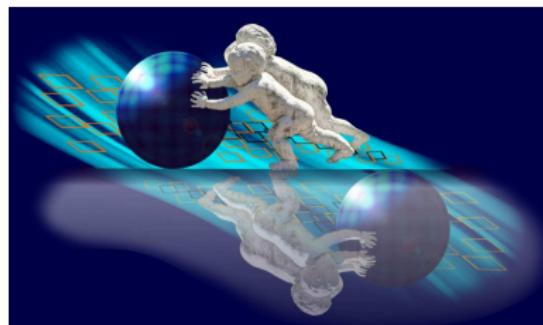


Model Stability From Shell Far

Frédéric Nowacki



SSNET'16 International Workshop, November 7th-11th 2016

Shell Model Far From Stability: Iol Mergers

Frédéric Nowacki



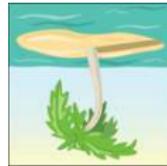
SSNET'16 International Workshop, November 7th-11th 2016

The Archipelago of Islands of Inversion



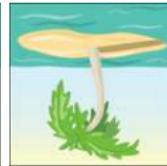
N=8

^{11}Li



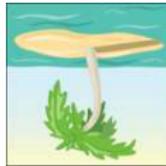
N=20

^{32}Mg



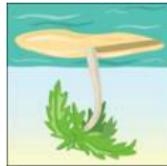
N=28

^{42}Si



N=40

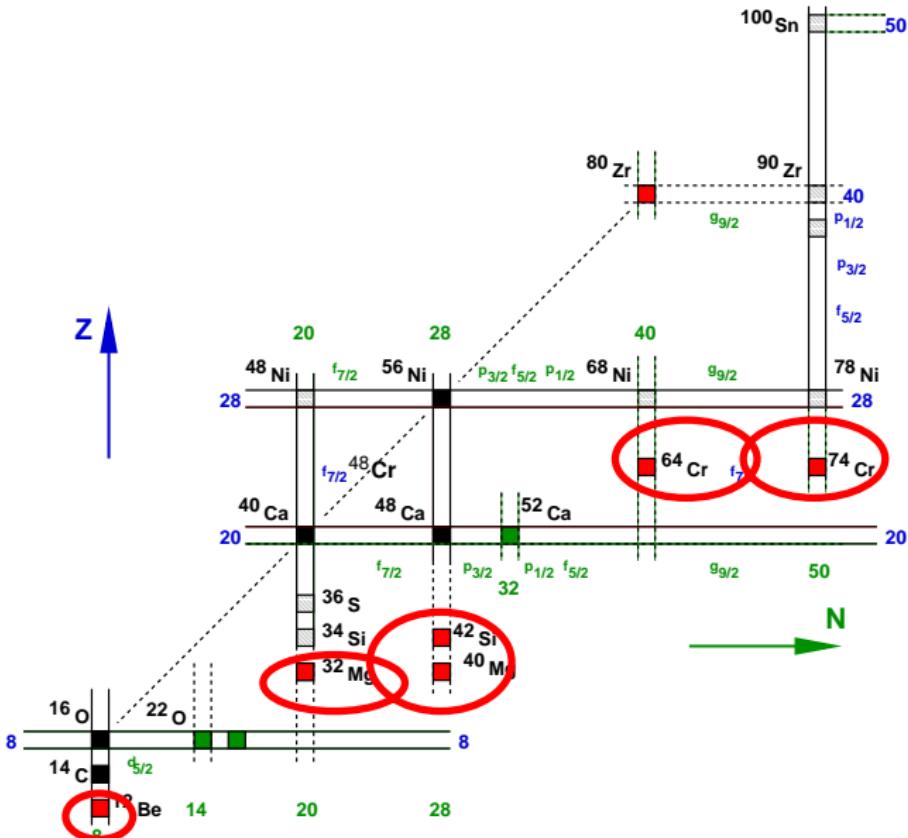
^{64}Cr



N=50

^{74}Cr

Landscape of medium mass nuclei: Mergers



N=40: SM framework

PHYSICAL REVIEW C 82, 054301 (2010)

Island of inversion around ^{64}Cr



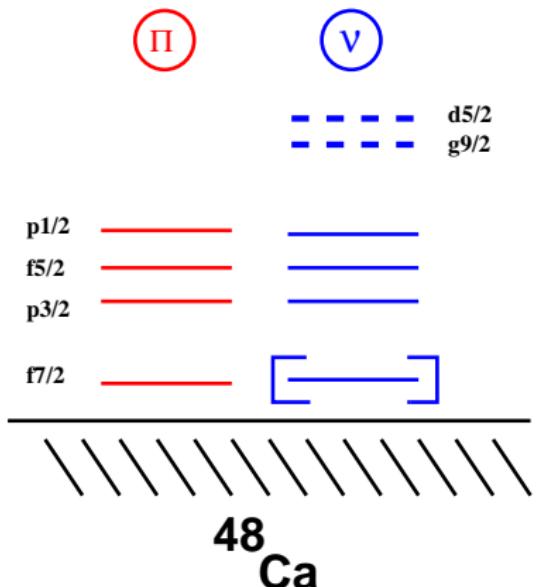
S. M. Lenzi,¹ F. Nowacki,² A. Poves,³ and K. Sieja^{2,*}

¹Dipartimento di Fisica dell'Università and INFN, Sezione di Padova, I-35131 Padova, Italy

²IPHC, IN2P3-CNRS et Université de Strasbourg, F-67037 Strasbourg, France

³Departamento de Física Teórica e IFT-UAM/CSIC, Universidad Autónoma de Madrid, E-28049 Madrid, Spain

(Received 10 September 2010; published 2 November 2010)



LNPS interaction:

- based on realistic TBME
- new fit of the pf shell (KB3GR, E. Caurier)
- monopole corrections
- $g_{9/2}-d_{5/2}$ gap now constrained to 2.5 Mev in ^{68}Ni

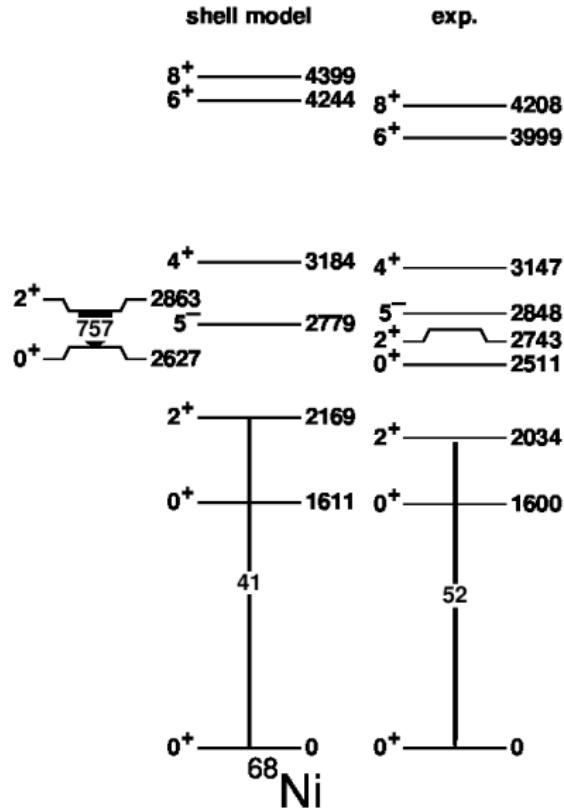
Calculations:

- Up to $14\hbar\omega$ excitations across $Z=28$ and $N=40$ gaps
- Matrix diagonalizations up to $2 \cdot 10^{10}$
- m-scheme code ANTOINE (non public parallel version)

Portal to lol at N=40: ^{68}Ni

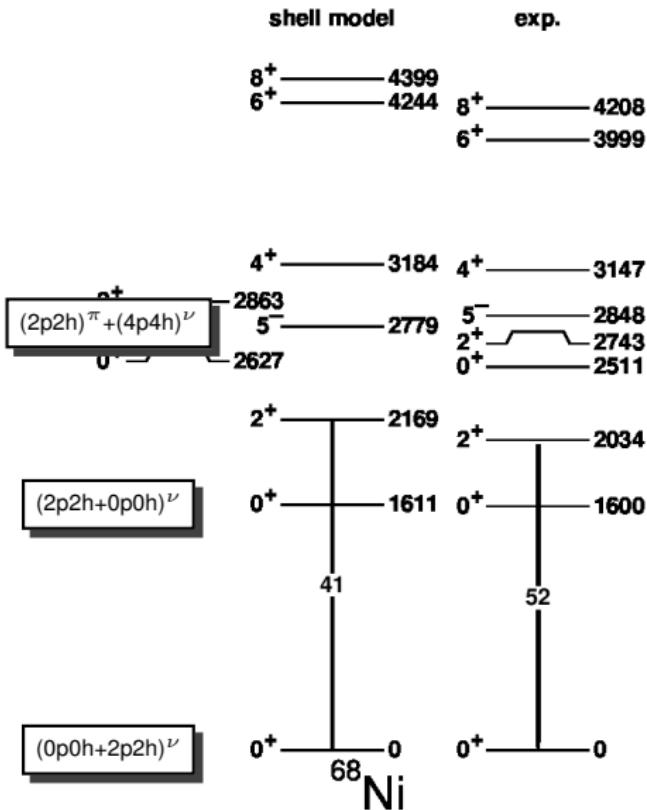
- at first approximation, ^{68}Ni has a double closed shell structure for GS
- But low lying structure much more complex
- three coexisting 0^+ states appear between 0 and ~ 2.5 MeV

- new location of 0_2^+ state !
Configuration mixing and relative transition rates between low-spin states in ^{68}Ni :
F. Recchia et al.
[Phys. Rev. C88, 041302\(R\) \(2013\)](#)
- prediction of very low-lying superdeformed band ($\beta_2 \sim 0.4$) of $6p6h$ nature!
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[Phys. Rev. C85, 0311301\(R\) \(2012\)](#)



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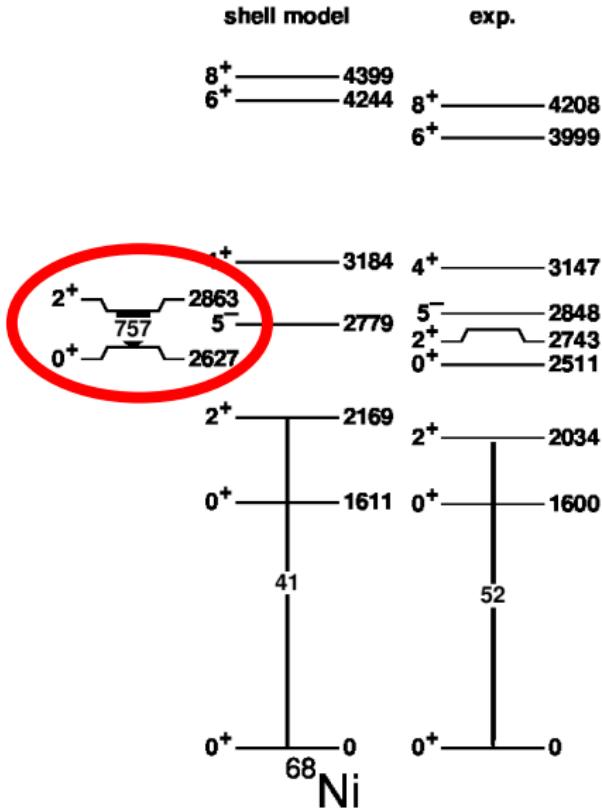


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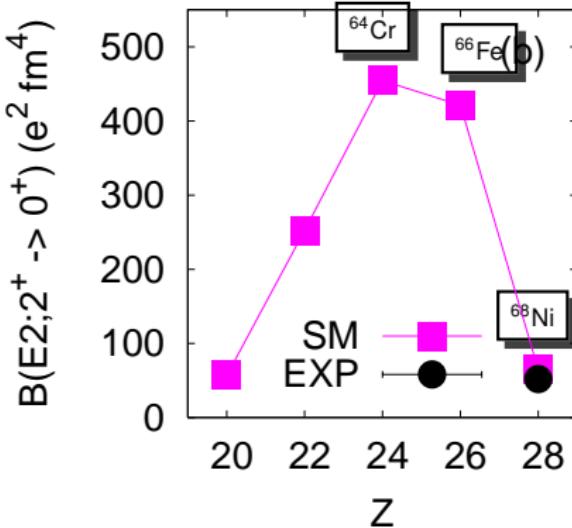
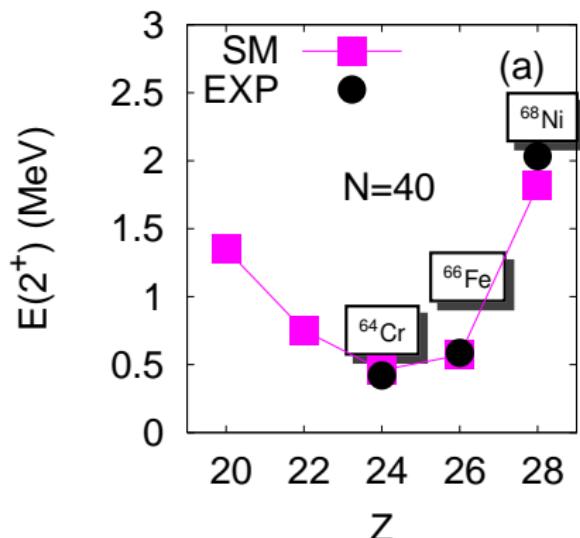
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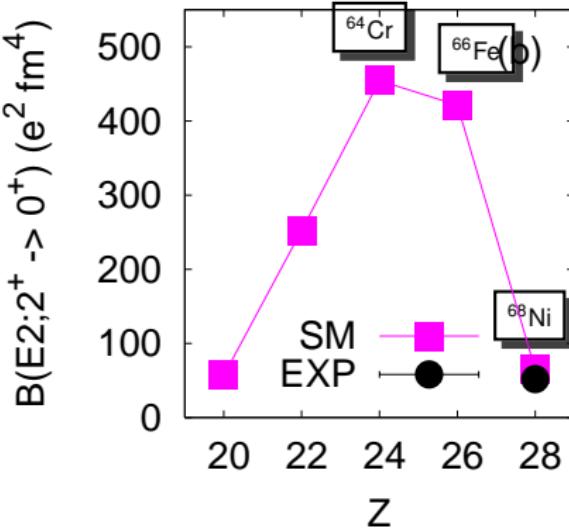
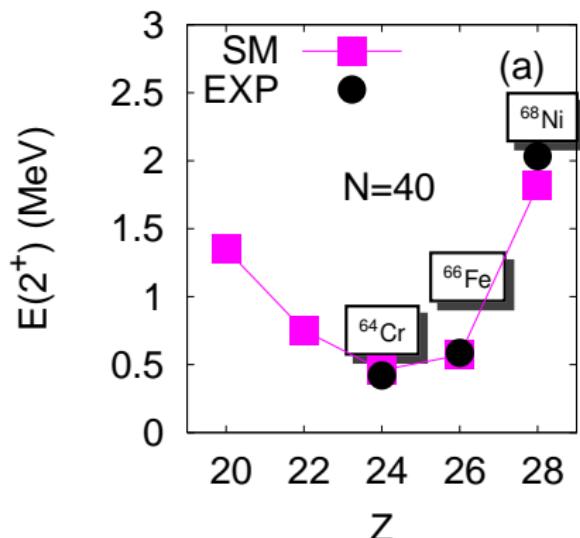


Shape transition at N=40



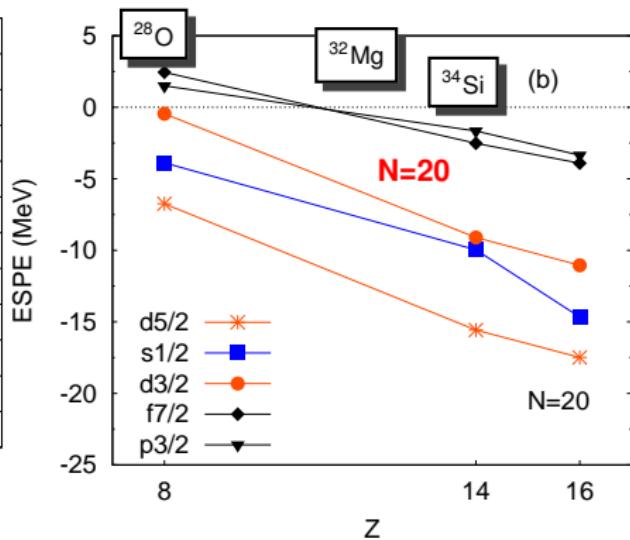
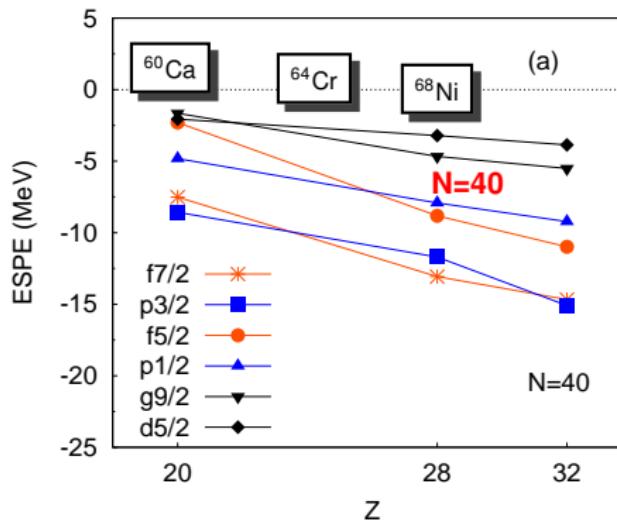
Nucleus	$\nu g_{9/2}$	$\nu d_{5/2}$	configuration
^{68}Ni	0.98	0.10	0p0h(51%)
^{66}Fe	3.17	0.46	4p4h(26%)
^{64}Cr	3.41	0.76	6p6h(23%)
^{62}Ti	3.17	1.09	4p4h(48%)

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Neutron effective single particle energies

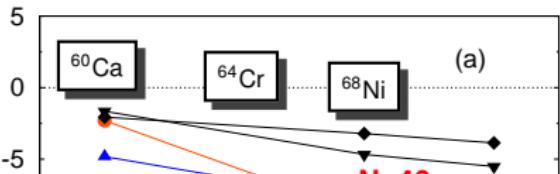


- reduction of the $\nu f_{5/2} - g_{9/2}$ gap with removing $f_{7/2}$ protons
- proximity of the quasi-SU3 partner $d_{5/2}$
- inversion of $d_{5/2}$ and $g_{9/2}$ orbitals
same ordering as CC calculations

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Neutron effective single particle energies

ECDE (MeV)



(a)

PRL 109, 032502 (2012)

PHYSICAL RE

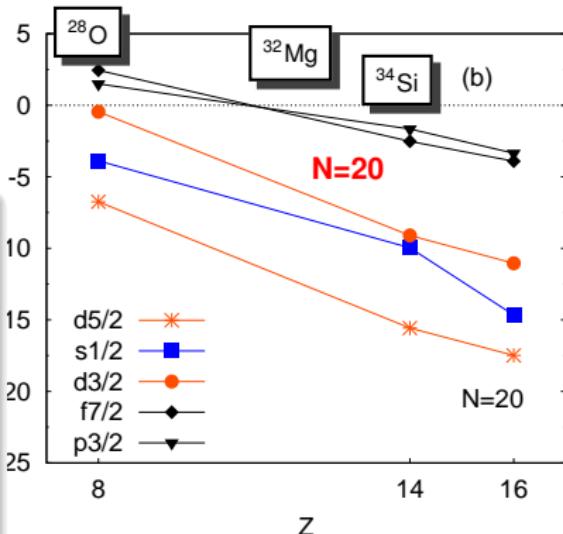
TABLE II. Energies of the $5/2^+$ and $9/2^+$ resonances in $^{53,55,61}\text{Ca}$. Re[E] is the energy relative to the one-neutron emission threshold, and the width is $\Gamma = -2\text{Im}[E]$ (in MeV).

^{53}Ca		^{55}Ca		^{61}Ca	
J^π	Re[E]	Γ	Re[E]	Γ	Re[E]
$5/2^+$	1.99	1.97	1.63	1.33	1.14
$9/2^+$	4.75	0.28	4.43	0.23	2.19

G. Hagen et al.

Phys. Rev. Lett. 109, 032502 (2012)

- removing $f_{7/2}$ protons
- proximity of the quasi-SU3 partner $d_{5/2}$
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Extension of collectivity N=40 towards N=50

PRL 115, 192501 (2015)

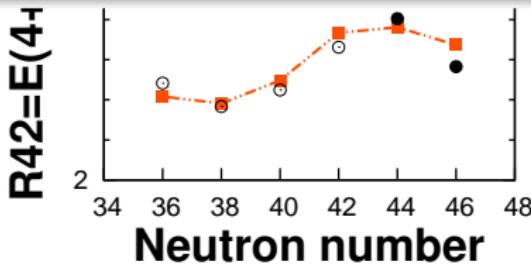
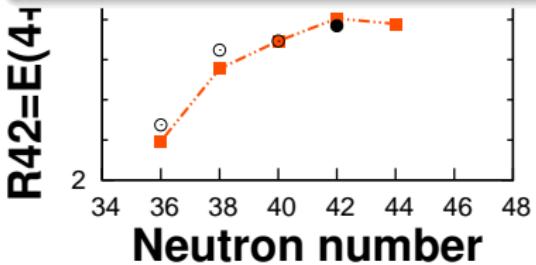
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week ending
6 NOVEMBER 2015

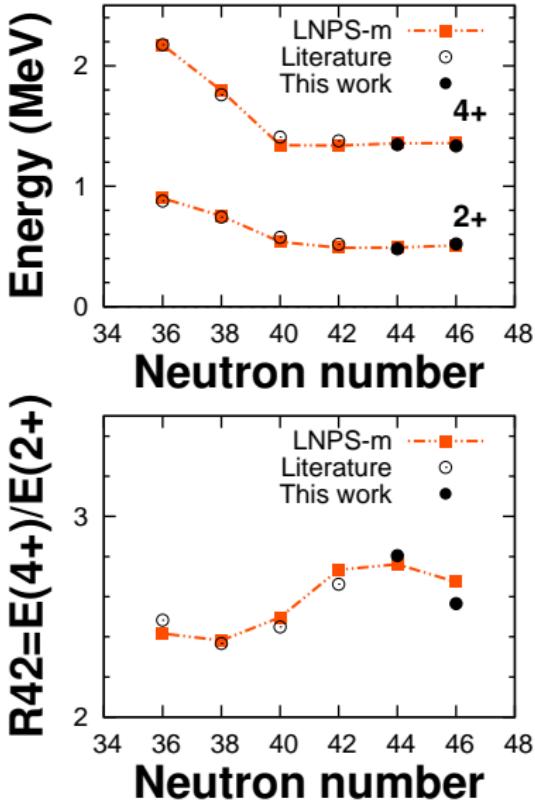
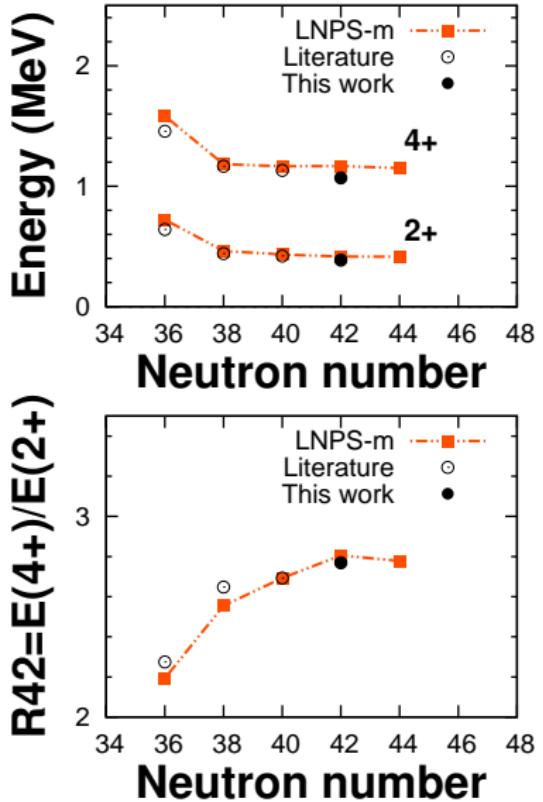
Extension of the $N = 40$ Island of Inversion towards $N = 50$: Spectroscopy of ^{66}Cr , $^{70,72}\text{Fe}$

C. Santamaría,² C. Louchart,³ A. Obertelli,^{1,2} V. Werner,^{3,4} P. Doornenbal,² F. Nowacki,⁵ G. Authelet,¹ H. Baba,² D. Carlet,¹ T. Château,¹ A. Corsi,¹ A. Delbart,¹ J.-M. Gheller,¹ A. Gillibert,¹ T. Isobe,² V. Lapoux,¹ M. Matsushita,⁶ S. Momiyama,^{2,7} T. Motobayashi,² M. Niikura,⁷ H. Otsu,² C. Péron,¹ A. Peyaud,¹ E. C. Pollacco,¹ J.-Y. Roussé,¹ H. Sakurai,^{2,7} M. Sasano,² Y. Shiga,^{2,8} S. Takeuchi,² R. Taniuchi,^{2,7} T. Uesaka,² H. Wang,² K. Yoneda,² F. Browne,⁹ L. X. Chung,¹⁰ Zs. Dombradi,¹¹ S. Franchoo,¹² F. Giacoppo,¹³ A. Gottardo,¹² K. Hadynska-Klek,¹³ Z. Korkulu,¹¹ S. Koyama,^{2,7} Y. Kubota,^{2,6} J. Lee,¹⁴ M. Lettmann,³ R. Lozeva,⁵ K. Matsui,^{2,7} T. Miyazaki,^{2,7} S. Nishimura,² L. Olivier,¹² S. Ota,⁶ Z. Patel,¹⁵ N. Pietralla,³ E. Sahin,¹³ C. Shand,¹⁵ P.-A. Söderström,² I. Stefan,¹² D. Steppenbeck,⁶ T. Sumikama,¹⁶ D. Suzuki,¹² Zs. Vajta,¹¹ J. Wu,^{2,17} and Z. Xu¹⁴

FIRST MINOS Experiment at RIKEN



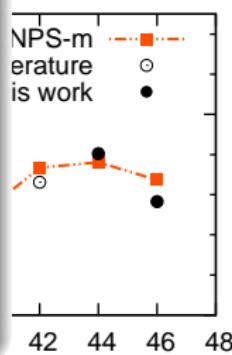
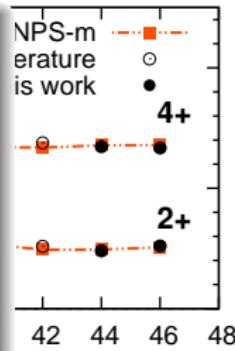
Extension of collectivity N=40 towards N=50



Extension of collectivity N=40 towards N=50

TABLE I: Quadrupole deformation properties of Cr and Fe isotopes. Energies are in MeV, $B(E2)$ in $e^2 \text{ fm}^4$, and Q in $e \text{ fm}^2$. Experimental energies are the same as Fig. 3.

	^{62}C	^{64}Cr	^{66}Cr	^{68}Cr	^{66}Fe	^{68}Fe	^{70}Fe	^{72}Fe
$E^*(2_1^+)$ exp.	0.44	0.42	0.39	-	0.57	0.52	0.48	0.52
$E^*(2_1^+)$ theo.	0.46	0.43	0.42	0.41	0.54	0.49	0.49	0.51
Q_{spec}	-38	-38	-39	-38	-37	-40	-39	-33
$B(E2) \downarrow$ th.	378	388	389	367	372	400	382	279
Q_{int} from Q_{spec}	135	136	137	132	131	140	135	116
Q_{int} from $B(E2)$	138	140	140	136	137	142	139	118
$<\beta>$	0.33	0.33	0.32	0.30	0.29	0.30	0.28	0.24
$E^*(4_1^+)$ exp.	1.17	1.13	1.07	-	1.41	1.39	1.35	1.33
$E^*(4_1^+)$ theo.	1.18	1.13	1.06	1.15	1.34	1.34	1.36	1.36
Q_{spec}	-49	-49	-46	-47	-47	-51	-48	-40
$B(E2) \downarrow$ th.	562	534	562	530	553	608	574	377
Q_{int} from Q_{spec}	135	134	134	130	129	141	132	111
Q_{int} from $B(E2)$	141	140	141	137	139	146	142	115
$<\beta>$	0.34	0.33	0.32	0.31	0.29	0.30	0.29	0.23

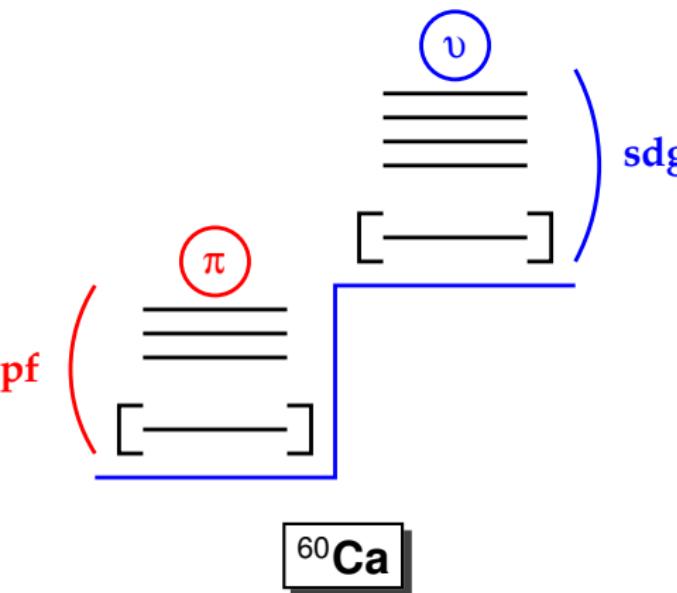


R42=E(4+)/E(2+) Energy (MeV)

Neutron number

Neutron number

Physics around ^{78}Ni



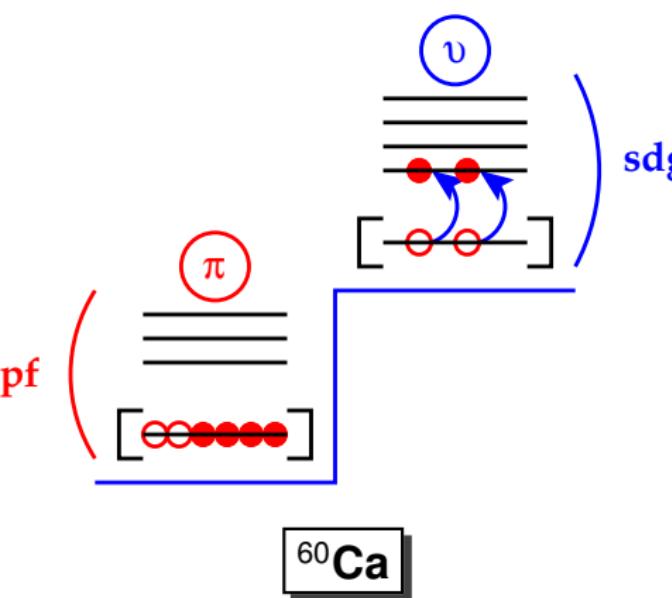
PFSDG-U interaction:

- realistic TBME
- pf shell for protons and gds shell for neutrons
- monopole corrections (3N forces)
- proton and neutrons gap ^{78}Ni fixed to phenomenological derived values

Calculations:

- excitations across $Z=28$ and $N=50$ gaps
- up to 2×10^{10} Slater Determinant basis states
- m-scheme code ANTOINE (non public version)
- J-scheme code NATHAN (parallelized version): 0.5×10^9 J basis states

Physics around ^{78}Ni



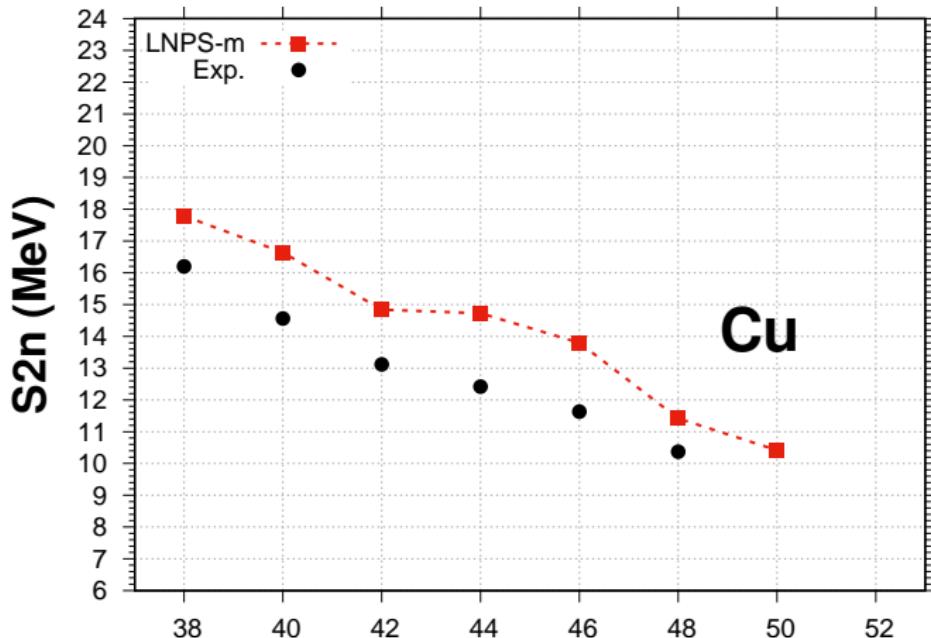
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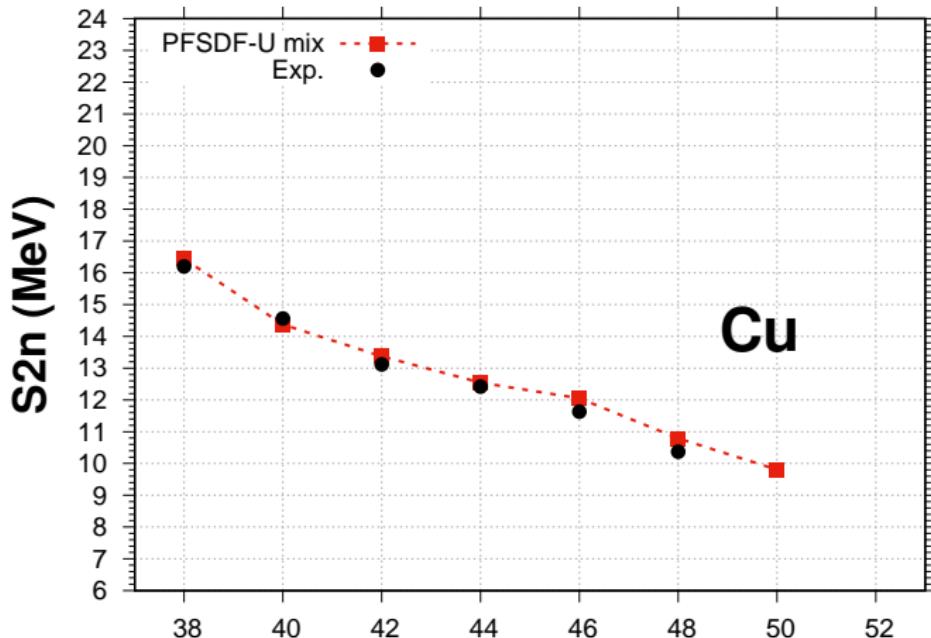
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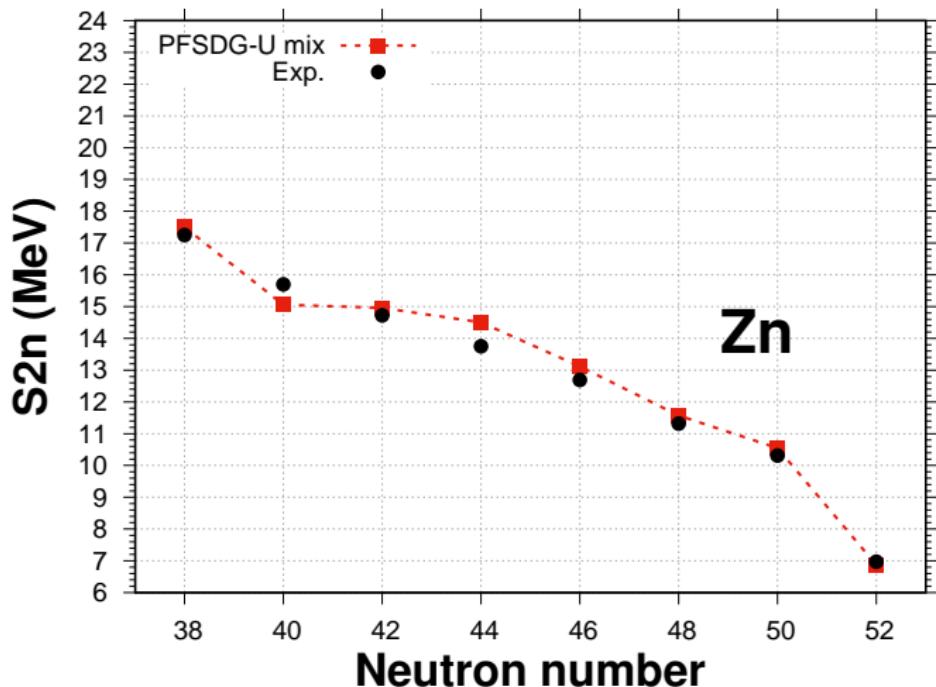
Neutron intruders constraints



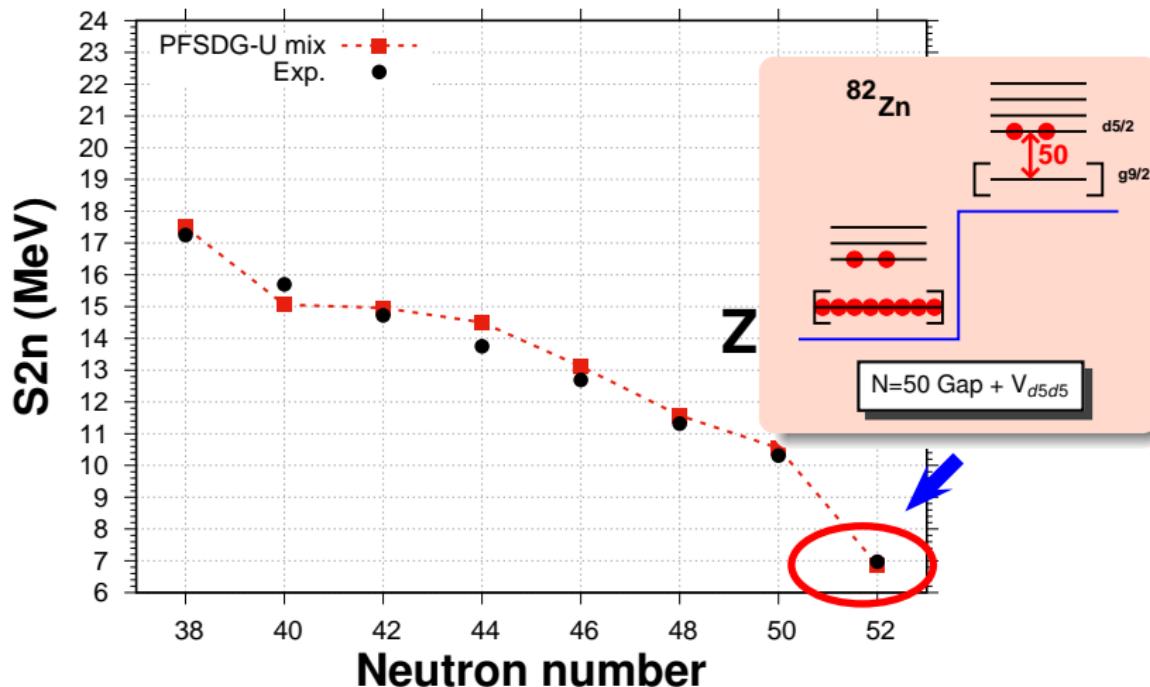
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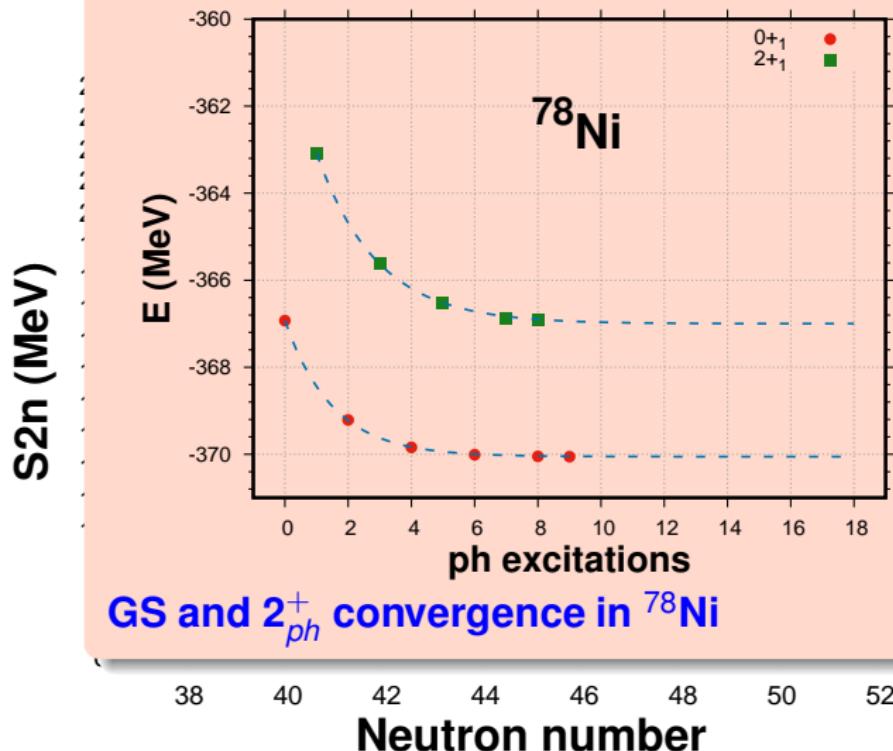
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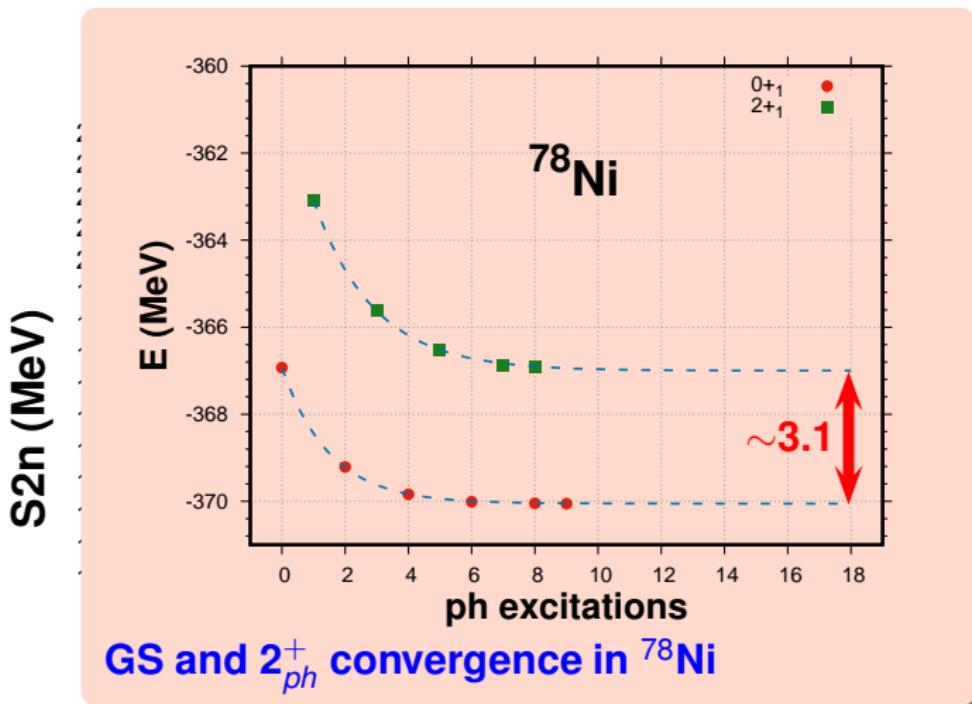
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Neutron intruders constraints



Neutron number

Spherical structure of ^{78}Ni

^{48}Ca (2^+) F [MeV]

PRL 117, 172501 (2016)

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week ending
21 OCTOBER 2016

Structure of ^{78}Ni from First-Principles Computations

G. Hagen,^{1,2} G. R. Jansen,^{3,1} and T. Papenbrock^{1,2}

¹*Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA*

²*Department of Physics and Astronomy, University of Tennessee, Knoxville, Tennessee 37996, USA*

³*National Center for Computational Sciences, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA*

(Received 4 May 2016; revised manuscript received 18 August 2016; published 17 October 2016)

Ab-initio CC predictions for ^{78}Ni

FIG. 2. Correlation between the energies of the 2_1^+ excited state in ^{48}Ca and ^{78}Ni , obtained from the interactions NNLO_{sat} (circle), “2.0/2.0 (PWA)” (square), “2.0/2.0 (EM)” (diamond), “2.2/2.0 (EM)” (triangle up), and “1.8/2.0 (EM)” (triangle down). The error bars estimate uncertainties from enlarging the model space from $N = 12$ to $N = 14$. The thin horizontal line marks the known energy of the 2_1^+ state in ^{48}Ca .

$N = 8$ $N = 10$ $N = 12$ $N = 14$ Exp

FIG. 3. Convergence of the first 2_1^+ excited state of ^{48}Ca and ^{78}Ni with increasing model-space size and compared to the data for the interaction 1.8/2.0 (EM) of Ref. [33].

Spherical structure of ^{78}Ni

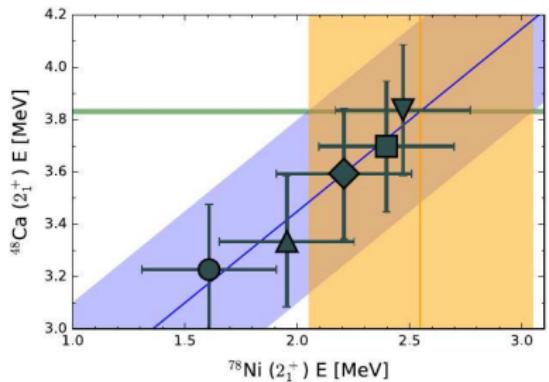


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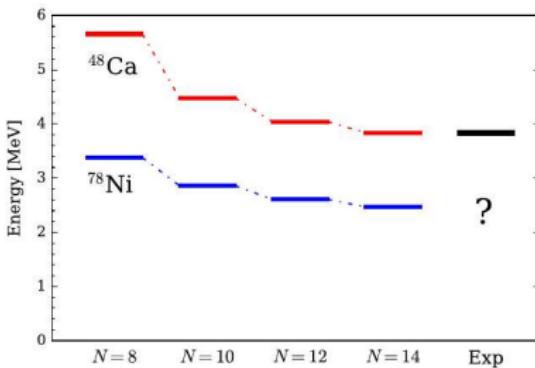


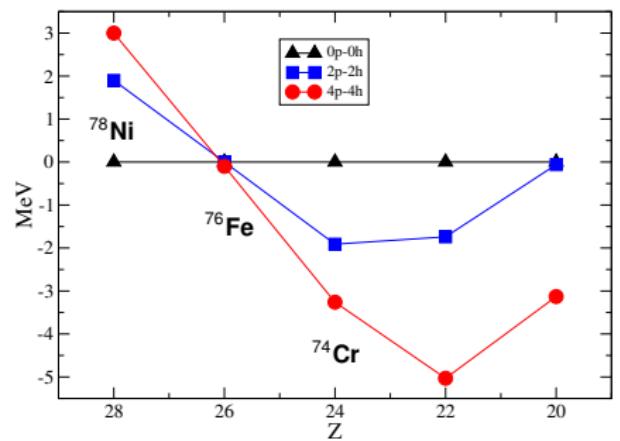
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Schematic SU3 predictions

PHYSICAL REVIEW C **92**, 024320 (2015)

Nilsson-SU3 self-consistency in heavy $N = Z$ nuclei

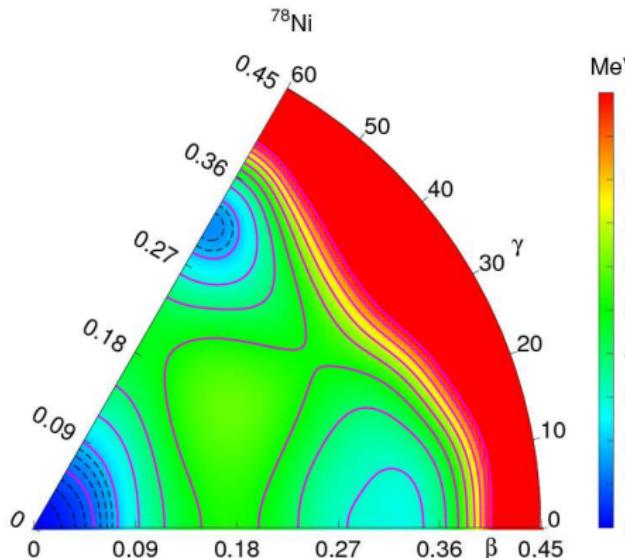
A. P. Zuker,¹ A. Poves,^{2,3} F. Nowacki,¹ and S. M. Lenzi⁴



- monopole + quadrupole model
- proton gap (5MeV) and neutron gap (5 MeV) estimates
- Quasi-SU3 (protons) and Pseudo-SU3 (neutrons) blocks
- $Q_s = (\langle 2q_{20} \rangle + 3.)b^2)^2/3.5$
- $E_n = G_n^{mp}(50) - \hbar\omega\kappa \left(\frac{\langle Q_0^m(\pi) \rangle}{15 b^2} + \frac{\langle Q_0^m(\nu) \rangle}{23 b^2} \right)^2$
- $G_n^{mp}(50) = n \left(\frac{3.0}{8} n_f^\pi + 2.25 \right) + \Delta(n) + \delta_p(n)$
- Prediction of Island of strong collectivity below ${}^{78}\text{Ni}$!!!

Shape coexistence in ^{78}Ni

- At first approximation, ^{78}Ni has a double closed shell structure for GS
- But very low-lying competing structures
- From the diagonalization, the first excited states in ^{78}Ni are :
 - $0_2^+ - 2_1^+$ predicted at 2.6-2.9 MeV and to be deformed intruders of a **rotational band !!!**
- “1p1h” 2_2^+ predicted at ~ 3.1 MeV
- Necessity to go **beyond (fpg $\frac{9}{2}$, d $\frac{5}{2}$) LNPS space** and **beyond ab-initio description**
- Portal to a new **Island of Inversion**

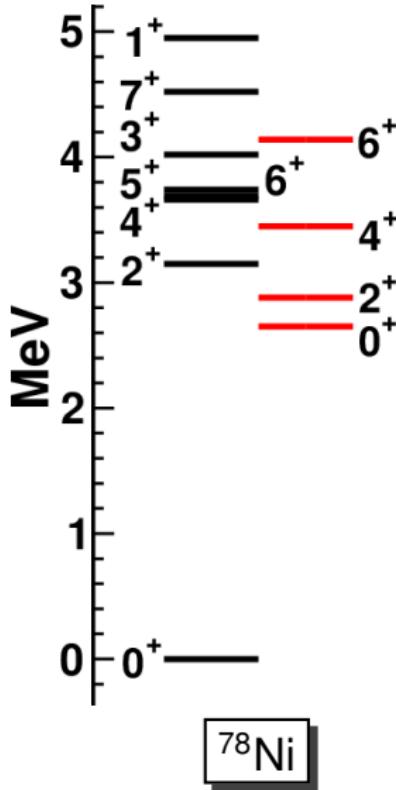


Constrained deformed HF in the SM basis

(B. Bounthong, PhD Thesis,
Strasbourg)

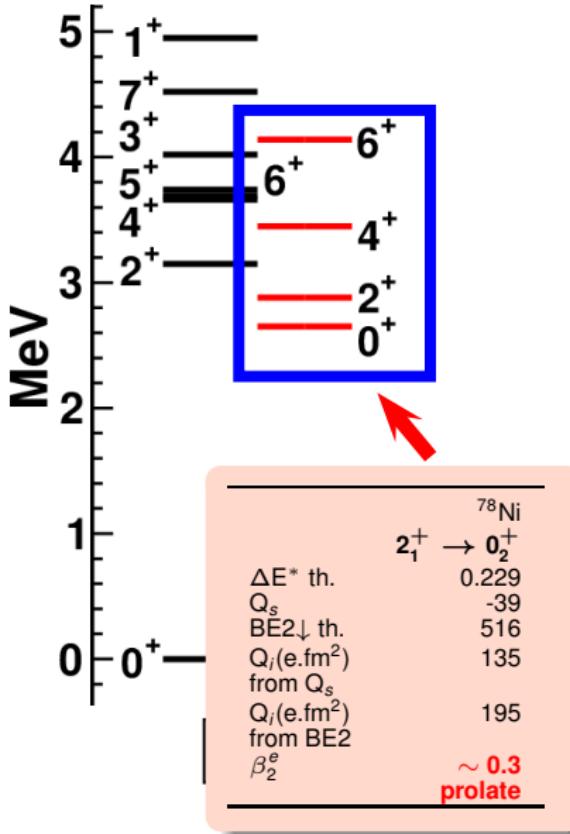
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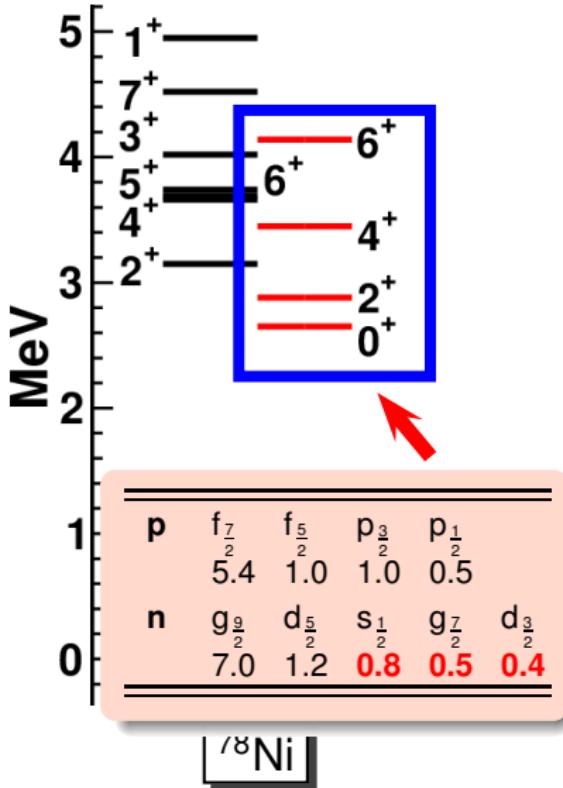
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- Necessity to go **beyond ($fpg_{\frac{9}{2}}d_{\frac{5}{2}}$) LNPS space** and **beyond ab-initio description**
- Portal to a new Island of Inversion

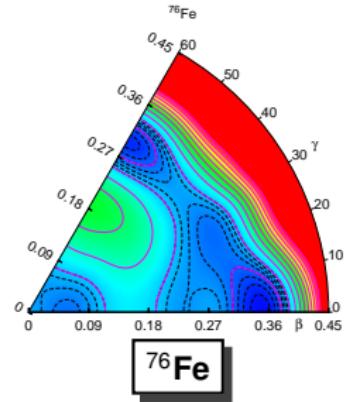
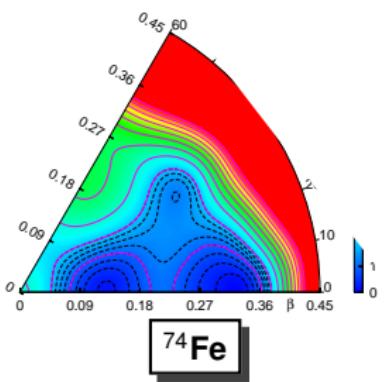
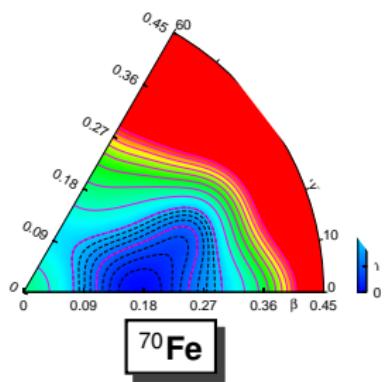
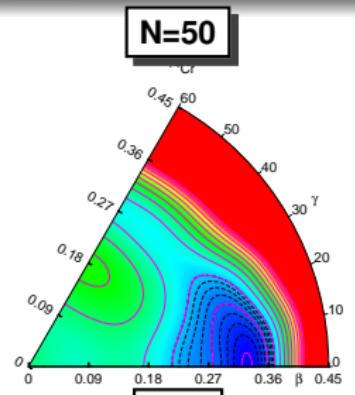
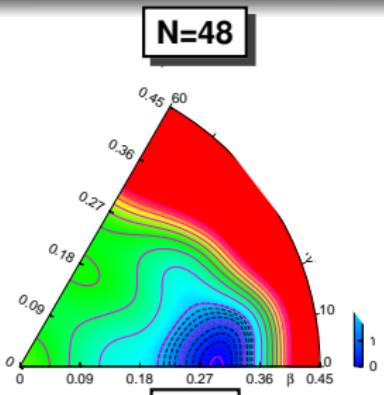
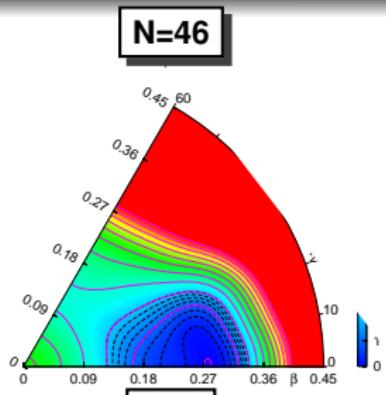


Shape coexistence in ^{78}Ni

- At first approximation, ^{78}Ni has a double closed shell structure for GS
- But very low-lying competing structures
- From the diagonalization, the first excited states in ^{78}Ni are :
 - $0_2^+ - 2_1^+$ predicted at 2.6-2.9 MeV and to be deformed intruders of a **rotational band !!!**
- “1p1h” 2_2^+ predicted at ~ 3.1 MeV
- Necessity to go **beyond ($fpg_{\frac{9}{2}}d_{\frac{5}{2}}$) LNPS space** and **beyond ab-initio description**
- Portal to a new Island of Inversion

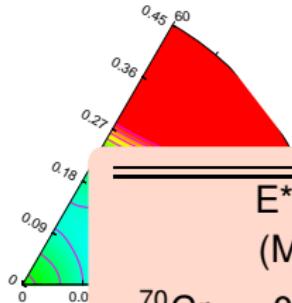


Island of Deformation below ^{78}Ni : PES's

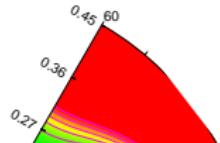


Island of Deformation below ^{78}Ni : PES's

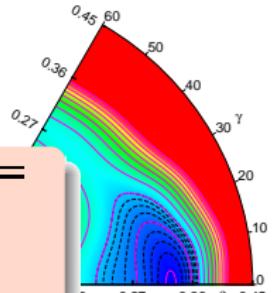
N=46



N=48

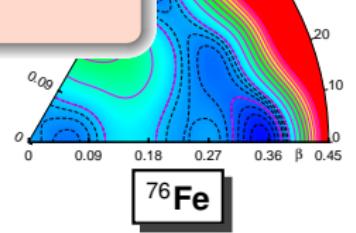
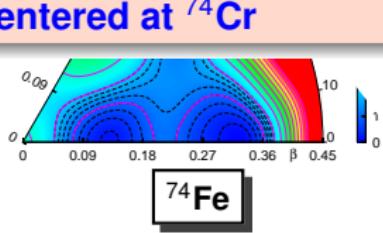
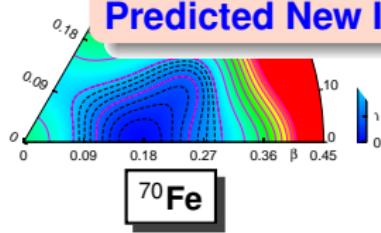


N=50

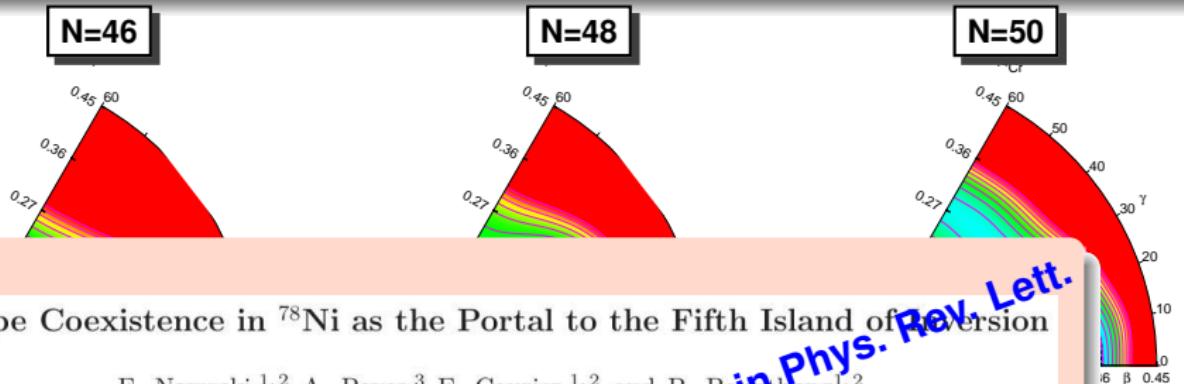


	$E^*(2_1^+)$ (MeV)	Q_s (e.fm ²)	$\text{BE}2\downarrow$ (e ² .fm ⁴)	Q_i^m (e.fm ²)	β^m
^{70}Cr	0.30	-41	420	340	0.26
^{72}Cr	0.23	-48	549	407	0.30
^{74}Cr	0.24	-51	630	552	0.39
^{72}Fe	0.44	-36	316	289	0.21
^{74}Fe	0.47	-39	330	308	0.22
^{76}Fe	0.35	-39	346	320	0.25

Predicted New Iol centered at ^{74}Cr



Island of Deformation below ^{78}Ni : PES's



Shape Coexistence in ^{78}Ni as the Portal to the Fifth Island of Inversion

F. Nowacki,^{1,2} A. Poves,³ E. Caurier,^{1,2} and B. Routhong^{1,2}

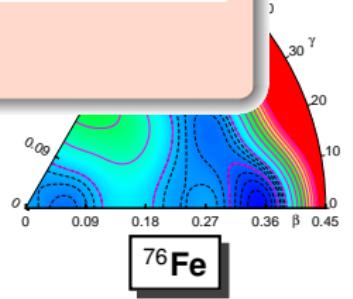
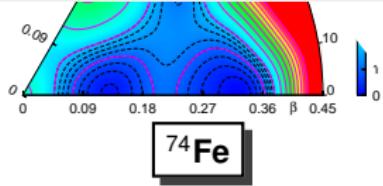
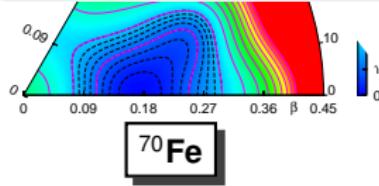
¹Université de Strasbourg, IPHC, 23 rue du Loess, F-67000 Strasbourg, France

²CNRS, UMR7178, 67037 Strasbourg, France

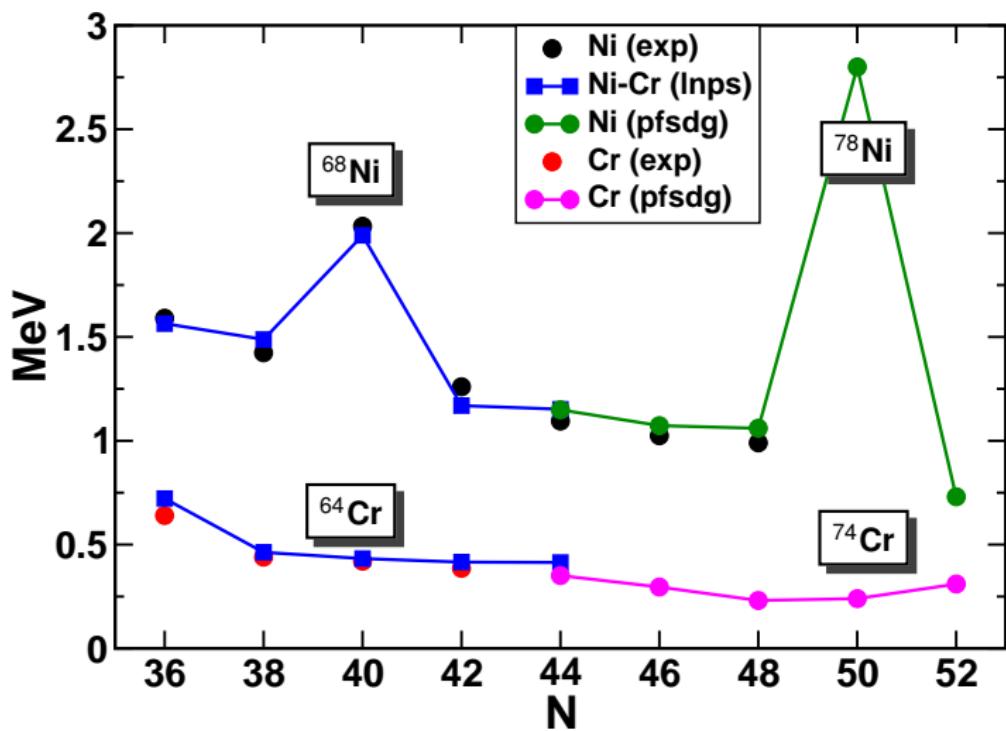
³Departamento de Física Teórica e IFT-UAM/CSIC,
Universidad Autónoma de Madrid, E-28049 Madrid, Spain
and Institute for Advanced Study, Université de Strasbourg

(Dated: October 7, 2016)

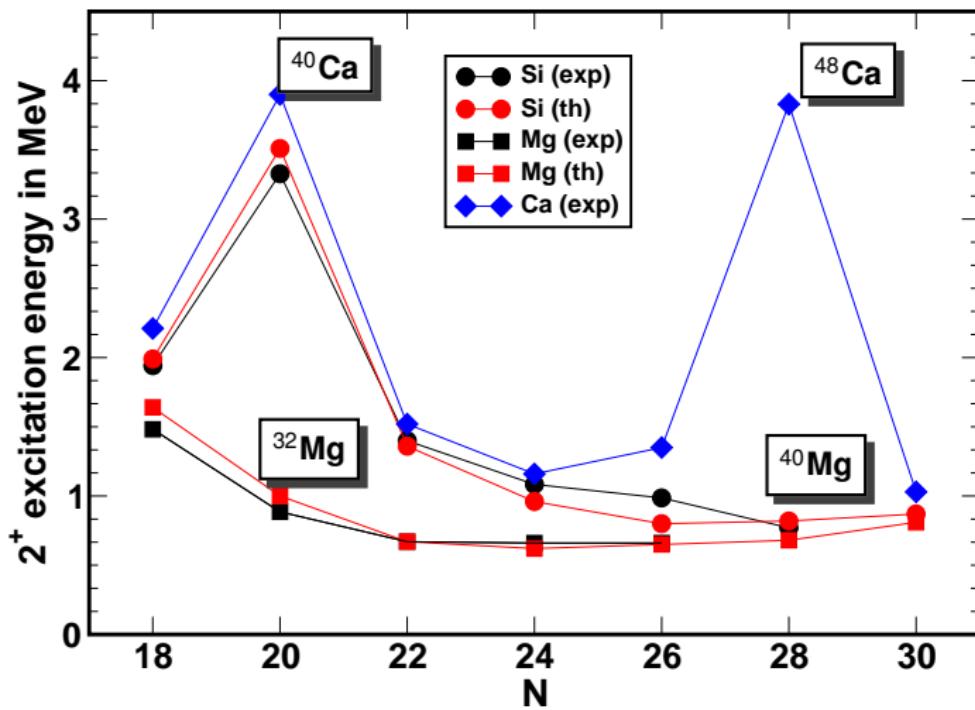
F. Nowacki et al., accepted for publication in Phys. Rev. Lett.



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



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



- 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" (Iol's) in nuclei with large neutron excess, and shape coexistence usually shows up as a its portal
- The Iol'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 Iol
- Shape coexistence in ^{78}Ni is the portal to a new Iol at N=50
- The Iol's at N=40 and N=50 merge in the Chromium isotopes.

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