Favoured high-spin states in $N \approx Z$ nuclei close to ^{100}Sn

Ingemar Ragnarsson

and

Gillis Carlsson

LUND INSTITUTE OF TECHNOLOGY
Lund University

Workshop, Kazimierz, Sept. 30 2006

Outline

- Special features of $I = 21^+$ state in ^{94}Ag.
- Microscopic energies at high spin - examples, typical values.
- Microscopic energies for fully aligned states with holes in $Z = N = 50$ core.
- Favoured shell energies for specific combinations of quadrupole deformation ε_2 and rotational frequency ω.
- Summary

$I = 21^+$ state in ^{94}Ag

- Long half-life of 0.39 s
- Decays by 'β-delayed γ or proton emission', 'direct 1-p' or 'direct 2-p' emission.
- Unexpected large 2p decay probability has been taken as evidence that this $I = 21^+$ state is strongly deformed (I. Mukha *et al.* Nature 439, 298 (2006))

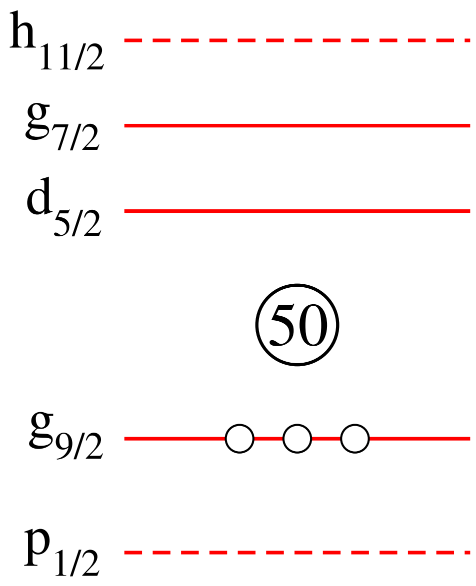
Aligned $I = 21^+$ state

$Z = 47, N = 47$

Ground state: $\pi(g_{9/2})^{-3}\ \nu(g_{9/2})^{-3}$

$I_{max} = 2 \cdot (9/2 + 7/2 + 5/2) = 21\hbar$

Small prolate deformation expected!



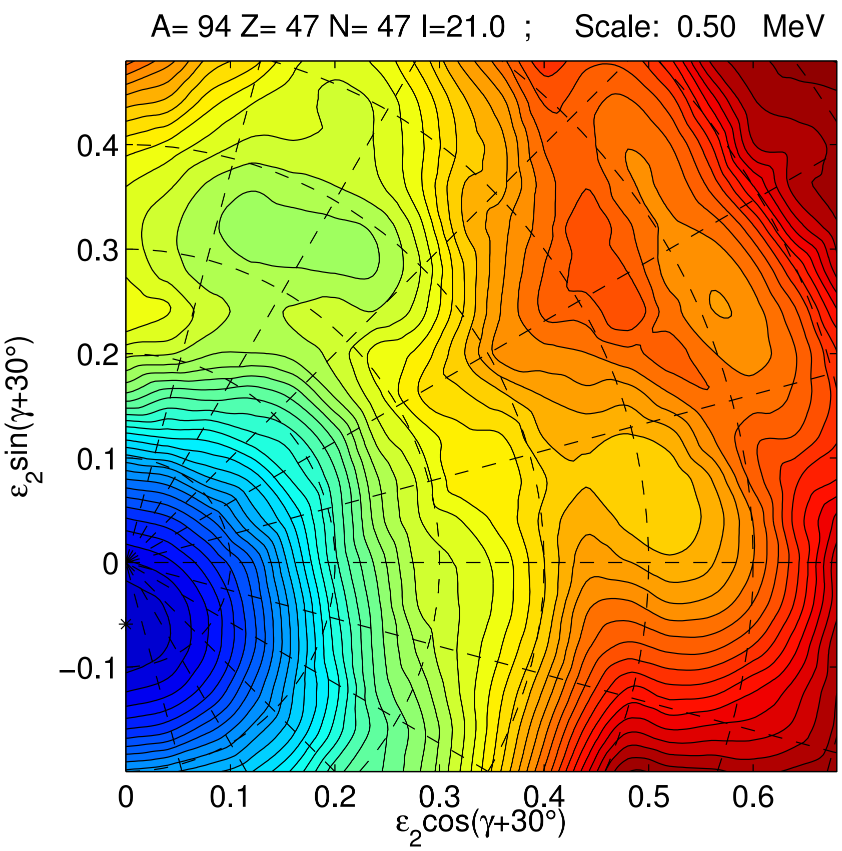
Aligned $I = 21^+$ state

$Z = 47, N = 47$

Ground state: $\pi(g_{9/2})^{-3}\ \nu(g_{9/2})^{-3}$

$I_{max} = 2 \cdot (9/2 + 7/2 + 5/2) = 21\hbar$

Small prolate deformation expected!



CNS calculations:
$\varepsilon \approx 0.06, \gamma = -120°$

Absolute energy ?

≈ 15 MeV excitation energy at $\varepsilon \approx 0.6$.

Nuclear mass

In the macroscopic-microscopic model, the nuclear mass is calculated as

$$\begin{aligned} E_{\rm tot}(Z,N) &= \min_{\varepsilon_i}\left[E_{\rm ld}(Z,N,\varepsilon_i)\right. \\ &+ \left. E_{\rm shell}(Z,N,\varepsilon_i) + \delta E_{\rm pair}(Z,N,\varepsilon_i)\right] \end{aligned}$$

An analogous formula at high spin, where pairing can be neglected, reads (G.B. Carlsson and IR, PRC, rapid comm. 2006)

$$E_{\rm tot}(Z,N,I) = \min_{\varepsilon_i}\left[E_{\rm rld}(Z,N,I,\varepsilon_i) + E_{\rm shell}(Z,N,I,\varepsilon_i)\right],$$

The rotating liquid drop energy can be written:

$$E_{\rm rld}(Z,N,I,\varepsilon_i) = E_{\rm ld}(Z,N,\varepsilon_i) + \frac{\hbar^2 I(I+1)}{2\mathcal{J}_{\rm rig.}(Z,N,\varepsilon_i)}$$

FRDM model

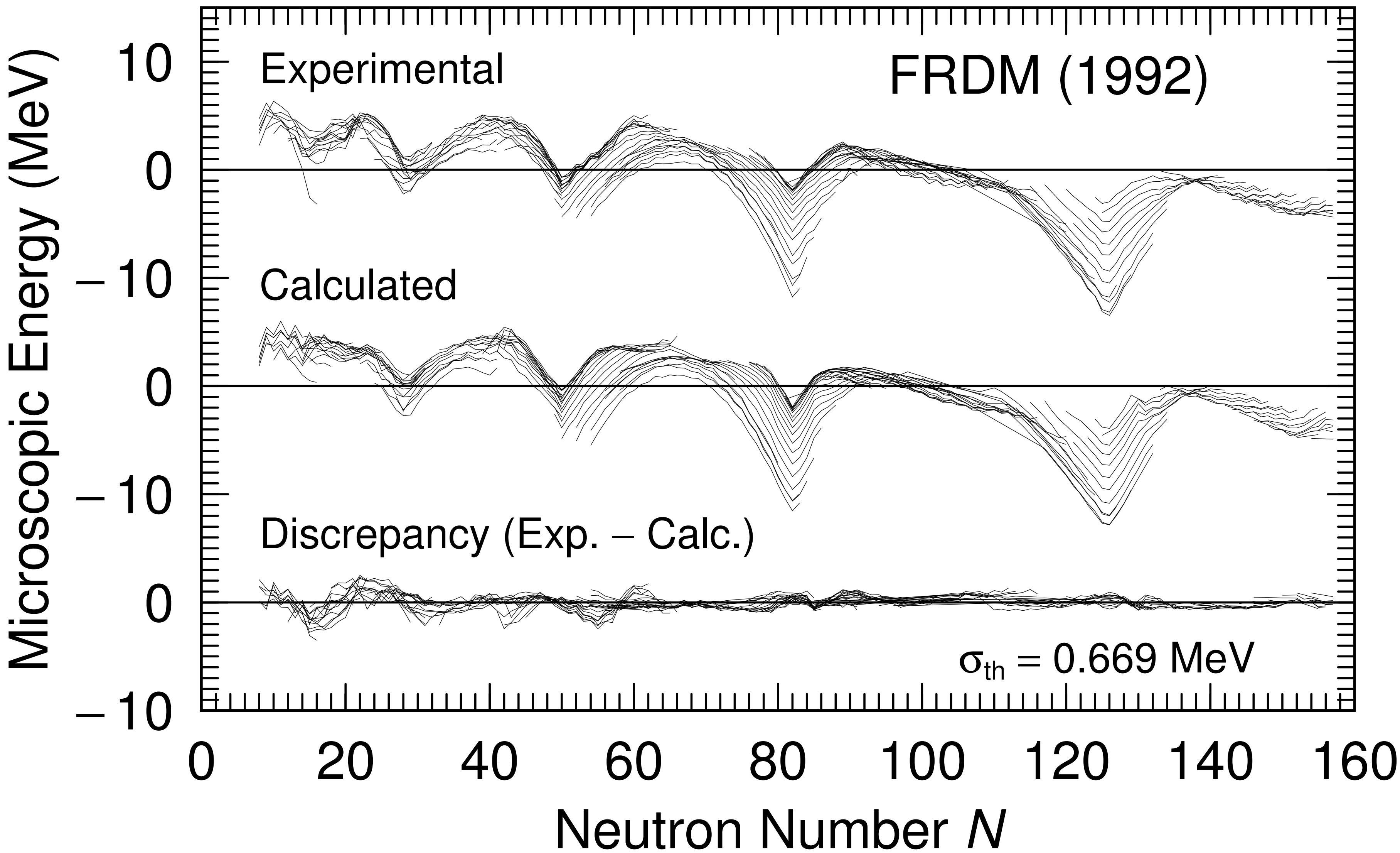


Figure 1

Parameters

Total energy:

$$E_{\rm tot}(Z,N,I) = \min_{\varepsilon_i}\left[E_{\rm rld}(Z,N,I,\varepsilon_i) + E_{\rm shell}(Z,N,I,\varepsilon_i)\right],$$

Rotating liquid drop energy:

$$E_{\rm rld}(Z,N,I,\varepsilon_i) = E_{\rm ld}(Z,N,\varepsilon_i) + \frac{\hbar^2 I(I+1)}{2\mathcal{J}_{\rm rig.}(Z,N,\varepsilon_i)}$$

E_{shell} from modified oscillator (CSN) - $A = 110$ parameters.

$E_{\rm ld}$: Lublin-Strasbourg drop (LSD model)

(with average E_{pair} removed, cf. poster by Nerlo-Pomorska *et al*)

$\mathcal{J}_{\rm rig.}$: diffuse surface: $r_0 = 1.16$ fm, $a = 0.6$ fm

(from fit of experimental $\langle r^2 \rangle$-values)

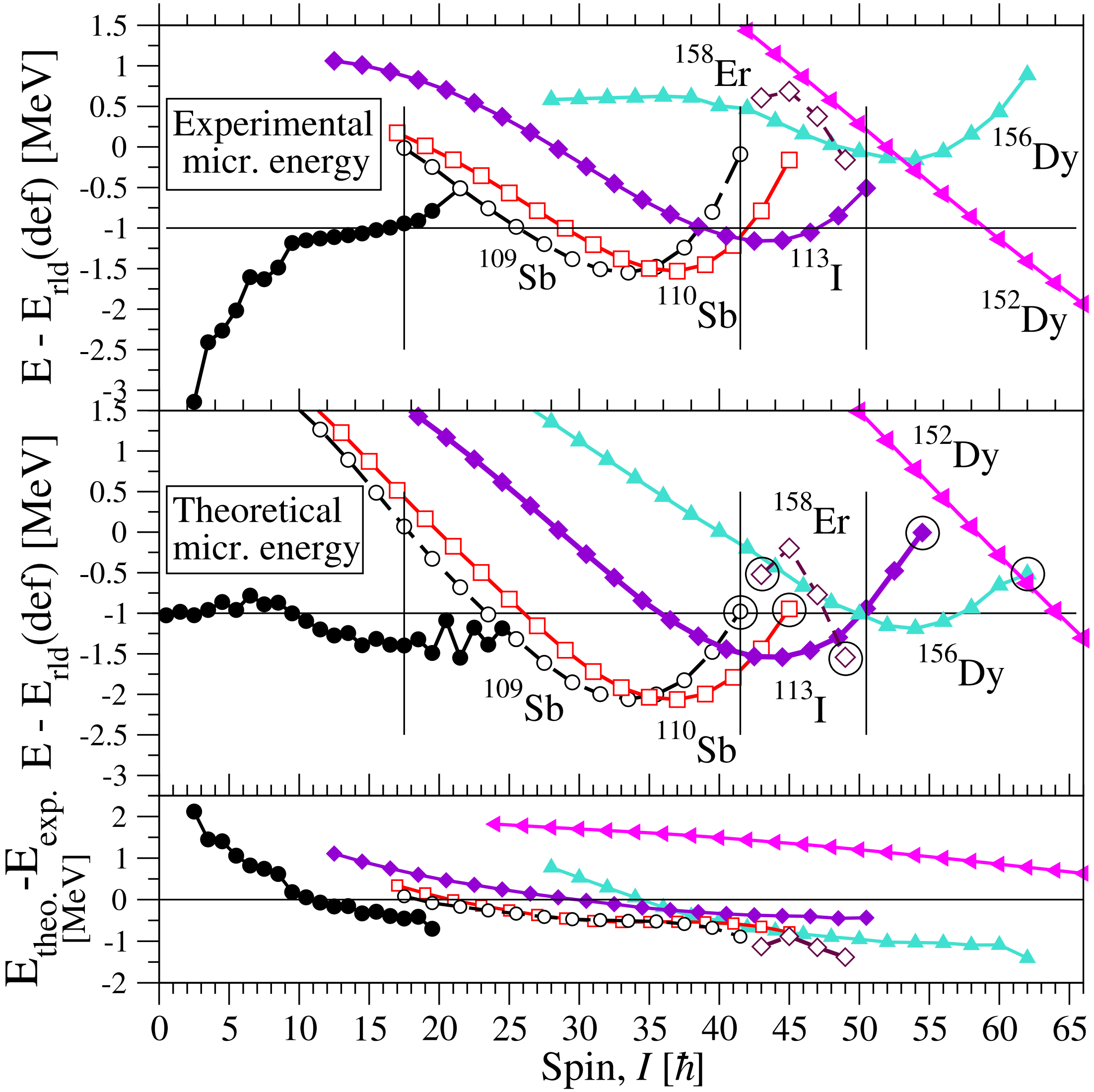
Microscopic energies-general

Microscopic energy for high spin states.

Min. value: ~ -2 MeV

Typical error: ± 1 MeV

Expected accuracy for $I = 21$ state in ^{94}Ag: ± 2 MeV

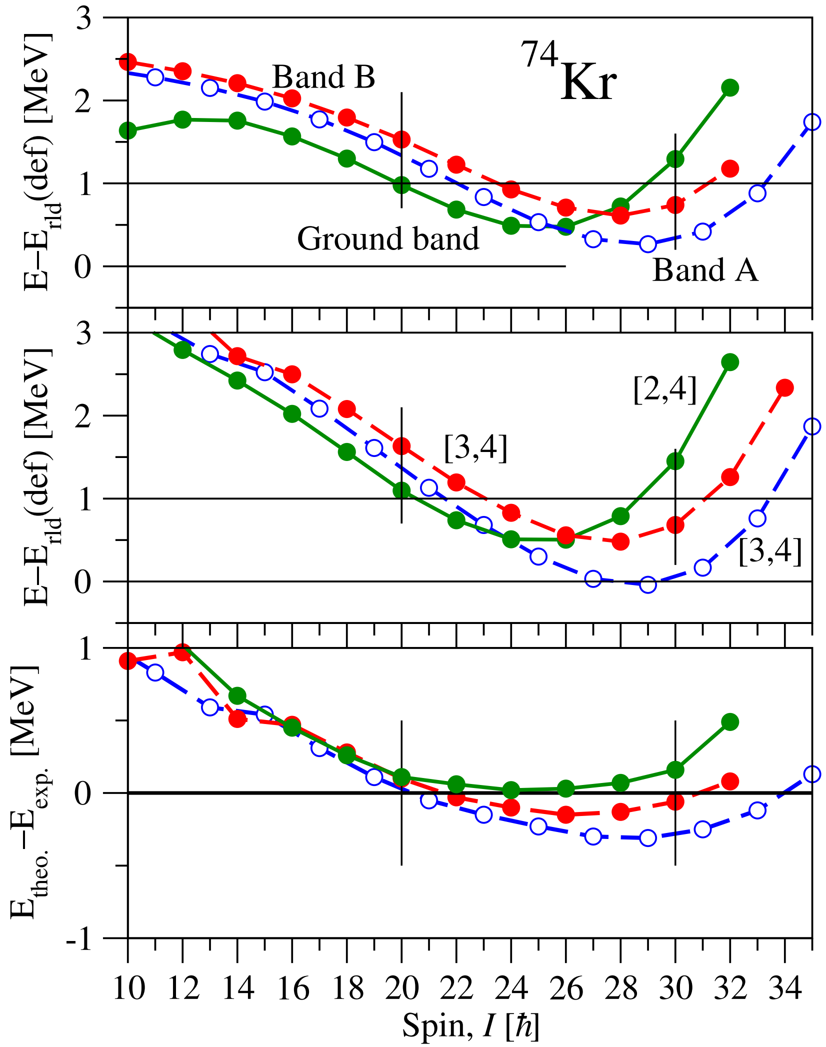


Microscopic energies - ^{74}Kr

^{74}Kr: 3 bands observed to I_{max}
but do not terminate
Large collectivity for $I = I_{max}$.

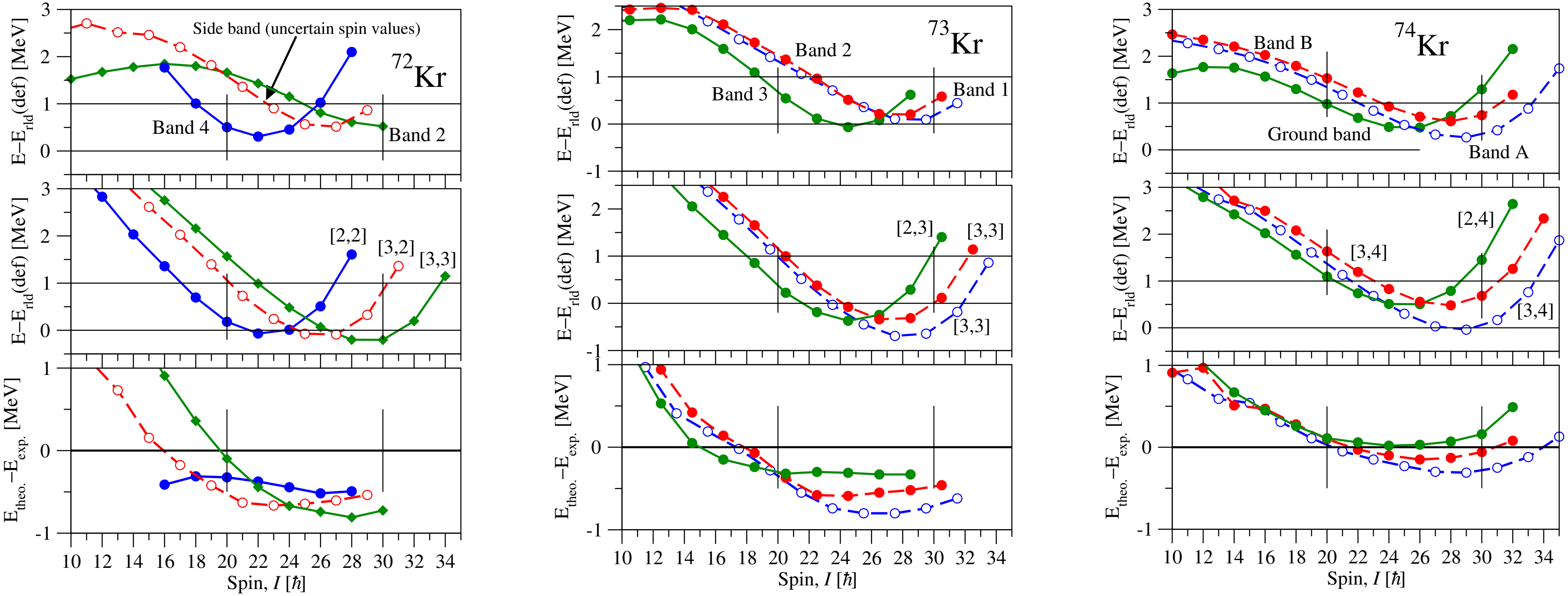
J.J. Valiente-Dubón *et al.* PRL 95, 232501 (2005)

Generally good agreement for absolute energies but:
Calculated energies too high for all bands close to $I = I_{max}$



[3,4]: $\pi(g_{9/2})^3\nu(g_{9/2})^4$

Microscopic energies - Kr isotopes



High-spin bands in $^{72-74}$Kr well described

(cf. talks by Afanasiev and Satula)

Absolute energies within $\sim \pm 0.7$ MeV.

Note the similarities between ^{73}Kr and ^{74}Kr.

Microscopic energies - ^{58}Ni

Large-deformation bands in ^{58}Ni.

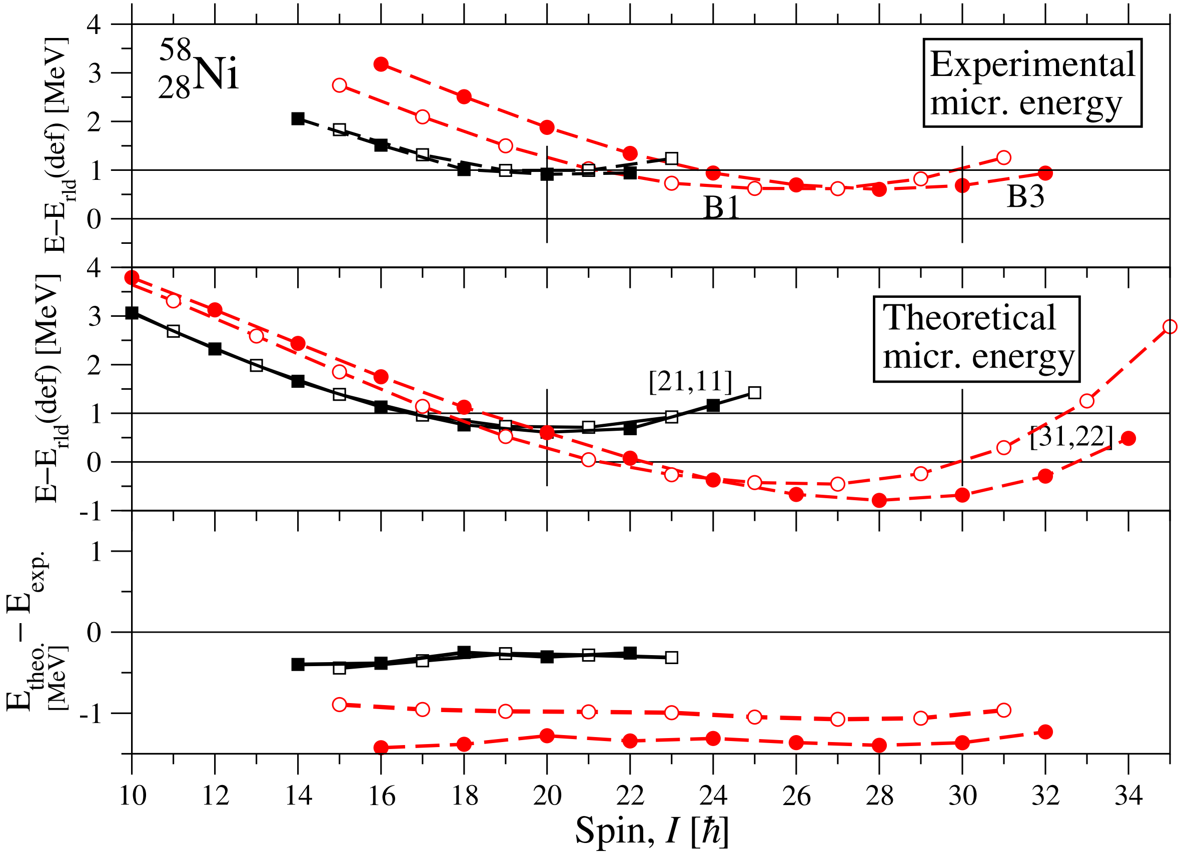
$$(f_{7/2})^{-3}(h_{9/2})^2$$

$$(f_{7/2})^{-5}(h_{9/2})^3$$

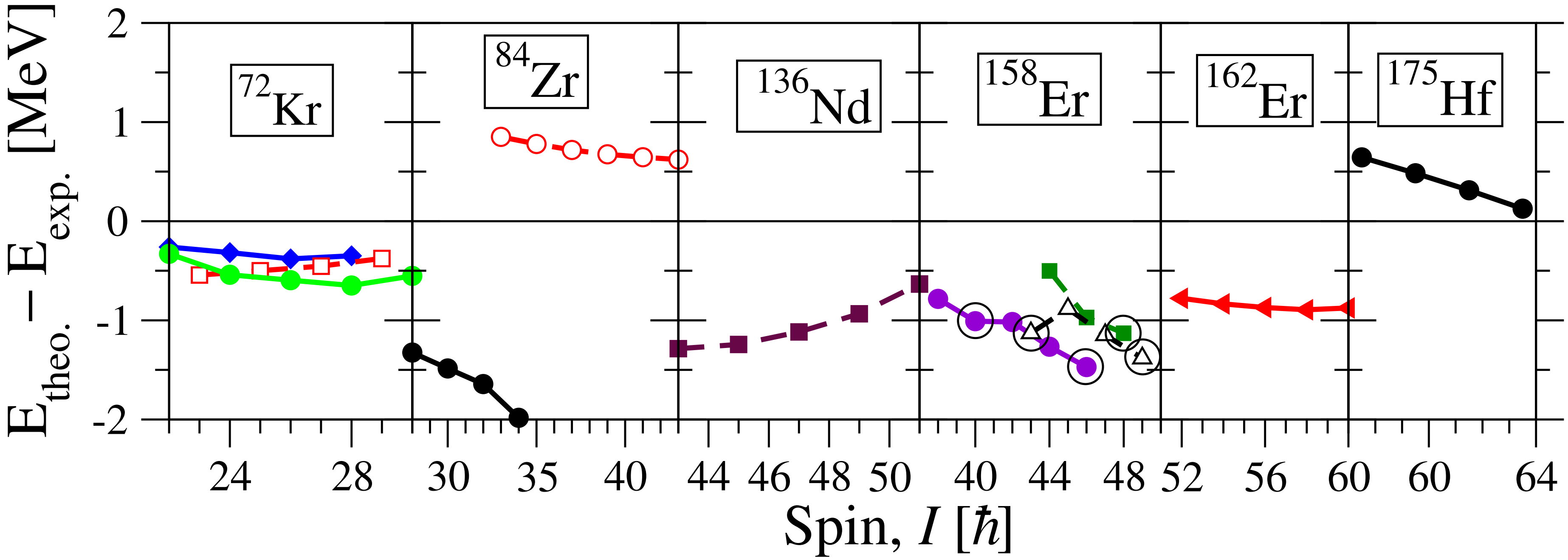
Well described in CNS - band crossing

D. Rudolph *et al.* PRL 96, 092501 (2006)

Error constant as function of I.



Typical errors in calc. E_{tot}



Typical error: ± 1 MeV Maximal error: ± 2 MeV

Microscopic energies - $A = 90 - 100$.

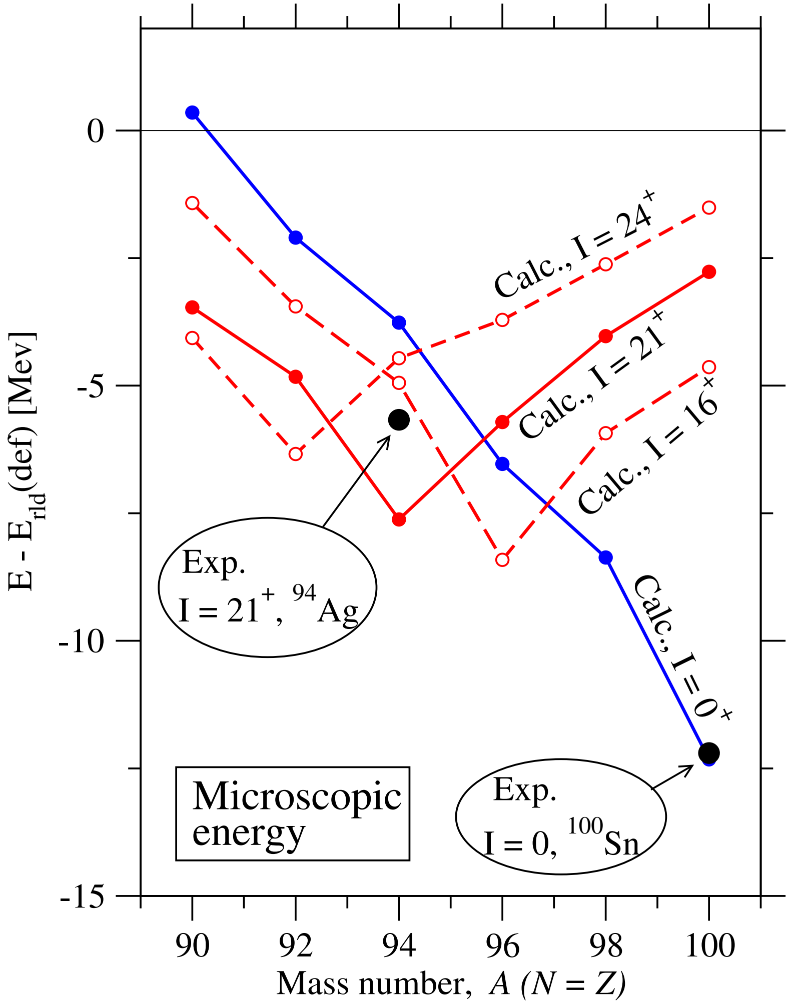
^{100}Sn; ground state:

$E_{micr} \approx -12$ MeV

^{96}Cd; $\pi(g_{9/2})^{-2}\ \nu(g_{9/2})^{-2}$
$I_{max} = 16\hbar$; $E_{micr} \approx -8$ MeV

^{94}Ag; $\pi(g_{9/2})^{-3}\ \nu(g_{9/2})^{-3}$
$I_{max} = 21\hbar$; $E_{micr} \approx -7$ MeV

^{92}Pd; $\pi(g_{9/2})^{-4}\ \nu(g_{9/2})^{-4}$
$I_{max} = 24\hbar$; $E_{micr} \approx -6$ MeV



Rotation around symmetry axis

One half of orbitals in a j-shell can be approx. degenerate for specific ratio, ω/ε.

$\Longrightarrow$

Regions of high level density

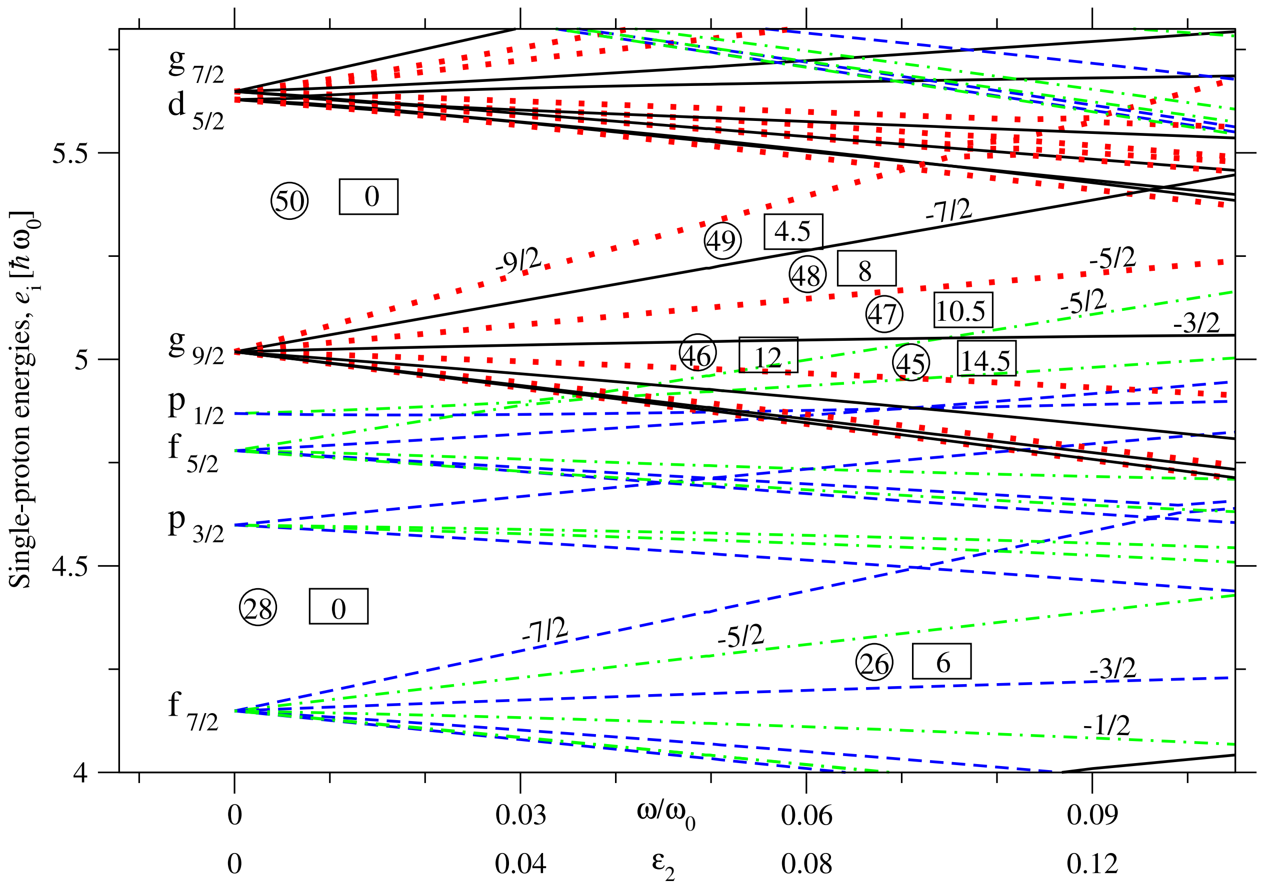
(cf. talk by J. Dudek)

and thus regions of low level density in between.

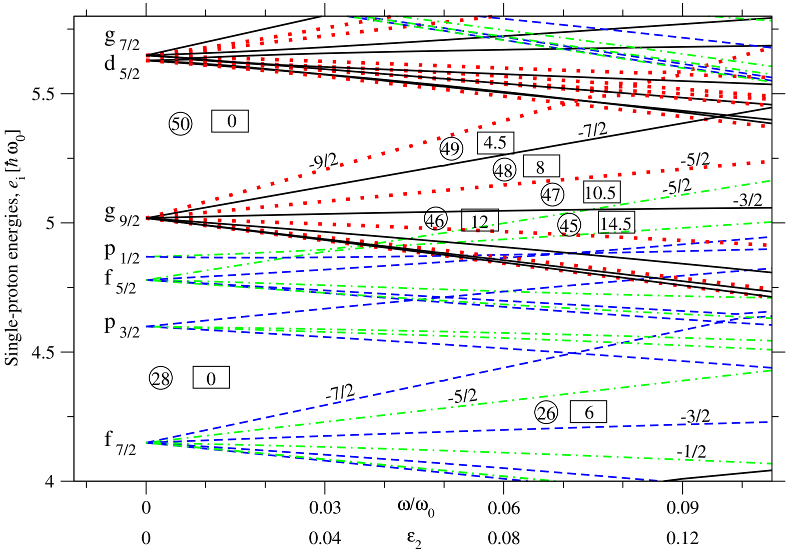
$\Longrightarrow$

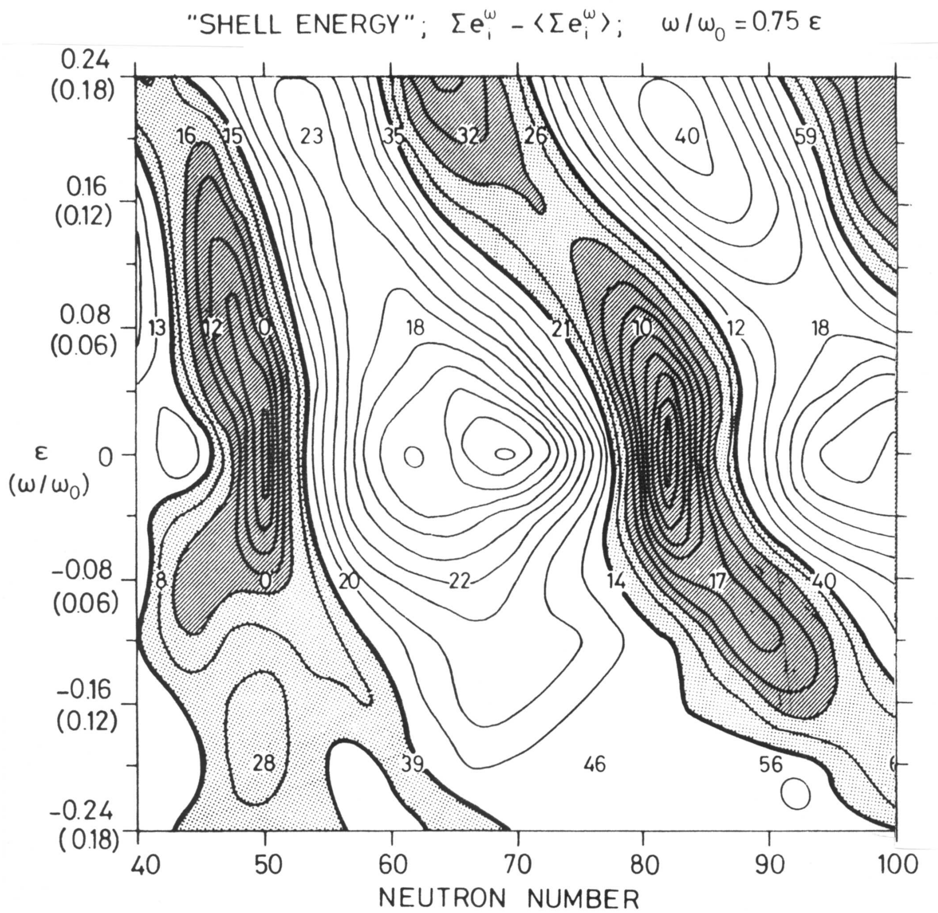
Very strong shell effects

(I.R., PLB 80B, 4 (1978))



Strong shell effects for p-h excitations





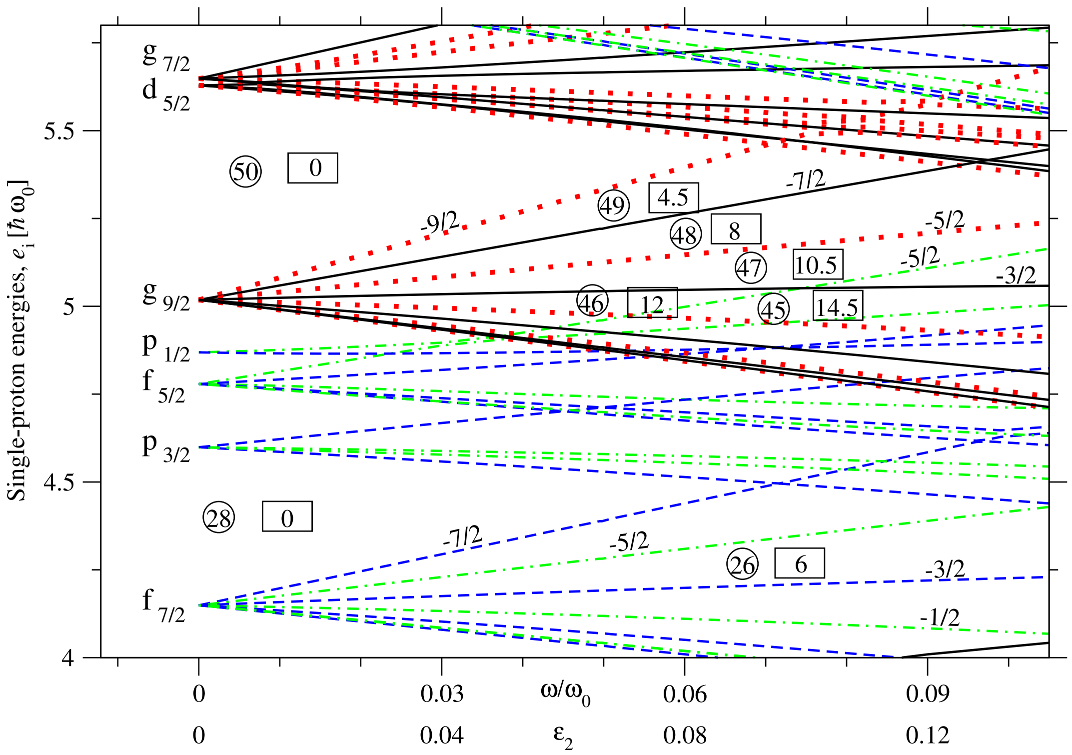
Note the ridges of high shell energy and the valleys of low favoured shell energies in between

For example $I = 12$ for $N = 46$.

Strong shell effects for p-h excitations

Combination of favoured particle numbers:

Z	N	I	E_{micr}	
			Exp	$Calc$
47	47	21	-5.6	-7.5
47	48	18.5	-7.2	-7.8
46	48	20	-5.8	-6.8
46	46	24		-6.4
45	45	25		-4.8
		29		-4.6



Exp. values uncertain $\sim \pm 1$ MeV

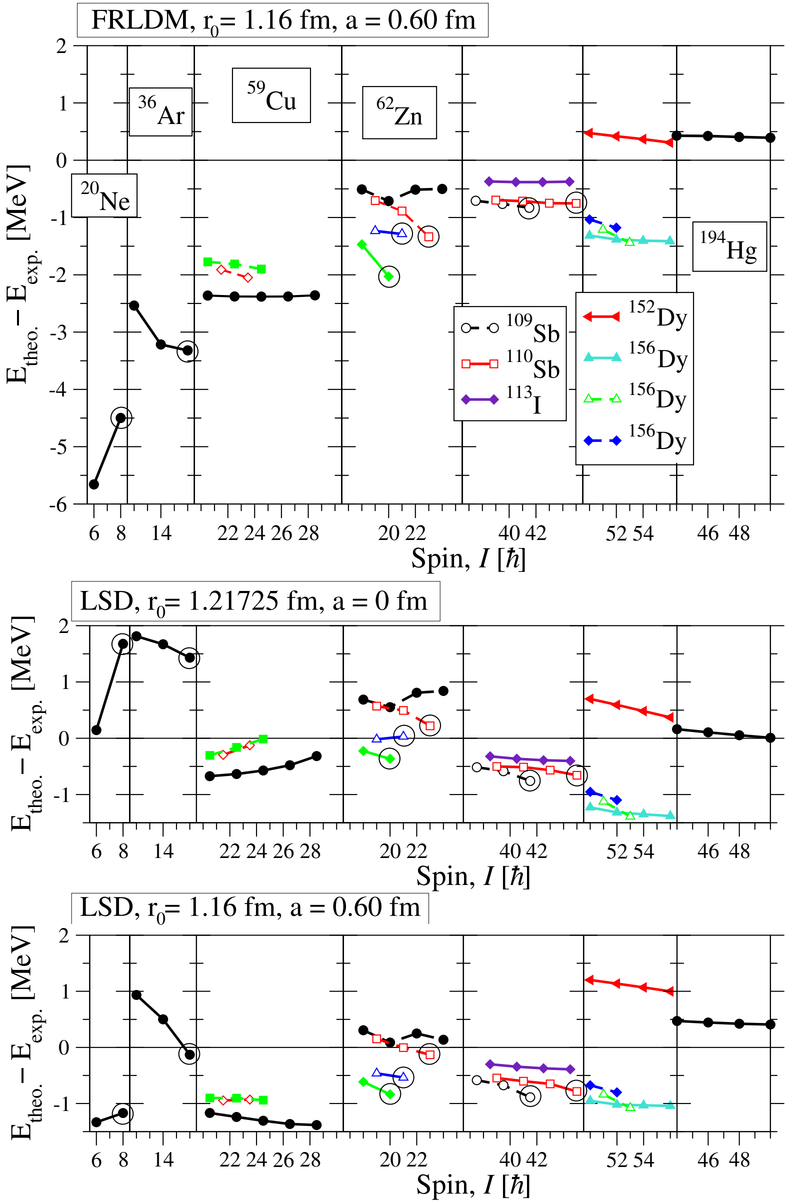
Conclusions

$I = 21$ state in ^{94}Ag:

- Very favoured energy - $Z = N = 47$ magic for $I = 10.5$.
- Small prolate deformation - axis ratio $\sim$ 1.06 : 1.

Region of nuclei with $N = Z = 45 - 50$ ($N \approx Z$):

- Large number of favoured energy fully aligned states - interesting to study.
- Important to measure masses (and thus binding energies of high-spin states) to the $N = Z$ line (or even beyond).



FRLDM, r0= 1.16 fm, a = 0.60 fm
20Ne
36Ar
59Cu
62Zn
194Hg
109Sb
110Sb
113I
152Dy
156Dy
156Dy
156Dy
Etheo. − Eexp. [MeV]
Spin, I [ħ]
LSD, r0= 1.21725 fm, a = 0 fm
Etheo. − Eexp. [MeV]
Spin, I [ħ]
LSD, r0= 1.16 fm, a = 0.60 fm
Etheo. − Eexp. [MeV]
Spin, I [ħ]