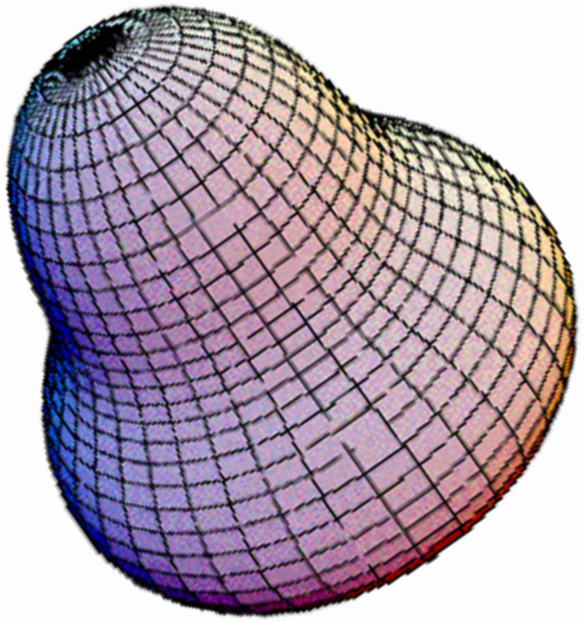
Octupole correlations in neutron-rich odd-mass nuclei

Kosuke Nomura - U. Zagreb

Padua, May 2018

Nuclear Octupoles

- Fundamental importance: Schiff moment, CP violation
- Evidenced by RIB experiments
- Prominent in odd systems

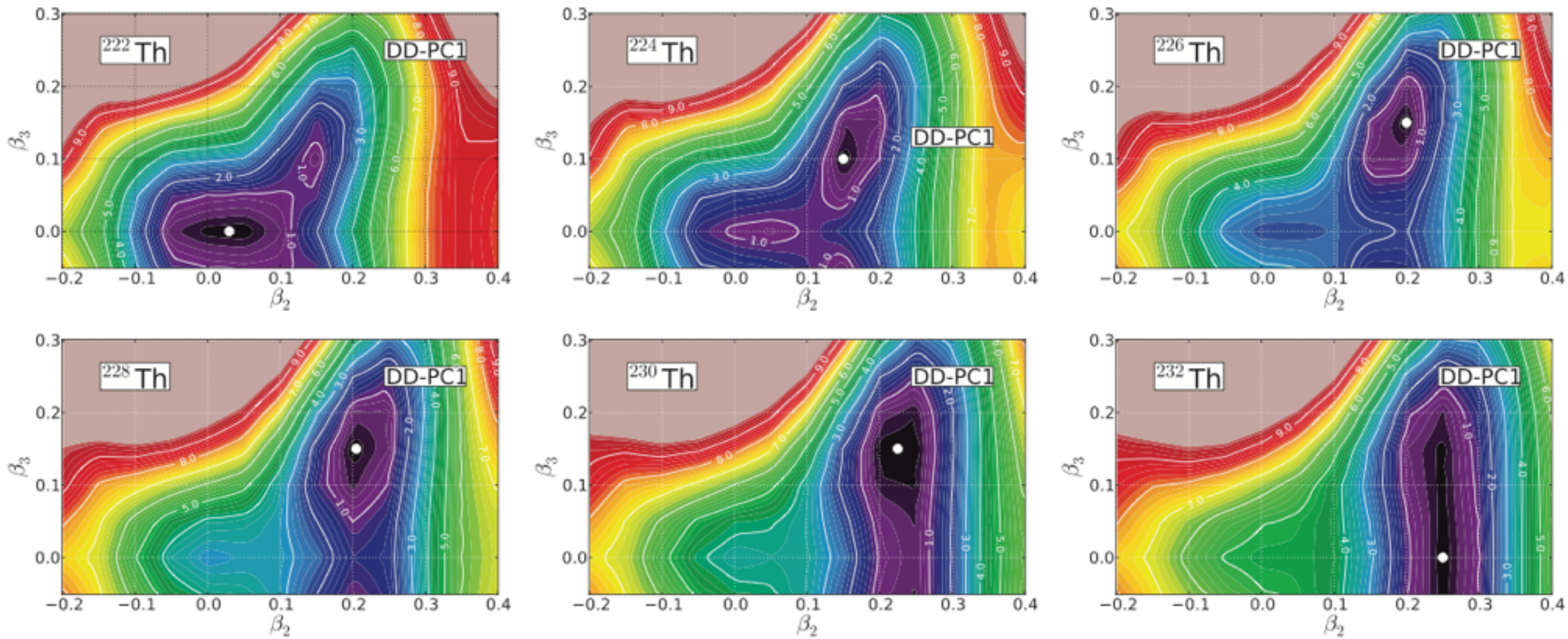


—> We use a DFT-based IBM/IBFM approach

- K.N., D. Vretenar, T. Niksic, B.-N. Lu, Phys. Rev. C 89, 024312 (2014)
- K.N., T. Niksic, D. Vretenar, Phys. Rev. C 93, 054305 (2016)
- K.N., T. Niksic, D. Vretenar, Phys. Rev. C 97, 024317 (2018)

Quadrupole-octupole shapes QPT in Th isotopes

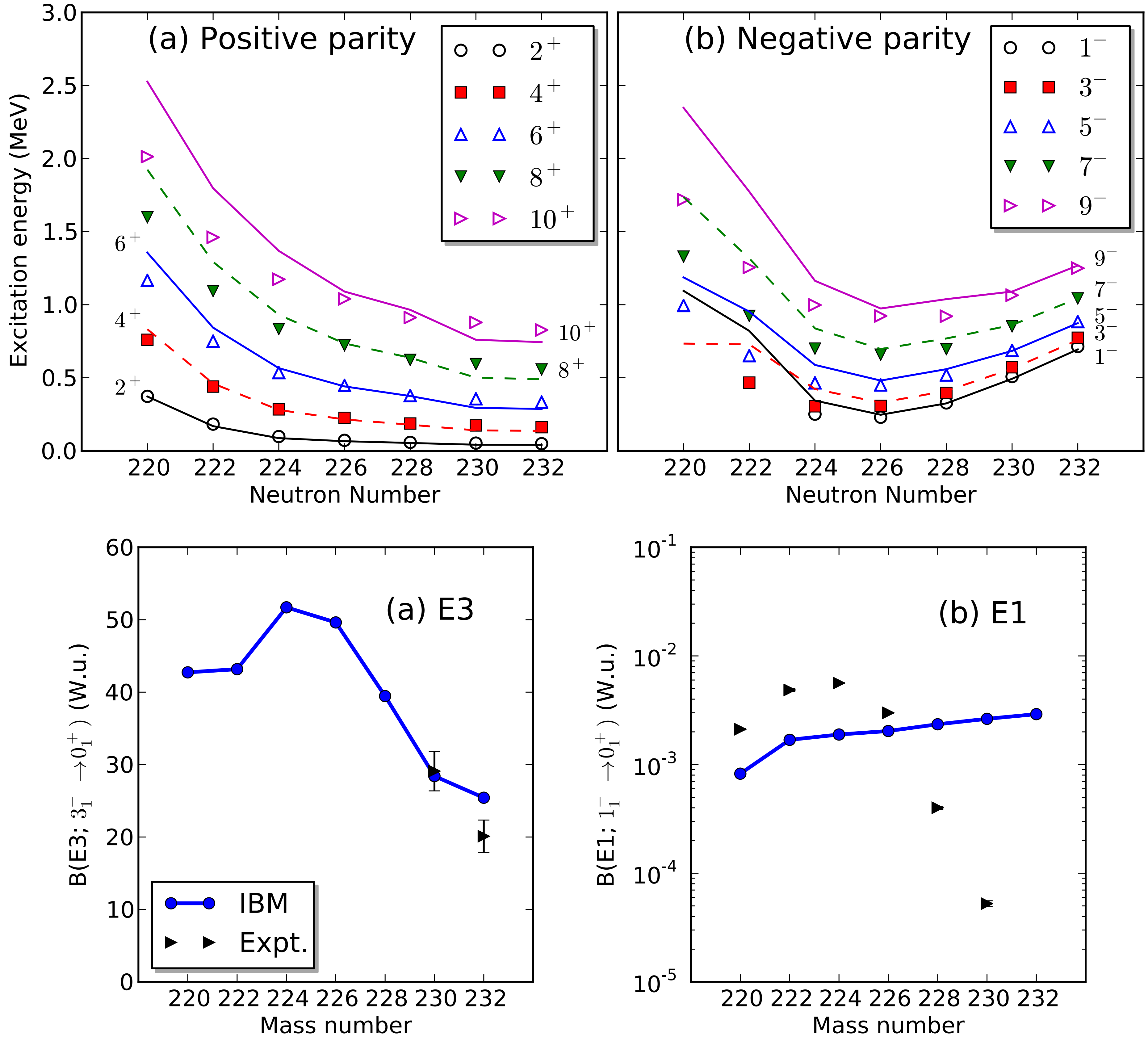
NOMURA, VRETENAR, NIKŠIĆ, AND LU PHYSICAL REVIEW C 89, 024312 (2014)



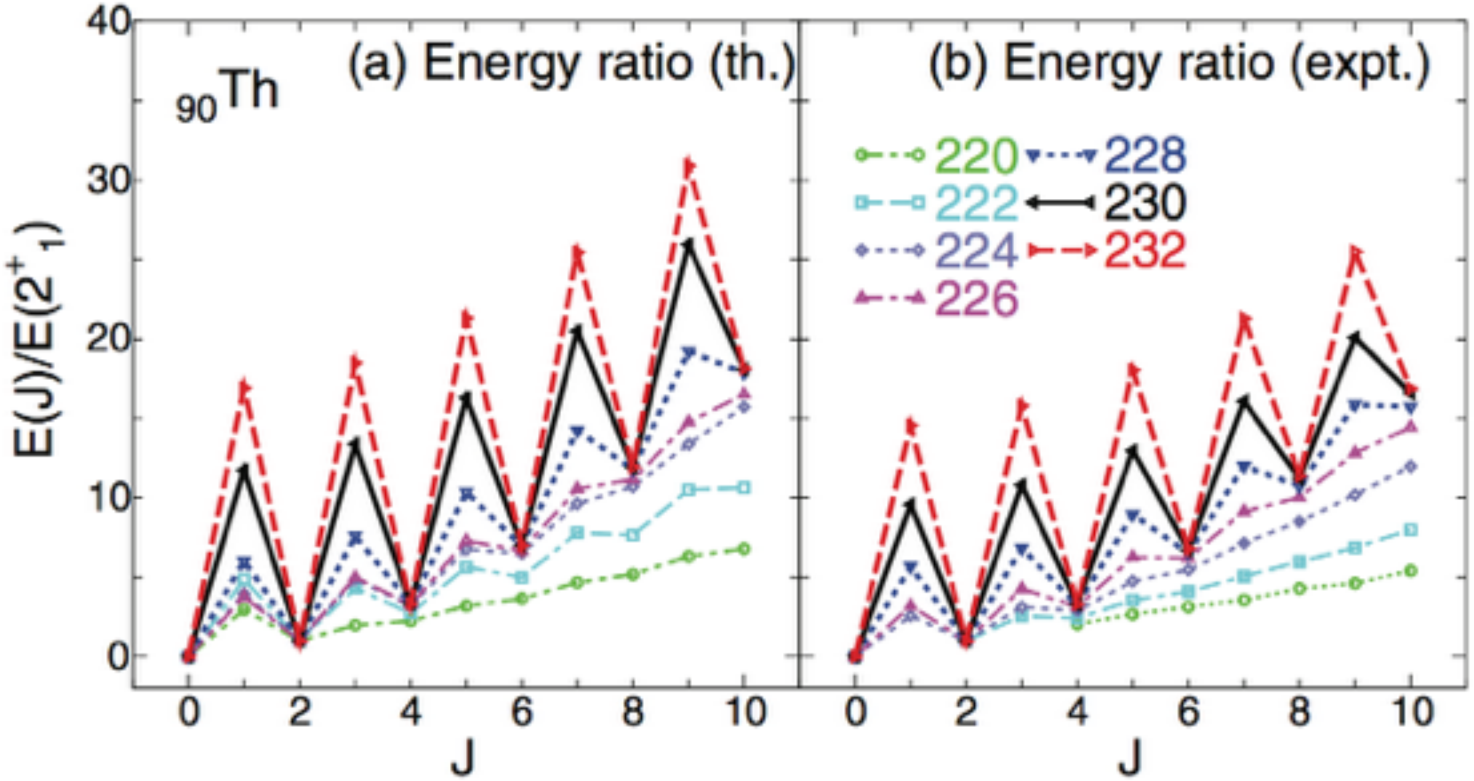
Rel. Hartree-Bogoliubov
with DD-PC1

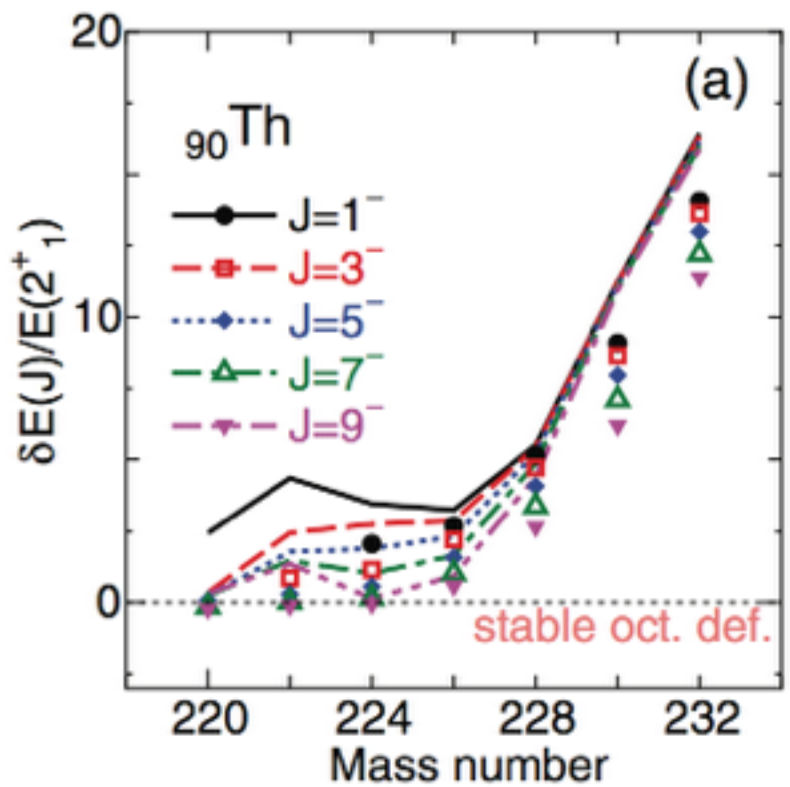
spectroscopic properties → calculated by the sdf-IBM Hamiltonian

Systematics of the calculated spectroscopic properties



Signatures of QPT





$$\delta E(J) = E(J^-) - \frac{\{E((J+1)^+) + E((J-1)^+)\}}{2}.$$

Particle-core coupling for odd nuclei

... we build interacting boson-fermion model (IBFM) Hamiltonian

$$\hat{H} = \hat{H}_B + \hat{H}_F + \hat{H}_{BF}$$

Input from DFT:

(i) Potential energy surface for even-even core

(ii) Spherical single-particle energies and occupation probabilities of odd particle

sd-IBFM

Iachello-Scholten (1979), O. Scholten (1985), etc.

$$\hat{H}_{\mathrm{B}} = \epsilon_d \hat{n}_d + \kappa \hat{Q} \cdot \hat{Q} + \kappa' \hat{L} \cdot \hat{L} \qquad \hat{H}_{\mathrm{F}} = \sum_j \epsilon_j [a_j^\dagger \times \tilde{a}_j]^{(0)}$$

$$\hat{H}_{\mathrm{BF}} = \sum_{j_a j_b} \Gamma_{j_a j_b} \hat{Q} \cdot [a_{j_a}^\dagger \times \tilde{a}_{j_b}]^{(2)}$$ ... dynamical

$$+ \sum_{j_a j_b j_c} \Lambda_{j_a j_b j_c} : [[a_{j_a}^\dagger \times \tilde{d}]^{(j_c)} \times [d^\dagger \times \tilde{a}_{j_b}]^{(j_c)}]^{(0)} :$$ ... exchange

$$+ \sum_{j_a} A_{j_a} [a_{j_a}^\dagger \times \tilde{a}_{j_a}]^{(0)} \hat{n}_d,$$ ... monopole

j-dependent coefficients

$$A_j = -A_0 \sqrt{2j+1}$$

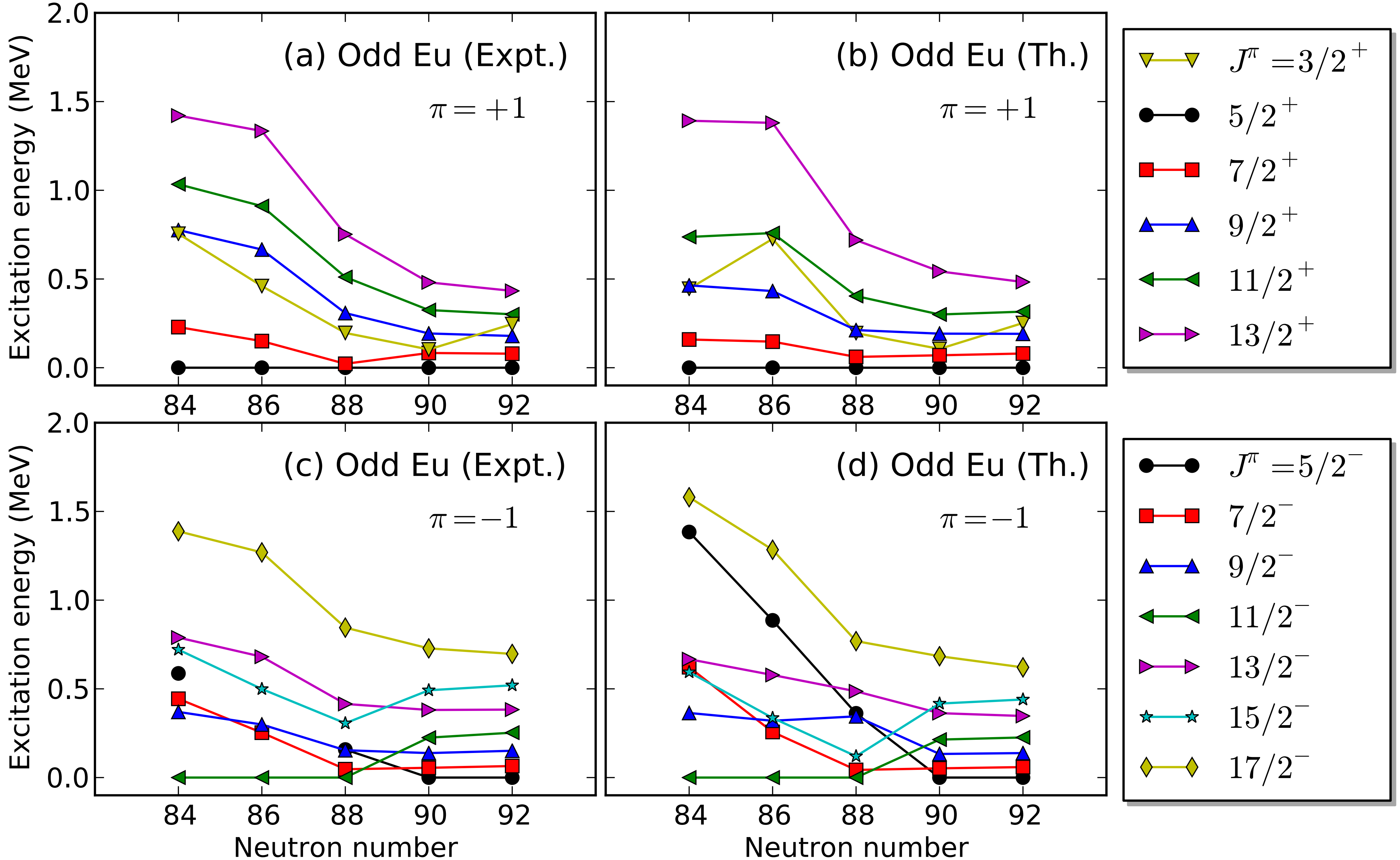
$$\Gamma_{j_a j_b} = \Gamma_0 \gamma_{j_a j_b}$$

$$\Lambda_{j_a j_b j_c} = -2\Lambda_0 \sqrt{\frac{5}{2j_c+1}} \beta_{j_a j_c} \beta_{j_b j_c}.$$

$$\gamma_{ij} = (u_i u_j - v_i v_j) q_{ij}^{(2)}, \quad \beta_{ij} = (u_i v_j + u_j v_i) q_{ij}^{(2)}$$

Strength parameters (A_0, Γ_0, Λ_0) fitted to experiment

Energy spectra in odd-mass Eu



sdf-IBFM

$$\hat{H}_B = \epsilon_d \hat{n}_d + \epsilon_f \hat{n}_f + \kappa_2 \hat{Q}\cdot\hat{Q} + \alpha \hat{L}_d \cdot \hat{L}_d + \kappa_3 : \hat{V}_3^\dagger \cdot \hat{V}_3 :$$

$$\hat{Q} = s^\dagger \tilde{d} + d^\dagger \tilde{s} + \chi_{dd}[d^\dagger \times \tilde{d}]^{(2)} + \chi_{ff}[f^\dagger \times \tilde{f}]^{(2)}.$$

$$\hat{V}_3^\dagger = s^\dagger \tilde{f} + \chi_{df}[d^\dagger \times \tilde{f}]^{(3)}.$$

$$\hat{H}_{BF} = \hat{H}_{BF}^{sd} + \hat{H}_{BF}^{f} + \hat{H}_{BF}^{sdf}.$$

$$\hat{H}_{BF}^{f} = \sum_{j_a j_b} \Gamma_{j_a j_b}^{ff} \hat{Q}_{ff} \cdot [a_{j_a}^\dagger \times \tilde{a}_{j_b}]^{(2)} + \sum_{j_a j_b j_c'} \Lambda_{j_a j_b j_c'}^{ff} : [[a_{j_a}^\dagger \times \tilde{f}]^{(j_c')} \times [f^\dagger \times \tilde{a}_{j_b}]^{(j_c')}]^{(0)} : + \sum_{j_a} A_{j_a}^{f} [a_{j_a}^{+} \times \tilde{a}_{j_a}]^{(0)} \hat{n}_f, \quad (8)$$

$$\hat{H}_{BF}^{sdf} = \sum_{j_a j_b'} \Gamma_{j_a j_b'}^{sf} \hat{V}_3^\dagger \cdot [a_{j_a}^\dagger \times \tilde{a}_{j_b'}]^{(3)} + \sum_{j_a j_b' j_c} \Lambda_{j_a j_b' j_c}^{df} : [[a_{j_a}^\dagger \times \tilde{d}]^{(j_c)} \times [f^\dagger \times \tilde{a}_{j_b'}]^{(j_c)}]^{(0)} : + \mathrm{H.c.}, \quad (9)$$

$$A_j^f = -A_0^f \sqrt{2j+1},$$

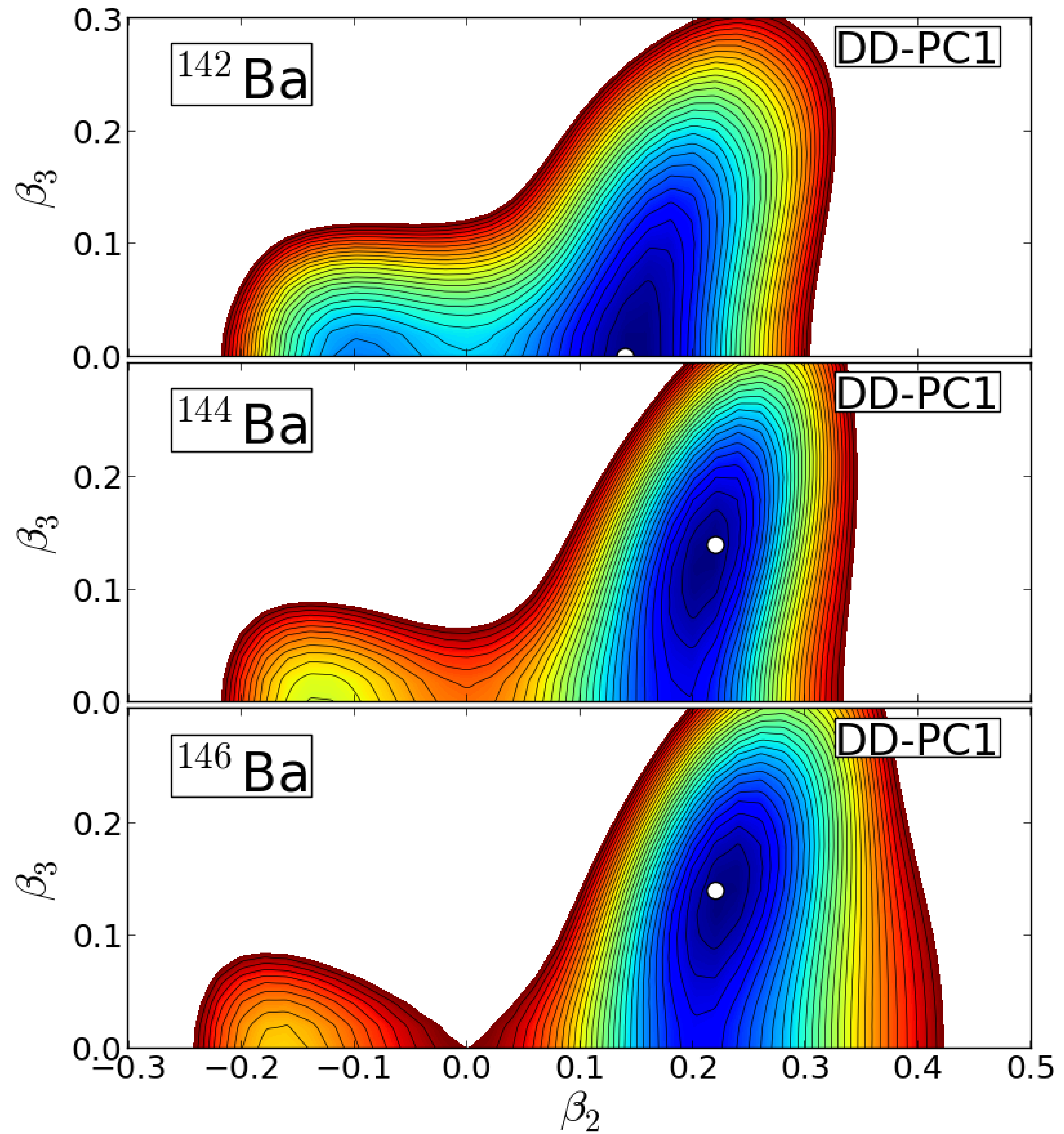
$$\Gamma_{j_a j_b}^{ff} = \Gamma_0^{ff} \gamma_{j_a j_b}^{(2)},$$

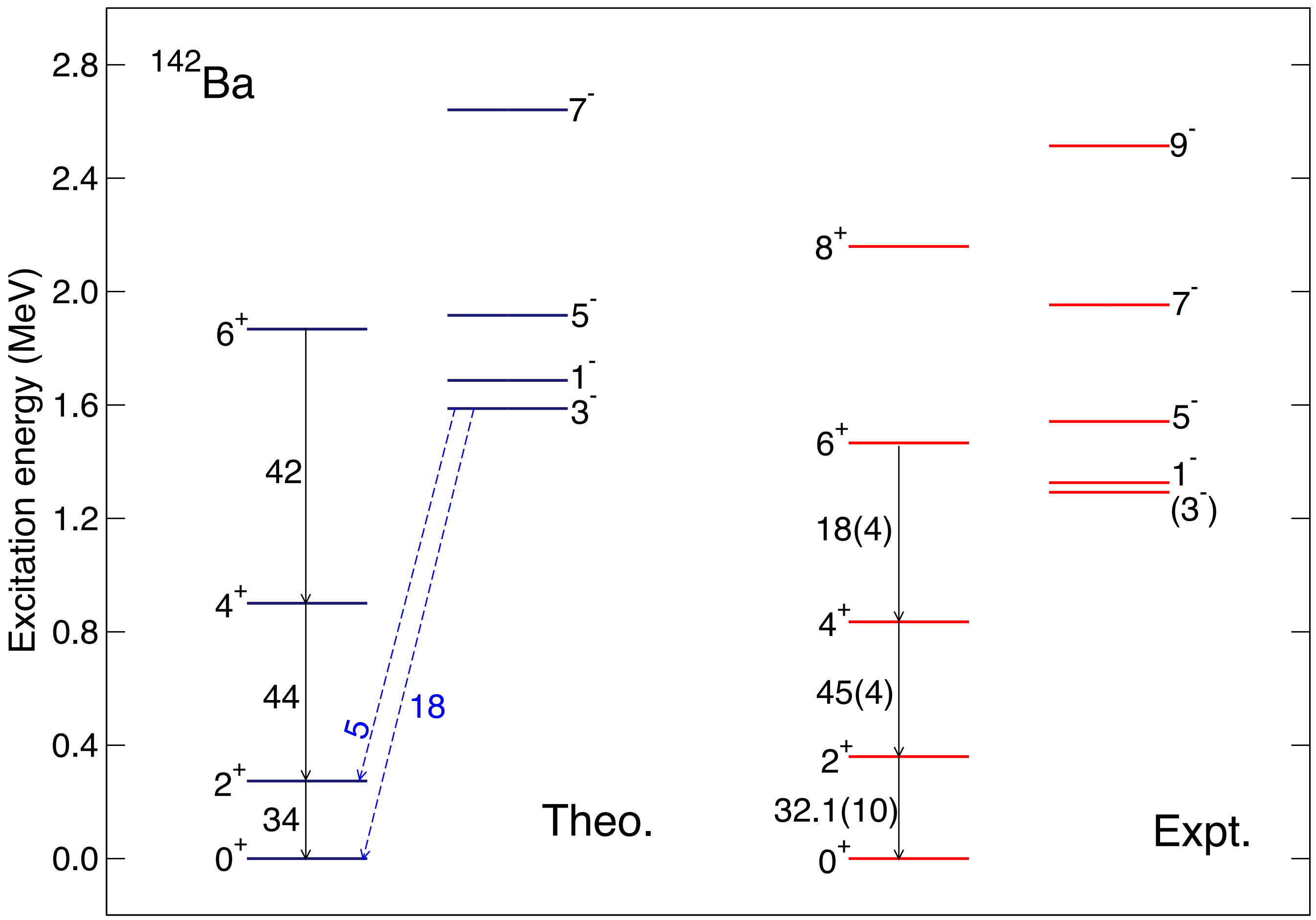
$$\Lambda_{j_a j_b j_c'}^{ff} = -2\Lambda_0^{ff} \sqrt{\frac{7}{2j_c'+1}} \beta_{j_a j_c'}^{(3)} \beta_{j_b j_c'}^{(3)},$$

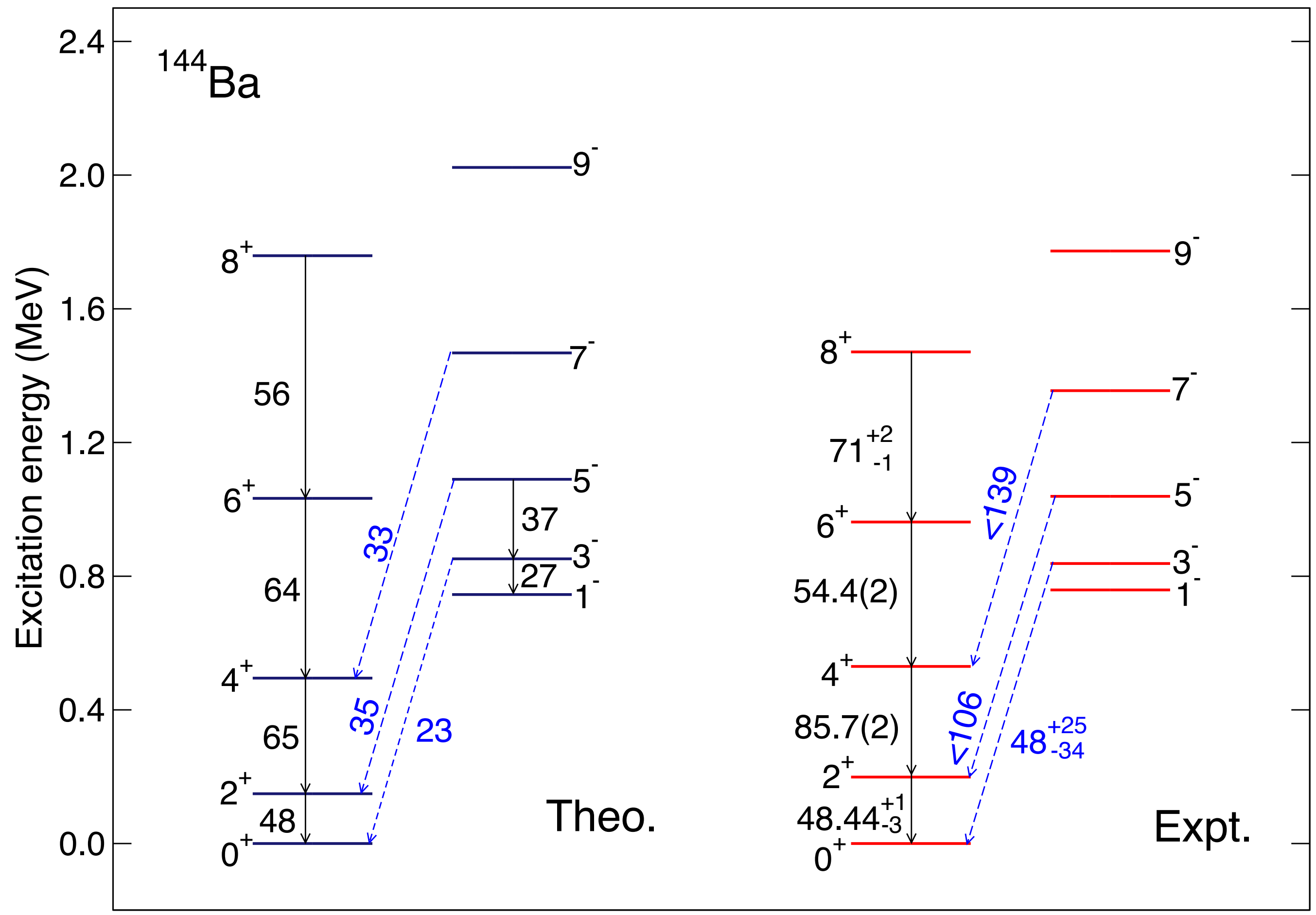
$$\Gamma_{j_a j_b'}^{sf} = \Gamma_0^{sf} \gamma_{j_a j_b'}^{(3)},$$

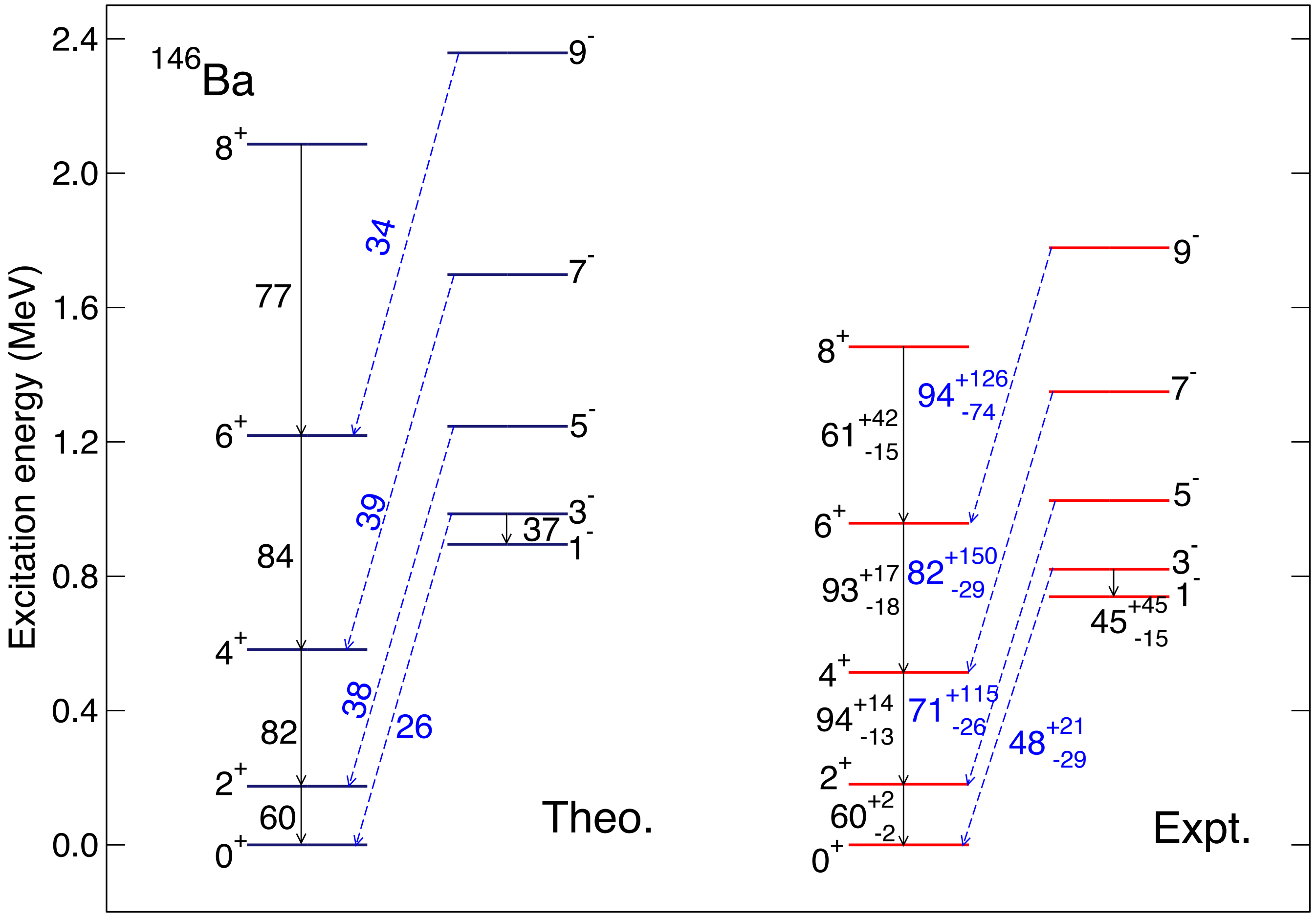
$$\Lambda_{j_a j_b' j_c}^{df} = -2\Lambda_0^{df} \sqrt{\frac{7}{2j_c+1}} \beta_{j_a j_c}^{(2)} \beta_{j_b' j_c}^{(3)}.$$

Octupole correlations in neutron-rich Ba

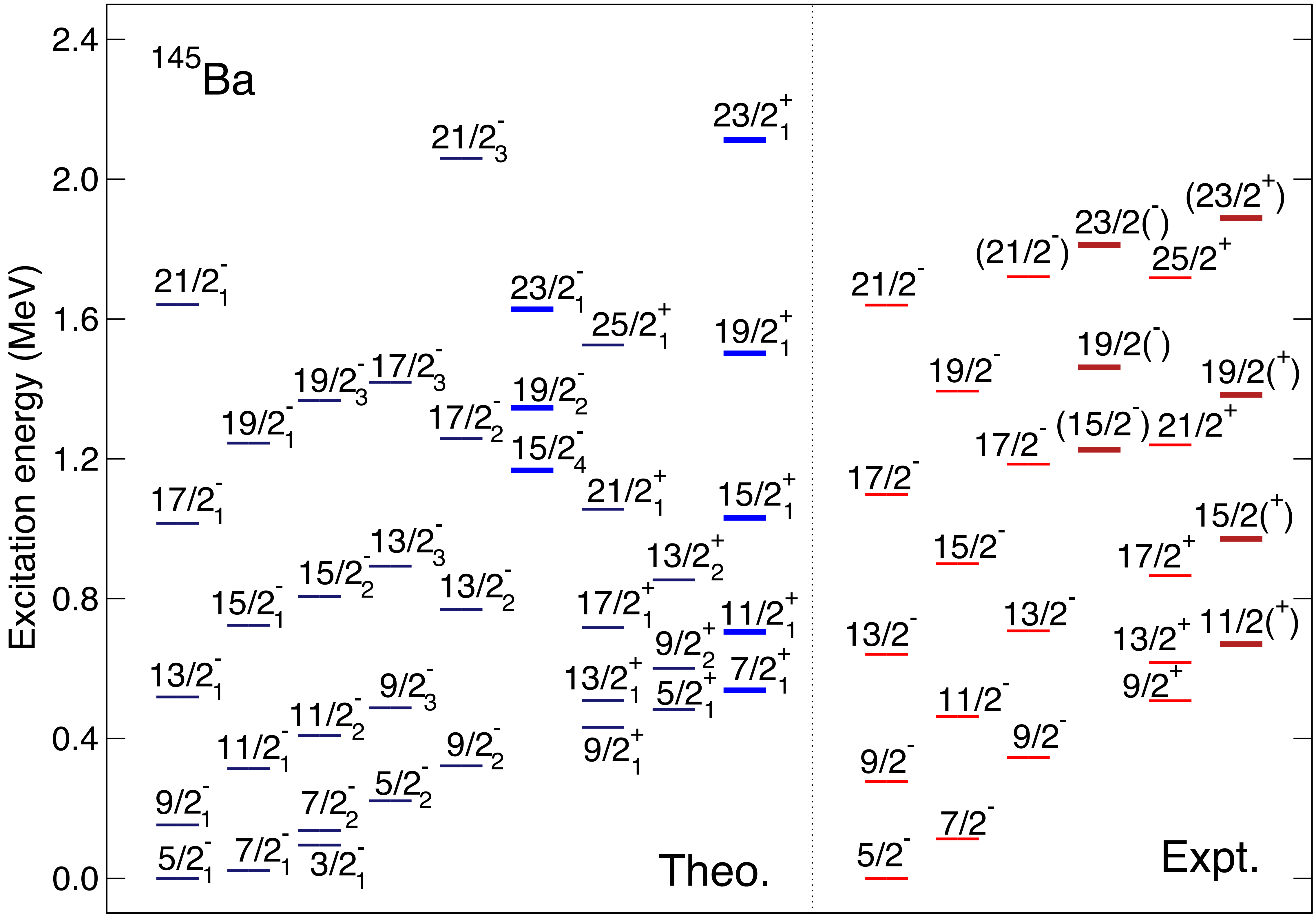








$B(E3)_{th} \approx 20\text{-}40$ W.u.



… predicts one-f boson bands at medium spin & energy

… large E3 decay to ground states, to be tested by experiment

Summary

DFT-based IBM/IBFM for octupoles

- reasonable description of energies, E3, etc.
- Signatures of quad-oct QPT
- systematic and computationally feasible prediction of heavy, odd-A systems
- extrapolation to even heavier nuclei, e.g., odd-A actinides, in progress

Thank you

TABLE III. Strength parameters of the boson-fermion interaction $\hat{H}_{BF}$ in Eq. (6) employed in the present calculation for the ^{143,145,147}Ba nuclei (in MeV units). The numbers in the upper (lower) row for each nucleus correspond to the unique-parity (normal-parity) single-particle configurations.

	Γ_0^{sd}	Γ_0^{ff}	Λ_0^{sd}	Λ_0^{ff}	A_0^d	A_0^f	Γ_0^{sf}	Λ_0^{df}
^{143}Ba	1.40	1.20	1.0	0.0	−0.75	−0.75	0.75	0.0
	0.35	0.12	1.1	1.1	−1.3	−1.3		
^{145}Ba	1.40	1.20	1.0	0.0	−0.80	0.0	0.75	0.0
	0.40	0.13	1.0	0.30	−1.0	−0.15		
^{147}Ba	1.40	1.20	1.0	0.0	−0.85	0.0	0.75	0.0
	0.45	0.15	0.60	0.60	−1.0	−0.30		