Microscopic particle-rotor model for low-lying spectrum of Λ hypernuclei

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H. Mei, K.H., J.M. Yao, and T. Motoba, arXiv:1404.4604

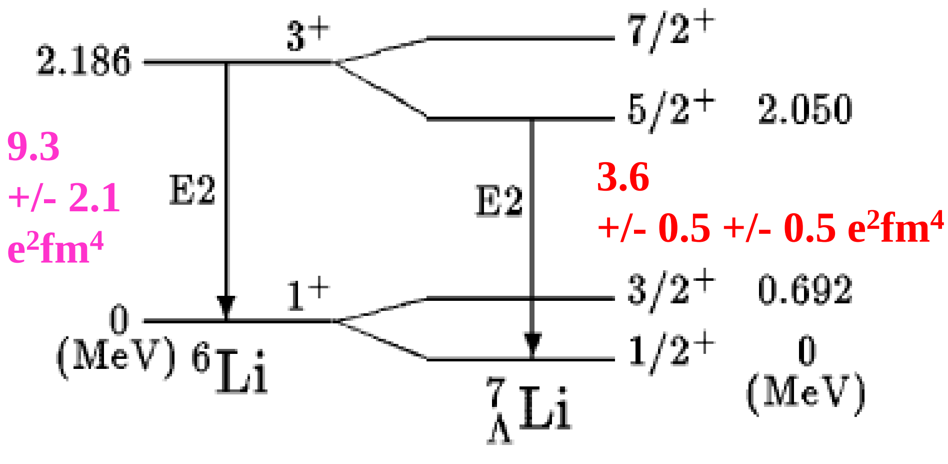
Introduction

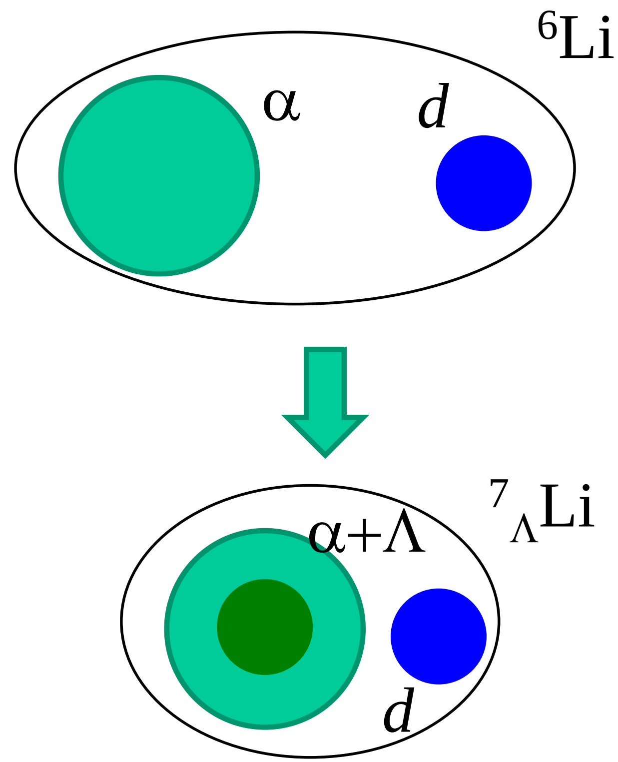
Impurity effects: one of the main interests of hypernuclear physics

how does Λ affect several properties of atomic nuclei?

- size, shape, density distribution, single-particle energy, shell structure, fission barrier……

✓ the most prominent example:
the reduction of B(E2) in $^{7}_{\Lambda}$Li



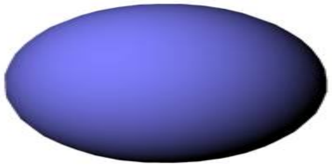


about 19% reduction of nuclear size
(shrinkage effect)

K. Tanida et al., PRL86 (‘01) 1982

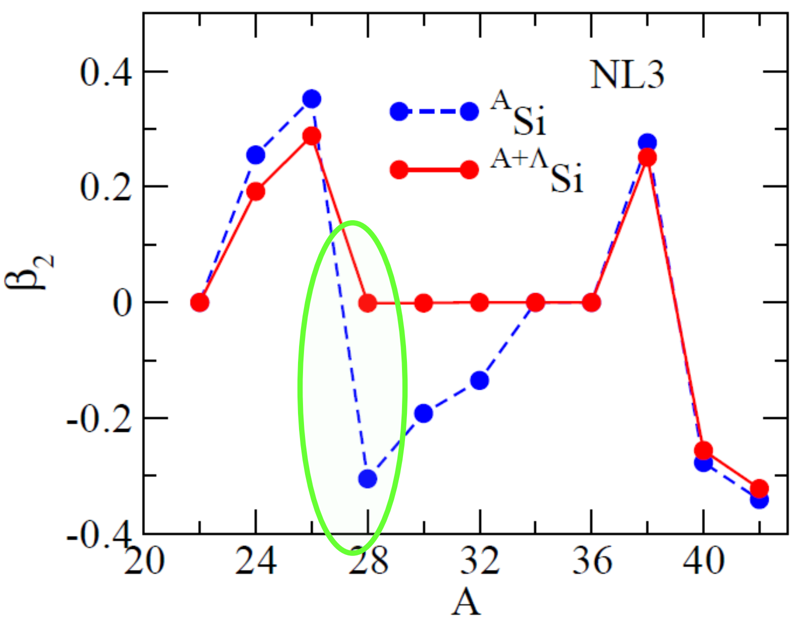
Mean-field approximation and beyond

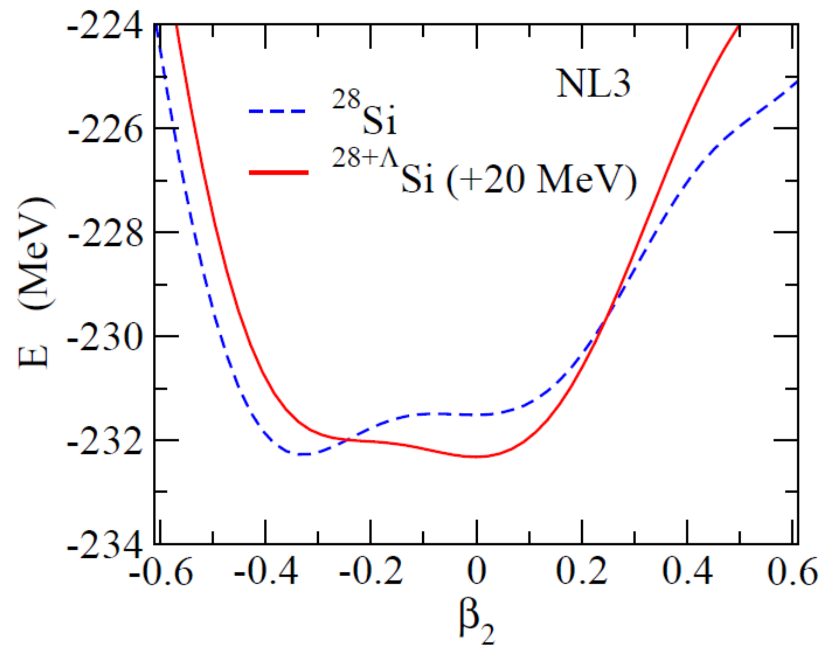
Self-consistent mean-field (Hartree-Fock) method:



- independent particles in a mean-field potential
- global theory for the whole nuclear chart
- intuitive picture for nuclear deformation
- optimized shape can be automatically determined

= suitable for a discussion on shape of hypernuclei





Myaing Thi Win and K.H., PRC78('08)054311

Mean-field approximation and beyond

Problems of mean-field approximation

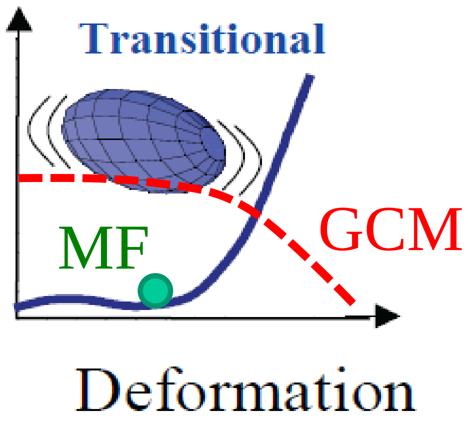
✓ body-fixed frame formalism → intuitive picture of nuclear def.

✓ spectrum: lab-frame ← transformation from intrinsic to lab. frames

$$|\Psi_{I_cM_c}(\beta)\rangle = \hat{P}^{I_c}_{M_cK_c}\hat{P}^N\hat{P}^Z|\Psi_{\rm MF}(\beta)\rangle$$

angular momentum + particle number projections

✓ quantum fluctuation

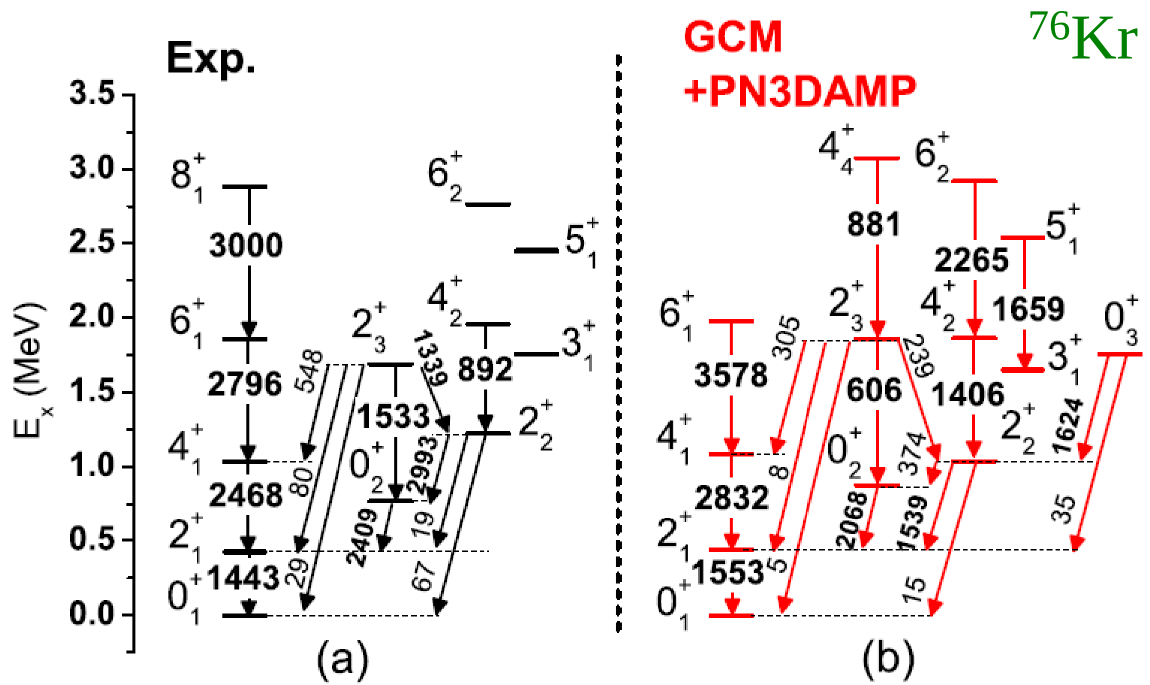


$$|\Phi_{I_cM_c}\rangle = \int d\beta\, f(\beta)|\Psi_{I_cM_c}(\beta)\rangle$$

generator coordinate method (GCM)

"beyond mean-field approximation"

beyond mean-field approximation



J.M. Yao, K.H. et al., PRC89 (‘14) 054306

◆ Difficulties for odd-mass nuclei (single-Λ hypernuclei)

✓ half-integer spins

✓ broken time-reversal symmetry

Our aim

Construct an alternative way to describe low-energy spectrum of single-Λ hypernuclei based on “beyond mean-field” approach

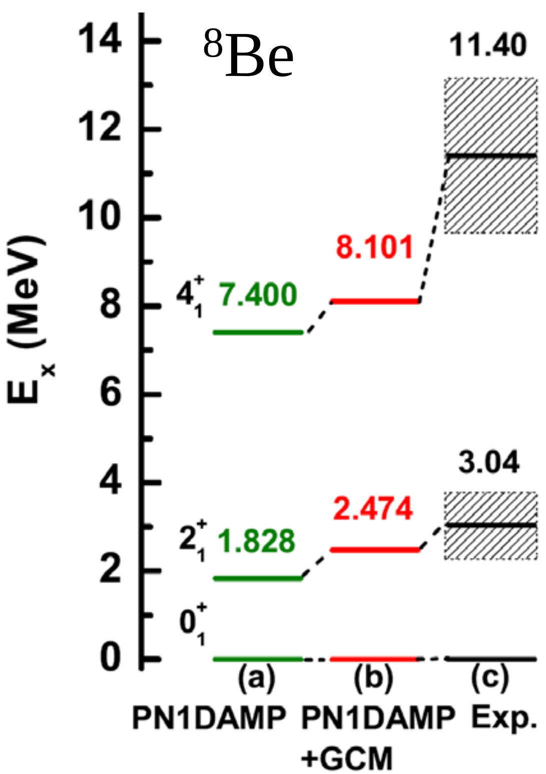
Microscopic Particle-Rotor Model for Λ hypernuclei

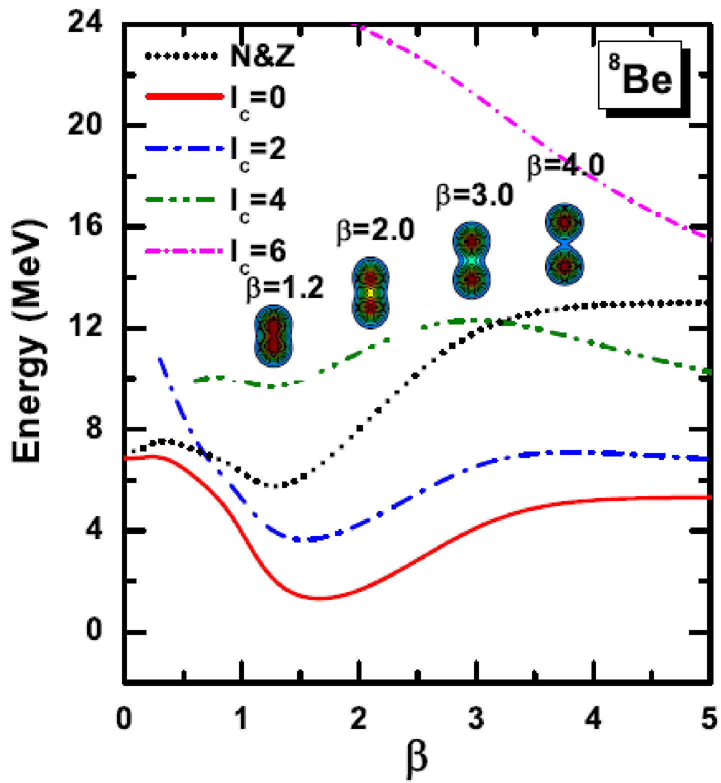
H. Mei, K.H., J.M. Yao, T. Motoba, arXiv:1404.4604

Λ + even-even core nucleus e.g., ${}^{9}_{\Lambda}$Be = ^{8}Be + Λ

- beyond mean-field calculations for e-e core

$$|\Phi_{I_cM_c}\rangle = \int d\beta\, f(\beta)|\Psi_{I_cM_c}(\beta)\rangle \qquad |\Psi_{I_cM_c}(\beta)\rangle = \hat{P}^{I_c}_{M_cK_c}\hat{P}^{N}\hat{P}^{Z}|\Psi_{\mathrm{MF}}(\beta)\rangle$$





✓ relativistic point coupling model with PCF-1

Microscopic Particle-Rotor Model for Λ hypernuclei

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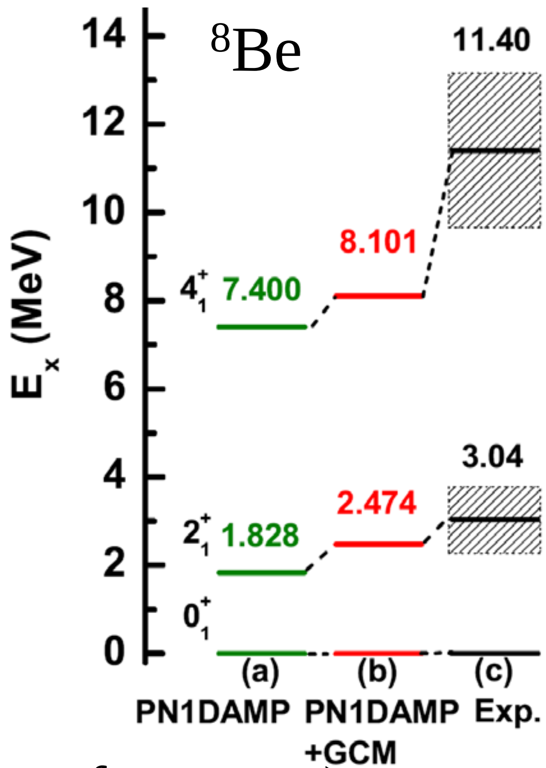
Λ + even-even core nucleus   e.g., ${}^{9}_{\Lambda}$Be = ^{8}Be + Λ

- beyond mean-field calculations for e-e core
- coupling of Λ to the core states

$$
\begin{aligned}
|\Phi_{IM}\rangle &= \left[\psi_{jl}(\boldsymbol{r}_\Lambda)\otimes|\Phi_{0+}\rangle\right]^{(IM)} \\
&\quad + \left[\psi_{j'l'}(\boldsymbol{r}_\Lambda)\otimes|\Phi_{2+}\rangle\right]^{(IM)} + \cdots
\end{aligned}
$$

Λ   core (GCM)



particle-core model with core excitations

cf. conventional particle-rotor model:

core states → macroscopic rotor (Wigner's D-functions) with a fixed deformation

our approach: a microscopic version of particle-rotor model

cf. no Pauli principle for Λ particle

Results for $^{9}_{\Lambda}$Be

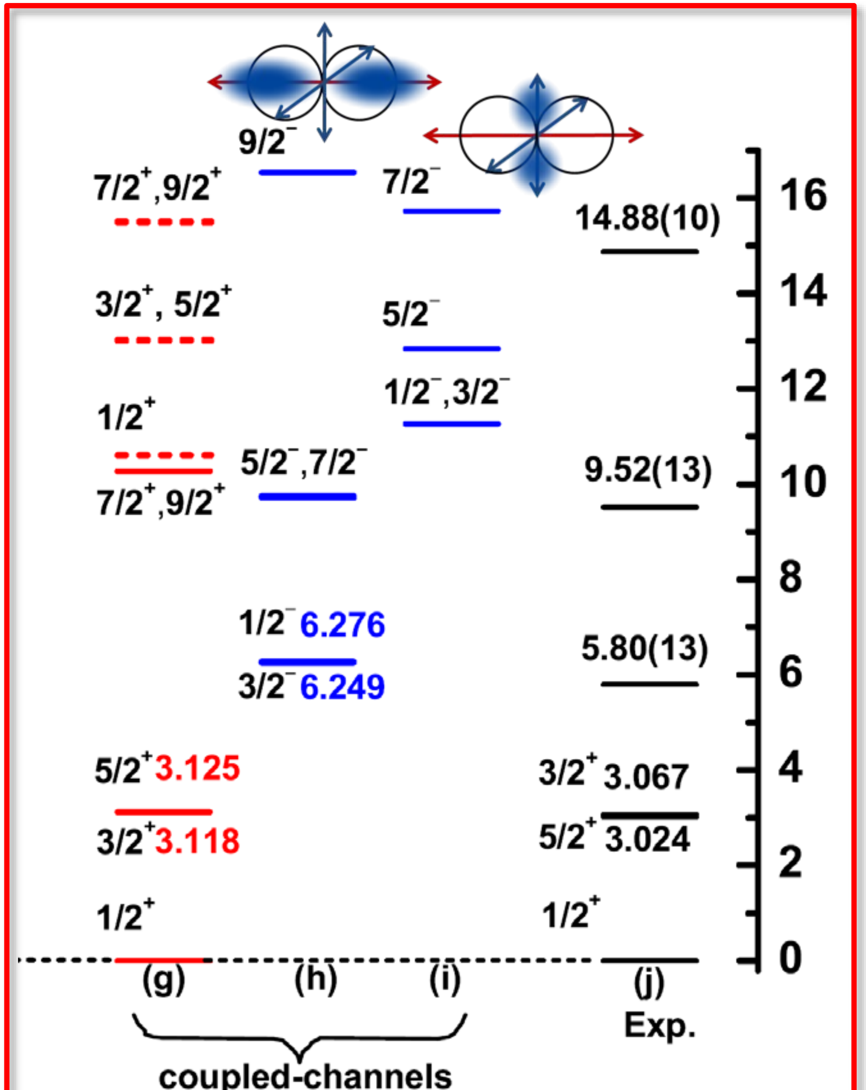
H. Mei, K.H., J.M. Yao, T. Motoba, arXiv:1404.4604

$$\mathcal{L}_{\Lambda N} = -\alpha_V^{N\Lambda}\delta(\boldsymbol{r}_\Lambda - \boldsymbol{r}_N) - \alpha_S^{N\Lambda}\gamma_\Lambda^0\delta(\boldsymbol{r}_\Lambda - \boldsymbol{r}_N)\gamma_N^0$$

parameters

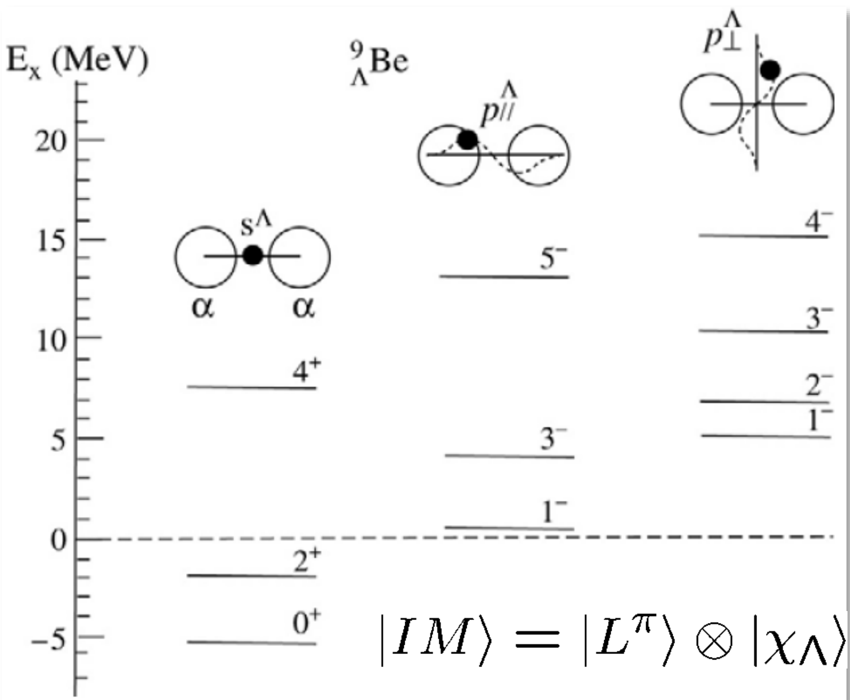
← B_Λ of $^{9}_{\Lambda}$Be

✓ coupling to 0_1^+, 2_1^+, and 4_1^+ of ^{8}Be



cf. α cluster model

T. Motoba et al., PTP70 (‘83) 189

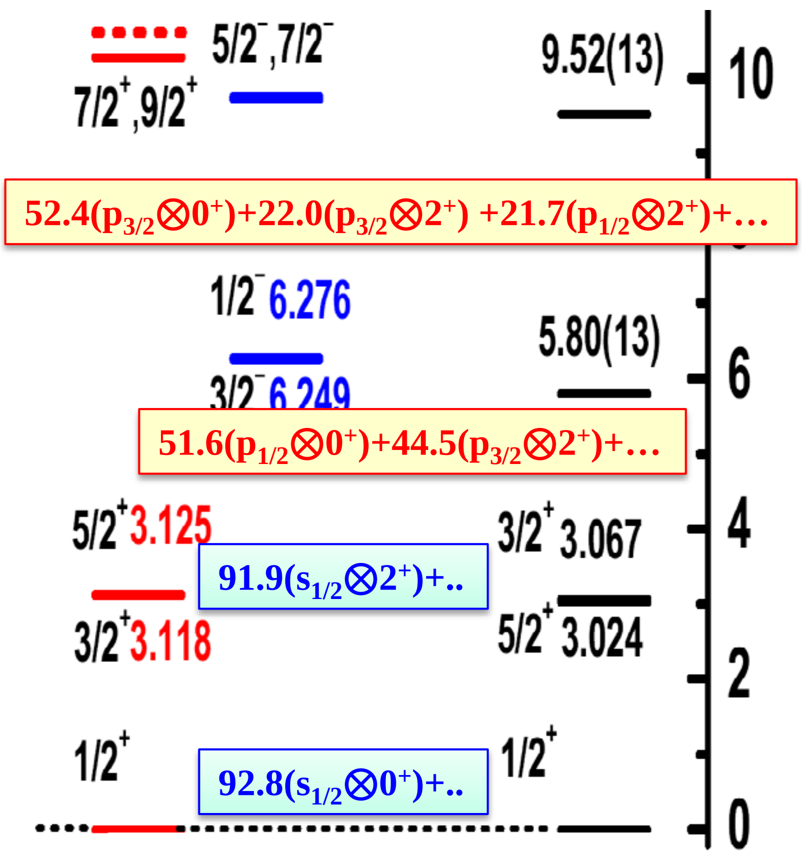


Results for $^{9}_{\Lambda}$Be

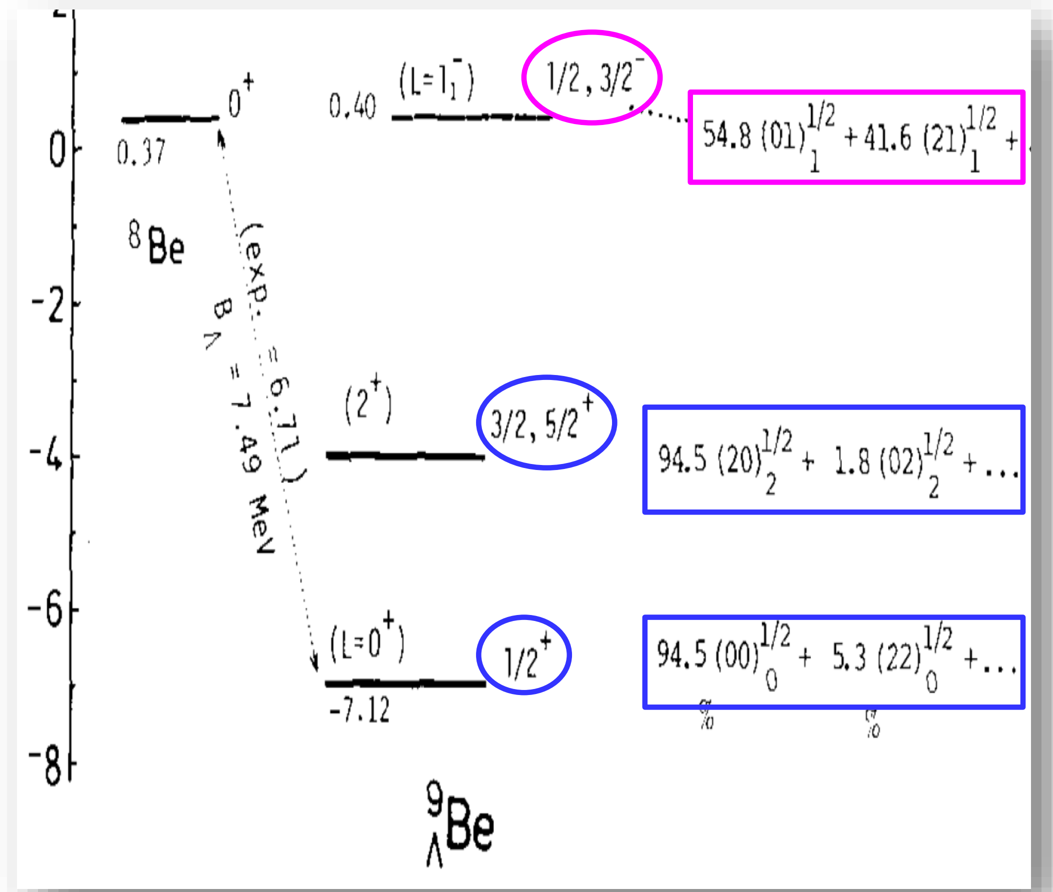
H. Mei, K.H., J.M. Yao, T. Motoba, arXiv:1404.4604

wave function components

microscopic particle-rotor



α-cluster model (Motoba et al., 1983)

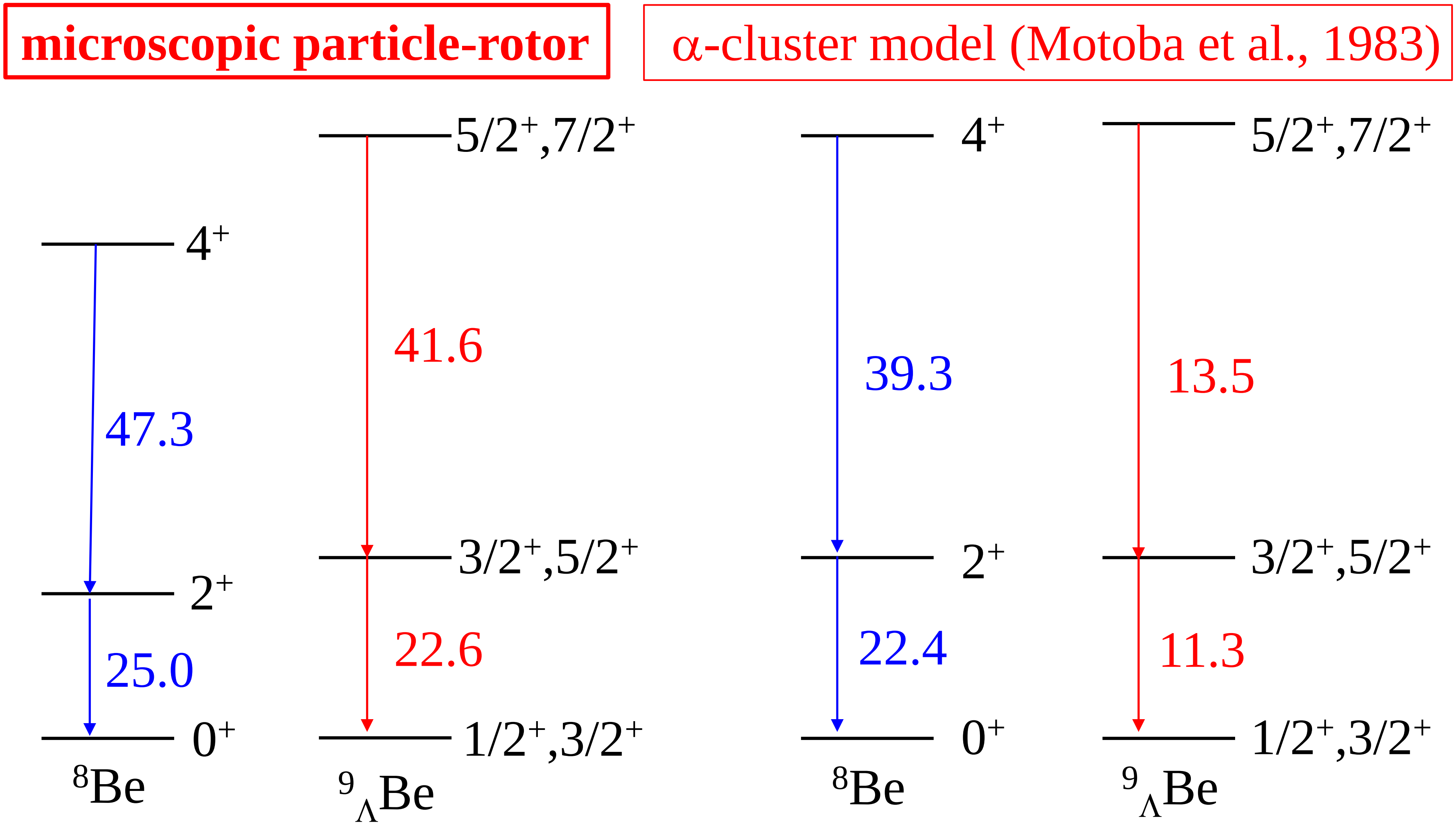


- almost pure Λ_s states for the g.s. rotational band
- large admixture of 0^+ and 2^+ states for the second band

Results for $^{9}_{\Lambda}$Be

H. Mei, K.H., J.M. Yao, T. Motoba, arXiv:1404.4604

B(E2) transition rates (e^2fm^4)



- much smaller reduction in B(E2) : role of higher states?

Summary

Microscopic particle-rotor model for Λ-hypernuclei

- Λ + GCM states for core
- microscopic version of particle-rotor model
- first calculation for low-lying spectrum based on mean-field type calculations
- application to $^{9}_{\Lambda}$Be : nice agreement with α cluster model (except for EM transitions)

Future perspectives

- applications to many Λ-hypernuclei (both rotational and vibrational core)
- extension to include triaxiality (cf. $^{25}_{\Lambda}$Mg)

Challenging problem

- application to formation reactions of hypernuclei
  ⟵ description of ordinary odd-mass nuclei: Pauli principle?

H. Mei, K.H., J.M. Yao, and T. Motoba, arXiv:1404.4604