Rotational enhancement of the level density in deformed nuclei

- Symmetry of the potential, degeneracies and level densities

- Rotational enhancement of the level density is caused by extra degrees of freedom of a deformed core – finite system illustrations

- Enhacement factors extracted from resolved states in well deformed nuclei – comparing to calculated enhancement factors

- Short mention of the fade-away of rotational enhancement with increasing excitation energy

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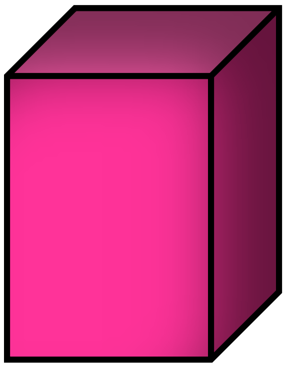
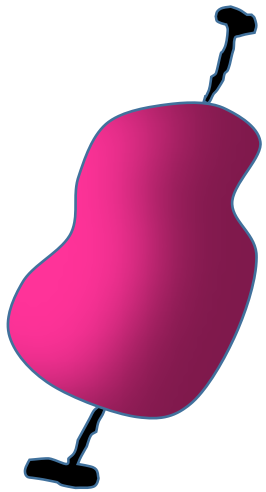
Inspired by the Trento Workshop July 2016





Irregular shape - no degeneracies - except for spin $\frac{1}{2}$:

$$\rho_{state} \equiv \rho(E, N, Z)$$

.

Spherical shape - angular momentum conserved,
leading to degeneracy and selection rules:

a) projection M:

$$\rho(N, Z, E, M) \approx \frac{1}{\sqrt{2\pi}\sigma_M} \exp\left(-\frac{M^2}{2\sigma_M^2}\right) \rho(E, N, Z)$$

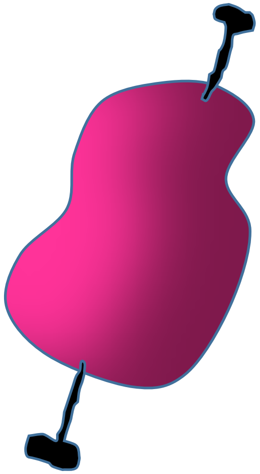
b) Angular momentum I:

$$\rho_{Bethe}(N, Z, E, I) \equiv \frac{d}{dM}|_{M=I+\frac{1}{2}} \{\rho(E, N, Z, M)\}$$

Recover state density:

$$\sum_I (2I+1)\, \rho_{Bethe}(N, Z, E, I) = \rho_{state}$$

Axial deformation



$\rho(E, N, Z)$

$\rho(E, N, Z, K)$

$$\sum_K \rho(E, N, Z, K) = \rho(E, N, Z)$$

Axial deformation plus rotor

$$\rho(E,N,Z,K)$$

.

$$\rho_{Ericsson}(E,N,Z,I) \equiv \sum_K \frac{1}{2}\rho(E - E_{rotor}\,,\; N,Z,K)$$

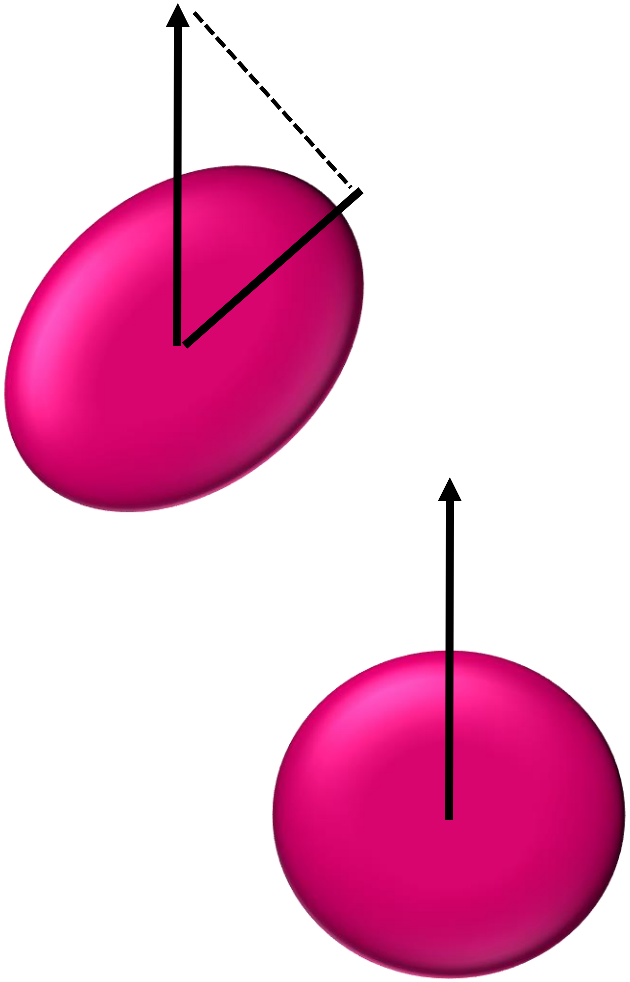
$$E_{rotor} = \frac{I(I+1) - K^2}{2\mathcal{J}_\perp}$$

$$\sum_I (2I+1)\rho_{Ericsson}(E,N,Z,I) \approx \sigma_\perp^2 \rho(E,N,Z)$$

$$\sigma_\perp^2 = T\mathcal{J}_\perp$$

Rotational enhancement is caused by the extra degrees of freedom of a deformed core

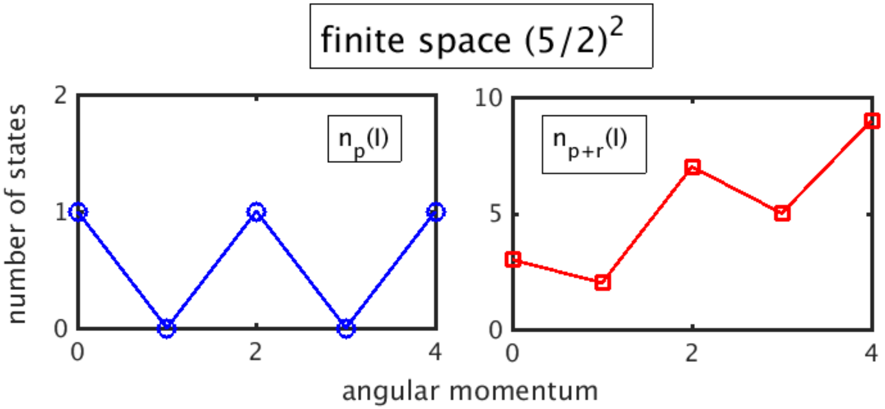
Enhancement at all angular momenta



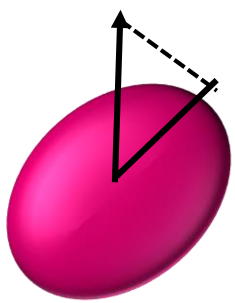
$$\frac{\rho_{Ericsson}(E,N,Z,I)}{\rho_{Bethe}(E,N,Z,I)} \approx \sigma_{\perp}^2$$

at all angular momenta

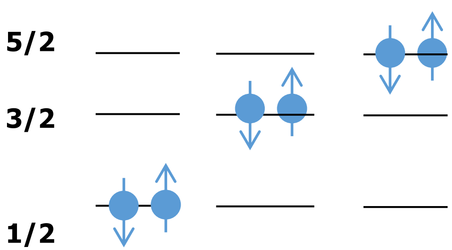
Finite spaces: 2 particles in d5/2



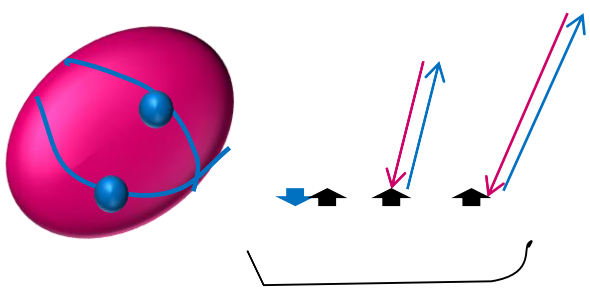
K -representation



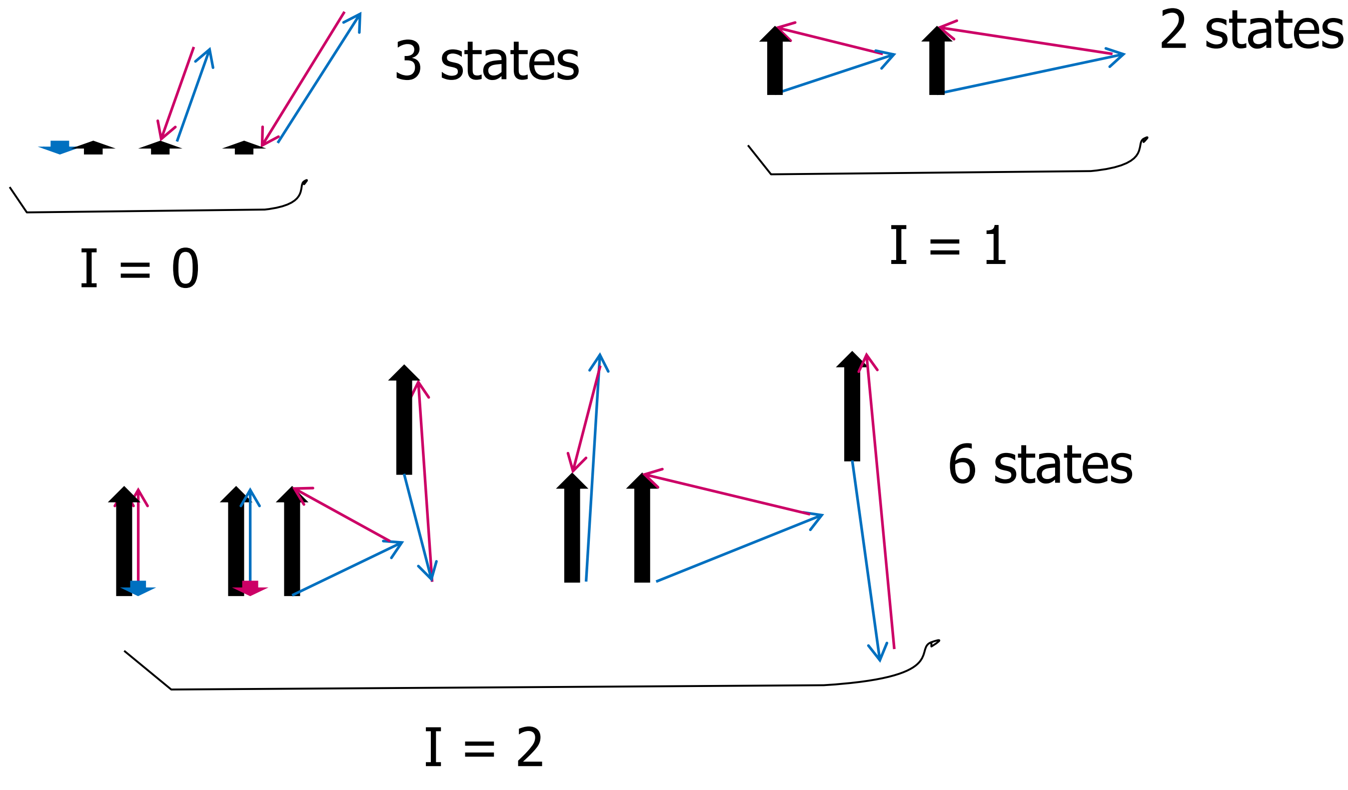
K=R=0:



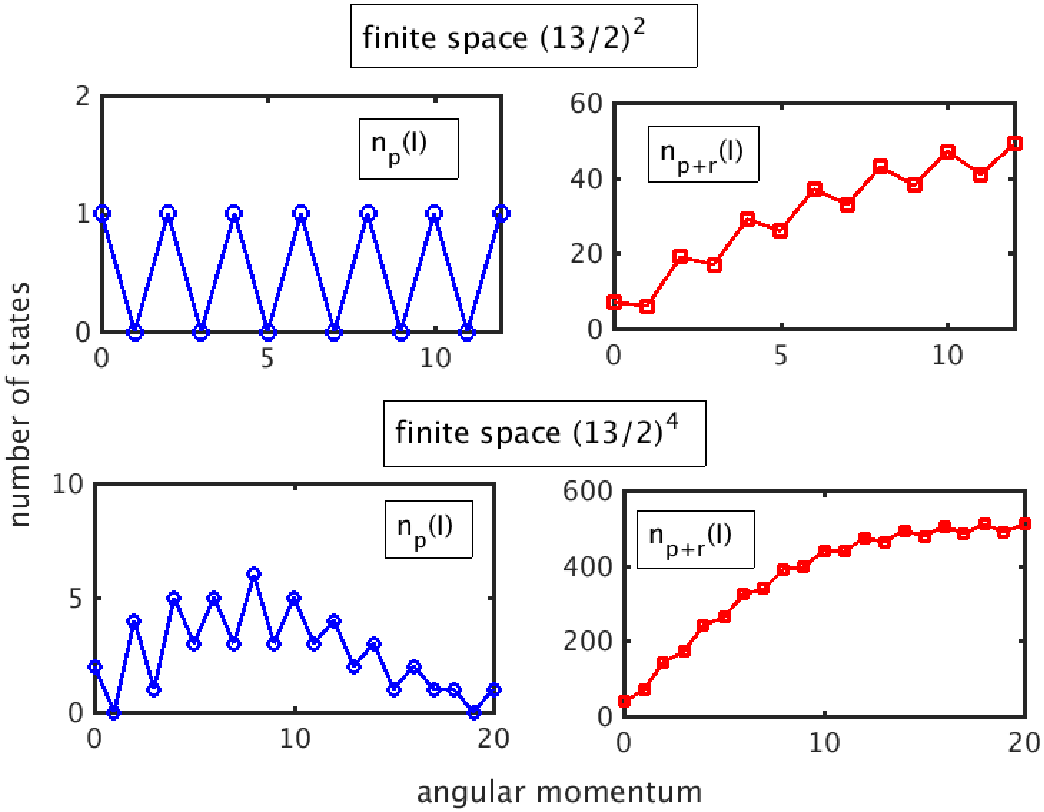
$(j_p j_r)I$ -representation



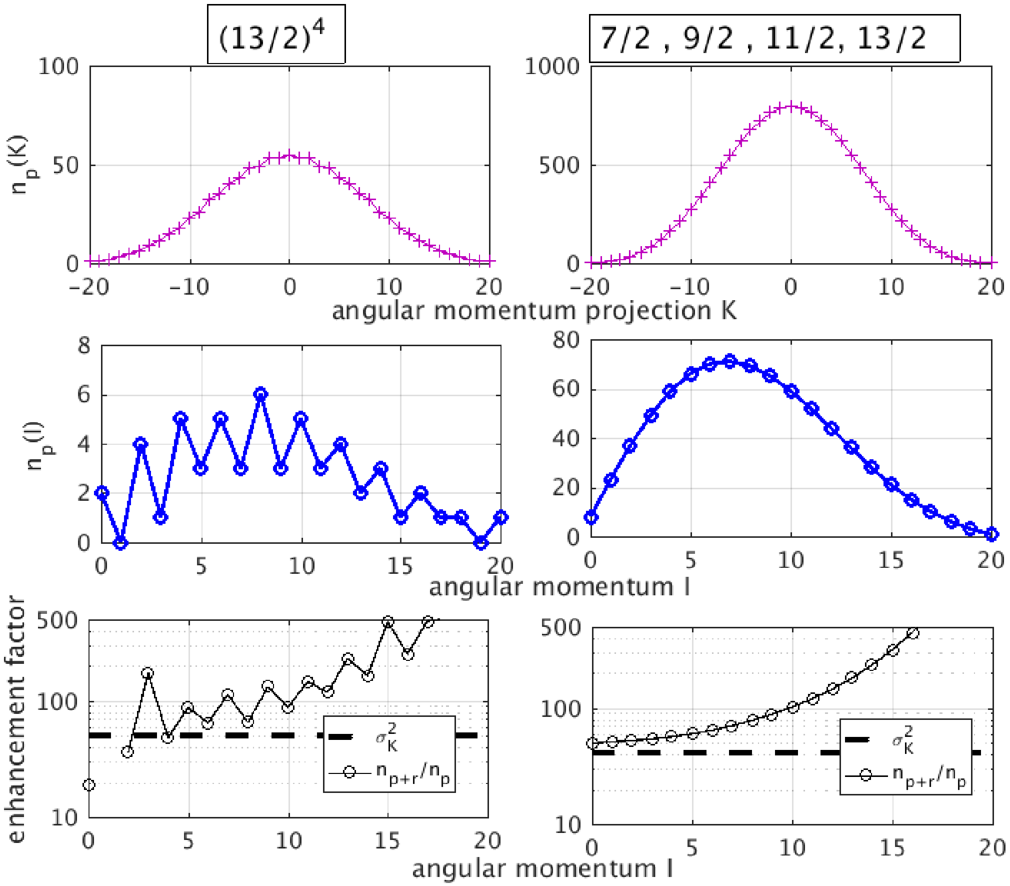
(d5/2)^2 – particle and rotor angular momenta



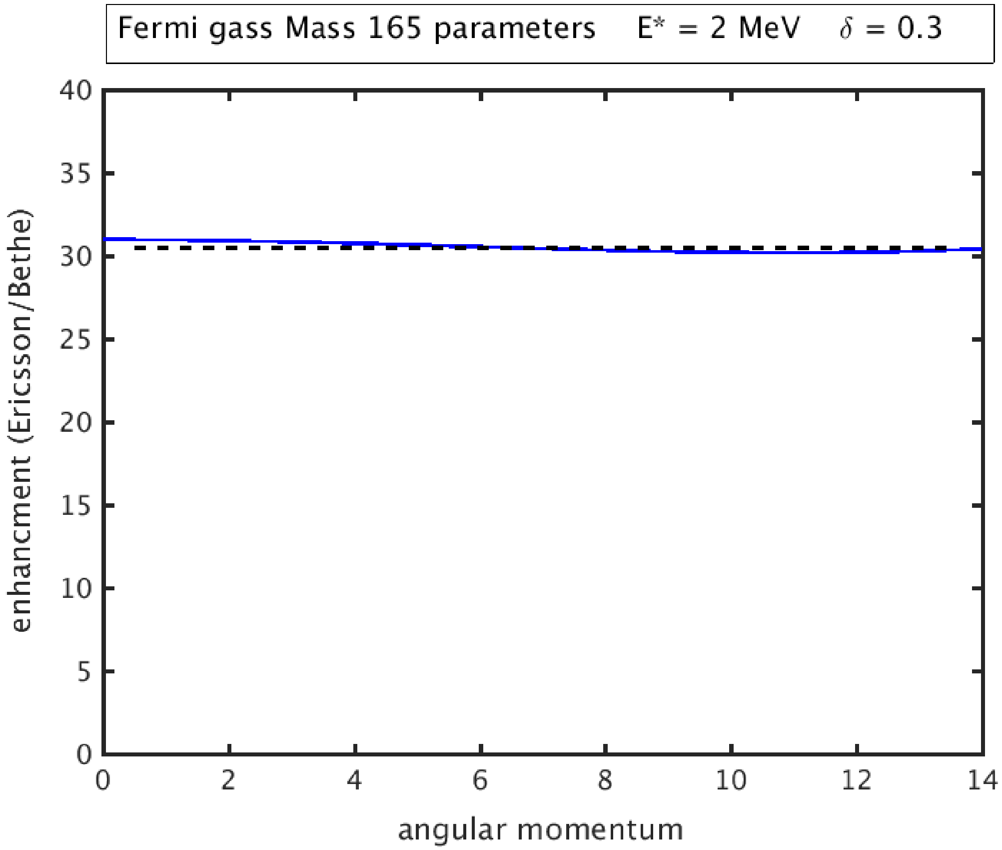
Finite spaces: 2 or 4 particles in i13/2



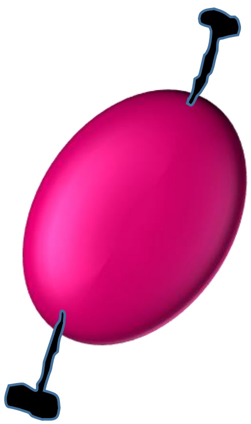
Finite spaces – K-distribution and rotational enhancement



Rotational enhancement – Fermi gas



Rotational enhancement – how to evaluate: Overall versus intrinsic level density



Intrinsic state density, fixed orientation,
angular momentum projection K

$$\sum_K \rho(E, N, Z, K) = \rho(E, N, Z)$$

Overall state density,
magnitude of angular momentum I

$$\sum_I (2I+1)\rho(E, N, Z, I) = F_e\,\rho(E, N, Z)$$

F_e: **enhancement factor**

For deformed nucleus

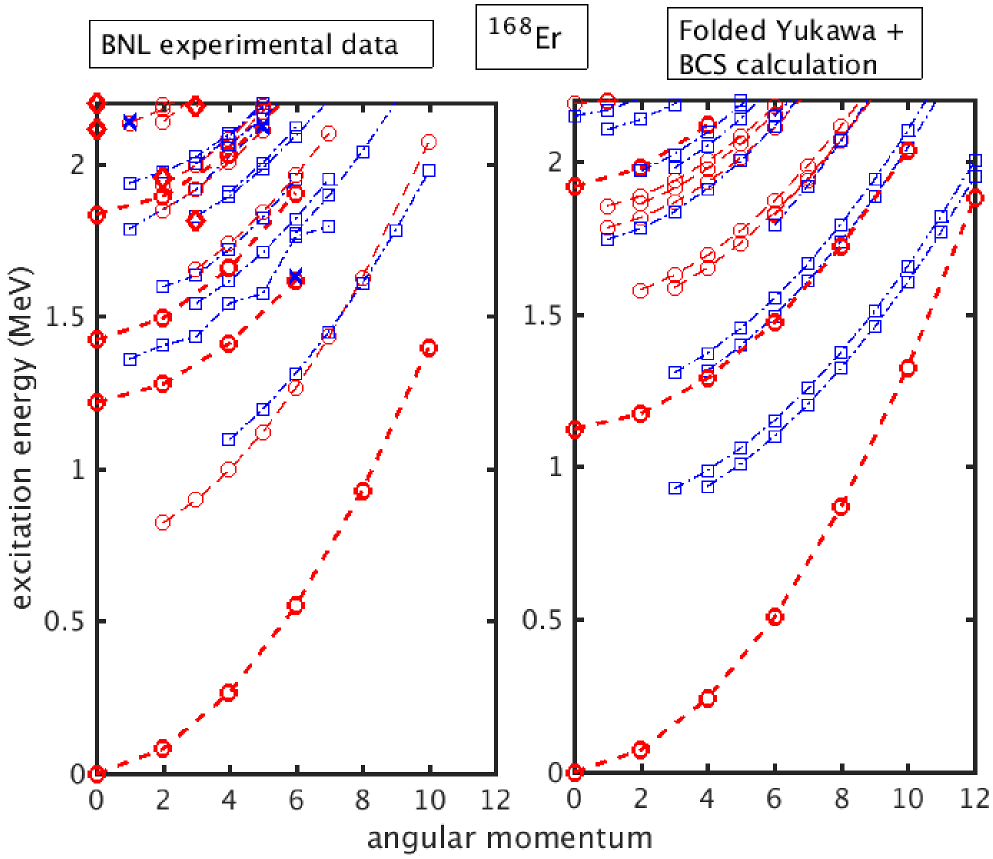
$$F_e = \sigma_\perp^2 = T\mathcal{J}_\perp$$

Requirements:

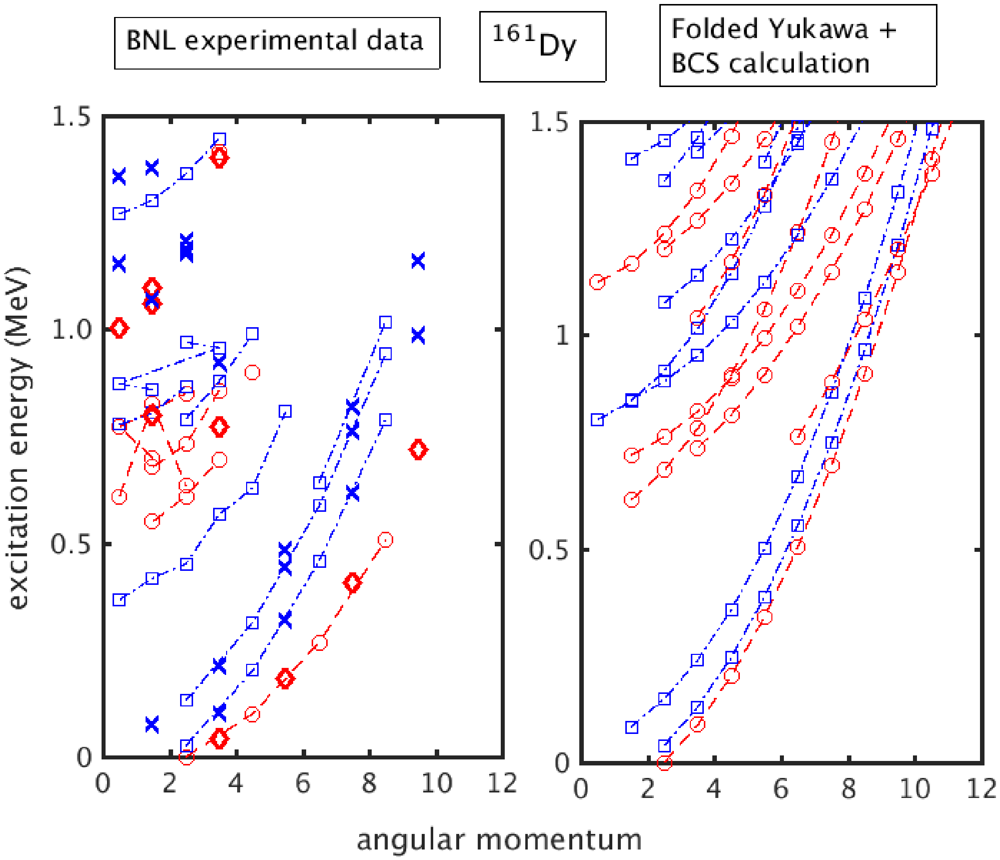
a) Identification of bandheads as intrinsic states

b) Summation over all K and over all I

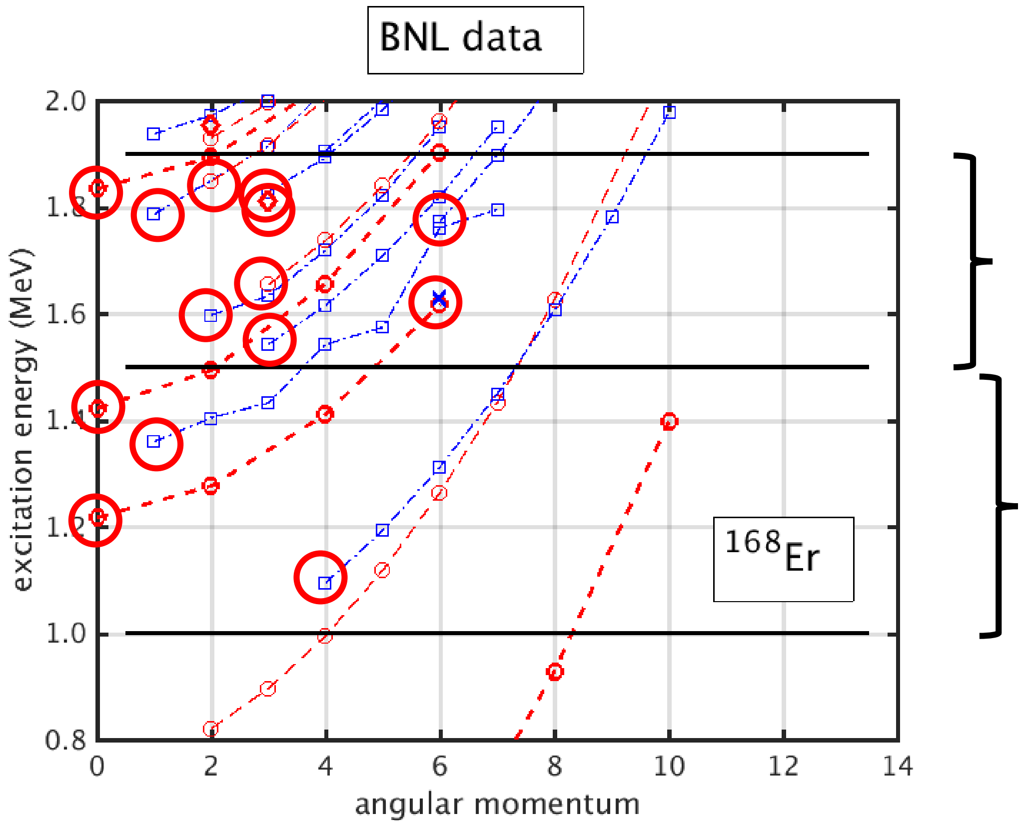
Example: 168 Er



Another example: 161 Dy



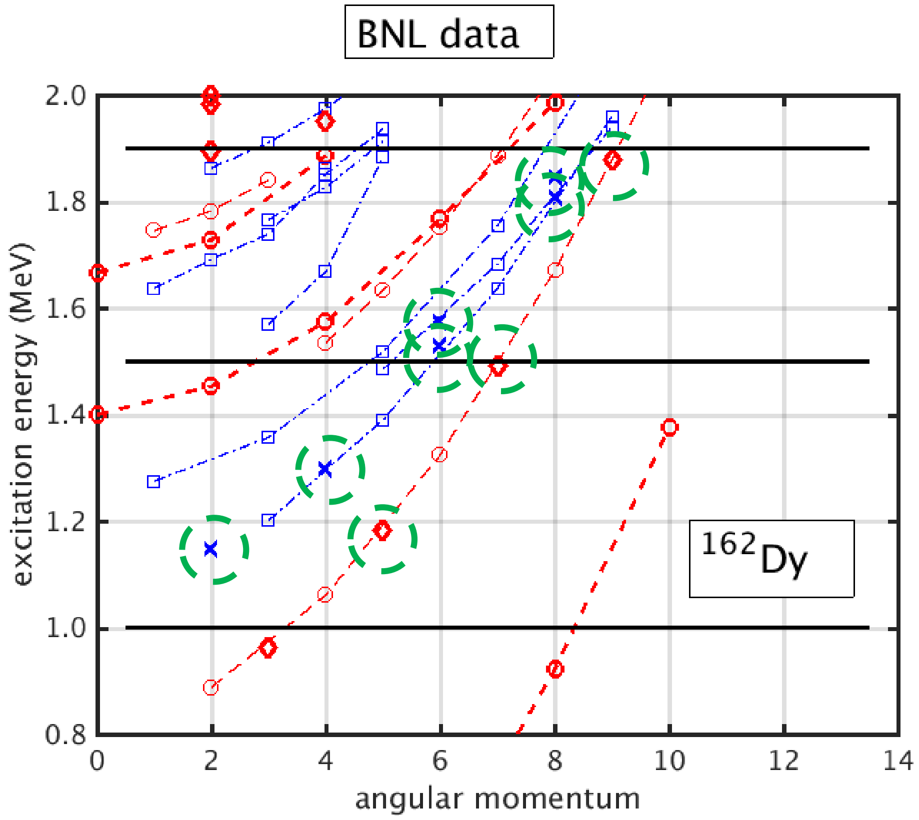
Bandheads – example: 168 Er



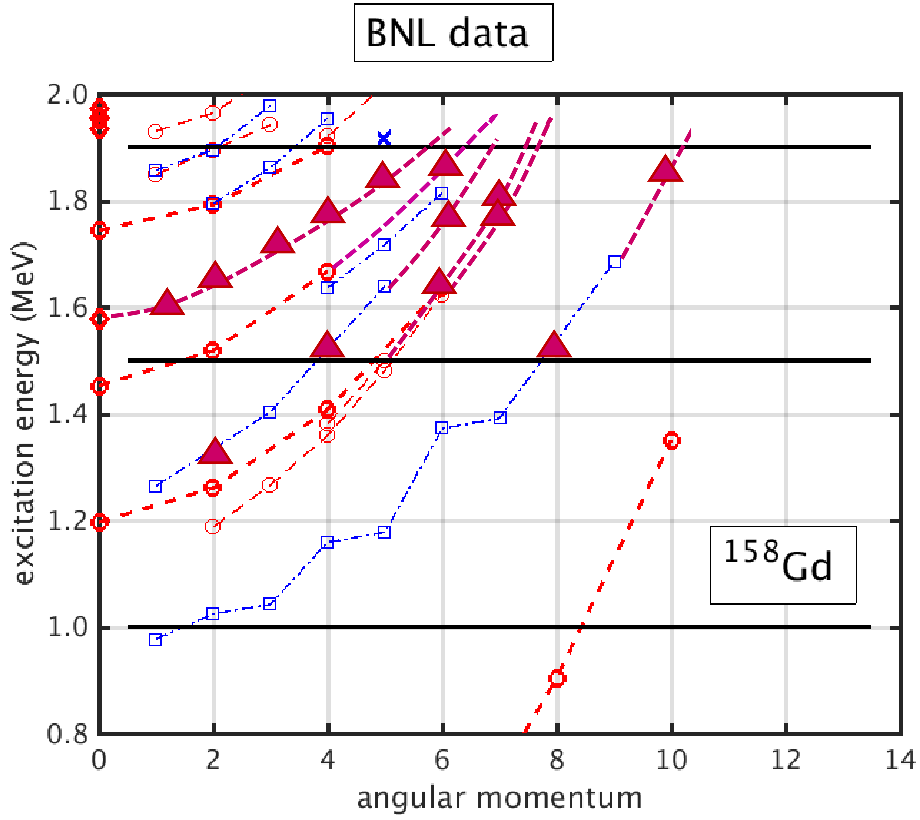
1.5 – 1.9 MeV

1.0 – 1.5 MeV

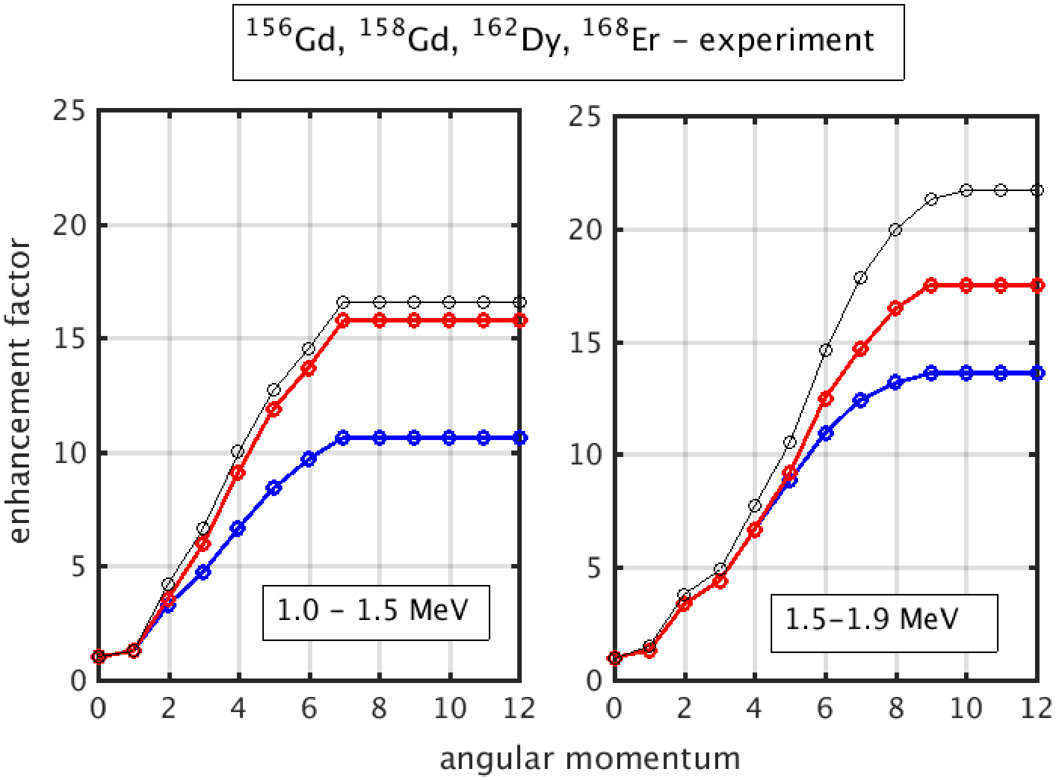
Assign BNL non-band states to bands - example: 162 Dy



Add-on to "complete" data - example: 158 Gd



Enhancement factors as function of maximal angular momentum

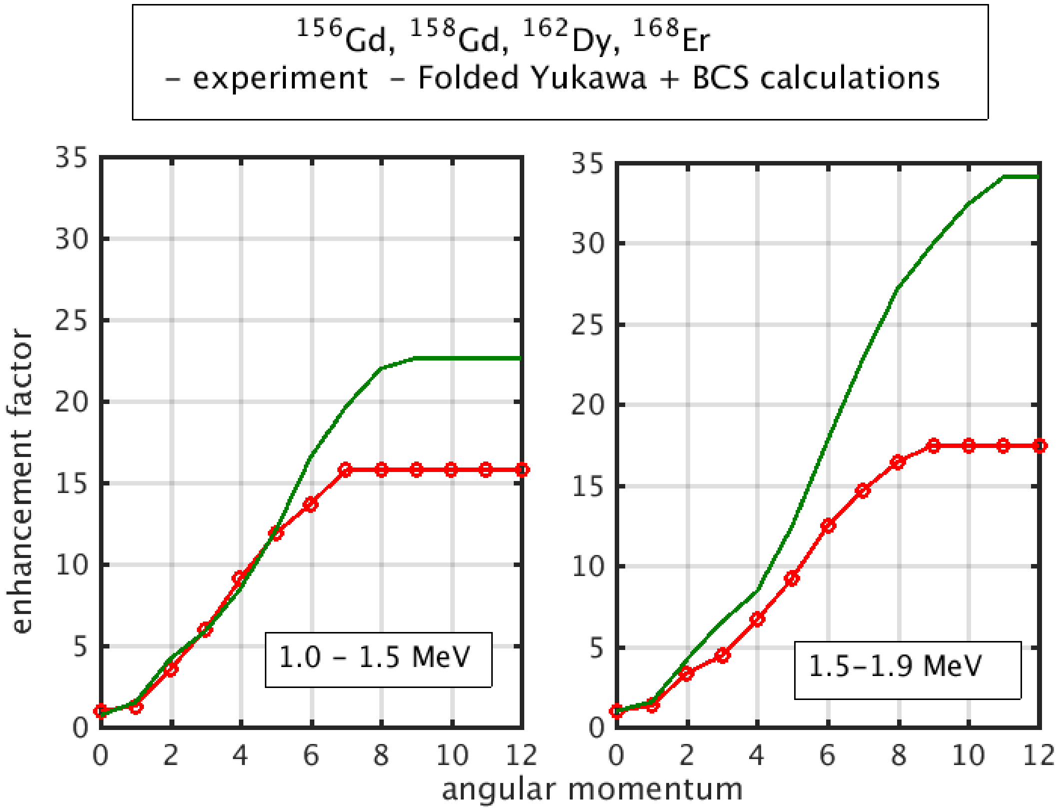


With Add-on and Assign

With states Assigned to bands

Strictly BNL data

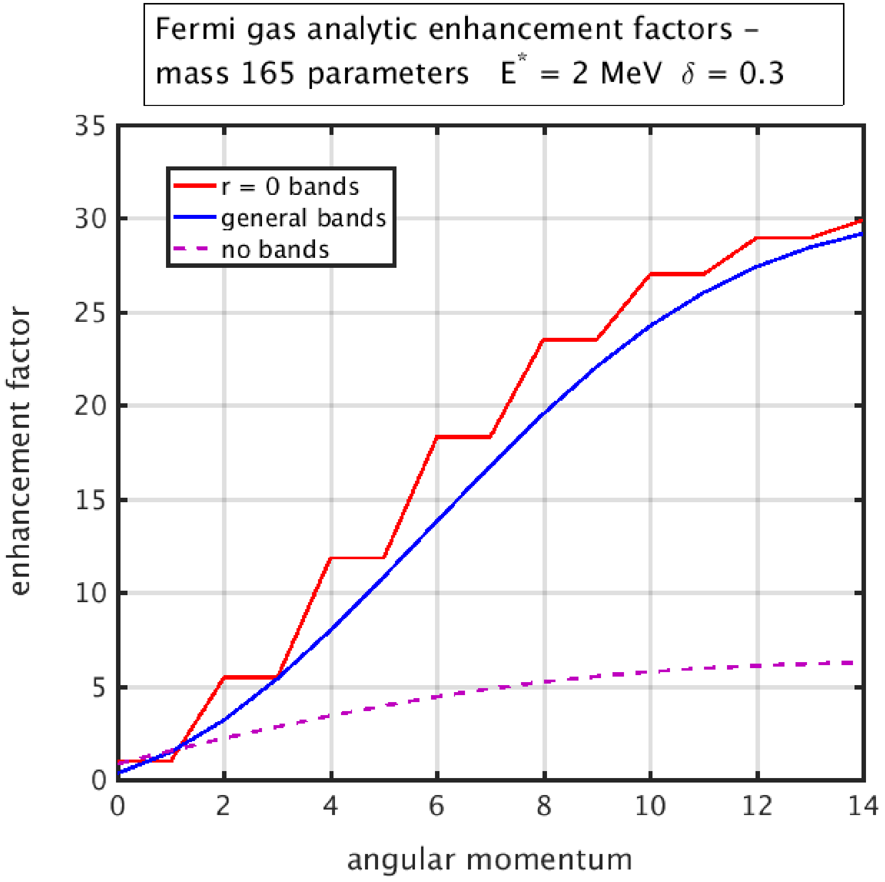
Enhancement factors – experiment and Folded Yukawa potential



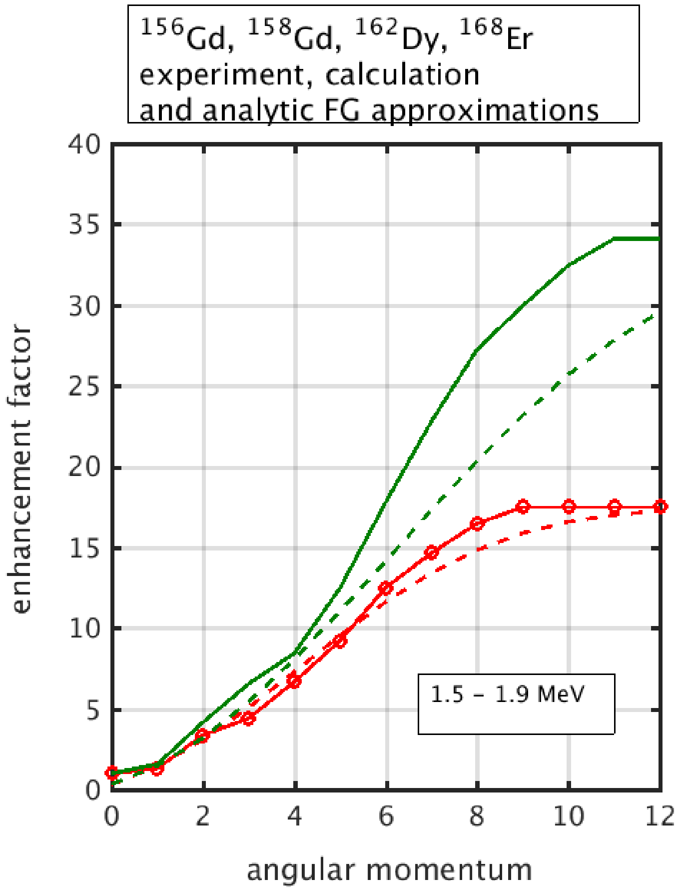
Calculated bands

Data - with states Assigned to bands

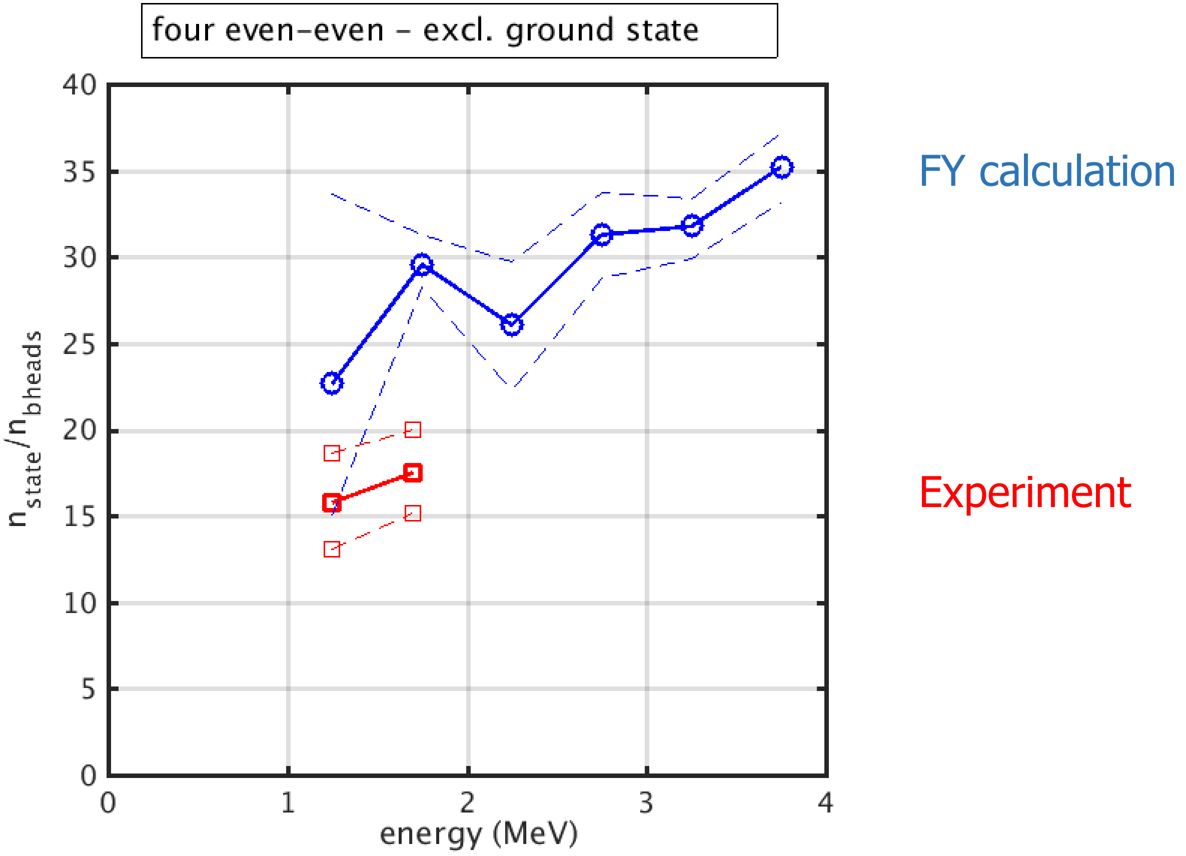
Enhancement factors from Fermi gas



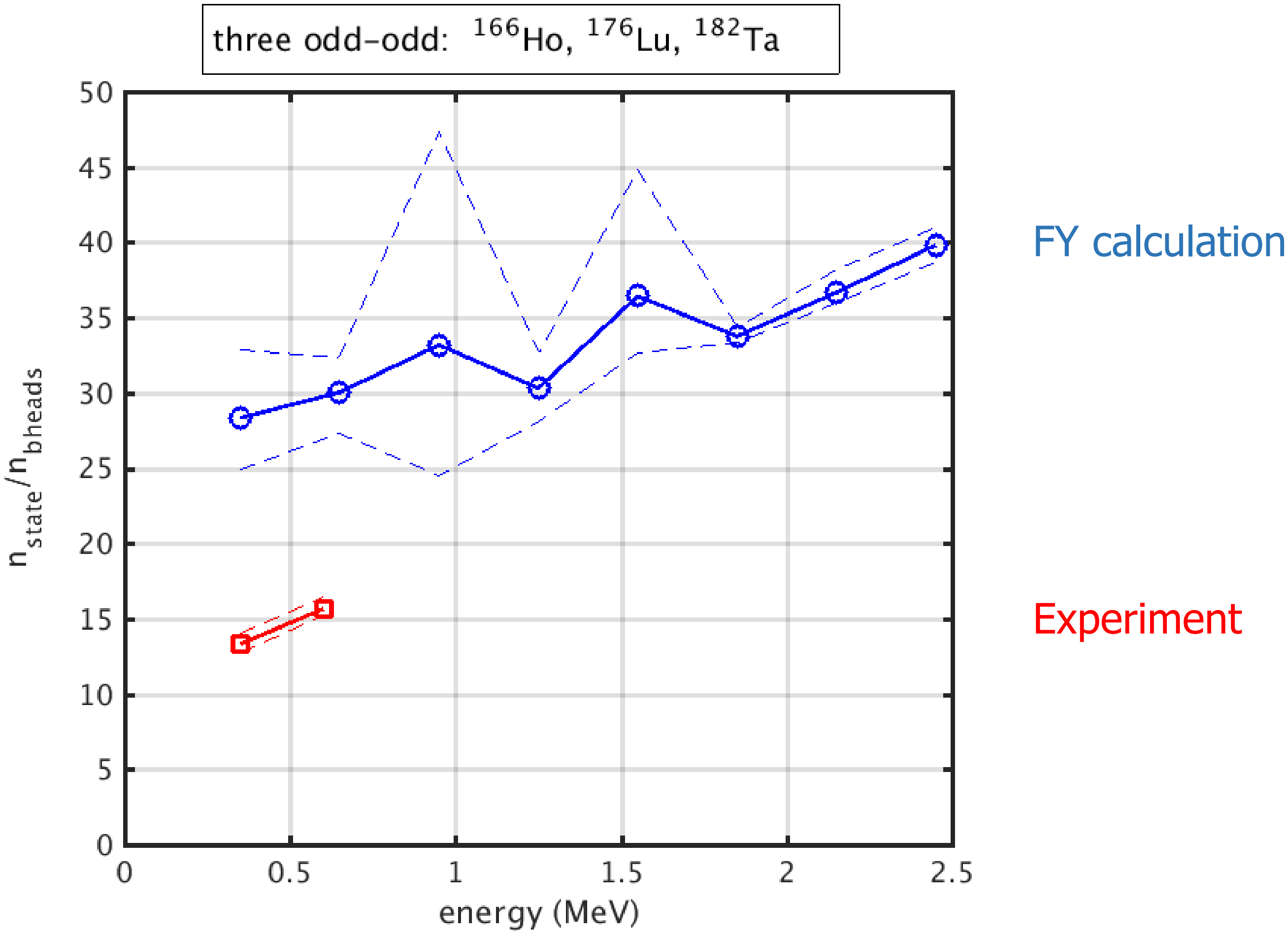
Comparison data, calc. and analytic



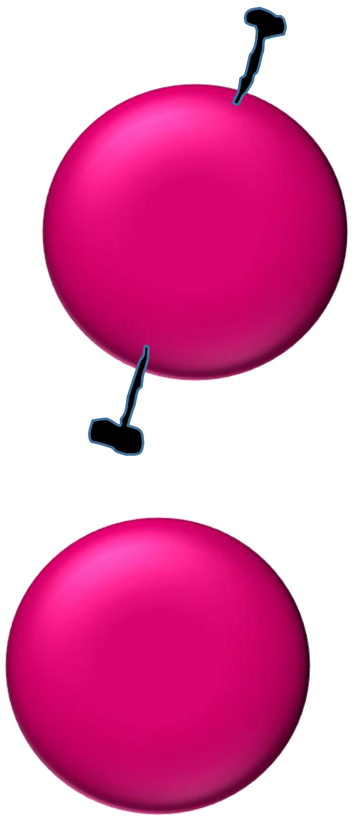
Enhancement four even-even nuclei



Enhancement three odd-odd nuclei



Problem: when bandheads do not represent intrinsic frame?



In theory: orientation of nucleus can still be held fixed

In experiment: Intrinsic states cannot be identified – all states will be counted as bandheads

Enhancement factor attains the value

$$F_e \approx \sqrt{\frac{\pi}{2}} \sigma_\perp$$

- a spurious result, to be compared to:

For deformed nucleus

$$F_e = \sigma_\perp^2 = T \mathcal{J}_\perp$$

For spherical nucleus

$$F_e \approx 1$$

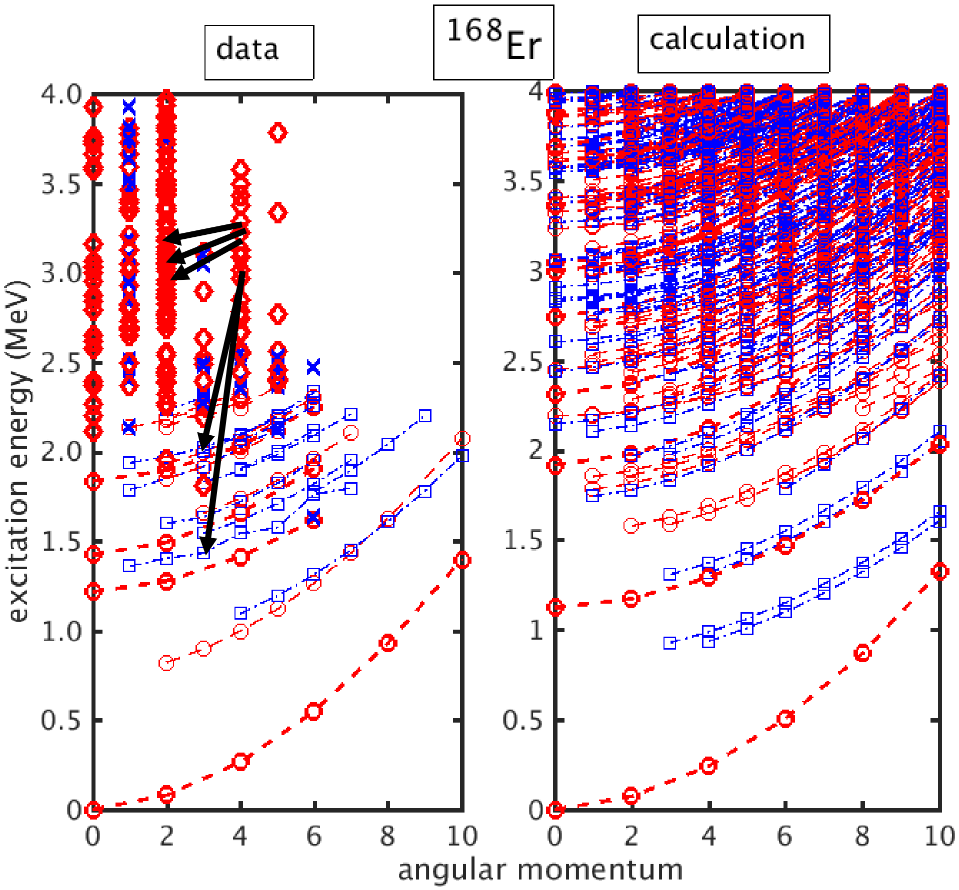
Limits to study of enhancement with resolved spectra

E2 strength is
Fragmented

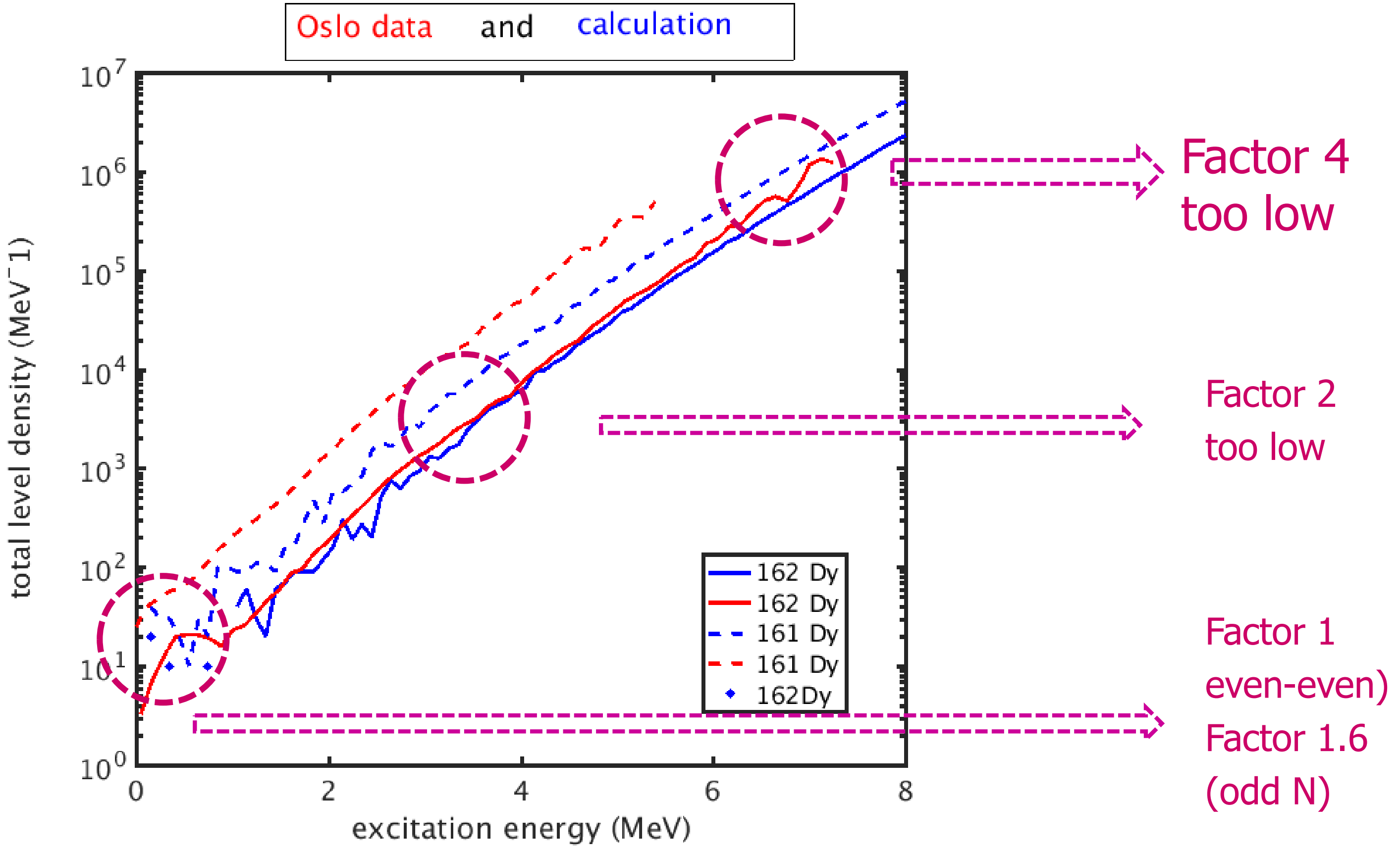
Cooling transitions
are faster

⇩

Band heads cannot
be identified



Overall Folded Yukawa level density at various energies: rotational enhancement included up to neutron sepration energy



Higher energies – fade-away of rotational enhancement

- Ericsson formula is from 1958
- Bjørnholm, Bohr and Mottelson, 1974: T around $h\varpi\ \delta$: nuclear orientation cannot be defined - orientation fluctuations strong: end of rotational enhancement.

- G. Hansen and A.S. Jensen, 1988: Elliot model: first order phase transition around that temperature in well deformed nuclei.

  Max of enhancement factor F_e=80 around E=35 MeV

- Komarov et.al., 2007: phase transition not seen in alpha particle evaporation

- Özen, Alhassid and Nakada, 2013 – rather light rare earth nuclei: enhancement factor F_e=10 around E=5, max of F_e=20 around E=10 MeV.

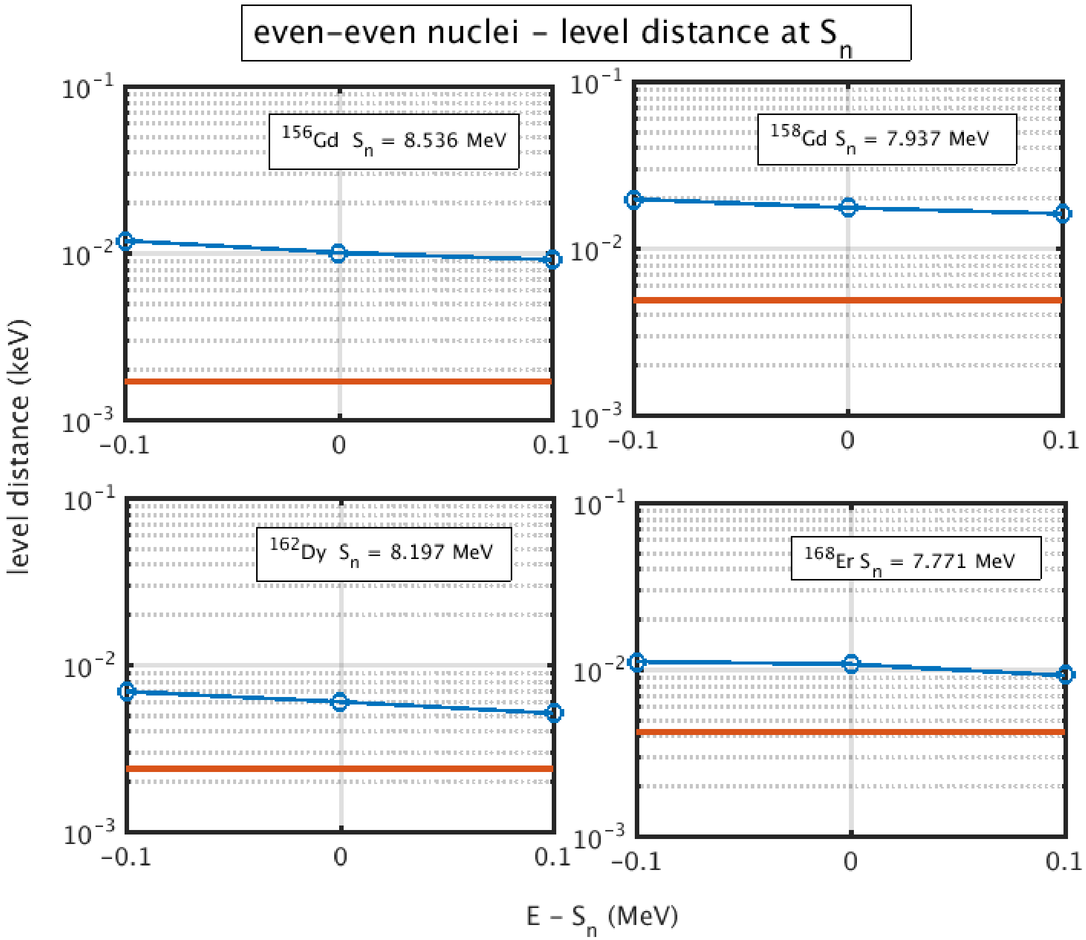
Conclusion

Rotational enhancement at low energies (T around 0.2 to 0.3 MeV) of the order of 16-20

Folded Yukawa + BCS calculation: enhancement of the order of 25-35

With resolved levels and bands: One cannot go to higher T – but maybe to other mass regions

Extra: level distance at S_n



Extra: level distance at S_n