Four strange guys

First Irregularly Scheduled Non-meeting of the IBA Circus, July, 1983, Brookhaven National Laboratory

A mini-Wigner effect in p-n interactions in heavy nuclei and the 0[110] transformation in the Nilsson scheme

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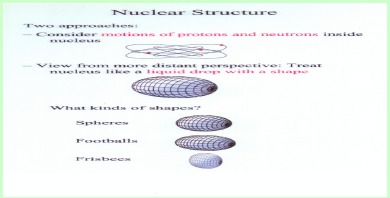
First, a brief remark on Franco's role in nuclear structure physics from a broader perspective -- from "30000 feet" as we say.

Themes and challenges of nuclear structure physics – common to many areas of Modern Science

· **Complexity out of simplicity -- Microscopic**

How the world, with all its apparent complexity and diversity, can be constructed out of a few elementary building blocks and their interactions

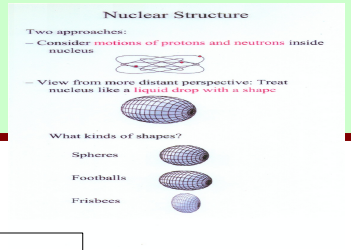
What is the force that binds nuclei? Why do nuclei do what they do?



· **Simplicity out of complexity – Macroscopic**

How the world of complex systems* can display such remarkable regularity and simplicity

What are the simple patterns that emerge in nuclei? What do they tell us about what nuclei do?



Nucleons orbit ~ 10 21 /s , occupy ~ 60% of the nuclear volume; 2 forces

The themes of **complexity** and **simplicity** have been used to describe nuclear structure in numerous major Documents in the last decade

- US LRP - 2007
- NuPECC Long Range Plans
- US Nat. Acad. RISAC Report -2008
- US Nat. Acad. Decadal Study – 2012
- Many others …..

This is not chance – it owes very much to the work and insights of Franco in promulgating the ideas of symmetries and simple patterns in nuclei for decades.

Many scientists do nice work. It is rare to find one who defines and transforms a field

and who does it basically with a pencil !!!

How I met the IBA (and Franco)

Serendipity in Physics

Themes and challenges of nuclear structure physics – common to many areas of Modern Science

Linking the two perspectives

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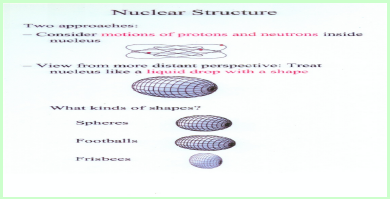

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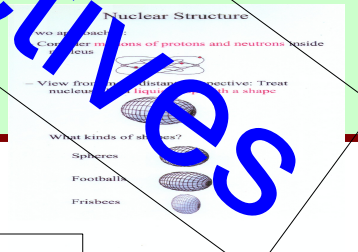

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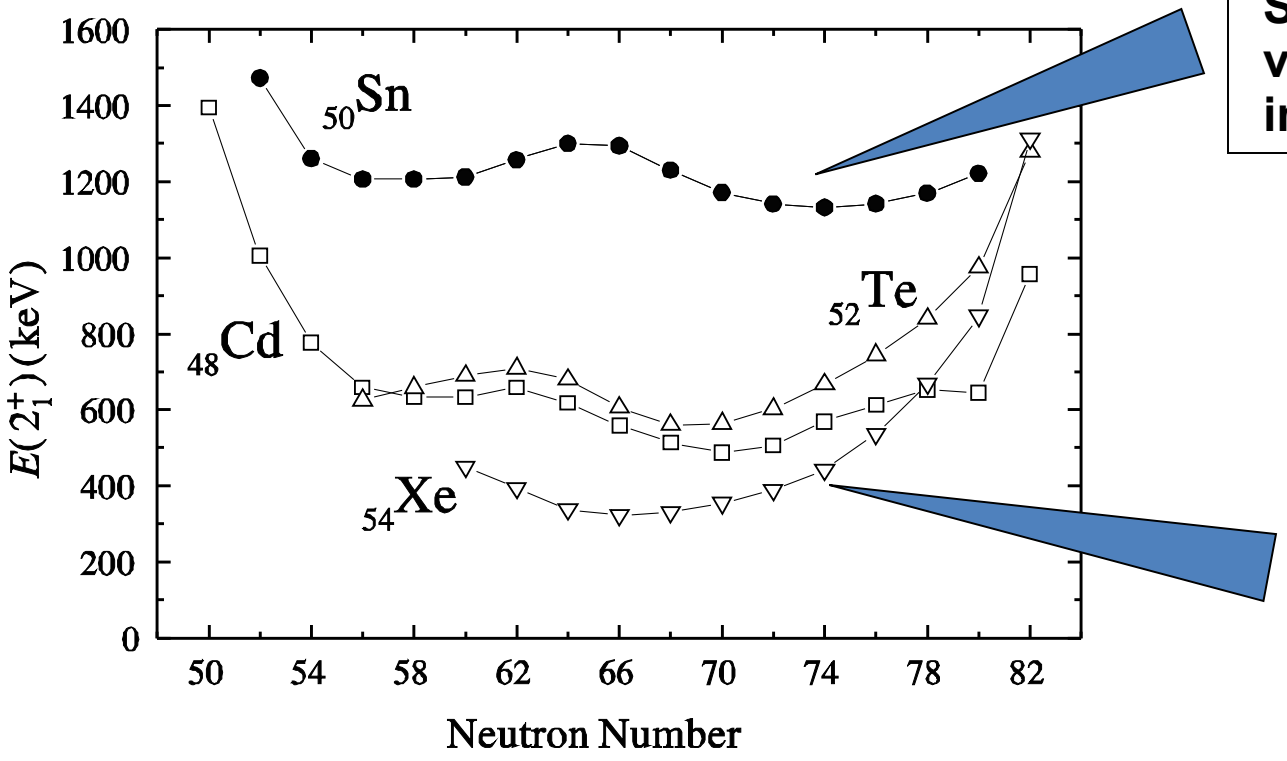
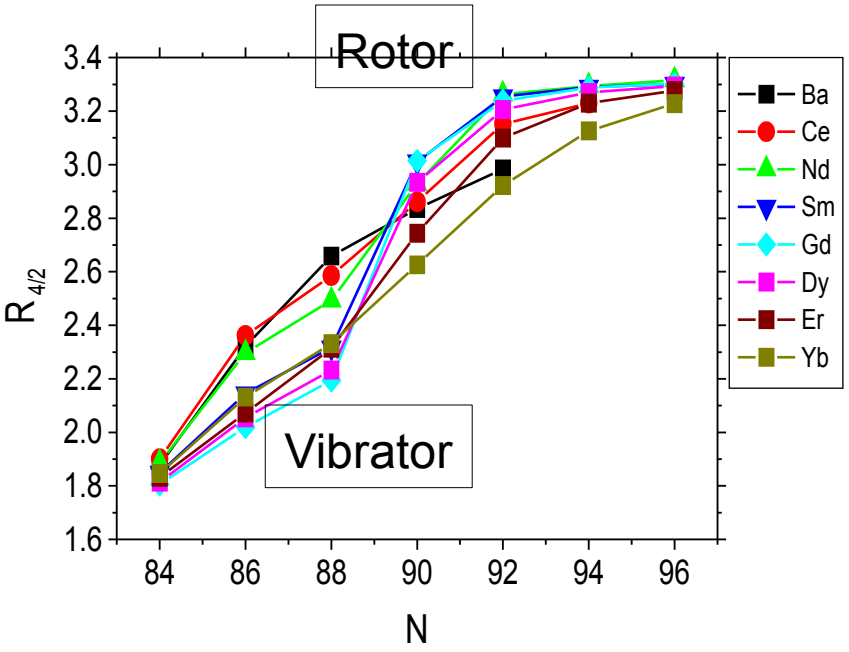
Importance of valence p-n interactions as drivers of collectivity

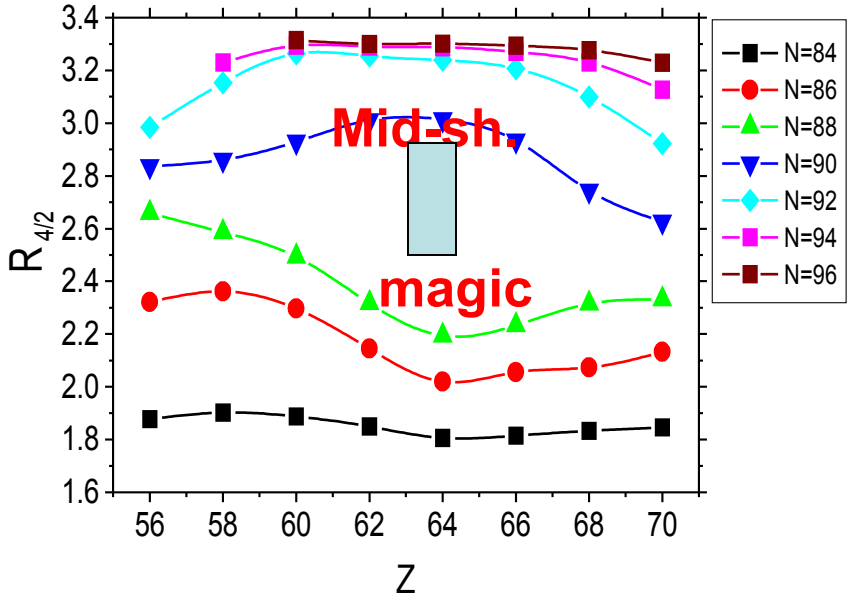


Sn – Magic: no valence p-n interactions

Both valence protons and neutrons

Seeing structural evolution
Different perspectives can yield different insights





Onset of deformation

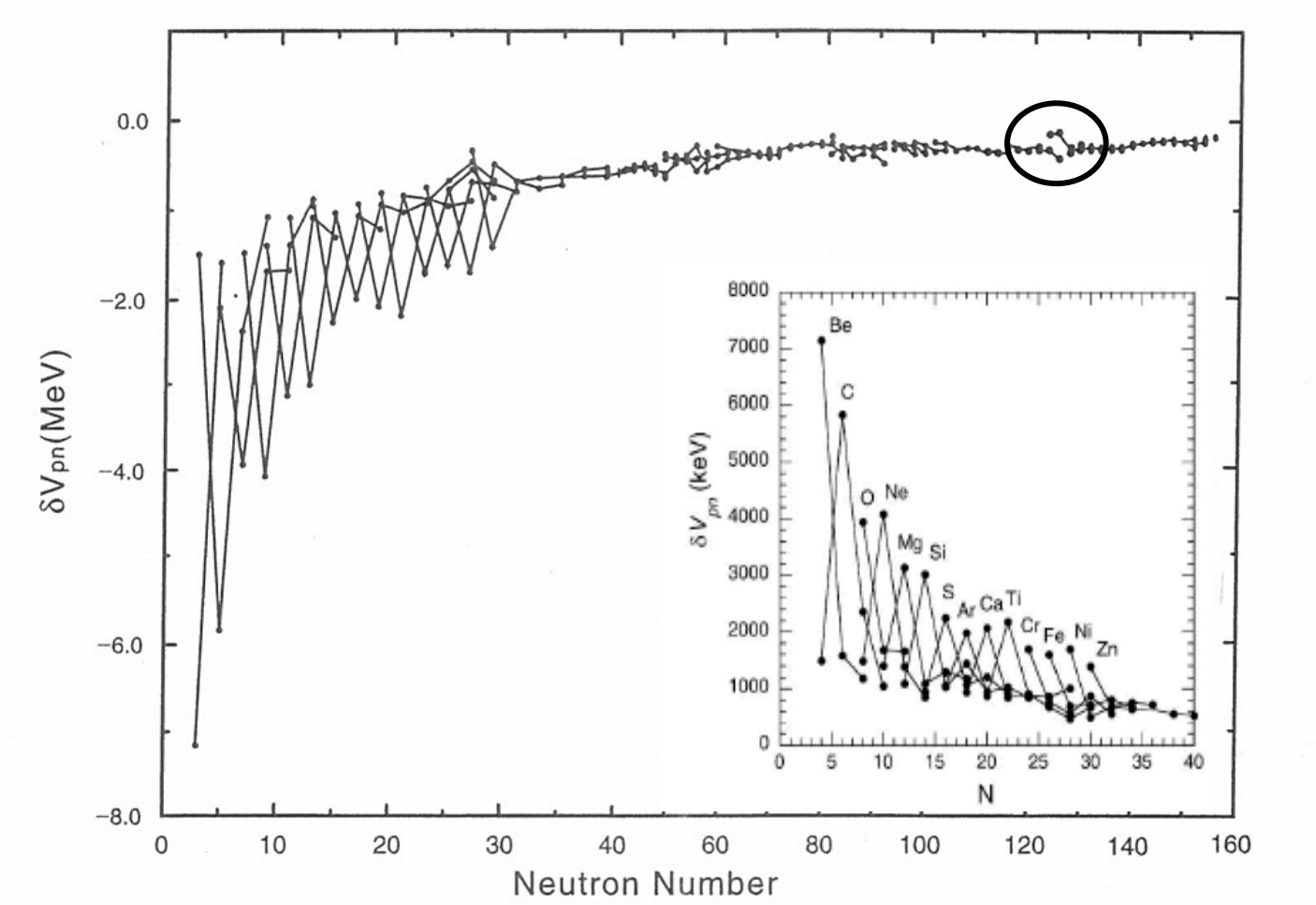
Onset of deformation
as a phase transition
mediated by a change in shell structure
driven by the p-n interaction

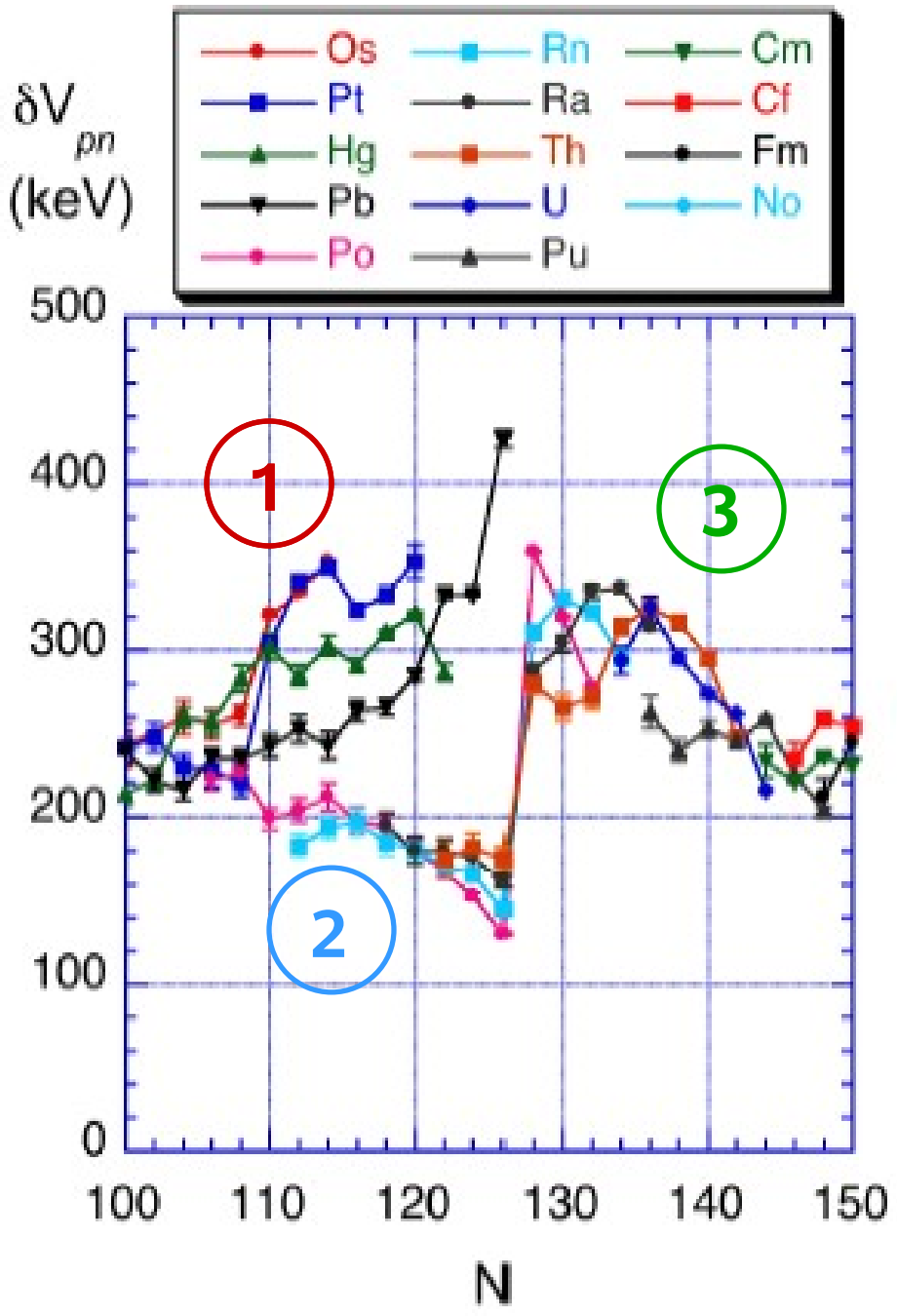
"Crossing" and "Bubble" plots as indicators of phase transitional regions mediated by sub-shell changes

Average empirical valence p-n interactions

Empirical interactions of the last proton with the last neutron

$$\delta Vpn\ (Z, N) = \tfrac{1}{4}\{[B(Z, N) - B(Z, N-2)] - [B(Z-2, N) - B(Z-2, N-2)]\}$$

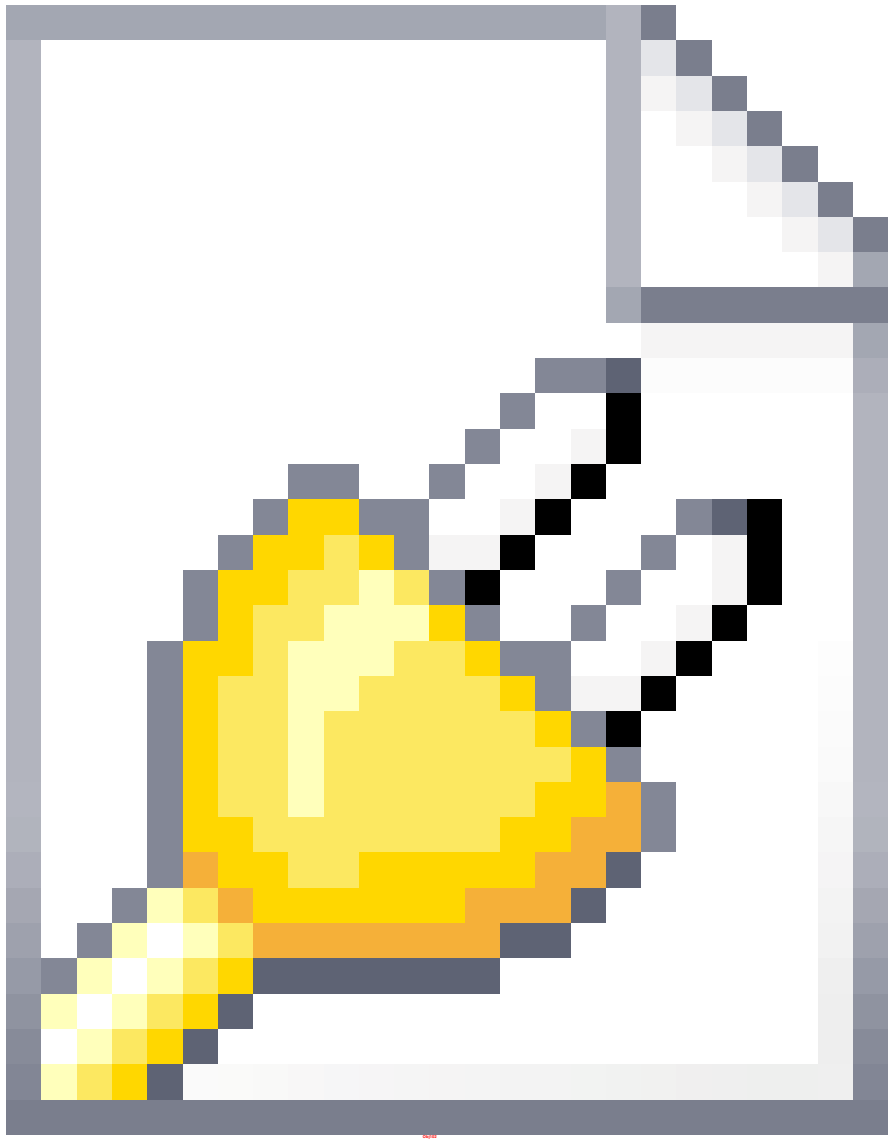




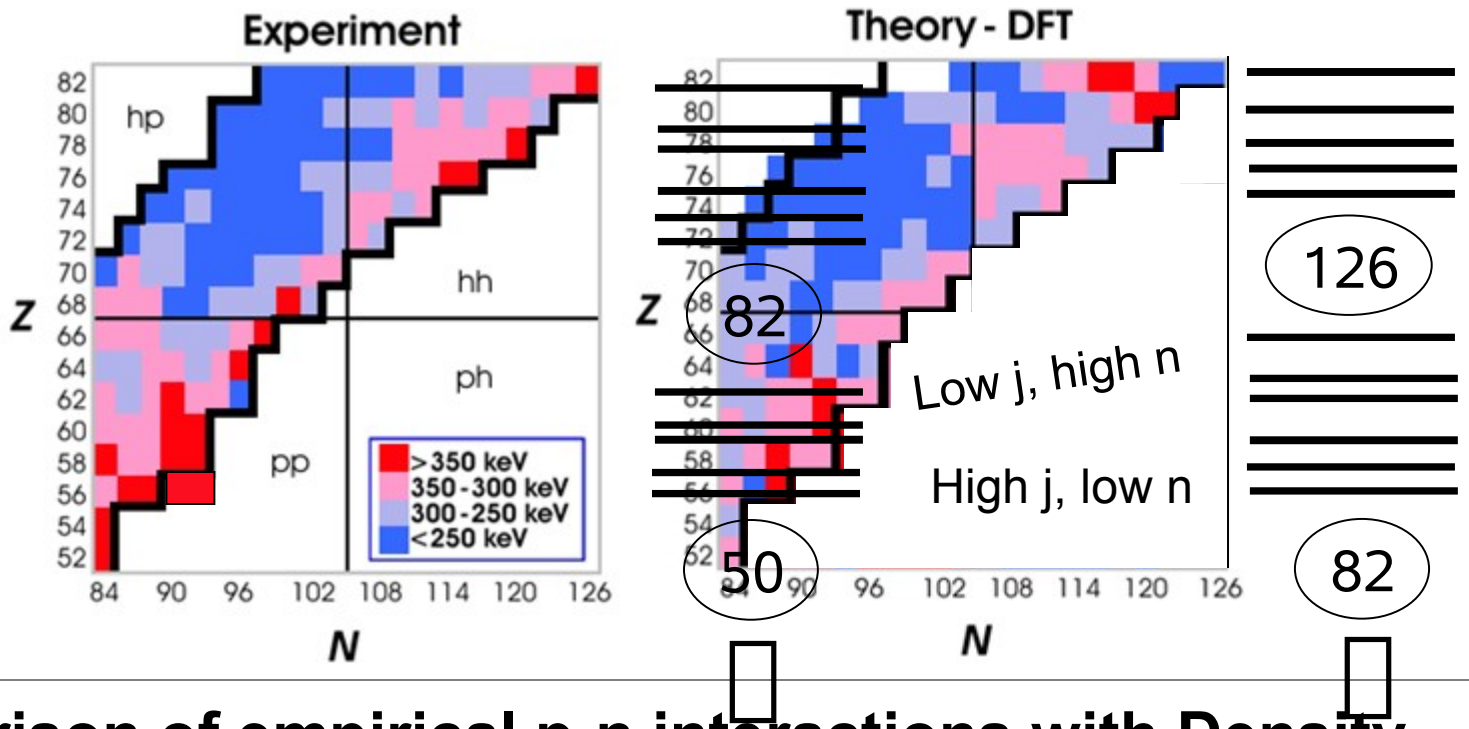
Z ≤ 82 , N < 126

Z > 82 , N > 126

Z > 82 , N < 126



Expect largest values near diagonal



Comparison of empirical p-n interactions with Density Functional Theory(DFT) with Skyrme forces and surface-volume pairing

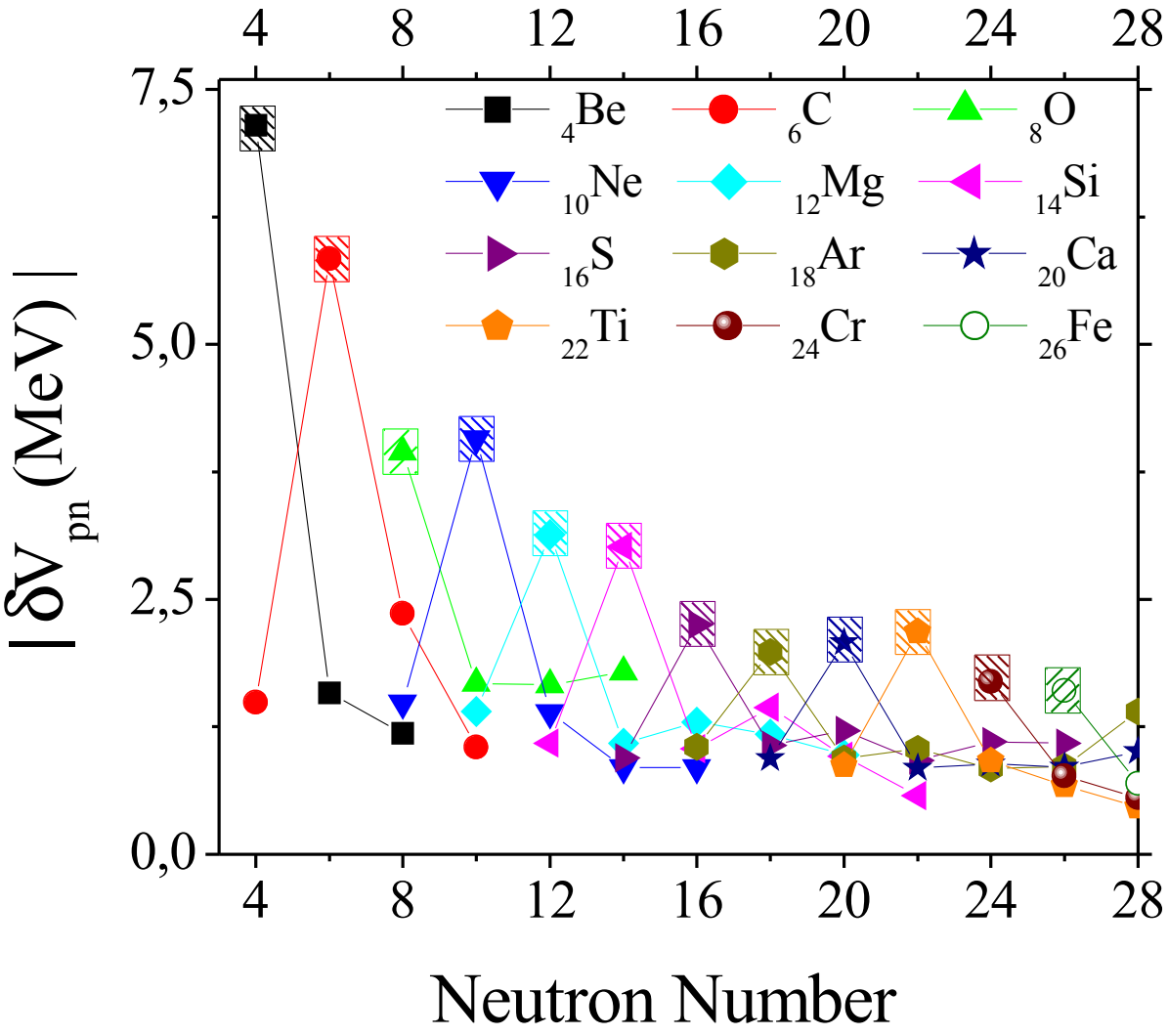
These DFT calculations accurate only to ~ 1 MeV.

δVpn allows one to focus on specific correlations.

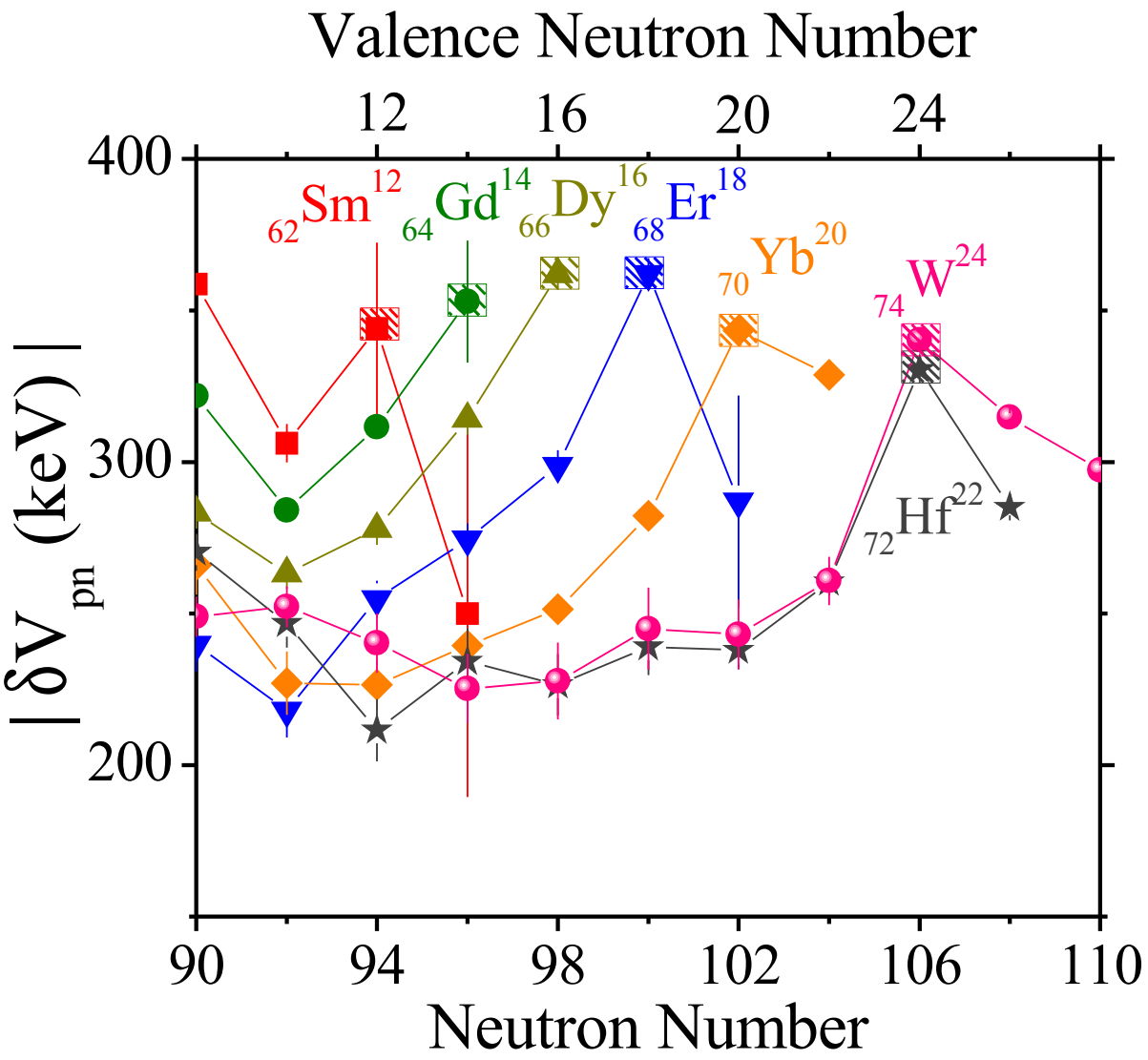
Recent measurements at ISOLTRAP/ISOLDE test these DFT calculations

M. Stoitsov, R. B. Cakirli, R. F. Casten, W. Nazarewicz, and W. Satula PRL 98, 132502 (2007);
D. Neidherr et al, Phys. Rev. **C 80**, 044323 (2009)

Spikes in δ Vpn in light N = Z nuclei

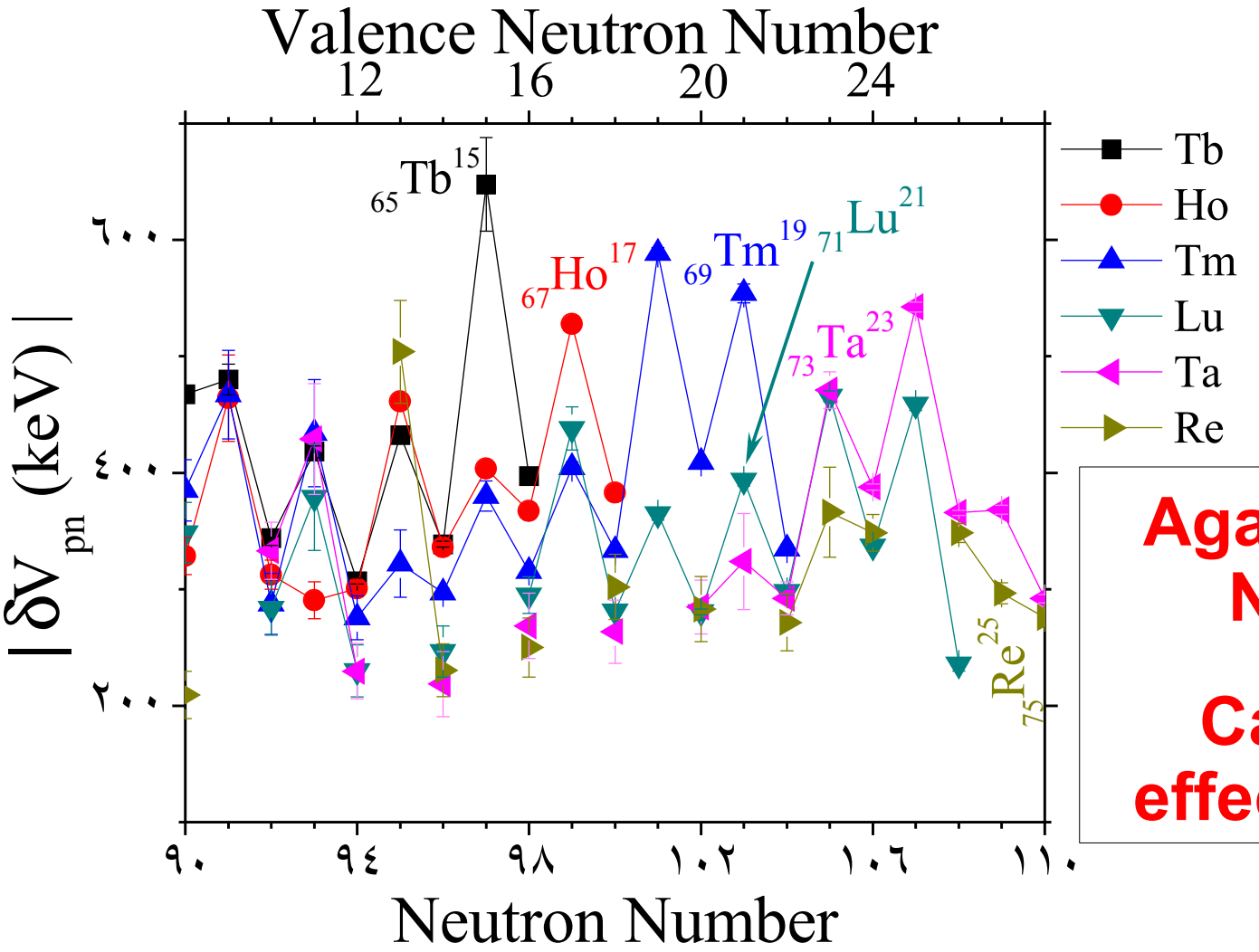


Heavy Nuclei: N = Z nuclei do not exist, Role of Coul., Spin orbit – any remnants?



Peaks for Nval ~ Zval

And now for odd – Z heavy nuclei



Again, peaks for Nval ~ Zval

Can also see effects of pairing

What is going on? Why these peaks? Consider orbits involved in Nilsson picture

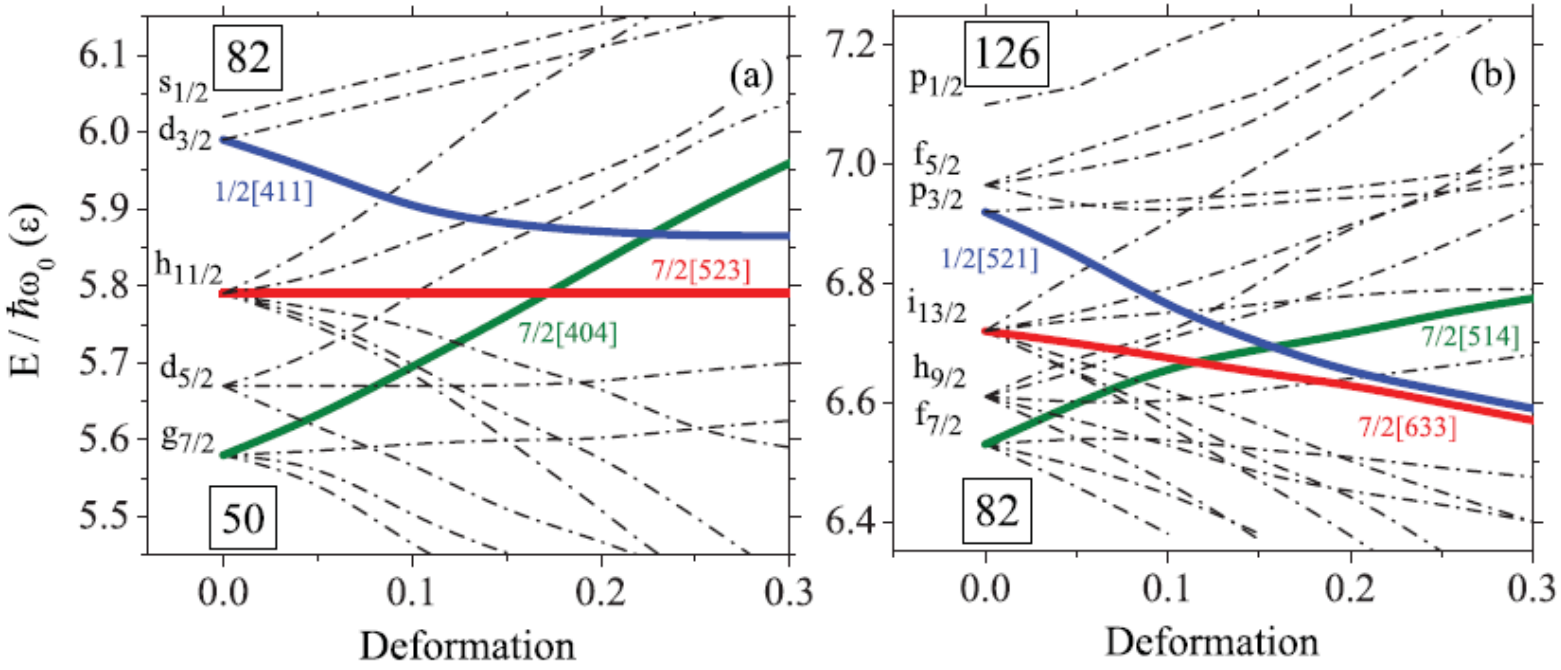
Nilsson orbits occupied in **Nval ~ Zval** rare earth nuclei

168 Er: p 7/2 [523]; n 7/2 [633]

172 Yb: p 1/2 [411]; n 1/2 [521]

178 Hf: p 7/2 [404]; n 7/2 [514]

See colored curves on Nilsson diagram. Note similar roles, slopes in each plot.
Identically colored orbits are "sister" orbits. What characterizes them?



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180 W: p 7/2 [404]; n 7/2 [514]

$\delta K[\delta N, \delta nz, \delta \Lambda] = 0[110]$

N and nz differ by one.

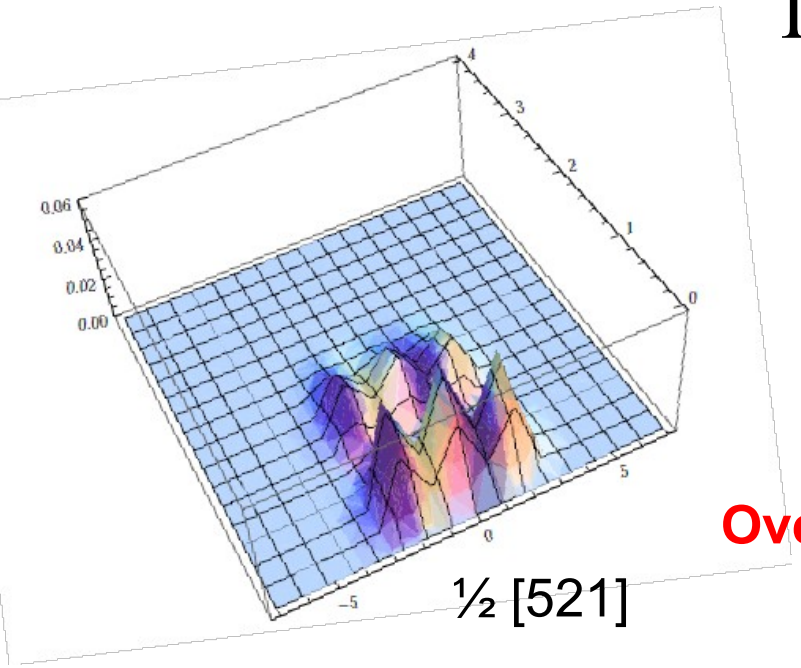
Since N = nx + ny + nz, nx + ny is conserved.

These unique "sister" orbits differ only by a single quantum in the z direction – ZQT

Hence, expect large spatial overlap, large p-n interactions.

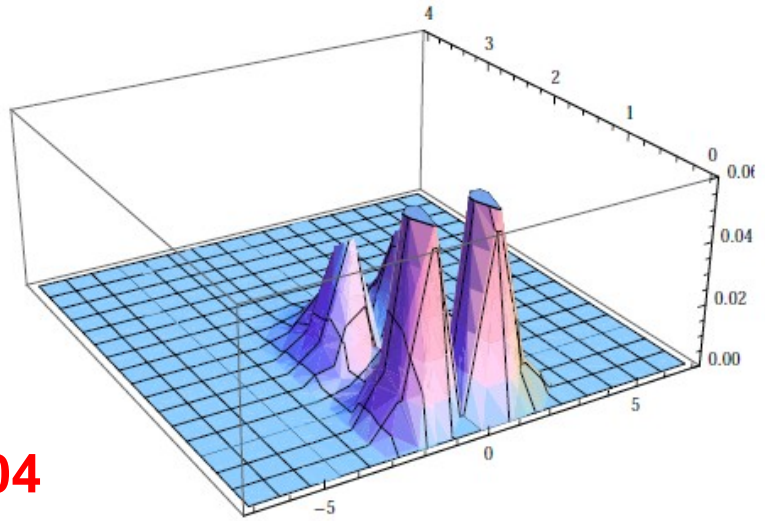
R.B. Cakirli, K. Blaum and R.F. Casten, Phys. Rev. C, 82 (2010) 061304 (R)

Spatial overlaps (ψp2 ψn2) of Nils. wave functions

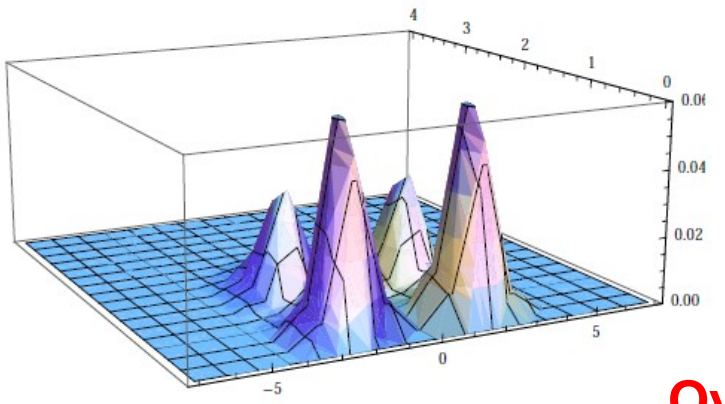


½ [521]

0 [110]
Overlap: 0.804

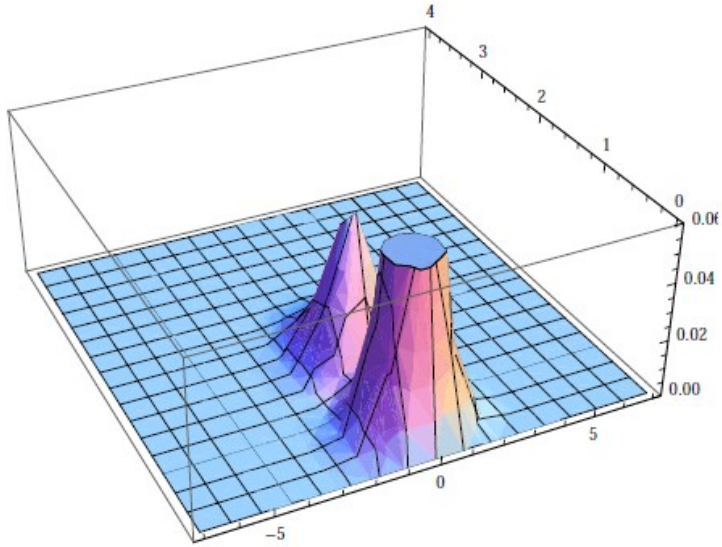


½ [411]



½ [631]

0 [330]
Overlap: 0.616



½ [301]

Probability overlaps of Nilsson Wave functions

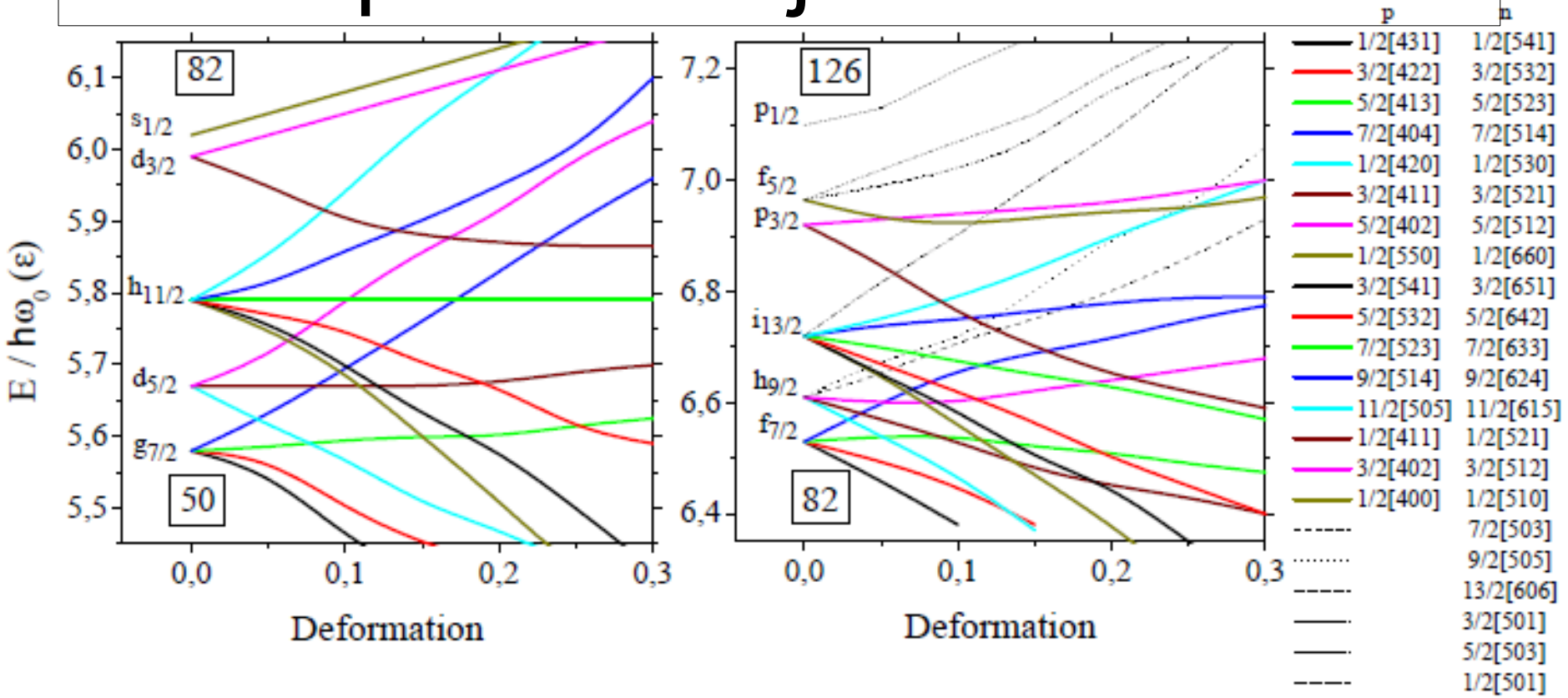
$|\delta n_z| + |\delta n_x + \delta n_y|$

$\delta n_z = 1$ → 0[110]

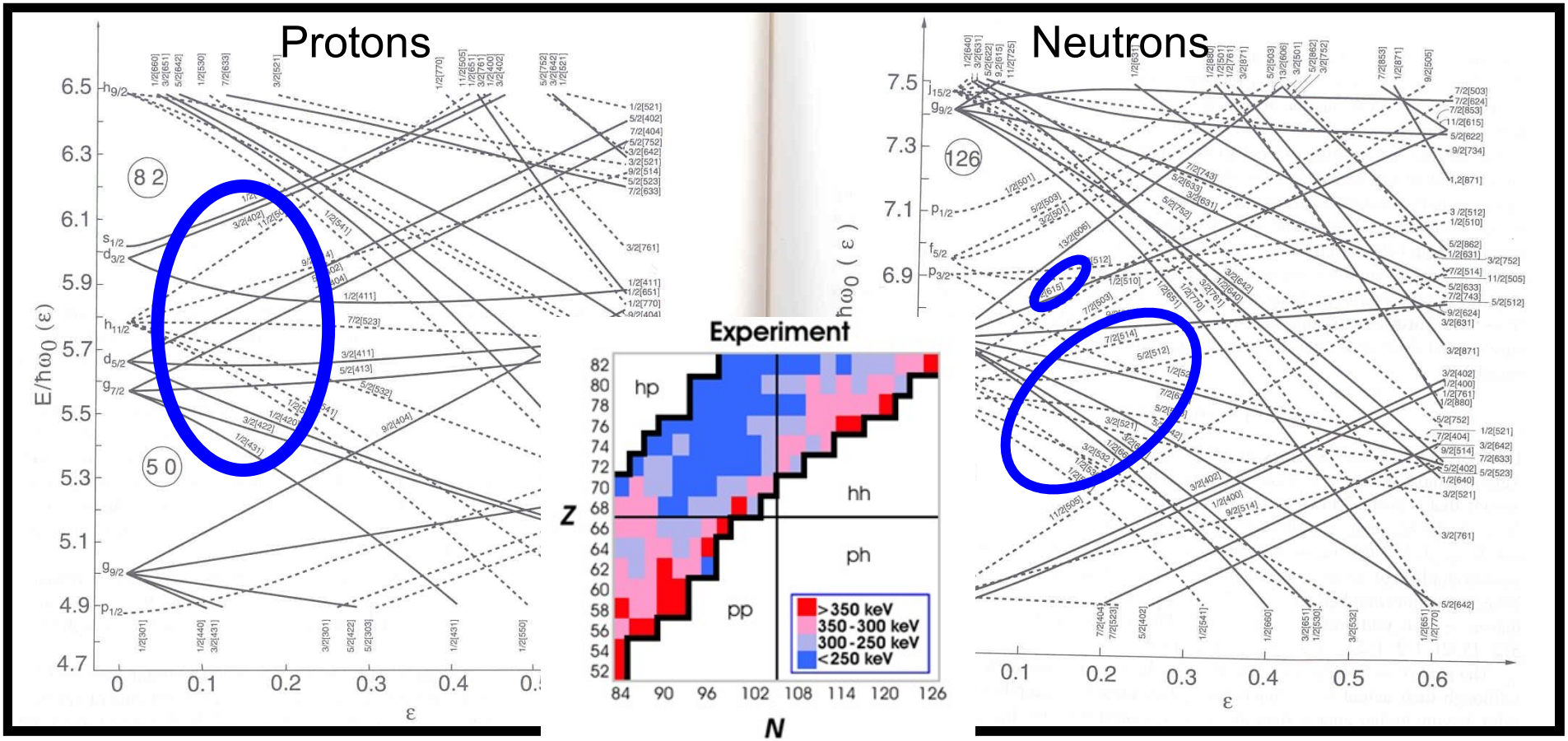
OR $|\delta n_x + \delta n_y| = 1$ → n-rich nuclei

So, in practice, the highest overlaps occur for exactly our case of 0[110] Nilsson orbit pairs

Moreover, these 0[110] orbits fill nearly in **synch** throughout a pair of major shells



Nilsson diagrams: 0[110] pairs



All 16 proton orbits related by 0[110] to 16 / 22 neutron orbits.
Enhanced p-n interactions as proton, neutrons fill together.

Neutron orbits not matched all have nz = 0, high lying. Do not contribute to prolate deformation.

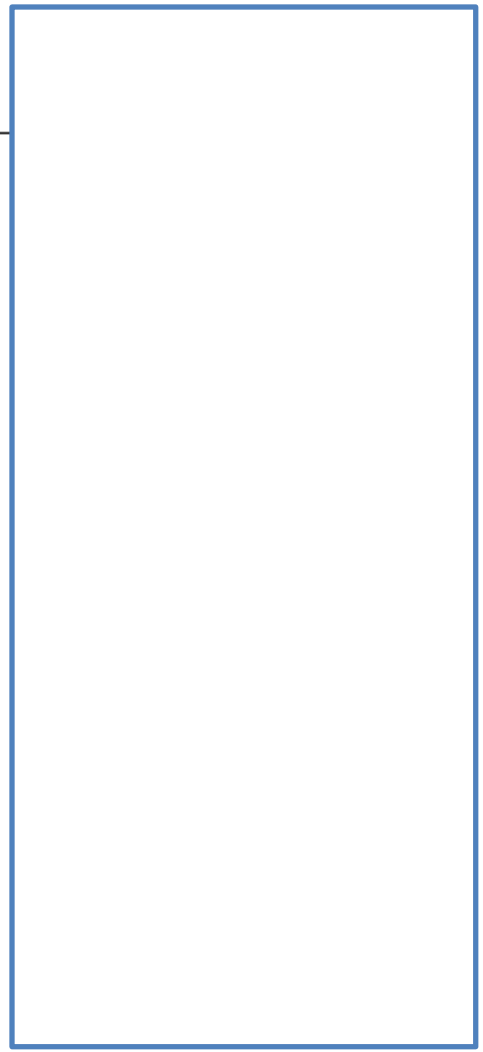
Locus of collectivity

Collectivity and maxima in δ Vpn

Maxima in δVpn and **Nval ~ Zval**

Relation of Harm. Osc. orbits and major shell structure

50-82	50-82
3s1/2	1/2[400]
2d3/2	1/2[411]
	3/2[402]
2d5/2	1/2[420]
	3/2[411]
	5/2[402]
1g7/2	1/2[431]
	3/2[422]
	5/2[413]
	7/2[404]
1h11/2	1/2[550]
	3/2[541]
	5/2[532]
	7/2[523]
	9/2[514]
	11/2[505]



Principal Collaborators

R. Burcu Cakirli
Dennis Bonatsos
Sophia Karampagia
Klaus Blaum

Thanks, Franco, for 36 years of inspiration and for your amazing insights into atomic nuclei, their beauty, and their symmetries !!!

5/29/12

Hap