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Session 1:
Transitional Nuclei and Shape Coexistence

Both sides of the story:
Shape coexistence
and
Quantum Phase Transitions

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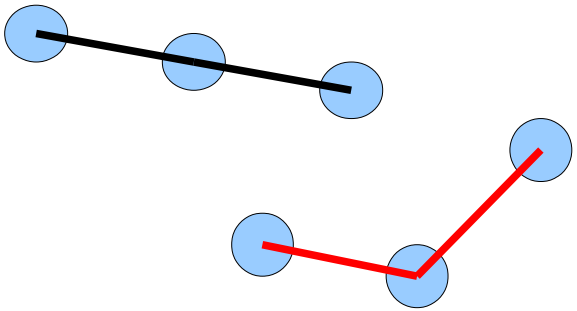
What is shape coexistence?

It appears in quantum systems where eigenstates with very different density distribution coexist.

Therefore, the existence of a geometric interpretation is implicit .

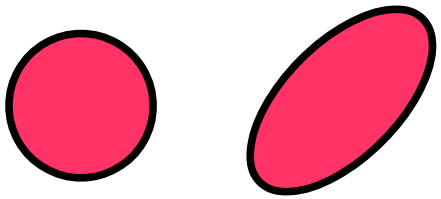
Molecules



$$q_{2,i} = \sqrt{5}\langle 0_i^+ | [\hat{Q} \times \hat{Q}]^{(0)} | 0_i^+ \rangle,$$

$$q_{3,i} = -\sqrt{\frac{35}{2}}\langle 0_i^+ [\hat{Q} \times \hat{Q} \times \hat{Q}]^{(0)} | 0_i^+ \rangle.$$

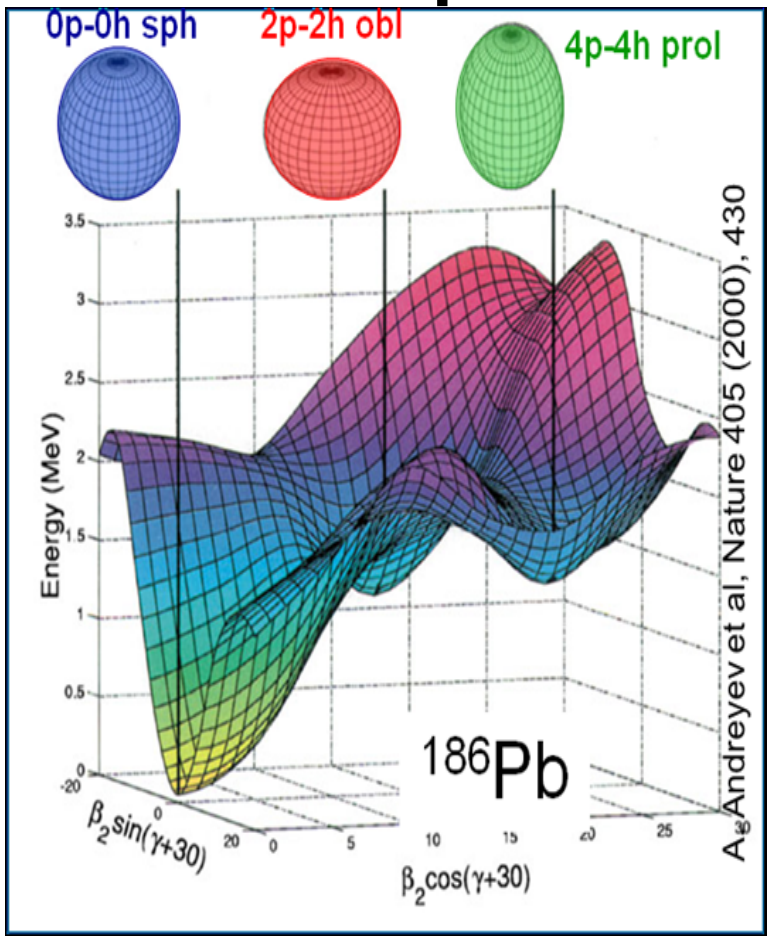
Nuclei

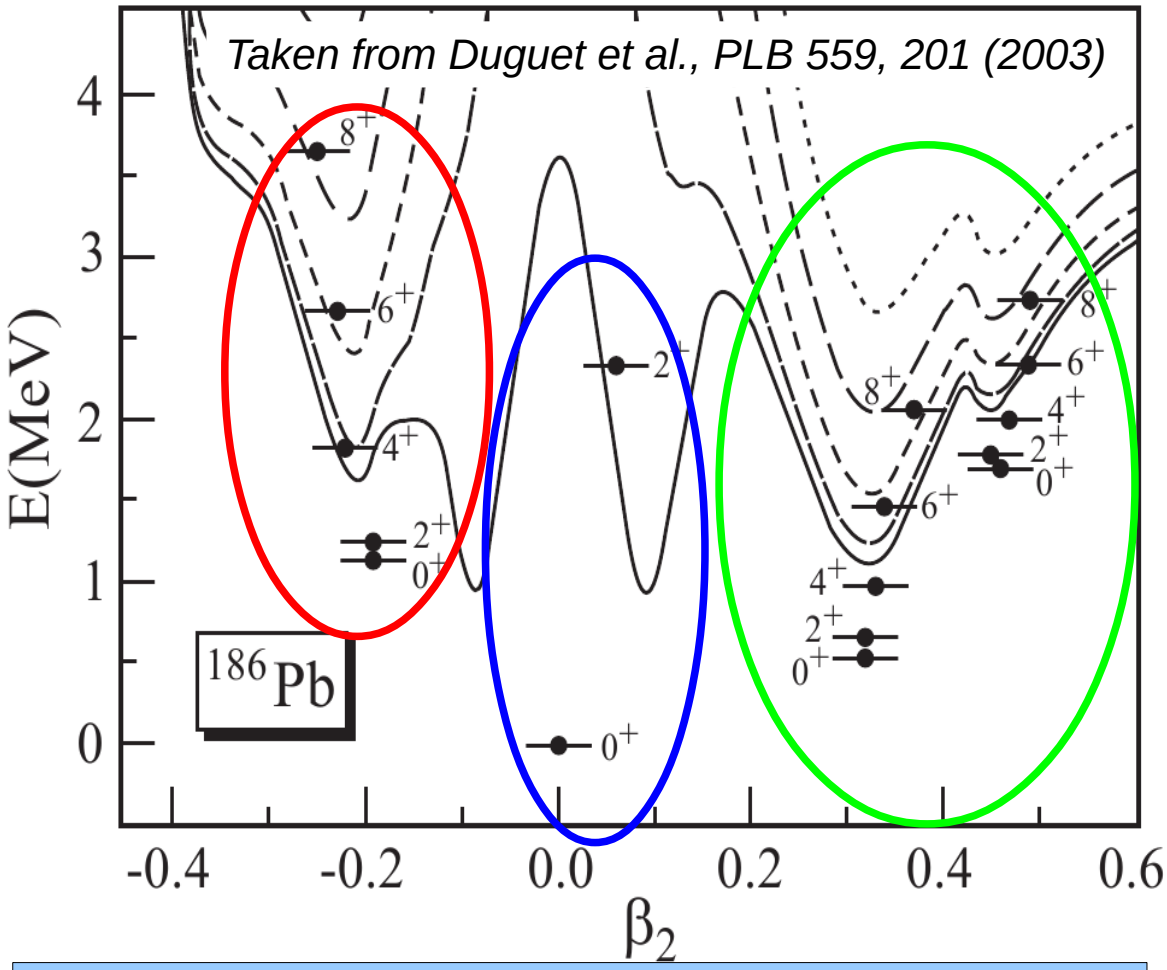


$$q_2 = q^2,$$

$$q_3 = q^3 \cos 3\delta,$$

Shape coexistence example

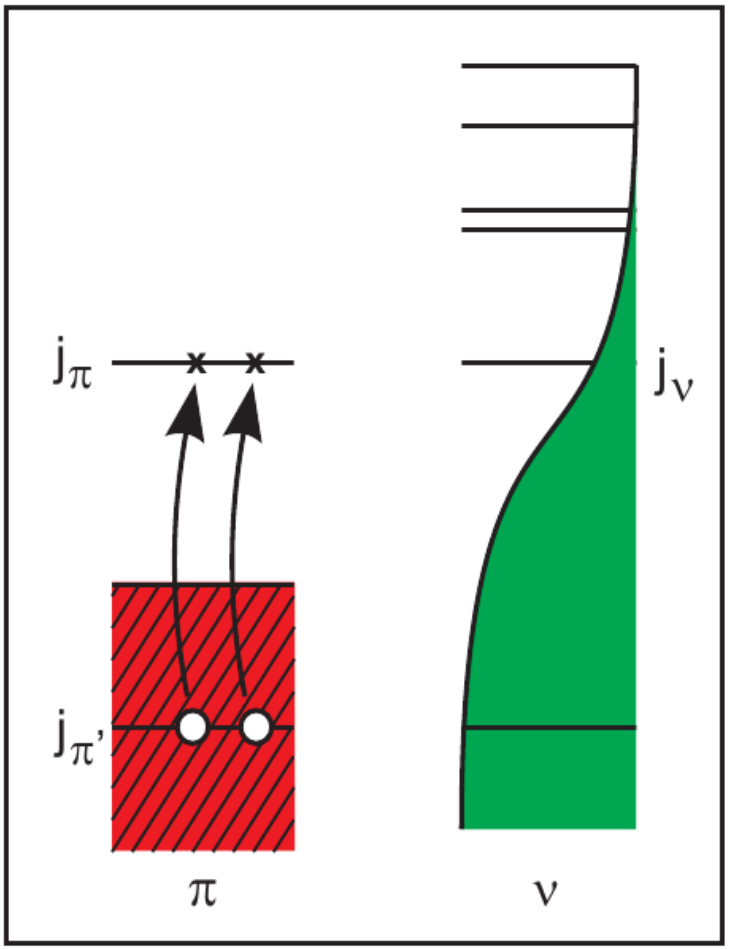




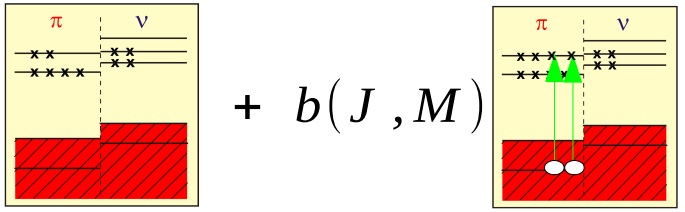
The angular momentum projected mean field plus the Generator Coordinate Method generates different bands with very different deformation.

Shell Model/Interacting Boson Model

- For nuclei near to closed shells, either for neutrons or for protons, it can be energetically favorable to have excitations of 2p-2h, 4p-4h … crossing the energy gap.
- The np-nh excitations have a lower excitation energy than expected due to the correlation energy: pairing and deformed correlations.
- Restricted to light and medium-heavy nuclei, at present.



$$\phi(J,M) = a(J,M) \quad + \quad b(J,M)$$



In heavy nuclei the huge model space imposes some kind of truncation: symmetry dictated truncation.

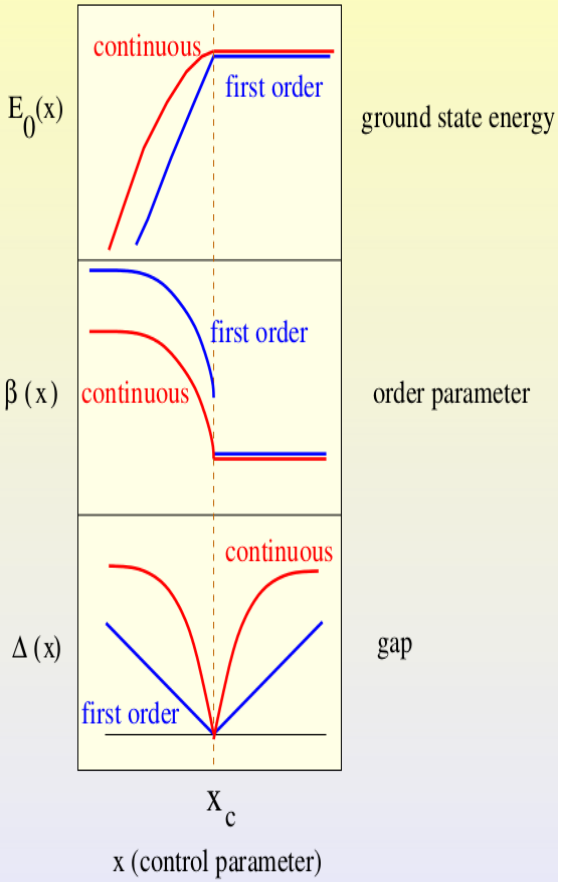
What is a QPT?

QPT occurs at some critical value, x_c, of the control parameter x that controls an interaction strength in the system's Hamiltonian $H(x)$. It is implicit a zero temperature.

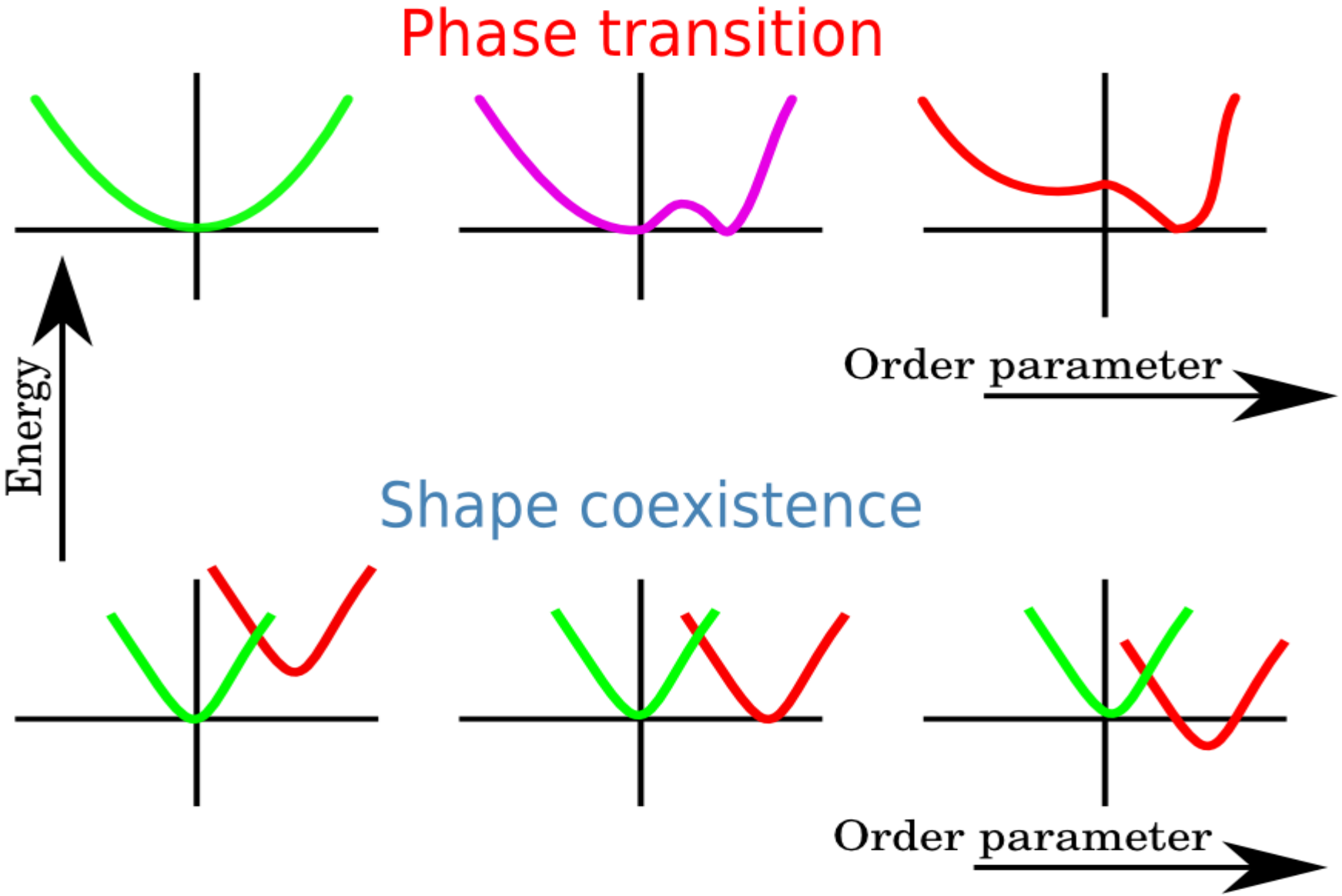
$$\hat{H} = x\,\hat{H}_1 + (1-x)\,\hat{H}_2$$

At the critical point:

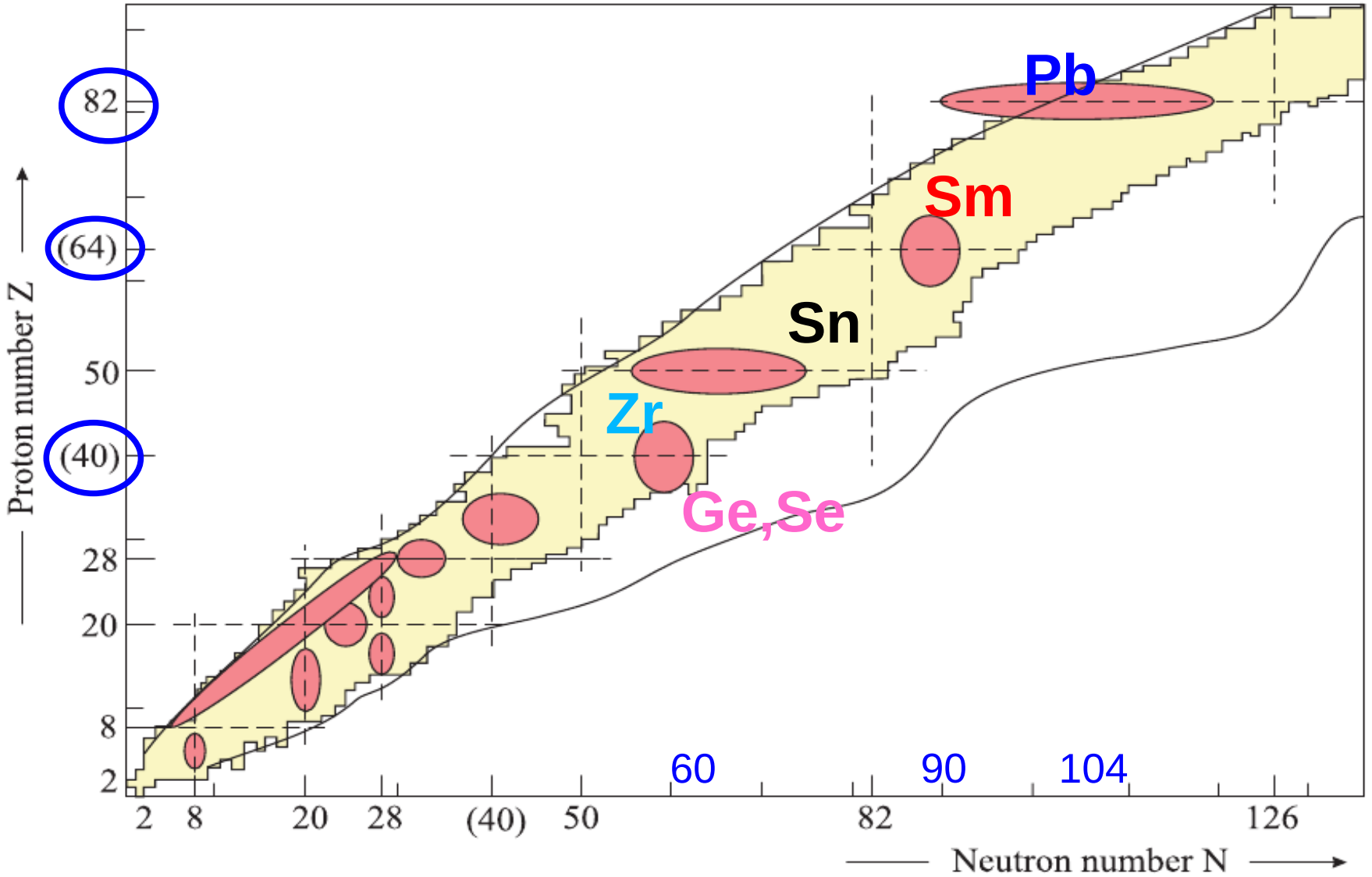
- The ground state energy is nonanalytic.
- The gap Δ between the first excited state and the ground state vanishes.



A schematic view



Many regions to be understood



K. Heyde and J. L. Wood, Rev. Mod. Phys. 83, 1467 (2011).

Plan for today

9.30-10.30

1) José-Enrique García-Ramos, "Both sides of the story: Shape coexistence and Quantum Phase Transitions" (10 min)
2) Katarzyna Wrzosek-Lipska, "Experimental evidences of shape coexistence in the Z=82 and A~100, N~60 regions" (25+5 min)
3) Volker Werner, "Prolate-oblate shape coexistence in Se isotopes from isomer spectroscopy" (15+5min)

10.30-11 h Coffee break

11-13 h

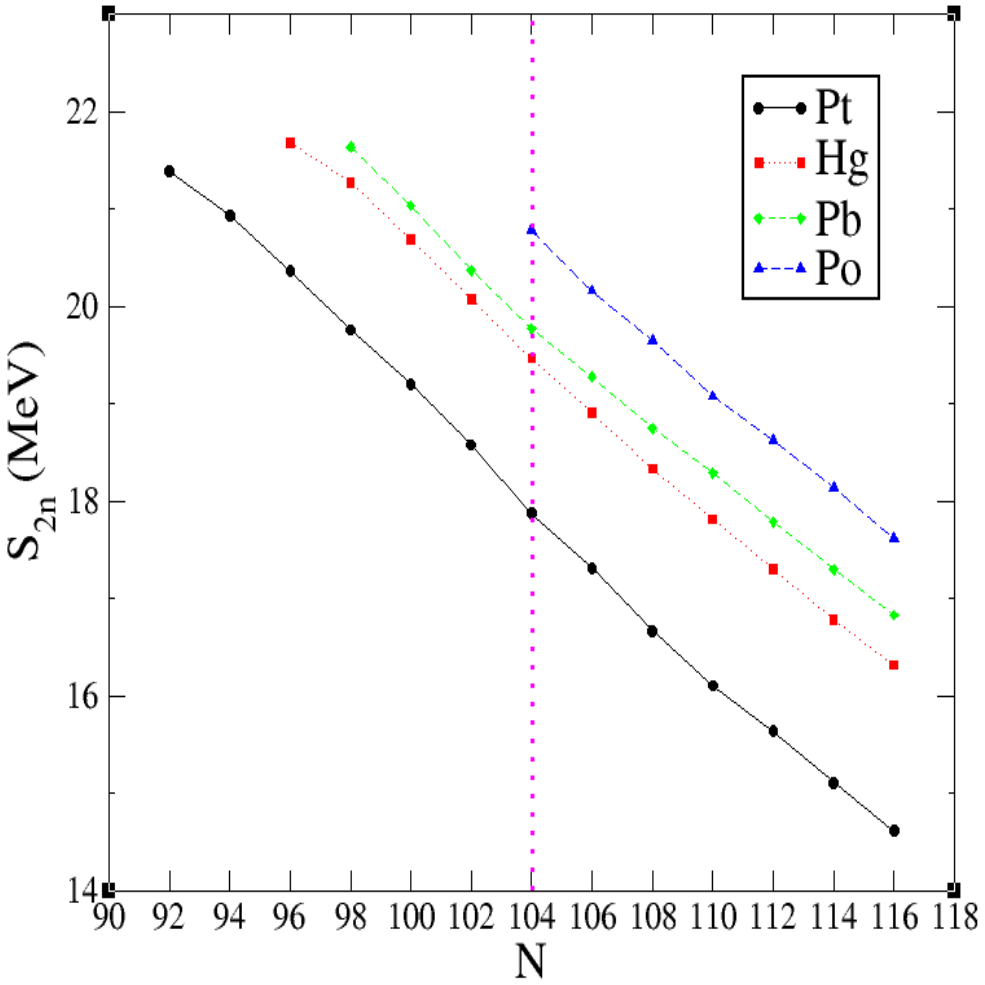
4) Mark Spieker, "Shape coexistence and collective low-spin states in ^{112,114}Sn studied with the (p,p'gamma) DSA coincidence technique and SONIC@HORUS" (15+5 min)
5) Dario Vretenar, "Shape-coexistence vs QPT in the rare-earth region", (15+5 min)
6) Geza Lévai, "Nuclear shape phase transitions described in terms of the sextic oscillator" (15+5 min)
7) Petrica Buganu, "Bohr model description of the critical point for the first order shape phase transition" (12+3min)
8) Panos Georgoudis, "Coexistent Shapes in the Bohr Hamiltonian: Limitations and phenomenological Challenges" (12+3min)
9) Sofia Karampagia "Quantum Phase Transitions within the Shell Model" (12+3min)
10) Mahmut Boyukata, "Signature of the gamma-softness in nuclei at the Se-Ge region" (12+3min)

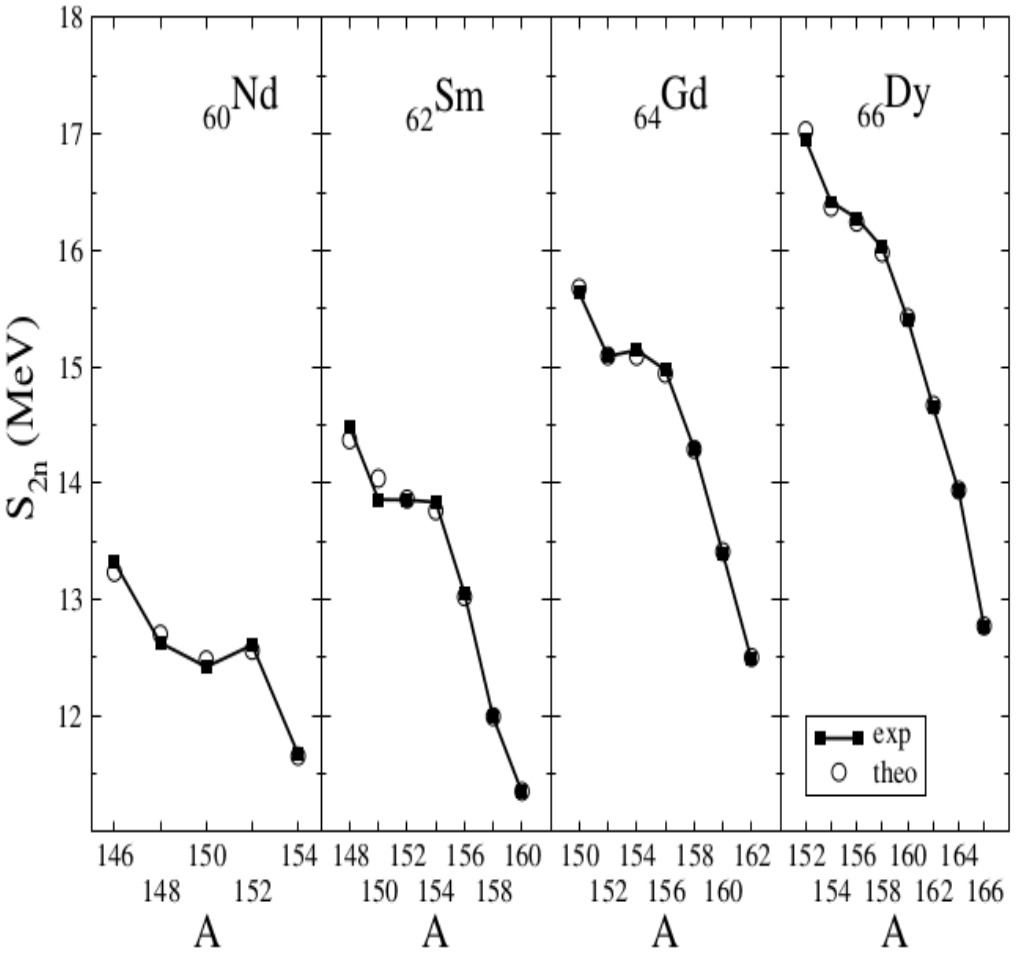
Some open questions

- Are both approaches compatible in a unified way?
- In particular cases, are both descriptions compatible?
- Can a Quantum Phase Transition be described in terms of the onset of intruder configurations?
- Is shape coexistence always present “before” a Quantum Phase Transition sets in, or are they fully disconnected?

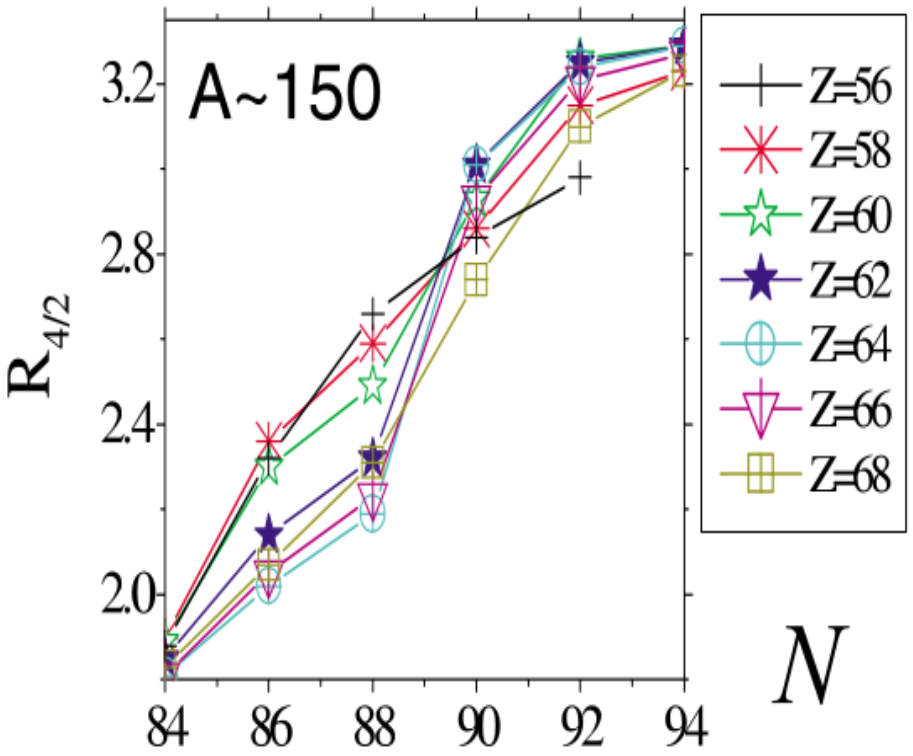
Let's start

2n separation energies





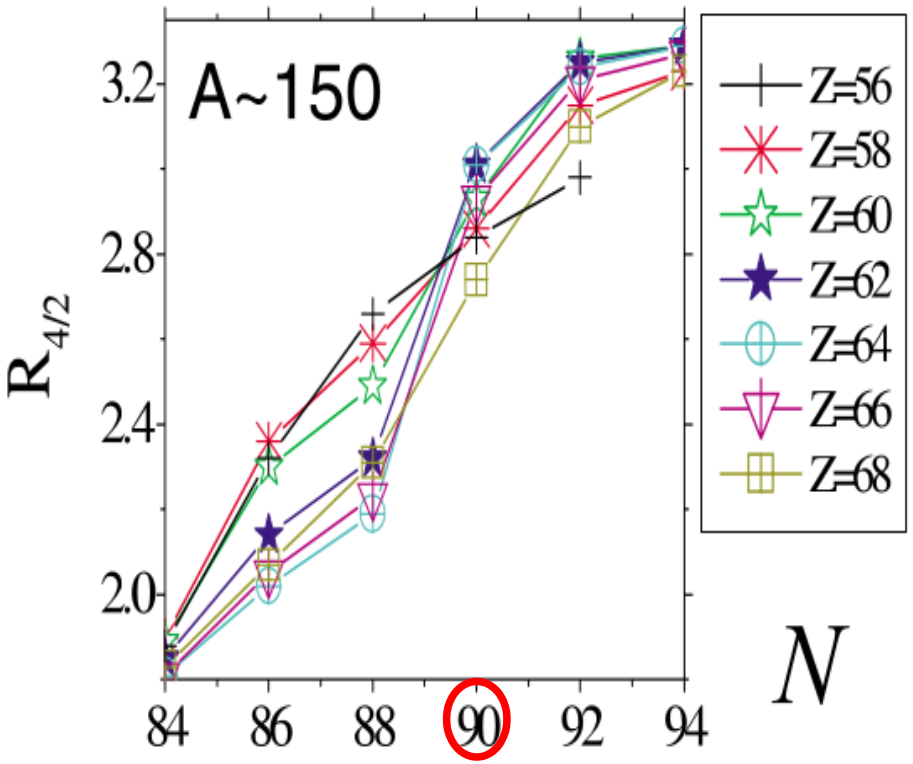
Energy ratios



P. Cejnar, J. Jolie, and R.F. Casten,
RPM 82, 2155 (2010)

E(4+)/E(2+) can be used as an order parameter and, therefore is a key observable to find where QPT develop

Energy ratios



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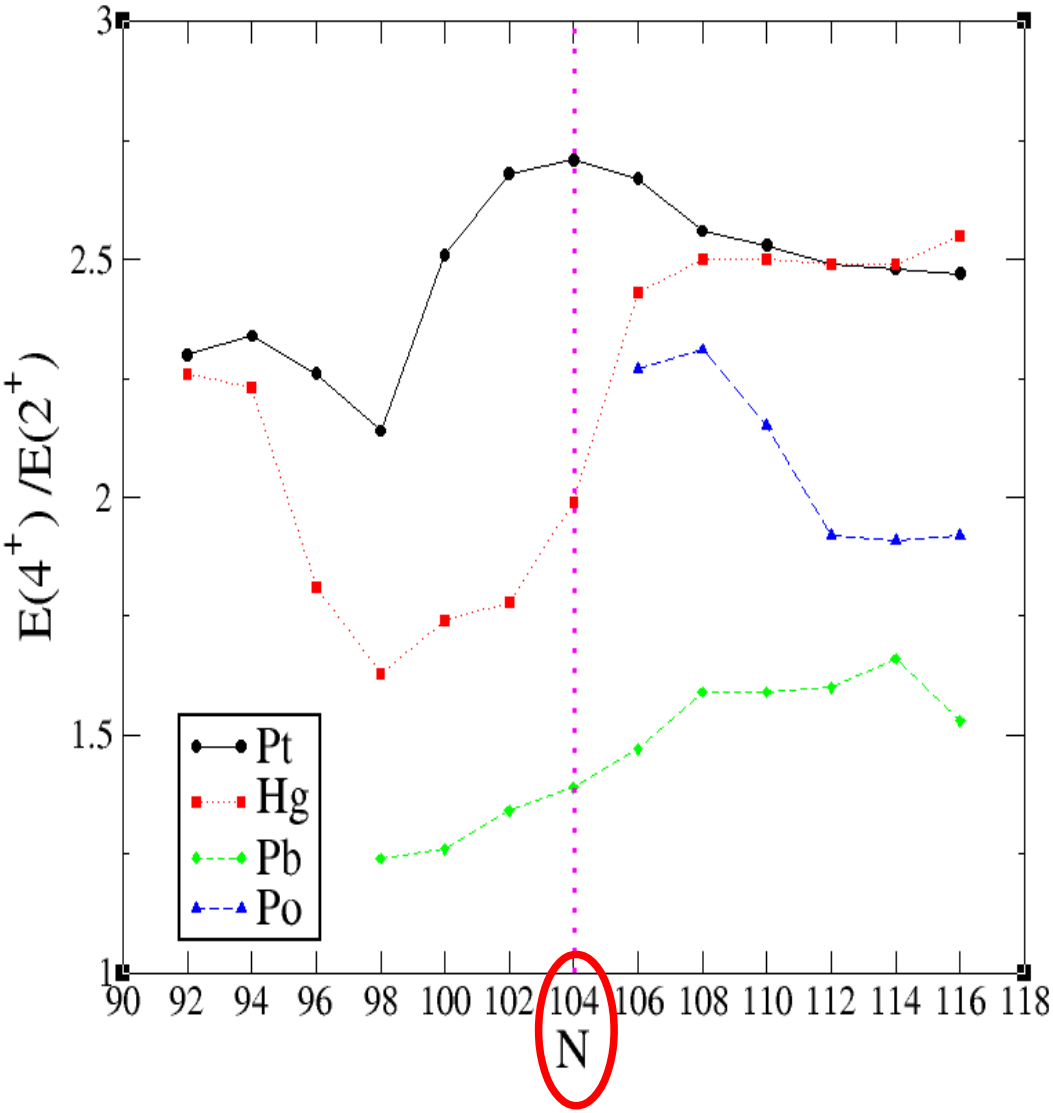
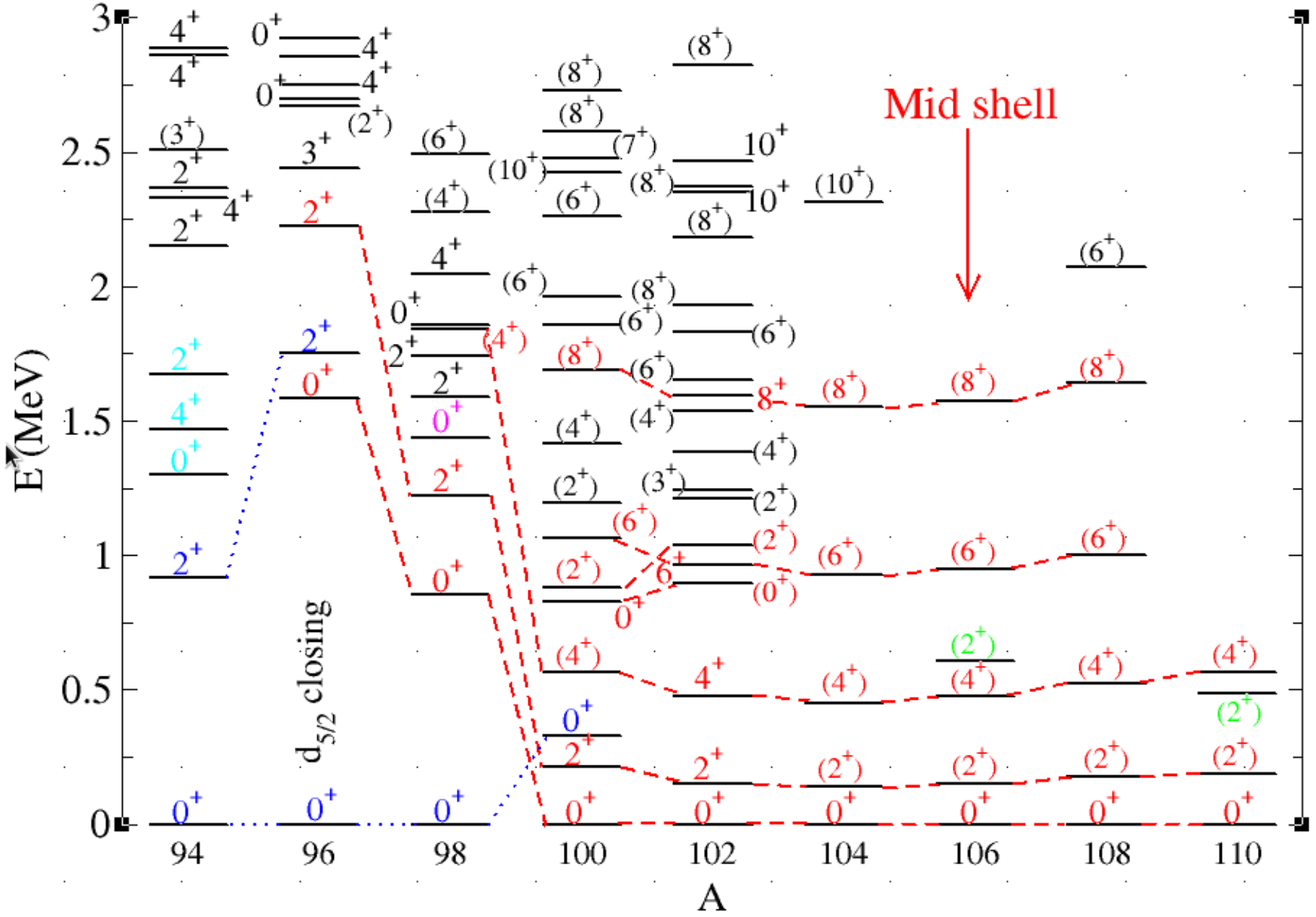
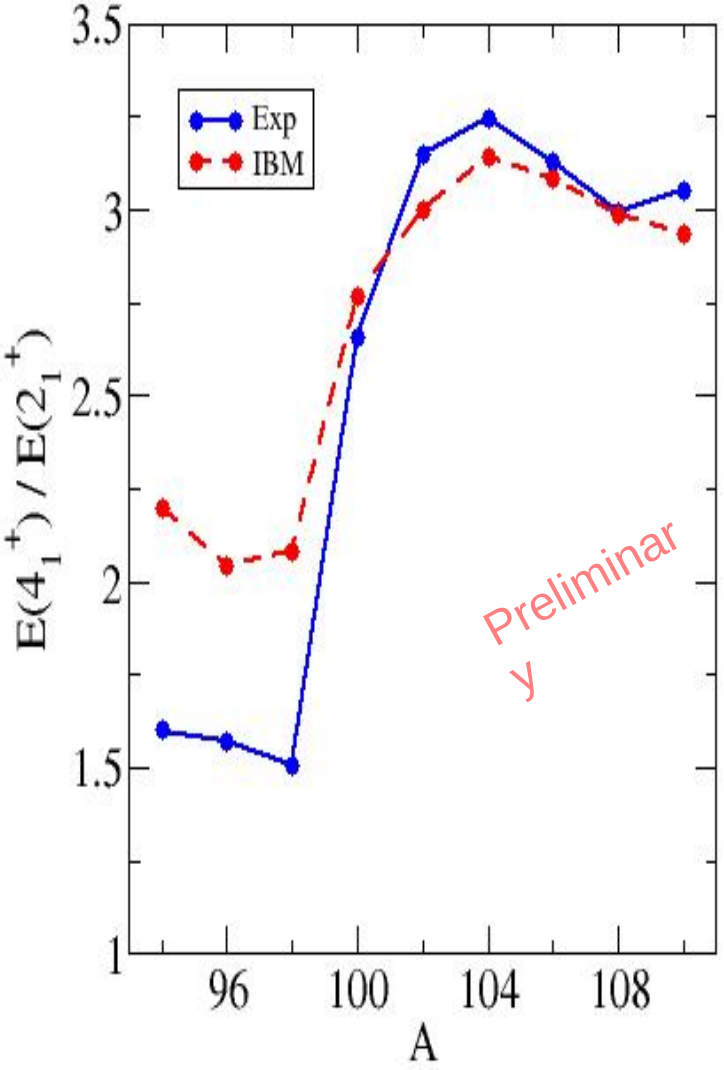
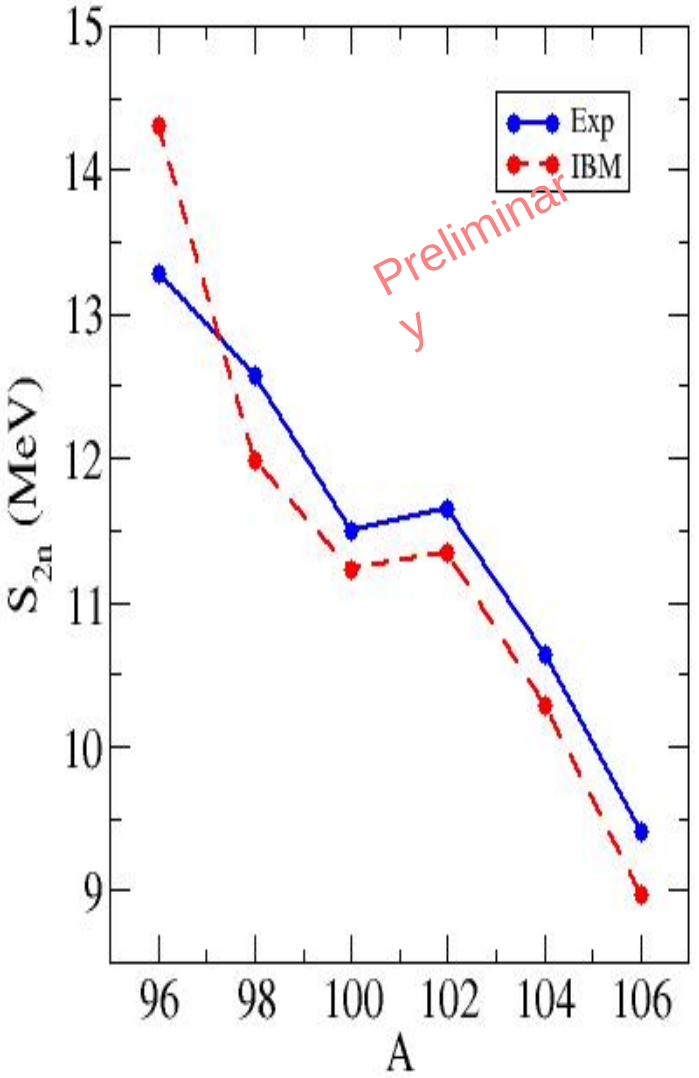


Z=40 subshell closure



Z=40 subshell closure





JEGR and K. Heyde, to be published