Low Energy Gamow-Teller Transitions in deformed $N = Z$ odd-odd Nuclei

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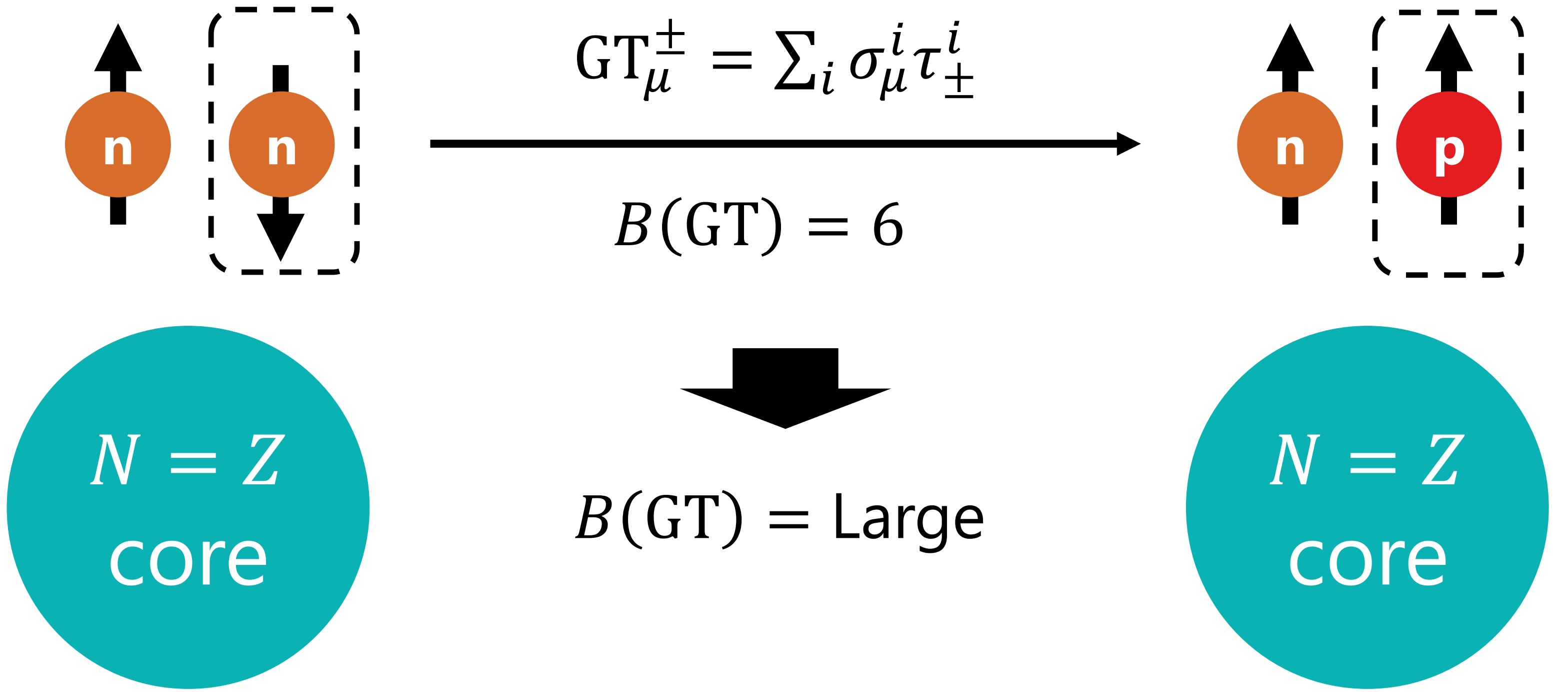
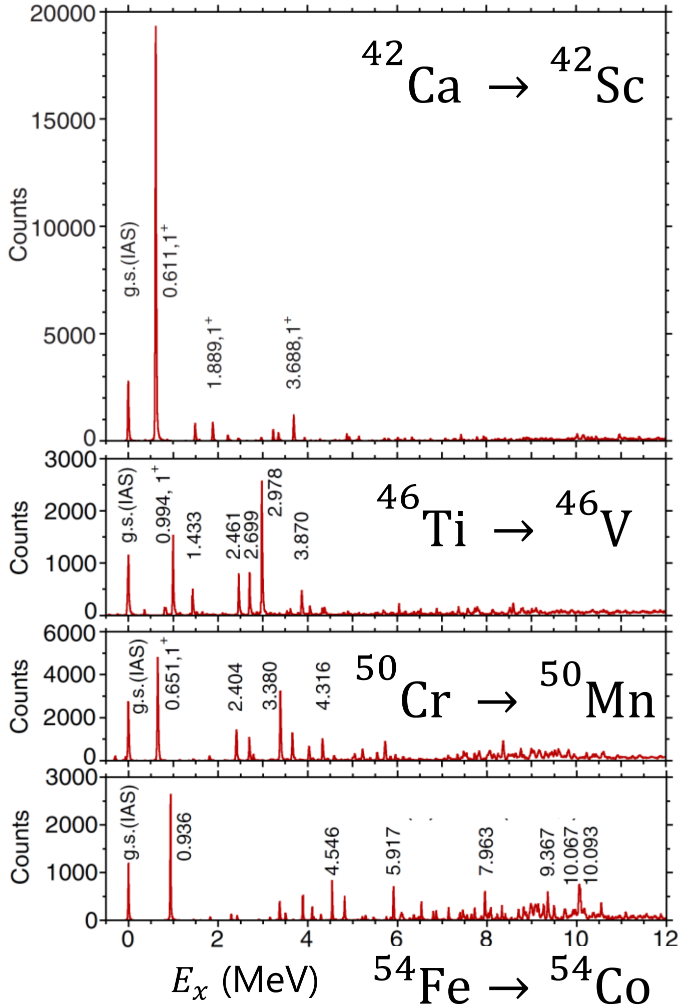
Gamow-Teller operator as a probe for spin-isospin-flip phenomena



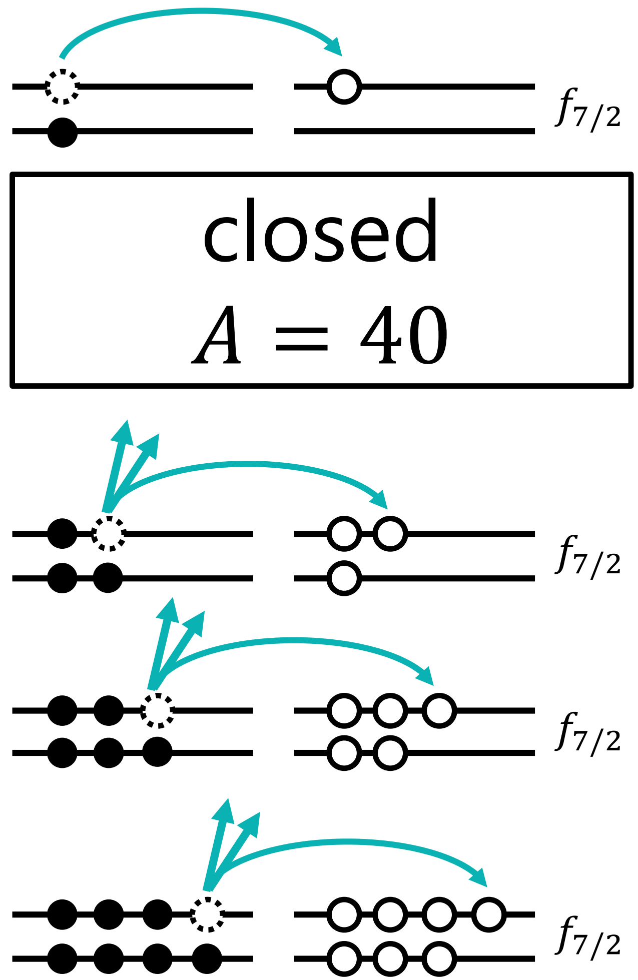
- The Gamow-Teller(GT) operator flips spin(s) and isospin(τ).
- For free NN particle, the GT strength is $B(\mathrm{GT}) \approx 6$.
- Even for NN with core nucleus, $B(\mathrm{GT})$ should be large if the core nuclei have $S = 0$ and $T = 0$ (saturated).

Low-Energy GT transitions($0_1^+ 1 \rightarrow 1_n^+ 0$) in pf-shell

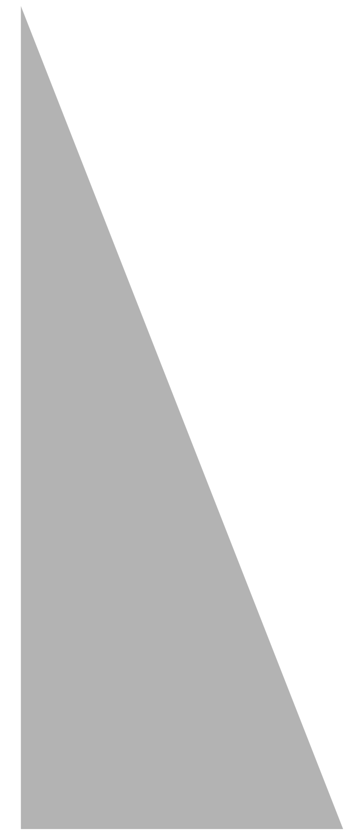
$N = Z + 2 \rightarrow N = Z = \text{odd}$



neutron proton



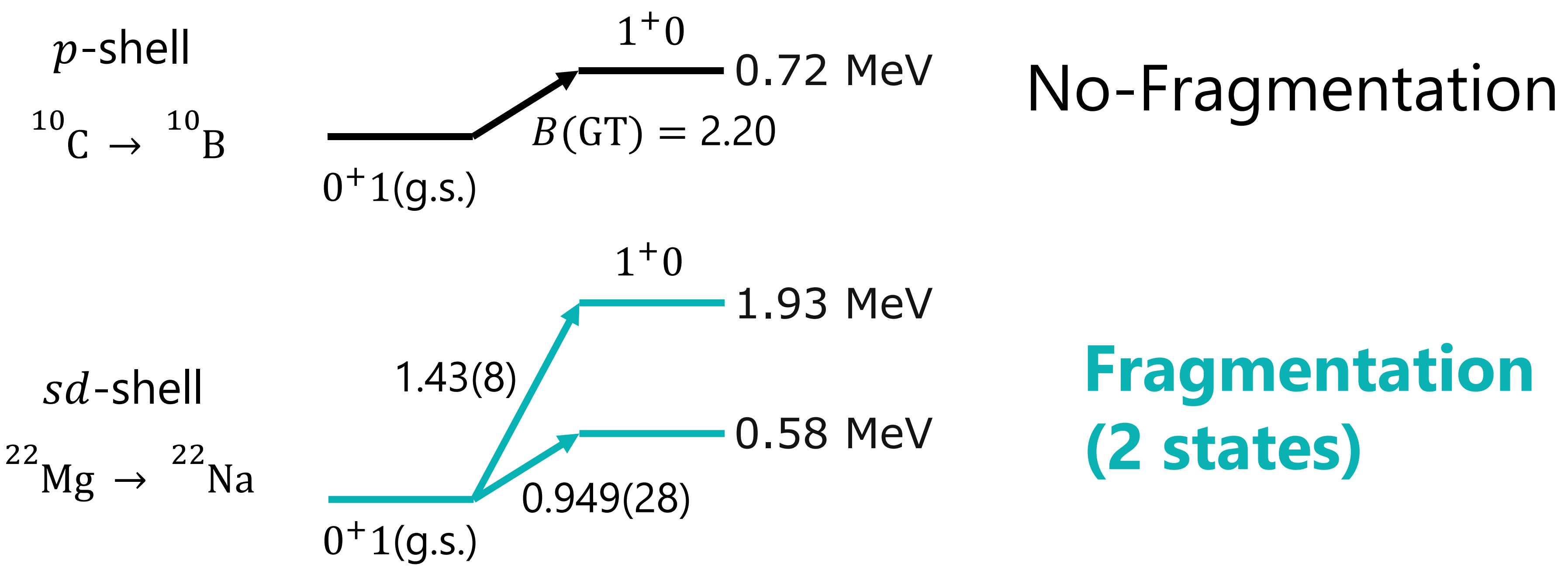
Concentration



Fragmentation (many states)

↑ Fig. 1 from Y. Fujita et al., Phys. Rev. Lett. 112, 112502 (2014)

Super allowed GT transitions($0^+_1 1 \rightarrow 1^+_n 0$) in p- and sd- shell deformed nuclei (experiment)



- Strong GT transitions $0^+1 \rightarrow 1^+0$ are found.
- The strength from ^{10}C is concentrated to $1^+_1 0$ while that from ^{22}Mg splits into $1^+_{1,2}0$.
- The sums of the B(GT) have comparable values between ^{10}C and ^{22}Mg.

Aim of this work

- **The fragmentations in GT($0_1^+1 \rightarrow 1_n^+0$) strengths of p- and sd- $N = Z =$ odd nuclei**
  - » Precursors for multi-fragmentations in heavier nuclei (including pf-shell)
  - » Dependence for deformation and LS interactions
- **The detailed descriptions for final 1^+0 states**
  - » Band structure caused by deformation and pn-pair correlation
  - » Comparison with Nilsson orbit
- **The difference between p-(^{10}B) and sd-shell(^{22}Na)**
  - » Existence of cluster structures
  - » The correspondence between the 2^+ states on g.s.-band and 1^+ final states

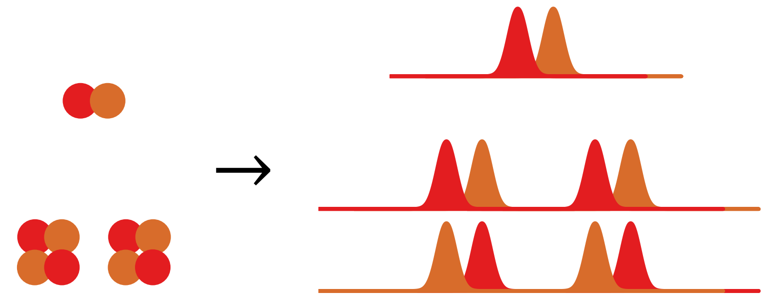
The framework of isospin projected AMD + GCM

Wave function

$$|\Phi\rangle = \mathcal{A}|\phi_1\rangle|\phi_2\rangle \dots |\phi_A\rangle$$

$$|\phi_i\rangle = \left(\frac{2\nu}{\pi}\right)^{\frac{4}{3}} \exp\left[-\nu\left(\boldsymbol{r}_i - \frac{\boldsymbol{Z}_i}{\sqrt{\nu}}\right)^2\right]|\xi_i\rangle|n_i\rangle$$

$|n_i\rangle = |p\rangle$ or $|n\rangle$ $\quad \nu =$ $0.235\ \mathrm{fm}^{-2}$ p-shell, $0.16\ \mathrm{fm}^{-2}$ sd-shell



Gaussian wave packet

A. Ono, H. Horiuchi, T. Maruyama and A. Onishi, Phys. Rev. Lett. 68 2898 (1992).

Hamiltonian

$$H = H_{\mathrm{phys}} + H_{\mathrm{const}}$$

$$H_{\mathrm{const}} = \eta_1[(\boldsymbol{\beta}\cos\boldsymbol{\gamma} - X)^2 + (\boldsymbol{\beta}\sin\boldsymbol{\gamma} - Y)^2]$$

T. Suhara and Y. Kanada-En'yo, Prog. Theor. Phys. 123, 303 (2010).

→control nuclear deformation and spatial development of the pn pair

Energy variation & GCM

HM and Y. Kanada-En'yo, Prog. Theor. Exp. Phys. 2016, 103D02 (2016)

$$\delta \frac{\langle\Phi|HP^{\pi}\boldsymbol{P^T}|\Phi\rangle}{\langle\Phi|P^{\pi}\boldsymbol{P^T}|\Phi\rangle} = 0 \qquad |\Psi\rangle = \sum_i c_i|\Phi_i\rangle$$

→control the isospin of the pn pair in valence orbit

Hamiltonian

$$H_{\mathrm{phys}} = K - K_{\mathrm{cm}} + \sum_{i<j} v_{\mathrm{c}}^{ij} + \sum_{i<j} v_{\mathrm{ls}}^{ij} + \sum_{i<j} v_{\mathrm{Coulomb}}^{ij}$$

Volkov No2

$$v_{\mathrm{c}}^{ij} = \left\{ v_1 \exp\left[-\left(\frac{r_{ij}}{a_1}\right)^2 \right] + v_2 \exp\left[-\left(\frac{r_{ij}}{a_2}\right)^2 \right] \right\} (w + bP_\sigma - hP_\tau - mP_\sigma P_\tau)$$

v_1=-60.65 MeV a_1=1.80 fm w=0.40

v_2=61.14 MeV a_2=1.01 fm b=h= 0.06

LS part of G3RS

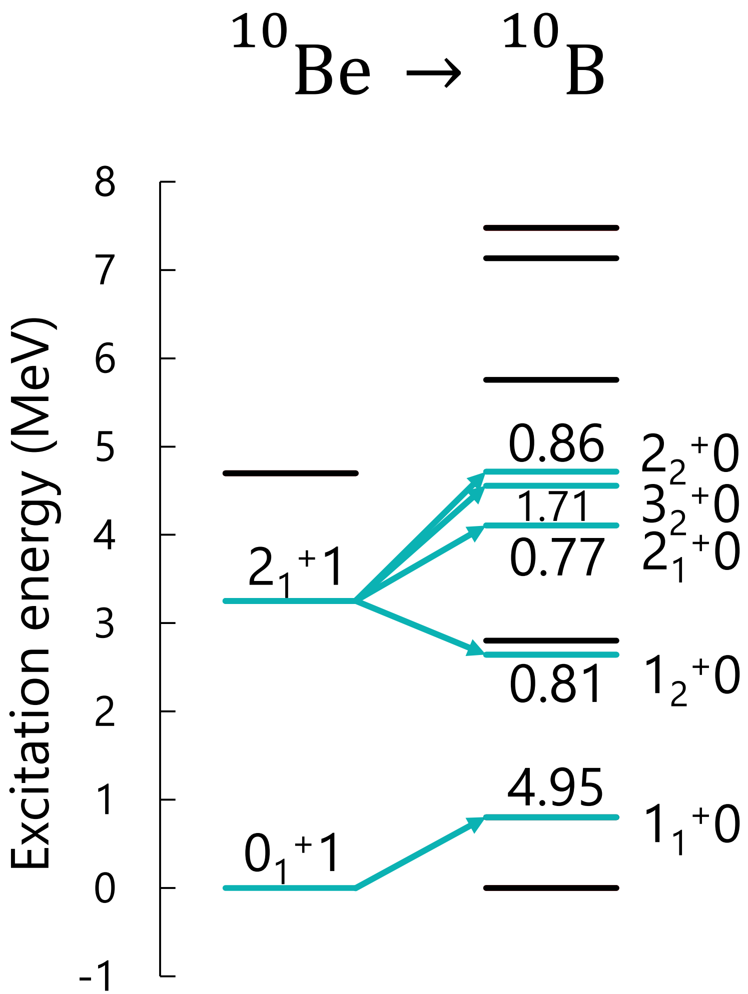
$$v_{\mathrm{ls}}^{ij} = \left\{ u_1 \exp\left[-\left(\frac{r_{ij}}{b_1}\right)^2 \right] + u_2 \exp\left[-\left(\frac{r_{ij}}{b_2}\right)^2 \right] \right\} \frac{1 + P_\sigma}{2} \frac{1 + P_\sigma P_\tau}{2} \boldsymbol{l}_{ij} \cdot \boldsymbol{s}_{ij}$$

$u_1 = -u_2$=1300 MeV on AMD variation
$u_1 = -u_2$=0-2600 MeV on GCM for analysis

b_1=0.60 fm

b_2=0.447 fm

Fragmentation of GT strength in ^{10}B and ^{22}Na



HM and Y. Kanada-En'yo, Phys. Rev. C **96**, 044318

strong

- $0_1^+1 \to \mathbf{1_1^+0}$
  - » **No-fragmentation**
  - » Super allowed ($B(\mathrm{GT}) \approx 6$)
- $2_1^+1 \to \mathbf{1_2^+0}, 2_{1,2}^+0, 3_2^+0$
  - » g.s.-band member($K = 0$)
  - » 1_2^+0 corresponds to 2_1^+1.
  - » Super allowed ($\sum B(\mathrm{GT}) = 4.15 \approx 6$)

weak

- $B(\mathrm{GT}; 0_1^+1 \to \mathbf{1_2^+0}) = 0.15$
- $B(\mathrm{GT}; 2_1^+1 \to \mathbf{1_1^+0}) = 0.06$

Fragmentation of GT strength in ^{10}B and ^{22}Na

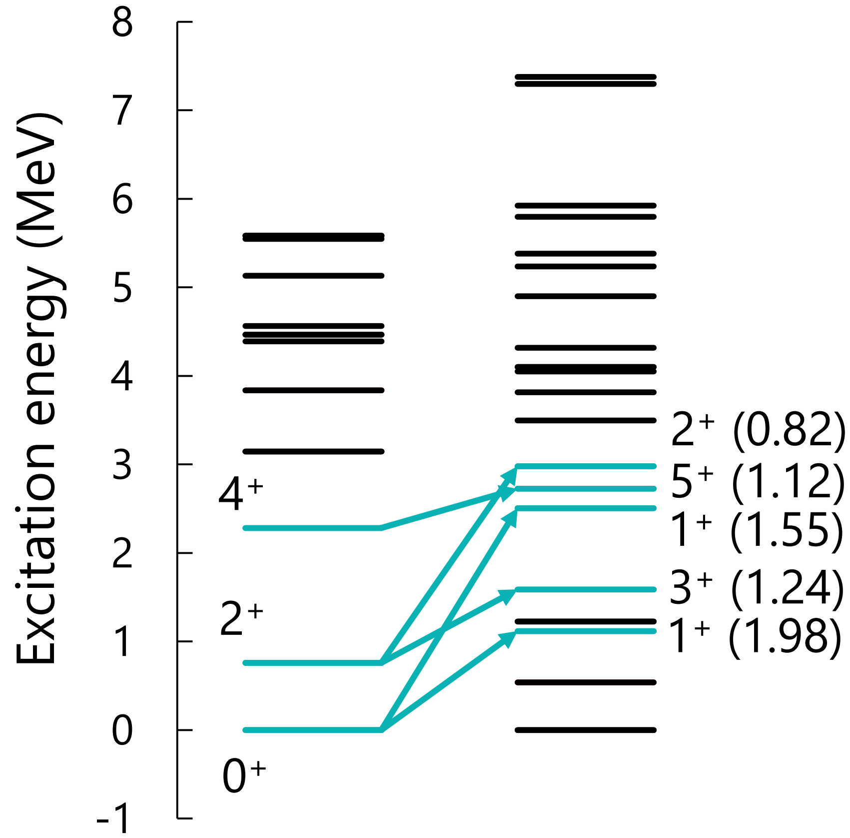
strong

- $0^+_1 1 \rightarrow \mathbf{1^+_{1,2} 0}$
  - » **Fragmentation (2 states)**
  - » Super allowed ($\sum B(\mathrm{GT}) = 3.53 \approx 6$)
- $2^+_1 1 \rightarrow 2^+_1 0, 3^+_2 0$
  - » g.s.-band member($K = 0$)
  - » Super allowed ($\sum B(\mathrm{GT}) = 2.06 \approx 6$)
- $4^+_1 1 \rightarrow 5^+_2 0$
  - » g.s.-band member($K = 0$)
  - » $B(\mathrm{GT}) = 1.12$

weak

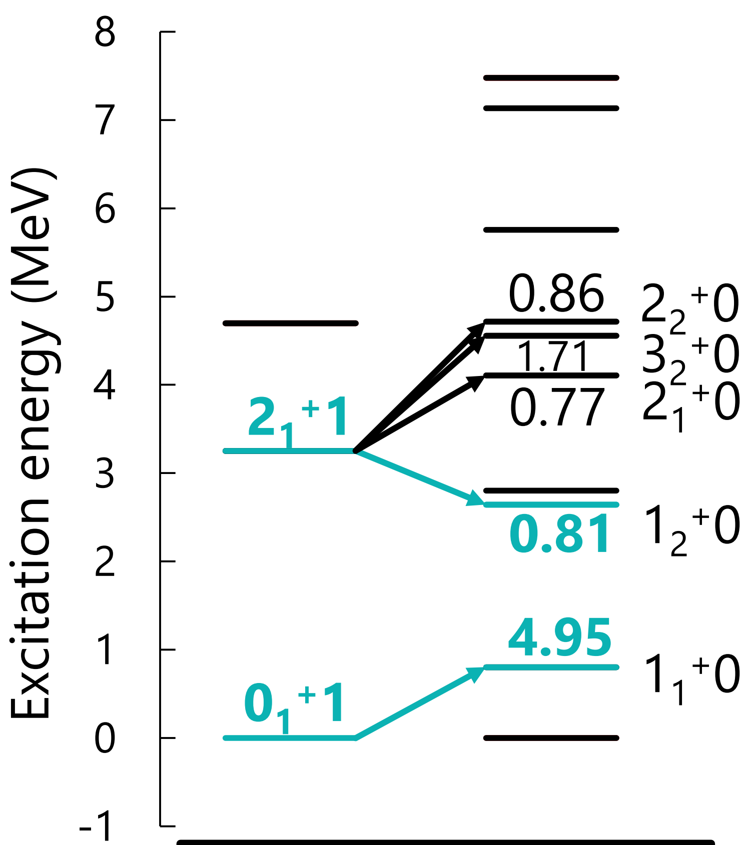
- $B(\mathrm{GT}; 2^+_1 1 \rightarrow \mathbf{1^+_1 0}) = 0.30$
- $B(\mathrm{GT}; 2^+_1 1 \rightarrow \mathbf{1^+_2 0}) = 0.37$

$^{22}\mathrm{Ne} \rightarrow {}^{22}\mathrm{Na}(T = 0)$

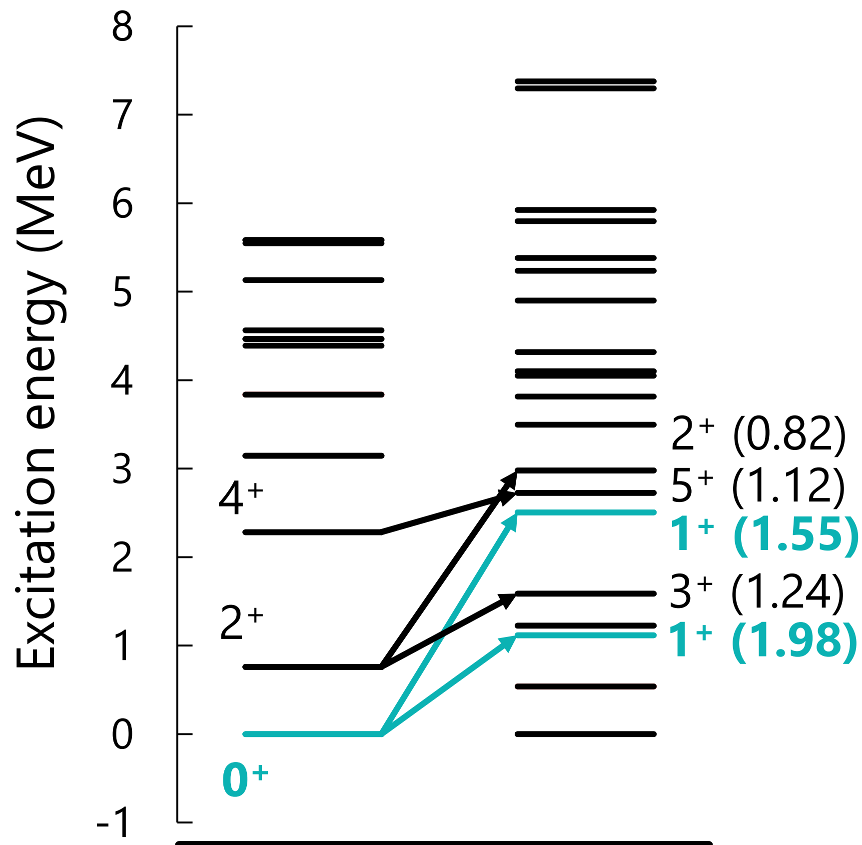


Fragmentation of GT strength in ^{10}B and ^{22}Na

$^{10}\mathrm{Be} \rightarrow {}^{10}\mathrm{B}$



$^{22}\mathrm{Ne} \rightarrow {}^{22}\mathrm{Na}(T=0)$



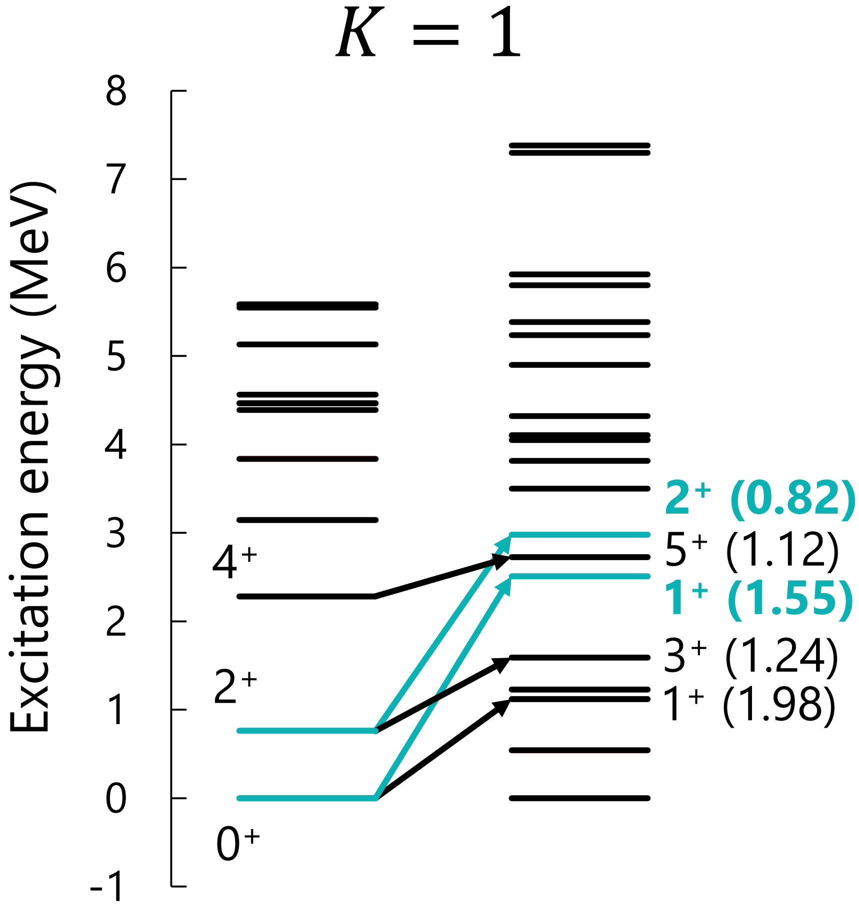
No-Fragmentation

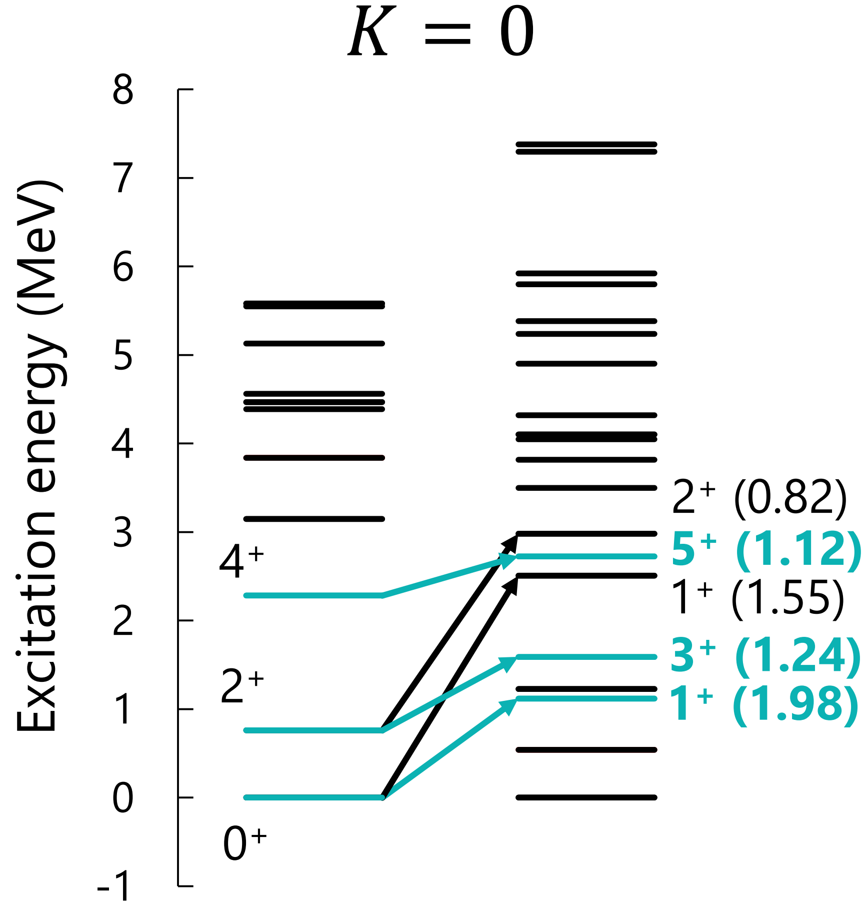
$0_1^+1 \rightarrow \mathbf{1_1^+0}$

Fragmentation

$0_1^+1 \rightarrow \mathbf{1_{1,2}^+0}$

$^{22}\mathrm{Na}(1^+_{1,2}0)$ states as K-band heads





$\mathbf{1^+_2 0}$ has 76.6% $K = 1$ component

[211 +3/2]^n[211 -1/2]^p

spin aligned($S_z = \pm 1$)

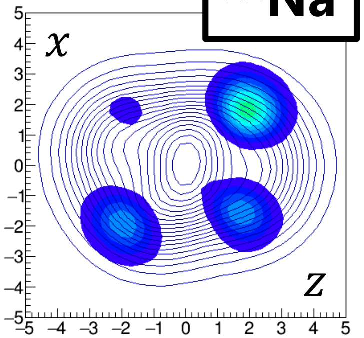
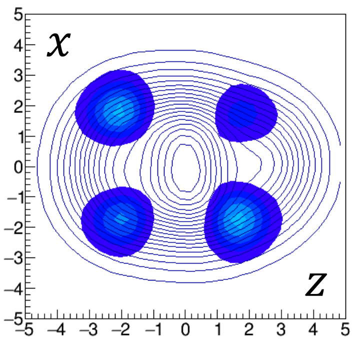
$\mathbf{1^+_1 0}$ has 82.7% $K = 0$ component

[211 +3/2]^n[211 -3/2]^p

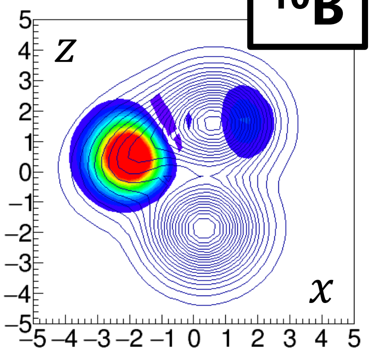
spin anti-aligned($S_z = 0$)

Spatial development of the pn pair and K-quanta

^{22}Na

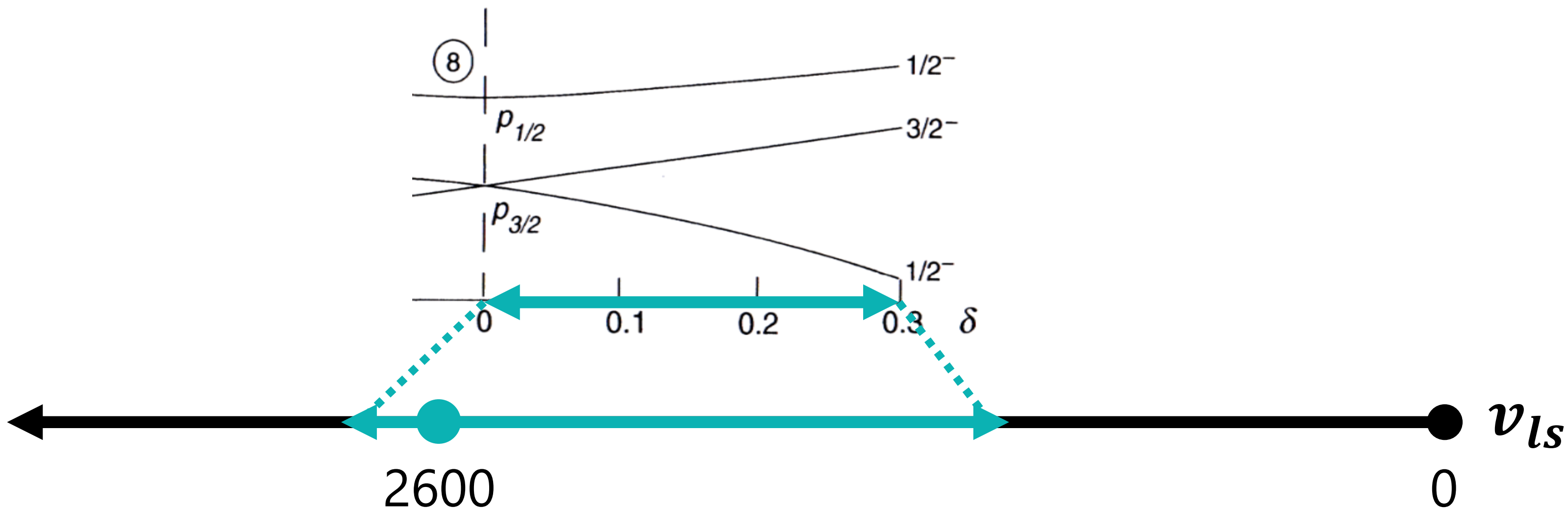
$1^+_2 0$ 	$K = 1$	[211 +3/2]^n[211 -1/2]^p	• The pn-pair is near the ^{20}Ne core. • K is a good quantum number because of strong deformation.
$1^+_1 0$ 	$K = 0$	[211 +3/2]^n[211 -3/2]^p	

^{10}B

$1^+_1 0$ 	K-mixing	$2\alpha + pn$	• The pn-pair is separated from the 2α core. • K-mixing occurs as a result of spatial development of the pn pair.

Dependence of deformation and LS interaction on GT strengths

- Deformation parameter can be mapped into spin-orbit interaction strength(v_{ls}).



- We change v_{ls} on GCM diagonalization from 0 MeV to 2600 MeV for same GCM bases.

$$\delta \frac{\langle \Phi | H P^{\pi} P^{T} | \Phi \rangle}{\langle \Phi | P^{\pi} P^{T} | \Phi \rangle} = 0 \quad \longrightarrow \quad |\Psi\rangle = \sum_i c_i |\Phi_i\rangle$$

$v_{ls} = 1300$ MeV

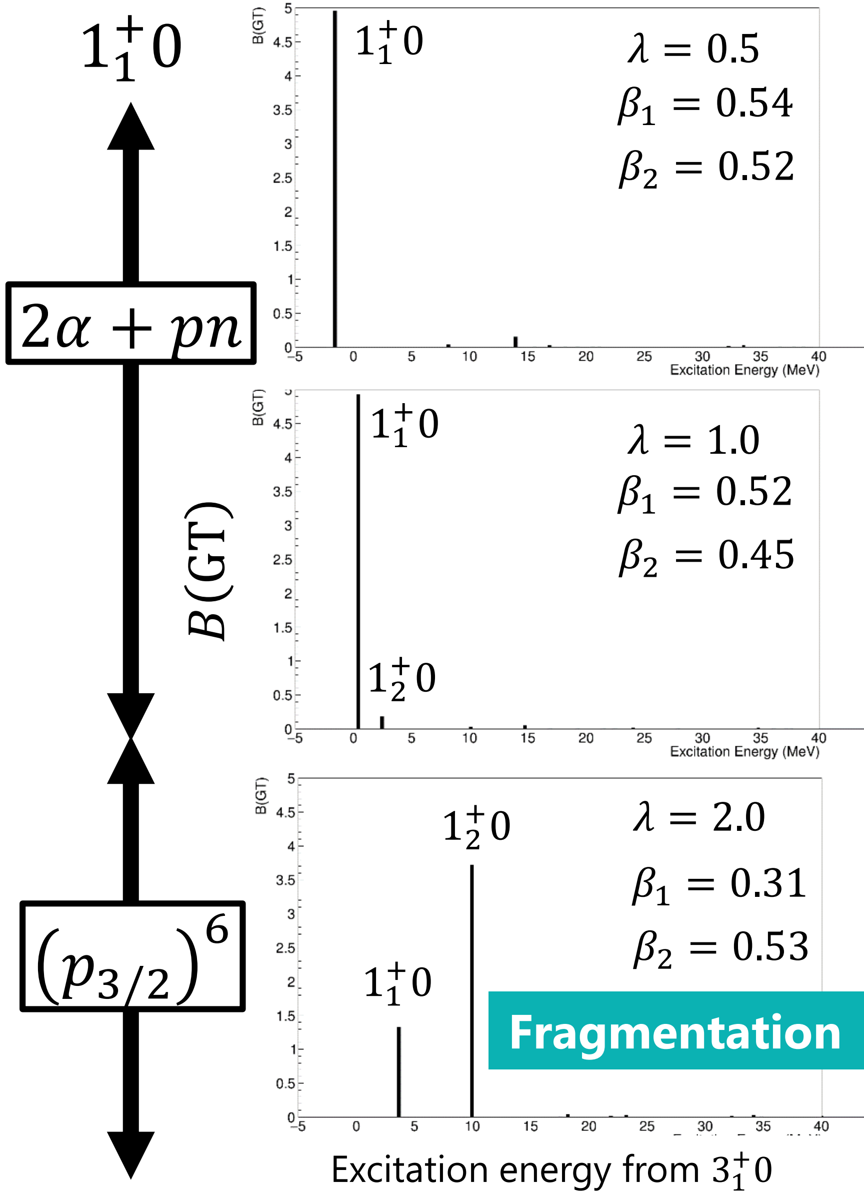
$v_{ls} = \lambda \times 1300$ MeV ($\lambda = 0 \sim 2$)

Dependence of deformation and LS interaction on GT strengths

- $^{10}\mathrm{Be}(0_1^+1) \rightarrow {}^{10}\mathrm{B}(1_n^+0)$
  - » $\beta(1_1^+0)$ decreases
  - » $\beta(1_2^+0)$ does not change
  - » **Fragmentation occurs ($\lambda = 2.0$)**
  - » GT strengths are pushed up to higher energy

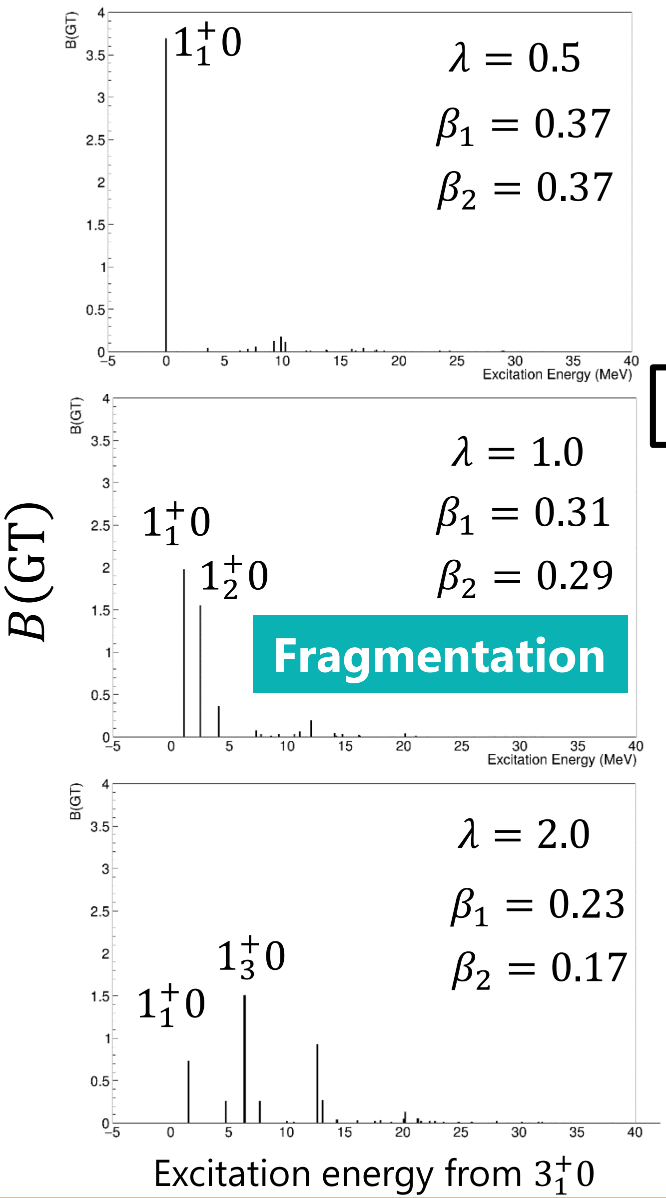
  as λ increases

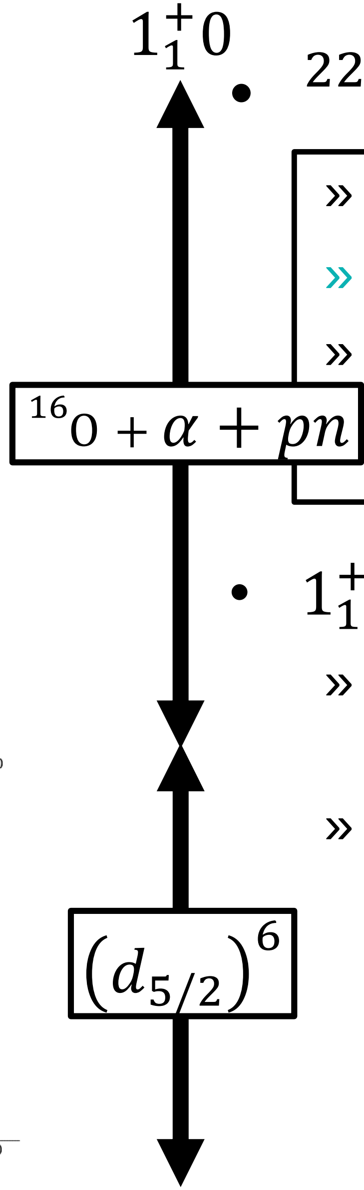
- 1_1^+0 Structures
  - » Custer structure($2\alpha + pn$) is found for $\lambda \leq 1.0$.
  - » Spherical shell configuration $(p_{3/2})^6$ is found for $\lambda = 2.0$.



Excitation energy from 3_1^+0

Dependence of deformation and LS interaction on GT strengths



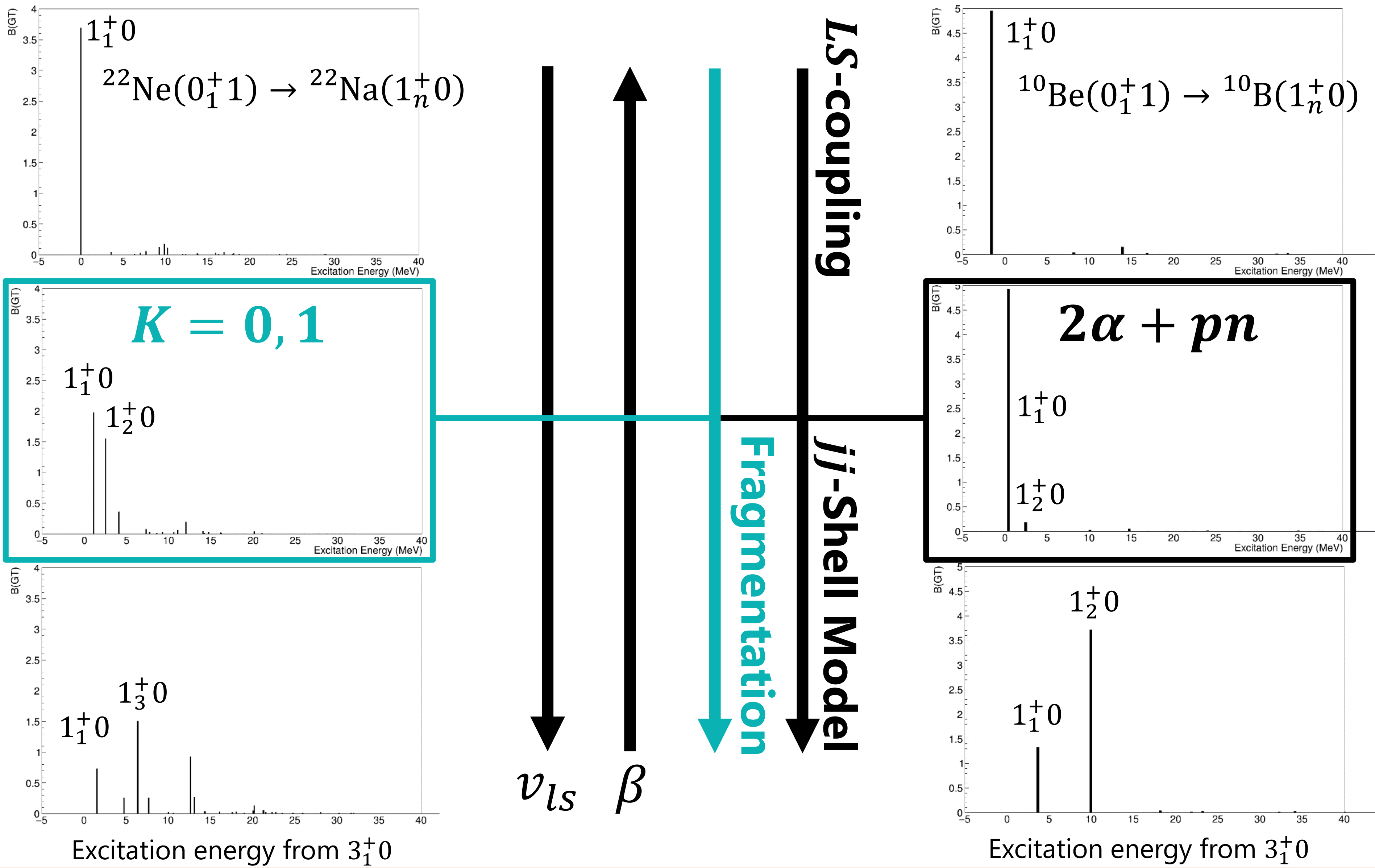


- $^{22}\mathrm{Ne}(0_1^+1) \rightarrow {}^{22}\mathrm{Na}(1_n^+0)$
  - » $\beta(1_{1,2}^+0)$ decreases
  - » **Fragmentation occurs ($\lambda \geq 1.0$)**
  - » GT strengths are pushed up to higher energy

  as λ increases

- 1_1^+0 Structures
  - » Custer structure ($^{16}\mathrm{O} + \alpha + pn$) is found for $\lambda \leq 1.0$.
  - » Spherical shell configuration $(d_{3/2})^6$ is found for $\lambda = 2.0$.

Dependence of deformation and *LS* interaction on GT strengths



Summary

- We have studied GT strengths by comparing p-([10]B) with sd-shell([22]Na) in this work.
  - **The fragmentations in GT($0_1^+1 \rightarrow 1_n^+0$) strengths of p- and sd- $N = Z =$ odd nuclei**
    - There is no fragmentation for ^{10}B($0_1^+1 \rightarrow \mathbf{1_1^+0}$)
    - GT strengths are fragmented into 2 states for ^{22}Na($0_1^+1 \rightarrow \mathbf{1_{1,2}^+0}$).
    - weak deformation and strong LS interaction causes GT fragmentation.
  - **The detailed descriptions for final 1^+0 states**
    - ^{10}B(1_1^+0) has cluster structure 2α+pn.
    - $K = 0,1$ bands are found for ^{22}Na($1_{1,2}^+0$).
    - $K = 0,1$ band heads($1_{1,2}^+0$) correspond to Nilsson orbit $[211\ {+3/2}]^n[211\ {-3/2}]^p$ and $[211\ {+3/2}]^n[211\ {-3/2}]^p$.