Nuclear Collectivity in the Shell Model Monte Carlo Approach

Cem Özen

Faculty of Engineering and Natural Sciences,
Kadir Has University
Istanbul, Turkey

4th Workshop on Nuclear Level Density and Gamma Strength

Oslo, May 27 - 31, 2013

Outline

Heavy Nuclei:

Outline

Heavy Nuclei:

- Emergence of collectivity

Outline

Heavy Nuclei:

- Emergence of collectivity
- State densities

Outline

Heavy Nuclei:

- Emergence of collectivity
- State densities
- Collective enhancement factors

Outline

Heavy Nuclei:

- Emergence of collectivity
- State densities
- Collective enhancement factors

Ni region:

Outline

Heavy Nuclei:

- Emergence of collectivity
- State densities
- Collective enhancement factors

Ni region:

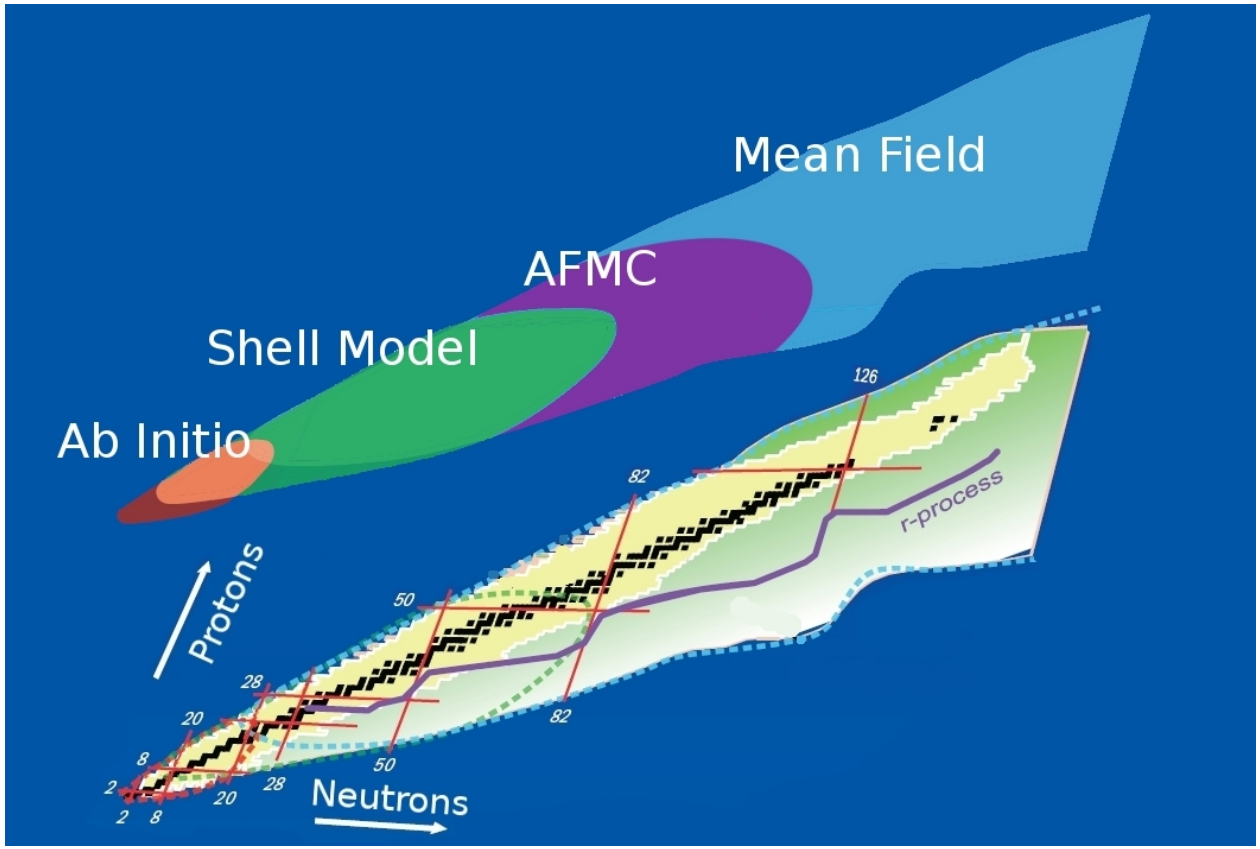
- Total and symmetry-projected state densities

Nuclear many-body problem
Extending SMMC (AFMC) to heavy nuclei

Özen, Ph.D. Thesis (2005)

Özen and Dean, Phys. Rev. C **73**, 014302 (2006)

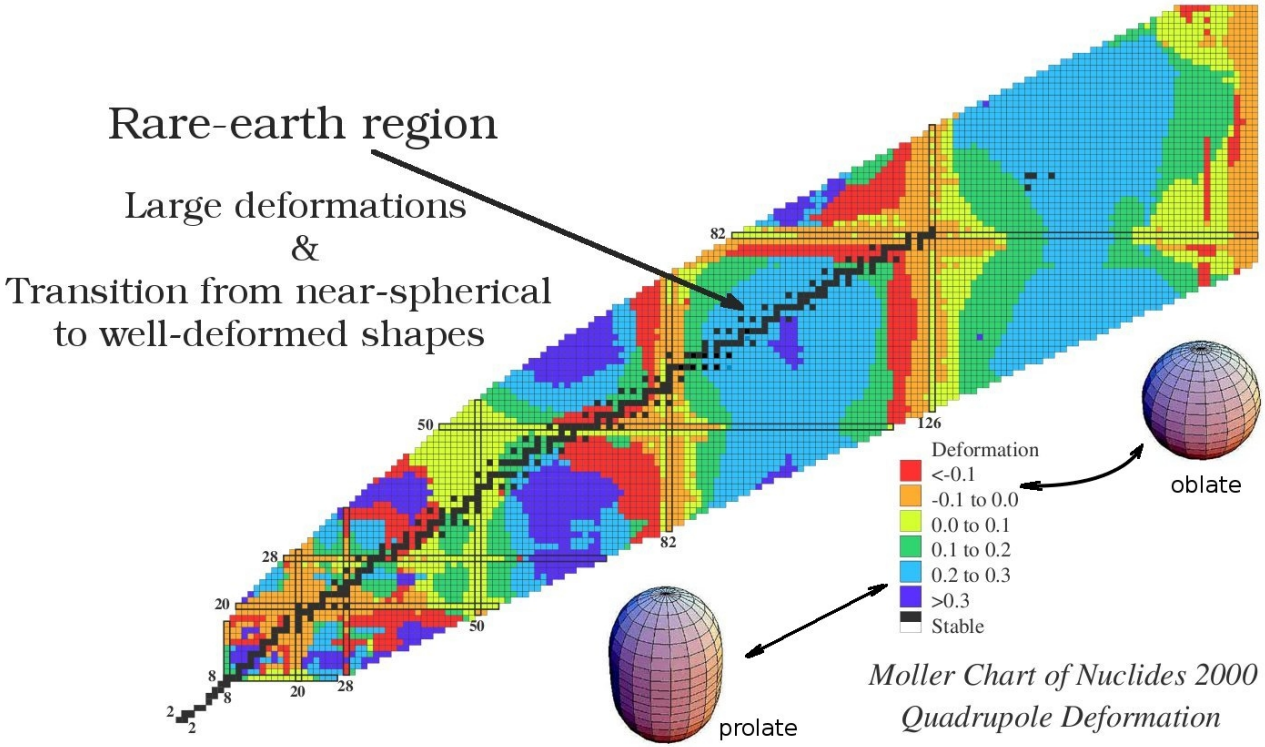
Alhassid, Fang, Nakada, Phys. Rev. Lett. **101**, 082501 (2008)



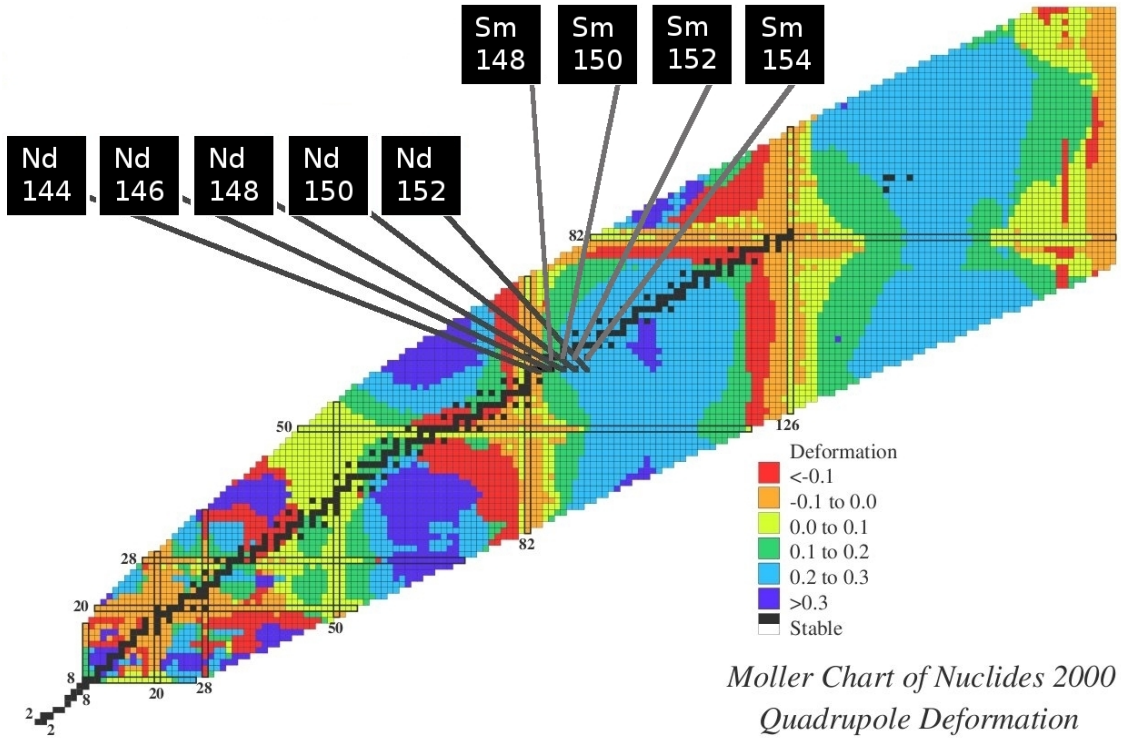
SMMC Applications for Heavy Nuclei

Rare-earth Region

SMMC Applications in the Rare-earth Region



SMMC Applications in the Rare-earth Region

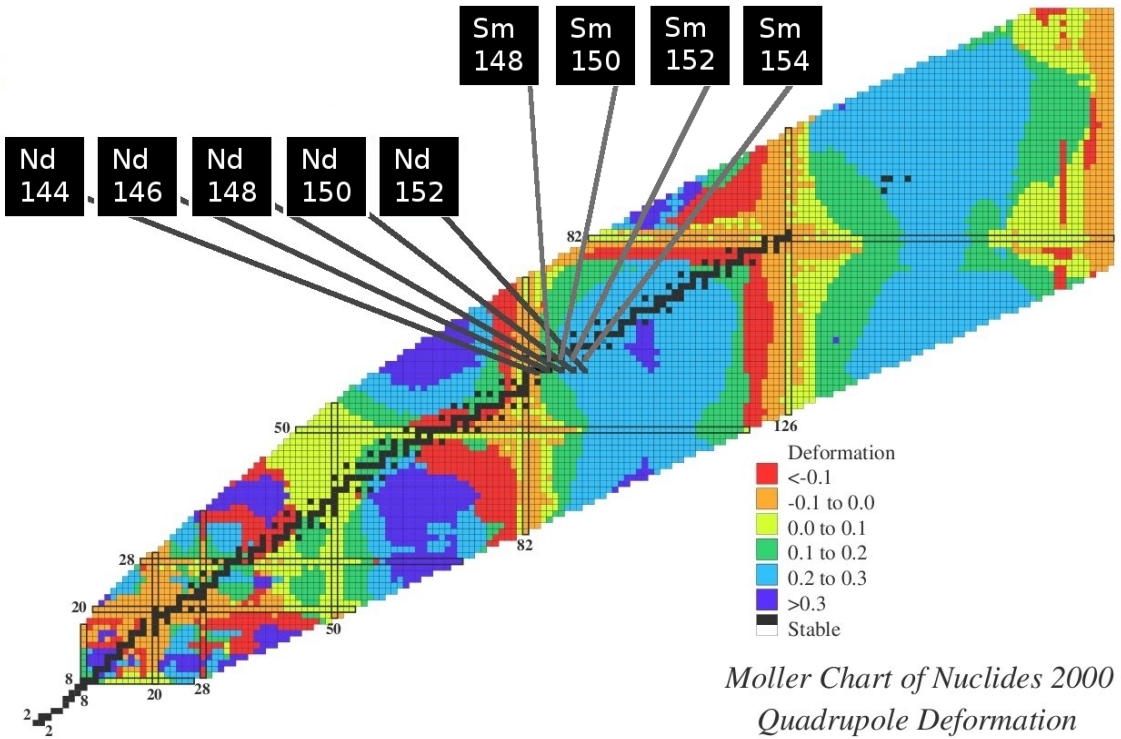


Moller Chart of Nuclides 2000
Quadrupole Deformation

SMMC Applications in the Rare-earth Region

Challenge: Demonstrate the crossover in a suitably chosen model space

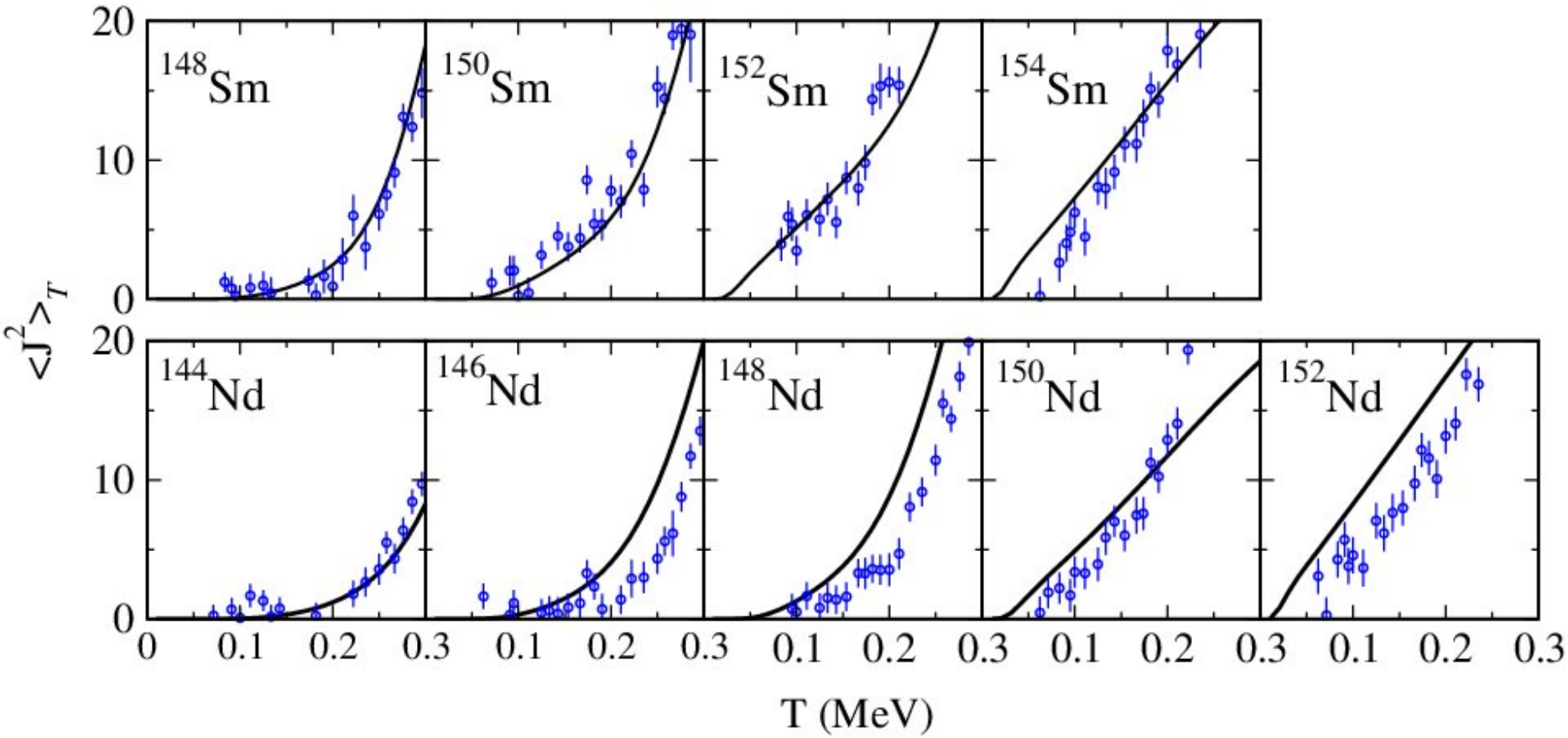
Can we identify a thermal observable to distinguish types of collectivity?



Moller Chart of Nuclides 2000
Quadrupole Deformation

Emergence of Collectivity

$\langle \mathbf{J}^2 \rangle_T$ as a signature of the crossover



Özen, Alhassid, Nakada, Phys. Rev. Lett. **110**, 042502 (2013).

Emergence of Collectivity

experimental measure for $\langle \mathbf{J}^2 \rangle_T$

In the absence of neutron resonance data, we use level counting data only:

$$Z(T) = \sum_i^N e^{-E_i/T}(2J_i + 1)$$

$$\langle \mathbf{J}^2 \rangle_T = \frac{1}{Z(T)} \sum_i^N J_i(J_i + 1)(2J_i + 1)e^{-E_i/T}$$

Emergence of Collectivity

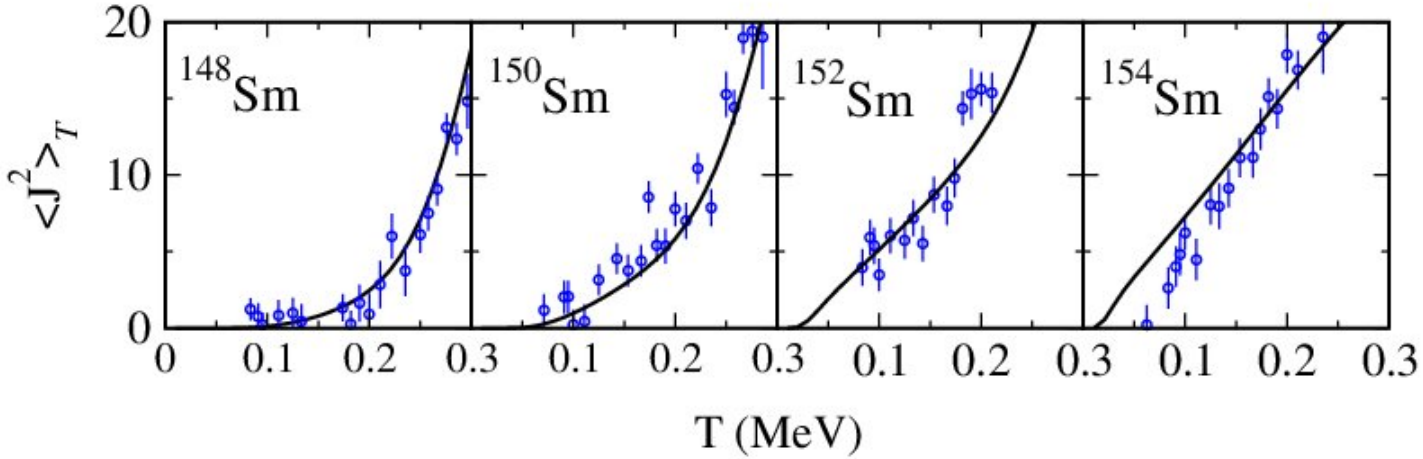
experimental measure for $\langle \mathbf{J}^2 \rangle_T$

If neutron resonance data is available, we use level counting + neutron resonance data:

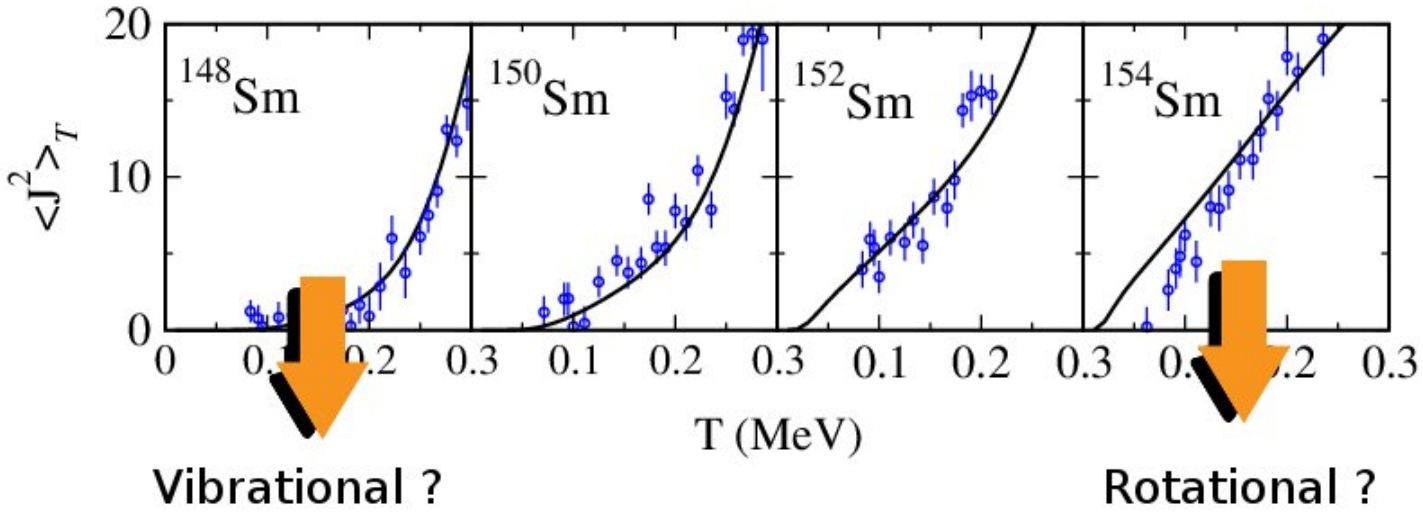
$$Z(T) = \sum_i^N e^{-E_i/T}(2J_i+1) + \int_{E_N}^{\infty} dE_x \rho_{BBF}(E_x) e^{-E_x/T}$$

$$\langle \mathbf{J}^2 \rangle_T = \frac{1}{Z(T)} \left(\sum_i^N J_i(J_i+1)(2J_i+1) e^{-E_i/T} + \int_{E_N}^{\infty} dE_x \, \rho_{BBF}(E_x) \, \langle \mathbf{J}^2 \rangle_{E_x} \, e^{-E_x/T} \right)$$

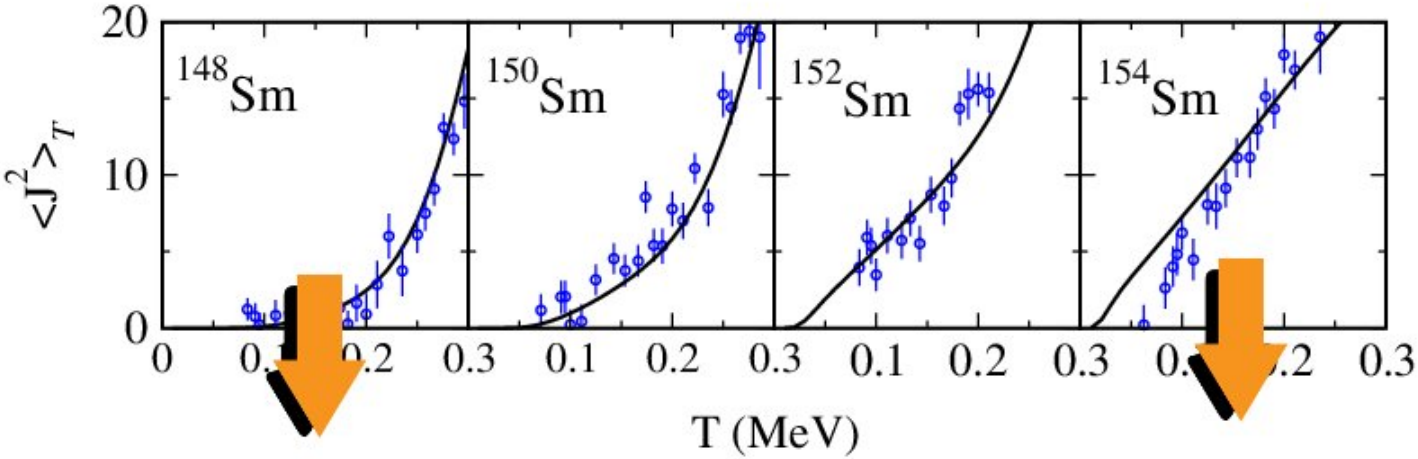
Emergence of Collectivity
quantitative evidence for the transition



Emergence of Collectivity
quantitative evidence for the transition



Emergence of Collectivity
quantitative evidence for the transition



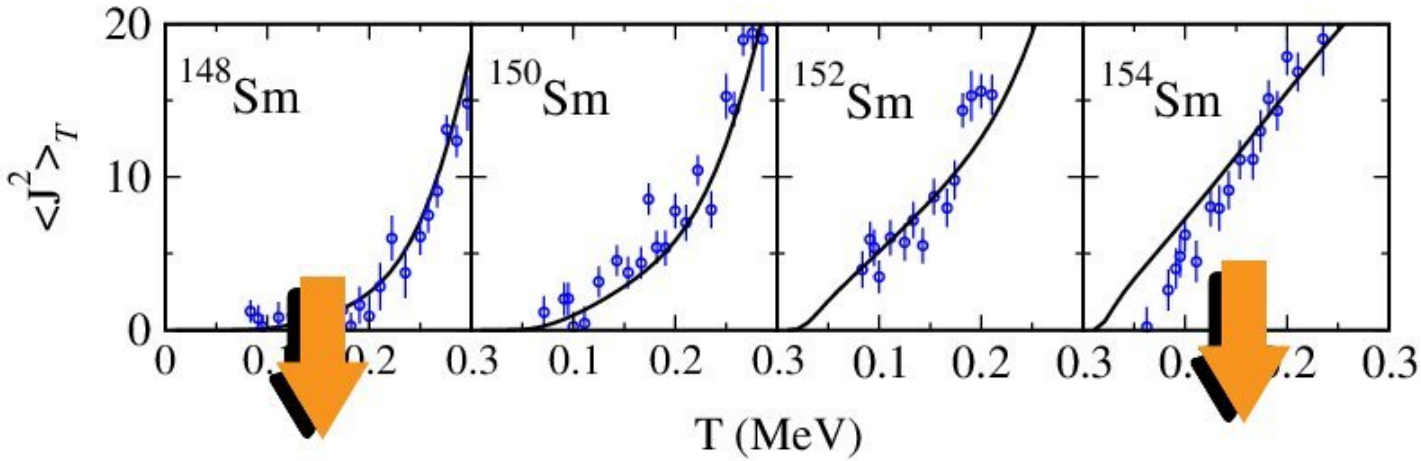
Vibrational ?

$$\langle \mathbf{J}^2 \rangle(T) \approx 30\, e^{-E_{2+}/T}/(1 - e^{-E_{2+}/T})^2$$

Rotational ?

$$\langle \mathbf{J}^2 \rangle(T) \approx 2IT$$

Emergence of Collectivity
quantitative evidence for the transition



Vibrational ?

$$\langle \mathbf{J}^2 \rangle(T) \approx 30\, e^{-E_{2+}/T}/(1 - e^{-E_{2+}/T})^2$$

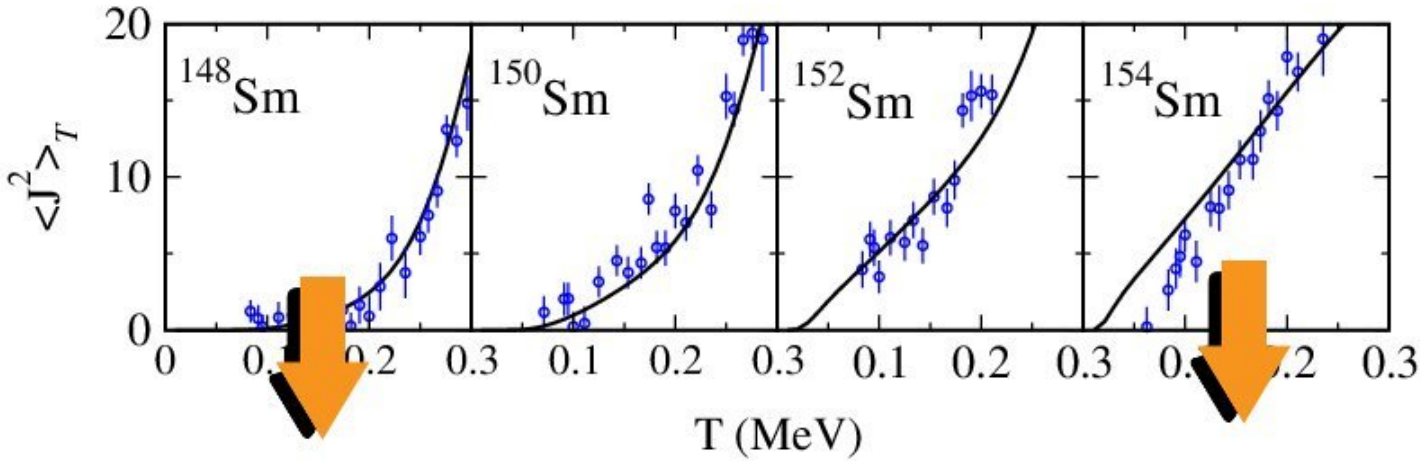
$$E_{2^+}^{\text{vib}} = 0.538 \pm 0.031 \text{ MeV},$$

Rotational ?

$$\langle \mathbf{J}^2 \rangle(T) \approx 2IT$$

$$E_{2^+}^{\text{rot}} = 0.087 \pm 0.006 \text{ MeV},$$

Emergence of Collectivity
quantitative evidence for the transition



Vibrational ?

$$\langle \mathbf{J}^2 \rangle(T) \approx 30\, e^{-E_{2+}/T}/(1 - e^{-E_{2+}/T})^2$$

$$E_{2+}^{\text{vib}} = 0.538 \pm 0.031 \text{ MeV},$$

$$E_{2+}^{\text{exp}} = 0.550 \text{ MeV}$$

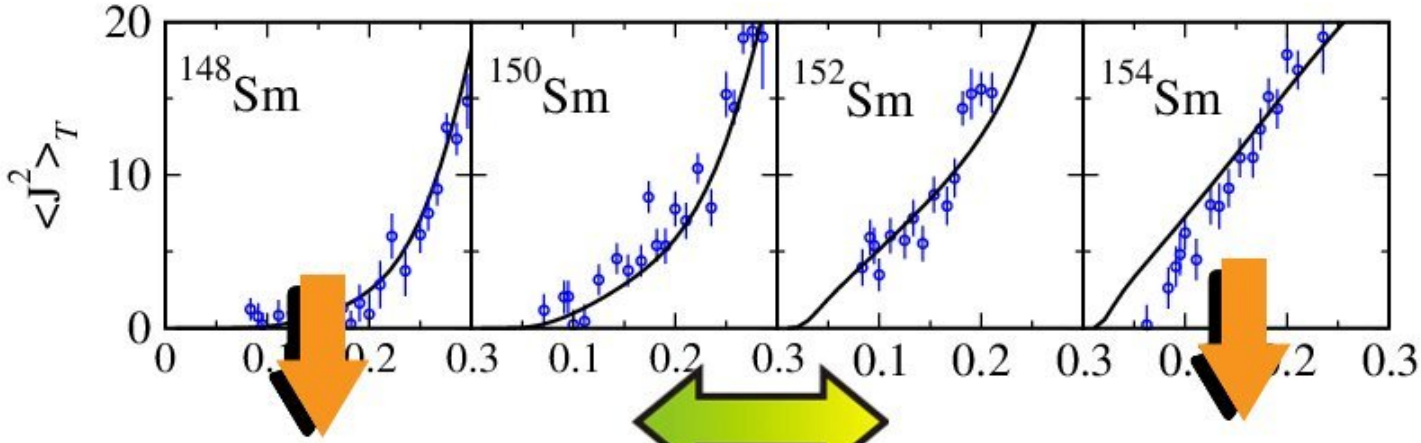
Rotational ?

$$\langle \mathbf{J}^2 \rangle(T) \approx 2IT$$

$$E_{2+}^{\text{rot}} = 0.087 \pm 0.006 \text{ MeV},$$

$$E_{2+}^{\bar{\text{exp}}} = 0.082 \text{ MeV}$$

Emergence of Collectivity
quantitative evidence for the transition



Vibrational ?

CROSSOVER

Rotational ?

$$\langle \mathbf{J}^2 \rangle(T) \approx 30\, e^{-E_{2+}/T}/(1-e^{-E_{2+}/T})^2$$

$$\langle \mathbf{J}^2 \rangle(T) \approx 2IT$$

$$E_{2+}^{\text{vib}} = 0.538 \pm 0.031 \text{ MeV},$$

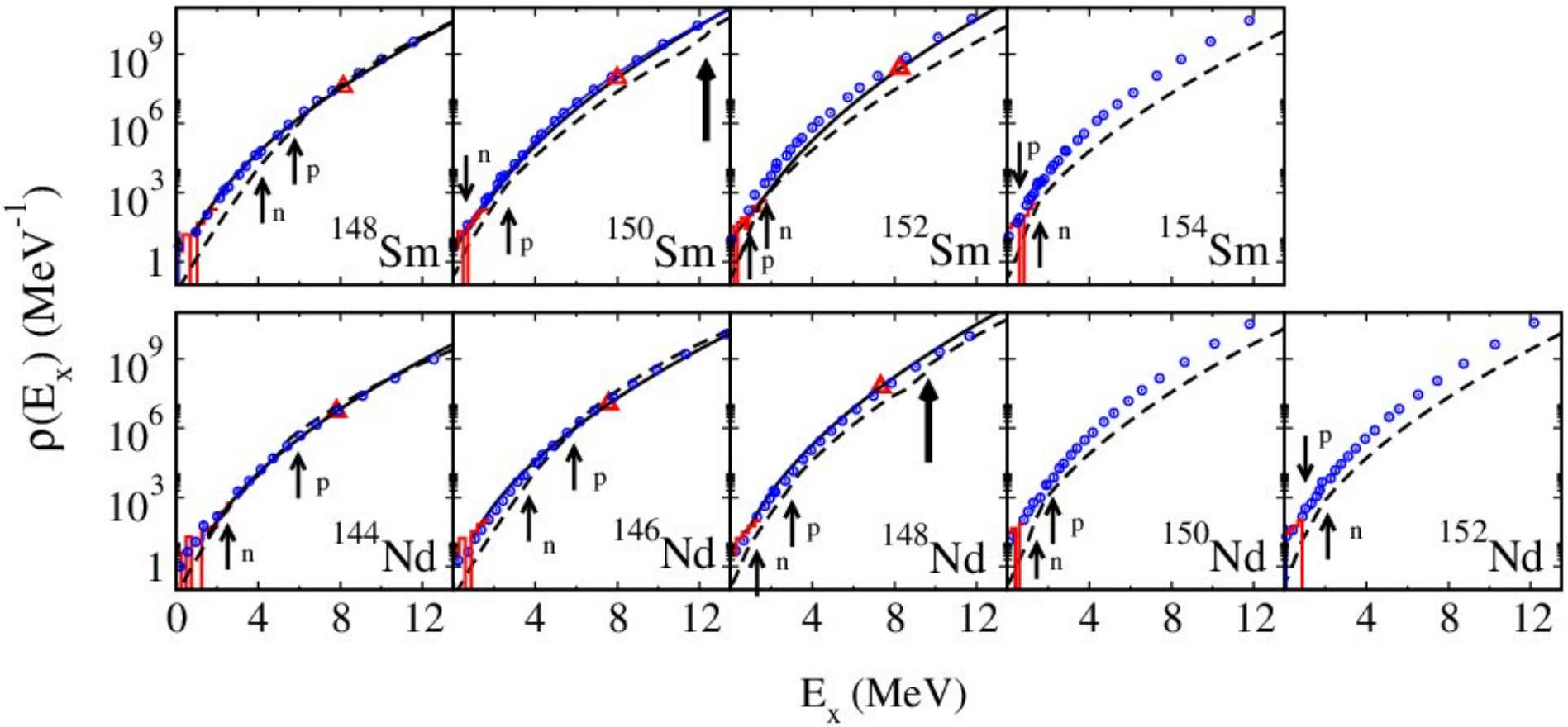
$$E_{2+}^{\text{exp}} = 0.550 \text{ MeV}$$

$$E_{2+}^{\text{rot}} = 0.087 \pm 0.006 \text{ MeV},$$

$$E_{2+}^{\text{exp}} = 0.082 \text{ MeV}$$

Total State Densities

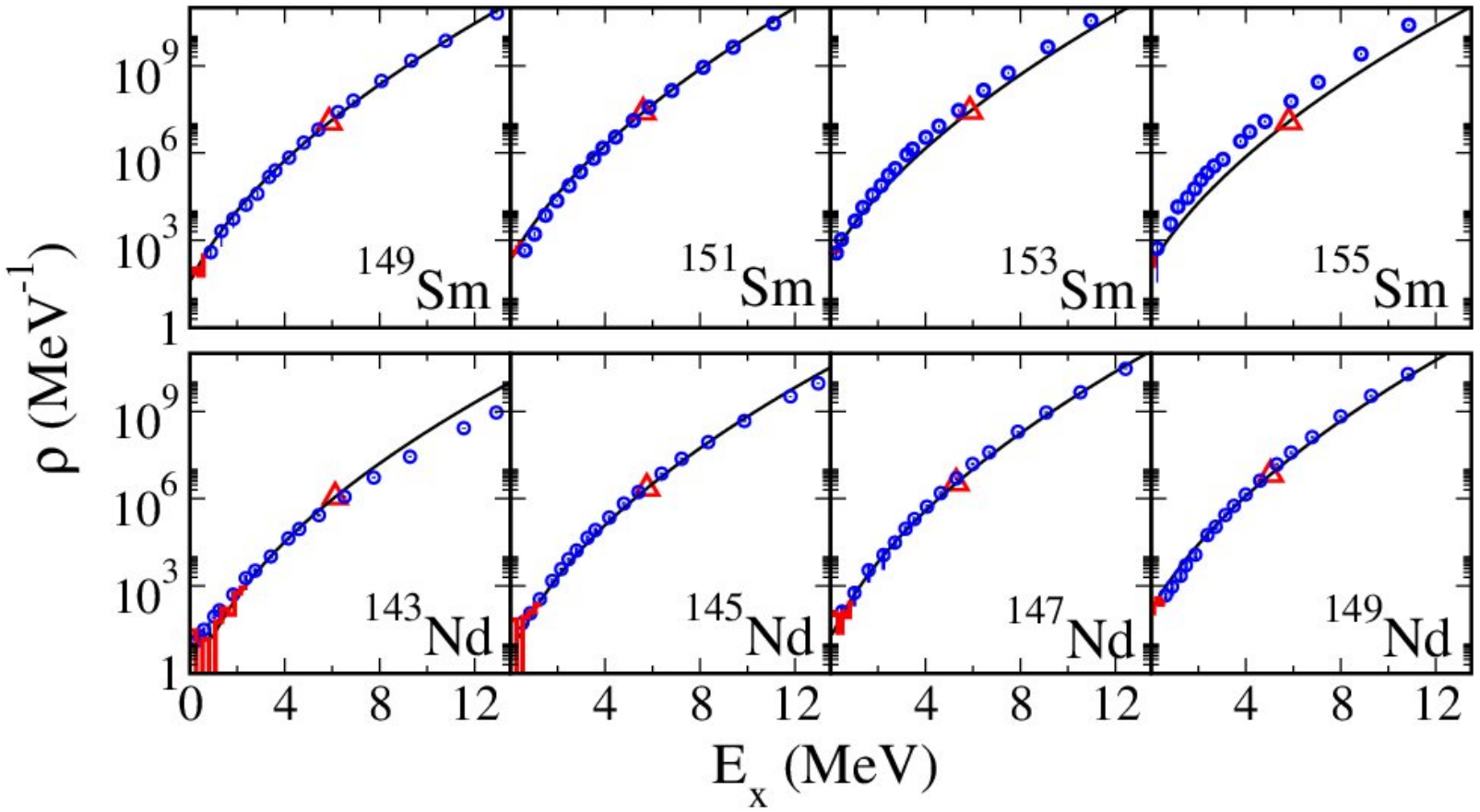
even-even nuclei



Özen, Alhassid, Nakada, Phys. Rev. Lett. **110**, 042502 (2013).

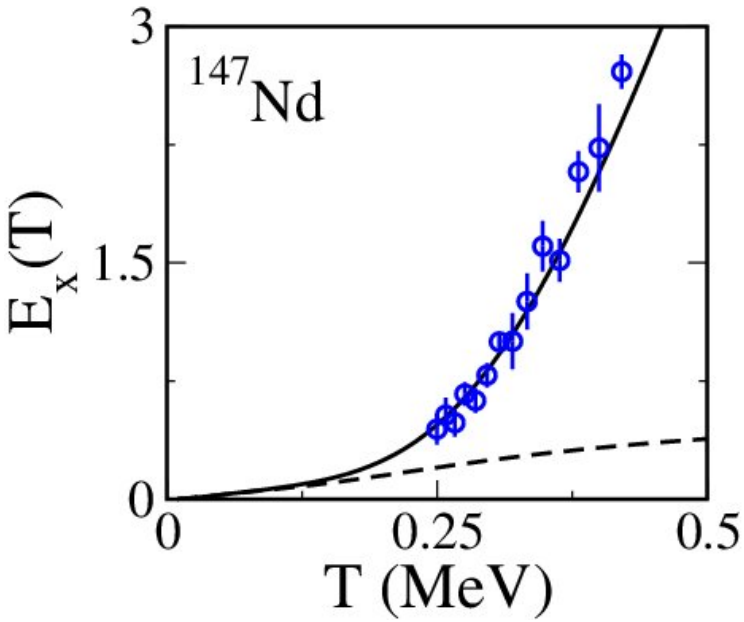
Alhassid, Özen, Nakada, arxiv:1305.5605, (submitted to Nucl. Data. Sheets)

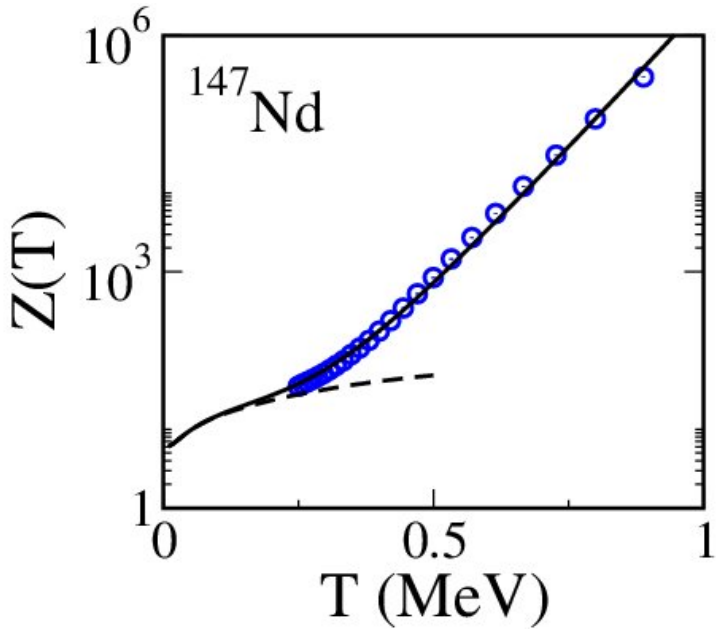
Total State Densities
odd-even nuclei



Özen, Alhassid, Nakada, arXiv:1304.7405, (submitted to Phys. Lett. B).

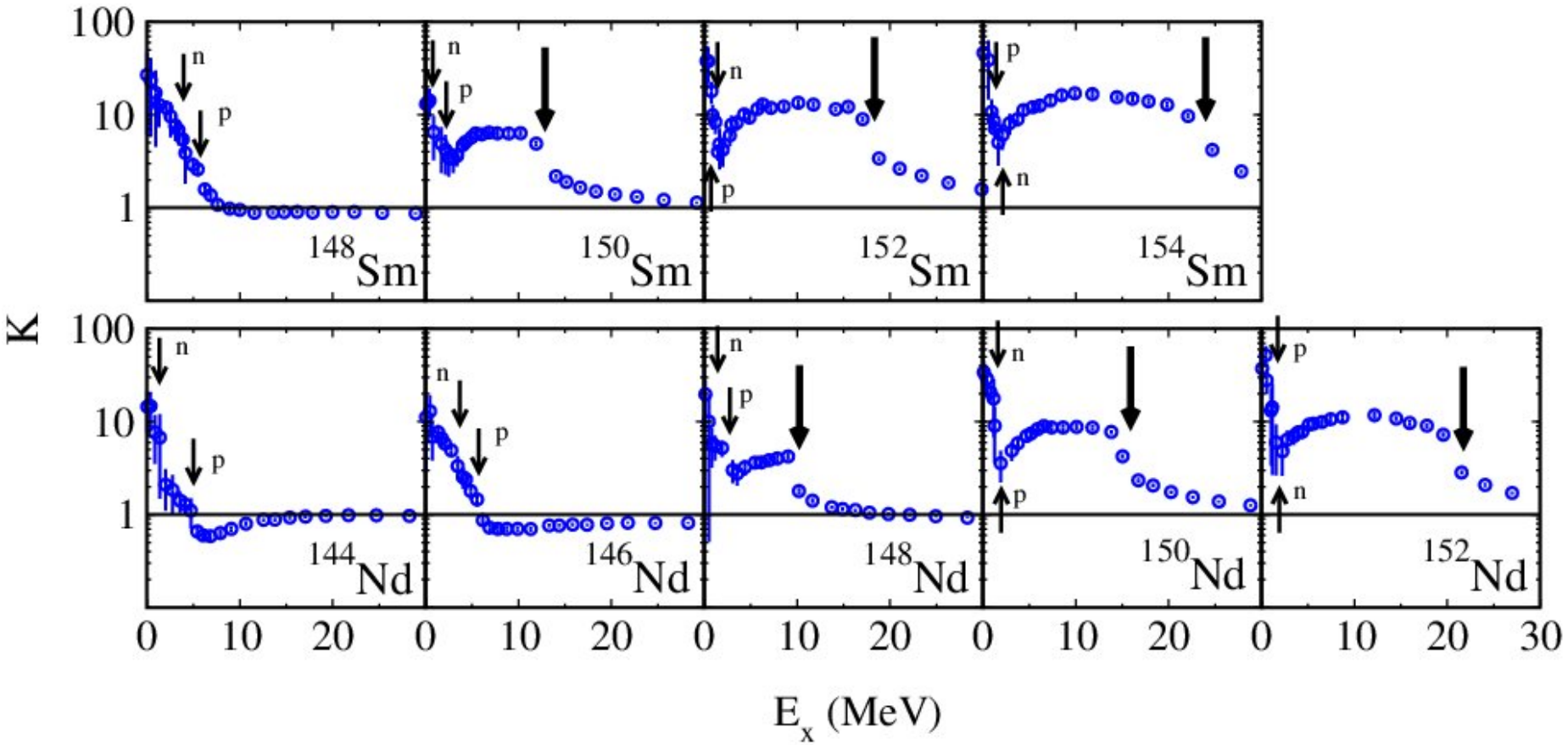
Odd-even nuclei
extraction of the ground state energy





Özen, Alhassid, Nakada, arXiv:1304.7405, (submitted to Phys. Lett. B).

Collective Enhancement Factors
energy dependence

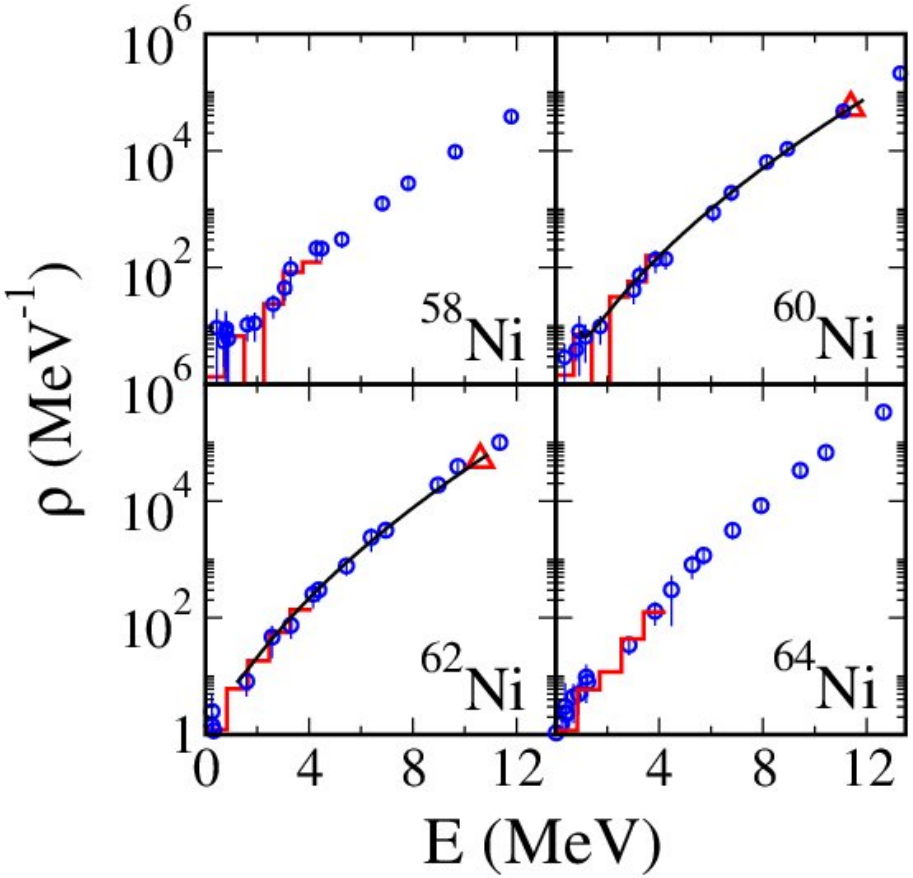


Özen, Alhassid, Nakada, Phys. Rev. Lett. **110**, 042502 (2013).

Alhassid, Özen, Nakada, arxiv:1305.5605, (submitted to Nucl. Data. Sheets)

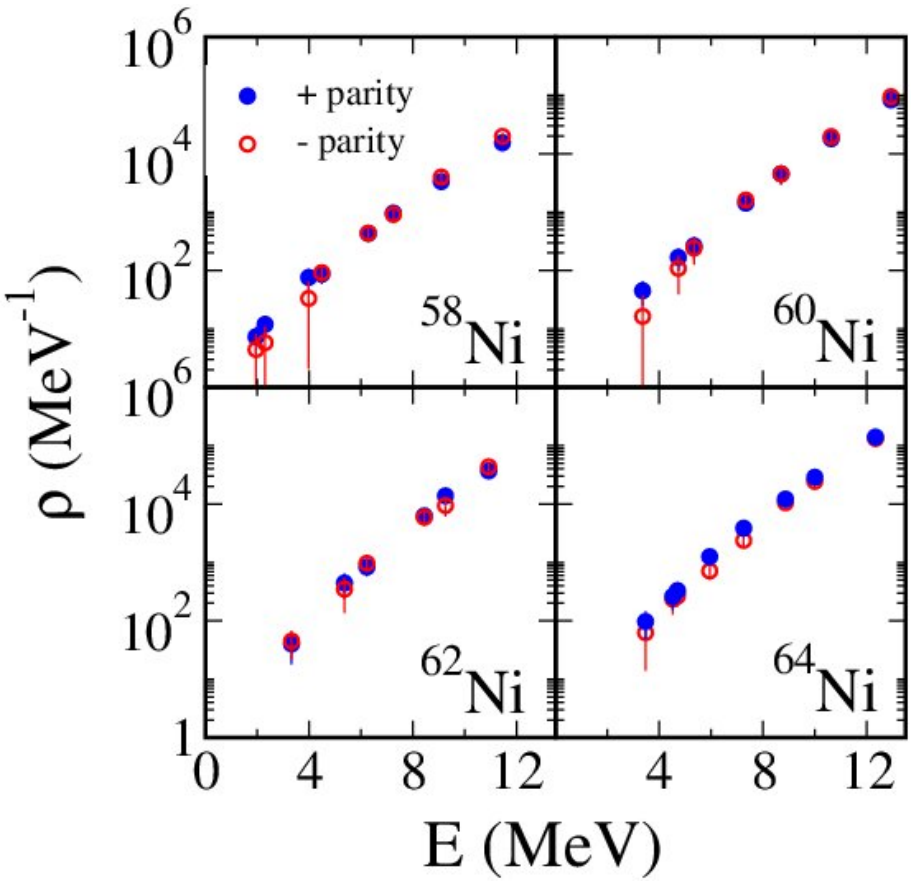
SMMC Applications in Ni Region
Preliminary Results

Total State Densities
preliminary results



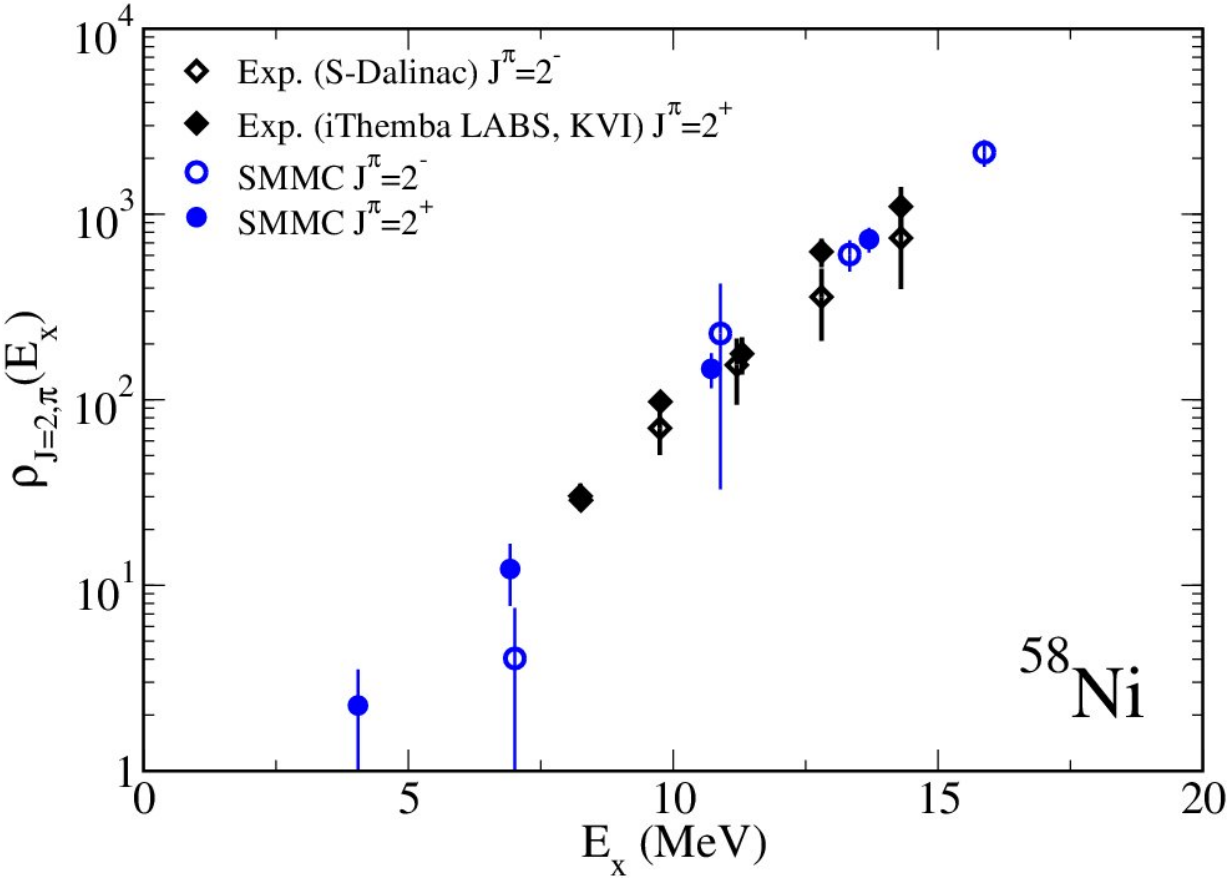
Özen, Nakada, Akyüz, (in progress)

Parity-projected State Densities
preliminary results



Özen, Nakada, Akyüz, (in progress)

Parity-projected State Densities: J=2 Channel
preliminary results



Özen, Nakada, Akyüz, (in progress)

Conclusions

- Using systematically produced Hamiltonians, we reproduce the crossover from vibrational to rotational collectivity in families of even-even Nd and Sm isotopes.
- We propose a practical approach to extract the ground state energy of odd-odd and odd-even nuclei.
- We calculate the total state densities and found them to be in excellent agreement with those extracted from experimental data.
- We extract the collective enhancement factors from the ratio of the SMMC to HFB state densities. Damping of these factors seem to be associated with the pairing and shape transitions occuring in these nuclei.
- Total and spin/parity-projected state densities of Ni isotopes are calculated. Early results indicate very good agreement with the experiment.

Acknowledgements

Collaborators:

Yoram Alhassid, Yale University, USA
Hitoshi Nakada, Chiba University, Japan
Enes Akyüz, Istanbul University, Turkey

Thank you for your attention!