Shell evolution far from stability: towards and beyond ^{78}Ni

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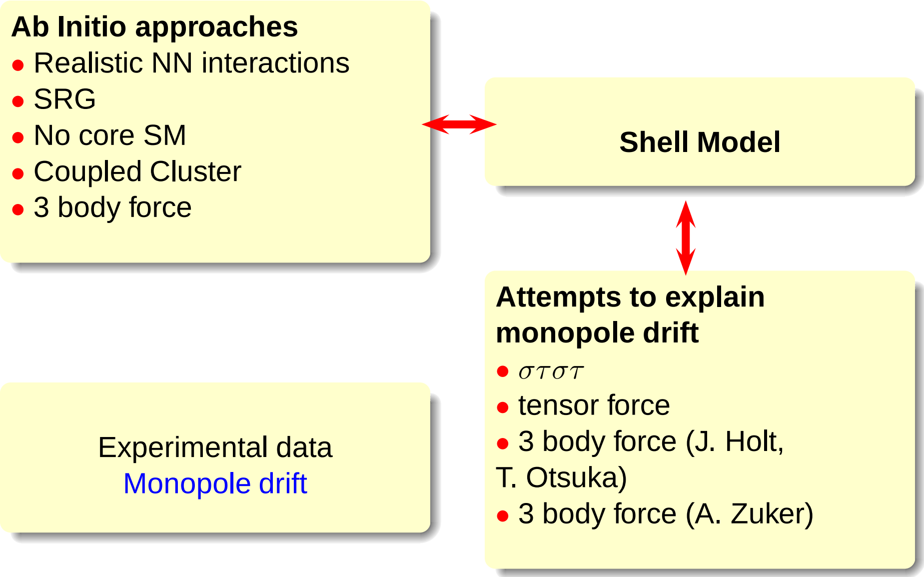
Trento, 29.07.2009

Introduction



Ab Initio approaches

- Realistic NN interactions
- SRG
- No core SM
- Coupled Cluster
- 3 body force

Shell Model

Attempts to explain monopole drift

- $\sigma\tau\sigma\tau$
- tensor force
- 3 body force (J. Holt, T. Otsuka)
- 3 body force (A. Zuker)

Experimental data

Monopole drift

Shell evolution: tensor force

$$V_T = (\vec{\tau}_1 \cdot \vec{\tau}_2)[(\vec{\sigma}_1 \cdot \vec{\sigma}_2)^2 \cdot Y_2]f(r)$$

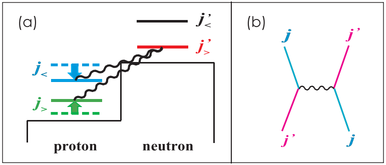


FIG. 1 (color). (a) Schematic picture of the monopole interaction produced by the tensor force between a proton in $j_{>,<} = l \pm 1/2$ and a neutron in $j'_{>,<} = l' \pm 1/2$. (b) Exchange processes contributing to the monopole interaction of the tensor force.

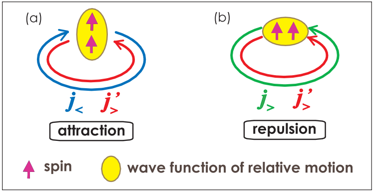


FIG. 2 (color). Intuitive picture of the tensor force acting two nucleons on orbits j and j'.

T. Otsuka et al., PRL 95 (2005)

Evolution of nuclear shells due to Tensor force

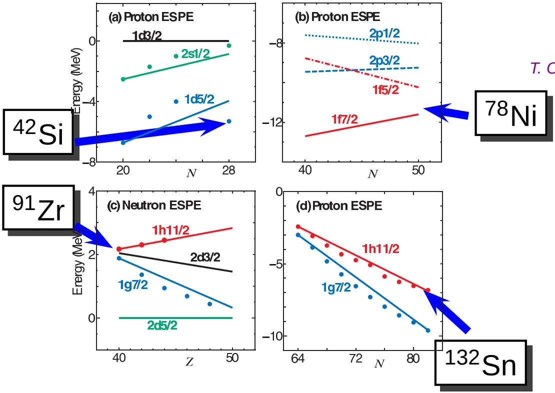


FIG. 4 (color). Proton (neutron) ESPE as a function of N (Z). Lines in (a)–(c) show the change of ESPE's calculated from the $\pi+\rho$ tensor force. Points represent the corresponding experimental data. (a) Proton ESPE's in Ca isotopes relative to $1d_{3/2}$. Points are from [13]. (b) Proton ESPE's in Ni isotopes; calculations only. See [19] for related experimental data. (c) Neutron ESPE's in $N = 51$ isotones relative to $2d_{5/2}$; points are from [21]. (d) Proton ESPE's in Sb isotopes; points are from [18]. Lines include a common shift of ESPE as well as the tensor effect (see the text).

T. Otsuka et al., Phys. Rev. Lett. ***95****, 232502-1 (2005)*

- $(2j_> + 1)V^T_{j_>,j'} + (2j_< + 1)V^T_{j_<,j'} = 0$
- reduction of spin-orbit partners splitting while filling j' shell

Shell evolution: tensor mechanism

What do we know?

- No double closure for ^{20}C (N=14) and ^{42}Si (N=28)
  $\leadsto$ Tensor mechanism at play

BUT

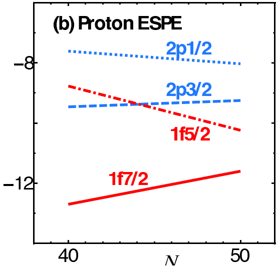
- Double closure for ^{132}Sn (N=82) and ^{208}Pb (N=126)

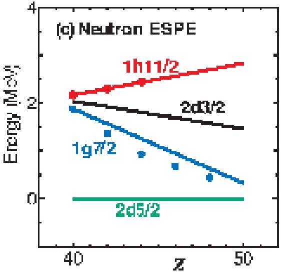
What about ”transition region” ^{78}Ni (N=50) ?

Outline

PART I: below ^{78}Ni

PART II: beyond ^{78}Ni



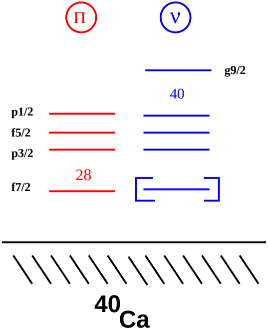


- filling neutron $g_{9/2}$ orbital

- filling proton $g_{9/2}$ orbital

SM framework: model spaces and interactions

PART I: below ^{78}Ni



- no center of mass excitations
- full calculations feasible
- important core excitations over $Z = 28$ and $N = 40$ gaps
- $Z = 28, 29, 30$
  $N = 40 - 50$

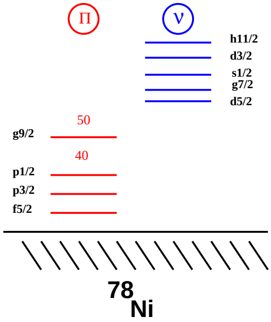
Interactions: CD-Bonn - G-matrix + monopole tuning

M. Hjorth-Jensen

SM framework: model spaces and interactions

PART II: beyond ^{78}Ni

- no center of mass excitations
- natural valence space for neutron rich nuclei below ^{132}Sn
- $Z = 38, 39, 40, 50$
  $N = 50 - 56$

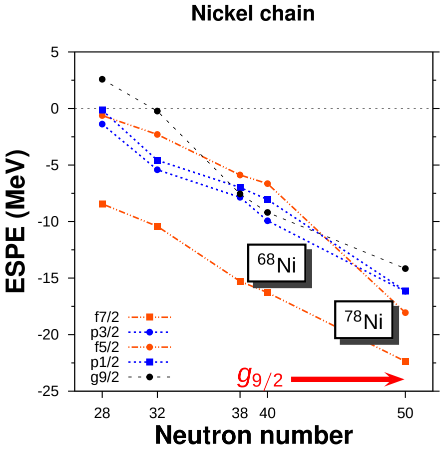


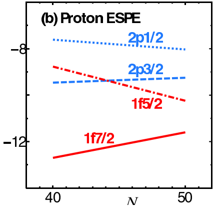
Interactions: CD-Bonn - G-matrix + monopole tuning

M. Hjorth-Jensen, pp- Lisetskiy

PART I: below ^{78}Ni

Weakening of the $Z = 28$ gap at $N = 50$

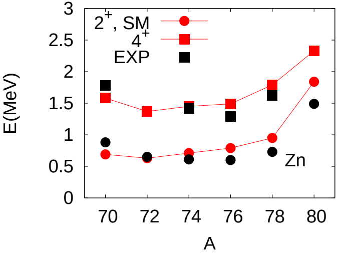


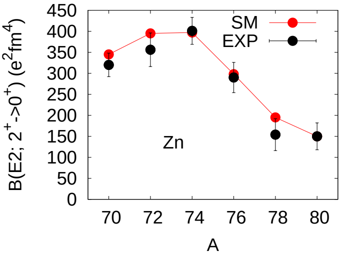


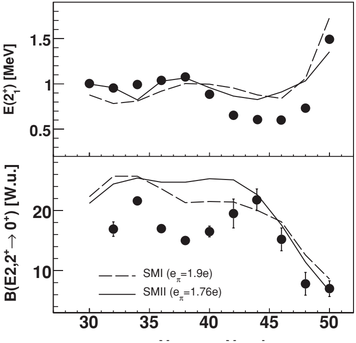
- Reduction of the proton $f_{5/2} - f_{7/2}$ gap when filling neutron $g_{9/2}$ orbital
- Crossing of proton $f_{5/2} - p_{3/2}$ orbitals in the mid-shell

PART I: below ^{78}Ni

zinc chain (Z=30)



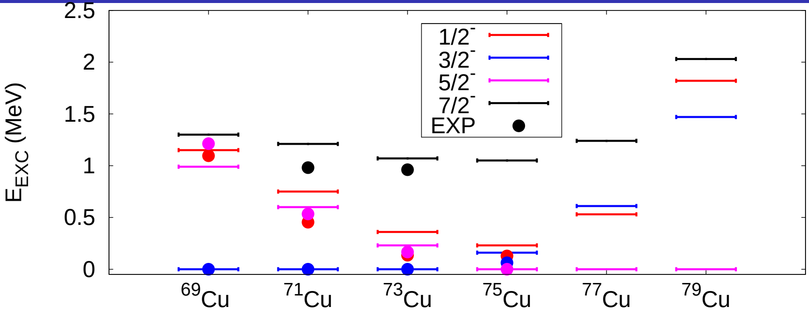


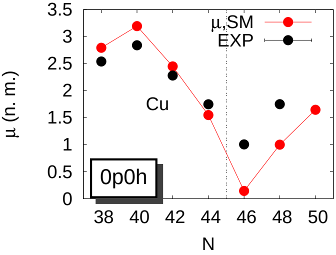


*I. Stefanescu et al. PRL**100**, 112502 (2008); J. Van De Walle et al. Phys. Rev.**C79**, 014309 (2009)*

PART I: below ^{78}Ni

copper chain (Z=29)

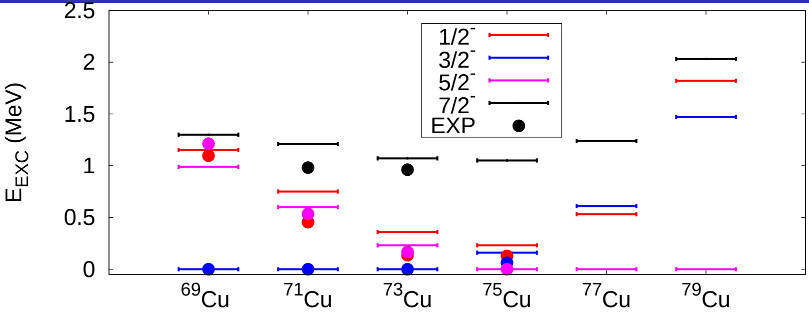


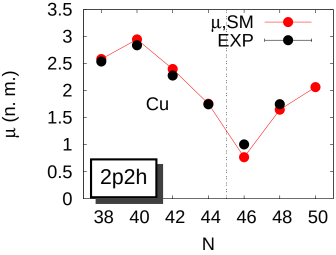


F.Nowacki and KS, to be published

PART I: below ^{78}Ni

copper chain (Z=29)





F.Nowacki and KS, to be published

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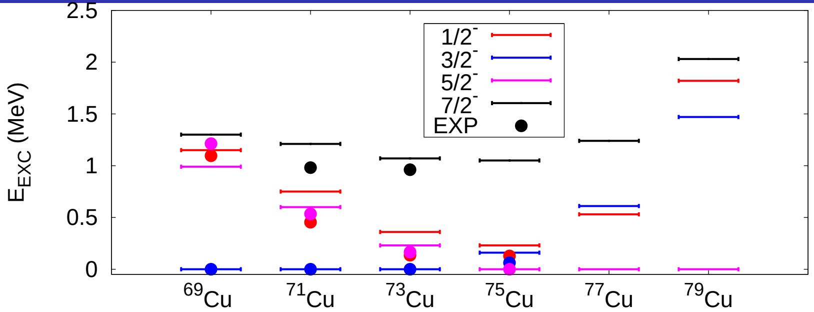
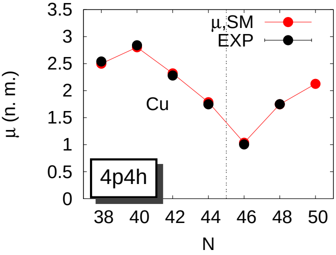
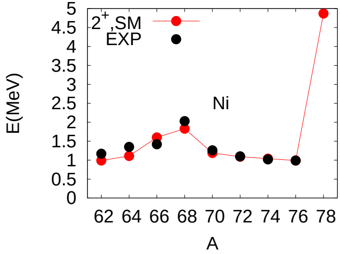


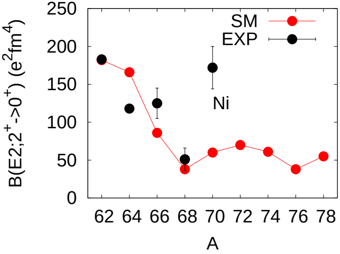


F.Nowacki and KS, to be published

PART I: below ^{78}Ni

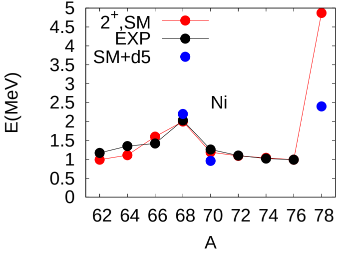
nickel chain (Z=28)

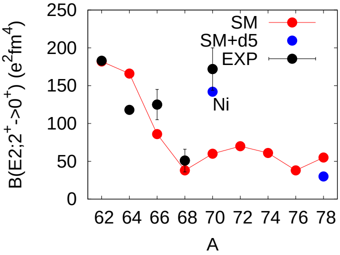


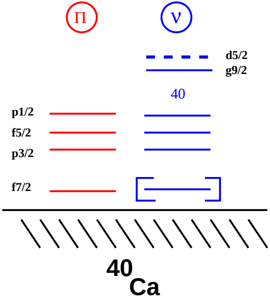


PART I: below ^{78}Ni

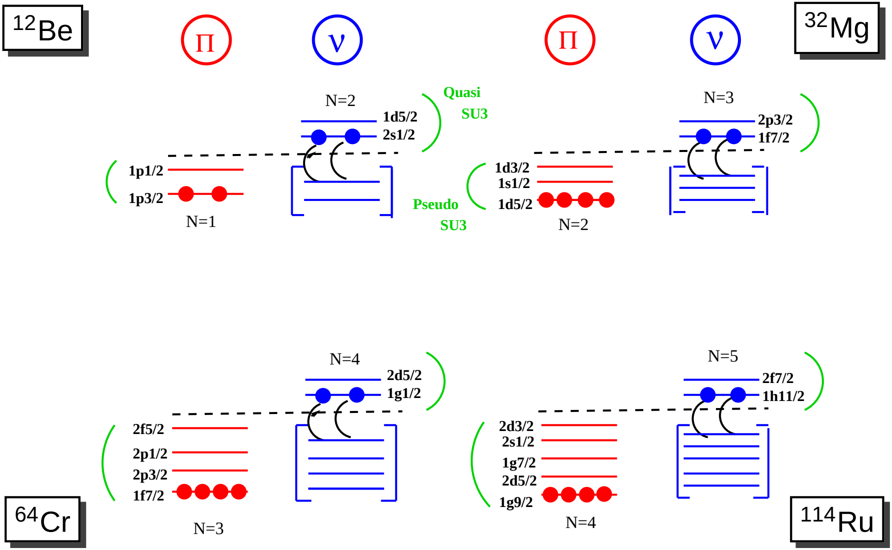
nickel chain (Z=28)



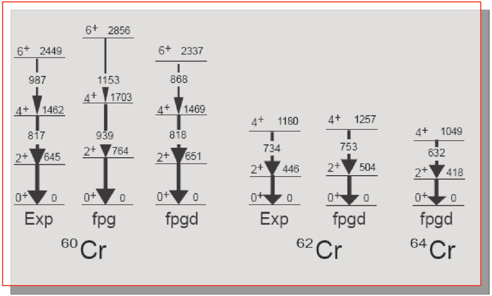


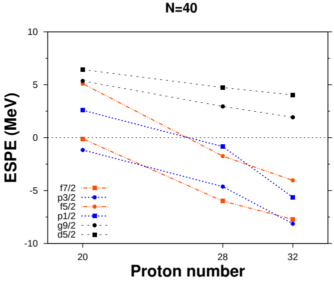


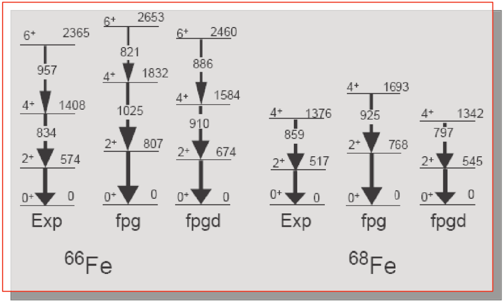
Developement of deformation at N=8,20,40,70

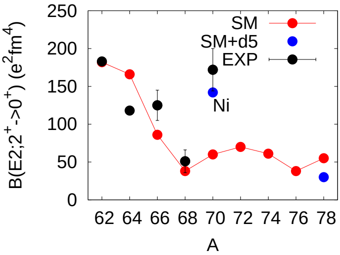


Island of inversion ^{68}Ni



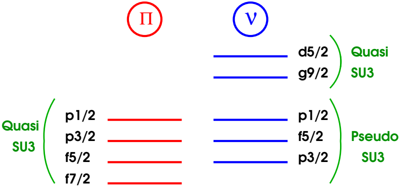






Island of inversion below ^{68}Ni

Evolution of collectivity in chromium isotopes at N=40



For ^{64}Cr:

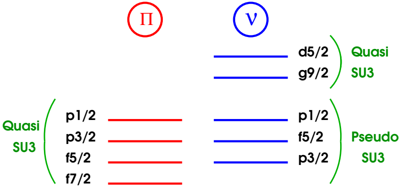
$$Q_a = 184 (e.fm^2)$$

$$Q_i = 80\% Q_a$$

	^{60}Cr	^{62}Cr	^{64}Cr
$E^*(2^+)$ (MeV)	0.65	0.50	0.45
Q_s(e.fm^2)	-35	-41	-41
BE2↓(e^2.fm^4)	368	440	440
Q_i(e.fm^2) from Q_s	121	143	143
Q_i(e.fm^2) from B(E2)	136	149	150
β	0.32	0.35	0.35
$E^*(4^+)$ (MeV)	1.47	1.26	1.10
Q_s(e.fm^2)	-43	-53	-53
BE2↓(e^2.fm^4)	538	657	655
Q_i(e.fm^2) from Q_s	118	145	146
Q_i(e.fm^2) from B(E2)	138	152	152
β	0.32	0.35	0.35

Island of inversion below ^{68}Ni

Evolution of collectivity in iron isotopes at N=40

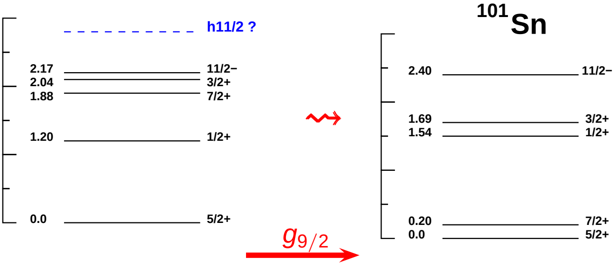


	^{66}Fe	^{68}Fe
$E^*(2^+)$ (MeV)	0.69	0.55
Q_S(e.fm^2)	-29	-43
BE2↓(e^2.fm^4)	365	503
Q_i(e.fm^2) from Q_S	101	149
Q_i(e.fm^2) from B(E2)	135	159
β	0.2	0.32
$E^*(4^+)$ (MeV)	1.62	1.33
Q_S(e.fm^2)	-33	-56
BE2↓(e^2.fm^4)	536	779
Q_i(e.fm^2) from Q_S	90	153
Q_i(e.fm^2) from B(E2)	137	166
β	0.2	0.32

- Rotor regime in ^{68}Fe but not yet in ^{66}Fe
- Structure differences between ^{66}Fe (2p2h) and ^{64}Cr (4p4h)

PART II: beyond ^{78}Ni

Shell evolution from ^{91}Zr to ^{101}Sn



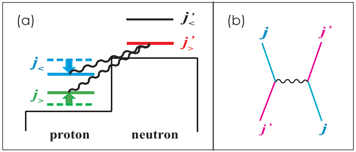


FIG. 1 (color). (a) Schematic picture of the monopole interaction produced by the tensor force between a proton in $j_{>,<} = l \pm 1/2$ and a neutron in $j'_{>,<} = l' \pm 1/2$. (b) Exchange processes contributing to the monopole interaction of the tensor force.

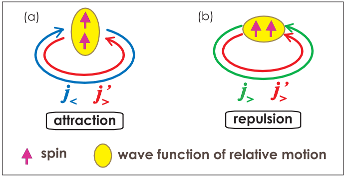
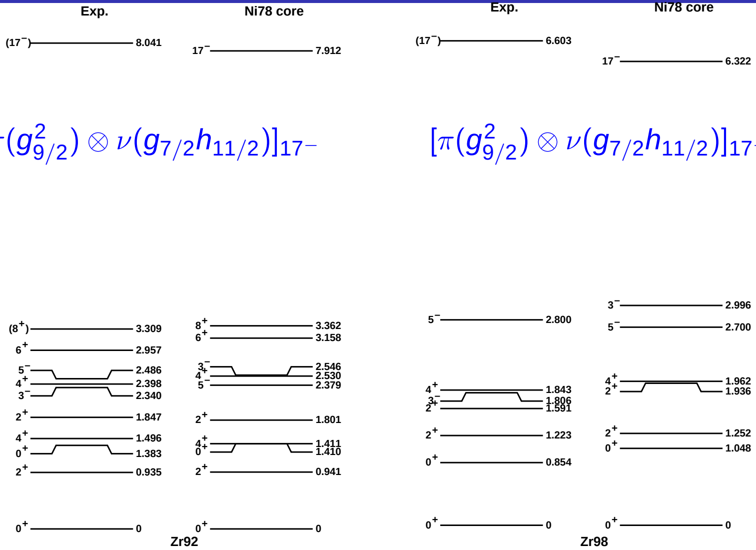


FIG. 2 (color). Intuitive picture of the tensor force acting two nucleons on orbits j and j'.

T. Otsuka et al., Phys. Rev. Lett. 72 (2001) 082502

High spin isomers as a hint for $\nu h_{11/2}$ centroid

Isomeric states in Zr isotopes



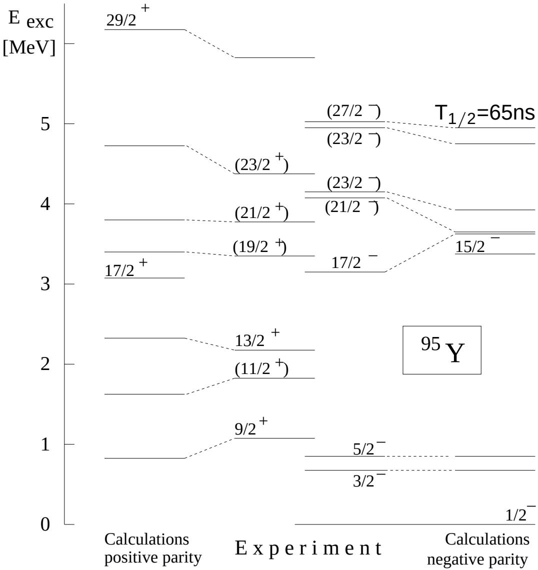
$[\pi(g^2_{9/2}) \otimes \nu(g_{7/2}h_{11/2})]_{17^-}$

$[\pi(g^2_{9/2}) \otimes \nu(g_{7/2}h_{11/2})]_{17^-}$

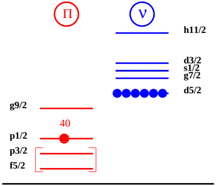
K.Sieja et al., Phys. Rev. C79 (2009) 064310.

High spin states as a hint for $\nu h_{11/2}$ centroid

Isomer in ^{95}Y



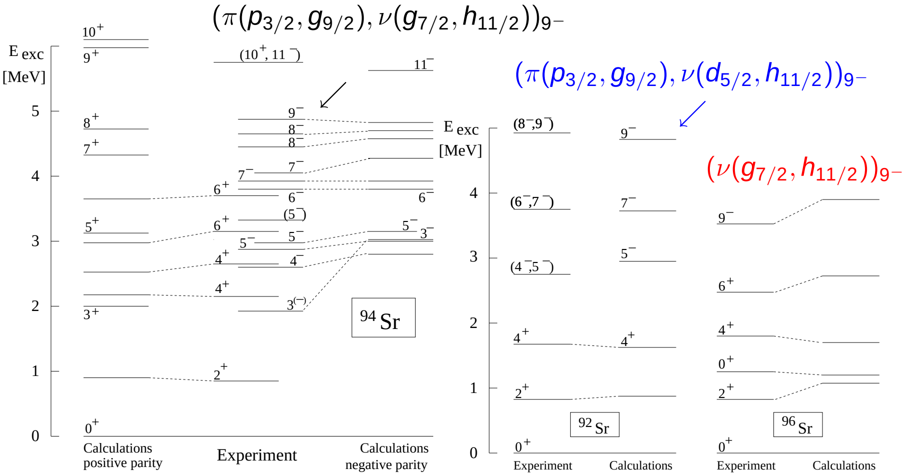
$\pi g^{1}_{9/2} \otimes (\nu g^{1}_{7/2} h^{1}_{11/2})$



W. Urban, K. Sieja et al., Phys. Rev. C79 (2009) 044304.

High spin states as a hint for $\nu h_{11/2}$ centroid

9^- states in Sr isotopes



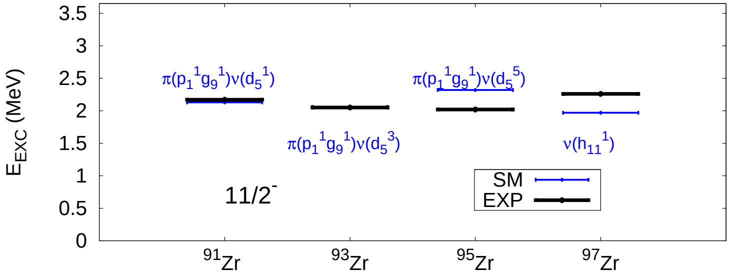
$(\pi(p_{3/2},g_{9/2}),\nu(g_{7/2},h_{11/2}))_{9^-}$

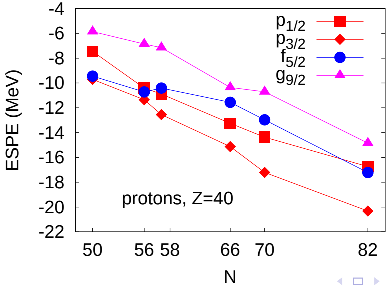
$(\pi(p_{3/2},g_{9/2}),\nu(d_{5/2},h_{11/2}))_{9^-}$

$(\nu(g_{7/2},h_{11/2}))_{9^-}$

T. Rzaca-Urban, K. Sieja, et al. Phys. Rev. C79 (2009) 024319.

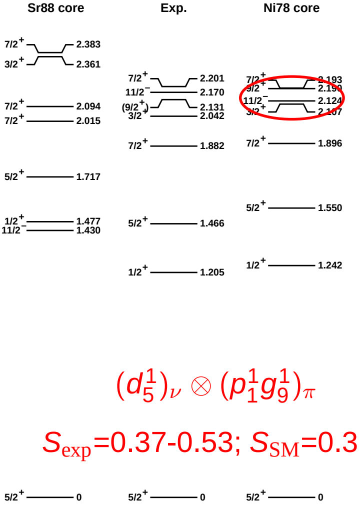
$11/2^-$ states in Zr isotopes





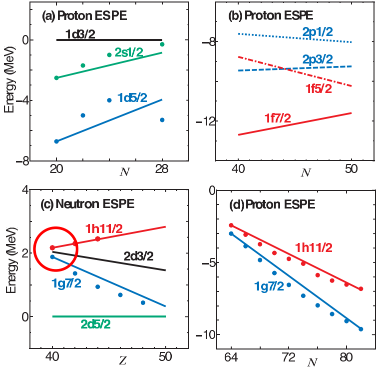
Shell evolution between ^{91}Zr and ^{101}Sn

Important case- ^{91}Zr



$$(d_{5}^{1})_{\nu} \otimes (p_{1}^{1} g_{9}^{1})_{\pi}$$

S_{exp}=0.37-0.53; S_{SM}=0.377



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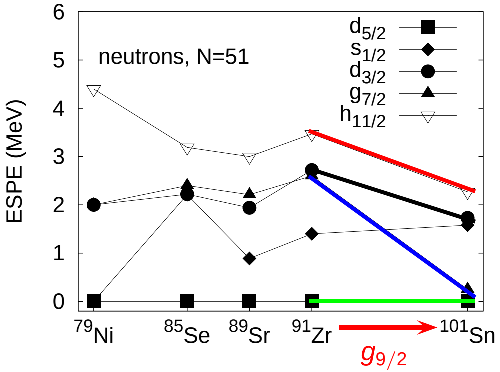
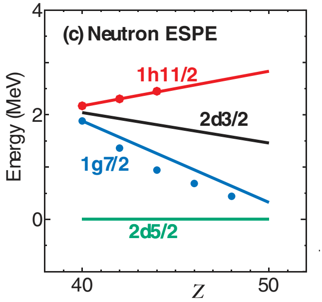
Shell evolution between ^{79}Ni and ^{101}Sn





- Attraction between proton $g_{9/2}$ and neutron $h_{11/2}$ orbitals

Summary

- Erosion of the $Z = 28$ gap in ^{78}Ni
  $\rightsquigarrow$reduction of the proton gap according to the tensor mechanism
- Core excitations crucial in SM description of neutron rich Ni, Cu, Zn isotopes

- $\nu h_{11/2}$ centroid determined at 3.5 MeV in ^{91}Zr
- Attraction of $\nu h_{11/2}$ and $\pi_{9/2}$ orbitals at $N = 50$

  $\rightsquigarrow$which part of the nuclear force wins over the tensor in heavy nuclei?

- Spin-tensor decomposition of the interaction in progress

Thanks to:

E. Caurier, F. Nowacki, A. Poves
S. Lenzi, H. Grawe, M. Gorska, W. Urban

Tin isotopes