

Deformations of *sd-pf* shell Λ hypernuclei

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M. I., K. Fukukawa, M. Kimura, E. Hiyama, H. Sagawa and Y. Yamamoto, Phys. Rev. C, in press.

Introduction

Knowledge of Λ N effective interaction

- Study of light (*s*, *p*-shell) Λ hypernuclei
 - Accurate solution of few-body problems^[1]
 - Λ N G-matrix effective interactions^[2]
 - Increases of experimental information^[3]

Development of theoretical models

- Through the study of unstable nuclei
Ex.) Antisymmetrized Molecular Dynamics (AMD)^[4]

Experiments at J-PARC and JLab

- Various Λ hypernuclei will be produced
 - sd*- and *pf*-shell Λ hypernuclei
 - neutron-rich Λ hypernuclei

Recent developments enable us to study structure of Λ hypernuclei

Framework: HyperAMD

(Antisymmetrized Molecular Dynamics for Hypernuclei) [5]

●Hamiltonian

$$\hat{H} = \hat{T}_N + \hat{V}_{NN} + \hat{T}_\Lambda + \hat{V}_{\Lambda N} \quad \begin{array}{l} \text{NN: Gogny D1S} \\ \text{\Lambda N: YNG-ESC08c} \end{array}$$

●Wave function

- Nucleon part: Slater determinant
Spatial part of single particle w.f. is described as Gaussian packet

$$\varphi_N(\vec{r}) = \frac{1}{\sqrt{A!}} \det[\varphi_i(\vec{r}_j)] \quad \varphi_i(r) \propto \exp\left[-\sum_{\sigma=x,y,z} \mu V_\sigma (r-Z_i)_\sigma^2\right] \chi_i \eta_i \quad \chi_i = \alpha_i \chi_\uparrow + \beta_i \chi_\downarrow$$

- Single particle w.f. of Λ hyperon
Superposition of Gaussian packets

$$\varphi_\Lambda(r) = \sum_m c_m \varphi_m(r) \quad \varphi_m(r) \propto \exp\left[-\sum_{\sigma=x,y,z} \mu V_\sigma (r-Z_m)_\sigma^2\right] \chi_m \eta_m \quad \chi_m = a_m \chi_\uparrow + b_m \chi_\downarrow$$

- Total w.f.: $\psi(\vec{r}) = \sum_m c_m \varphi_m(r_\Lambda) \otimes \frac{1}{\sqrt{A!}} \det[\varphi_i(\vec{r}_j)]$

●Procedure

Variational Calculation

- Imaginary time development method $\frac{dX_i}{dt} = \frac{\kappa}{h} \frac{\partial H^\pm}{\partial X_i^*}$
- Variational parameters: $X_i = Z_i, z_i, \alpha_i, \beta_i, a_i, b_i, v_i, c_i$

Angular Momentum Projection

$$|\Phi_K^s; JM\rangle = \int d\Omega D_{MK}^{J*}(\Omega) R(\Omega) |\Phi^{s+}\rangle$$

Generator Coordinate Method (GCM)

- Superposition of w.f. with different configurations $|\Psi^{J\pm M}\rangle = \sum_{sK} g_{sK} |\Phi_K^s; J^\pm M\rangle$
- Diagonalization of $H_{sK,s'K'}^{J\pm}$ and $N_{sK,s'K'}^{J\pm}$
 $H_{sK,s'K'}^{J\pm} = \langle \Phi_K^s; J^\pm M | \hat{H} | \Phi_{K'}^{s'}; J^\pm M \rangle$
 $N_{sK,s'K'}^{J\pm} = \langle \Phi_K^s; J^\pm M | \Phi_{K'}^{s'}; J^\pm M \rangle$

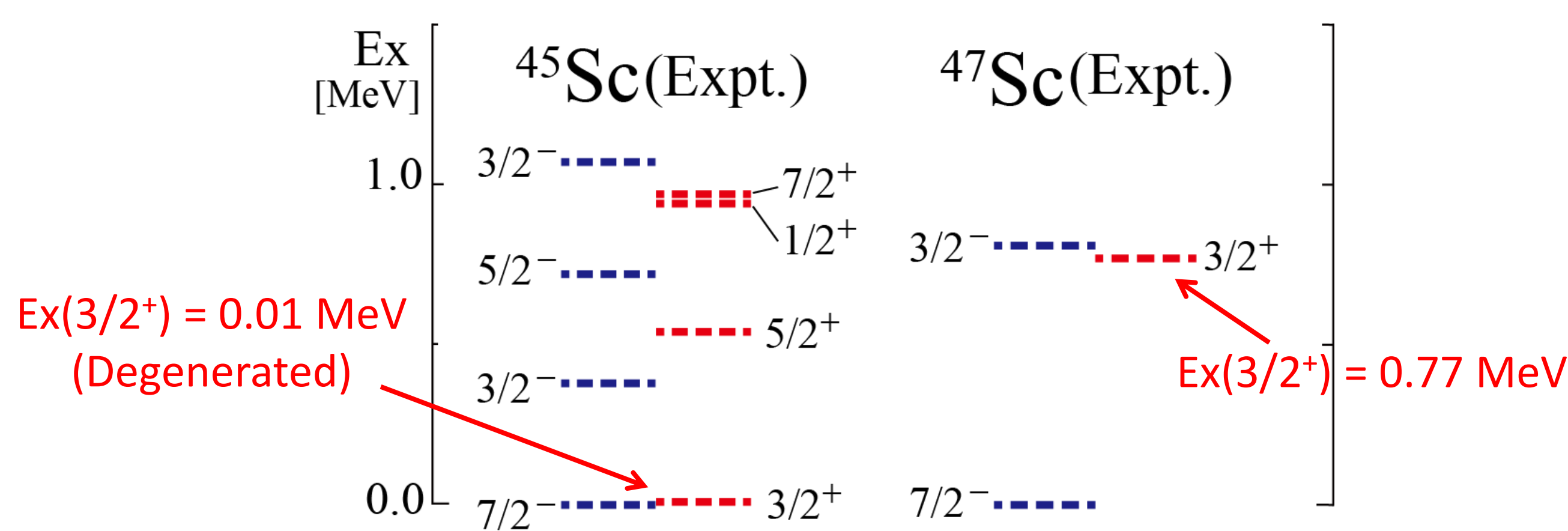
- AMD can describe **dynamical changes** of various structure
- No assumption** on clustering and deformation

Deformations of *sd-pf* shell normal nuclei

Coexistence of deformations

Ex.) ^{45}Sc , ^{47}Sc [6,7]

- Low-lying pos.-parity states exist due to deformation
 - 7/2⁺ (g. s.): (almost) spherical
 - Low-lying 3/2⁺: deformed
- Explained by Nilsson model

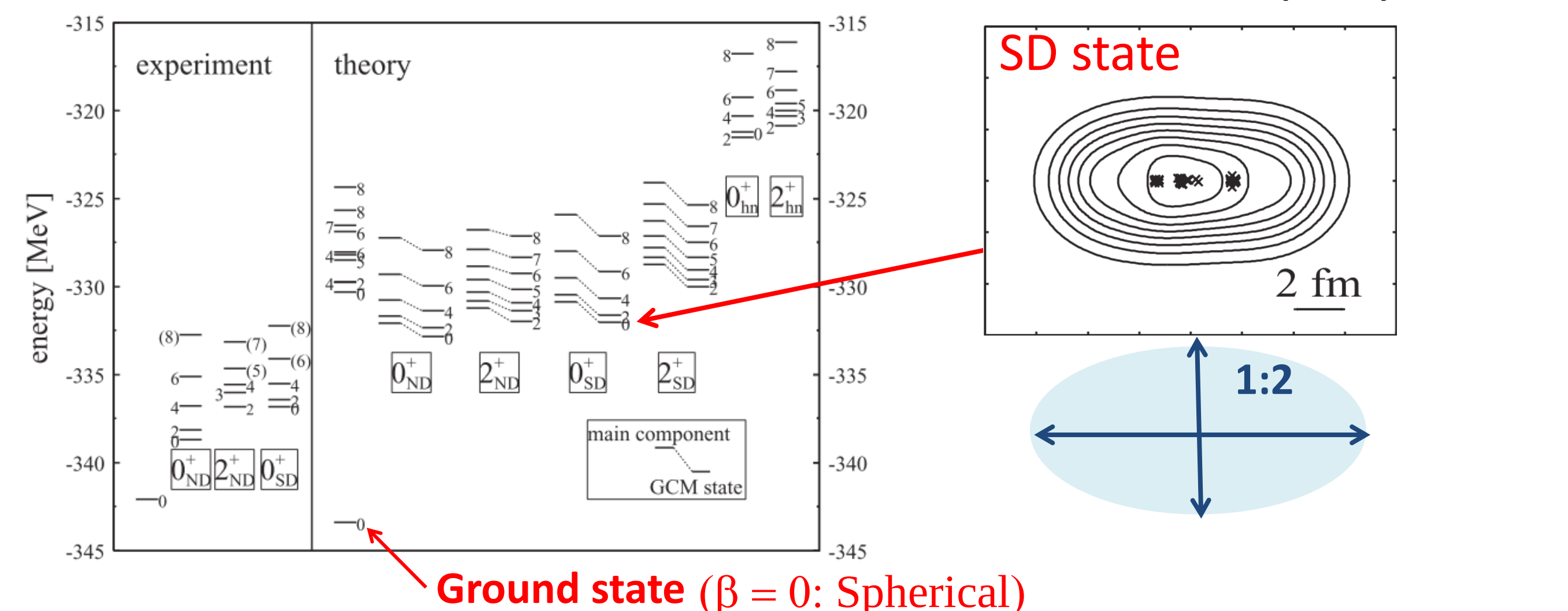


B_Λ is different depending on deformation? Λ particle changes excitation spectra?

Existence of superdeformed (SD) states

Ex.) ^{40}Ca [8,9,10]

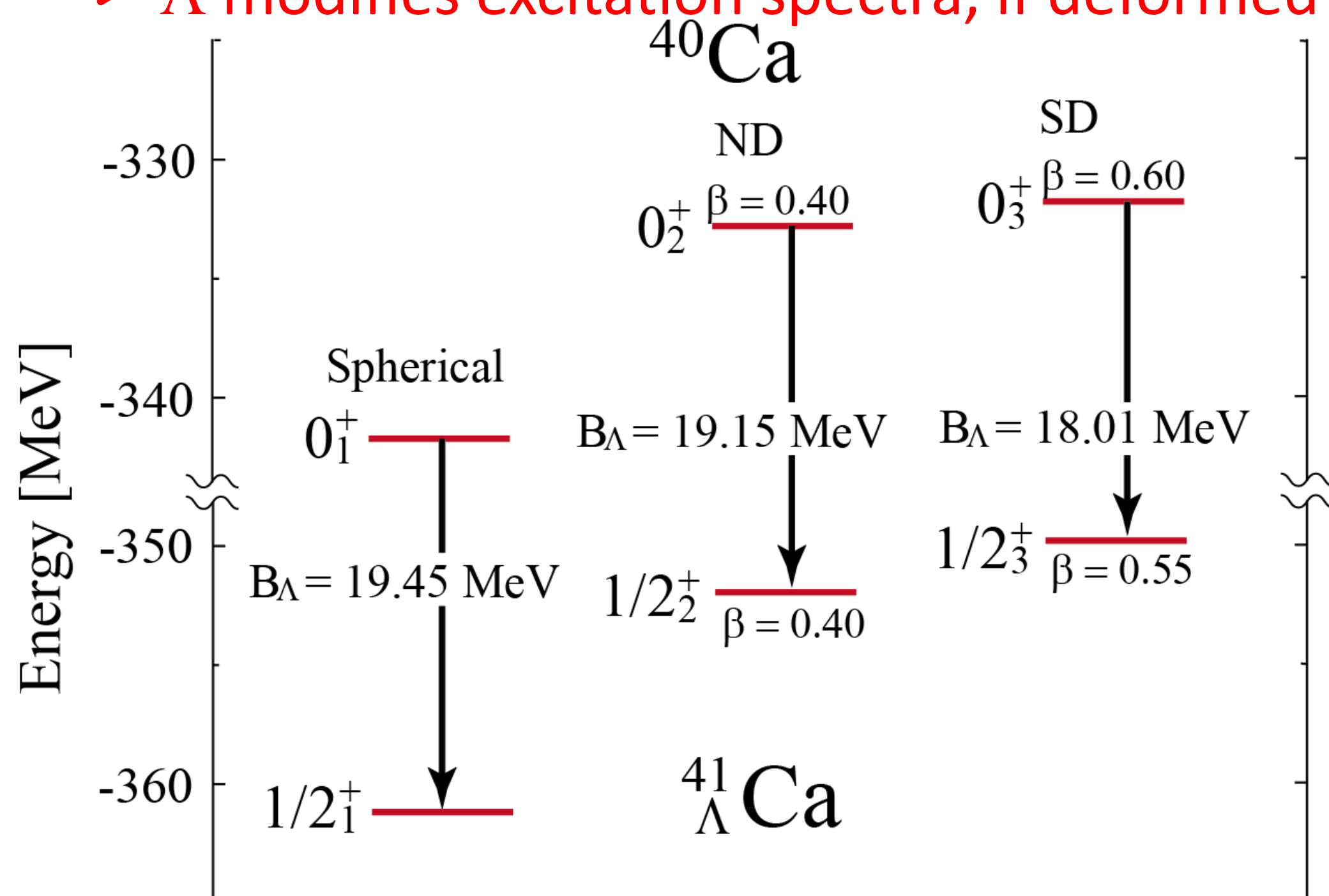
- SD states: 1:2 axis ratio of deformation
- In ^{40}Ca , SD states coexist with normal deformed (ND) states



Figures (^{40}Ca) are taken from Y. Taniguchi, *et al.*, PRC **76**, 044317 (2007)

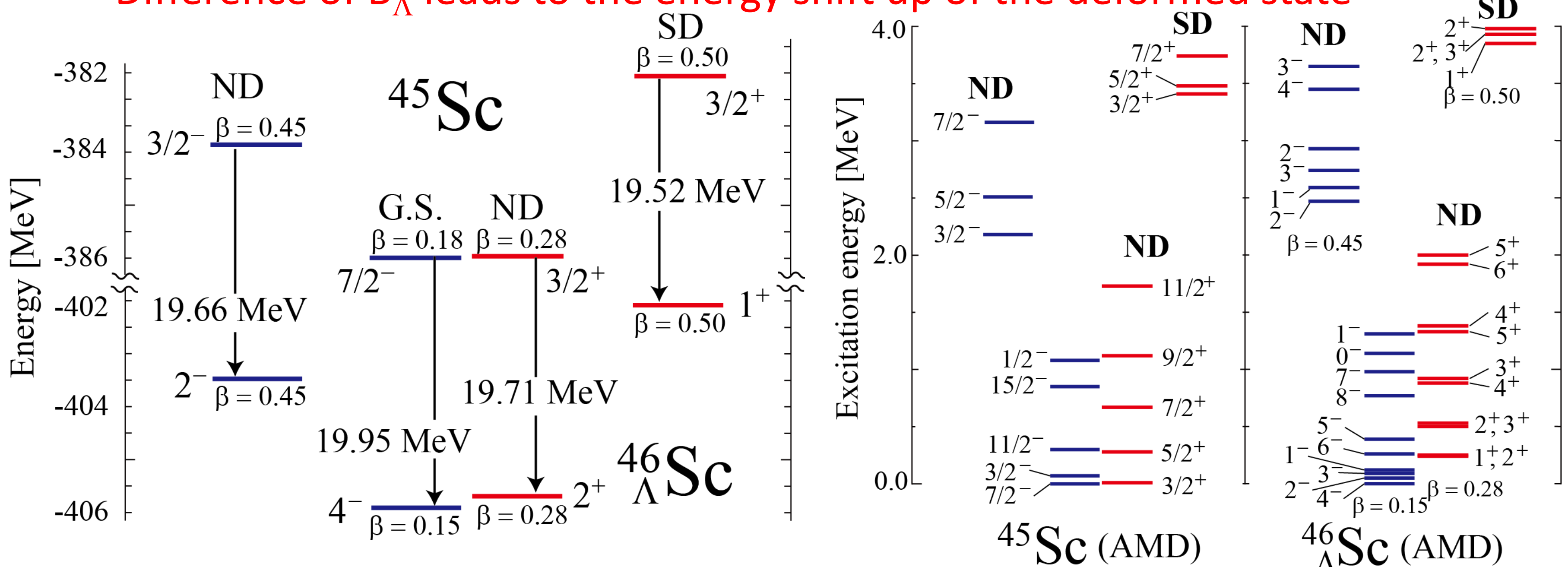
Results: B_Λ in SD states

- In ^{41}Ca , SD and ND states appear by adding Λ
- B_Λ is different depending on deformations
→ Λ modifies excitation spectra, if deformed



Results: Various deformed states in ^{46}Sc and ^{48}Sc

- In ^{45}Sc and ^{47}Sc , we predict ND and SD states with *mp-mh* configuration
- In ^{46}Sc and ^{48}Sc , B_Λ is smaller in the deformed states than the g.s.
→ Difference of B_Λ leads to the energy shift up of the deformed state



We hope that these states are observed by JLab experiments

References

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- [2] PTP suppl. **185** (2010)
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- [4] Y. Kanada-En'yo et al., PTP **93** (1995), 115.
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- [6] I. P. Johnstone, NPA **110**(1968)429
- [7] J. Styczen, *et al.*, NPA **262**(1976) 317
- [8] W. Gerace and A. Green, NPA **93**, 110(1967); NPA **123**, 241 (1969)
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Summary and Future plans

- To reveal how is difference of B_Λ in deformed states, we applied HyperAMD to ^{41}Ca , ^{46}Sc and ^{48}Sc .
- We predict existence of SD states in ^{41}Ca and ^{46}Sc , and various ND states in ^{41}Ca , ^{46}Sc and ^{48}Sc
- B_Λ is different among the ground, deformed and SD states

Future plans

- To predict the production cross sections
- Comparison of B_Λ with cluster states: ^{13}C (Hoyle + Λ)