The Inversion Archipelago at the Neutron Rich Shores

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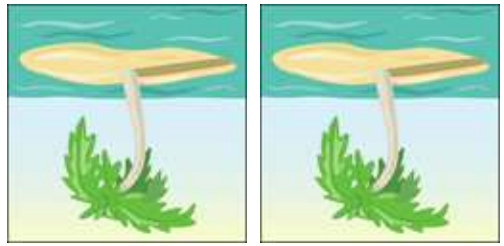
Outline

- Basics
- ^{68}Ni: The Portal to the N=40 Iol
- ^{78}Ni: The Portal to the N=50 Iol
- Mergers
- Conclusions

The Archipelago of Islands of Inversion

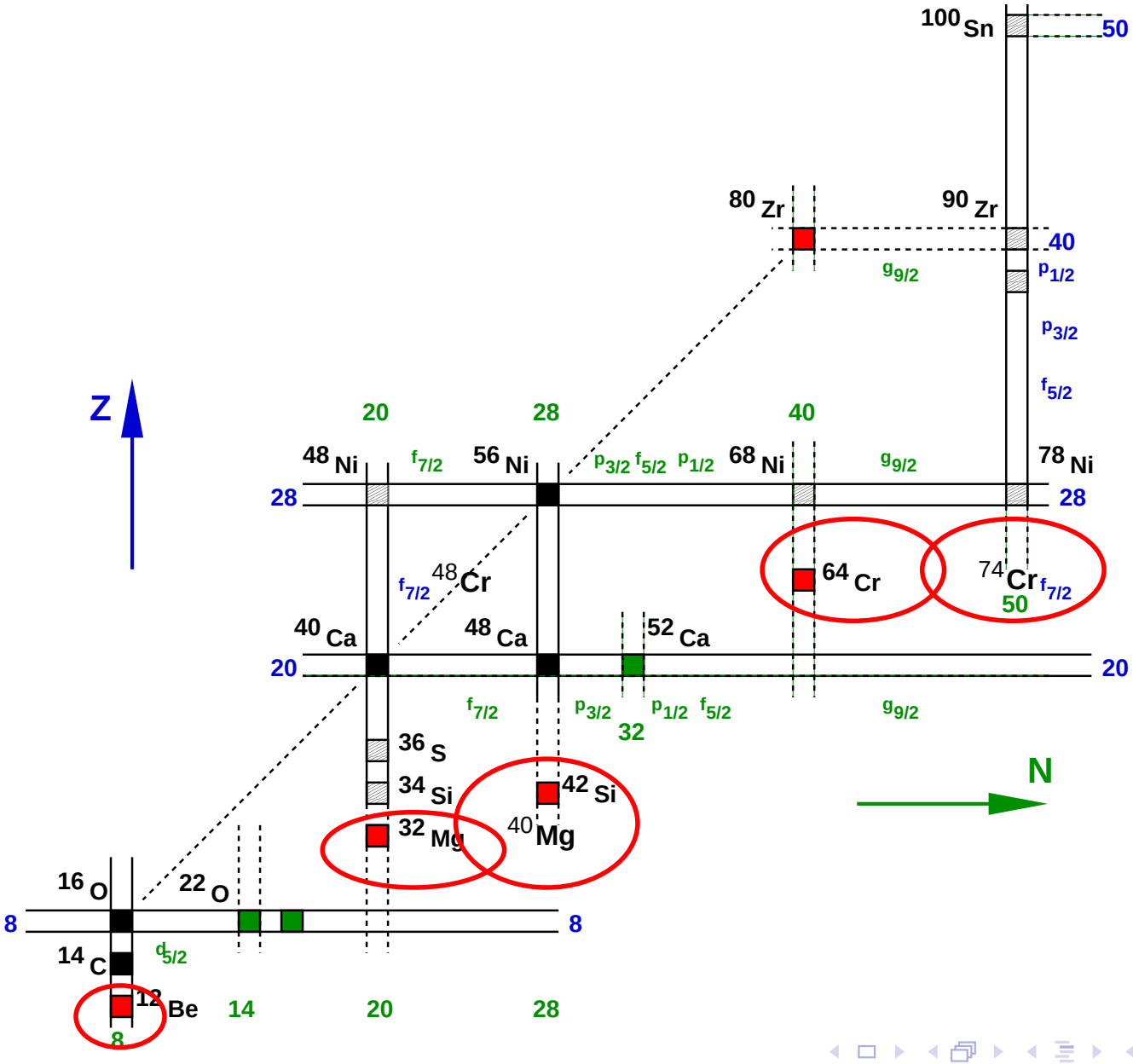




N=8 **N=20** **N=28** **N=40** **N=50**

^{11}Li **^{32}Mg** **^{42}Si** **^{66}Fe** **^{74}Cr**

Landscape of medium mass nuclei



The Plot

- **The two basic players in the nuclear dynamics are the spherical mean field and the multipole hamiltonian:** $H = \mathcal{H}_m + \mathcal{H}_M$
- **Magic numbers are associated to large energy gaps in the spherical mean field. Therefore, to promote particles above the Fermi level costs a large amount of energy.**
- **The Multipole Hamiltonian is responsible for the very strong nuclear correlations**
- **It is proper to the nucleus that, quite often, certain highly correlated configurations (dubbed ”intruders”) overwhelm their loss of mean field energy with their huge gains in correlation energy.**

The Spherical Mean Field (Monopole Hamiltonian)

$$\mathcal{H}_m = \sum n_i \epsilon_i + \sum \frac{1}{(1+\delta_{ij})} \overline{V}_{ij}\, n_i (n_j - \delta_{ij})$$

the coefficients $\overline{V}$ are angular averages of the two body matrix elements, or centroïds of the two body interaction:

$$\overline{V}_{ij} = \frac{\sum_J V^J_{ijij}[J]}{\sum_J [J]}$$

the sums run over Pauli allowed values.

The Spherical Mean Field (Monopole Hamiltonian)

This can be written as well as:

$$\mathcal{H}_m = \sum_i n_i \left[\epsilon_i + \sum_j \frac{1}{(1+\delta_{ij})} \overline{V}_{ij} \left(n_j - \delta_{ij} \right) \right]$$

Thus

$$\mathcal{H}_m = \sum_i n_i \;\; \hat{\epsilon}_i([n_j])$$

We call these $\hat{\epsilon}_i([n_j])$ effective single particle energies (ESPE)

Effective Single Particle Energies

They give the evolution of the underlying (non observable) spherical mean field (aka, shell evolution) as we add particles in the valence space, as well as the variations of the spherical mean field in a single nucleus for states which have different configurations.

They are the control parameter for the nuclear dynamics, given the universality of the nuclear correlators.

Monopole anomalies of the realistic NN interactions

They are the more blatant in the neutron-neutron interaction; for instance not producing neither a magic ^{48}Ca, nor the right location of the neutron drip line in the Oxygen isotopes

On the contrary their monopole neutron proton tensor part is correct, and the spin orbit splittings well accounted for.

Nowadays the blame is put in the missing residual three body effects, and the ”ab initio” (sometimes transformed in ”ab exitu”) practitioners are making lots of efforts to cure them.

The Nuclear Correlators (Multipole Hamiltonian)

- **The multipole hamiltonian is responsible for the collective nuclear behavior. It is universal and well given by the realistic NN interactions. Its main components are:**
- **BCS-like isovector and isoscalar pairing. When pairing dominates, as in the case of nuclei with only neutrons (or only protons) on top of a doubly magic nucleus, it produces nuclear superfluids.**
- **Quadrupole-Quadrupole and Octupole-Octupole terms of very simple nature ($r^\lambda Y_\lambda \cdot r^\lambda Y_\lambda$) which tend to make the nucleus deformed. In this limit, the pairing correlations mainly show up as responsible for the moment of inertia of the nuclear rotors.**

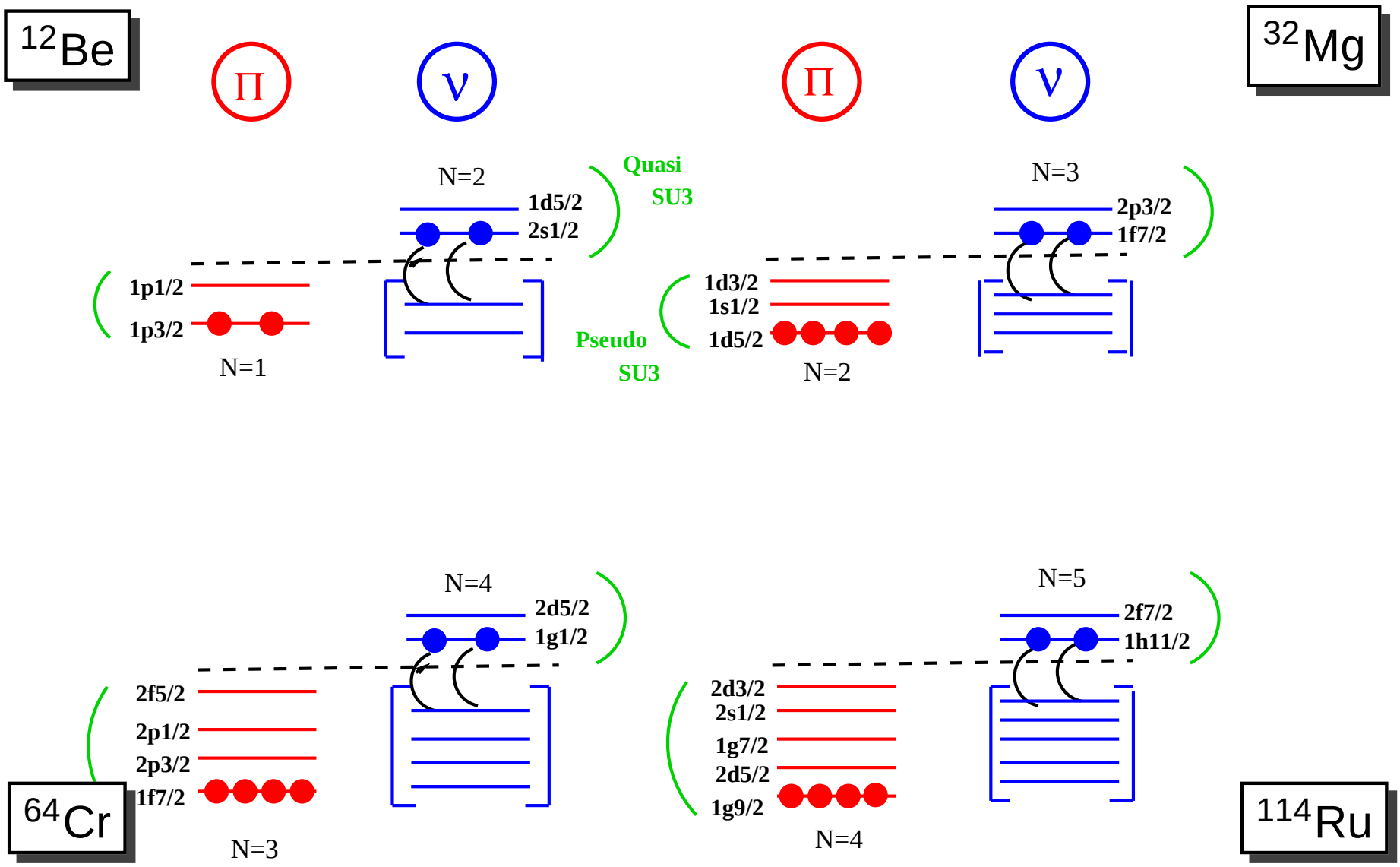
When do the quadrupole correlations thrive in the nucleus?

- **The fact that the spherical nuclear mean field is close to the HO has profound consequences, because the dynamical symmetry of the HO, responsible for the accidental degeneracies of its spectrum, is SU(3), among whose generators it is the quadrupole operator.**
- **When valence protons an neutrons occupy the degenerate orbits a major oscillator shell, and for an attractive Q·Q interaction, the many body problem has an analytical solution in which the ground state of the nucleus is maximally deformed (Elliott's model)**

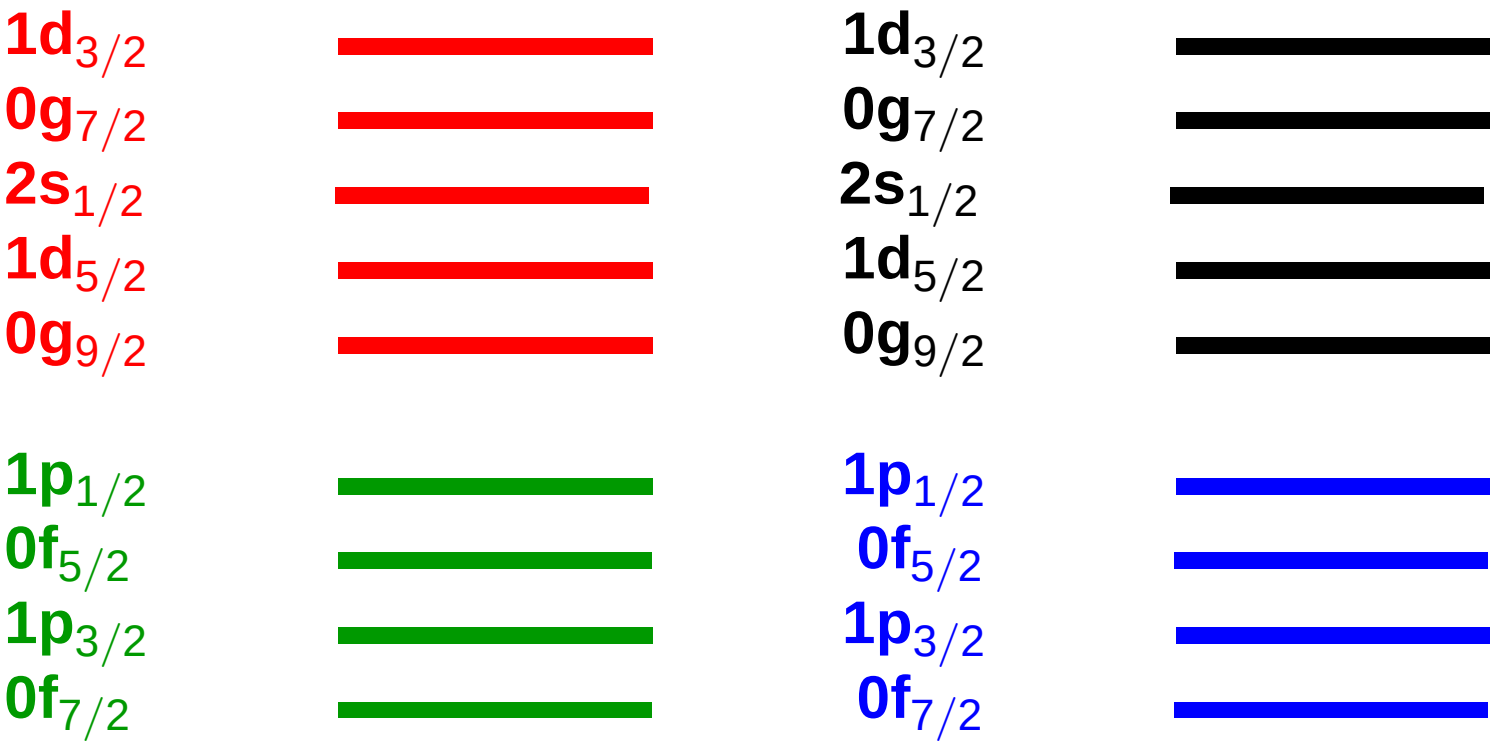
When do the quadrupole correlations thrive in the nucleus?

- **In cases when both valence neutrons and protons occupy quasi-degenerate orbits with $\Delta j = 2$ and $\Delta j = 2$, including $j = p + 1/2$ (Quasi-SU3), or quasi-spin multiplets (Pseudo-SU3)**
- **For example, $0f_{7/2}$ and $1p_{3/2}$, or $0g_{9/2}$ $1d_{5/2}$ and $2s_{1/2}$ form Quasi-SU3 multiplets and $0f_{5/2}$, $1p_{3/2}$ and $1p_{1/2}$ a Pseudo-SU3 triplet**

How deformation sets in at N=8, 20, 40, 70. Universality



The pf-sdg valence space

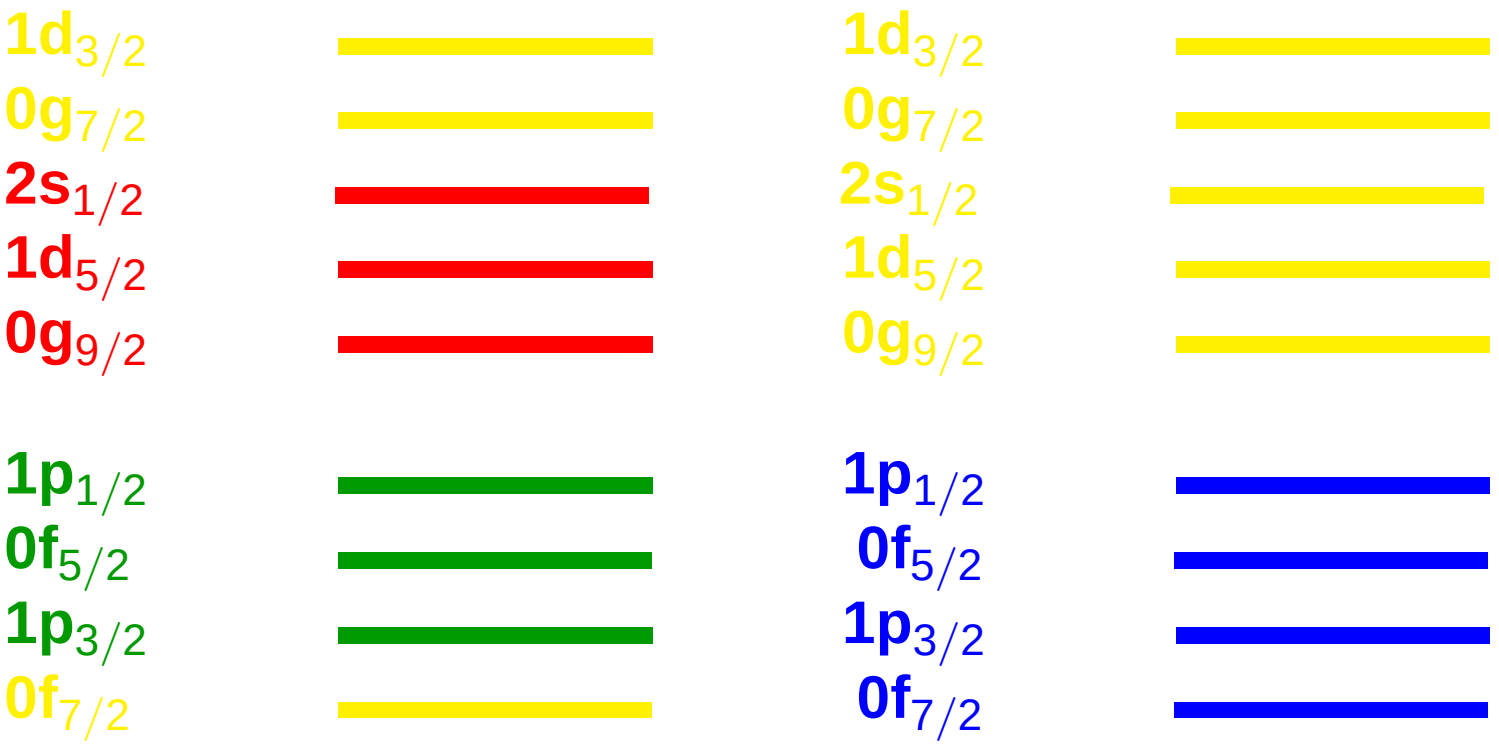


For this valence space we propose the PFSDG-U interaction

The pf-sdg valence space

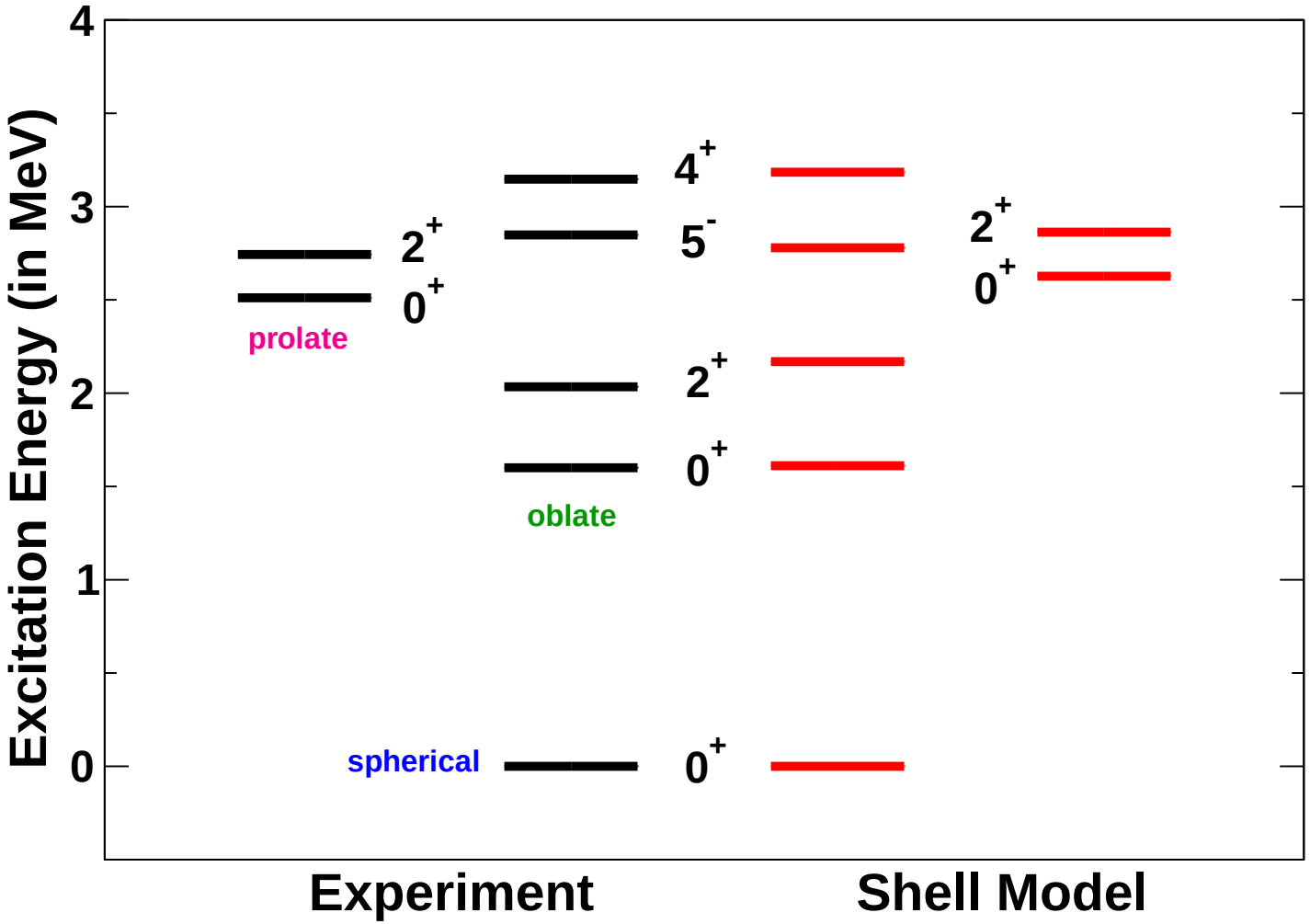
- **Few (if any) nuclei would demand the full *pfsdg* space, which however contains a wealth of sub valence spaces full of physical insight, both at the neutron rich and at the neutron deficient side.**
- **For instance, the *gds* valence space for protons and neutrons can cope with the physics around ^{100}Sn including its recently measured hyper allowed β decay**
- **^{56}Ni, instead can be understood in the *pf* sub valence space, with a little help of the the 0g9/2 orbit for Dirk Rudolf's super deformed band**
- **Other valence spaces at the neutron rich edge will be discussed next**

The LNPS valence space; N=40



Yellow orbits are blocked

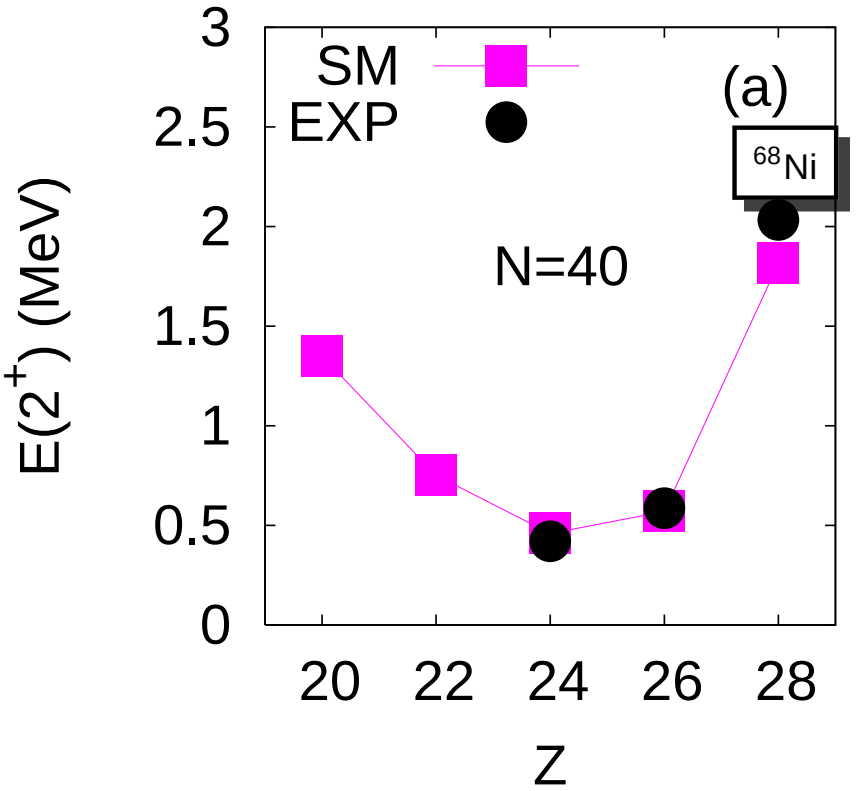
The Portals to the Iols: ^{68}Ni

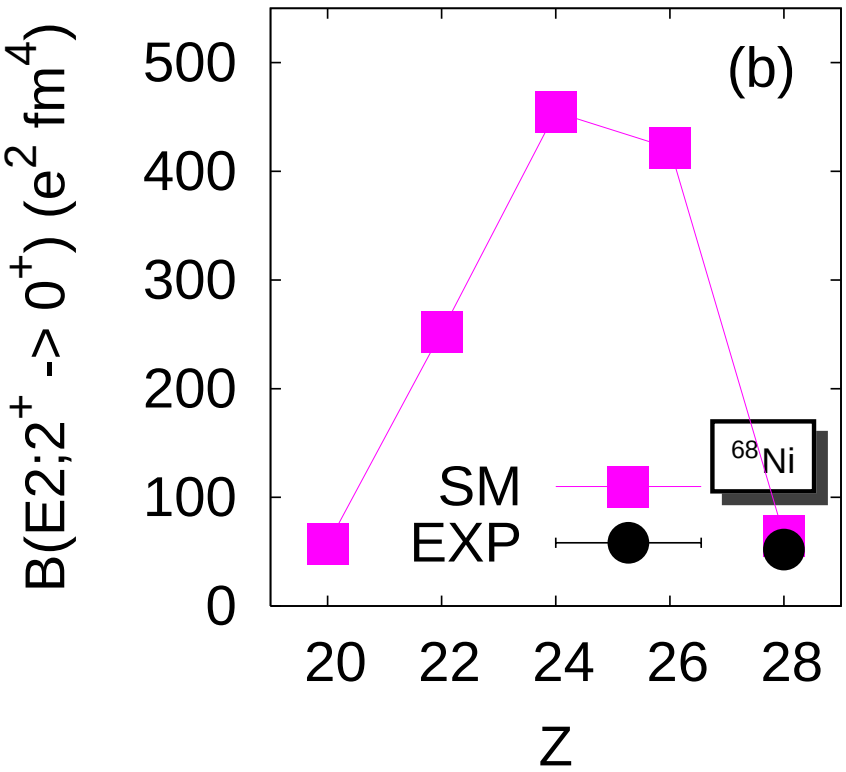


The island of inversion south of ^{68}Ni

- **Removing protons from the 0f$_{7/2}$ orbit, activates the quadrupole collectivity, which, in turn, favors the np-nh neutron configurations across N=40, that take advantage of the quasi-SU3 coherence of the doublet 0g$_{9/2}$- 1d$_{5/2}$.**
- **Large scale SM calculations in the valence space of the full *pf*-shell for the protons and the 0f$_{5/2}$ 1p$_{3/2}$ 1p$_{1/2}$ 0g$_{9/2}$ and 1d$_{5/2}$ orbits for the neutrons, predict a new region of deformation centered at ^{64}Cr.**

Shape transition at N=40





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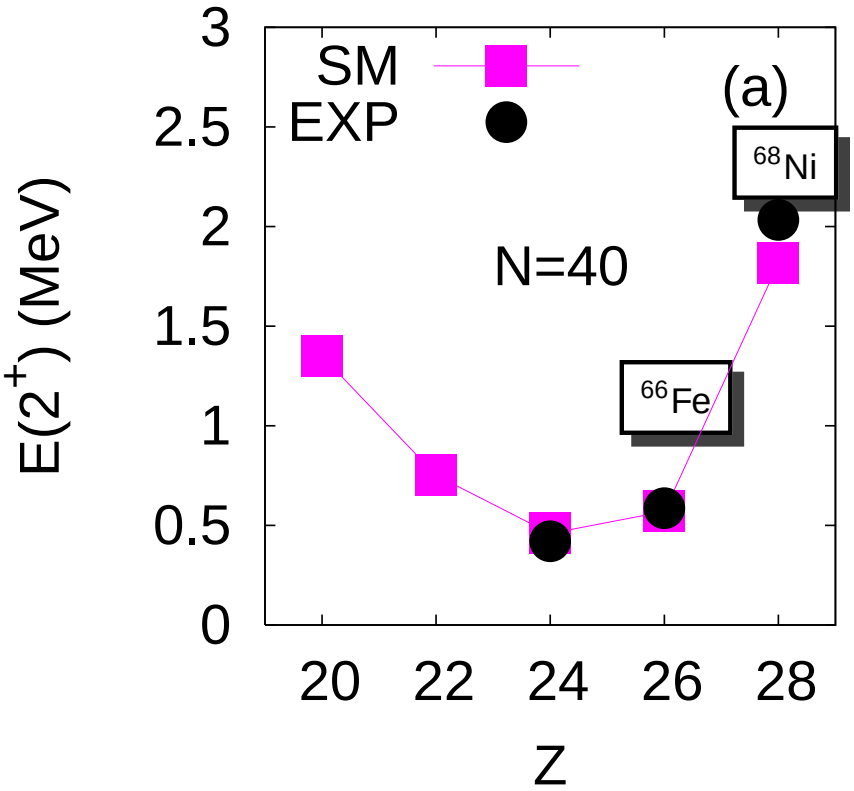
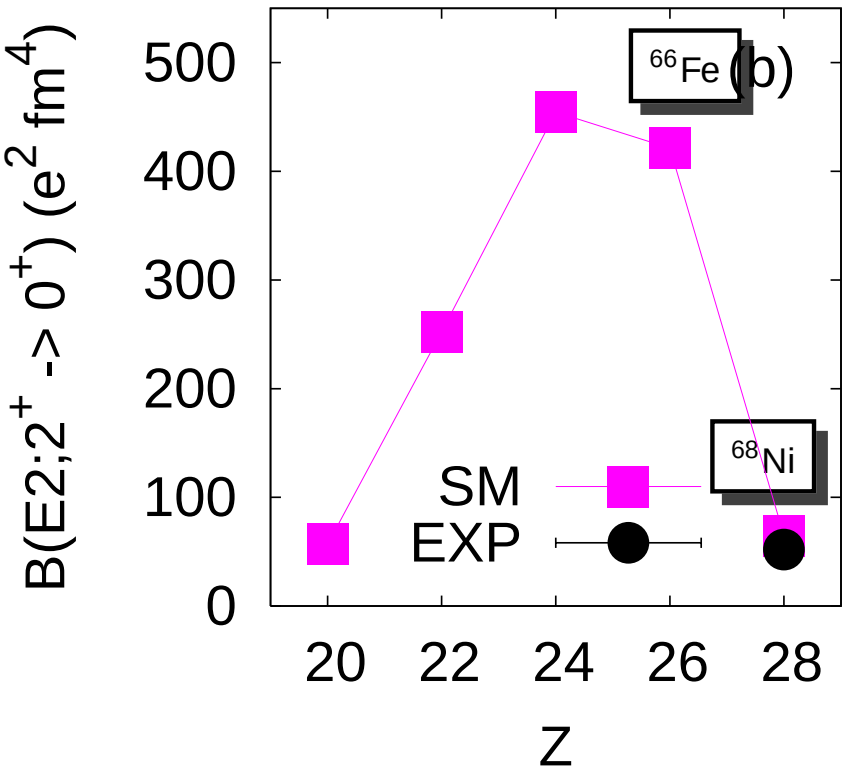
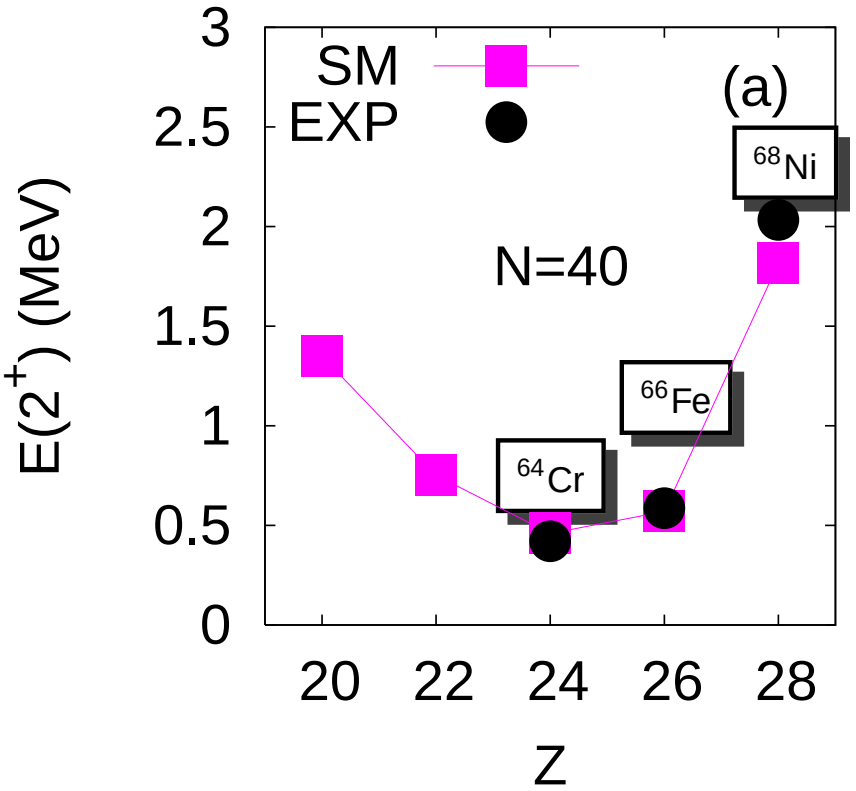
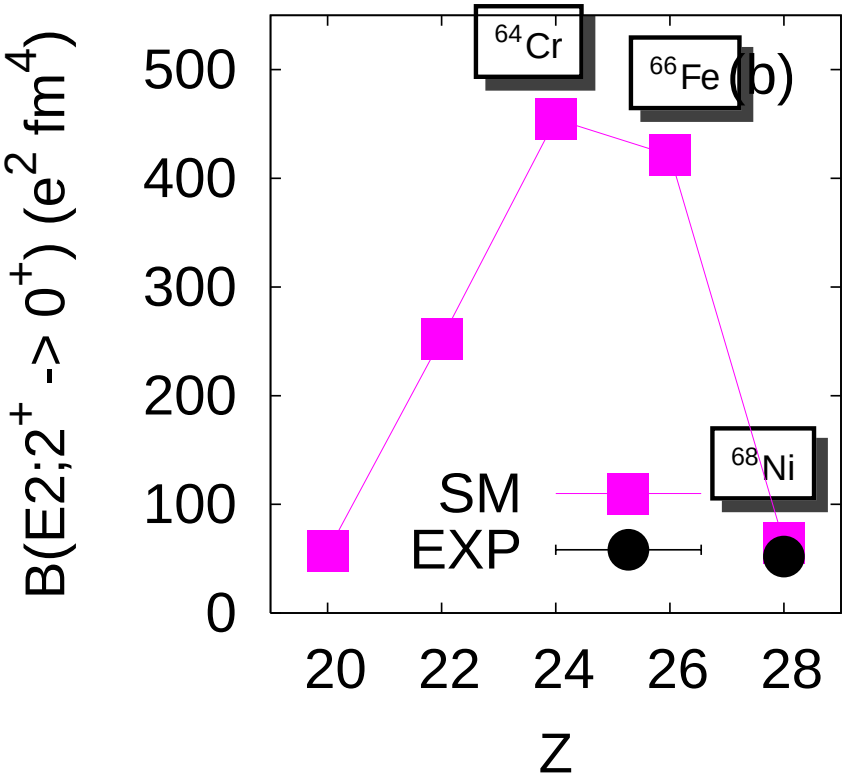


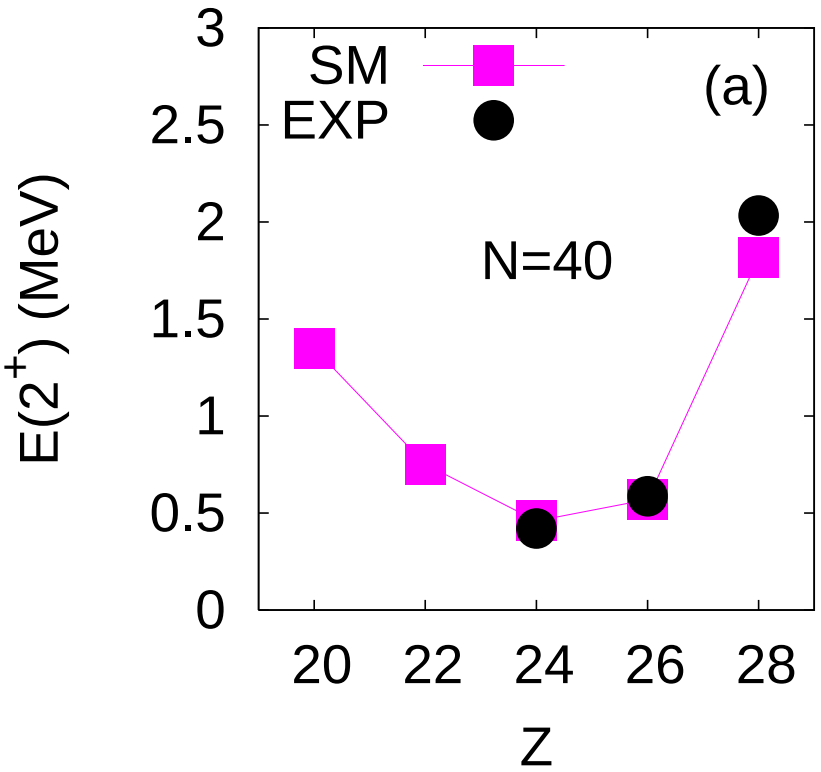


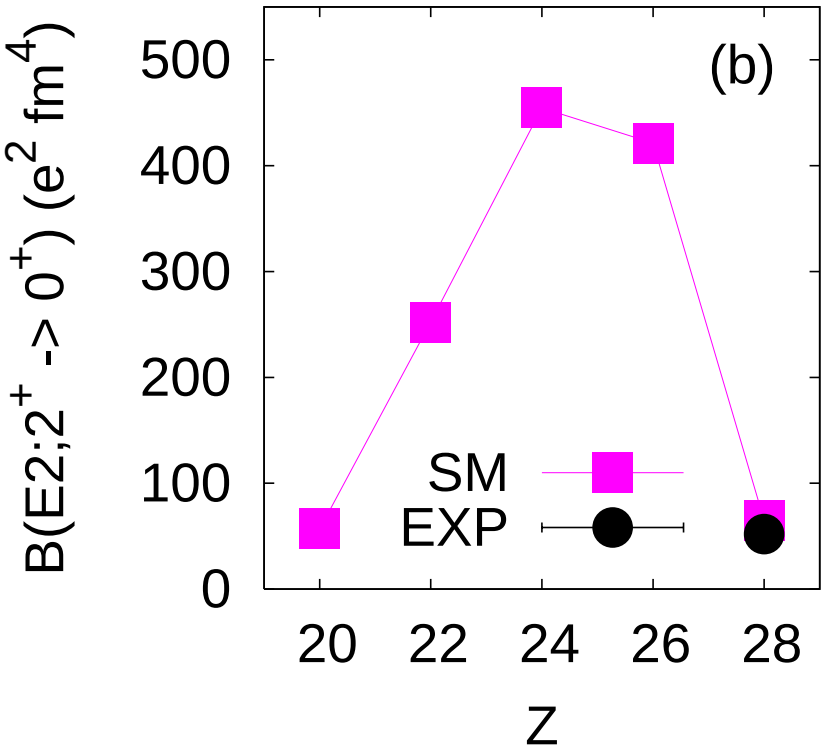
Shape transition at N=40



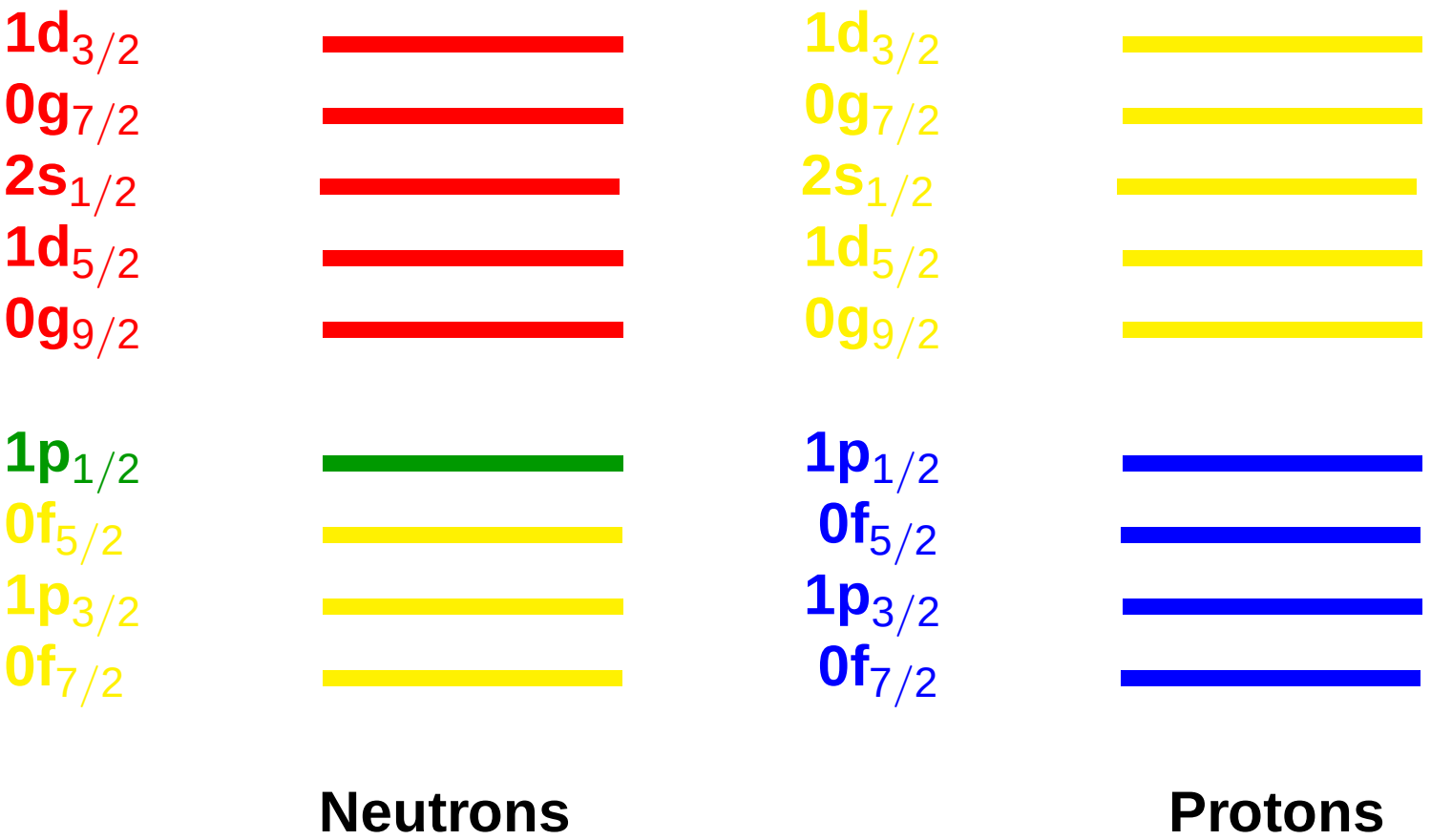


The N=40 isotones

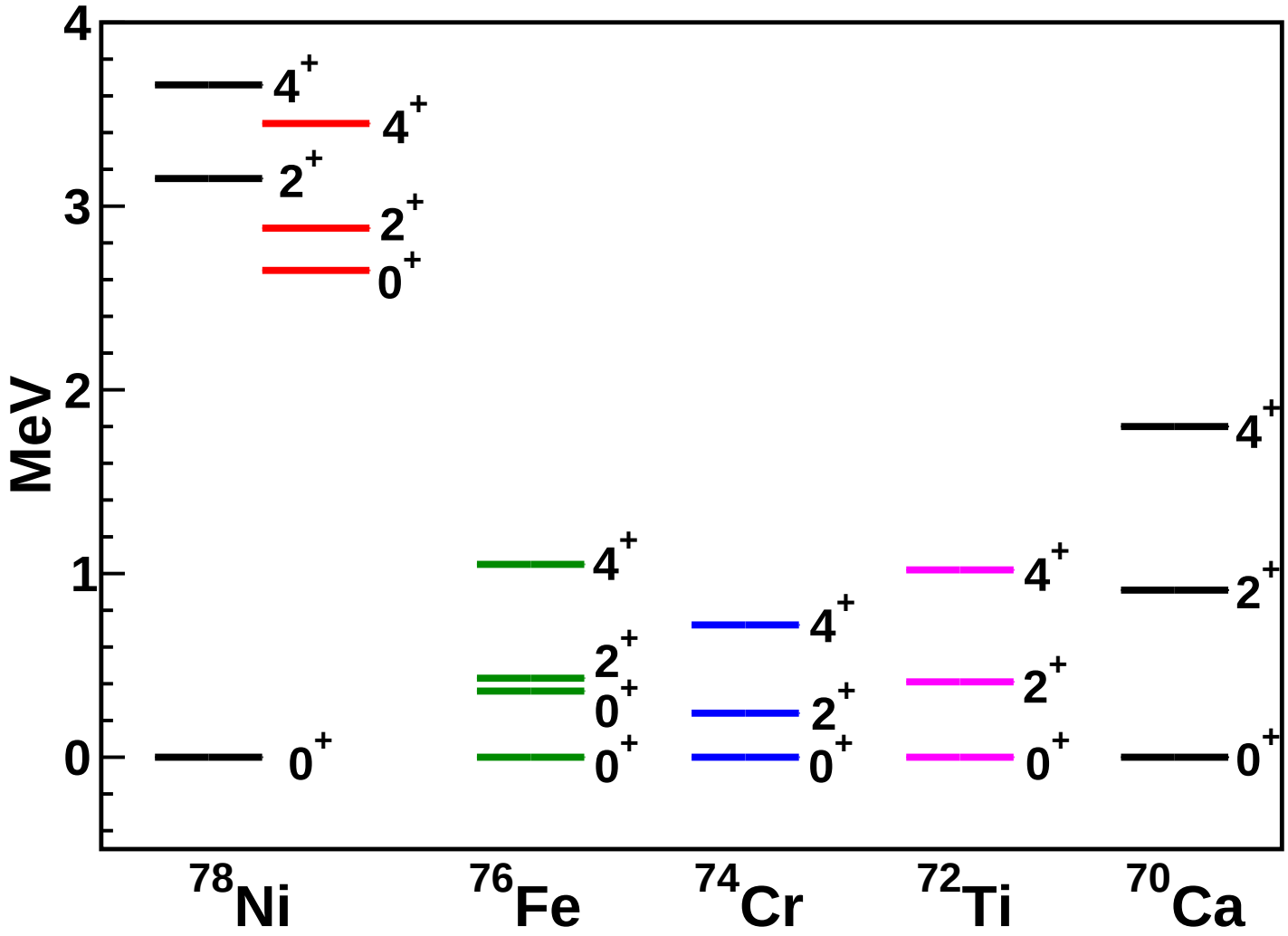




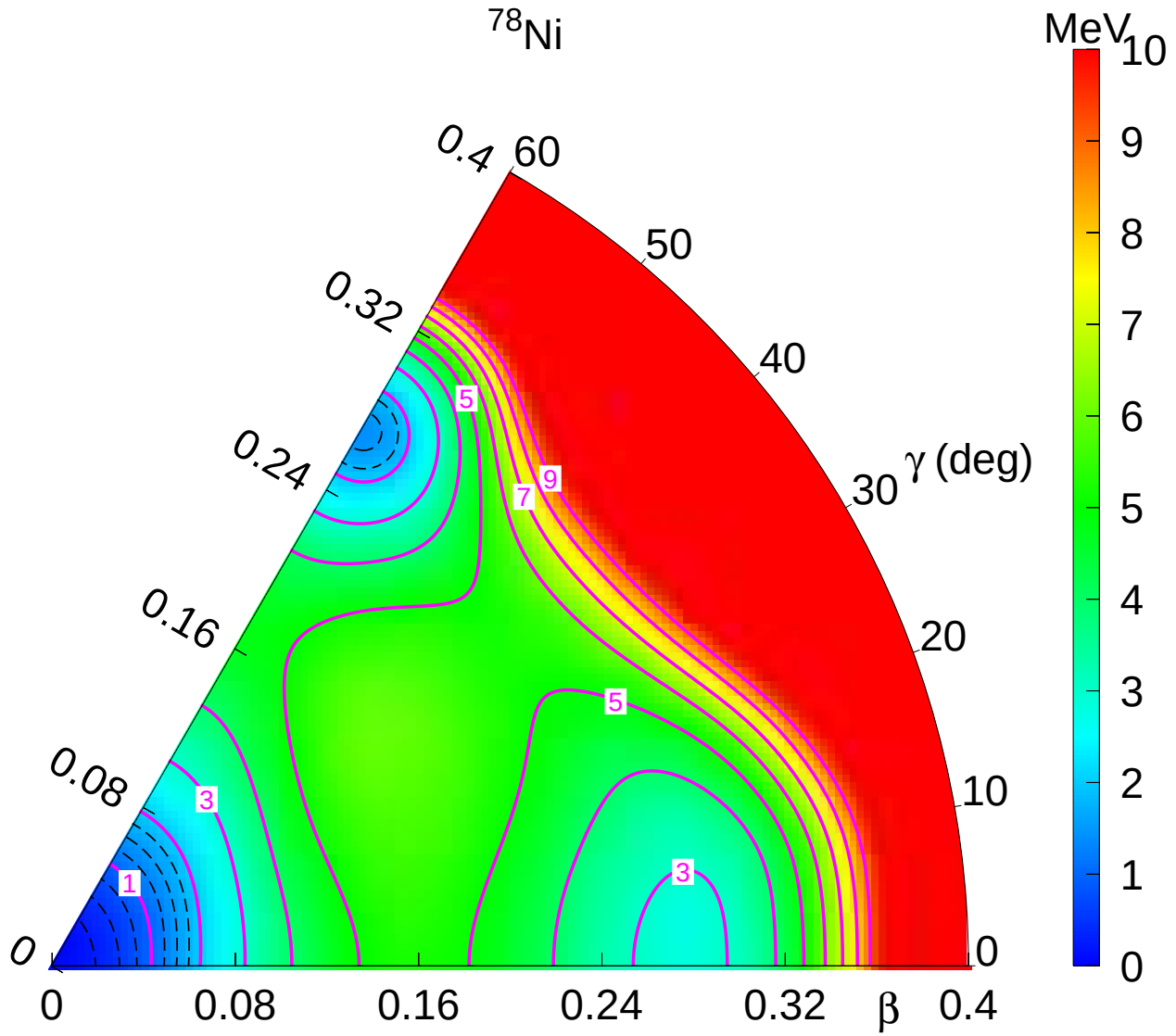
The pf-sdg valence space at N=50



The Portal to the Fifth Iol: ^{78}Ni



The Intrinsic Frame View



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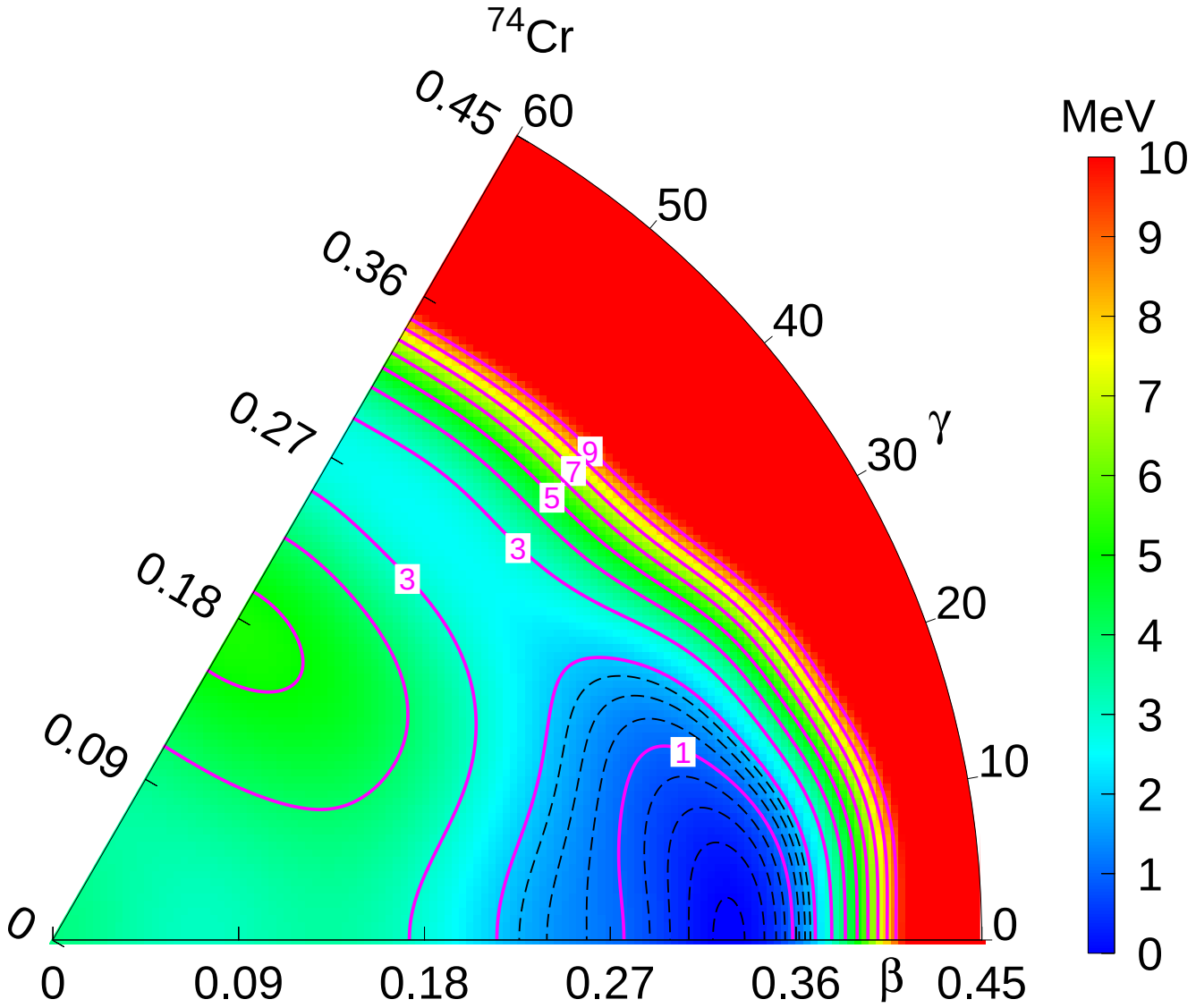
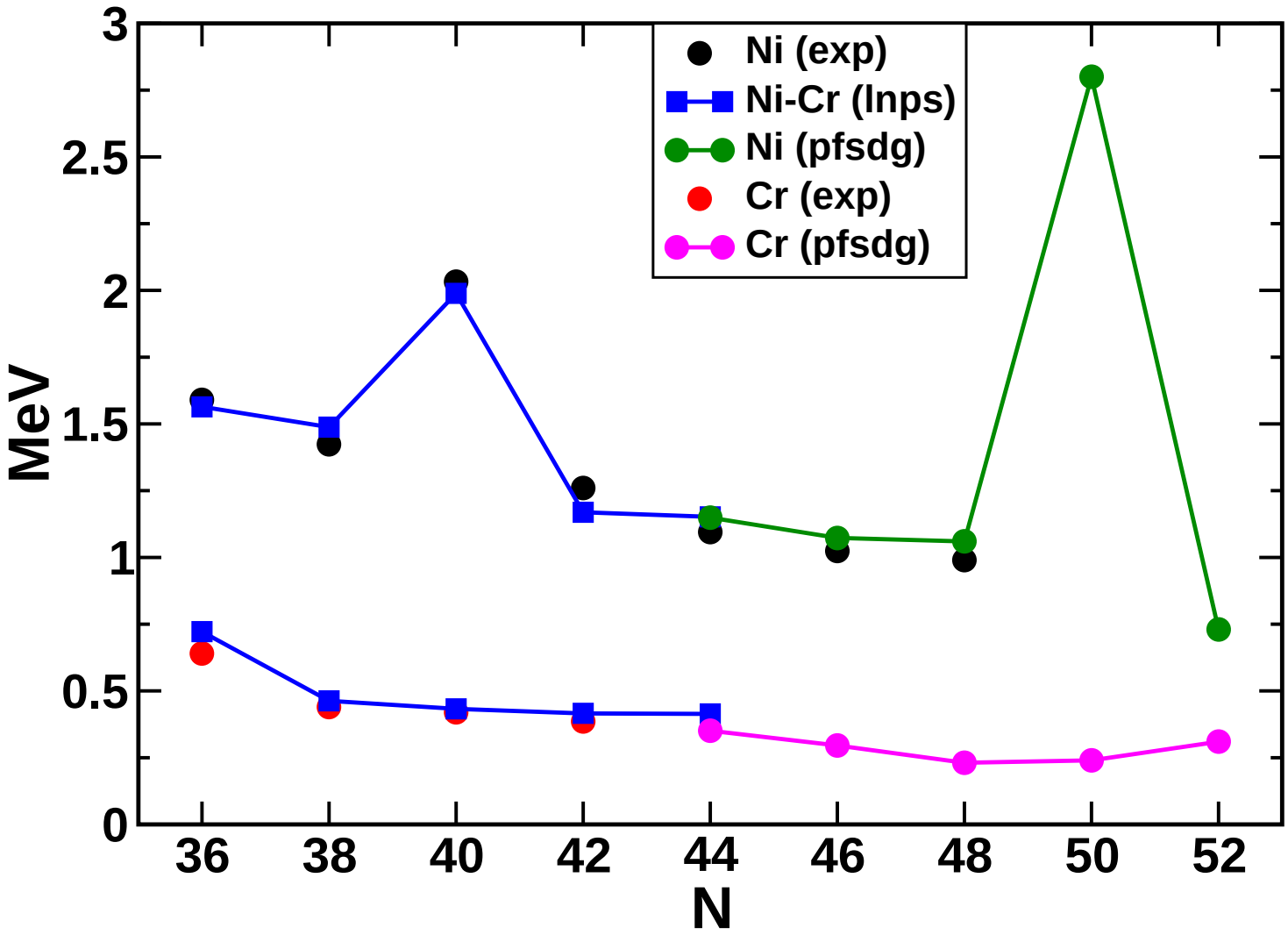
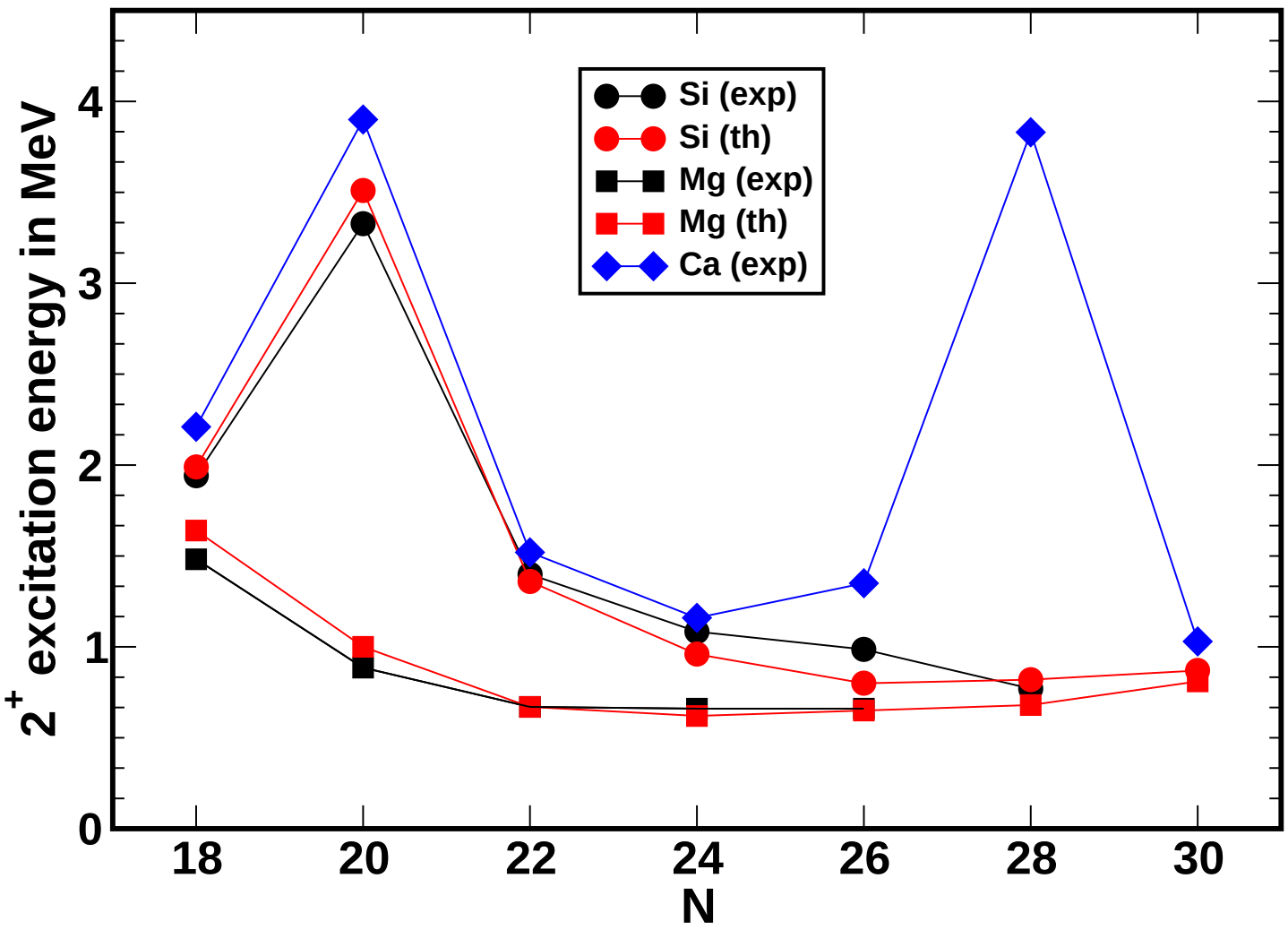


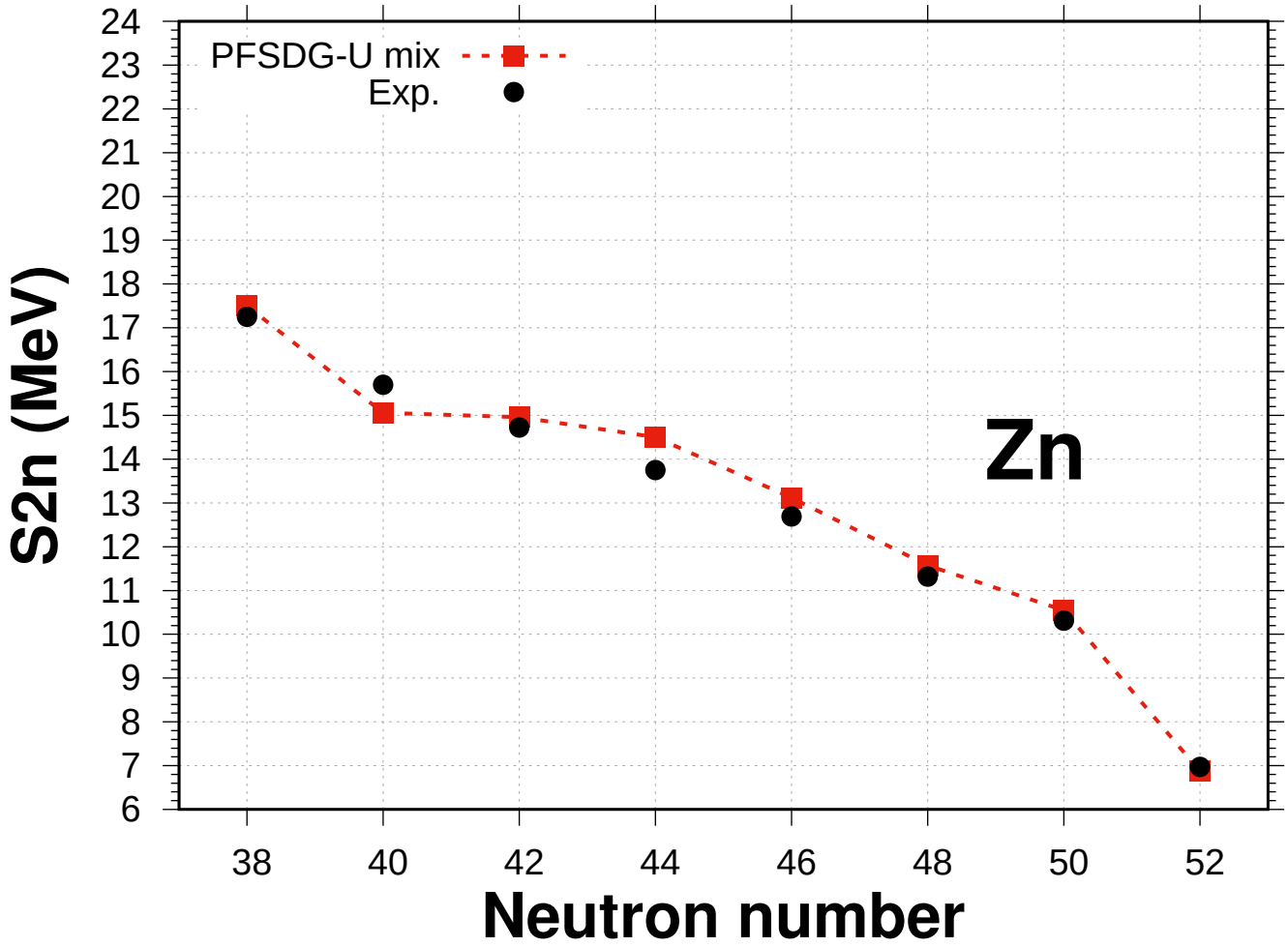
The N=40 and N=50 IoI's Merge



Like the N=20 and N=28 IoI's did



Other observables: Two neutron separation energies



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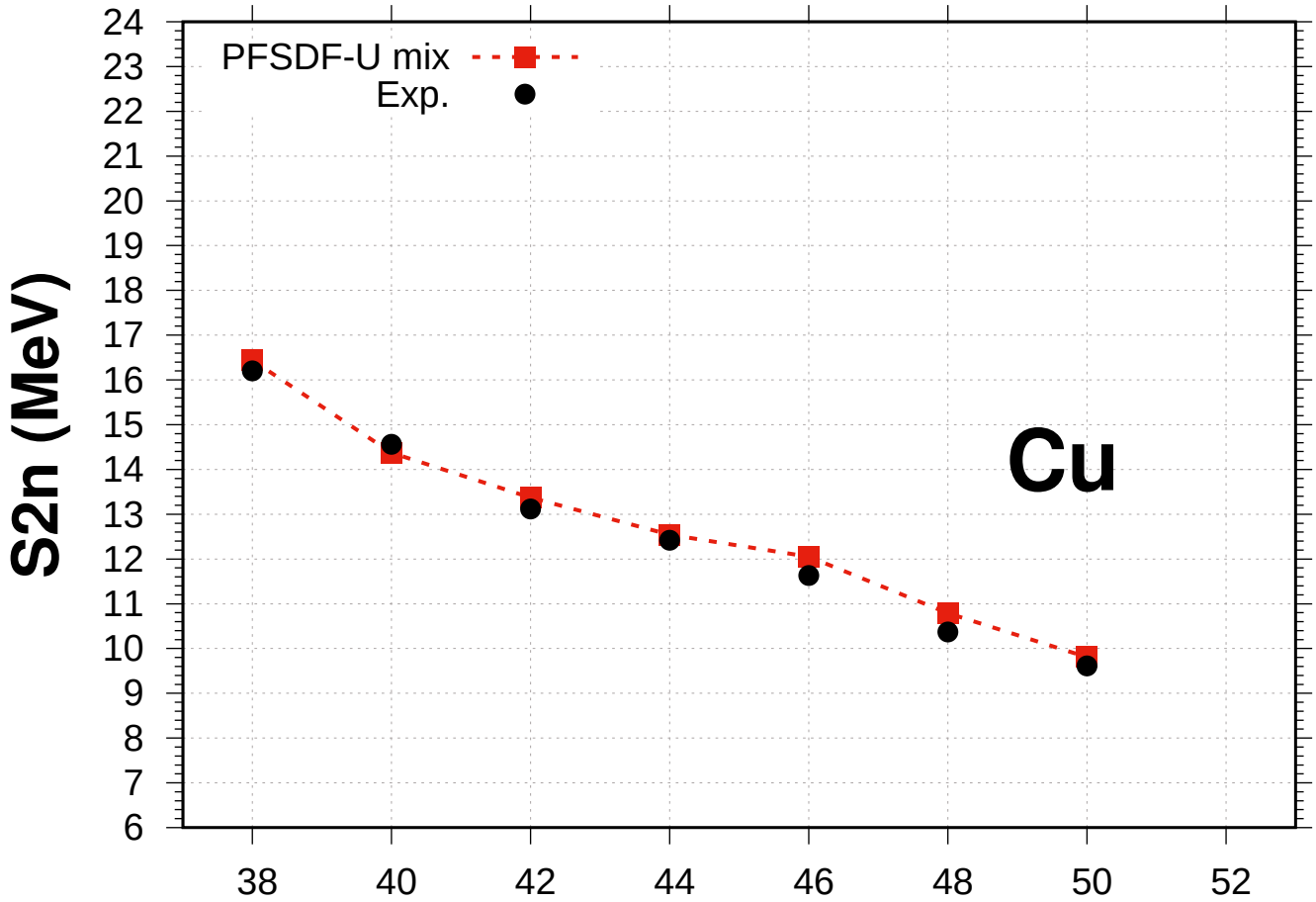

Conclusions

- The physics around magic or semi-magic closures depends of subtle balances between the spherical mean field and the (very large) correlation energies of the open shell configurations at play
- There is a common mechanism explaining the appearance of ”islands of inversion/deformation” (IoI’s) in nuclei with large neutron excess, and shape coexistence usually shows up as a its portal
- The IoI’s at N=20 and N=28 merge in the Magnesium isotopes.
- ^{68}Ni is a case of triple coexistence, precursor of the N=40 IoI
- Shape coexistence in ^{78}Ni is the portal to a new IoI at N=50
- The IoI’s at N=40 and N=50 merge in the Chromium isotopes.