Shell evolution in the neutron rich calcium isotopes

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Collaborators

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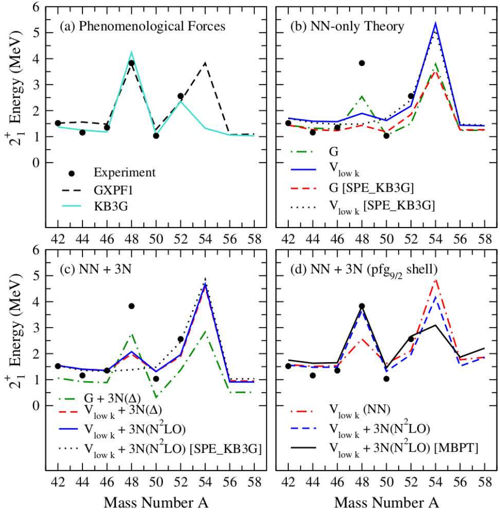
- Hai Ah Nam (ORNL)
- Thomas Papenbrock (ORNL, UTK)

Outline

- Evolution of shell structure in neutron rich calcium isotopes.
- Preliminary results using N^2LO (POUNDerS).
- Notes on three nucleon forces and outlook.

Shell evolution in neutron rich calcium isotopes.



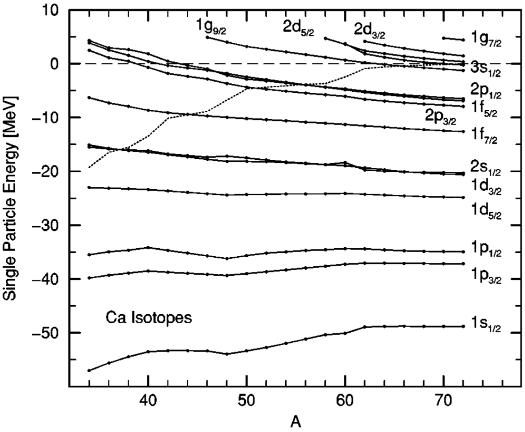
Details

- J. D. Holt, T. Otsuka, A. Schwenk and T. Suzuki, J Phys G39 085111 (2012)..
- $J^{\pi} = 2^{+}$ systematics in even calcium isotopes.

Main features

- Threebody forces needed to make ^{48}Ca magic.
- Different models have ^{54}Ca magic, semi magic and not magic at all.

Evolution of single particle energies



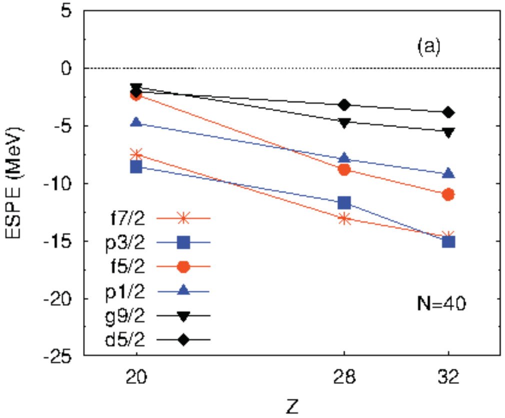
Technical details

- J. Meng, H. Toki, J. Y. Zeng, S. Q. Zhang and S. -G. Zhou, PRC 65 041302(R) (2002).
- Relativistic mean-field including continuum effects.

Main features

- Bunching of single-particle energies outside the *pf*-shell.
- No shell-gap in ^{60}Ca - ^{70}Ca.
- Large deformations and no shell-closure.
- Continuum effects responsible for bound ^{60}Ca - ^{72}Ca.

Evolution of single particle energies



Technical details

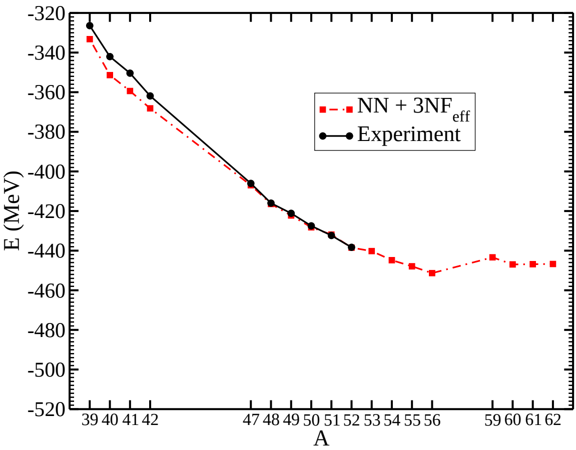
- S. M. Lenzi, F. Nowacki, A. Poves and K. Sieja, PRC 82 054301 (2010).
- Shell-model calculation in the *pf*-shell including $0g_{9/2}$ and $2d_{5/2}$ for neutrons.

Main features

- Inversion of the $0g_{9/2}$ and the $2d_{5/2}$ single particle states in ^{60}Ca.
- Bunching of levels including the $0f_{5/2}$ state indicates no shell-closure.

Binding energies in calcium isotopes

G. Hagen, M. Hjorth-Jensen, GRJ, R. Machleidt, and T. Papenbrock,
PRL109 032502 (2012)



Technical details

- Chiral interaction at N^3LO.
- Density dependent three body force with $k_F = 0.95 \mathrm{fm}^{-1}$, $c_D = -0.2$ and $c_E = 0.735$. $N_{max} = 18$ and $\hbar\omega = 26$ MeV.
- Mass of ^{51}Ca and ^{52}Ca from A. T. Gallant *et al.*, PRL 109, 032506 (2012)

Main features

- Total binding energies agree well with experimental masses.
- ^{60}Ca is not magic.
- Three nucleon force is repulsive.

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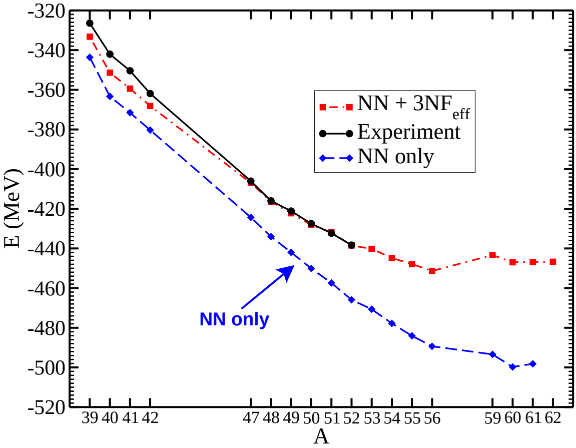

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$J^\pi = 2^+$ systematics in even calcium isotopes

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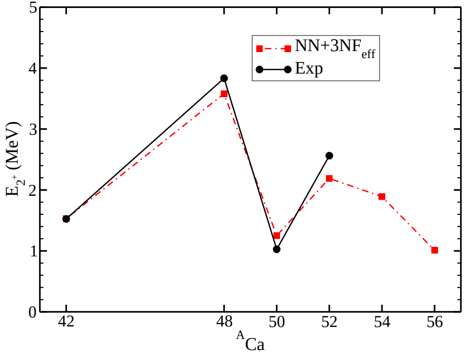

	^{48}Ca	^{52}Ca	^{54}Ca
E_{2^+}(CC)	3.58	2.19	1.89
E_{2^+}(Exp)	3.83	2.56	n.a.
E_{4^+}/E_{2^+}(CC)	1.17	1.80	2.36
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S_n(CC)	9.45	6.59	4.59
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Main features

- Good agreement between theory and experiment.
- Shell closure in ^{48}Ca.
- Sub-shell closure in ^{52}Ca.
- Predict weak sub-shell closure in ^{54}Ca.

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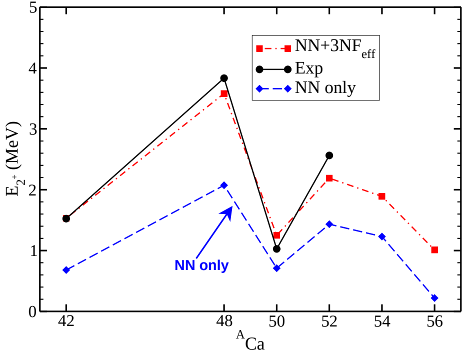

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Spectra in calcium isotopes

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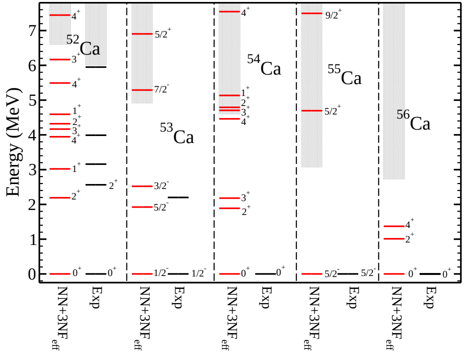
PRL109 032502 (2012)



	^{53}Ca		^{55}Ca		^{61}Ca	
J^π	Re[E]	Γ	Re[E]	Γ	Re[E]	Γ
$5/2^+$	1.99	1.97	1.63	1.33	1.14	0.62
$9/2^+$	4.75	0.28	4.43	0.23	2.19	0.02

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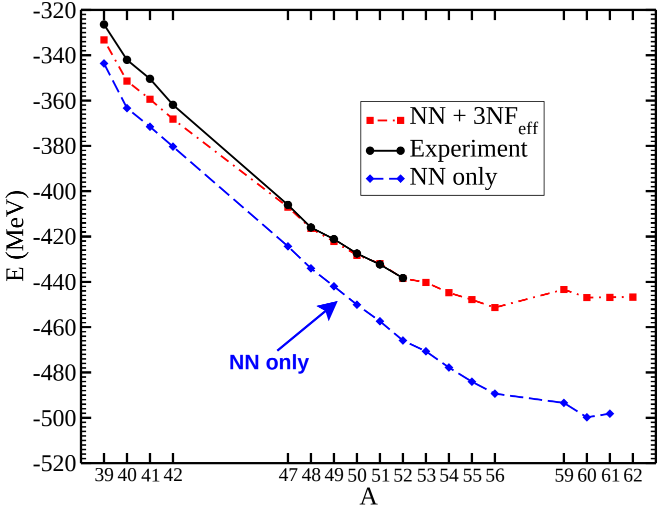
- Continuum included for selected weakly bound and resonant states.

Main features

- Inversion of $g_{9/2}$ and $d_{5/2}$.
- $1/2^+$ groundstate in ^{61}Ca.
- Continuum effects are crucial.

Calcium isotopes with NNLO (POUNDerS)

Preliminary



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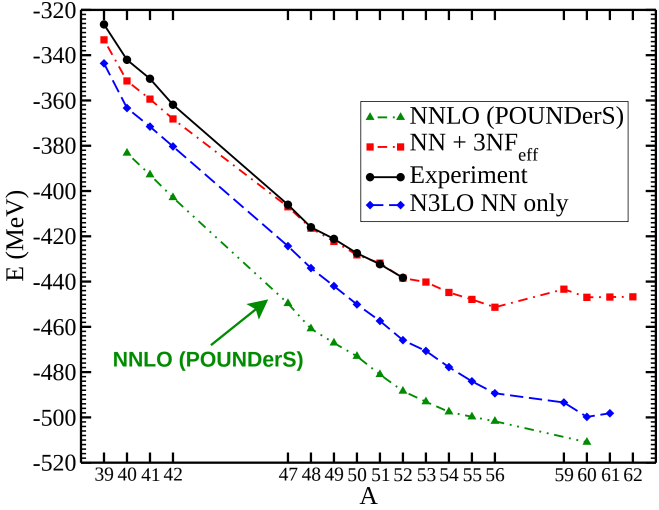

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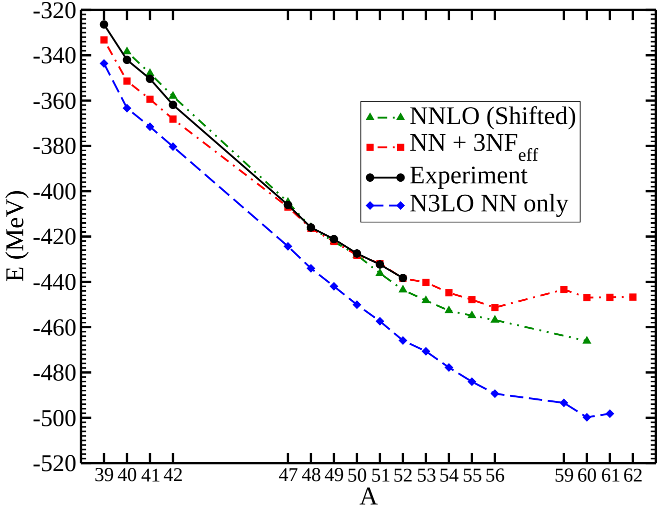

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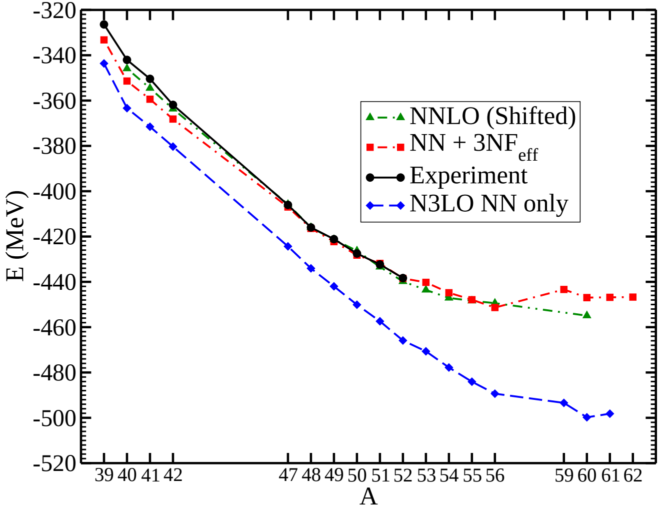
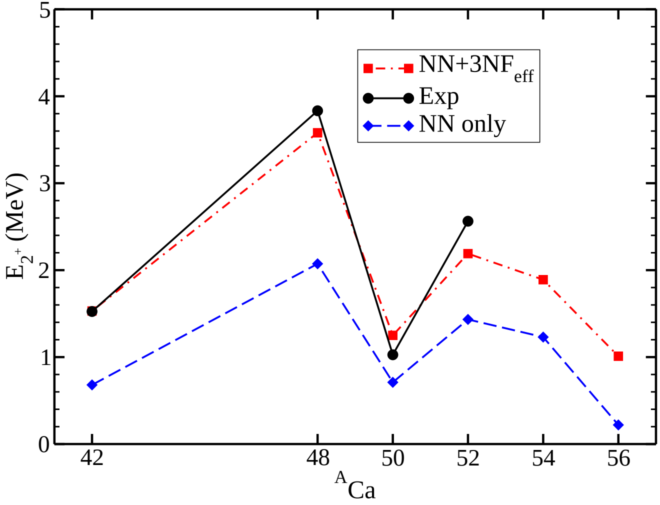


$J^\pi = 2^+$ systematics with NNLO (POUNDerS)

Preliminary



$J^{\pi} = 2^{+}$ systematics with NNLO (POUNDerS)

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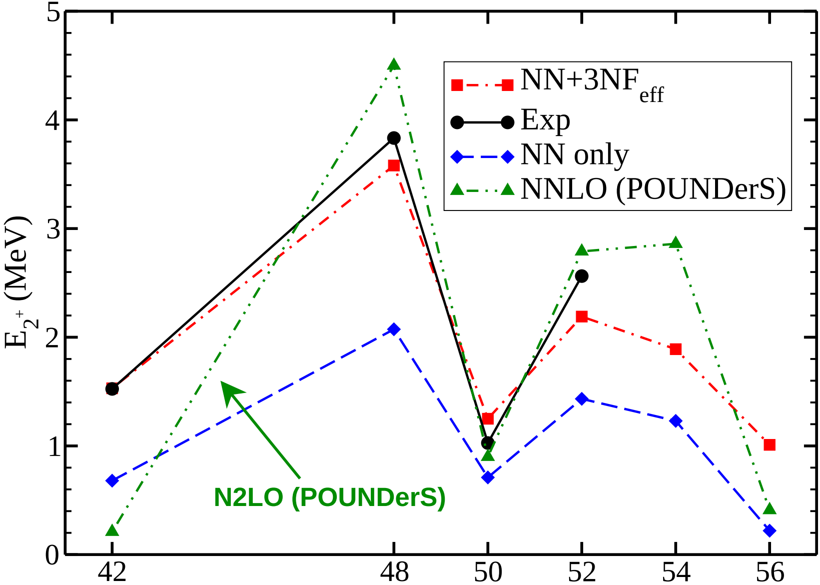

Notes on three nucleon forces

- Need $N_{\max} > 20$ for converged results.
- Possible, but the cost will be in the order of 10^8 cpu-hours.
- Relative energies converges faster.
- Main culprit – Transformation brackets.
- Exploring different architectures (GPU, MIC etc..).