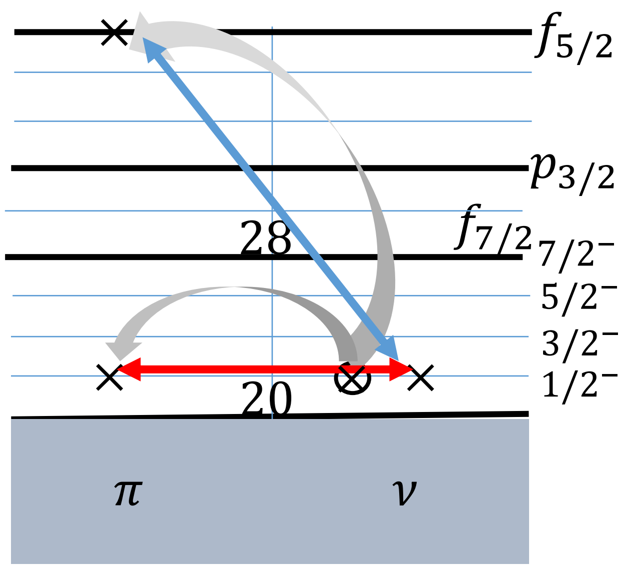
3. Summary

p-p interaction attractive

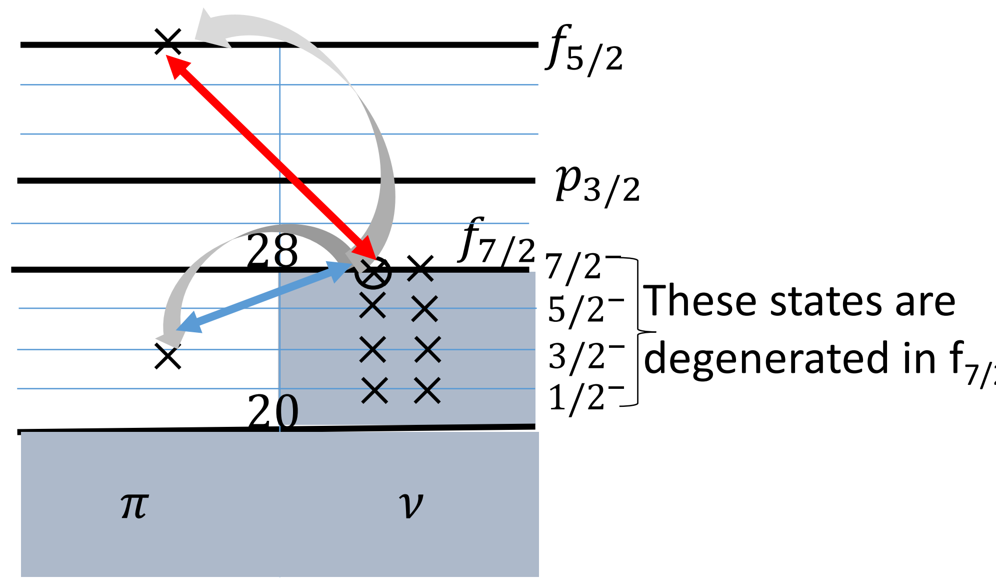
p-h interaction repulsive

TF in GT transition : repulsive? attractive?

$$\boldsymbol{f_{5/2}, f_{7/2}: attractive(p-p)} \qquad \boldsymbol{f_{5/2}, f_{7/2}: repulsive(p-h)}$$



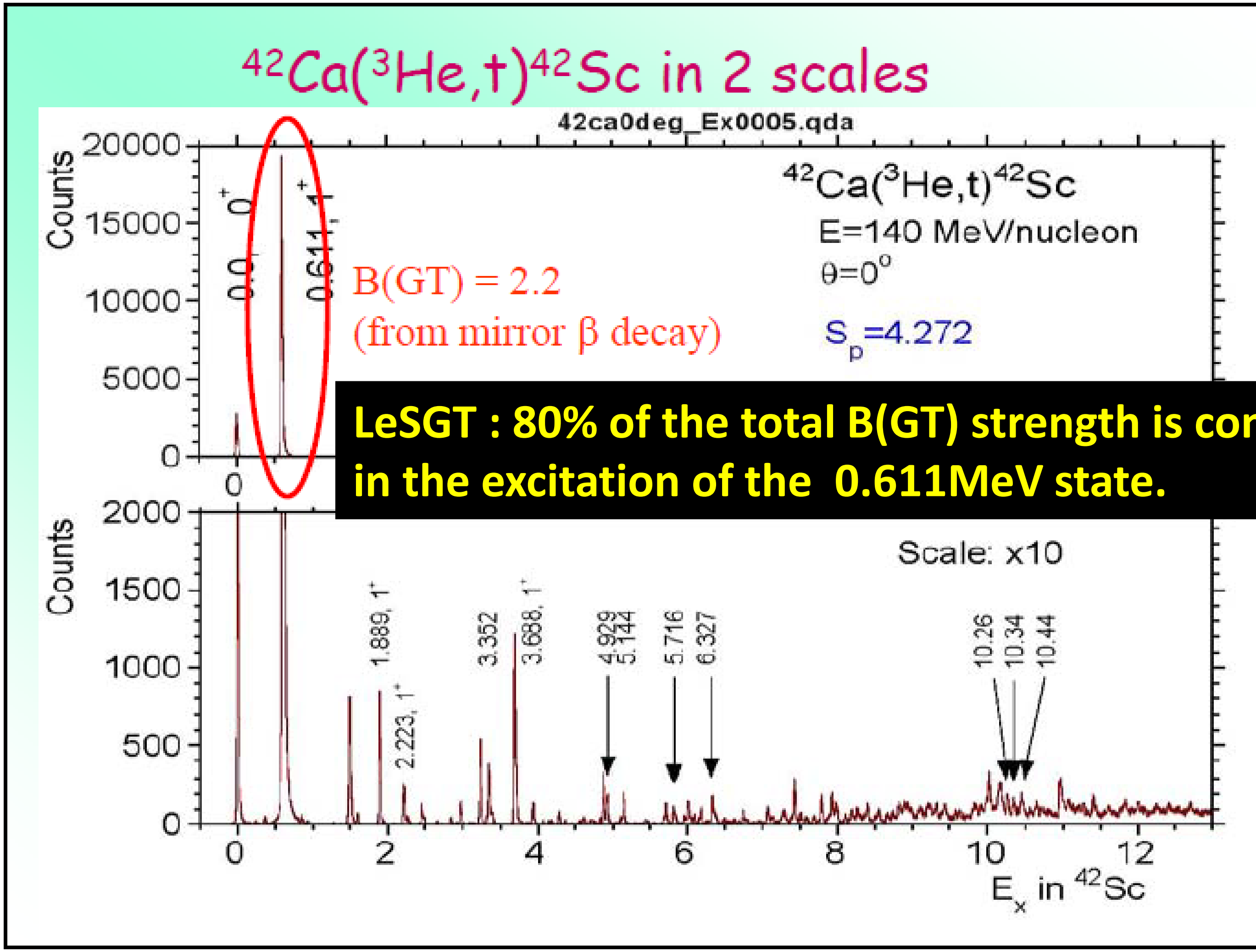
$${}^{42}_{20}Ca_{22} \rightarrow {}^{42}_{21}Sc_{21}$$



$${}^{48}_{20}Ca_{28} \rightarrow {}^{48}_{21}Sc_{27}$$

✓ **It depends on which orbit the nucleon is occupied.**

❖ Low-energy super GT state(LeSGT) in N=Z+2 nuclei



LeSGT : 80% of the total B(GT) strength is concentrated in the excitation of the 0.611MeV state.

From Y. Fujita's talk

GT strength Calculations:
HFB+QRPA + pairing int.

Bai, Sagawa, Colo et al., PL B 719 (2013) 116

The density dependent contact pairing interactions are adopted for both $T=1$ and $T=0$ channels,

IV $$V_{T=1}(\mathbf{r}_1,\mathbf{r}_2) = V_0\frac{1-P_\sigma}{2}\left(1-\frac{\rho(\mathbf{r})}{\rho_0}\right)\delta(\mathbf{r}_1-\mathbf{r}_2), \quad (1)$$

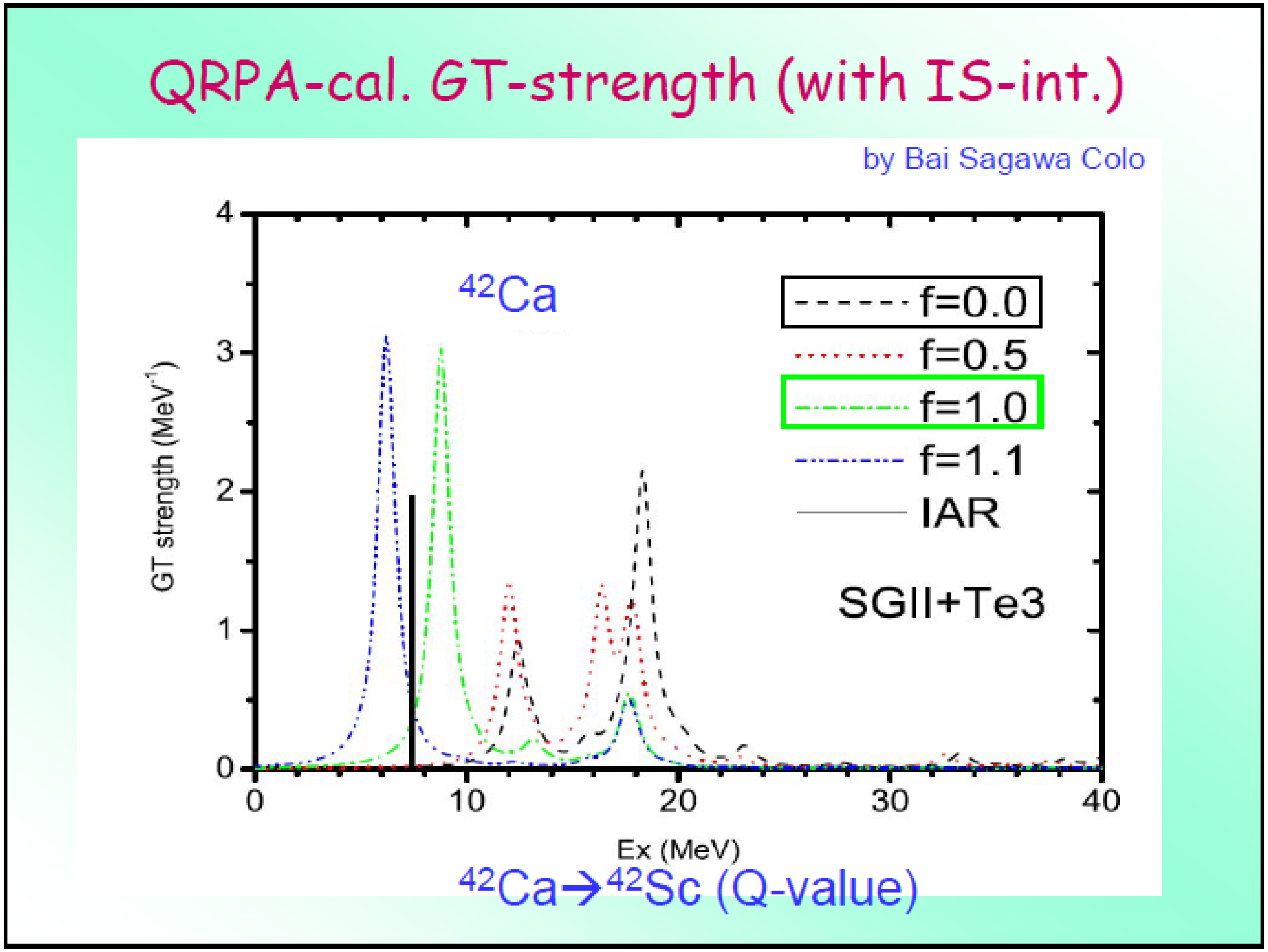
IS $$V_{T=0}(\mathbf{r}_1,\mathbf{r}_2) = f V_0\frac{1+P_\sigma}{2}\left(1-\frac{\rho(\mathbf{r})}{\rho_0}\right)\delta(\mathbf{r}_1-\mathbf{r}_2), \quad (2)$$

Results (using Skyrme int. SGII)

at f=0: there is little strength in the lower energy part,

at f=1.0~1.7: coherent low-energy strength develops!

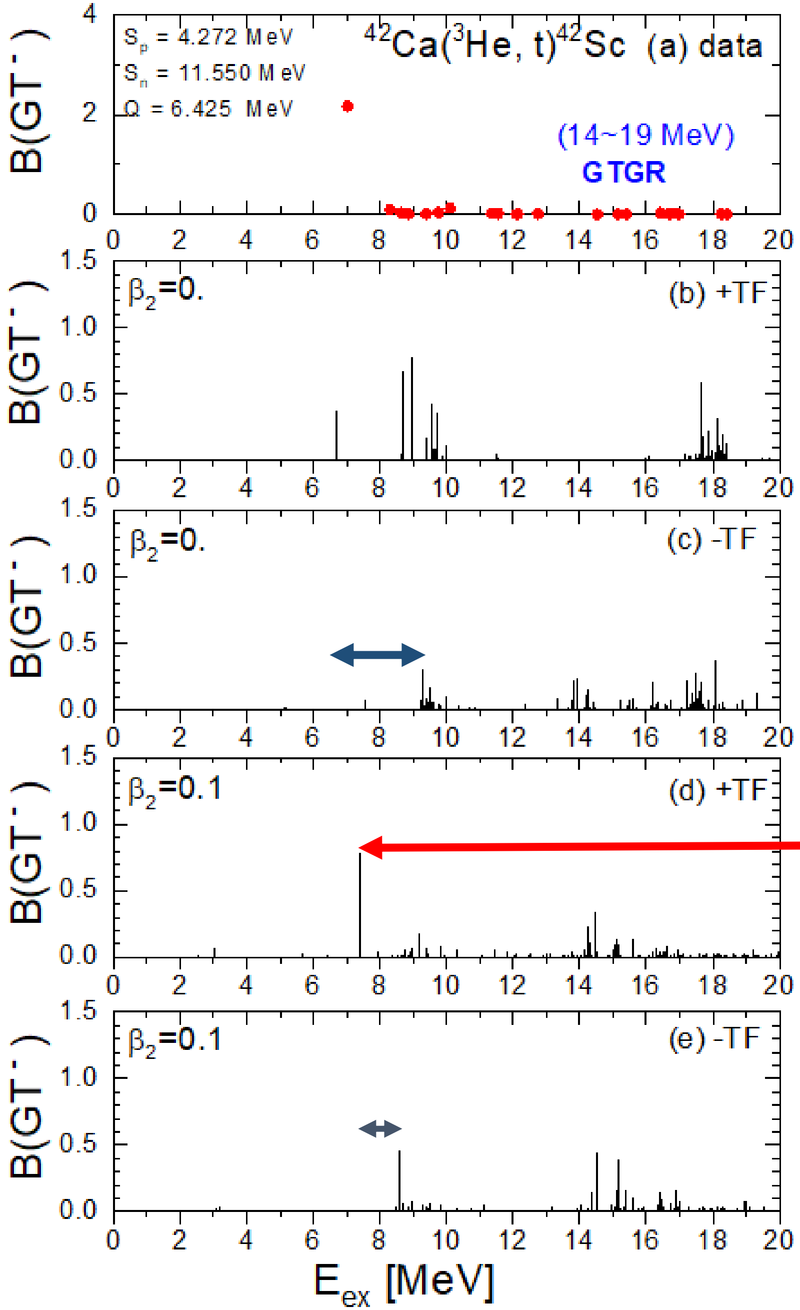
❖ Low-energy super GT state(LeSGT)



- ✓ **Isoscalar(IS) pairing has spin-triplet(S=1).**
- ✓ **TF has also spin-triplet.**

❖ Role of TF in GT states for ^{42}Ca

E. Ha *et al.* Prog. Theor. Exp. Phys. (2022) 043D01



✓ **TF** has non-central property.

✓ **TF** could be closely associated with the nuclear deformation.

	$\beta_2(E2)$	$\beta_2(FRDM)$	$\beta_2(RMF)$
^{42}Ca	0.245	0.	0.

$$g_{pp}/g_{ph} = 1.7$$

$g_{pp}(g_{ph})$:strength of particle-particle(particle-hole)

The attractive TF plays a crucial role in shifting the main GT peak to the low excitation-energy region leading to the LeSGT.

✓ **The effect of TF decreases with the nuclear deformation.**

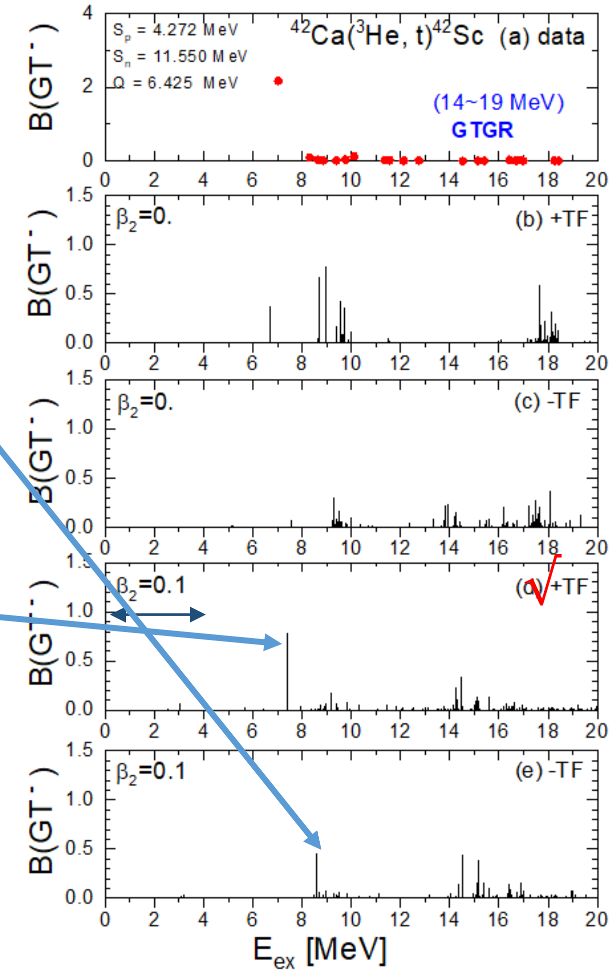
❖ Role of TF in GT states

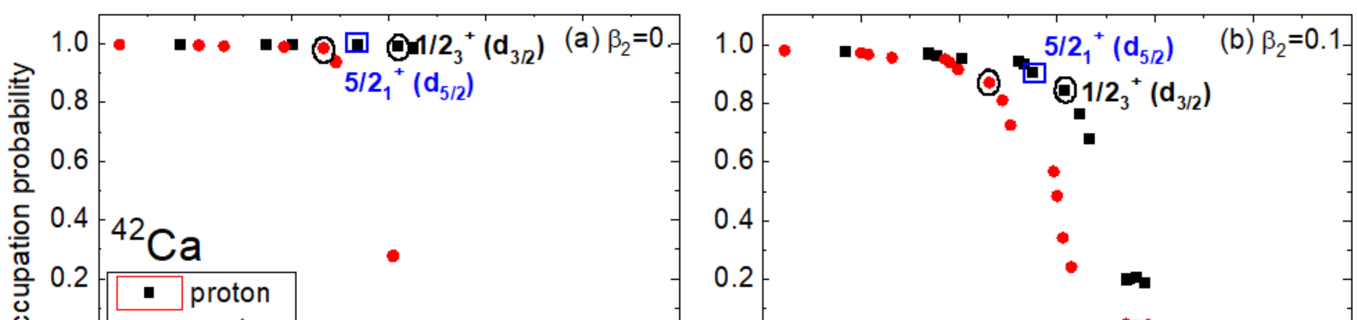
PTEP **2022**, 043D01 E. Ha et al.

Table 3. Particle configurations of the main GT transition in Eq. (12) for the low-lying GT state for ^{42}Sc at E_{ex} = 7.42 MeV and E_{ex} = 8.59 MeV in Figs. 1(d) and (e).

β_2	E_{ex} [MeV]	B(GT)	Nilsson configuration	Spherical configuration	GT transition amplitude
0.1 (w/o TF)	8.59	0.45	$(\pi 1/2_3^-, \nu 1/2_3^-)$	[π $f7/2$, ν $f7/2$]	0.37
			$(\pi 1/2_3^-, \nu 3/2_2^-)$	[π $f7/2$, ν $f7/2$]	0.14
			$(\pi 3/2_2^-, \nu 1/2_3^-)$	[π $f7/2$, ν $f7/2$]	0.11
			$(\pi 1/2_5^-, \nu 3/2_2^-)$	[π $f5/2$, ν $f7/2$]	0.14
0.1 (with TF)	7.42	0.78	$(\pi 1/2_3^+, \nu 1/2_3^+)$	[π $d3/2$, ν $d3/2$]	0.10
			$(\pi 1/2_3^-, \nu 1/2_3^-)$	[π $f7/2$, ν $f7/2$]	0.11
			$(\pi 3/2_2^+, \nu 5/2_1^+)$	[π $d3/2$, ν $d5/2$]	0.16
			$(\pi 5/2_1^+, \nu 3/2_2^+)$	[π $d5/2$, ν $d3/2$]	0.11
			$(\pi 5/2_2^-, \nu 7/2_1^-)$	[π $f5/2$, ν $f7/2$]	0.08

attractive TF





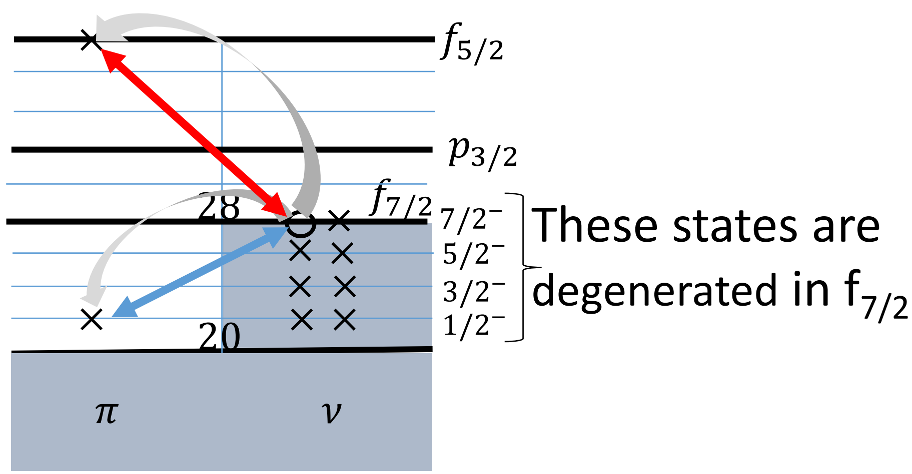
✓ The nucleons on the fermi surface contribute to make the LeSGT peak.

❖ particle-hole interaction in doubly magic nucleus

TF in GT transition: repulsive? attractive?

$(f_{5/2}, f_{7/2})$ $(g_{7/2}, g_{9/2})$

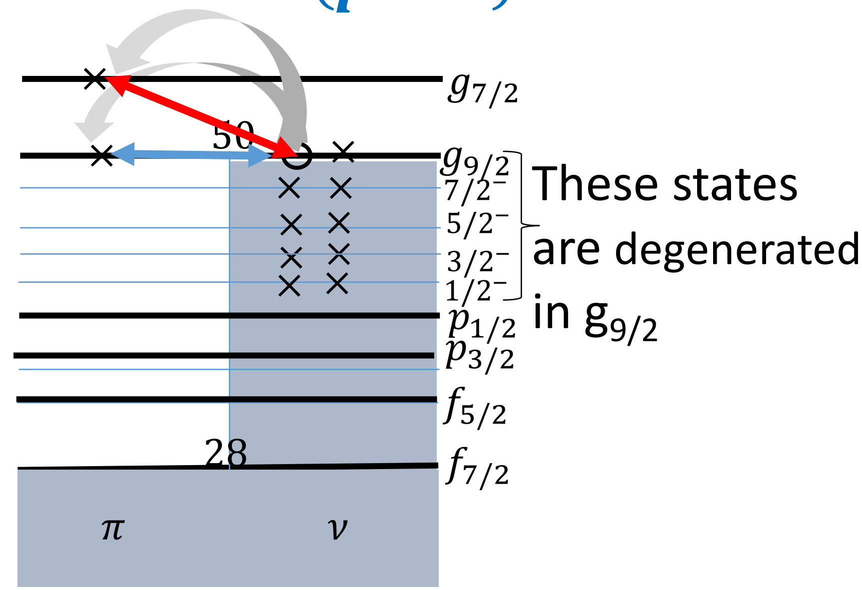
repulsive $(p-h)$



$^{48}_{20}Ca_{28} \rightarrow {}^{48}_{21}Sc_{27}$

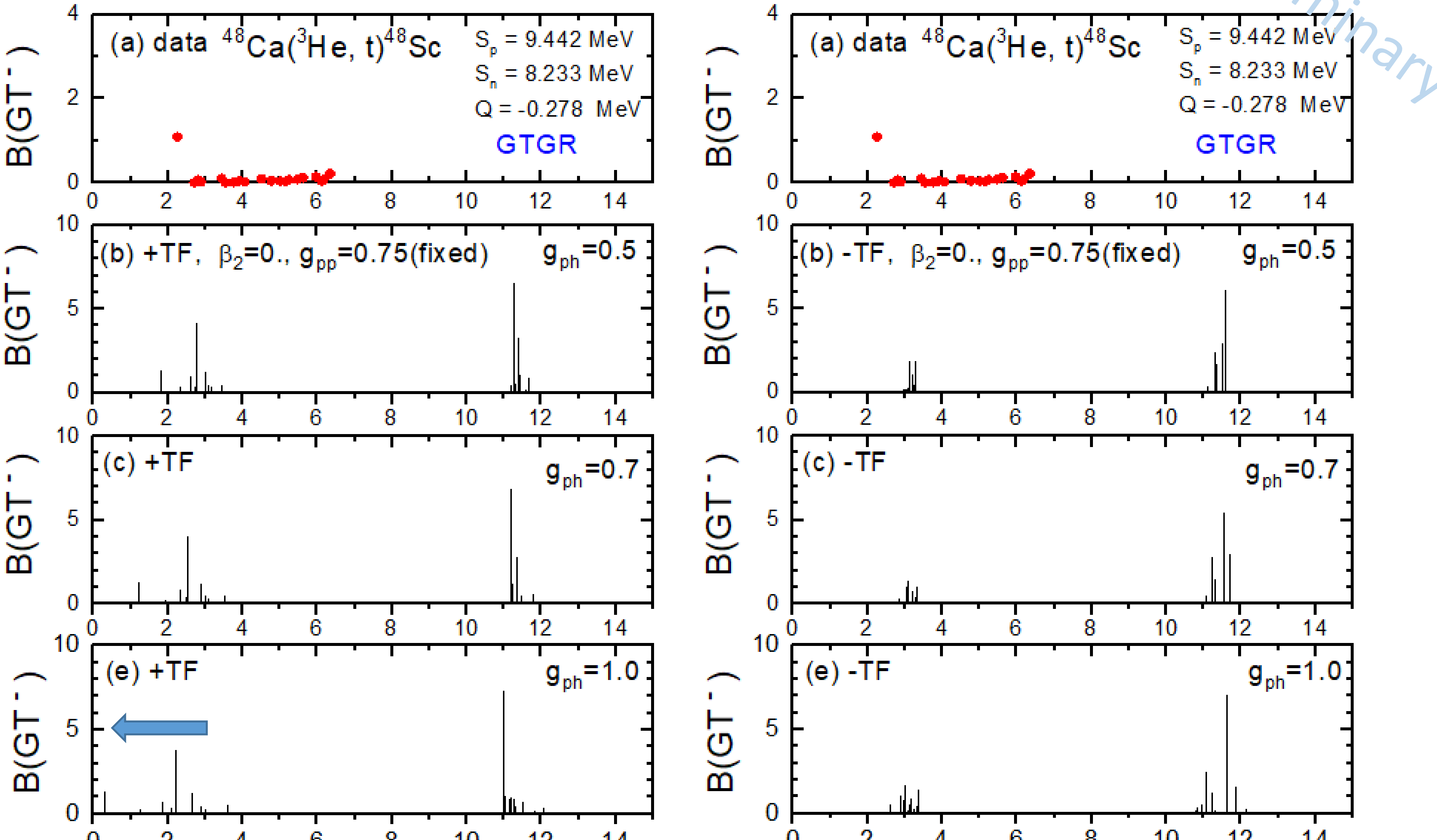
$(f_{7/2}, f_{7/2})$ $(g_{9/2}, g_{9/2})$

attractive $(p-h)$



$^{78}_{28}Ni_{50} \rightarrow {}^{78}_{29}Cu_{49}$

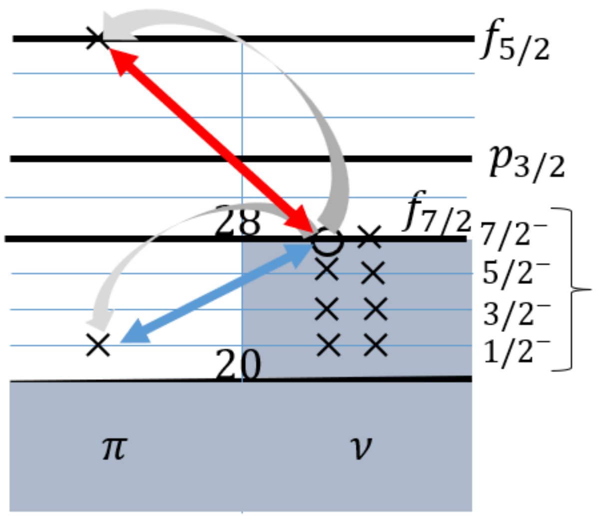
❖ Role of TF in GT states for ^{48}Ca



✓ As the g_{ph} increases, the low-lying excited GT states are shifted to the lower region.

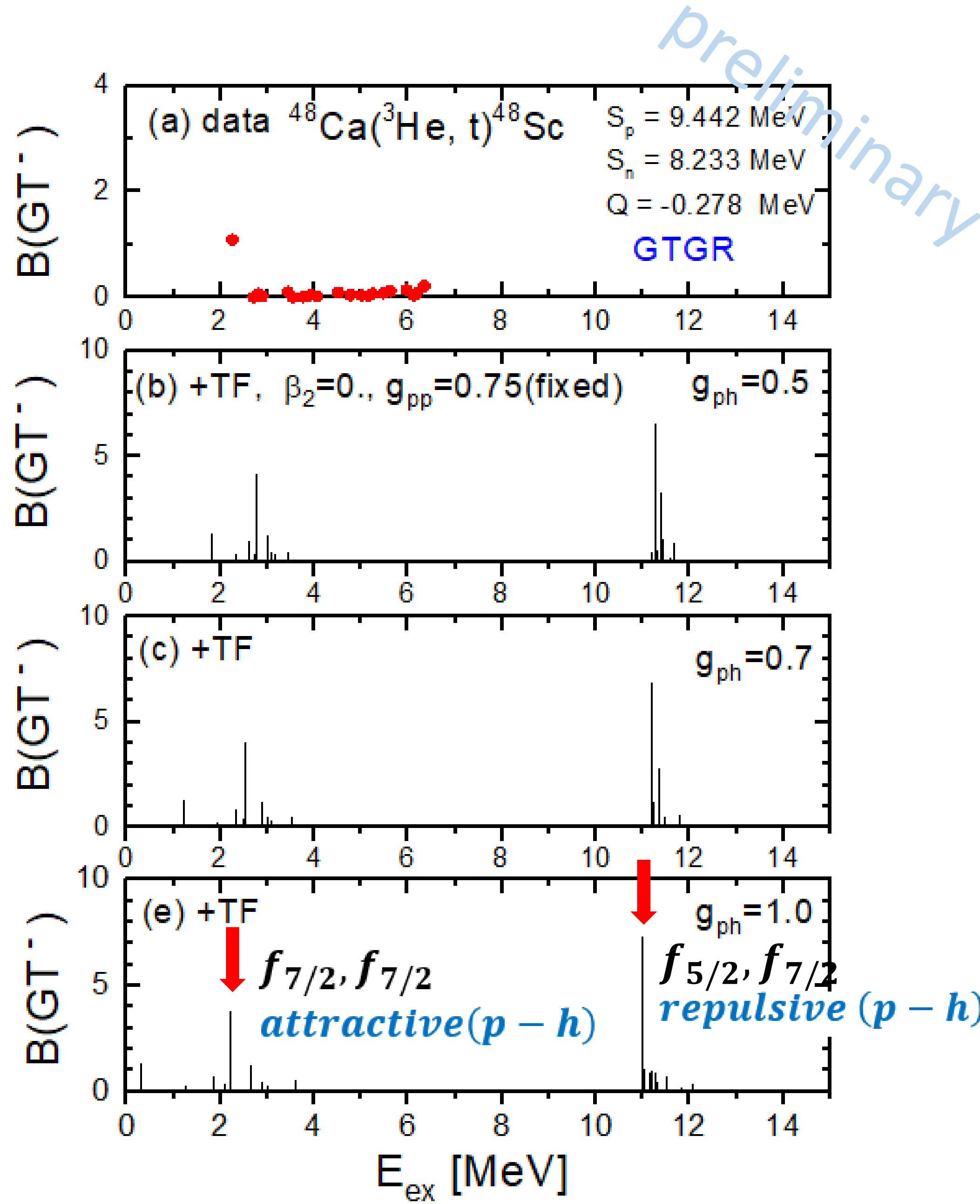
$(f_{5/2}, f_{7/2})\ (g_{7/2}, g_{9/2})$

repulsive $(p-h)$



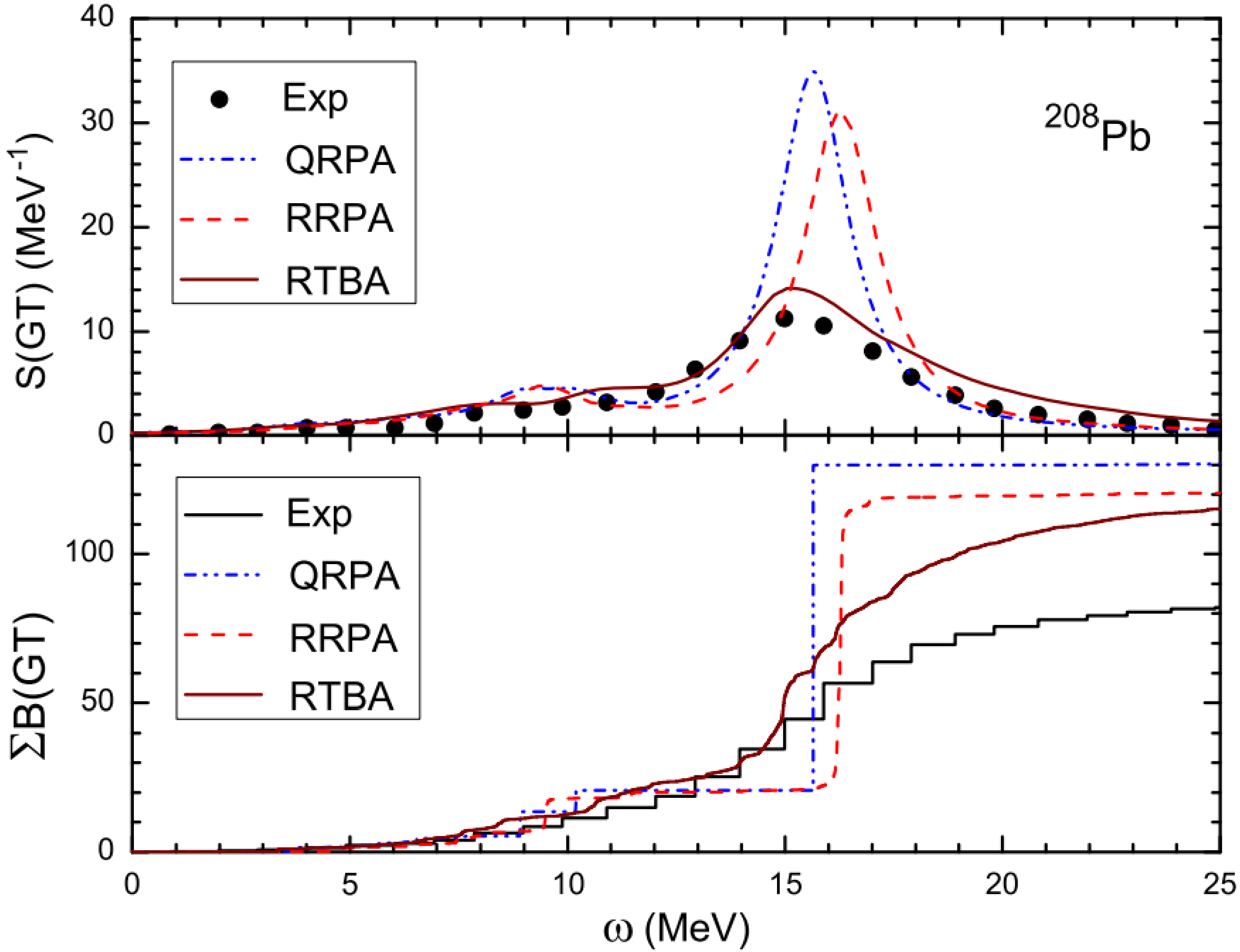
These states are degenerated in spherical nucleus.

$^{48}_{20}Ca_{28} \rightarrow {}^{48}_{21}Sc_{27}$



❖ B(GT) for ^{208}Pb

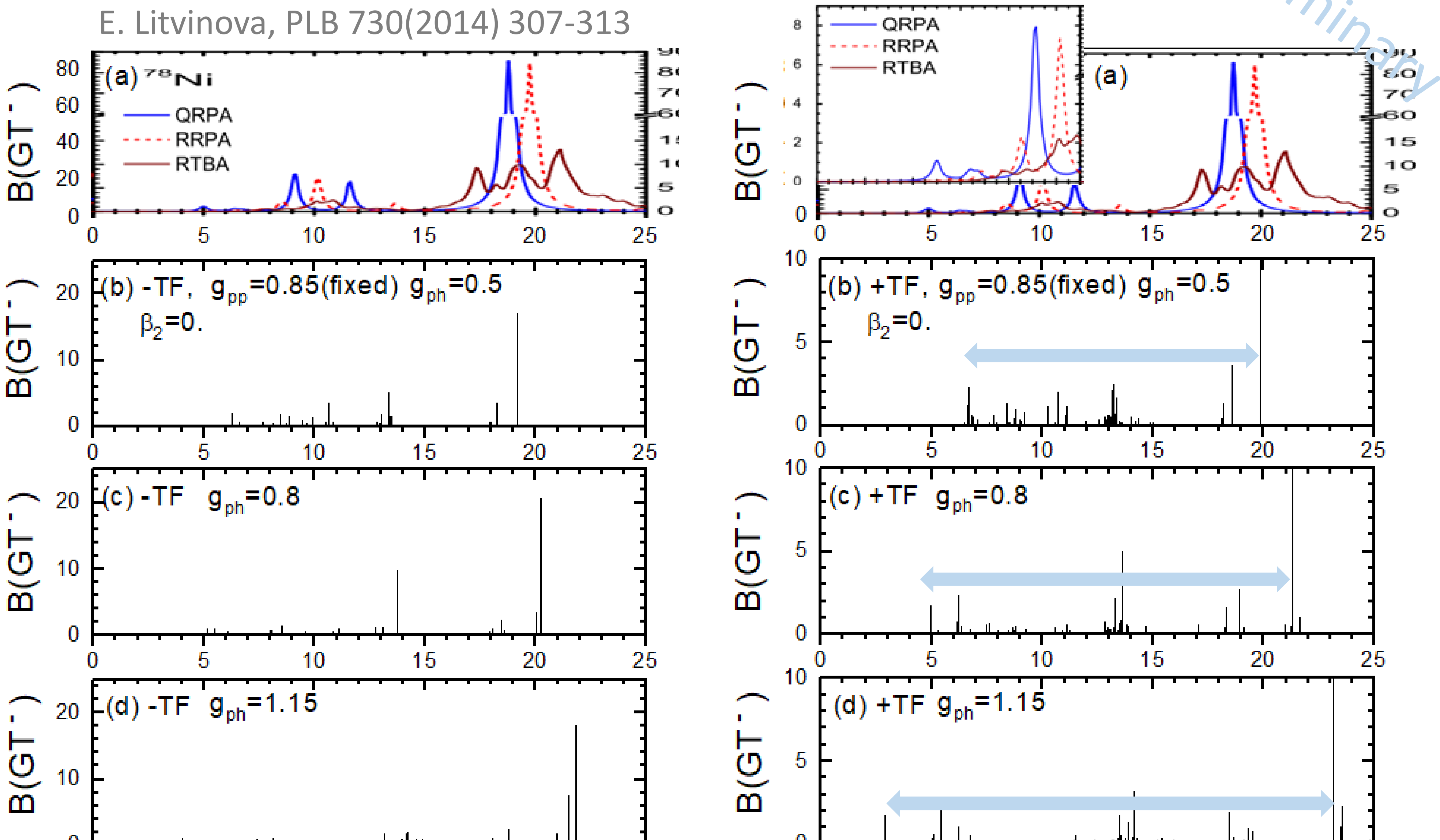
E. Litvinova, PLB 730(2014) 307-313



* RTBA : relativistic time blocking approximation

❖ Role of TF in GT states for ^{78}Ni

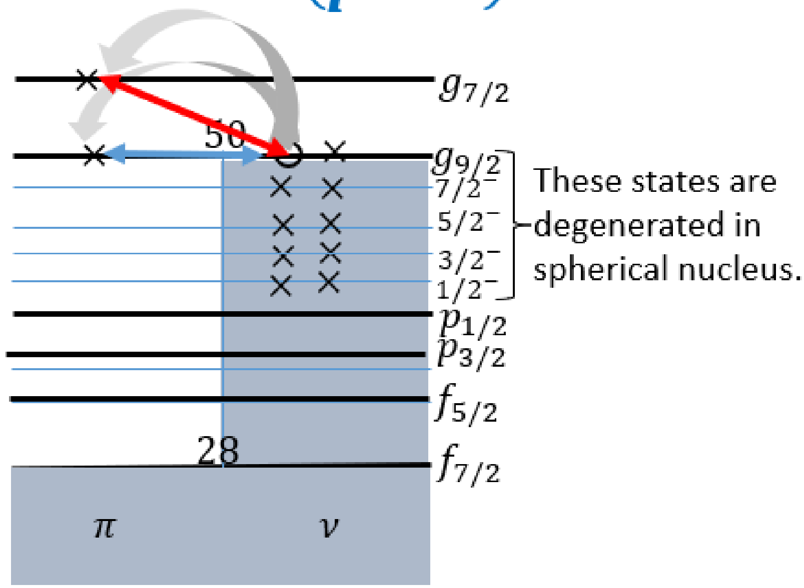
E. Litvinova, PLB 730(2014) 307-313



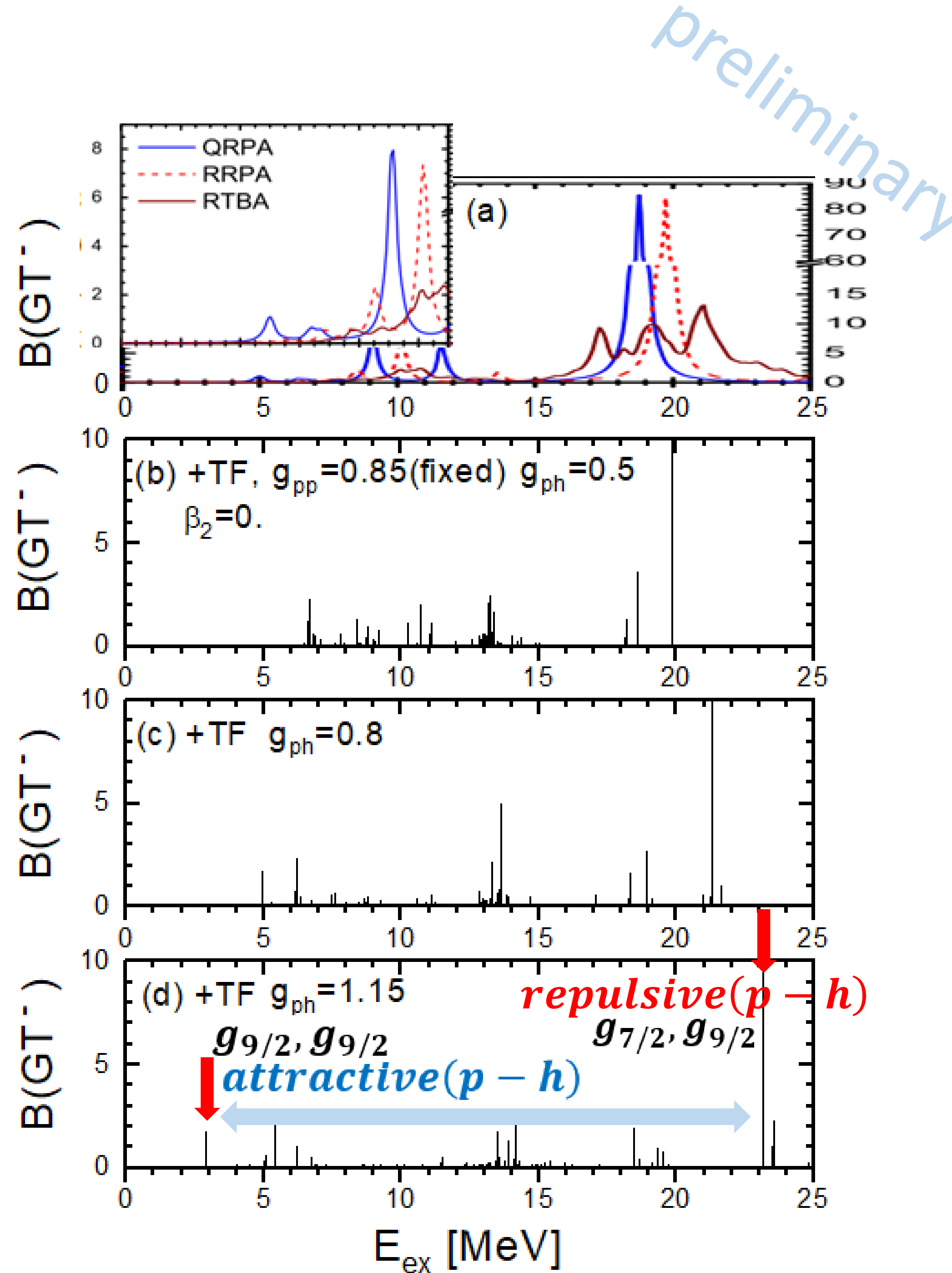
✓ As the g_{ph} increases, the spacing of the first peak and GTGR becomes wider.

$(f_{7/2}, f_{7/2})$ $(g_{9/2}, g_{9/2})$

$\mathbf{attractive(p-h)}$



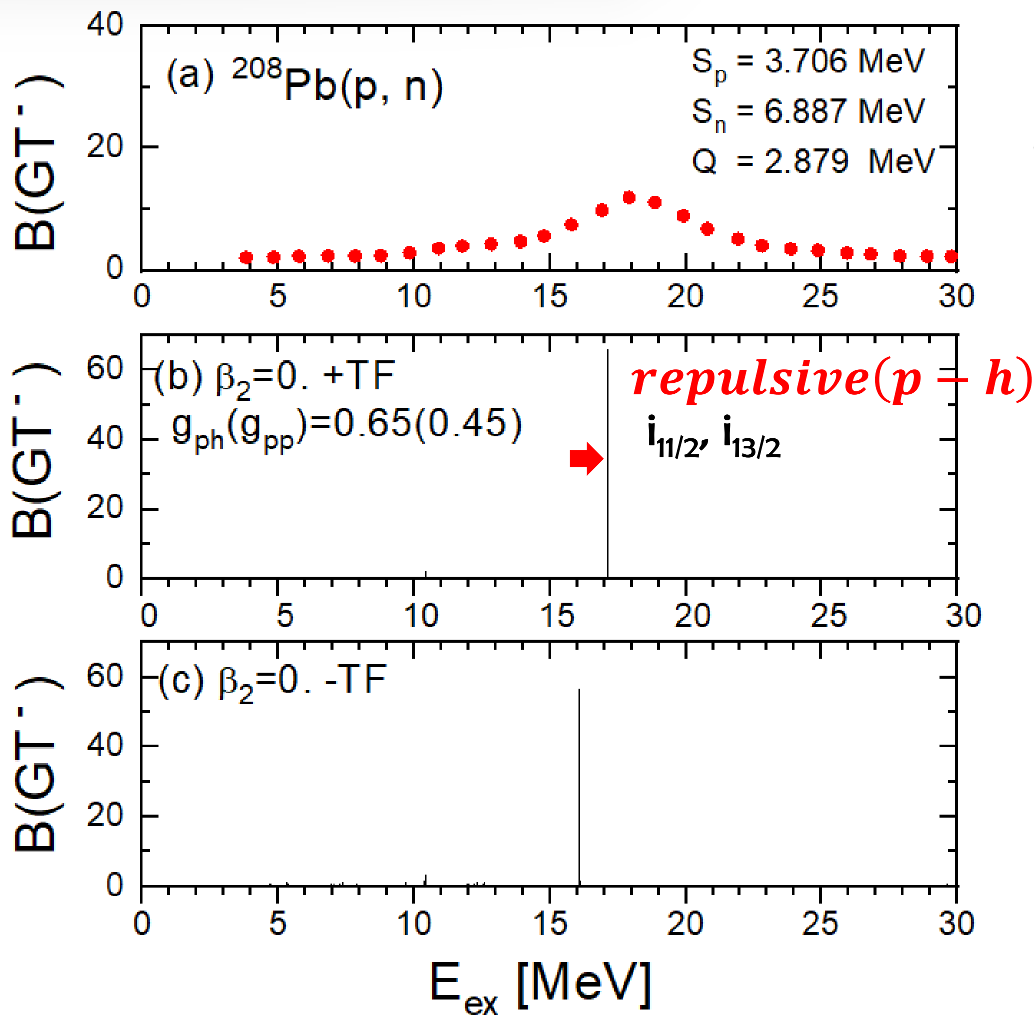
$^{78}_{28}Ni_{50} \rightarrow ^{78}_{29}Cu_{49}$



❖ Role of TF in GT states for ^{208}Pb

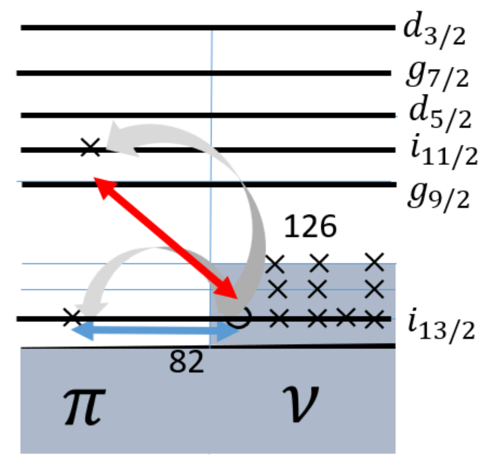
preliminary

T. Wakasa et al., PRC 85(2012) 064600



$\boldsymbol{repulsive\ (p-h)}$

$(i_{11/2}, i_{13/2})$



$^{208}_{82}Pb_{126} \rightarrow {}^{208}_{83}Bi_{125}$

Contents

❖ Summary

1. We investigated the tensor force (TF) effect on the Gamow-Teller transition strength distribution in ^{42,48}Ca and ^{78}Ni.

2. We found that an attractive TF affects not only the ground state but also plays a crucial role in shifting the main GT peak to the low excitation-energy region leading to the LeSGT for ^{42}Ca.

3. GT exited states are sensitive on p-h interaction in TF for ^{48}Ca and ^{78}Ni.

4. GTGR states(first excited states) are shifted to the high-lying(low-lying) energy by effect of repulsive(attractive) TF for ^{48}Ca and ^{78}Ni.

5. This study will also apply to other doubly magic nuclei, ^{132}Sn.