Signatures of shape phase transitions in odd-mass Eu nuclei

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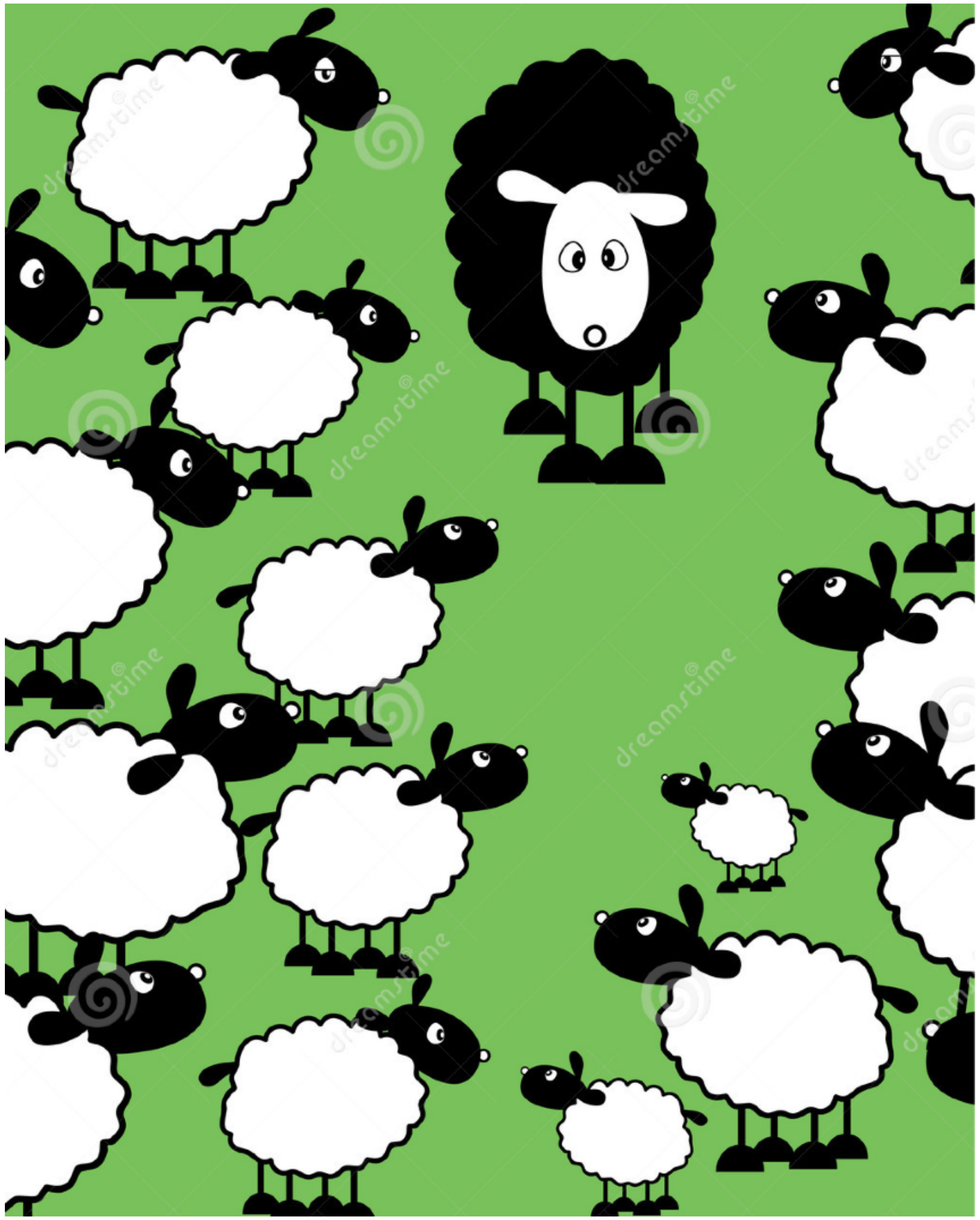

… influence of the unpaired fermion on the location and nature of the phase transition.

… empirical signatures of QPTs in odd-A nuclei.

… definition and computation of order parameters.

Ground-state shape-phase transitions in odd-mass Eu isotopes

S. QUAN, Z. P. LI, D. VRETENAR, AND J. MENG
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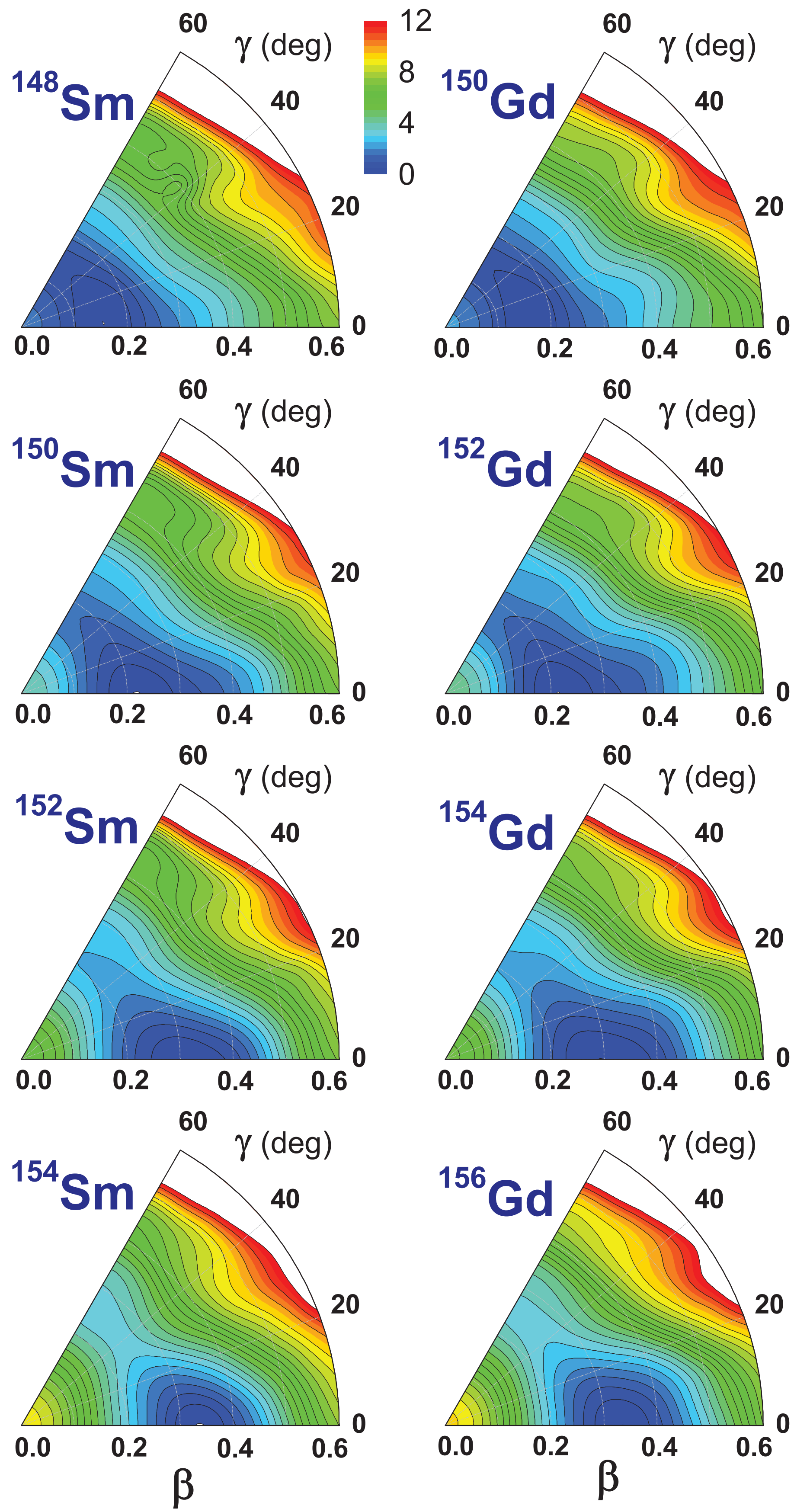


Self-consistent RHB triaxial quadrupole energy surfaces. PC-PK1 energy density functional and finite-range separable pairing interaction.

The core-quasiparticle coupling model

... ansatz for the wave function:

$$|\alpha J M_J\rangle^A = \sum_{\mu j,\nu R} \Big\{ U_{\alpha J}(\mu j,\nu R)\big[a^\dagger_{\mu j m_j}|\nu R M_R\rangle\big]^{A-1}_{JM_J} + V_{\alpha J}(\mu j,\nu R)\big[a_{\mu j m_j}|\nu R M_R\rangle\big]^{A+1}_{JM_J} \Big\}$$

...particle coupled to the (A-1) core and hole coupled to the (A+1) core.

The Hamiltonian of CQC model:

$$\begin{aligned} H &= H_{\mathrm{qp}} + H_{\mathrm{c}} \\ &= \begin{pmatrix} (\varepsilon^{A-1}-\lambda)+\Gamma^{A-1} & \Delta^{A+1} \\ \Delta^{\dagger A-1} & -(\varepsilon^{A+1}-\lambda)-\Gamma^{A+1} \end{pmatrix} + \begin{pmatrix} E^{A-1} & 0 \\ 0 & E^{A+1} \end{pmatrix} \end{aligned}$$

$$(\varepsilon^{A\pm1}-\lambda) = (\varepsilon^{A\pm1}_{\mu j}-\lambda)\delta_{\mu j,\mu' j'}\delta_{\nu R,\nu' R'}$$

$$(E^{A\pm1}) = E^{A\pm1}_{\nu R}\delta_{\mu j,\mu' j'}\delta_{\nu R,\nu' R'}$$

The core-quasiparticle quadrupole interaction:

$$(\Gamma^{A\pm1}) = -\chi(-1)^{j+R+J}\begin{Bmatrix} j & 2 & j' \\ R' & J & R \end{Bmatrix}\langle\mu j\|\hat{Q}_2\|\mu' j'\rangle^{A\pm1}\langle\nu R\|\hat{Q}_2\|\nu' R'\rangle^{A\pm1}$$

The pairing field:

$$(\Delta^{A+1}) = (\Delta^{A-1}) = \langle\nu R; A-1|\hat{\Delta}|\nu' R'; A+1\rangle\delta_{\mu j,\mu' j'} \approx \frac{1}{2}(\Delta_{\nu R}^{A-1} + \Delta_{\nu R}^{A+1})\delta_{\mu j,\mu' j'}\delta_{\nu R,\nu' R'} \equiv (\Delta)$$

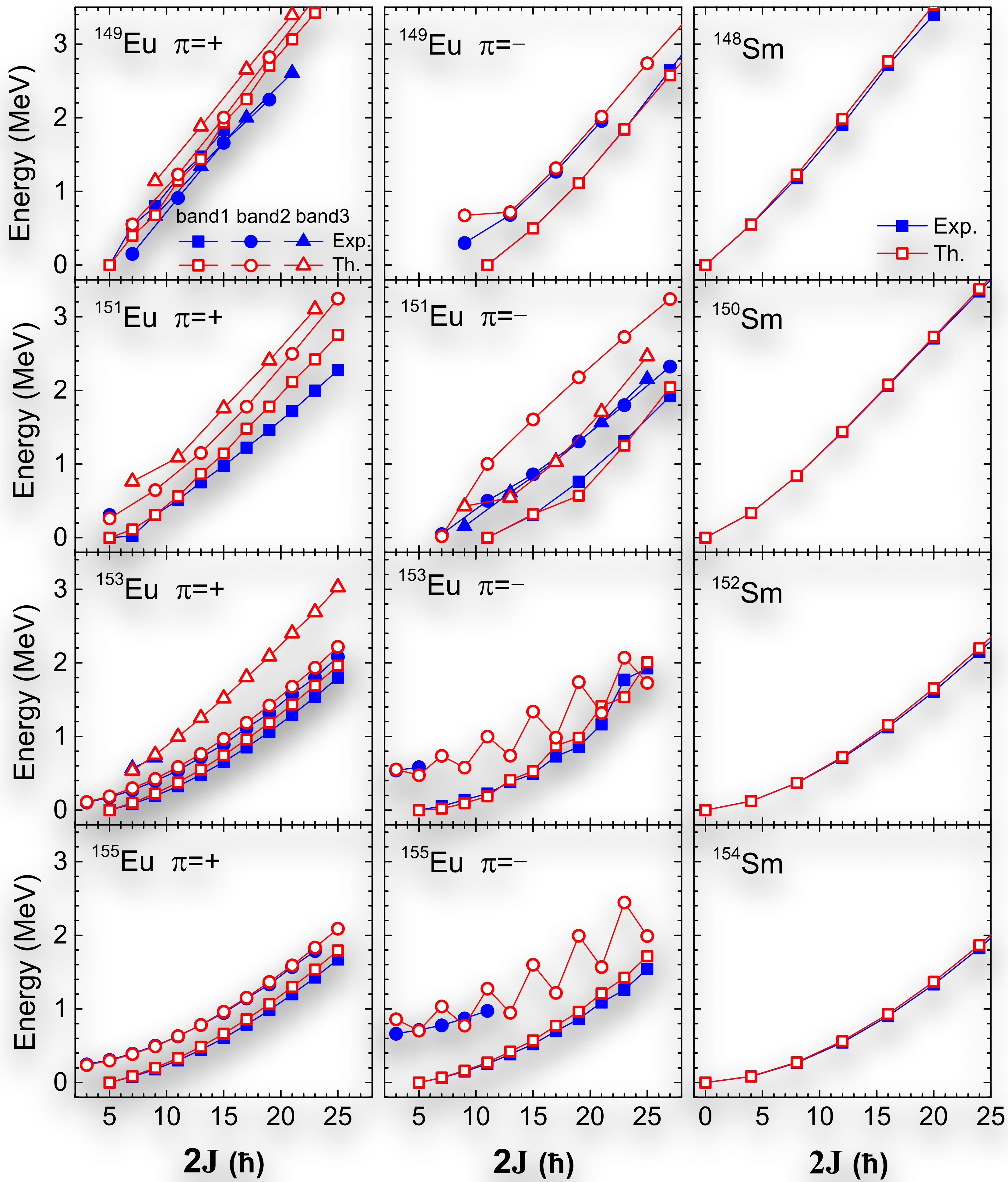
average pairing gaps

5D quadrupole collective Hamiltonian:

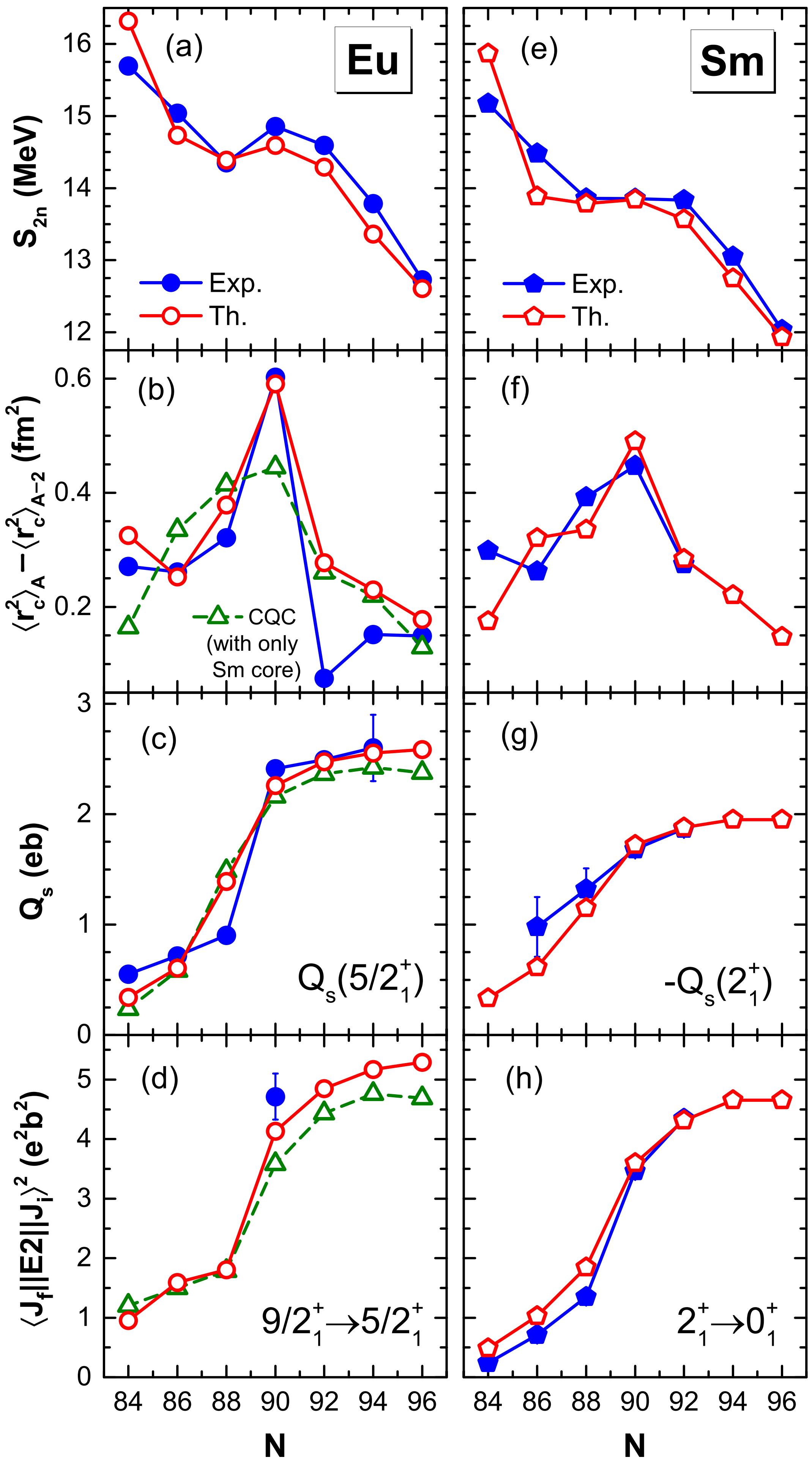
$$\begin{aligned}\hat{H}_{\text{coll}} = -\frac{\hbar^2}{2\sqrt{wr}}&\left\{\frac{1}{\beta^4}\left[\frac{\partial}{\partial\beta}\sqrt{\frac{r}{w}}\beta^4 B_{\gamma\gamma}\frac{\partial}{\partial\beta} - \frac{\partial}{\partial\beta}\sqrt{\frac{r}{w}}\beta^3 B_{\beta\gamma}\frac{\partial}{\partial\gamma}\right]\right.\\
&\left.+\frac{1}{\beta\sin 3\gamma}\left[-\frac{\partial}{\partial\gamma}\sqrt{\frac{r}{w}}\sin 3\gamma B_{\beta\gamma}\frac{\partial}{\partial\beta} + \frac{1}{\beta}\frac{\partial}{\partial\gamma}\sqrt{\frac{r}{w}}\sin 3\gamma B_{\beta\beta}\frac{\partial}{\partial\gamma}\right]\right\}\\
&+\frac{1}{2}\sum_{k=1}^{3}\frac{\hat{J}_k^2}{\mathcal{I}_k} + V_{\text{coll}}\ .\end{aligned}$$

⇒ the eigenvalue equation:

$$\begin{pmatrix} (\varepsilon^{A-1}-\lambda) + \Gamma^{A-1} + E^{A-1} & \Delta \\ \Delta & -(\varepsilon^{A+1}-\lambda) - \Gamma^{A+1} + E^{A+1} \end{pmatrix}\begin{pmatrix} U \\ V \end{pmatrix} = E_{\alpha J}\begin{pmatrix} U \\ V \end{pmatrix}$$



^{149}Eu π=+
^{149}Eu π=−
^{148}Sm
^{151}Eu π=+
^{151}Eu π=−
^{150}Sm
^{153}Eu π=+
^{153}Eu π=−
^{152}Sm
^{155}Eu π=+
^{155}Eu π=−
^{154}Sm
band1 band2 band3
Exp.
Th.
Energy (MeV)
2J (ħ)

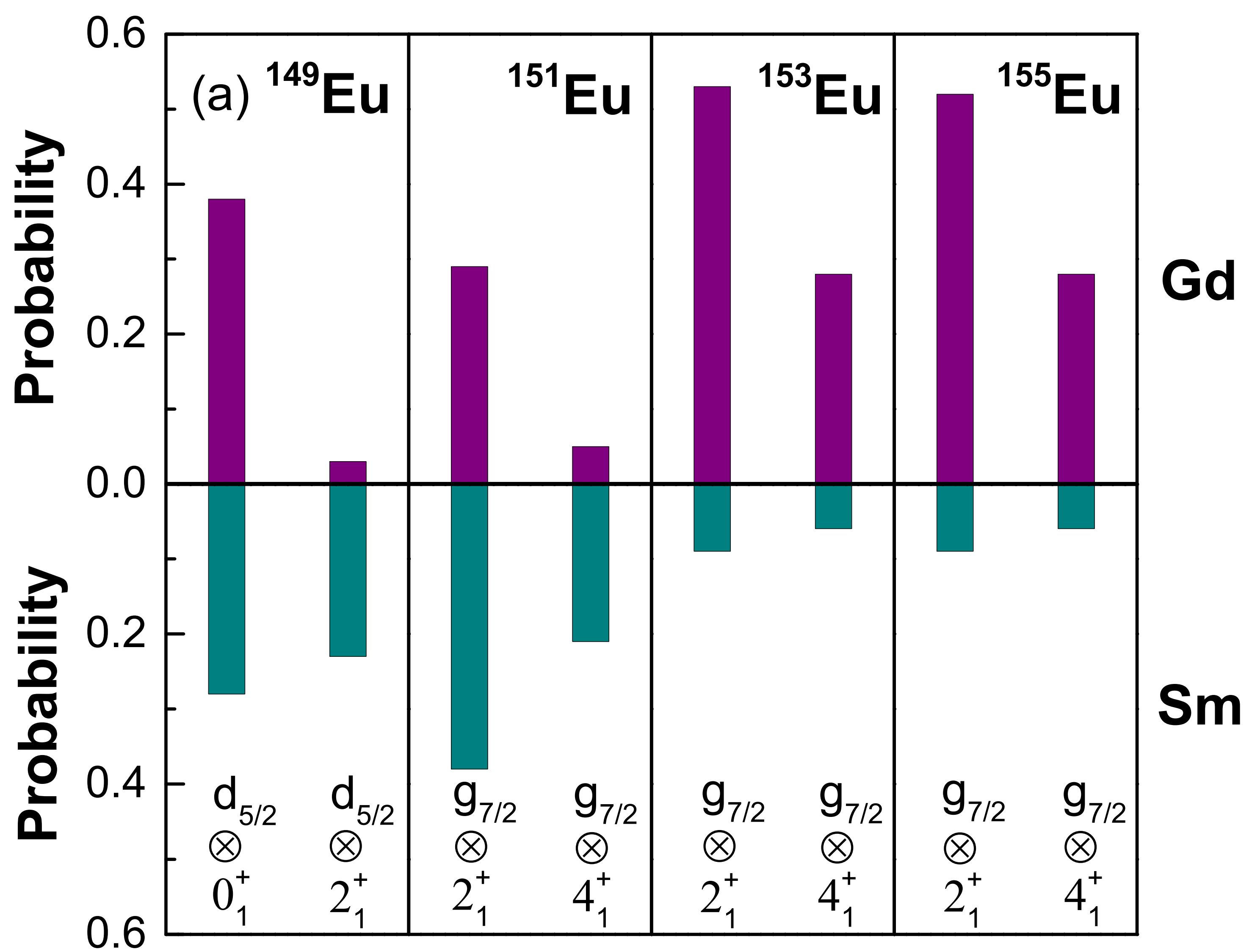


… observables that can be related to order parameters as functions of the control parameter - neutron number.

… discontinuities at N=90 for the odd-mass Eu isotopes are steeper than those in the even-even Sm nuclei.

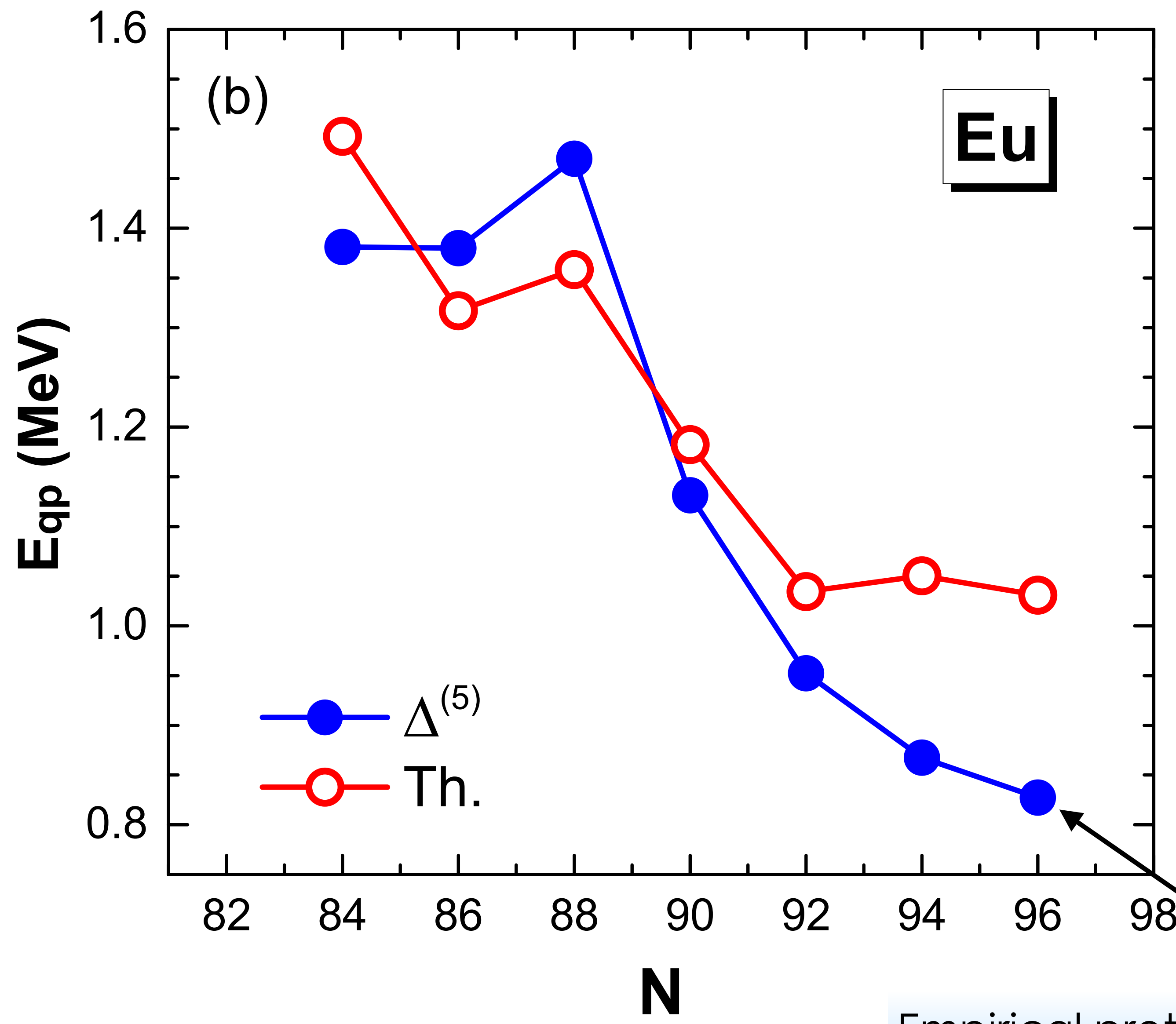
The quadrupole interaction between the core and the unpaired fermion reinforces the QPT in odd-mass nuclei compared with the adjacent even-even isotopes.

Probabilities of the dominant configurations in the ground states of the Eu isotopes.



⇒ rapid transition from states in which, because of shape fluctuations, the unpaired proton is almost equally coupled to both the Sm and Gd core yrast states, to ground states in the N =90 and N =92 Eu nuclei in which the proton is predominantly coupled to the Gd core.

The quasiparticle energy of the ground state corresponds to the lowest eigenvalue of the CQC Hamiltonian ⇒ difference between the total energy of the odd-mass nucleus and the average value of the energies of the two even-even cores.



Empirical proton pairing gaps calculated by using the five-point formula.

… low-energy spectra and observables related to order parameters for a first-order nuclear QPT between spherical and axially deformed shapes in odd-mass Eu isotopes.

Two-neutron separation energies, isotope shifts, spectroscopic quadrupole moments, and E2 reduced transition matrix elements reproduce available data and exhibit sharper discontinuities at neutron number N = 90 compared with those in adjacent even-even Sm and Gd isotopes.

The amplification of the QPT in the odd-mass system $\Rightarrow$ shape polarization effect of the unpaired proton.