LoI SPES

Spectroscopy studies around ^{78}Ni and beyond N=50 via transfer and Coulomb excitation reactions

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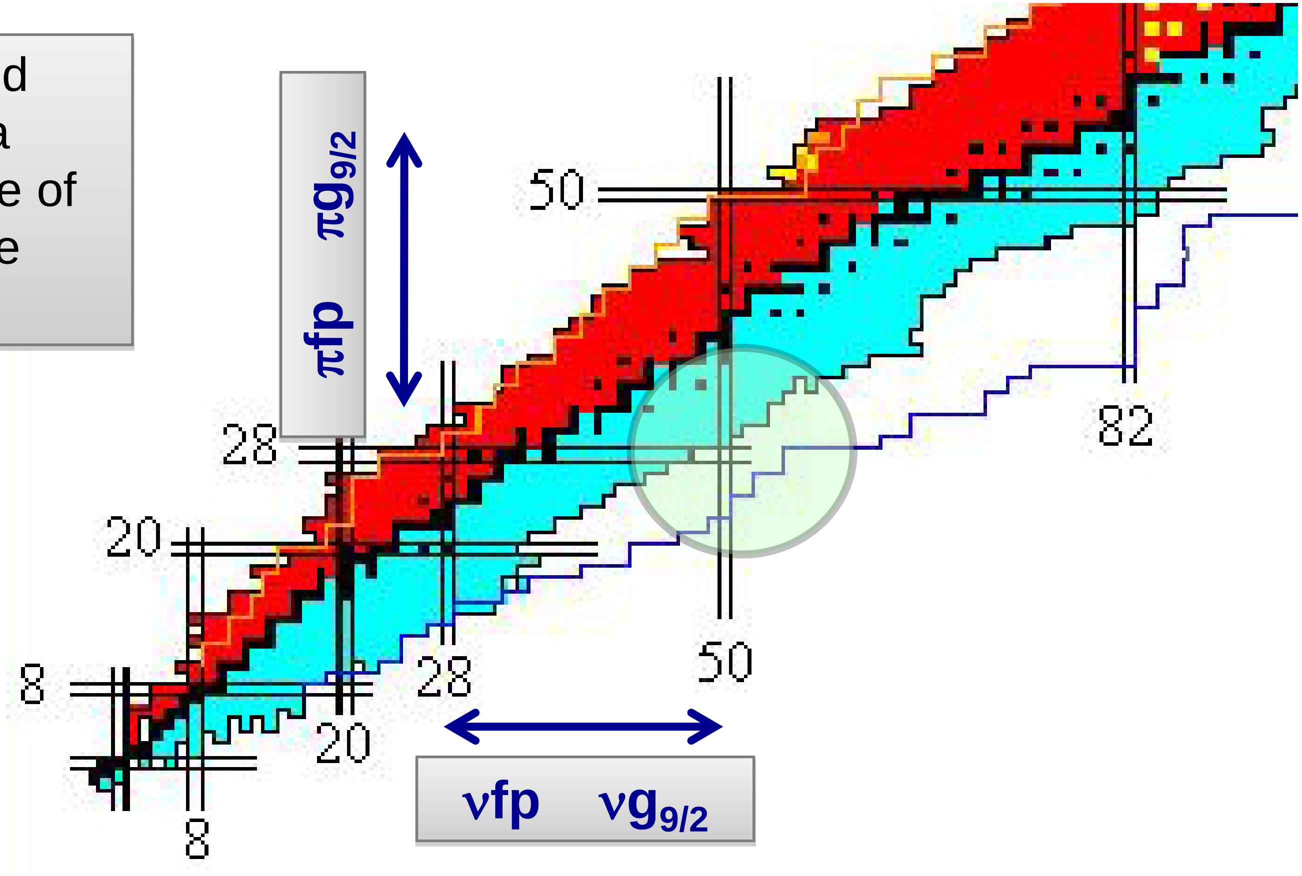
Overview

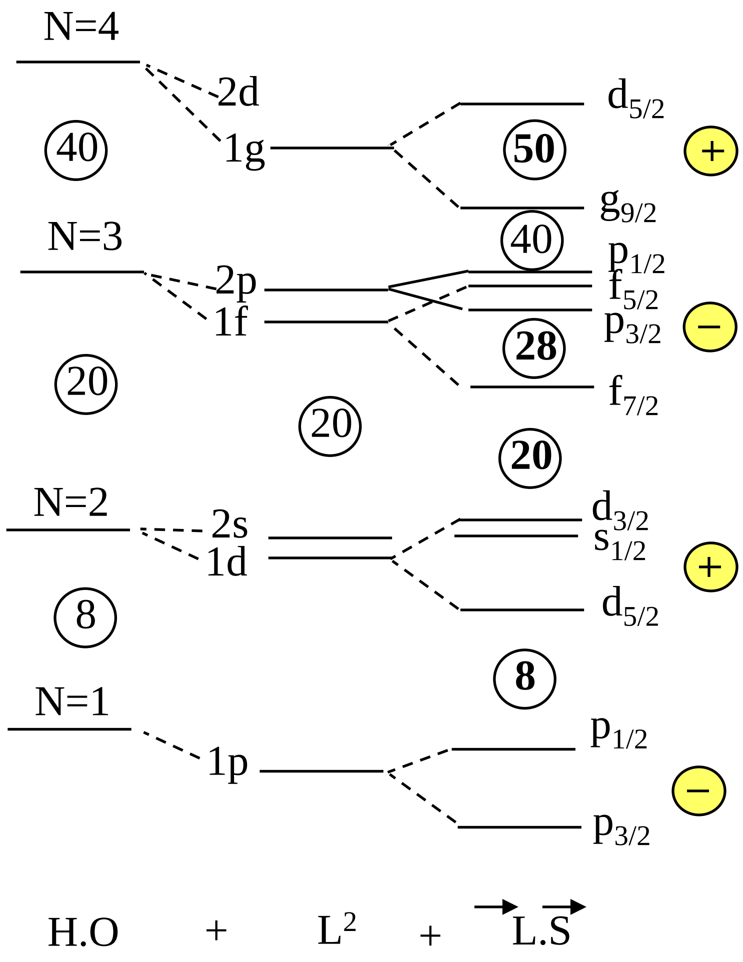
- Study of nuclei in the region of ^{78}Ni
  - Along Z=28
  - Along N=50
  - Beyond N=50
- Physics cases for SPES
- Experimental apparatus
- Summary/Remarks

Ductu naturae

Magic numbers and their evolution as a direct consequence of the character of the nuclear force.



The “spin-orbit” magic numbers



Reduction of N=50 gap by tensor force $\pi f_{5/2}$-νg
Behaviour of ^{78}Ni ?

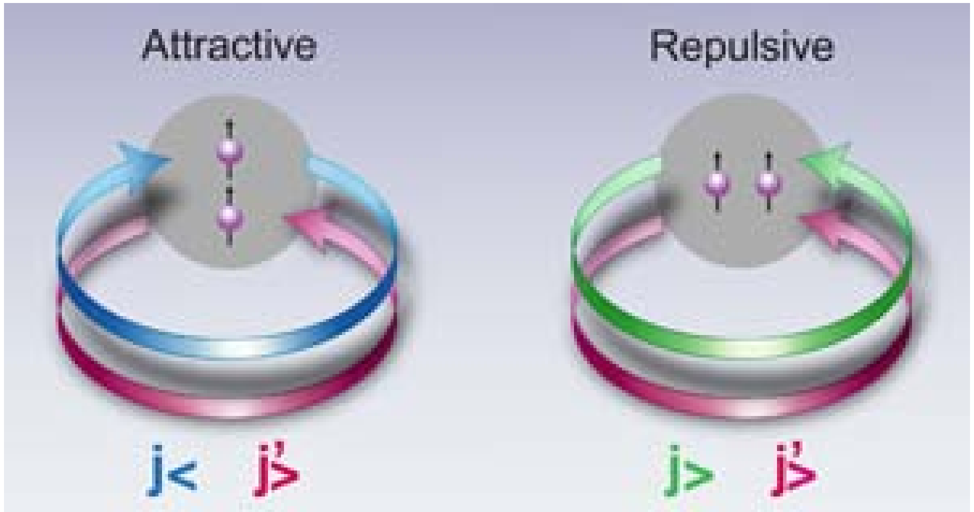
Reduction of N=28 gap by tensor force $\pi d_{3/2}$-νf
strongly deformed ^{42}Si

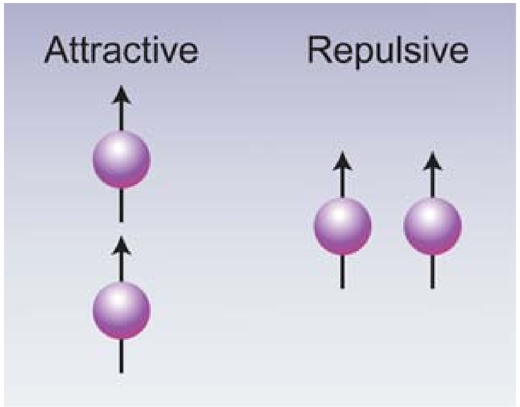
Reduction of N=20 triggered by $\pi d_{5/2}$-$\nu d_{3/2}$
Island of inversion, large collectivity

N=8 collapses at ^{12}Be
Triggered by the $\pi p_{3/2}$-$\nu p_{1/2}$ interaction

Tensor interaction

Systematic variation of effective single-particle energies due to the tensor interaction





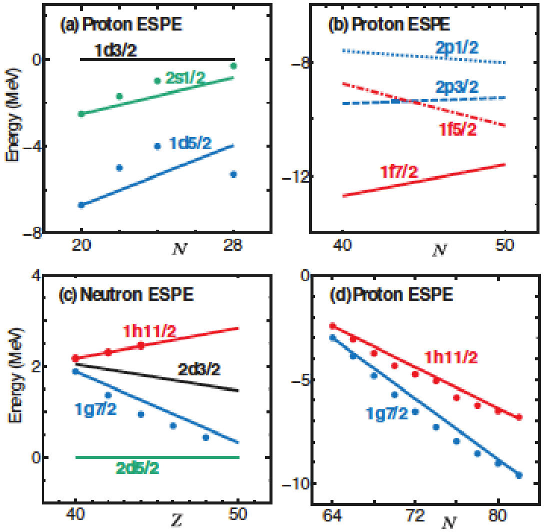
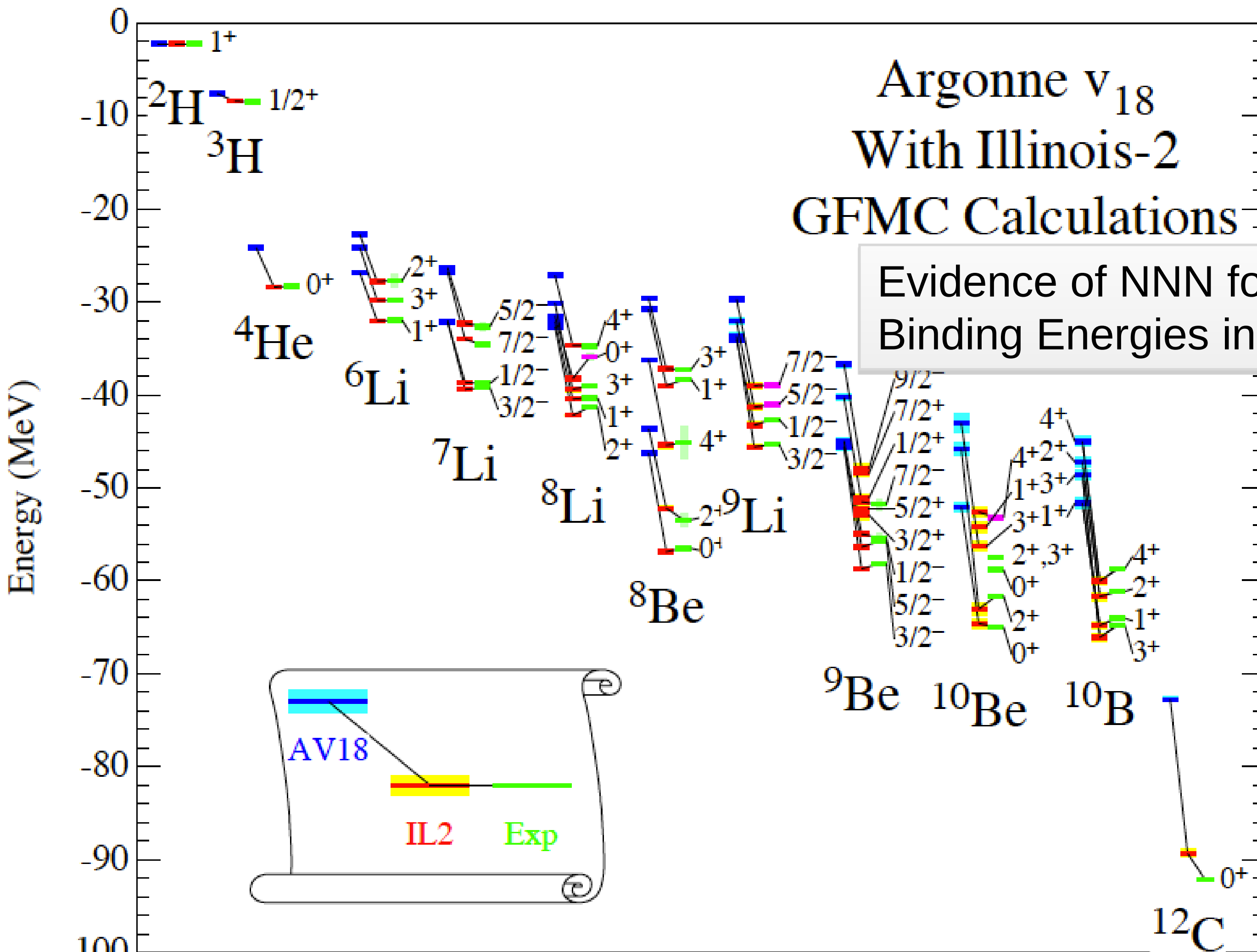


FIG. 4 (color). Proton (neutron) ESPE as a function of N (Z). Lines in (a)–(c) show the change of ESPE's calculated from the $\pi + \rho$ tensor force. Points represent the corresponding experimental data. (a) Proton ESPE's in Ca isotopes relative to $1d_{3/2}$. Points are from [13]. (b) Proton ESPE's 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).

$$V_T = (\tau_1 \tau_2)\,(\,[\sigma_1 \sigma_2]^{(2)}\, Y^{(2)}(\Omega)\,)\, Z(r)$$

T. Otsuka et al. PRL 95, 232502 (2005)

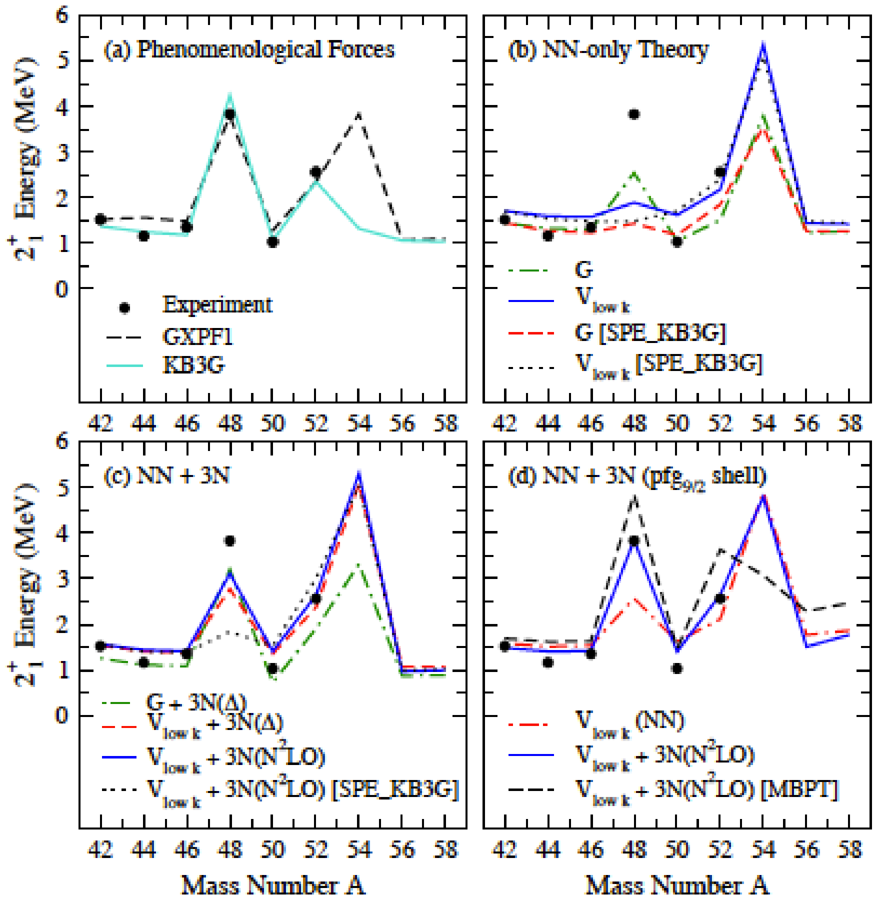
Indication of three body forces NNN



Evidence of NNN forces in the Binding Energies in light nuclei

Courtesy of C. Pipier, Argonne National lab.

NNN in the Ca region



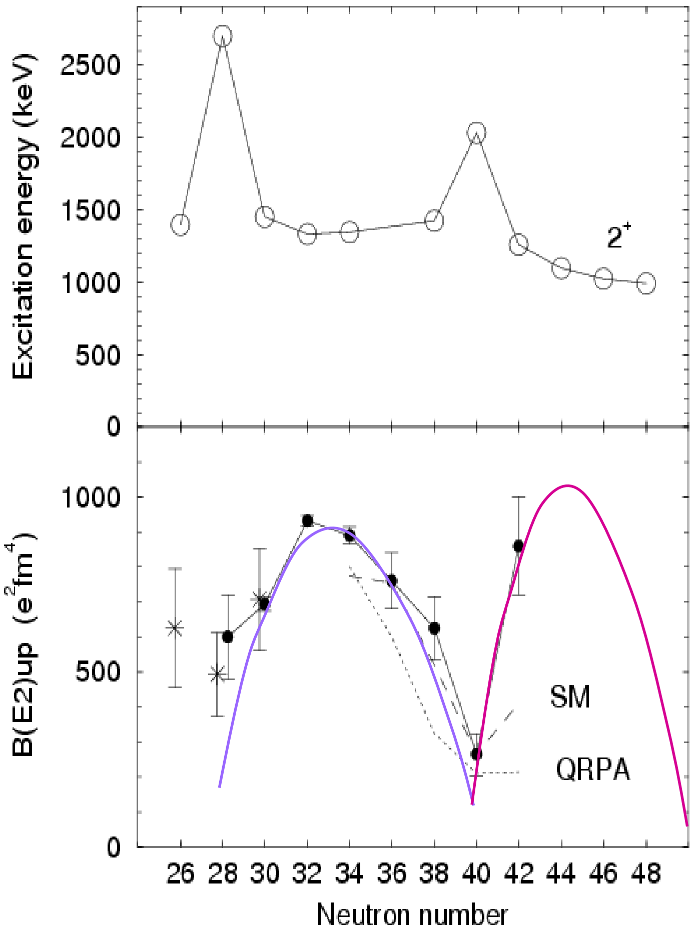
Microscopic calculations with well-established two-nucleon NN, do not reproduce N=28.

However NN and NN+3N forces predict the N=28 shell gap, but with quantitative differences.

The changes due to 3N forces are amplified in neutron-rich nuclei and will play a crucial role for matter at the extremes

T. Otsuka et al., PRL105, 032501 (2010)
J.D. Holt et al., arXiv:1009.5984v1 (2010)

Evolution along Z=28 - ^{78}Ni



O. Sorlin et al. PRL 88 (2002) 092501
O. Perru et al. PRL 96 (2006) 232501
G. Kraus et al. PRL 73 (1994) 1773.

The rigidity of the gap in ^{78}Ni is also an important issue in astrophysics because it is a waiting point in the r-process.

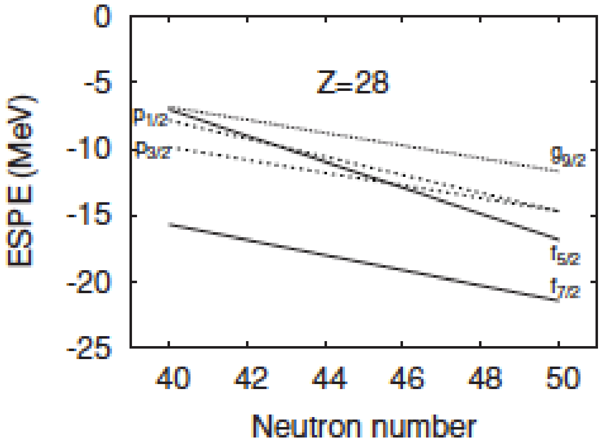
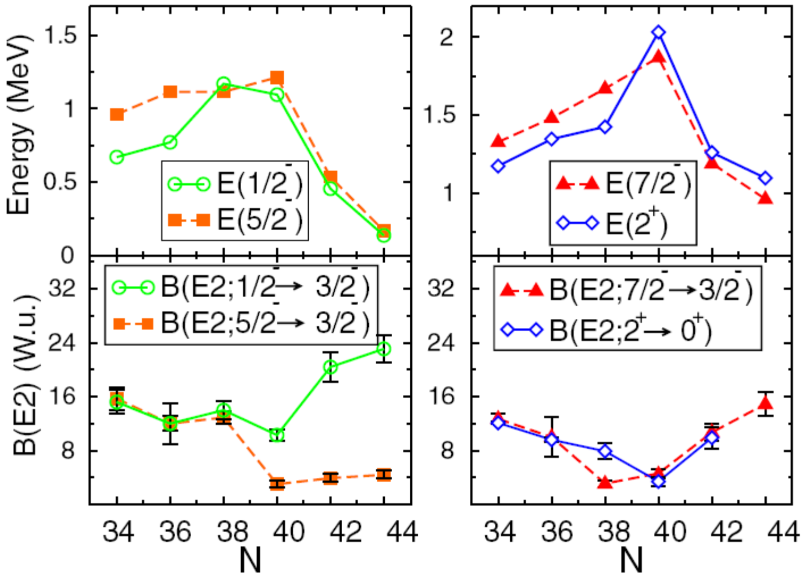


FIG. 1. Evolution of proton effective single-particle energies between ^{68}Ni and ^{78}Ni.

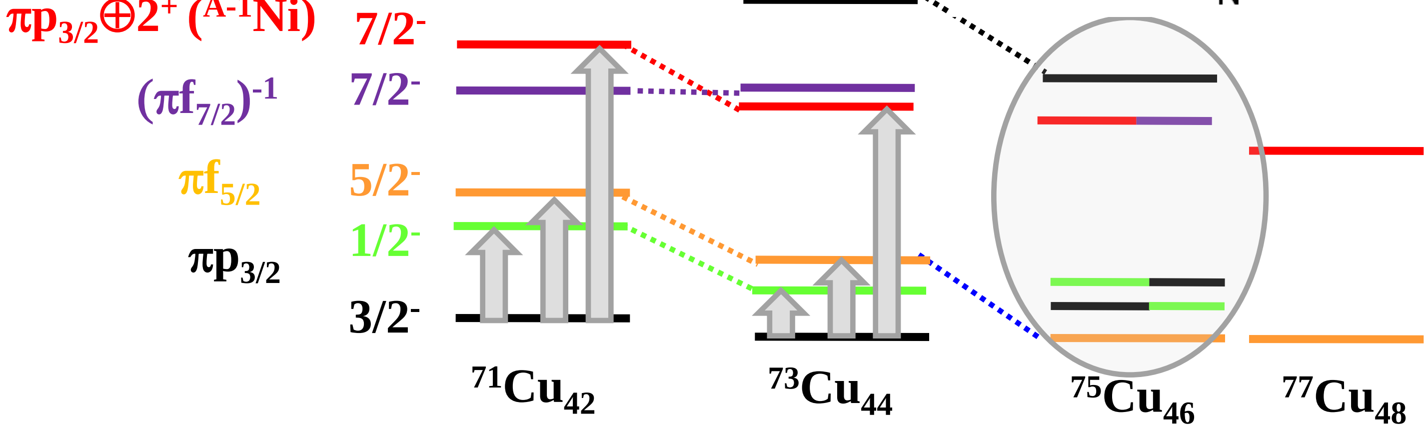
K. Sieja et al., PRC81, 061303 (2010)

Cu isotopes, Z=29

Collectivity of the $7/2_1^-$ state probe the $B(0^+ \rightarrow 2^+)$ in ^{76}Ni



Magnetic moment measurement confirmed the inversion of the $f_{5/2}$ with the $p_{3/2}$ in ^{75}Cu



S. Franchoo et al., PRL 81, 3100(1998), I. Stefanescu *et al.*, PRL 100, 112502 (2008) , K. Flanagan PRL, 103, 142501 (2009), J. M. Daugas PRC 81, 034304 (2010)

Along the N=50

Highly precision mass measurements

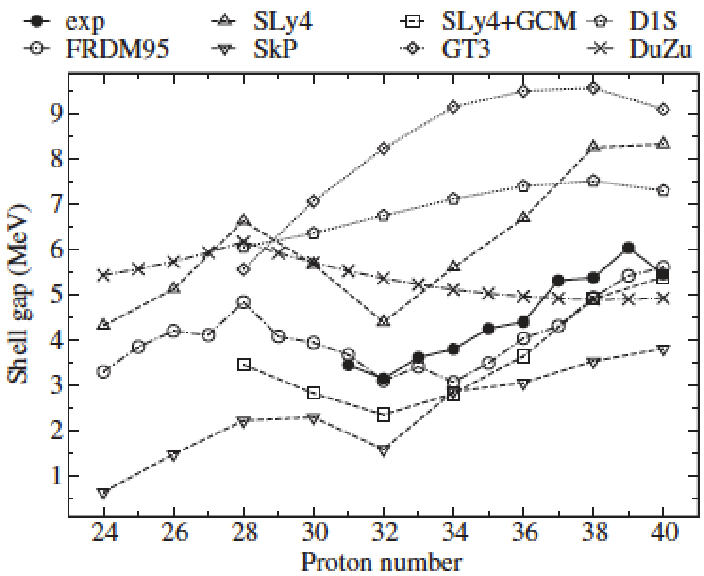


FIG. 4. Evolution of the $N = 50$ shell gap and comparison to theoretical models.

Two neutron shell gap energies

^{80}Zn Coulex

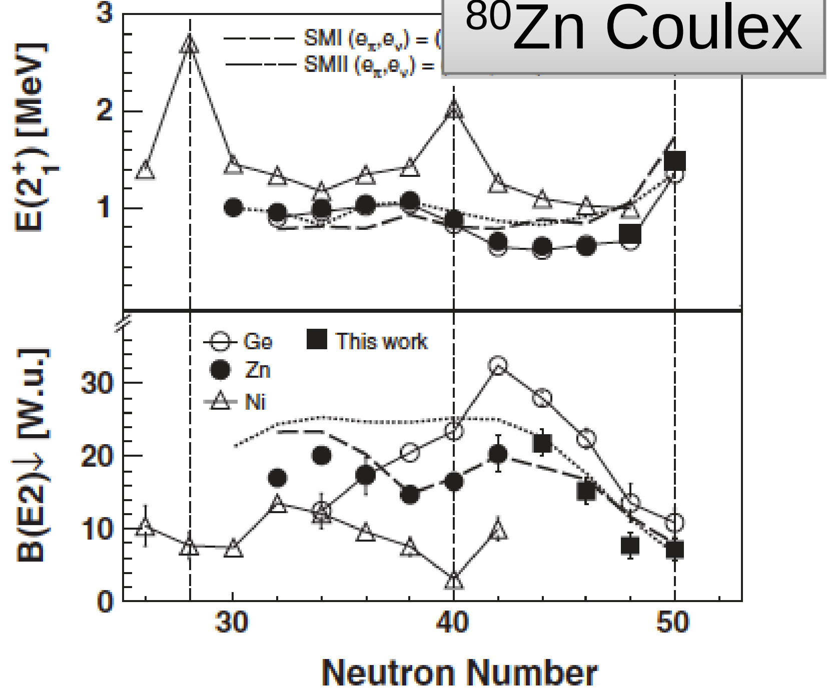
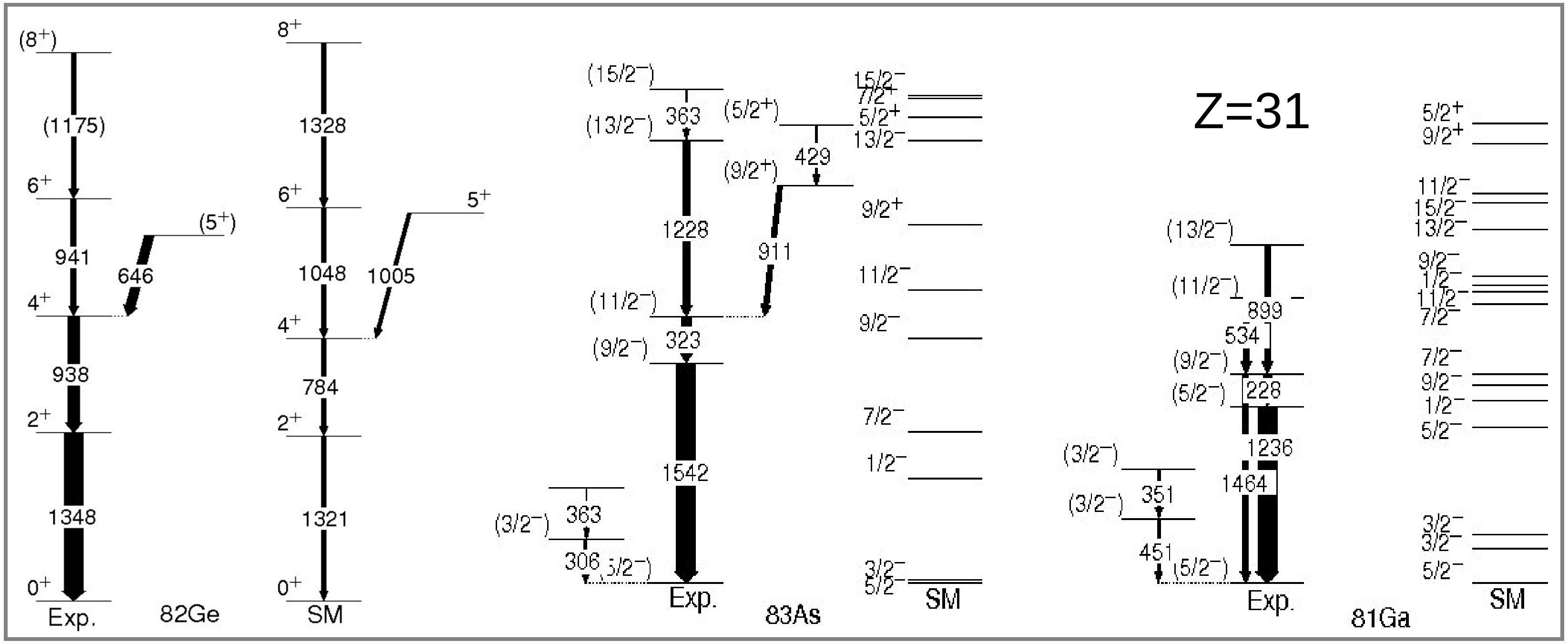


FIG. 2. $E(2^+_1)$ and $B(E2)\downarrow$ systematics for Ni ($Z = 28$), Zn ($Z = 30$), and Ge ($Z = 32$) isotopes. $B(E2)\downarrow$ values were taken from Refs. [6,7,9,10,18,30]. The dashed and dotted lines correspond to SM calculations for Zn isotopes.

J. Hakala et al., PRL101, 052502 (2008)

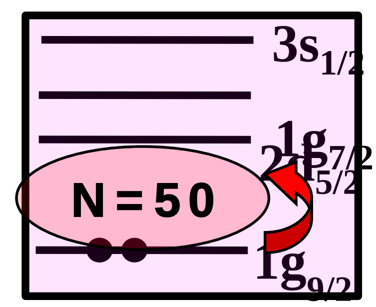
J. Van de Walle et al., PRL99, 142501 (2007)

The N=50 isotones



E. Sahin and G. De Angelis PLB (to be published)
Y.H. Zhang PRC70, 024301 (2004)

Shell Model calcuations: 2p-2h excitations across the N=50 shell to $2d_{5/2}$-$1g_{7/2}$-$3s_{1/2}$ (Lisetsky) for **4.7 MeV** of the shell gap value→No reduction of the shell gap



Beyond N=50 - Deformation

The land of deformation south of ^{68}Ni

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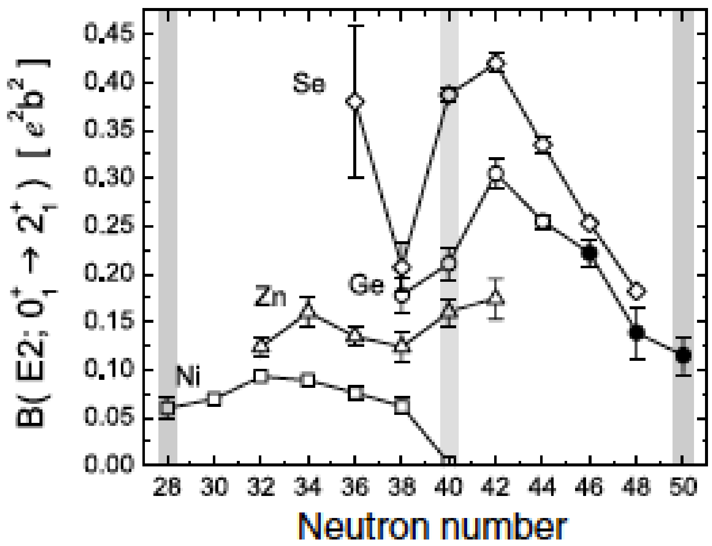
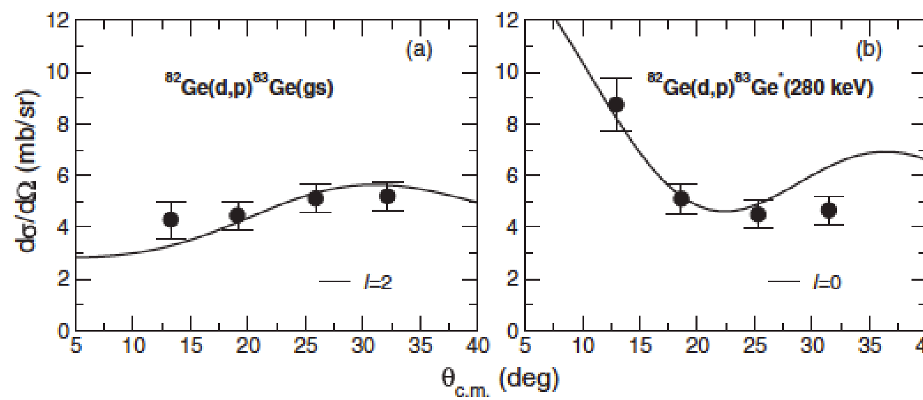
(Dated: September 10, 2010)

Involvement of the quasi-SU(3) in the explanation of the deformation in the N=40 region

^{78,80,82}Ge Coulex



^{84}Se(d,p)^{85}Se (N=51)



Proton angular distributions for GS and 462keV Ex

- Coulex: ^{78,80,82}Ge E. Padilla-Rodal et al., PRL94, 122501 (2005)
- Relativistic Coulex + knockout: ^{82}Ge and ^{84}Se A. Gade et al., PRC81, 064326 (2010)
- (d,p): ^{83}Ge and ^{85}Se: J.S. Thomas et al., PRC76, 044302 (2007)

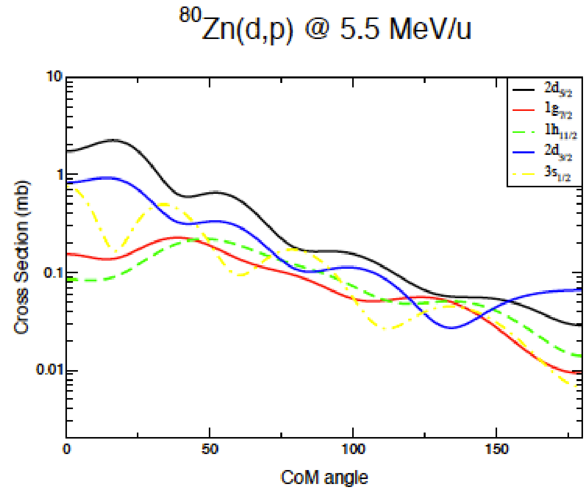
Physics cases considered

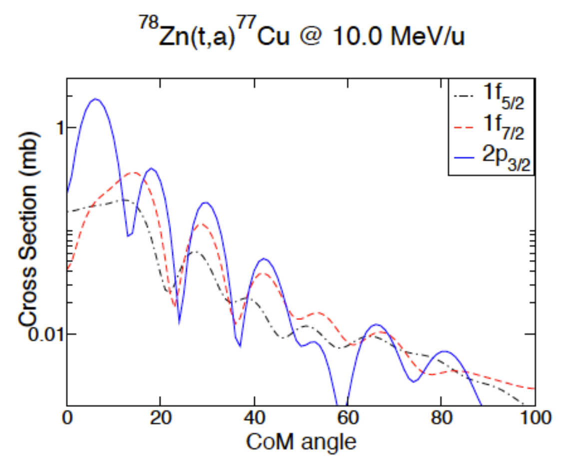
- Coulomb excitation neutron-rich ^{86,88}Se and ^{84}Ge – Evolution of deformation quasi-SU(3).

- Coulomb excitation ^{73,75,77}Cu, population of collective states - Infer deformation on the Ni isotopes.

- (d,p) ^{81,82}Ga, ^{79,80}Zn – single particle orbital around N=50 $g_{9/2}$, $d_{5/2}$, $s_{1/2,}$ $d_{3/2}$ and $g_{7/2}$.Gap stability

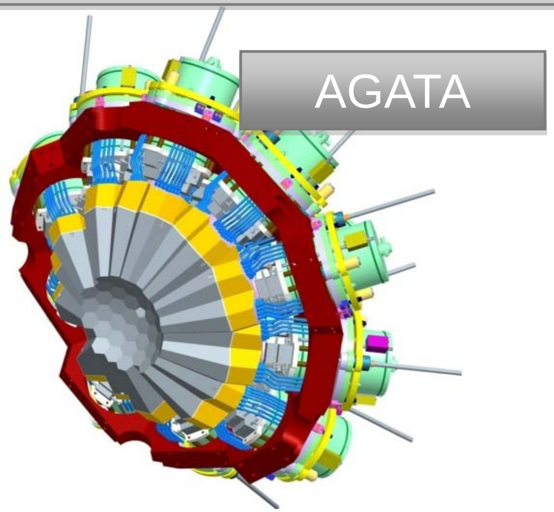
- (t,α) to selectively populate single proton states in odd-A ^{73,75,77,79}Cu isotopes- $p_{3/2}$, $f_{5/2}$ and $f_{7/2}$. Proton removal from the GS of Zn.

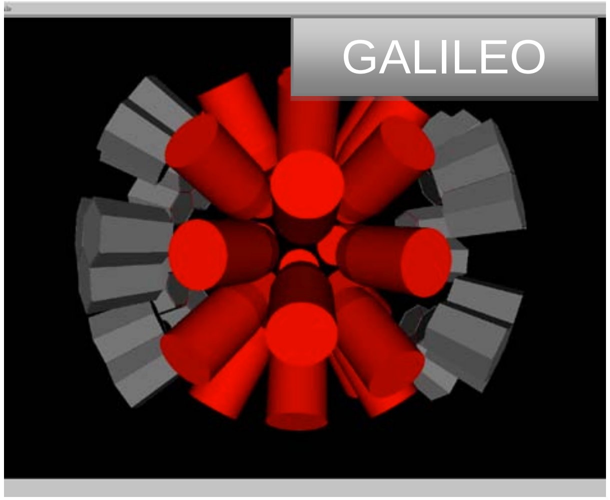




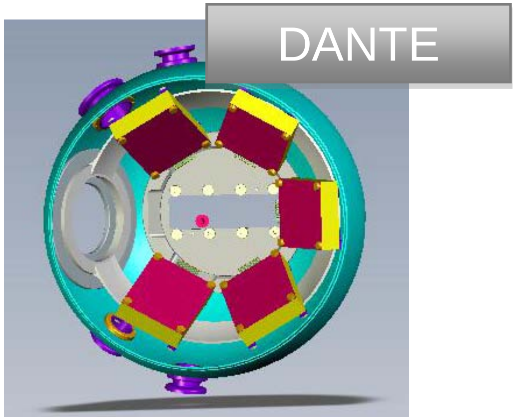
Detection systems

Gamma ray arrays





Charged particle/heavy ion detectors



Summary

- Study of the low-lying properties of isotopes near by ^{78}Ni and beyond N=50 with the SPES beams.
- Shell evolution in the region – Tensor interaction, rigidity of the gaps when going towards ^{78}Ni
- Changes due to 3N forces are amplified in neutron-rich nuclei and will play a crucial role for matter at the extremes.
- Use of Coulomb excitation, (d,p) and (t,α) reactions to study the region
- Sensitive detection systems to be used like: AGATA, GALILEO, TRACE, DANTE
- There is no a universal technique to measure the physical properties along an isotopic chain
- Concerns: beam purity > 20%, intensity10^3-10^4, energy 10MeV/u