Present status of perturbative calculation of effective shell-model hamiltonians

Nunzio Itaco

Università di Napoli Federico II
Istituto Nazionale di Fisica Nucleare - Sezione di Napoli

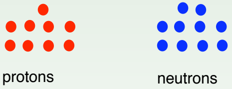
International Collaborations in Nuclear Theory:
Theory for open-shell nuclei near the limits of stability
May 11-29, 2015
Michigan State University and FRIB/NSCL

Introductory remark

What is a realistic effective shell-model hamiltonian ?

An example: ^{19}F

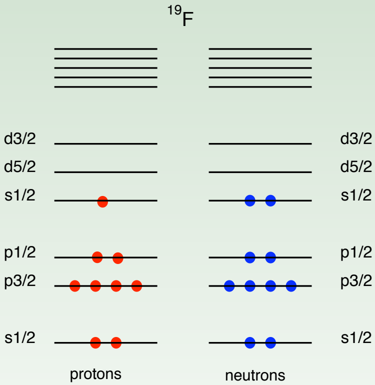
^{19}F



- 9 protons & 10 neutrons interacting
- spherically symmetric mean field (e.g. harmonic oscillator)
- 1 valence proton & 2 valence neutrons interacting in a truncated model space

The degrees of freedom of the core nucleons and the excitations of the valence ones above the model space are not considered explicitly.

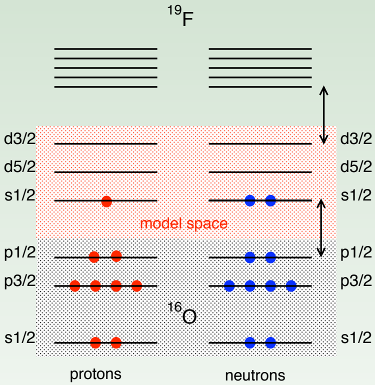
An example: ^{19}F



- 9 protons & 10 neutrons interacting
- spherically symmetric mean field (e.g. harmonic oscillator)
- 1 valence proton & 2 valence neutrons interacting in a truncated model space

The degrees of freedom of the core nucleons and the excitations of the valence ones above the model space are not considered explicitly.

An example: ^{19}F



- 9 protons & 10 neutrons interacting
- spherically symmetric mean field (e.g. harmonic oscillator)
- 1 valence proton & 2 valence neutrons interacting in a truncated model space

The degrees of freedom of the core nucleons and the excitations of the valence ones above the model space are not considered explicitly.

Effective shell-model hamiltonian

The shell-model hamiltonian has to take into account in an effective way all the degrees of freedom not explicitly considered

Two alternative approaches

- phenomenological
- microscopic

$$V_{NN} \ (+V_{NNN}) \Rightarrow \text{many-body theory} \Rightarrow H_{\text{eff}}$$

Definition

The eigenvalues of H_{eff} belong to the set of eigenvalues of the full nuclear hamiltonian

Effective shell-model hamiltonian

The shell-model hamiltonian has to take into account in an effective way all the degrees of freedom not explicitly considered

Two alternative approaches

- phenomenological
- microscopic

$$V_{NN} \ \ (+V_{NNN}) \Rightarrow \text{many-body theory} \Rightarrow H_{\rm eff}$$

Definition

The eigenvalues of $H_{\rm eff}$ belong to the set of eigenvalues of the full nuclear hamiltonian

Effective shell-model hamiltonian

The shell-model hamiltonian has to take into account in an effective way all the degrees of freedom not explicitly considered

Two alternative approaches

- phenomenological
- microscopic

$$V_{NN} \;\; (+V_{NNN}) \Rightarrow \text{many-body theory} \Rightarrow H_{\rm eff}$$

Definition

The eigenvalues of $H_{\rm eff}$ belong to the set of eigenvalues of the full nuclear hamiltonian

Effective shell-model hamiltonian

The shell-model hamiltonian has to take into account in an effective way all the degrees of freedom not explicitly considered

Two alternative approaches

- phenomenological
- microscopic

$$V_{NN} \ \ (+V_{NNN}) \Rightarrow \text{many-body theory} \Rightarrow H_{\rm eff}$$

Definition

The eigenvalues of $H_{\rm eff}$ belong to the set of eigenvalues of the full nuclear hamiltonian

Effective shell-model hamiltonian

The shell-model hamiltonian has to take into account in an effective way all the degrees of freedom not explicitly considered

Two alternative approaches

- phenomenological
- microscopic

$$V_{NN} \ \ (+V_{NNN}) \Rightarrow \text{many-body theory} \Rightarrow H_{\rm eff}$$

Definition

The eigenvalues of $H_{\rm eff}$ belong to the set of eigenvalues of the full nuclear hamiltonian

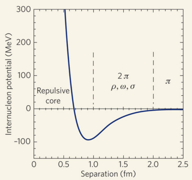
Workflow for a realistic shell-model calculation

1. Choose a realistic *NN* potential (*NNN*)
2. Determine the model space better tailored to study the system under investigation
3. Derive the effective shell-model hamiltonian by way of a many-body theory
4. Calculate the physical observables (energies, e.m. transition probabilities, ...)

Realistic nucleon-nucleon potential: V_{NN}

Several realistic potentials $\chi^2/datum \simeq 1$: CD-Bonn, Argonne V18, Nijmegen, ...

Strong short-range repulsion



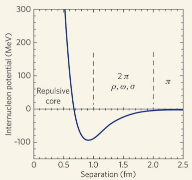
How to handle the short-range repulsion ?

- Brueckner G matrix
- low-momentum NN potentials
  - V_{low-k} (Lee-Suzuki or SRG)

Realistic nucleon-nucleon potential: V_{NN}

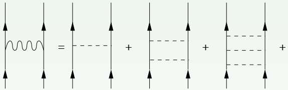
Several realistic potentials $\chi^2/datum \simeq 1$:
CD-Bonn, Argonne V18, Nijmegen, ...

Strong short-range repulsion



How to handle the short-range repulsion ?

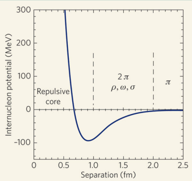
- Brueckner G matrix
- low-momentum NN potentials
  - $V_{\mathrm{low-k}}$ (Lee-Suzuki or SRG)
  - chiral potentials rooted in EFT



Realistic nucleon-nucleon potential: V_{NN}

Several realistic potentials $\chi^2/datum \simeq 1$:
CD-Bonn, Argonne V18, Nijmegen, ...

Strong short-range repulsion



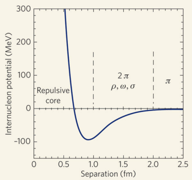
How to handle the short-range repulsion ?

- Brueckner *G* matrix
- low-momentum *NN* potentials
  - $V_{\mathrm{low-k}}$ (Lee-Suzuki or SRG)
  - chiral potentials rooted in EFT

Realistic nucleon-nucleon potential: V_{NN}

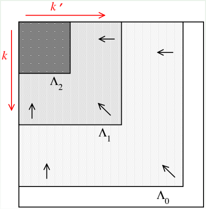
Several realistic potentials $\chi^2/datum \simeq 1$:
CD-Bonn, Argonne V18, Nijmegen, ...

Strong short-range repulsion



How to handle the short-range repulsion ?

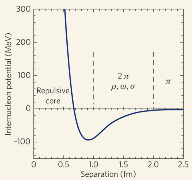
- Brueckner G matrix
- low-momentum NN potentials
  - $V_{\mathrm{low-k}}$ (Lee-Suzuki or SRG)
  - chiral potentials rooted in EFT



Realistic nucleon-nucleon potential: V_{NN}

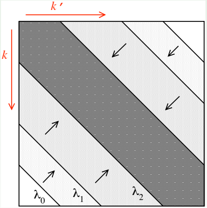
Several realistic potentials $\chi^2/datum \simeq 1$:
CD-Bonn, Argonne V18, Nijmegen, ...

Strong short-range repulsion



How to handle the short-range repulsion ?

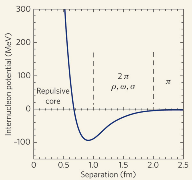
- Brueckner *G* matrix
- low-momentum *NN* potentials
  - $V_{\rm low-k}$ (Lee-Suzuki or SRG)
  - chiral potentials rooted in EFT



Realistic nucleon-nucleon potential: V_{NN}

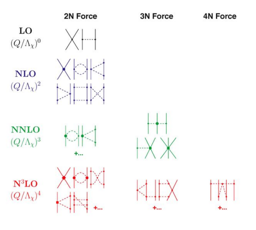
Several realistic potentials $\chi^2/datum \simeq 1$: CD-Bonn, Argonne V18, Nijmegen, ...

Strong short-range repulsion



How to handle the short-range repulsion ?

- Brueckner *G* matrix
- low-momentum *NN* potentials
  - $V_{\rm low-k}$ (Lee-Suzuki or SRG)
  - chiral potentials rooted in EFT



The shell-model effective hamiltonian

A-nucleon system Schrödinger equation

$$H|\Psi_\nu\rangle = E_\nu|\Psi_\nu\rangle$$

with

$$H = H_0 + H_1 = \sum_{i=1}^{A}(T_i + U_i) + \sum_{i<j}(V_{ij}^{NN} - U_i)$$

Model space

$$|\Phi_i\rangle = [a_1^\dagger a_2^\dagger \, ... \, a_n^\dagger]_i|c\rangle \Rightarrow P = \sum_{i=1}^{d}|\Phi_i\rangle\langle\Phi_i|$$

Model-space eigenvalue problem

$$H_{\text{eff}}P|\Psi_\alpha\rangle = E_\alpha P|\Psi_\alpha\rangle$$

The shell-model effective hamiltonian

$$\left(\begin{array}{c|c} PHP & PHQ \\ \hline QHP & QHQ \end{array}\right)$$

$$\mathcal{H} = X^{-1}HX$$

$$\Longrightarrow$$

$$Q\mathcal{H}P = 0$$

$$\left(\begin{array}{c|c} P\mathcal{H}P & P\mathcal{H}Q \\ \hline 0 & Q\mathcal{H}Q \end{array}\right)$$

$$H_{\rm eff} = P\mathcal{H}P$$

Suzuki & Lee $\Rightarrow X = e^{\omega}$ with $\omega = \left(\begin{array}{c|c} 0 & 0 \\ \hline Q\omega P & 0 \end{array}\right)$

The shell-model effective hamiltonian

$$\left(\begin{array}{c|c} PHP & PHQ \\ \hline QHP & QHQ \end{array}\right) \quad \begin{array}{c} \mathcal{H} = X^{-1}HX \\ \Longrightarrow \\ Q\mathcal{H}P = 0 \end{array} \quad \left(\begin{array}{c|c} P\mathcal{H}P & P\mathcal{H}Q \\ \hline 0 & Q\mathcal{H}Q \end{array}\right)$$

$$H_{\mathrm{eff}} = P\mathcal{H}P$$

Suzuki & Lee $\Rightarrow X = e^{\omega}$ with $\omega = \left(\begin{array}{c|c} 0 & 0 \\ \hline Q\omega P & 0 \end{array}\right)$

The shell-model effective hamiltonian

$$\left(\begin{array}{c|c} PHP & PHQ \\ \hline QHP & QHQ \end{array}\right) \underset{Q\mathcal{H}P=0}{\overset{\mathcal{H}=X^{-1}HX}{\Longrightarrow}} \left(\begin{array}{c|c} P\mathcal{H}P & P\mathcal{H}Q \\ \hline 0 & Q\mathcal{H}Q \end{array}\right)$$

$$H_{\text{eff}} = P\mathcal{H}P$$

Suzuki & Lee $\Rightarrow X = e^{\omega}$ with $\omega = \left(\begin{array}{c|c} 0 & 0 \\ \hline Q\omega P & 0 \end{array}\right)$

The shell-model effective hamiltonian

$$\left(\begin{array}{c|c} PHP & PHQ \\ \hline QHP & QHQ \end{array}\right) \quad \begin{array}{c} \mathcal{H} = X^{-1}HX \\ \Longrightarrow \\ Q\mathcal{H}P = 0 \end{array} \quad \left(\begin{array}{c|c} P\mathcal{H}P & P\mathcal{H}Q \\ \hline 0 & Q\mathcal{H}Q \end{array}\right)$$

$$H_{\text{eff}} = P\mathcal{H}P$$

Suzuki & Lee $\Rightarrow X = e^{\omega}$ with $\omega = \left(\begin{array}{c|c} 0 & 0 \\ \hline Q\omega P & 0 \end{array}\right)$

The shell-model effective hamiltonian

$$\left(\begin{array}{c|c} PHP & PHQ \\ \hline QHP & QHQ \end{array}\right) \underset{Q\mathcal{H}P = 0}{\overset{\mathcal{H} = X^{-1}HX}{\Longrightarrow}} \left(\begin{array}{c|c} P\mathcal{H}P & P\mathcal{H}Q \\ \hline 0 & Q\mathcal{H}Q \end{array}\right)$$

$$H_{\text{eff}} = P\mathcal{H}P$$

Suzuki & Lee $\Rightarrow X = e^{\omega}$ with $\omega = \left(\begin{array}{c|c} 0 & 0 \\ \hline Q\omega P & 0 \end{array}\right)$

The shell-model effective hamiltonian

Folded-diagram expansion

$\hat{Q}$-box vertex function

$$\hat{Q}(\epsilon) = PH_1P + PH_1Q\frac{1}{\epsilon - QHQ}QH_1P$$

$\Rightarrow$ Recursive equation for $H_{\rm eff}$ $\Rightarrow$ iterative techniques (Krenciglowa-Kuo, Lee-Suzuki, ...)

$$H_{\rm eff} = \hat{Q} - \hat{Q}' \int \hat{Q} + \hat{Q}' \int \hat{Q} \int \hat{Q} - \hat{Q}' \int \hat{Q} \int \hat{Q} \int \hat{Q} \cdots ,$$

generalized folding

The perturbative approach to the shell-model H^{eff}

$$\hat{Q}(\epsilon) = PH_1P + PH_1Q\frac{1}{\epsilon - QHQ}QH_1P$$

The $\hat{Q}$-box can be calculated perturbatively

$$\frac{1}{\epsilon - QHQ} = \sum_{n=0}^{\infty} \frac{(QH_1Q)^n}{(\epsilon - QH_0Q)^{n+1}}$$

The diagrammatic expansion of the $\hat{Q}$-box

The perturbative approach to the shell-model $H^{\rm eff}$

$$\hat{Q}(\epsilon) = PH_1P + PH_1Q\frac{1}{\epsilon - QHQ}QH_1P$$

The $\hat{Q}$-box can be calculated perturbatively

$$\frac{1}{\epsilon - QHQ} = \sum_{n=0}^{\infty} \frac{(QH_1Q)^n}{(\epsilon - QH_0Q)^{n+1}}$$

The diagrammatic expansion of the $\hat{Q}$-box

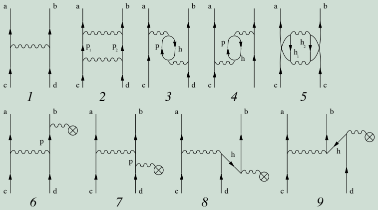
The perturbative approach to the shell-model $H^{\rm eff}$

$$\hat{Q}(\epsilon) = PH_1P + PH_1Q\frac{1}{\epsilon - QHQ}QH_1P$$

The $\hat{Q}$-box can be calculated perturbatively

$$\frac{1}{\epsilon - QHQ} = \sum_{n=0}^{\infty} \frac{(QH_1Q)^n}{(\epsilon - QH_0Q)^{n+1}}$$

The diagrammatic expansion of the $\hat{Q}$-box



- $H^{\rm eff}$ for systems with one and two valence nucleons
- $\hat{Q}$-box $\Rightarrow$ Goldstone diagrams up to third order in V_{NN} (up to 2p-2h core excitations)
- Padè approximant [2|1] of the $\hat{Q}$-box

$$[2|1] = V^0_{Qbox} + V^1_{Qbox} + V^2_{Qbox}(1 - (V^2_{Qbox})^{-1} V^3_{Qbox})^{-1} \quad ,$$

The perturbative approach to the shell-model H^{eff}

- H^{eff} for systems with one and two valence nucleons
- $\hat{Q}$-box $\Rightarrow$ Goldstone diagrams up to third order in V_{NN} (up to 2p-2h core excitations)
- Padè approximant [2|1] of the $\hat{Q}$-box

$$[2|1] = V^0_{Qbox} + V^1_{Qbox} + V^2_{Qbox}(1 - (V^2_{Qbox})^{-1} V^3_{Qbox})^{-1} \quad ,$$

The perturbative approach to the shell-model H^{eff}

- H^{eff} for systems with one and two valence nucleons
- $\hat{Q}$-box $\Rightarrow$ Goldstone diagrams up to third order in V_{NN} (up to 2p-2h core excitations)
- Padè approximant [2|1] of the $\hat{Q}$-box

$$[2|1] = V^0_{Qbox} + V^1_{Qbox} + V^2_{Qbox}(1 - (V^2_{Qbox})^{-1} V^3_{Qbox})^{-1} \quad ,$$

Test case: *p*-shell nuclei

- L. Coraggio (INFN)
- A. Covello (UNINA and INFN)
- A. Gargano (INFN)
- T. T. S. Kuo (SUNY at Stony Brook)
- N. I. (UNINA and INFN)

L.Coraggio, A. Covello, A. Gargano, N. I., and T. T. S. Kuo, Ann. Phys. **327** *2125 (2012)*

First, some convergence checks !

Test case: *p*-shell nuclei

- $V_{NN} \Rightarrow$ chiral N^3LO potential by Entem & Machleidt (smooth cutoff $\simeq 2.5\ \mathrm{fm}^{-1}$)
- H_{eff} for two valence nucleons outside ^{4}He
- Single-particle energies and residual two-body interaction are derived from the theory. No empirical input

First, some convergence checks !

Test case: *p*-shell nuclei

- $V_{NN} \Rightarrow$ chiral N^{3}LO potential by Entem & Machleidt (smooth cutoff $\simeq$ 2.5 fm^{-1})
- $H_{\rm eff}$ for two valence nucleons outside ^{4}He
- Single-particle energies and residual two-body interaction are derived from the theory. No empirical input

First, some convergence checks !

Convergence checks

The intermediate-state space Q

Q-space is truncated: intermediate states whose unperturbed excitation energy is greater than a fixed value E_{max} are disregarded

$$|\epsilon_0 - QH_0Q| \leq E_{\rm max} = N_{\rm max}\hbar\omega$$

^{6}Li yrast states

results quite stable for $N_{\rm max} \geq 20$

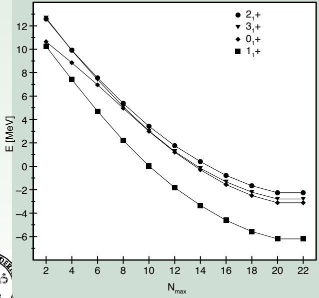
Convergence checks

The intermediate-state space Q

Q-space is truncated: intermediate states whose unperturbed excitation energy is greater than a fixed value E_{max} are disregarded

$$|\epsilon_0 - QH_0Q| \leq E_{\mathrm{max}} = N_{\mathrm{max}}\hbar\omega$$

^{6}Li yrast states



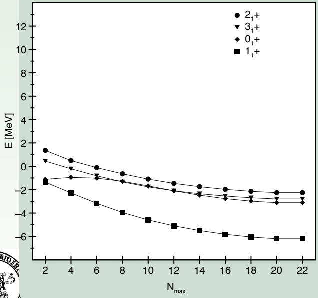
results quite stable for $N_{\mathrm{max}} \geq 20$

The intermediate-state space Q

Q-space is truncated: intermediate states whose unperturbed excitation energy is greater than a fixed value E_{max} are disregarded

$$|\epsilon - QH_0Q| \leq E_{\rm max} = N_{\rm max}\hbar\omega$$

^{6}Li yrast states



results much more stable

Convergence checks

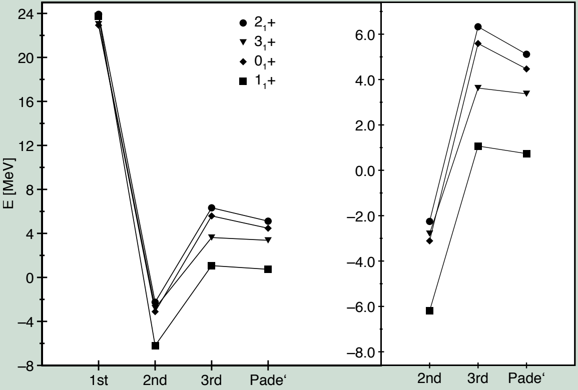
Order-by-order convergence

Compare results from $H^{\text{eff}}_{\text{1st}}$, $H^{\text{eff}}_{\text{2nd}}$, $H^{\text{eff}}_{\text{3rd}}$ and $H^{\text{eff}}_{\text{Padè}}$

Convergence checks

Order-by-order convergence

Compare results from $H^{\rm eff}_{\rm 1st}$, $H^{\rm eff}_{\rm 2nd}$, $H^{\rm eff}_{\rm 3rd}$ and $H^{\rm eff}_{\rm Padè}$



Convergence checks

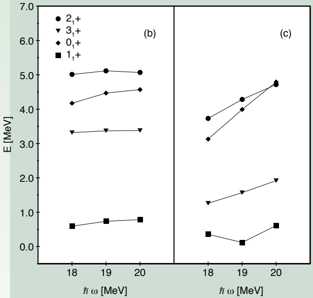
Dependence on $\hbar\omega$

Auxiliary potential $U \Rightarrow$ harmonic oscillator potential

Convergence checks

Dependence on $\hbar\omega$

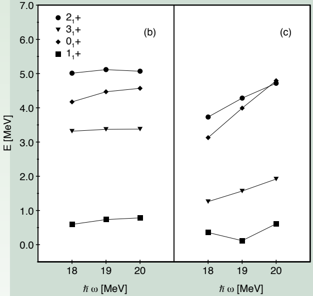
Auxiliary potential $U \Rightarrow$ harmonic oscillator potential



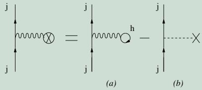
Convergence checks

Dependence on $\hbar\omega$

Auxiliary potential $U \Rightarrow$ harmonic oscillator potential



HF-insertions



- zero in a self-consistent basis
- neglected in most applications
- disregard of HF-insertions introduces relevant dependence on $\hbar\omega$

Benchmark calculation

Approximations are under control ... and what about the accuracy of the results ?

Compare the results with the “exact” ones

ab initio no-core shell model (NCSM)

P. Navrátil, E. Caurier, Phys. Rev. C **69**, 014311 (2004)

P. Navrátil *et al.*, Phys. Rev. Lett. **99**, 042501 (2007)

Benchmark calculation

Approximations are under control ... and what about the accuracy of the results ?

Compare the results with the “exact” ones

ab initio no-core shell model (NCSM)

P. Navrátil, E. Caurier, Phys. Rev. C **69**, 014311 (2004)

P. Navrátil *et al.*, Phys. Rev. Lett. **99**, 042501 (2007)

Benchmark calculation

Approximations are under control ... and what about the accuracy of the results ?

Compare the results with the “exact” ones

ab initio no-core shell model (NCSM)

P. Navrátil, E. Caurier, Phys. Rev. C **69**, 014311 (2004)

P. Navrátil *et al.*, Phys. Rev. Lett. **99**, 042501 (2007)

Benchmark calculation

Approximations are under control ... and what about the accuracy of the results ?

Compare the results with the “exact” ones

ab initio no-core shell model (NCSM)

P. Navrátil, E. Caurier, Phys. Rev. C **69**, 014311 (2004)

P. Navrátil *et al.*, Phys. Rev. Lett. **99**, 042501 (2007)

Benchmark calculation

To compare our results with NCSM we need to start from a translationally invariant Hamiltonian

$$H_{int} = \left(1 - \frac{1}{A}\right) \sum_{i=1}^{A} \frac{p_i^2}{2m} + \sum_{i<j=1}^{A} \left(V_{ij}^{NN} - \frac{\mathbf{p_i} \cdot \mathbf{p_j}}{mA} \right) =$$

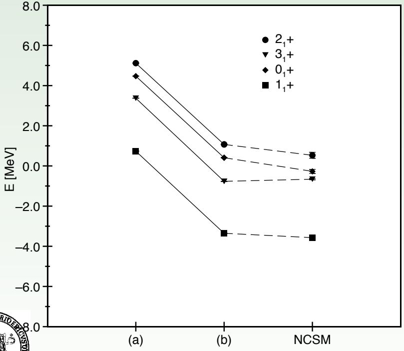
$$= \left[\sum_{i=1}^{A} \left(\frac{p_i^2}{2m} + U_i \right) \right] + \left[\sum_{i<j=1}^{A} \left(V_{ij}^{NN} - U_i - \frac{p_i^2}{2mA} - \frac{\mathbf{p_i} \cdot \mathbf{p_j}}{mA} \right) \right]$$

Benchmark calculation

To compare our results with NCSM we need to start from a translationally invariant Hamiltonian

$$H_{int} = \left(1 - \frac{1}{A}\right) \sum_{i=1}^{A} \frac{p_i^2}{2m} + \sum_{i<j=1}^{A} \left(V_{ij}^{NN} - \frac{\mathbf{p_i} \cdot \mathbf{p_j}}{mA} \right) =$$

$$= \left[\sum_{i=1}^{A} \left(\frac{p_i^2}{2m} + U_i \right) \right] + \left[\sum_{i<j=1}^{A} \left(V_{ij}^{NN} - U_i - \frac{p_i^2}{2mA} - \frac{\mathbf{p_i} \cdot \mathbf{p_j}}{mA} \right) \right]$$



(a) not translationally invariant Hamiltonian

(b) purely intrinsic hamiltonian

Benchmark calculation

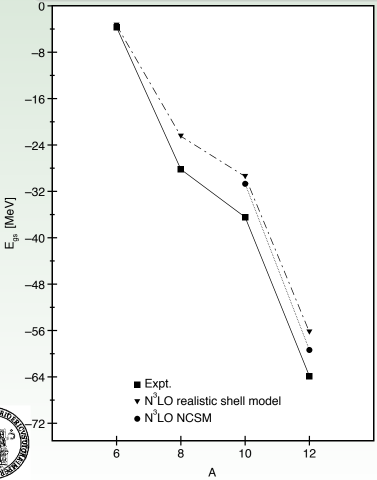
Remark

H^{eff} derived for 2 valence nucleon systems $\Rightarrow$ 3-, 4-, .. *n*-body components are neglected

Benchmark calculation

Remark

H^{eff} derived for 2 valence nucleon systems $\Rightarrow$ 3-, 4-, .. n-body components are neglected



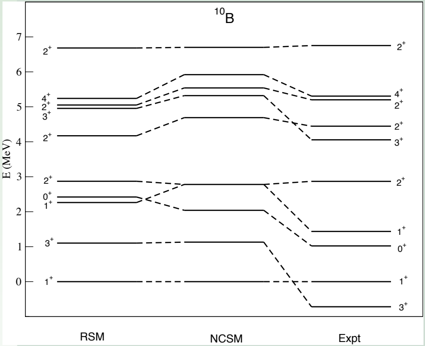
- ground-state energies for $N = Z$ nuclei
- discrepancy grows with the number of valence nucleons

Benchmark calculation

^{10}B relative spectrum

Benchmark calculation

^{10}B relative spectrum



- discrepancy $\leq$ 1 MeV
- minor role of many-body correlations

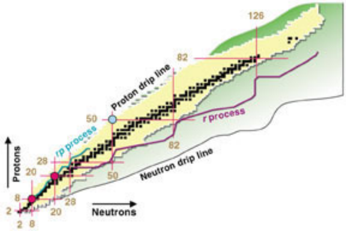
Nuclear models and predictive power

Nuclear model ⇒ Accurate reproduction of experimental data

⇓

Predictive power

RIBs & advances in detection techniques ⇒ unknown structure of nuclei towards the drip lines



Realistic shell-model calculations

realistic shell-model calculations in different mass regions

$\Downarrow$

results in good agreement with experimental data

Can realistic shell-model calculations be predictive ?

few selected examples

Realistic shell-model calculations

realistic shell-model calculations in different mass regions

$\Downarrow$

results in good agreement with experimental data

Can realistic shell-model calculations be predictive ?

few selected examples

Realistic shell-model calculations

realistic shell-model calculations in different mass regions

$\Downarrow$

results in good agreement with experimental data

Can realistic shell-model calculations be predictive ?

few selected examples

Few selected physics cases

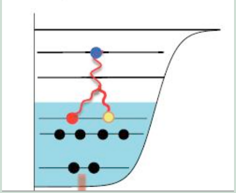
- neutron-deficient tin isotopes
- Sn isotopes beyond $N = 82$
- heavy calcium isotopes

Single-particle energies from the experiment $\Rightarrow$ reduced role of $3N$ force

Few selected physics cases

- neutron-deficient tin isotopes
- Sn isotopes beyond $N = 82$
- heavy calcium isotopes

Single-particle energies from the experiment $\Rightarrow$ reduced role of $3N$ force



Neutron-deficient Sn isotopes

^{100}Sn is the heaviest particle-bound doubly-magic nucleus with $N = Z$

Neutron-deficient Sn isotopes

^{100}Sn is the heaviest particle-bound doubly-magic nucleus with $N = Z$

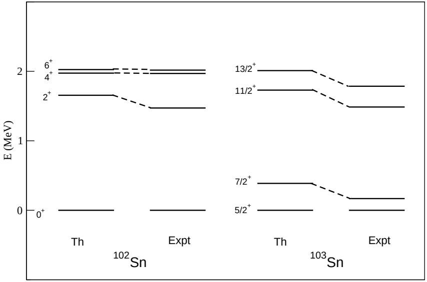
PHYSICAL REVIEW C VOLUME 54, NUMBER 4 OCTOBER 1996

Realistic shell-model calculations for neutron deficient Sn isotopes

F. Andreozzi,[1] L. Coraggio,[1] A. Covello,[1] A. Gargano,[1] T. T. S. Kuo,[2] Z. B. Li,[2] and A. Porrino[1]
[1]*Dipartimento di Scienze Fisiche, Università di Napoli Federico II and Istituto Nazionale di Fisica Nucleare, Mostra d'Oltremare, Pad. 20, 80125 Napoli, Italy*
[2]*Department of Physics, SUNY, Stony Brook, New York 11794*
(Received 27 November 1995; revised manuscript received 28 June 1996)

⇒ $^{102-105}$Sn studied starting from Bonn A *NN* potential
⇒ $g_{7/2}dsh_{11/2}$ model space with ^{100}Sn inert core
⇒ SP energies from analysis of low-energy spectra of heavier tin isotopes ($105 \leq A \leq 111$)
⇒ predictions for the (at that time) unknown spectra of $^{102-103}$Sn

Neutron-deficient Sn isotopes: shell-model results



- very good agreement with experiment
- overestimation of 2^+ energy in ^{102}Sn $\rightarrow$ Z=50 cross-shell excitations (see Luigi's talk)

Sn isotopes beyond $N = 82$

10th International Spring Seminar on Nuclear Physics: New Quests in Nuclear Structure IOP Publishing
Journal of Physics: Conference Series **267** (2011) 012019 doi:10.1088/1742-6596/267/1/012019

Shell-model study of exotic Sn isotopes with a realistic effective interaction

A Covello[1,2], L Coraggio[2], A Gargano[2] and N Itaco[1,2]
[1]Dipartimento di Scienze Fisiche, Università di Napoli Federico II,
Complesso Universitario di Monte S. Angelo, I-80126 Napoli, Italy
[2]Istituto Nazionale di Fisica Nucleare,
Complesso Universitario di Monte S. Angelo, I-80126 Napoli, Italy

$\Rightarrow$ shell-model study of Sn isotopes beyond N = 82
$\Rightarrow$ $V_{\mathrm{low-k}}$ from CD-Bonn *NN* potential
$\Rightarrow$ $h_{9/2} f p i_{13/2}$ model space with ^{132}Sn inert core
$\Rightarrow$ SP energies from ^{133}Sn

Sn isotopes beyond $N = 82$

10th International Spring Seminar on Nuclear Physics: New Quests in Nuclear Structure IOP Publishing
Journal of Physics: Conference Series **267** (2011) 012019 doi:10.1088/1742-6596/267/1/012019

Shell-model study of exotic Sn isotopes with a realistic effective interaction

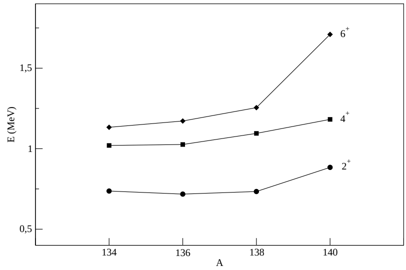
A Covello[1,2], L Coraggio[2], A Gargano[2] and N Itaco[1,2]
[1]Dipartimento di Scienze Fisiche, Università di Napoli Federico II,
Complesso Universitario di Monte S. Angelo, I-80126 Napoli, Italy
[2]Istituto Nazionale di Fisica Nucleare,
Complesso Universitario di Monte S. Angelo, I-80126 Napoli, Italy

$\Rightarrow$ shell-model study of Sn isotopes beyond N = 82

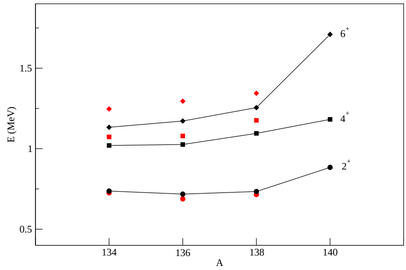
... It is the aim of our study to compare the results of our calculations with the available experimental data and to make predictions for the neighboring heavier isotopes ...

Sn isotopes beyond $N = 82$

Excitation energies of the 2_1^+, 4_1^+, and 6_1^+ states in Sn isotopes



Excitation energies of the 2_1^+, 4_1^+, and 6_1^+ states in Sn isotopes



PRL **113,** 132502 (2014) PHYSICAL REVIEW LETTERS week ending 26 SEPTEMBER 2014

Yrast 6^+ Seniority Isomers of ^{136,138}Sn

G. S. Simpson,[1,2,3] G. Gey,[3,4,5] A. Jungclaus,[6] J. Taprogge,[6,7,5] S. Nishimura,[5] K. Sieja,[8] P. Doornenbal,[5] G. Lorusso,[5] P.-A. Söderström,[5] T. Sumikama,[9] Z. Y. Xu,[10] H. Baba,[5] F. Browne,[11,5] N. Fukuda,[5] N. Inabe,[5] T. Isobe,[5] H. S. Jung,[12,*] D. Kameda,[5] G. D. Kim,[13] Y.-K. Kim,[13,14] I. Kojouharov,[15] T. Kubo,[5] N. Kurz,[15] Y. K. Kwon,[13] Z. Li,[16] H. Sakurai,[5,10]

Heavy calcium isotopes

LETTER

doi:10.1038/nature12226

Masses of exotic calcium isotopes pin down nuclear forces

F. Wienholtz[1], D. Beck[2], K. Blaum[3], Ch. Borgmann[3], M. Breitenfeldt[4], R. B. Cakirli[3,5], S. George[1], F. Herfurth[2], J. D. Holt[6,7], M. Kowalska[8], S. Kreim[3,8], D. Lunney[9], V. Manea[9], J. Menéndez[6,7], D. Neidherr[2], M. Rosenbusch[1], L. Schweikhard[1], A. Schwenk[7,6], J. Simonis[6,7], J. Stanja[10], R. N. Wolf[1] & K. Zuber[10]

⇒ first mass measurements of ^{53}Ca and ^{54}Ca

⇒ new method of precision mass spectroscopy with ISOLTRAP

Heavy calcium isotopes

LETTER

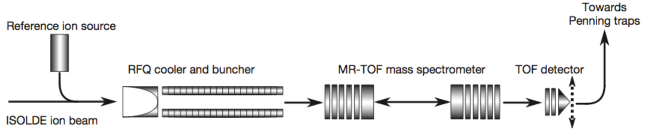
doi:10.1038/nature12226

Masses of exotic calcium isotopes pin down nuclear forces

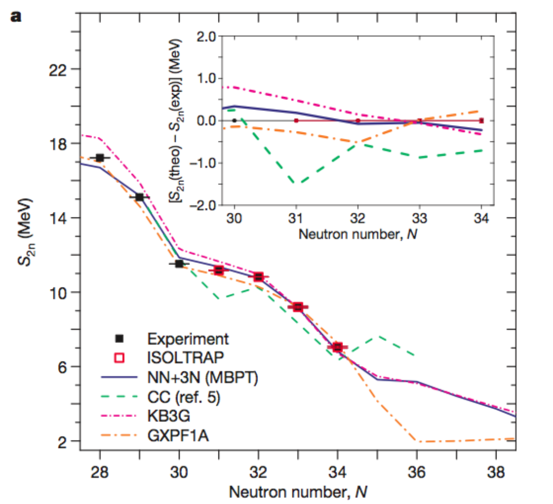
F. Wienholtz[1], D. Beck[2], K. Blaum[3], Ch. Borgmann[3], M. Breitenfeldt[4], R. B. Cakirli[3,5], S. George[1], F. Herfurth[2], J. D. Holt[6,7], M. Kowalska[8], S. Kreim[3,8], D. Lunney[9], V. Manea[9], J. Menéndez[6,7], D. Neidherr[2], M. Rosenbusch[1], L. Schweikhard[1], A. Schwenk[7,6], J. Simonis[6,7], J. Stanja[10], R. N. Wolf[1] & K. Zuber[10]

⇒ first mass measurements of ^{53}Ca and ^{54}Ca

⇒ new method of precision mass spectroscopy with ISOLTRAP

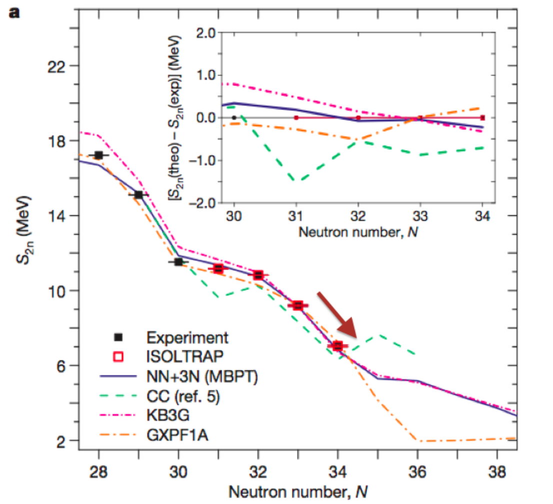


Heavy calcium isotopes



" ... pronounced decrease in S_{2n} revealed by the new ^{53}Ca and ^{54}Ca ISOLTRAP masses ..."

Heavy calcium isotopes



" ... pronounced decrease in S_{2n} revealed by the new ^{53}Ca and ^{54}Ca ISOLTRAP masses ..."

Heavy calcium isotopes

LETTER

doi:10.1038/nature12522

Evidence for a new nuclear ‘magic number’ from the level structure of ^{54}Ca

D. Steppenbeck[1], S. Takeuchi[2], N. Aoi[3], P. Doornenbal[2], M. Matsushita[1], H. Wang[2], H. Baba[2], N. Fukuda[2], S. Go[1], M. Honma[4], J. Lee[2], K. Matsui[5], S. Michimasa[1], T. Motobayashi[2], D. Nishimura[6], T. Otsuka[1,5], H. Sakurai[2,5], Y. Shiga[7], P.-A. Söderström[2], T. Sumikama[8], H. Suzuki[2], R. Taniuchi[5], Y. Utsuno[9], J. J. Valiente-Dobón[10] & K. Yoneda[2]

⇒ spectroscopic study of ^{54}Ca

⇒ proton knockout reactions involving ^{55}Sc and ^{56}Ti projectiles

Heavy calcium isotopes

LETTER

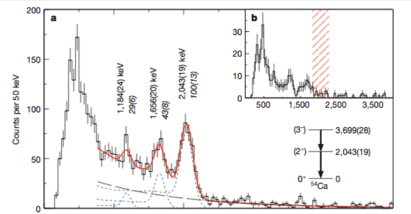
doi:10.1038/nature12522

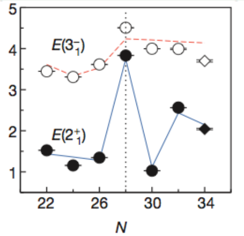
Evidence for a new nuclear 'magic number' from the level structure of ^{54}Ca

D. Steppenbeck[1], S. Takeuchi[2], N. Aoi[3], P. Doornenbal[2], M. Matsushita[1], H. Wang[2], H. Baba[2], N. Fukuda[2], S. Go[1], M. Honma[4], J. Lee[2], K. Matsui[5], S. Michimasa[1], T. Motobayashi[2], D. Nishimura[6], T. Otsuka[1,5], H. Sakurai[2,5], Y. Shiga[7], P.-A. Söderström[2], T. Sumikama[8], H. Suzuki[2], R. Taniuchi[5], Y. Utsuno[9], J. J. Valiente-Dobón[10] & K. Yoneda[2]

⇒ spectroscopic study of ^{54}Ca

⇒ proton knockout reactions involving ^{55}Sc and ^{56}Ti projectiles





Heavy calcium isotopes

PHYSICAL REVIEW C **80**, 044311 (2009)

Spectroscopic study of neutron-rich calcium isotopes with a realistic shell-model interaction

L. Coraggio,[1] A. Covello,[1,2] A. Gargano,[1] and N. Itaco[1,2]
[1]*Istituto Nazionale di Fisica Nucleare, Complesso Universitario di Monte S. Angelo, Via Cintia, I-80126 Napoli, Italy*
[2]*Dipartimento di Scienze Fisiche, Università di Napoli Federico II, Complesso Universitario di Monte S. Angelo, Via Cintia, I-80126 Napoli, Italy*
(Received 30 July 2009; published 12 October 2009)

⇒ shell-model study of neutron-rich calcium isotopes
⇒ *fp* model space with ^{40}Ca inert core
⇒ predictions for the (at that time) unknown spectra of $^{53-56}$Ca

Heavy calcium isotopes

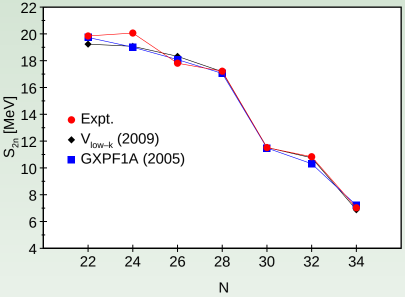
PHYSICAL REVIEW C **80**, 044311 (2009)

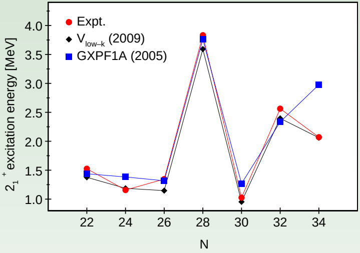
Spectroscopic study of neutron-rich calcium isotopes with a realistic shell-model interaction

L. Coraggio,[1] A. Covello,[1,2] A. Gargano,[1] and N. Itaco[1,2]
[1]*Istituto Nazionale di Fisica Nucleare, Complesso Universitario di Monte S. Angelo, Via Cintia, I-80126 Napoli, Italy*
[2]*Dipartimento di Scienze Fisiche, Università di Napoli Federico II, Complesso Universitario di Monte S. Angelo, Via Cintia, I-80126 Napoli, Italy*
(Received 30 July 2009; published 12 October 2009)

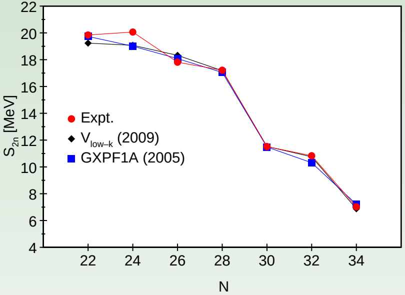
- $\Rightarrow$ shell-model study of neutron-rich calcium isotopes
- $\Rightarrow$ *fp* model space with ^{40}Ca inert core
- $\Rightarrow$ predictions for the (at that time) unknown spectra of $^{53-56}$Ca

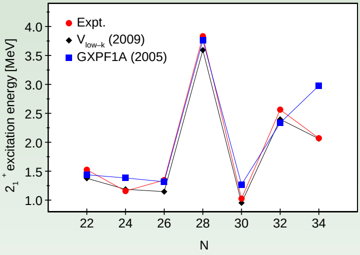
Heavy calcium isotopes: shell-model results

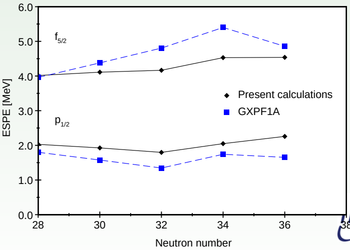




Heavy calcium isotopes: shell-model results







different monopole properties

Takeaway points

- predictive power of realistic shell model
- role of many-body correlations
- importance of HF insertions