

Nuclear shapes and collective excitations in the microscopically guided algebraic theory

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Plan of this talk

Combined approach of algebraic theory of interacting bosons and nuclear energy density functional theory for nuclear shapes and excitations

We will focus on its extension to odd-mass nuclei

Refs: K.N., T. Niksic, D. Vretenar,
PRC93, 054305 (2016); arXiv:1610.00469 [nucl-th]

Microscopic theories for odd nuclei - motivation

- Variety of mean-field approaches, nuclear energy density functional theory (DFT)
- Quantitative study of spectroscopy should include **beyond-mean-field effects** (symmetry & correlation) which presents major computational efforts.
 - Breaking of time-reversal symmetry
 - Blocking at each deformation

Ref: B. Bally, B. Avez, M. Bender, P.-H. Heenen, PRL113, 162501 (2014)

We develop an alternative method for a systematic and feasible description of odd nuclei.

The method

Self-consistent mean-field (SCMF) calculation
within nuclear DFT

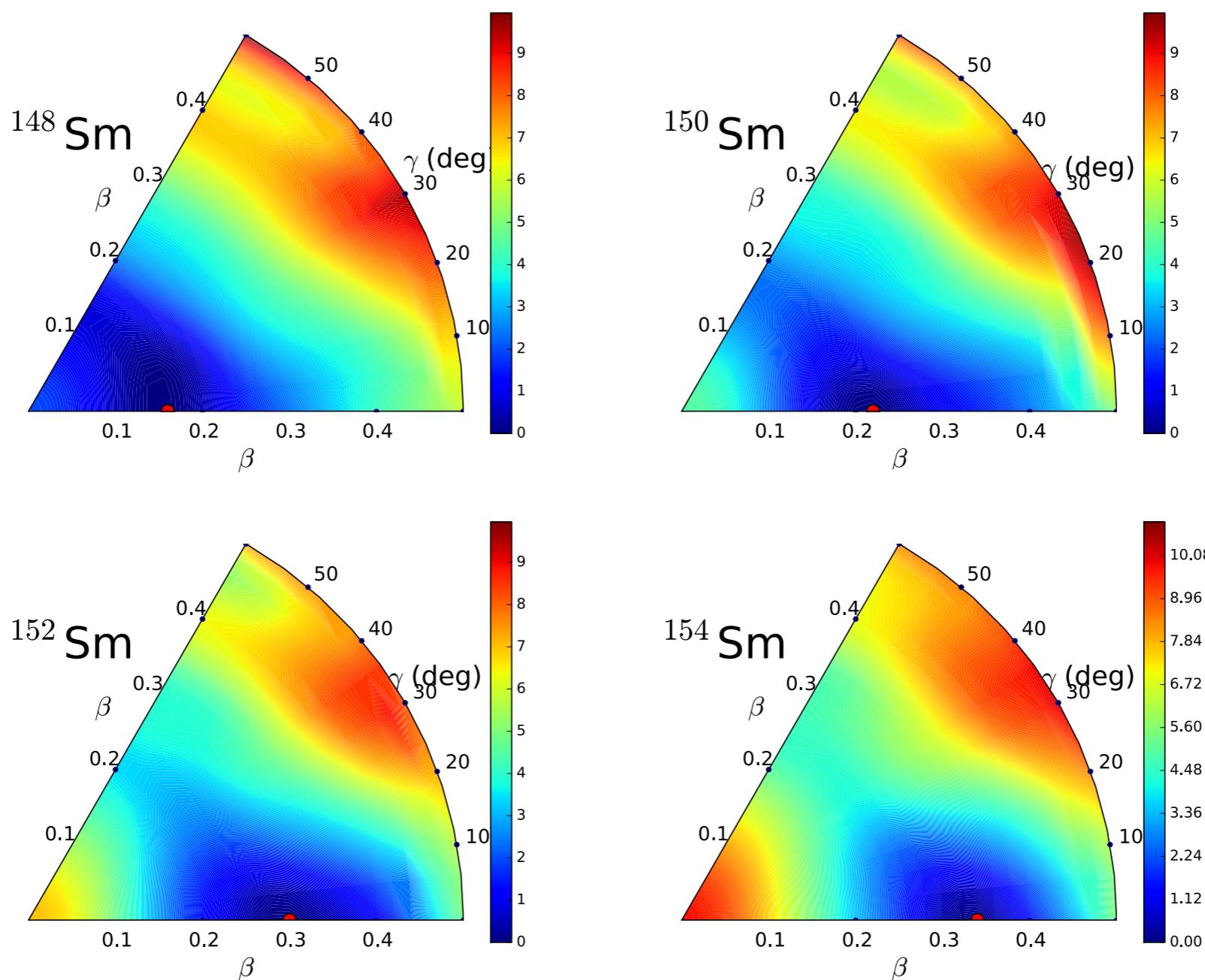


Particle-**Core** coupling Hamiltonian

Even-even core is described in terms of bosonic degrees of freedom (interacting boson model), while particle-core coupling is treated by interacting **boson-fermion** Model (IBFM)

Even-even core: SCMF results

Deformation energy surfaces calculated by the relativistic Hartree-Bogoliubov method with the functional DD-PC1



IBFM Hamiltonian: $H = H_B + H_F + H_{BF}$

$$\hat{H}_B = \epsilon_d \hat{n}_d + \kappa \hat{Q}_B \cdot \hat{Q}_B + \kappa' \hat{L} \cdot \hat{L}$$

$$\hat{H}_F = \sum_j \epsilon_j [a_j^\dagger \times \tilde{a}_j]^{(0)}$$

Single-particle energy

$$\hat{H}_{BF} = \sum_{jj'} \Gamma_{jj'} \hat{Q}_B \cdot [a_j^\dagger \times \tilde{a}_{j'}]^{(2)} + \sum_{jj''j''} \Lambda_{jj'}^{j''} : [[d^\dagger \times \tilde{a}_j]^{(j'')} \times [a_{j'}^\dagger \times \tilde{d}]^{(j'')}]^{(0)} : + \sum_j A_j [a^\dagger \times \tilde{a}_j]^{(0)} \hat{n}_d,$$

quadrupole term

exchange term

monopole term

j-dependence of the coefficients:

$$\Gamma_{jj'} = \Gamma_0 (u_j u_{j'} - v_j v_{j'}) Q_{jj'}$$

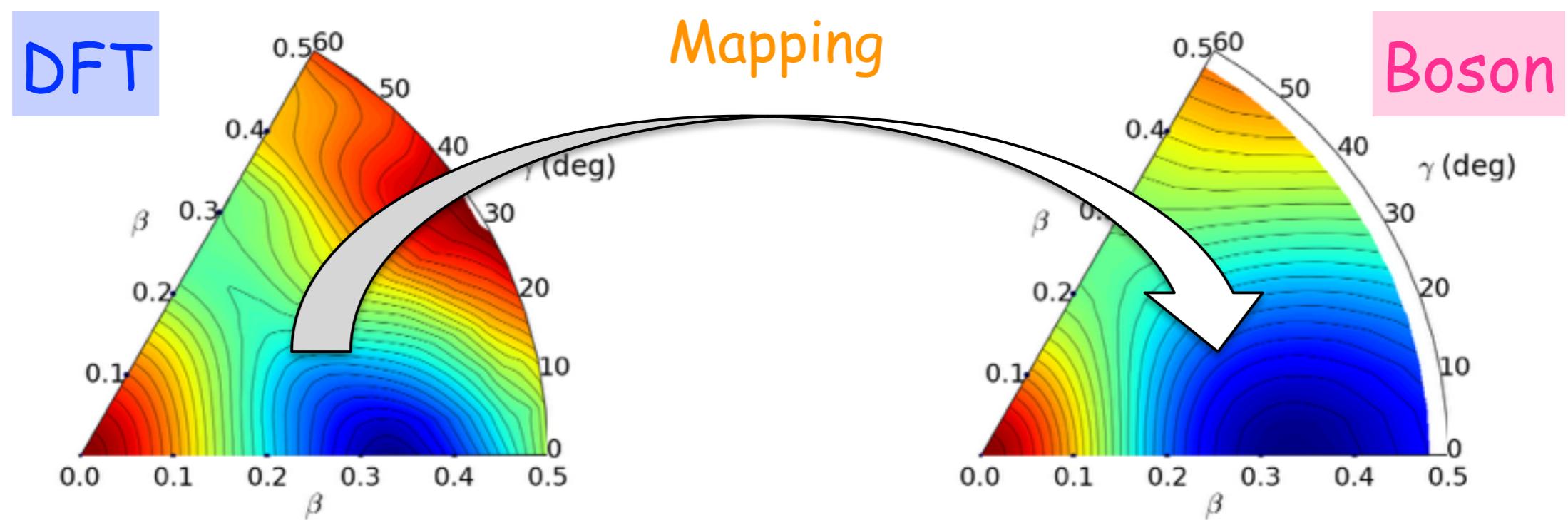
$$\Lambda_{jj'}^{j''} = -2\Lambda_0 \sqrt{\frac{5}{2j''+1}} (u_j v_{j'} + v_j u_{j'}) (u_{j'} v_{j''} + v_{j'} u_{j''}) Q_{jj'} Q_{j'j''}$$

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

Occupation probability: $u_j^2 + v_j^2 = 1$

Step 1. determine H_B

Fermionic (DFT) energy surface is mapped onto the corresponding bosonic one around minimum. Boson parameters are completely determined from the mapping.



Step 2. determine H_{BF} (and H_F)

$$H = H_B + H_F + H_{BF}$$

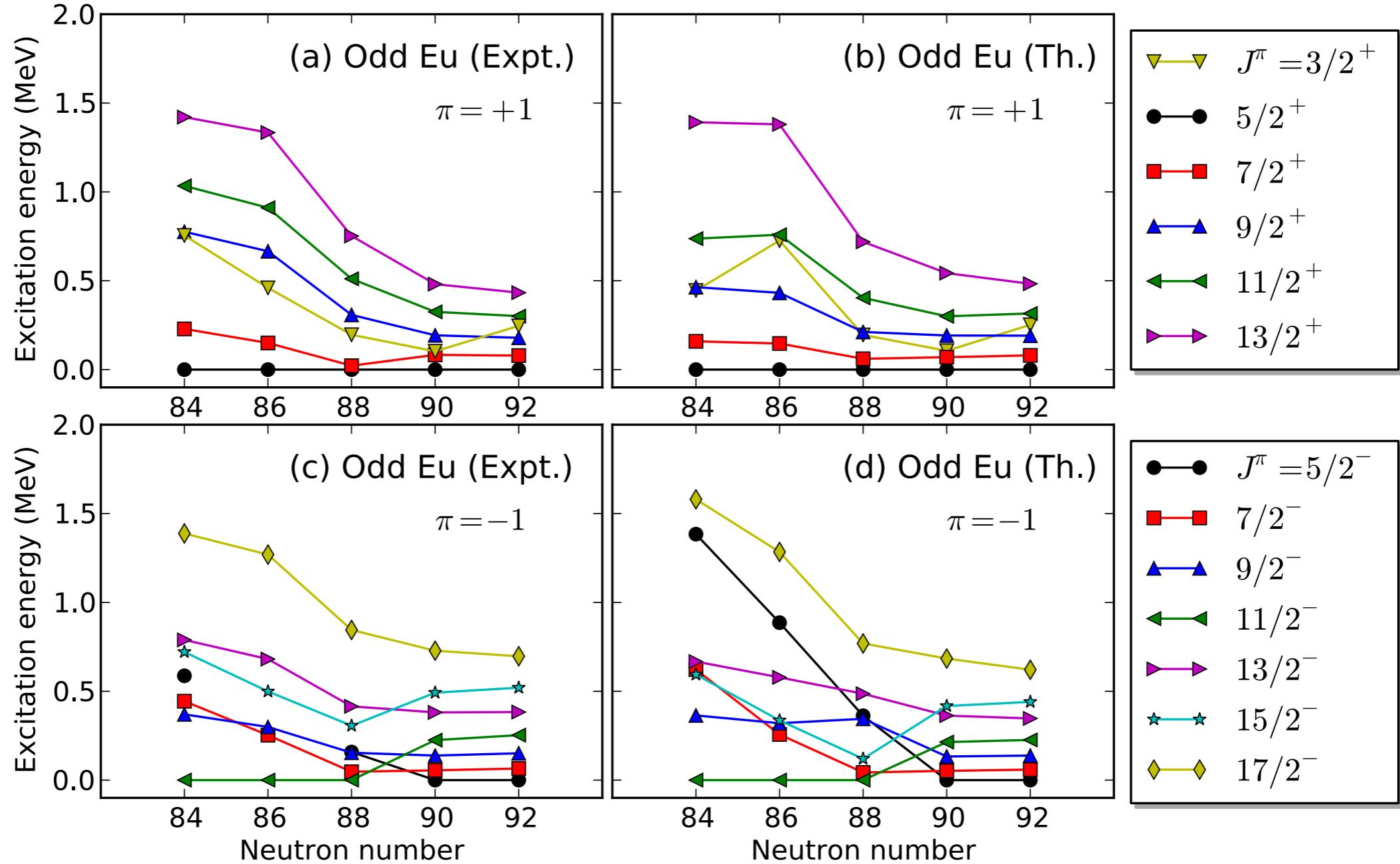
Determined by the mapping from SCMF energy surface

Occupation probabilities v_j^2 at zero deformation; Input from SCMF

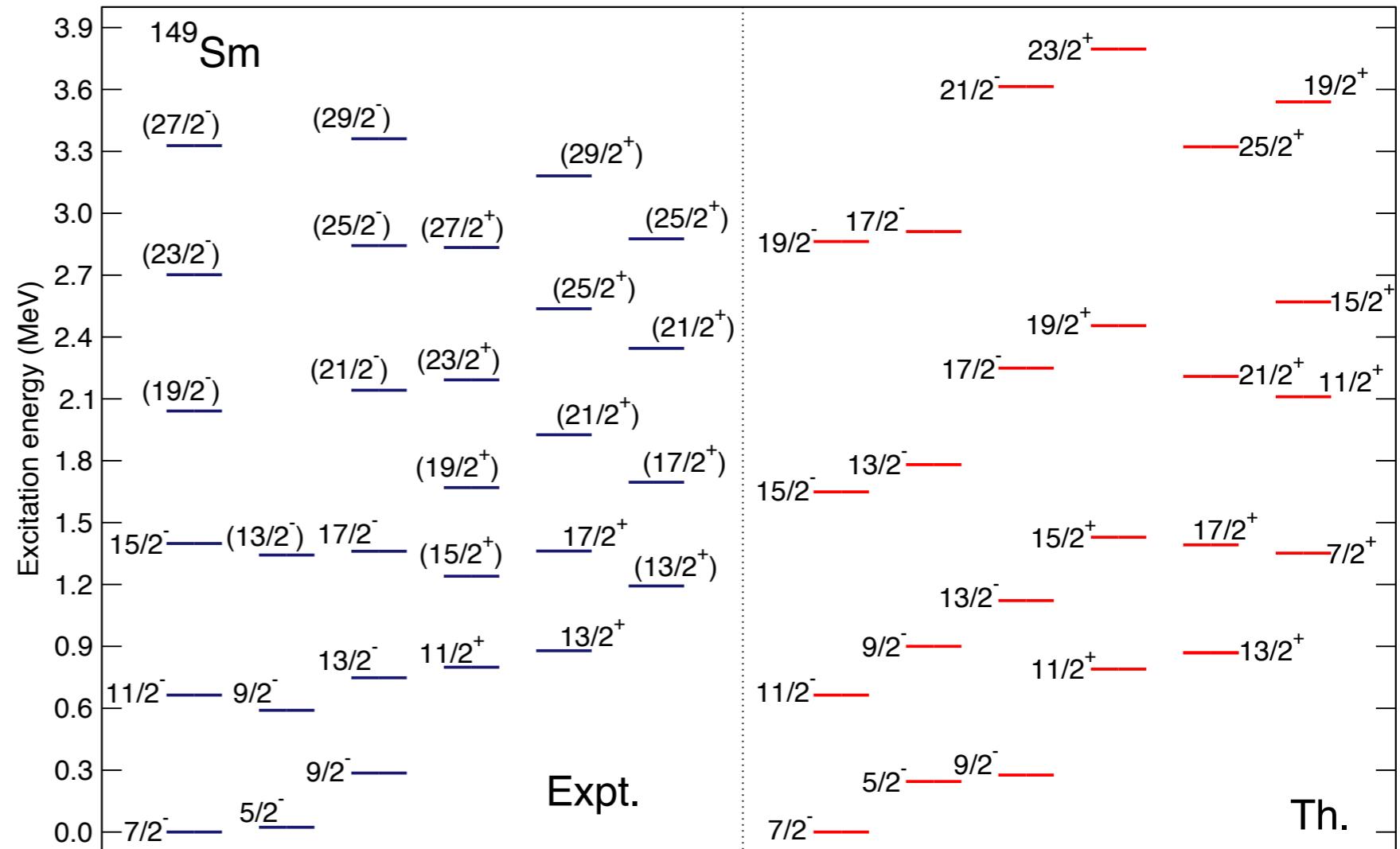
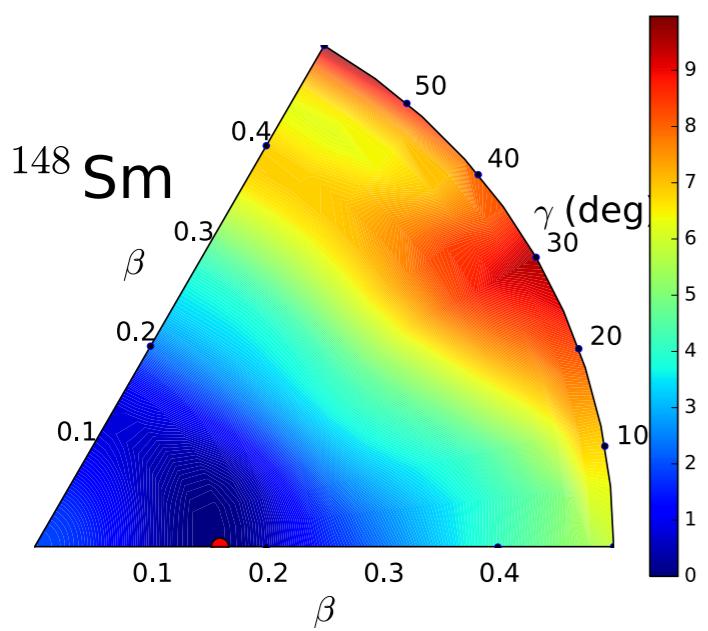
Single-particle energy ε_j at zero deformation; Input from SCMF

Only the strength parameters for H_{BF} (Γ_0, Λ_0 and A_0) have to be fitted to data...

Energy systematics in odd Eu (even Sm + odd proton)

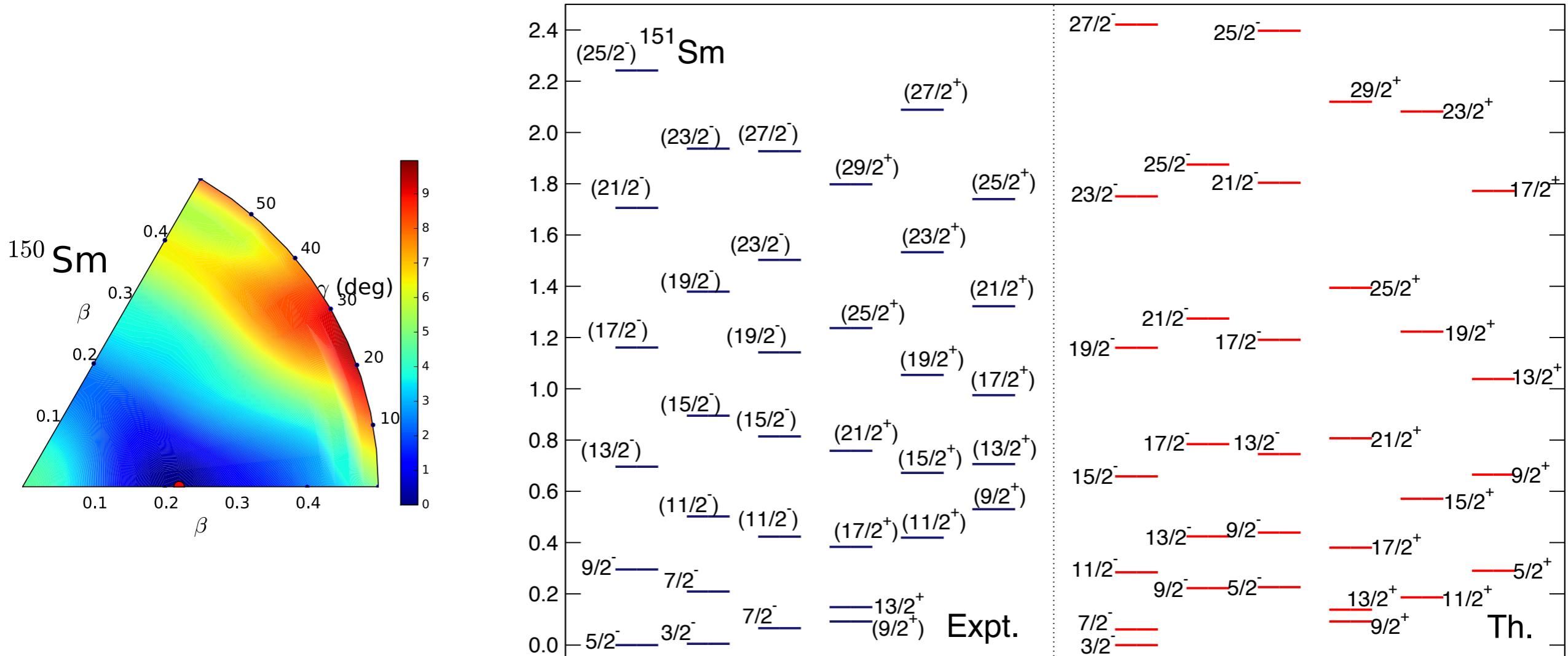


Energy spectra in ^{149}Sm



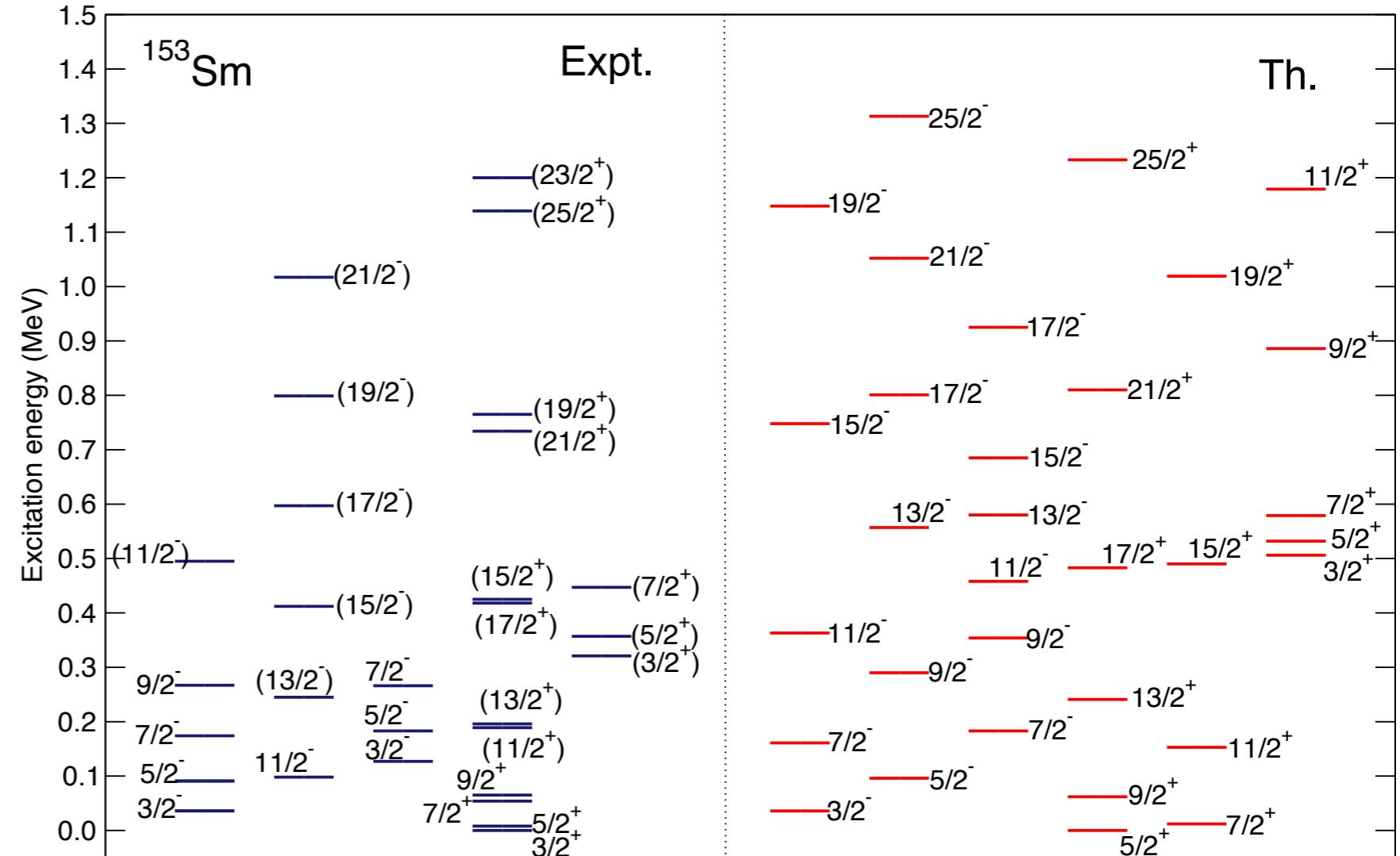
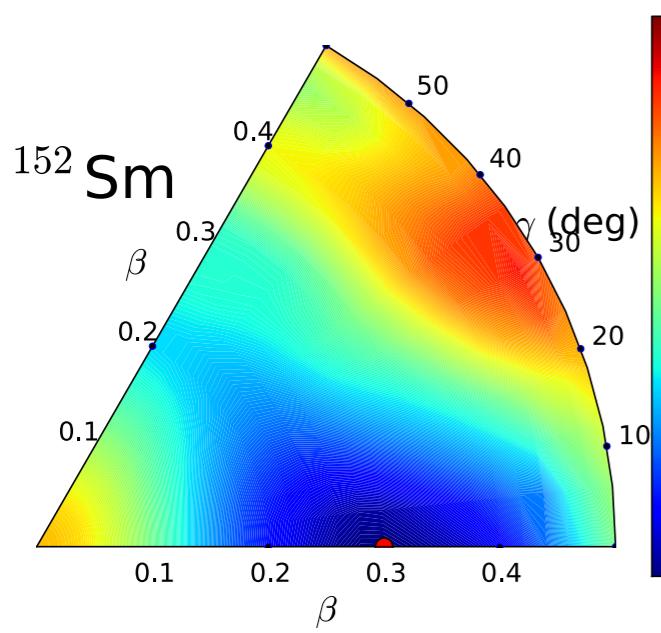
- Both positive- and negative-parity bands show vibrational-like spectra with the $\Delta J=2$ systematics, decoupled from the core

Energy spectra in ^{151}Sm



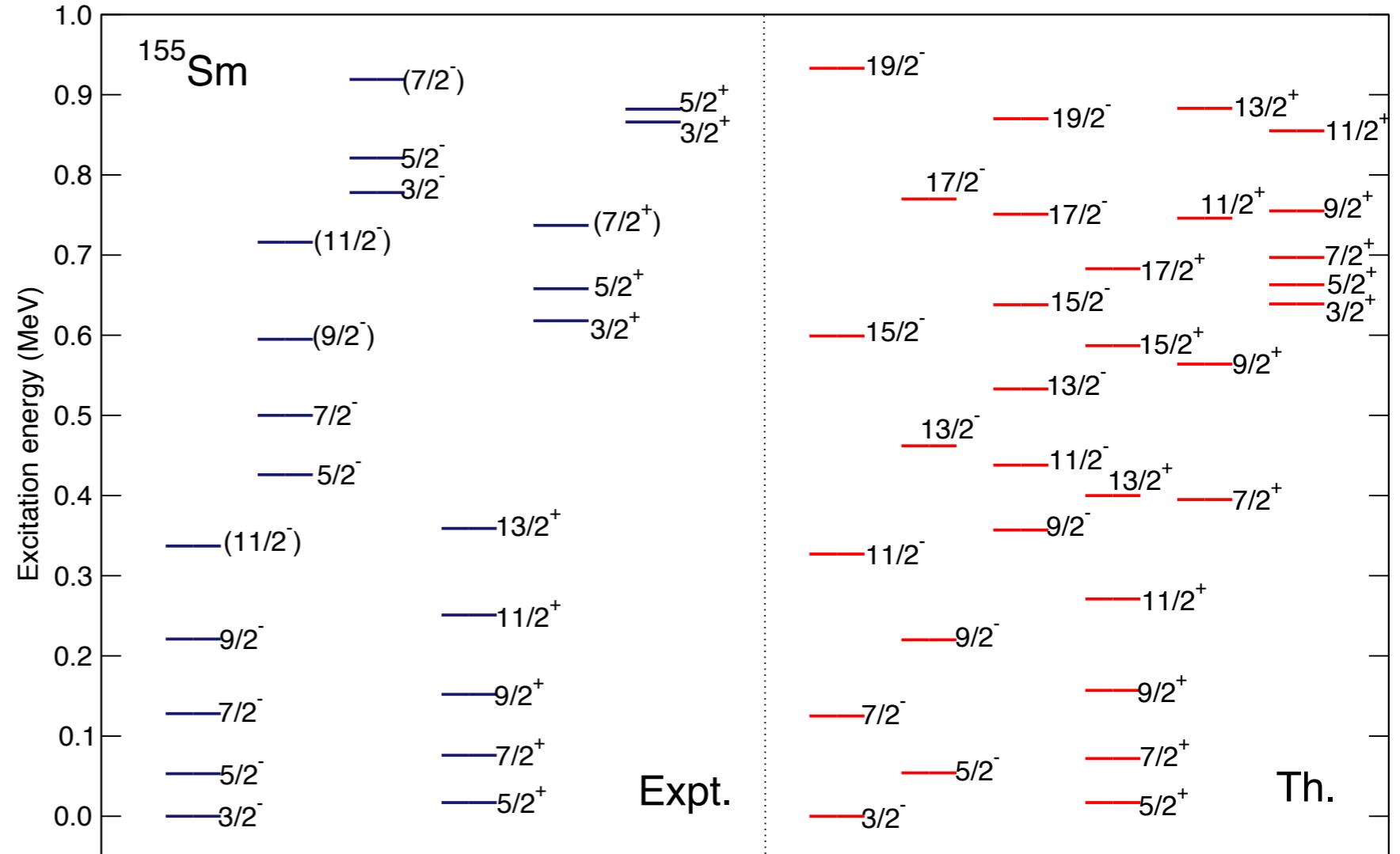
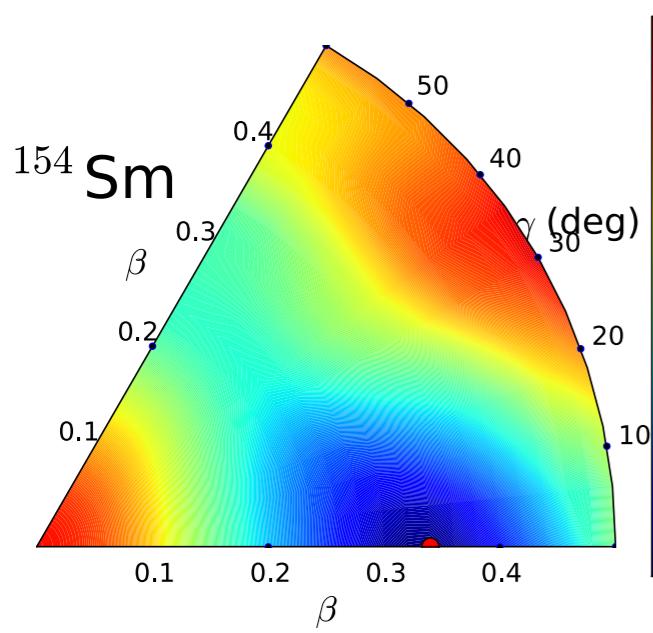
- Perturbation to vibrational-like level scheme, both positive- and negative-parity bands show the $\Delta J=2$ systematics

Energy spectra in ^{153}Sm



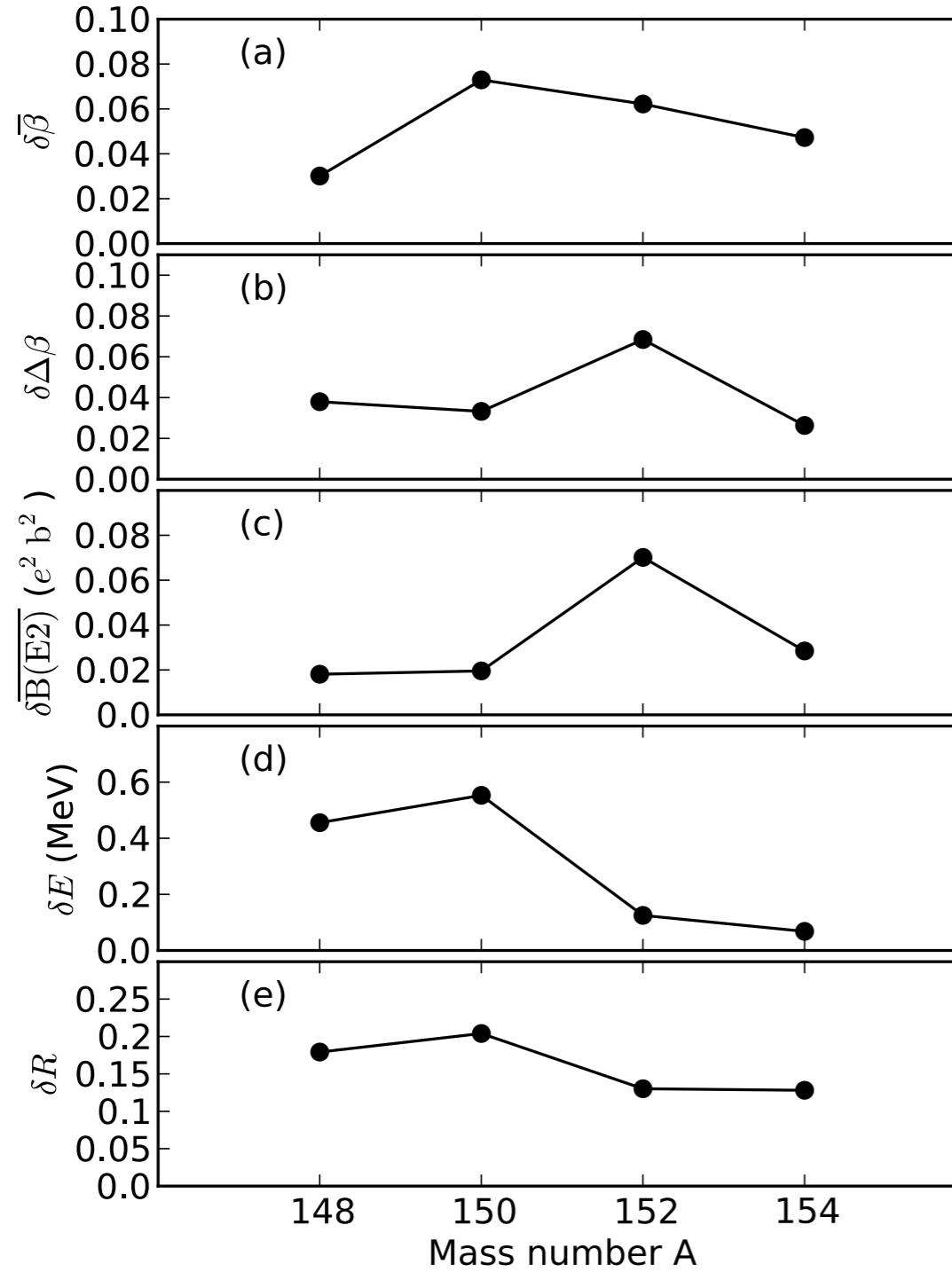
- Coexistence of strong- ($\Delta J=1$) and weakly-coupling ($\Delta J=2$) bands for positive parity
- Negative-parity bands with the $\Delta J=1$ systematics in the strong-coupling limit

Energy spectra in ^{155}Sm



- Looks more regular. Rotational bands following the $J(J+1)$ rule with the $\Delta J=1$ systematics in the strong-coupling limit

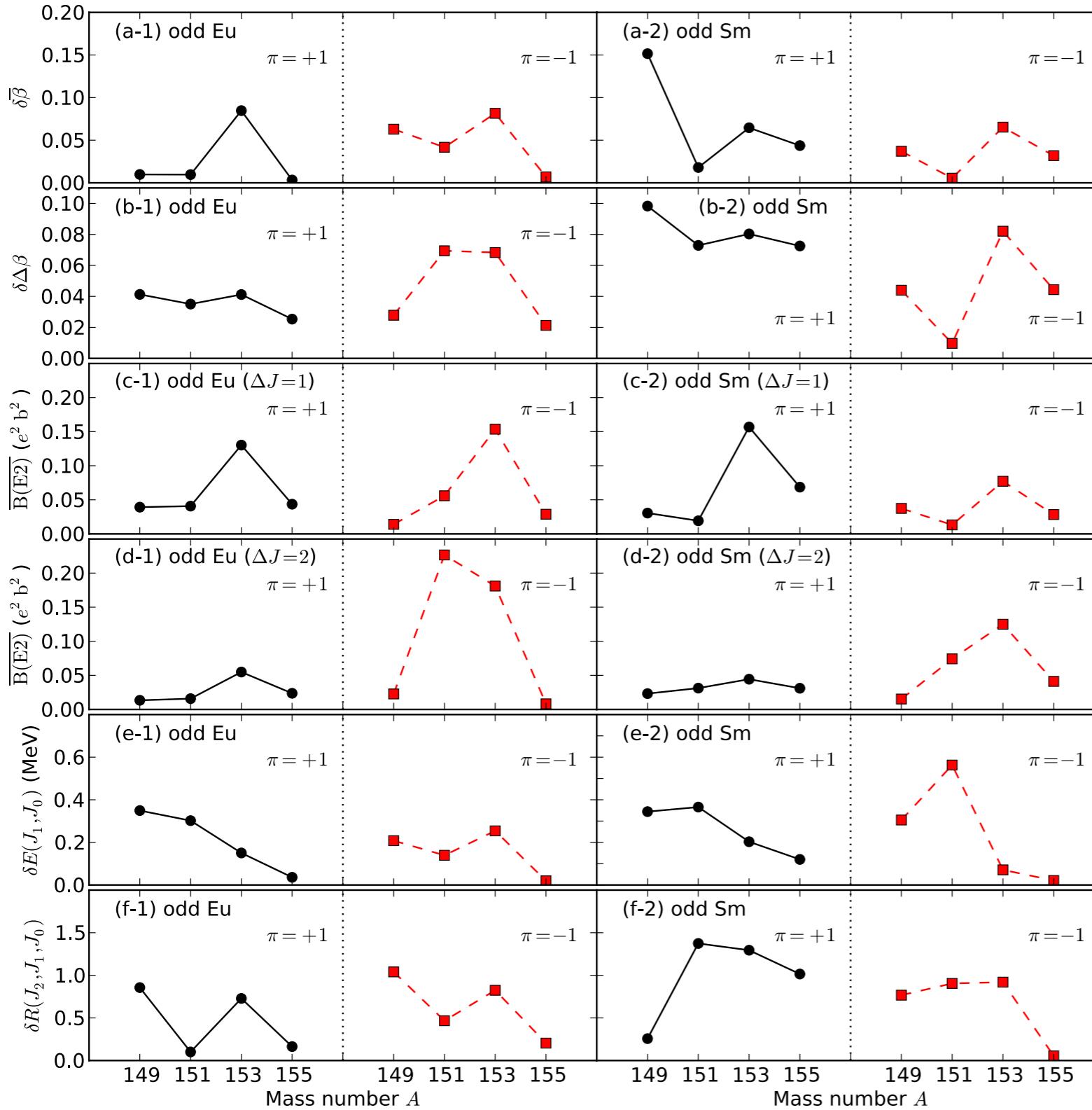
Spherical-deformed quantum phase transitions (QPTs) in even Sm



$$\delta\mathcal{O} = \frac{1}{3} \sum_{i=1}^3 |\mathcal{O}_{i,A} - \mathcal{O}_{i,(A-2)}|$$

Differentials of calculated quantities (averaged in the lowest three $K=0+$ bands) between neighbouring isotopes exhibit a kink at around $A=150$ or 152 where the potential is soft.

Signatures of QPT in odd- A systems



- Kink is also found at $A=151$ or 153 in the presence of odd proton (odd Eu) and neutron (odd Sm).
- Addition of the odd particle leads to the QPT at the same location as in the even-even boson-core nuclei.

Summary

An alternative microscopic approach to odd- A nuclei based on the nuclear DFT and particle-boson-core coupling (IBFM).

The method gave an excellent quantitative description of low-lying structure of odd Eu and Sm, and has the promise to predict a wealth of new data on medium-mass and heavy odd nuclei.