Beyond-mean-field approach to low-lying spectra of Λ hypernuclei

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1. *Introduction*
2. *Mean-field approximation and beyond*
3. *Microscopic particle-rotor model for hypernuclei*
4. *Results for $^{13}_{\Lambda}$C, $^{21}_{\Lambda}$Ne, and $^{155}_{\Lambda}$Sm*
5. *Summary*

H. Mei, K.H., J.M. Yao, and T. Motoba, PRC90 ('14) 064302
PRC91 ('15) 064305

Introduction

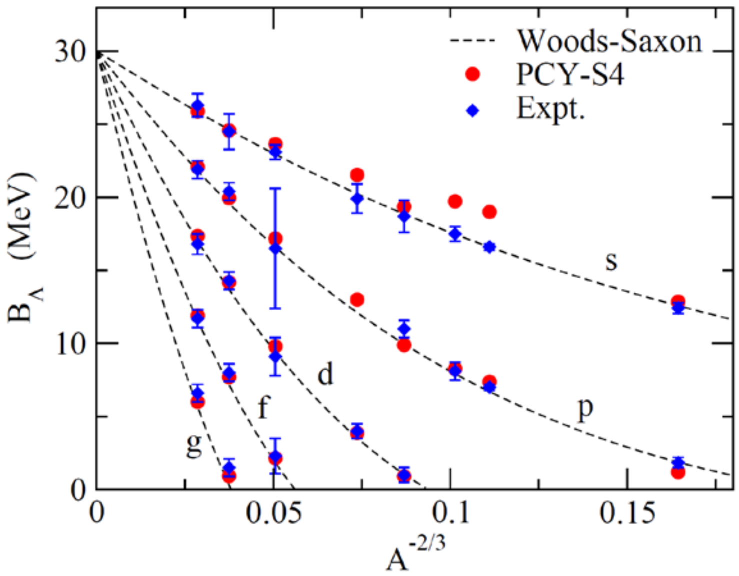
Impurity effects: one of the main interests of hypernuclear physics

how does Λ affect several properties of atomic nuclei?

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

Theoretical approaches:

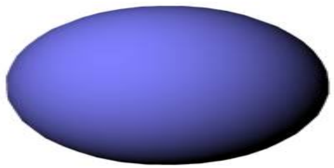
- ✓ cluster model
- ✓ shell model
- ✓ AMD (Isaka's talk)
- ✓ self-consistent mean-field models (Zhou and Vesely's talks)



A figure from a recent review:
K.H. and J.M. Yao, arXiv:1410.7531

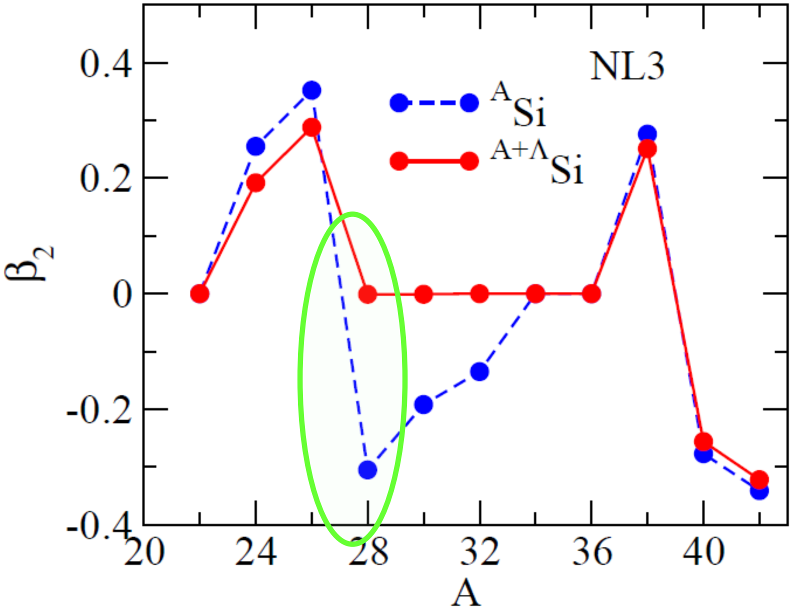
Mean-field approximation and beyond

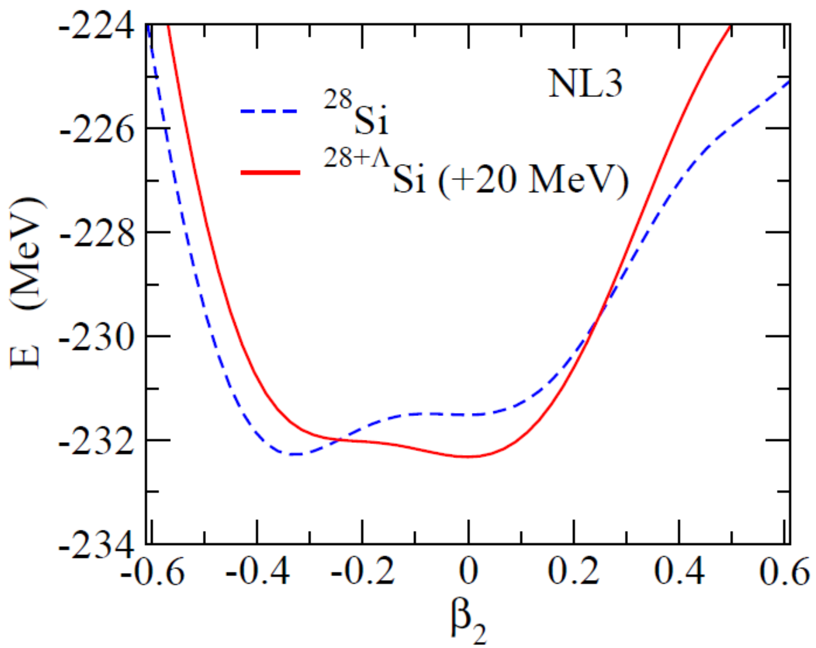
Self-consistent mean-field (Hartree-Fock) method:



- 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

Drawbacks of the mean-field approximation : nuclear spectrum

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

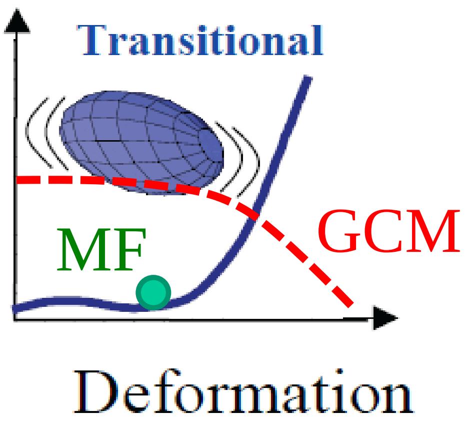
✓ spectrum: lab-frame ← transformation from intrinsic to lab. frames

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

angular momentum + particle number projections

nuclear spectrum: requires to go beyond the mean-field approximation

✓ quantum fluctuation

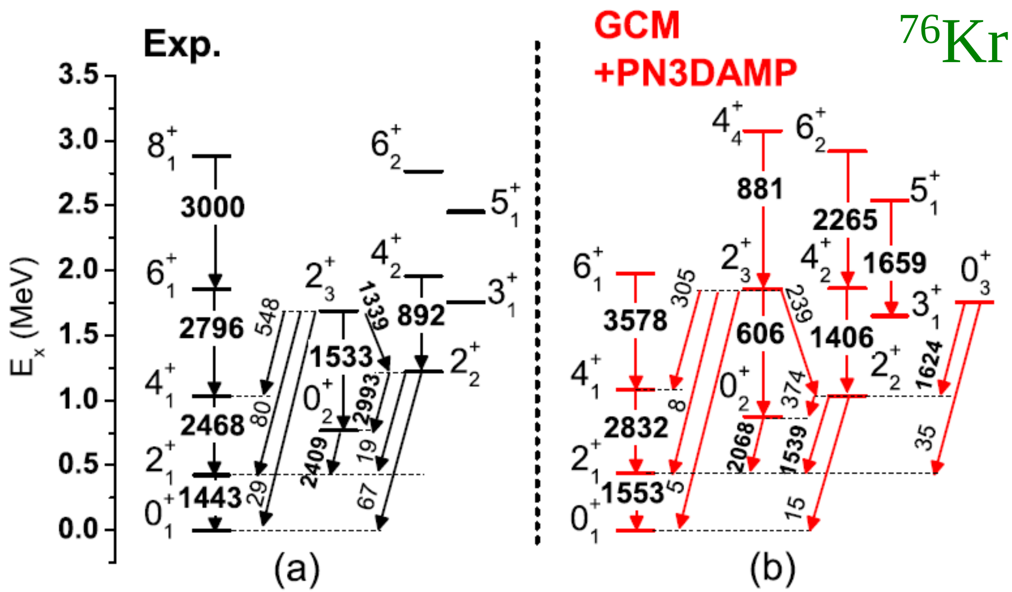


$$\boxed{|\Phi_{I_cM_c}\rangle = \int d\beta\, f(\beta)|\Psi_{I_cM_c}(\beta)\rangle}$$

generator coordinate method (GCM)

beyond the mean-field approximation

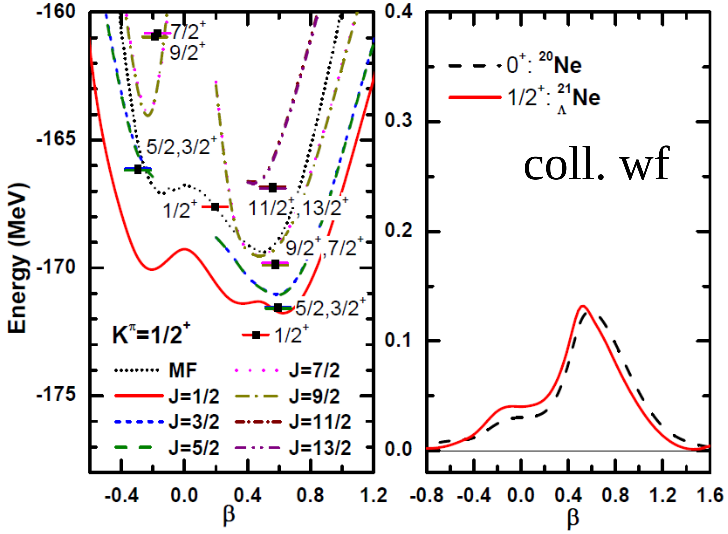
beyond mean-field approximation



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

beyond mean-field approximation

◆ Projection+GCM for the whole (A_c+1) system



H. Mei, K.H. and J.M. Yao, in preparation

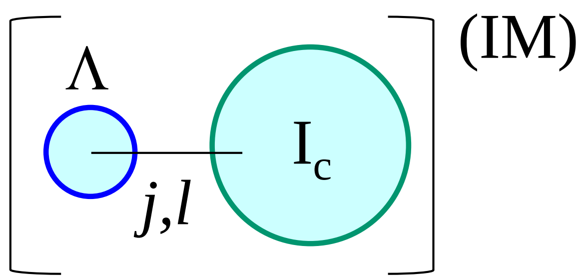
◆ Microscopic particle-rotor model for single-Λ hypernuclei

H. Mei, K.H., J.M. Yao, and T. Motoba, PRC90('14)064302, PRC91('15) 064305

i) beyond mean-field calculations for e-e core: $|\Phi_{0+}\rangle, |\Phi_{2+}\rangle, |\Phi_{4+}\rangle, \cdots$

ii) coupling of Λ to the core states

$$|\Phi_{IM}\rangle = \sum_{j,l,I_c}$$



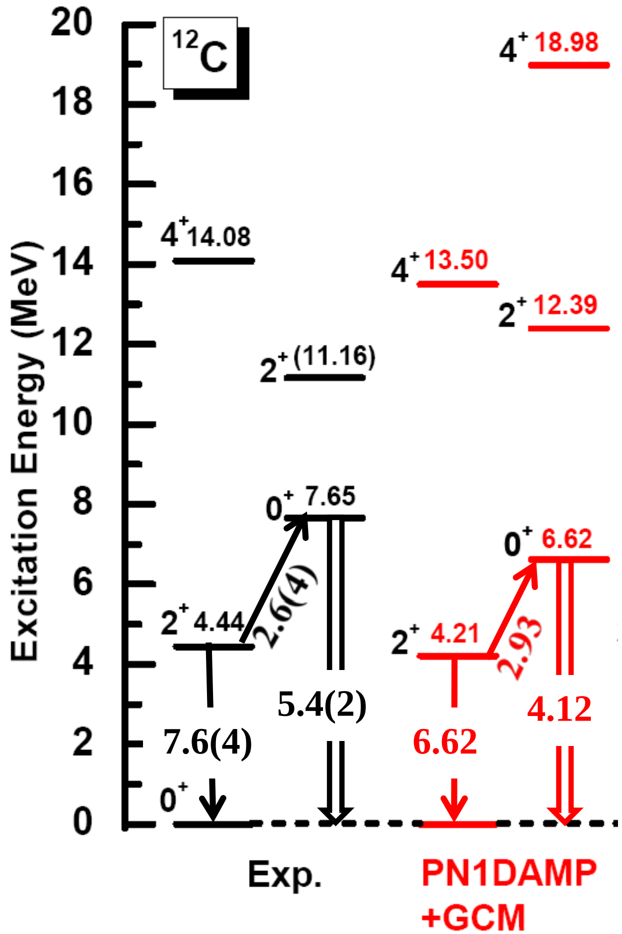
Λ+core model with core excitations

Microscopic Particle-Rotor Model for Λ hypernuclei

Example: $^{13}{}_{\Lambda}C$

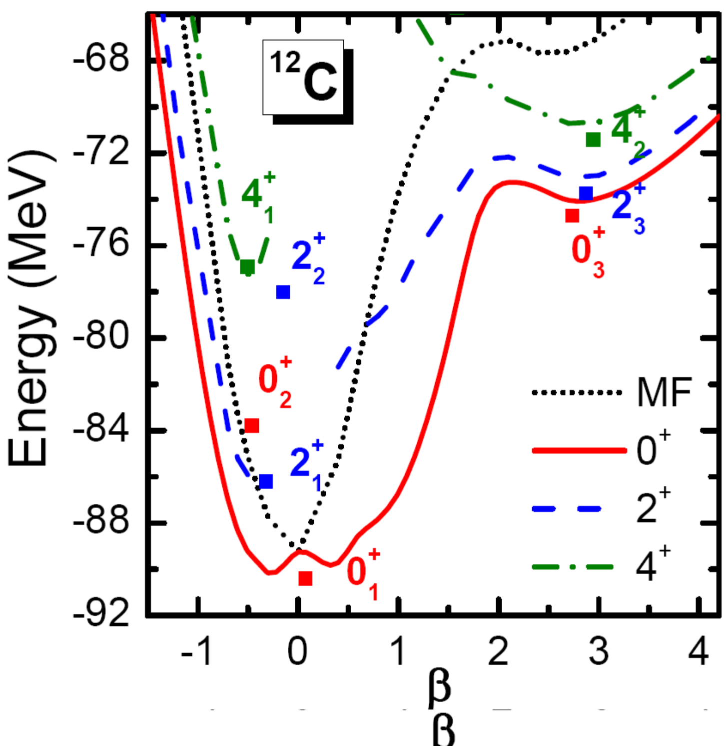
i) beyond mean-field calculations for e-e core (^{12}C) : GCM + projections

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



✓ axial symmetry

✓ relativistic PC-F1



Microscopic Particle-Rotor Model for Λ hypernuclei

Example: $^{13}{}_{\Lambda}C$

(i) beyond mean-field calculations for e-e core (^{12}C)

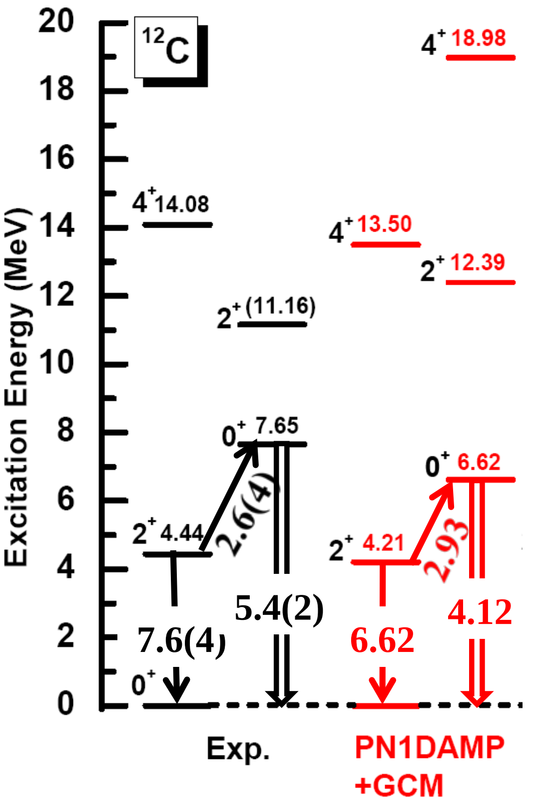
(ii) coupling of Λ to the core states

$$|\Phi_{IM}\rangle = \sum_{j,l,I_c} \left[\psi_{jl}(\boldsymbol{r}_\Lambda) \otimes |\Phi_{I_c}\rangle\right]^{(IM)}$$

Λ core

$$|1/2^+\rangle = \alpha\,|s_{1/2} \otimes 0^+\rangle + \beta\,|d_{5/2} \otimes 2^+\rangle + \cdots$$

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

Results for $^{13}{}_{\Lambda}$C

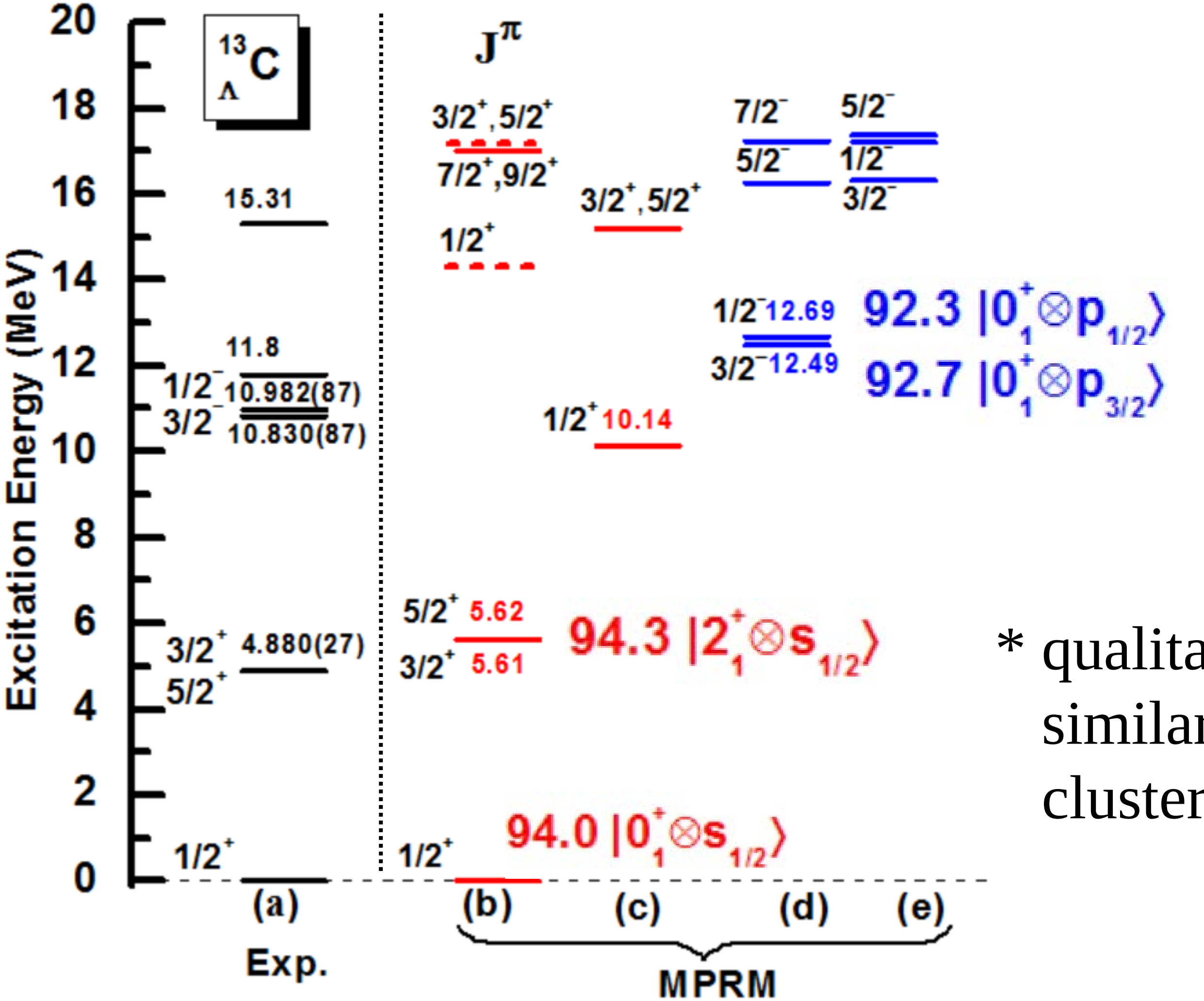
H. Mei, K.H., J.M. Yao, T. Motoba, PRC91('15) 064305

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

parameters

← B_Λ of $^{13}{}_{\Lambda}$C

✓ coupling to 0^+, 2^+, and 4^+ of ^{12}C



ls splitting:
199 keV
cf. expt.
152+/-90 keV

* qualitatively similar to the previous cluster model calc.

Results for $^{13}_{\Lambda}C$

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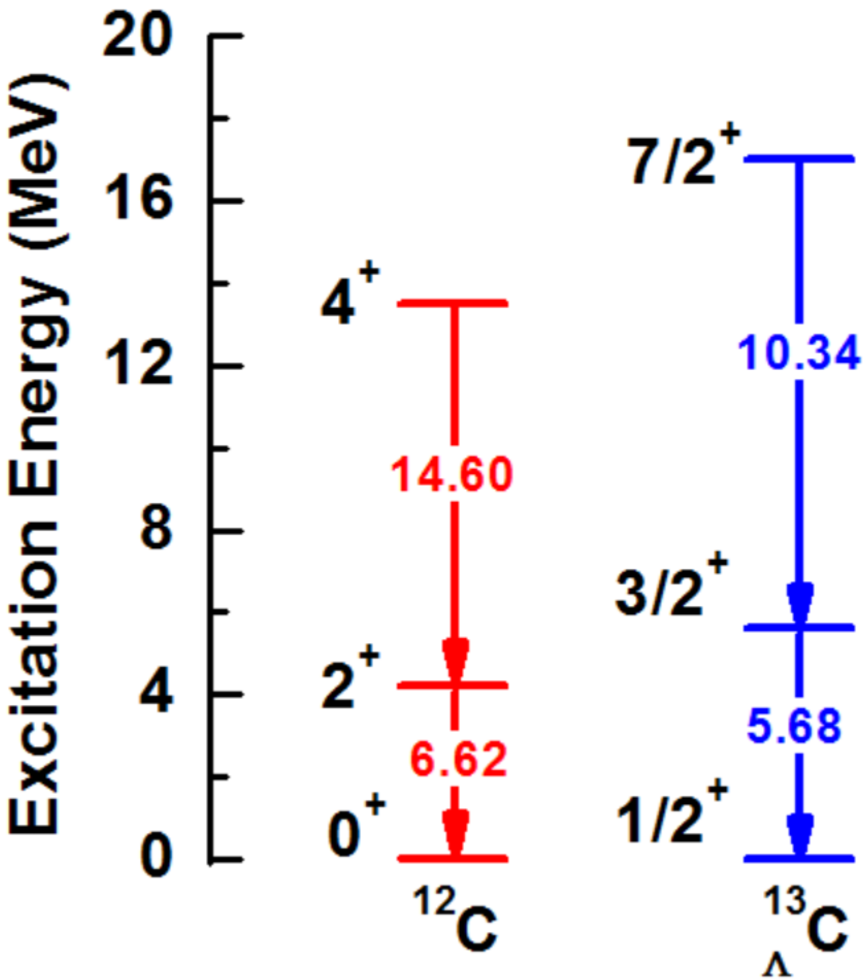
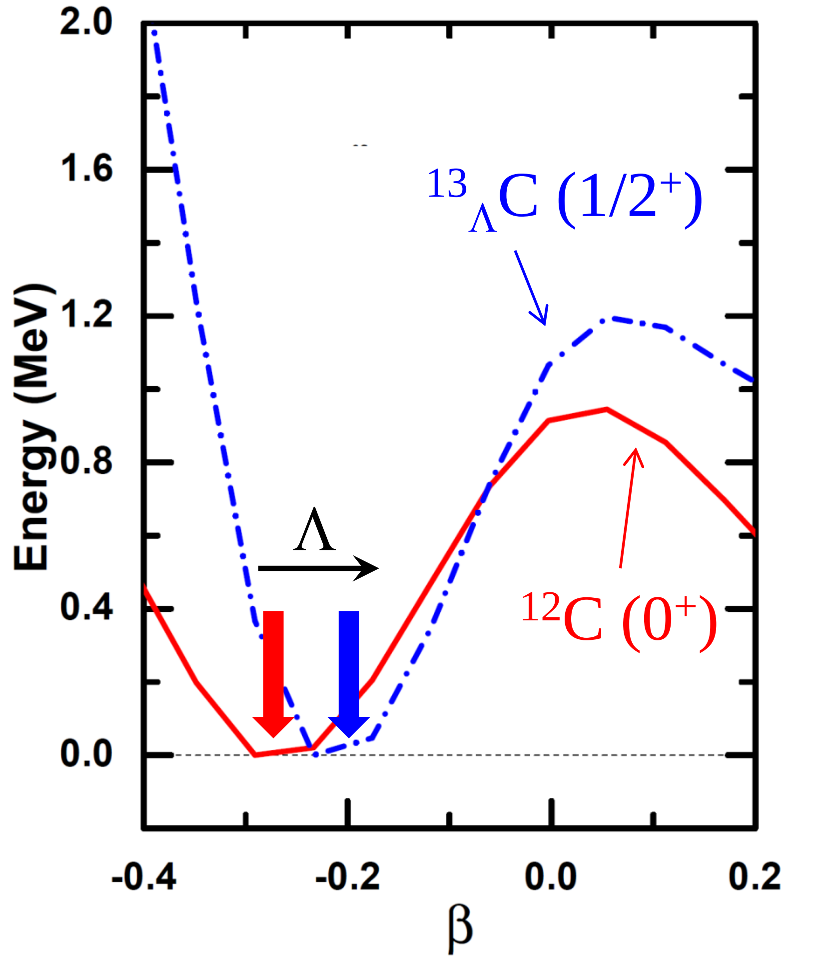
B(E2) transition rates (e^{2}fm^4)





	^{12}C	$^{13}_{\Lambda}C$
β	-0.29	-0.23
r_p (fm)	2.44	2.39

➢ B(E2) : ~ 14% reduction

Results for $^{21}{}_{\Lambda}Ne$

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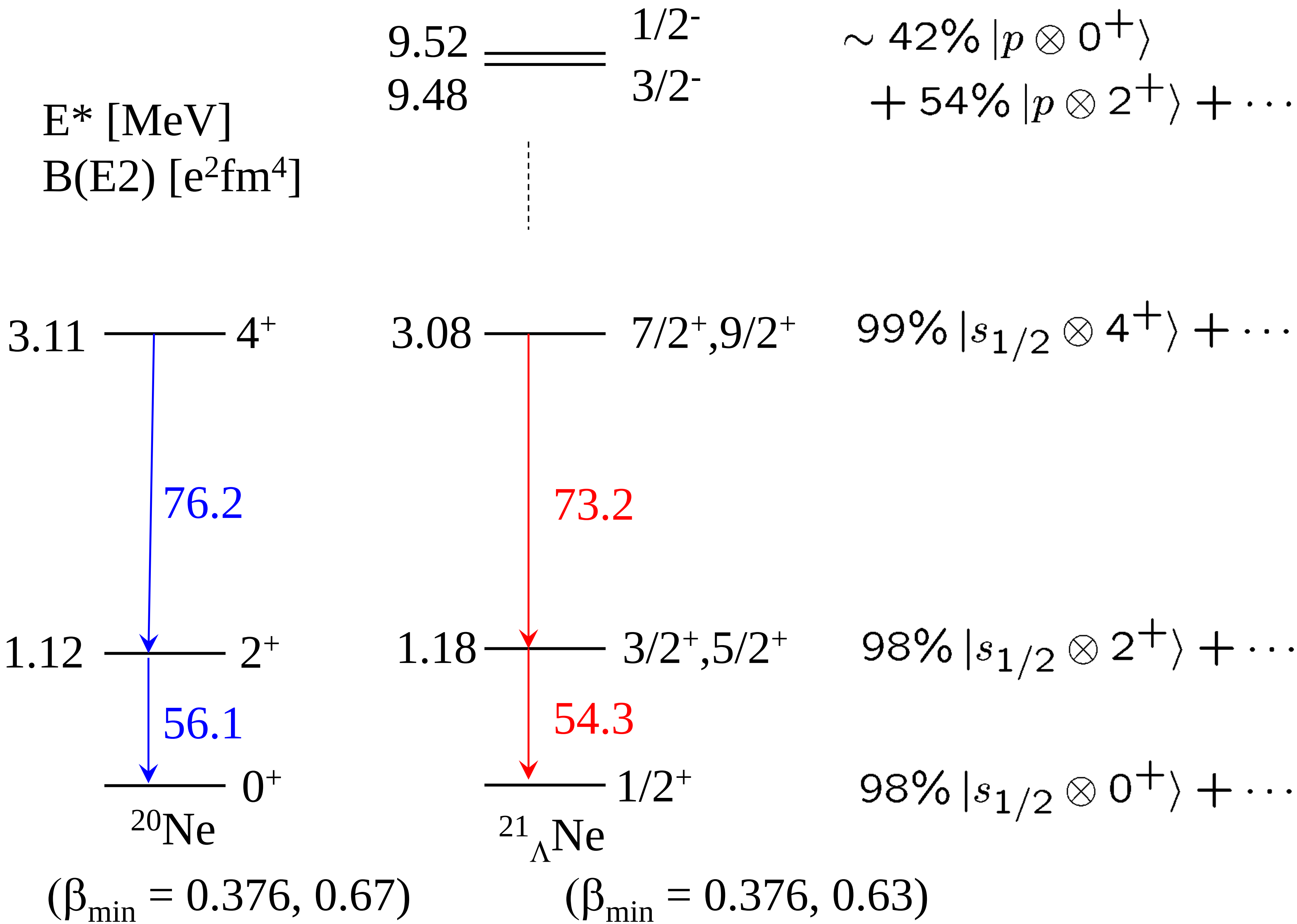

Results for $^{155}{}_{\Lambda}$Sm

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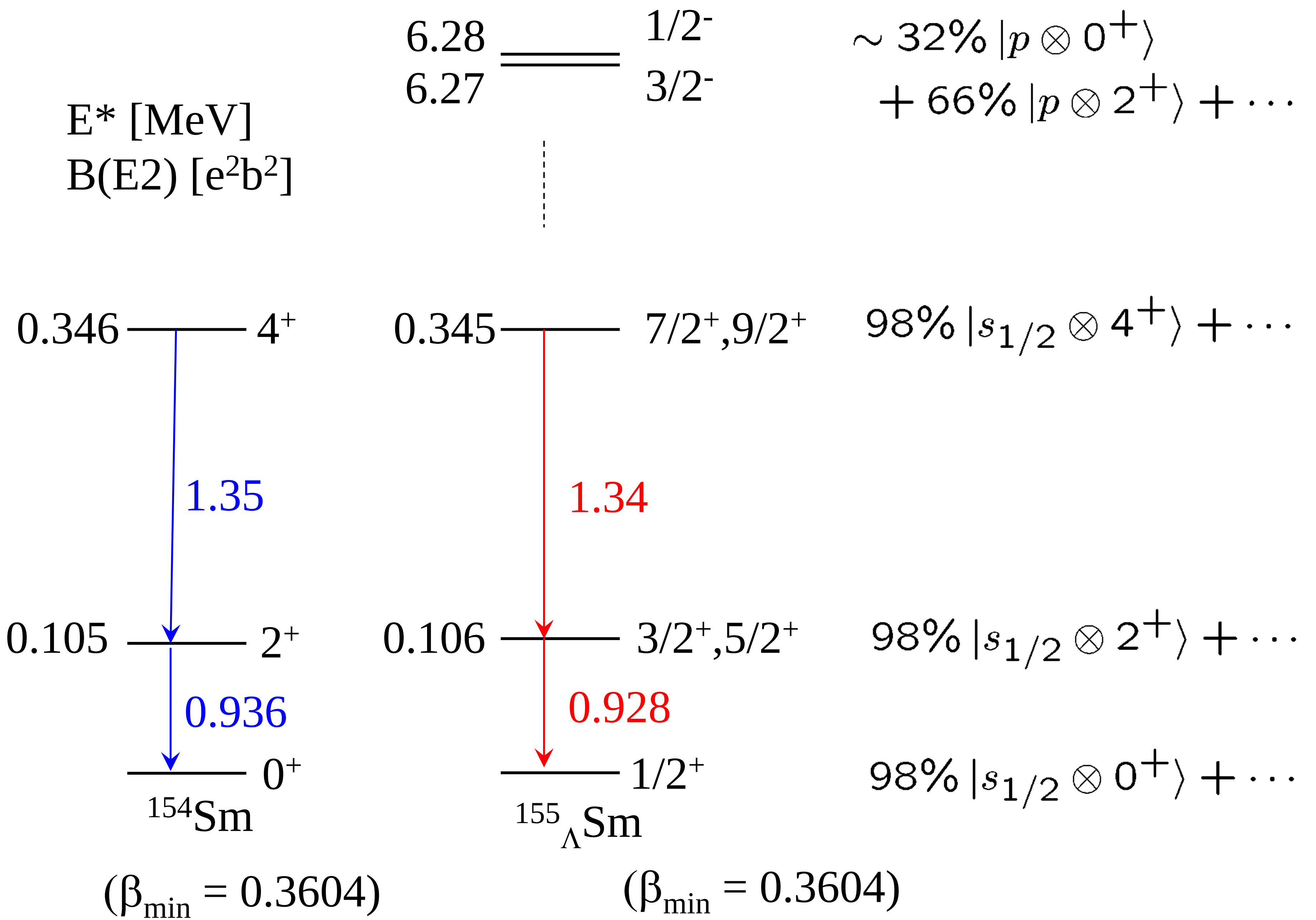

Summary

Microscopic particle-rotor model for spectrun of 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 $^{13}{}_{\Lambda}$C: good agreement with the experimental data
- reduction of B(E2) due to a change in def. param.
- application to heavier hypernuclei: $^{21}{}_{\Lambda}$Ne and $^{155}{}_{\Lambda}$Sm

Future perspectives

- more consistent interaction (the derivative and tensor terms)
  : in progress
- extension to include triaxiality (cf. $^{25}{}_{\Lambda}$Mg)

Challenging problem

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