15 Dec. (2016)

Second proton-neutron random phase approximation studied by the Lipkin-Meshkov-Glick (LMG) model in SU(4) group

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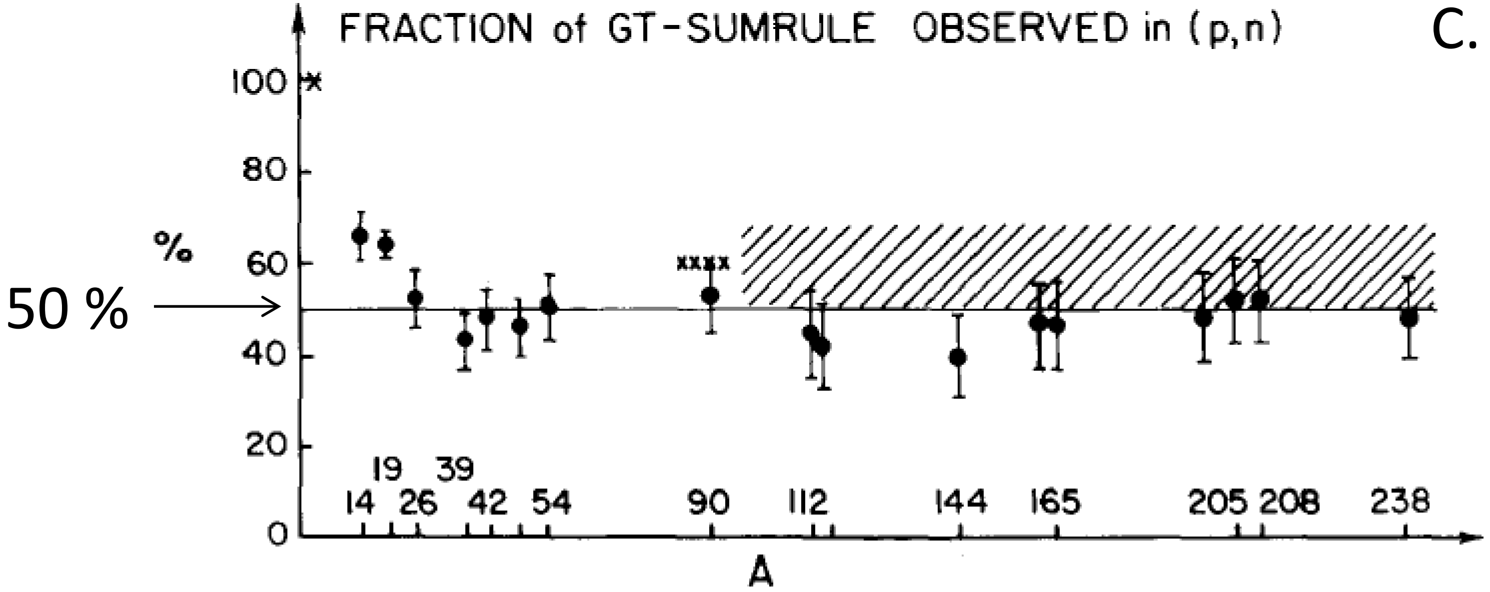
First Tsukuba-CCS-RIKEN joint workshop on microscopic theories of nuclear structure and dynamics (12-16 Dec.)

This work was supported by JSPS KAKENHI Grant No. 25400303.

Background ~ GT Quenching Problem ~

Gamow-Teller (GT) Strength up to E*=30 MeV

C. Gaarde, NPA396(1983) p.127



Two causes which might produce the quenching

1. Δ-h configuration
2. multi particle-multi hole configuration

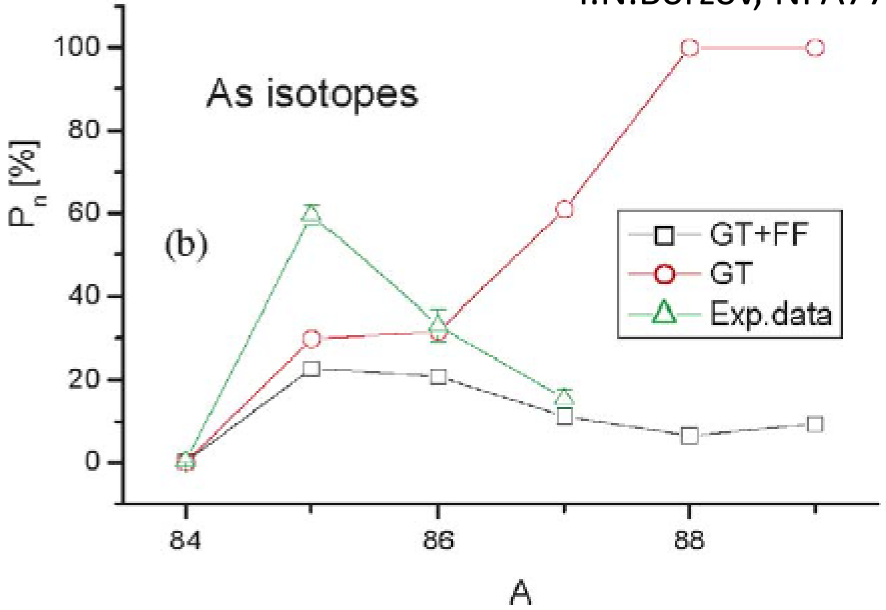
Background ~ β-delayed Neutron ~

Theory can reproduce β Half-lives …

FRDM+QRPA, RHB+QRPA, HFB+QRPA

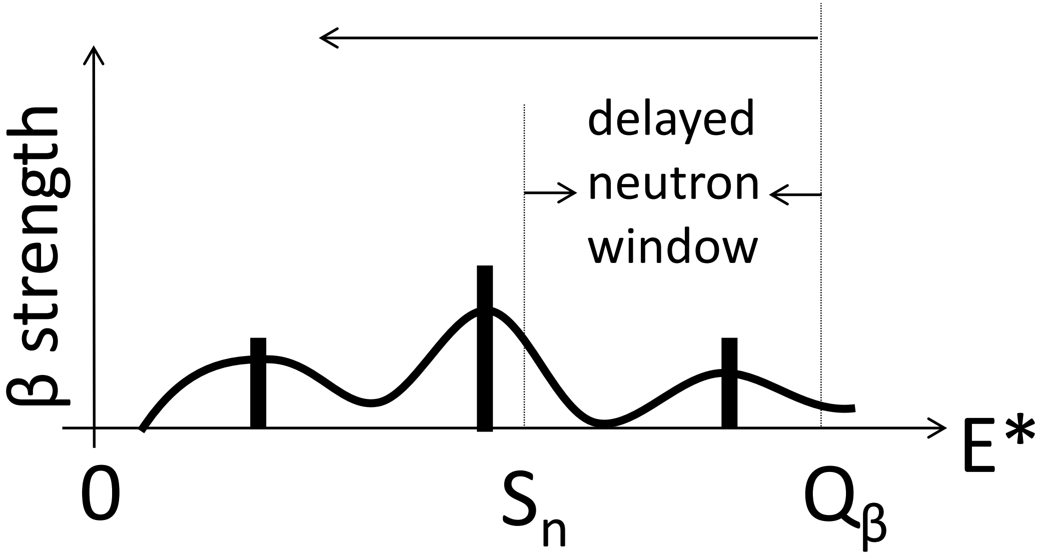
β-delayed Neutron Branching Ratio

I.N.Borzov, NPA777, 645(2006)



Difference between Theory & Exp.

Main Problem causing the difference may be "Spreading Width."



Background ~ Theoretical Works ~

◆1p1h RPA and TDA with Skyrme force

96-99% of sum-rule found in E*<20 MeV

◆2p2h TDA (STDA) with Skyrme FM, PRC **93**, 044319 (2016)

80-88% of Sum-rule in E*<20 MeV for 48Ca

◆Second RPA with G-matrix obtained by Bonn potential (HM3A)

70-75% of Sum-rule in E*< ~20 MeV for 48Ca & 90Zr S. Drozdz, et al., PLB166, 18 (1986)

◆Perturbative calculation G.F. Bertsch and I. Hamamoto, PRC26, 1323 (1982).

About 50 % of Sum-rule for 90Zr.

Does really proton-neutron STDA and SRPA work well?

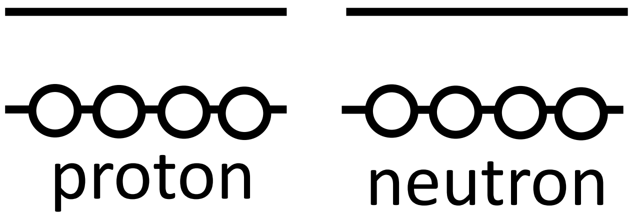
To confirm reliability of proton-neutron STDA & SRPA

We adopt the Lipkin-Meshkov-Glick (LMG) Model

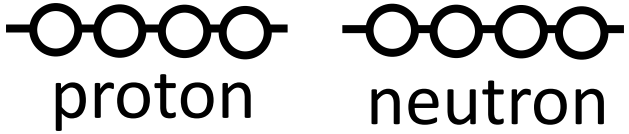
(enable to compare the model with exact solution)

Several Examples:

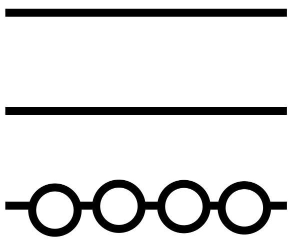
1) proton-neutron QRPA in SO(5) group,
   J. G. Hirsch et al., PRC56, 199 (1997)



2) proton-neutron RPA in SU(2) x SU(2) group,
   S. Stoica et al., PRC64, 017303 (2001)



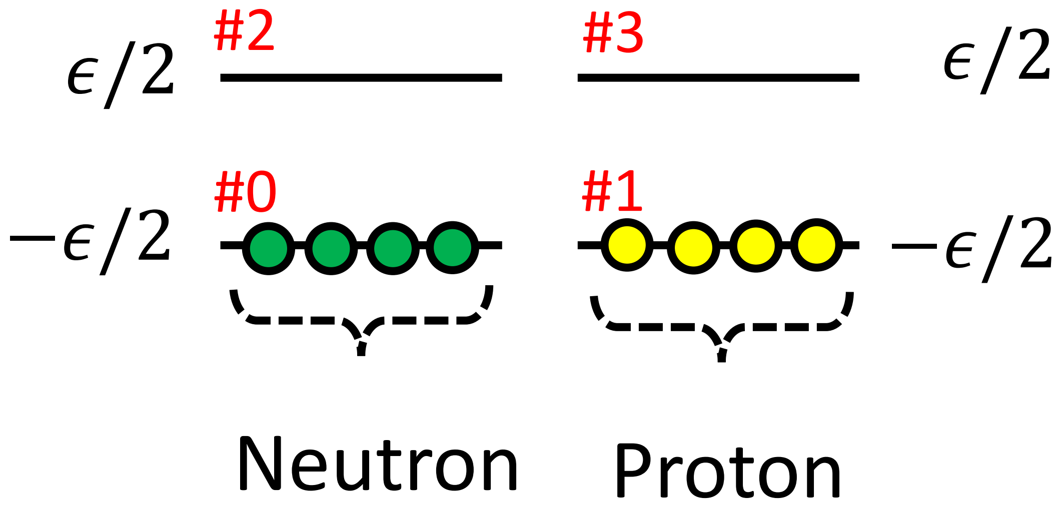
3) SRPA in SU(3) group,
   D. Gambacurta, PRC73, 024319 (2006)



Formalism

pnSRPA and pnSTDA are Investigated by LMG model in **SU(4) group**

Levels



Commutation Relation

$$[K_{ij}, K_{kl}] = \delta_{kj} K_{il} - \delta_{il} K_{kj},$$

where $$K_{ij} = \sum_m a^\dagger_{im} a_{jm}$$

$$K_z \equiv \sum_i K_{ii}$$

Phonon Operator 1p1h $\Theta^+ = K_{30} + K_{21}$

2p2h $\theta^+ = (K_{30} + K_{21})(K_{20} + K_{31})$

- #0 & #1 states are fully occupied by neutron and proton.
- #0 & #2 states are assigned to neutron low and upper states.
- #1 & #3 states are assigned to proton low and upper states, respectively.

Model Hamiltonian

Only $\tau_+\tau_-, \tau_-\tau_+$ channels are considered in two-body interaction

$$H = \sum_i e_i K_{ii} + \underbrace{V_0(K_{21}K_{12} + K_{30}K_{03})}_{\text{p-h}} + \underbrace{V_1(2K_{21}K_{30} + 2K_{12}K_{30})}_{\text{p-p}}$$

$$+\underbrace{V_2(K_{30}K_{23} + K_{21}K_{32} + K_{30}K_{01} + K_{21}K_{10} + c.c)}_{\text{3p-1h \& 1p-3h}} \quad \underbrace{+V_3(K_{23}K_{32})}_{\text{4p}}$$

--- Model parameters ---

$$V_0 = 0.2\epsilon/N \quad V_1 = \kappa\epsilon/N \quad V_2 = -\kappa\epsilon/(5N) \quad V_3 = \kappa\epsilon/(25N) \quad N = N_n + N_p$$

We will see the excitation energy and transition strength as a function of κ

Exact Wave Function

$$|\Phi\rangle = \sum_{\alpha,\beta,\gamma,\delta} C_{\alpha\beta\gamma\delta}\,|N_n - \beta - \gamma, N_p - \alpha - \delta, \alpha + \gamma, \beta + \delta\rangle$$

$$= \sum_{\alpha,\beta,\gamma,\delta} C_{\alpha\beta\gamma\delta}\,(K_{21})^{\alpha}(K_{30})^{\beta}(K_{20})^{\gamma}(K_{31})^{\delta}|HF\rangle$$

Dimension to be solved $\propto N^4$

$C_{\alpha\beta\gamma\delta}$ are derived from diagonalization of H with $|\Phi\rangle$

Formalism

proton neutron RPA

D. Gambacurta, PRC73, 024319 (2006)

$$Q^\dagger = \frac{X\Theta^+ - Y\Theta^-}{\sqrt{\langle HF|[\Theta^-,\Theta^+]|HF\rangle}}$$

RPA ground state

$$Q|RPA\rangle = 0$$

$$|RPA\rangle \Rightarrow |HF\rangle$$

RPA Equation

$$\begin{pmatrix} A & B \\ B^* & A^* \end{pmatrix}\begin{pmatrix} X \\ Y \end{pmatrix} = \hbar\omega \begin{pmatrix} G & 0 \\ 0 & -G^* \end{pmatrix}\begin{pmatrix} X \\ Y \end{pmatrix}$$

proton neutron SRPA

$$Q^\dagger = \frac{X\Theta^+ - Y\Theta^-}{\sqrt{\langle HF|[\Theta^-,\Theta^+]|HF\rangle}} + \frac{\mathcal{X}\theta^+ - \mathcal{Y}\theta^-}{\sqrt{\langle HF|[\theta^-,\theta^+]|HF\rangle}}$$

SRPA Equation

$$\begin{pmatrix} \mathcal{A} & \mathcal{B} \\ \mathcal{B}^* & \mathcal{A}^* \end{pmatrix}\begin{pmatrix} \mathcal{X} \\ \mathcal{Y} \end{pmatrix} = \hbar\omega \begin{pmatrix} \mathcal{G} & 0 \\ 0 & -\mathcal{G}^* \end{pmatrix}\begin{pmatrix} \mathcal{X} \\ \mathcal{Y} \end{pmatrix}$$

$$\mathcal{A} = \begin{pmatrix} A & A_{12} \\ A_{21} & A_{22} \end{pmatrix} \quad \mathcal{B} = \begin{pmatrix} B & 0 \\ 0 & 0 \end{pmatrix}$$

Transition Operator

$\beta^- transition$

$$M^- = \chi \sum_{mm\prime} a^\dagger_{3m} a_{0m\prime}$$

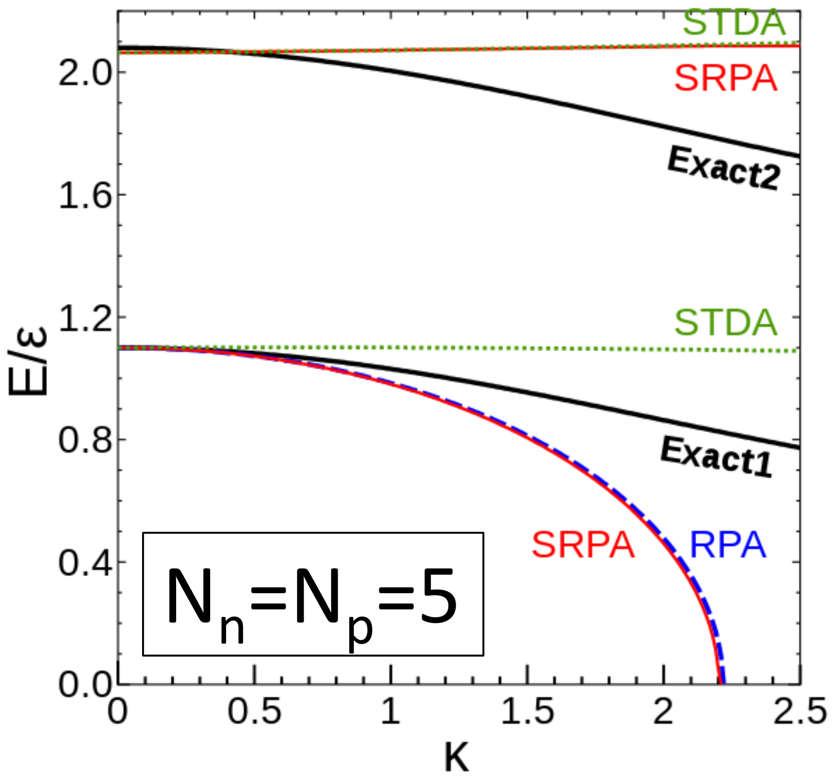
$\beta^+ transition$

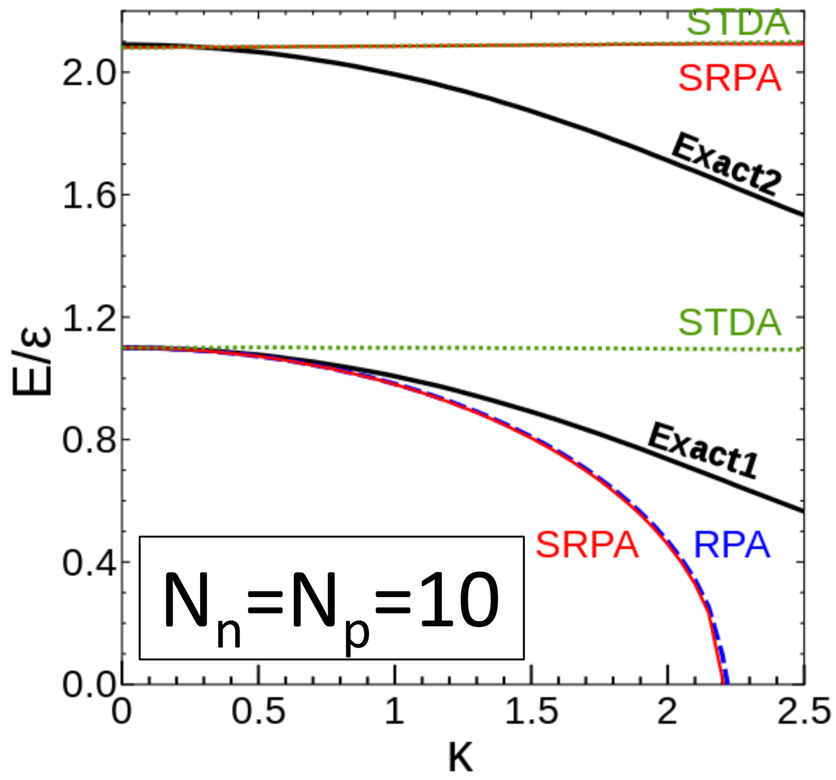
$$M^+ = \chi \sum_{mm\prime} a^\dagger_{2m} a_{1m\prime}$$

Result: Excitation Energy

2nd Excited State →

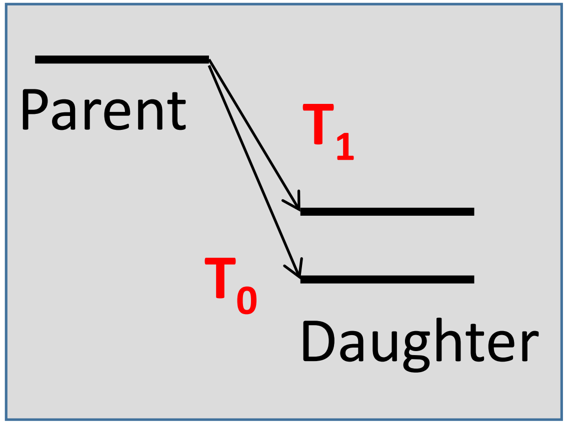
1st Excited State →





1. At small κ, RPA, SRPA, STDA are in a good agreement with the exact.
2. For 1st Excitation energy, RPA & SRPA are close.
3. For 2nd Excitation energy, SRPA & STDA are close.

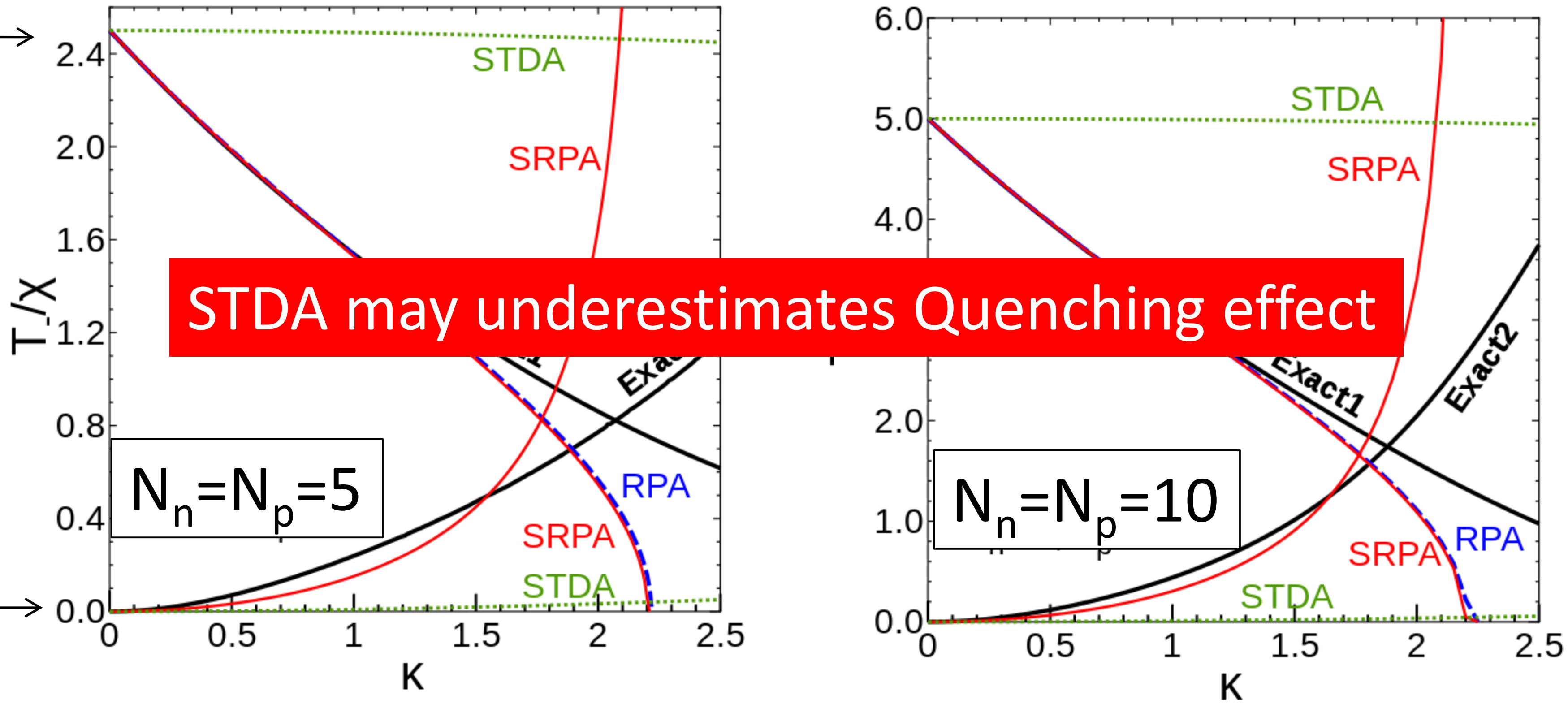
Result: Transition Strength of β-



T_0 of 1st Excited State

T_1 of 2nd Excited State

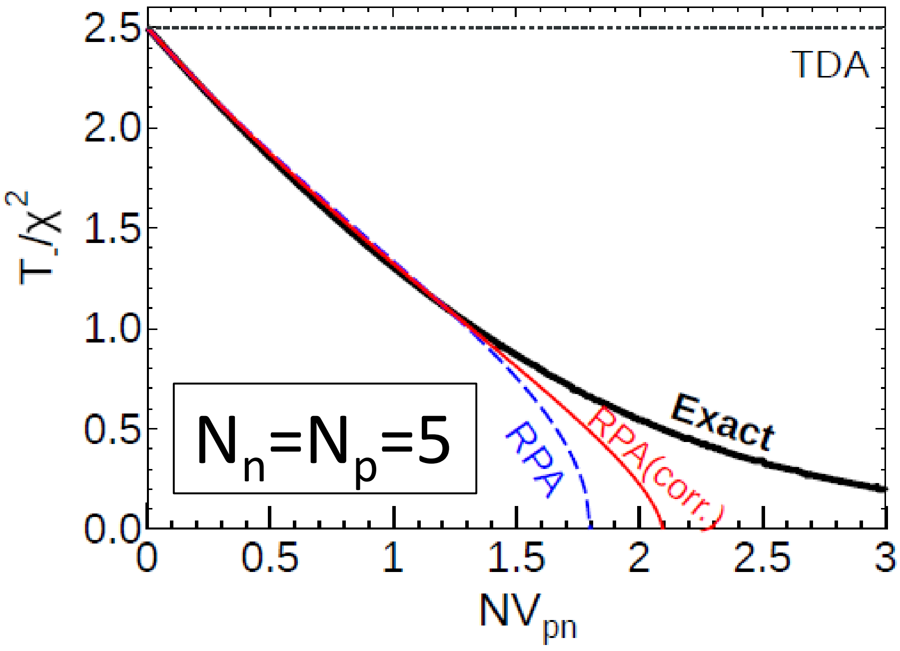
STDA may underestimates Quenching effect



1. For T_0, RPA and SRPA work well up to κ=1.5.
2. For T_1, SRPA works reasonably up to κ=1.5.
3. For both T_0 and T_1, STDA shows a large deviation from the exact from a small κ.

1) SRPA takes into account ground state correlation to some extent, which STDA doesn't.

2) The same difference is obtained between RPA and TDA →

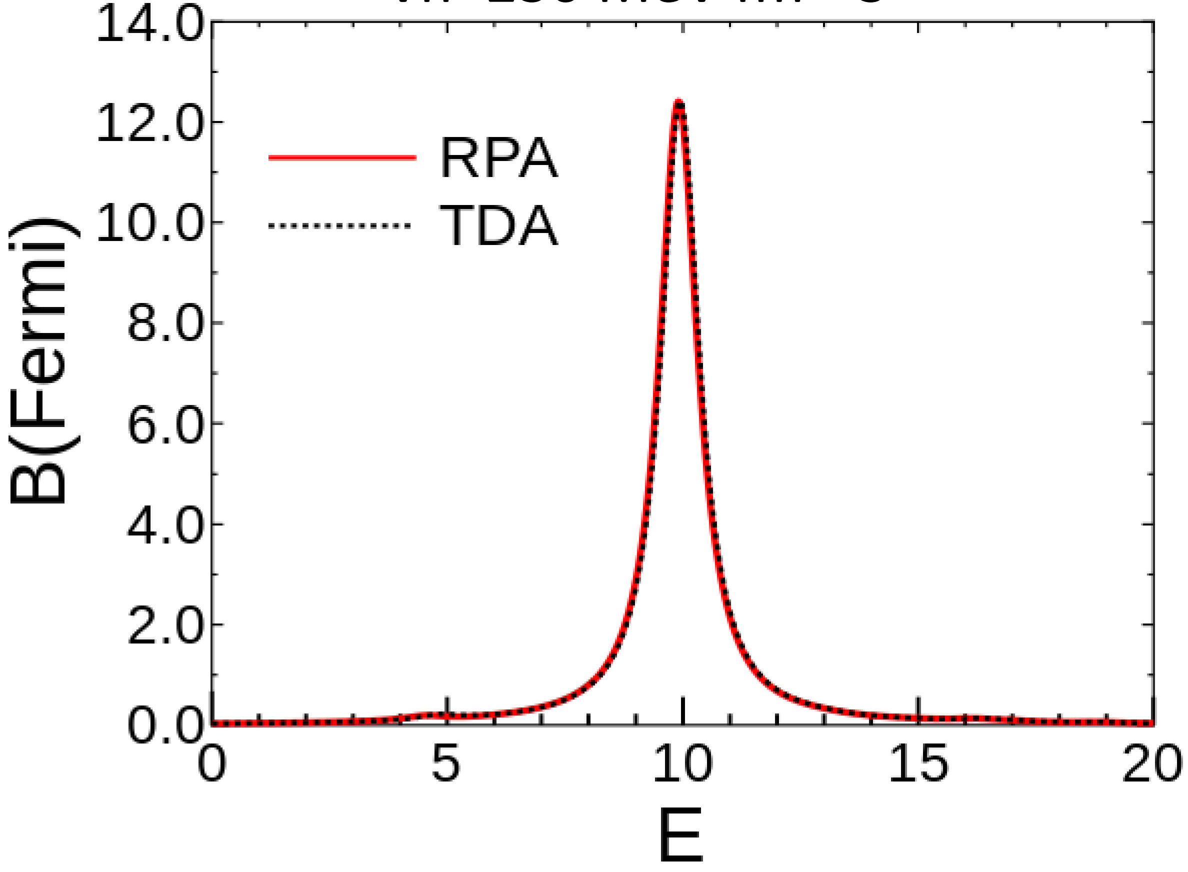


3) In the charge exchange channel, the ground state correlation generally doesn't play a significant role. Namely, we usually see results at small κ in a realistic nucleus (see Next Slide)

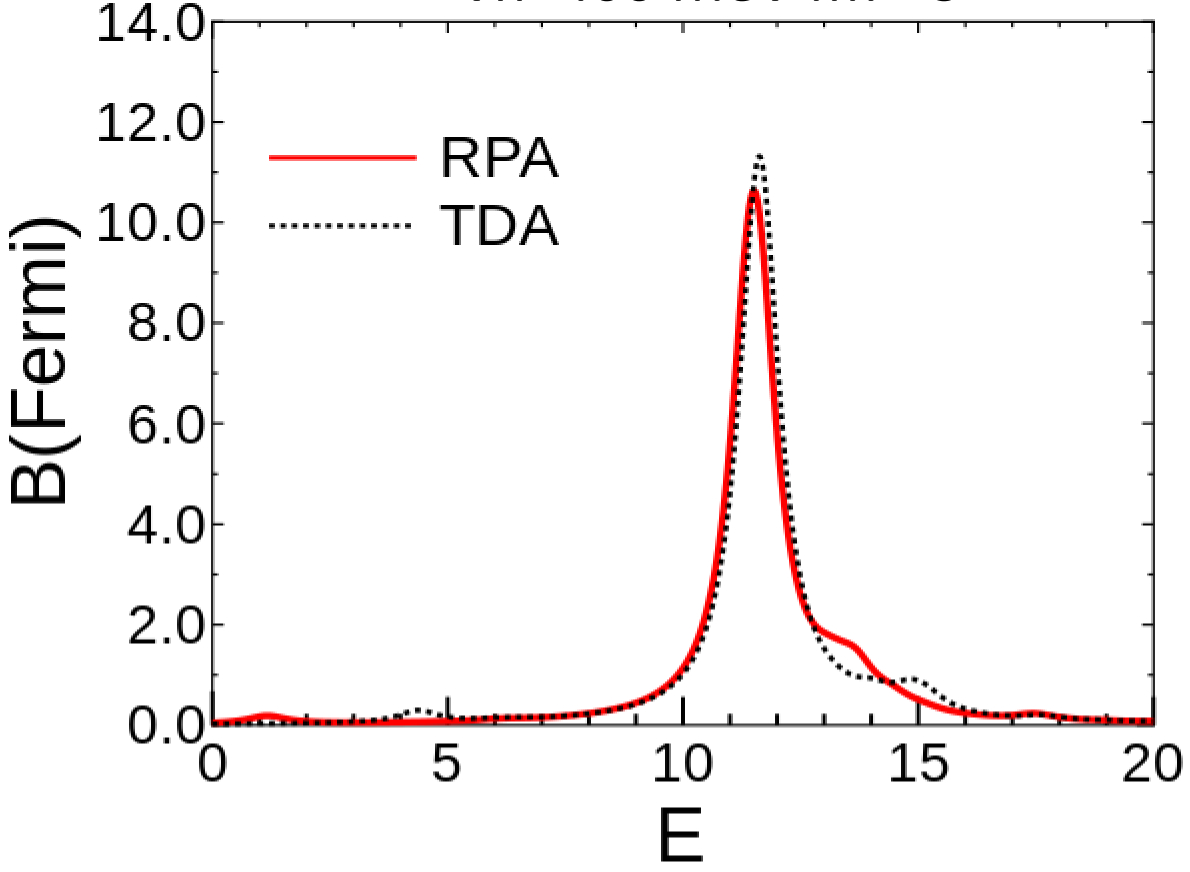
4) But we have used zero-range force in STDA. We might have used a large κ?? ← Further analysis is in progress.

Result: 120Sn Fermi Transision

Volume type pairing
Vn=230 MeV fm^-3



Volume type pairing
Vn=400 MeV fm^-3



If ground state significantly differs from HF state, TDA shows different distribution from RPA.

Summary

Investigate proton-neutron SRPA & STDA with LMG Model in SU(4) group

1) At small κ, SRPA & STDA work well for excited state
But, STDA is now accurate enough for transition strength

This might be one of the factors producing difference SRPA and STDA calculations on the GT quenching effect.

2) SRPA seems to work well as compared the exact solution.
Higher correlation is required ? or we cannot exclude a contribution of Δ-h coupling to explain the quenching problem.