Unitarily Transformed Interactions and Three-Body Forces

Sabine Reinhardt

Institut für Kernphysik, TU Darmstadt

TECHNISCHE UNIVERSITÄT DARMSTADT

Overview

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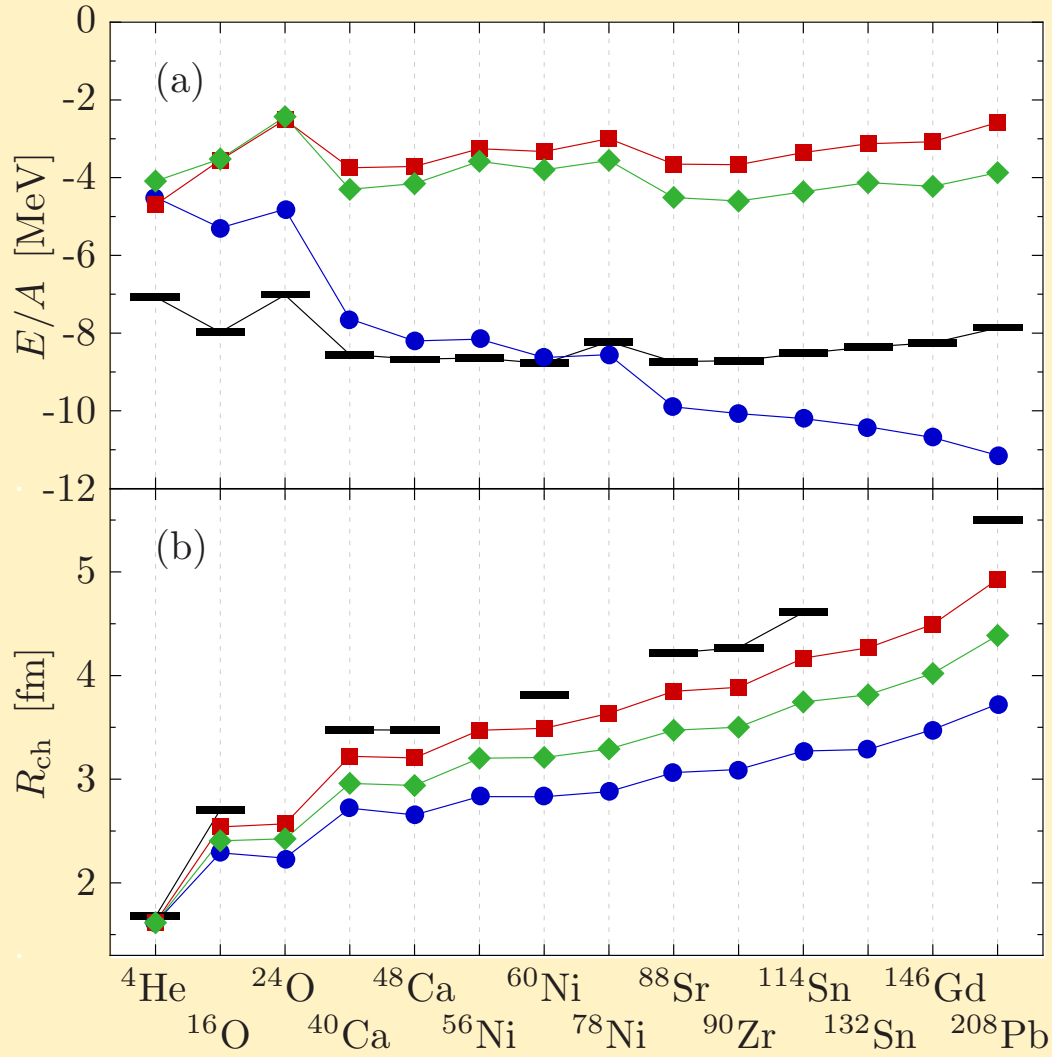
  - Correlation Functions
- Three-Body Interaction
- Results
  - Hartree-Fock
  - Many-Body Perturbation Theory
- Outlook: N3LO Interaction
- Summary

Motivation

Hartree-Fock with Two-Body Interactions



- SRG
- UCOM (SRG-generated)
- UCOM (variation)

- SRG-generated UCOM and variationally generated UCOM:
  - realistic trends of binding energies
  - but too small values
  - charge radii underestimated

$\longrightarrow$ repulsive three-body interaction

SRG-Mapping

Correlation Functions

- derive UCOM correlation functions $R_+(r)$ and $\vartheta(r)$ from SRG evolution:

  (i) perform SRG evolution

  $\longrightarrow$ matrix elements for certain partial wave

  (ii) solve two-body problem using evolved matrix elements

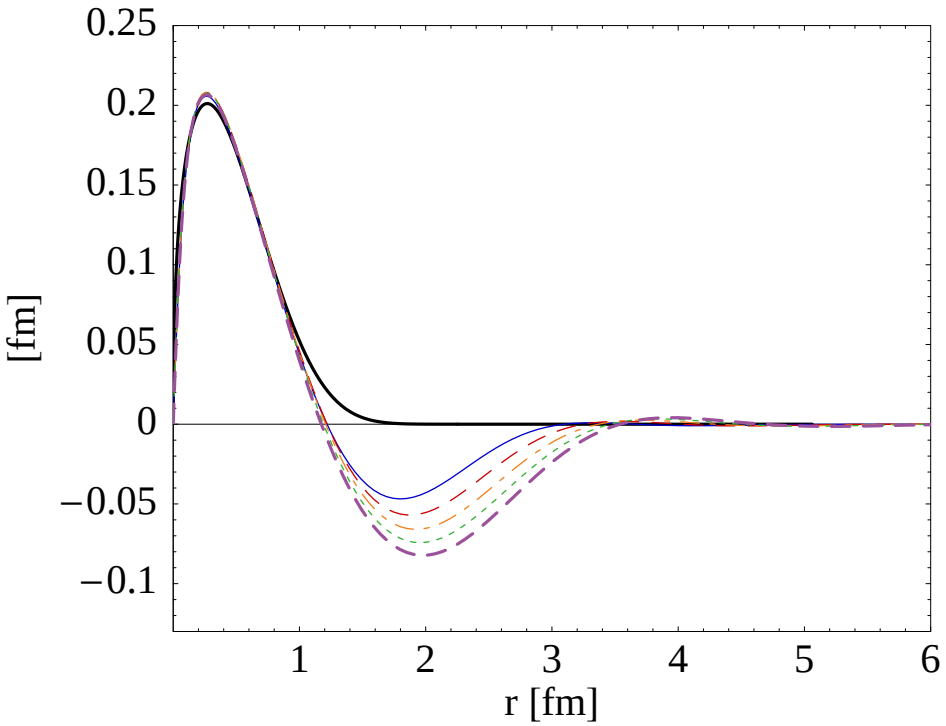
  (iii) map evolved two-body solution onto initial eigenstate:

  $$\left|\Phi^{(0)}\right\rangle = \mathbf{C}\left|\Phi^{(\alpha)}\right\rangle = \mathbf{C}_{\Omega}\mathbf{C}_{r}\left|\Phi^{(\alpha)}\right\rangle$$

  $\longrightarrow$ obtain correlation functions for UCOM generators

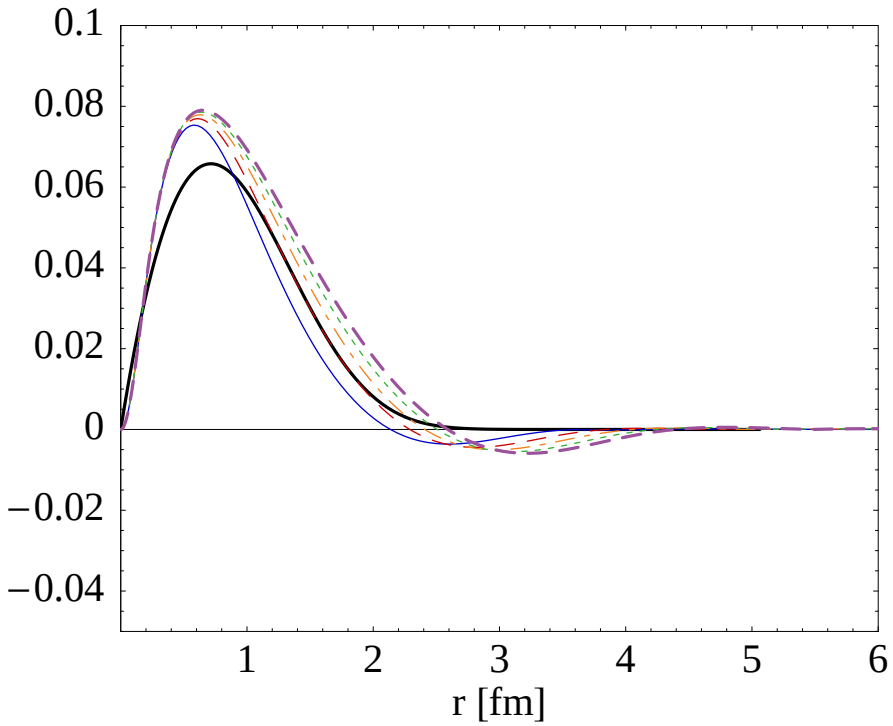
SRG

Correlation Functions for AV18



- SRG-generated correlation functions: negative contributions at larger distances

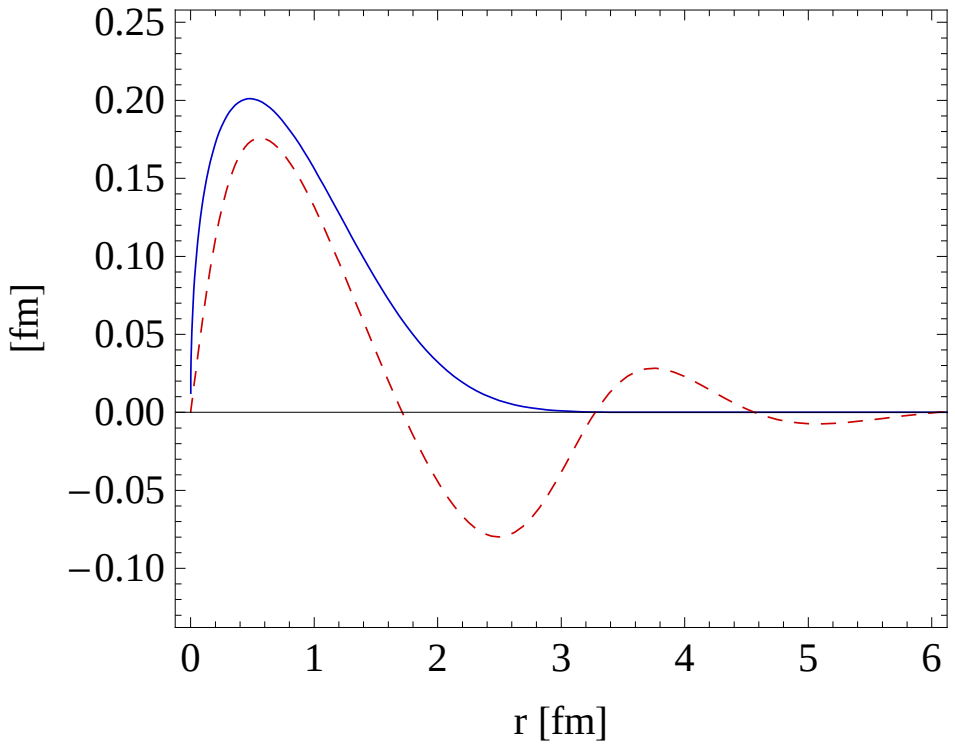
Tensor Correlation Functions



- good agreement of short-range behavior
- range depending on flow parameter

SRG

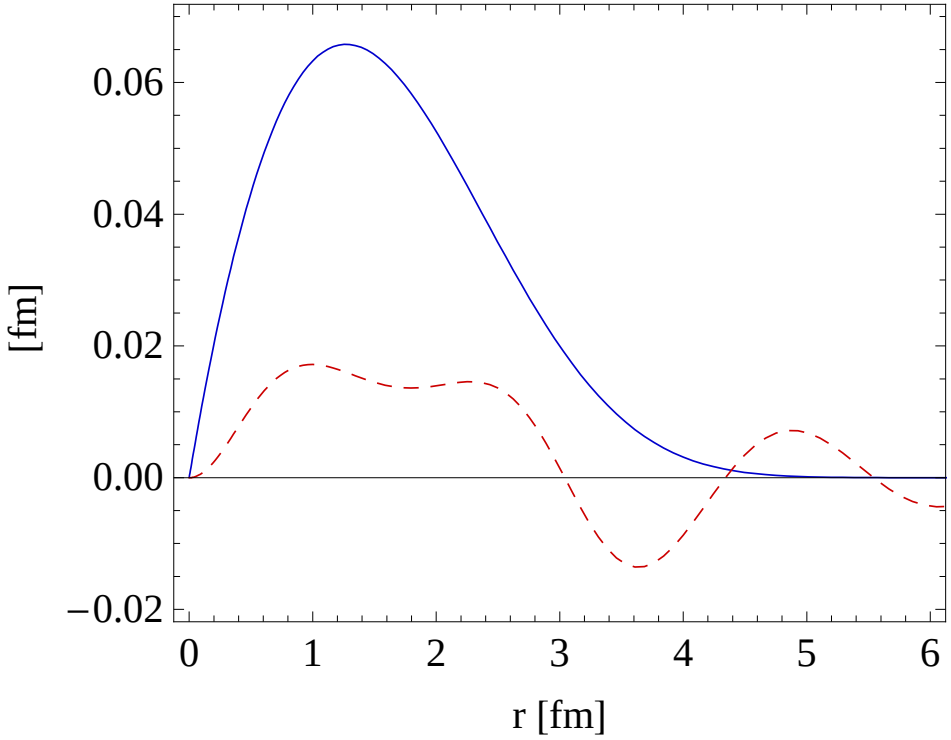
Correlation Functions



energy minimization (AV18)

SRG-mapping (N3LO)

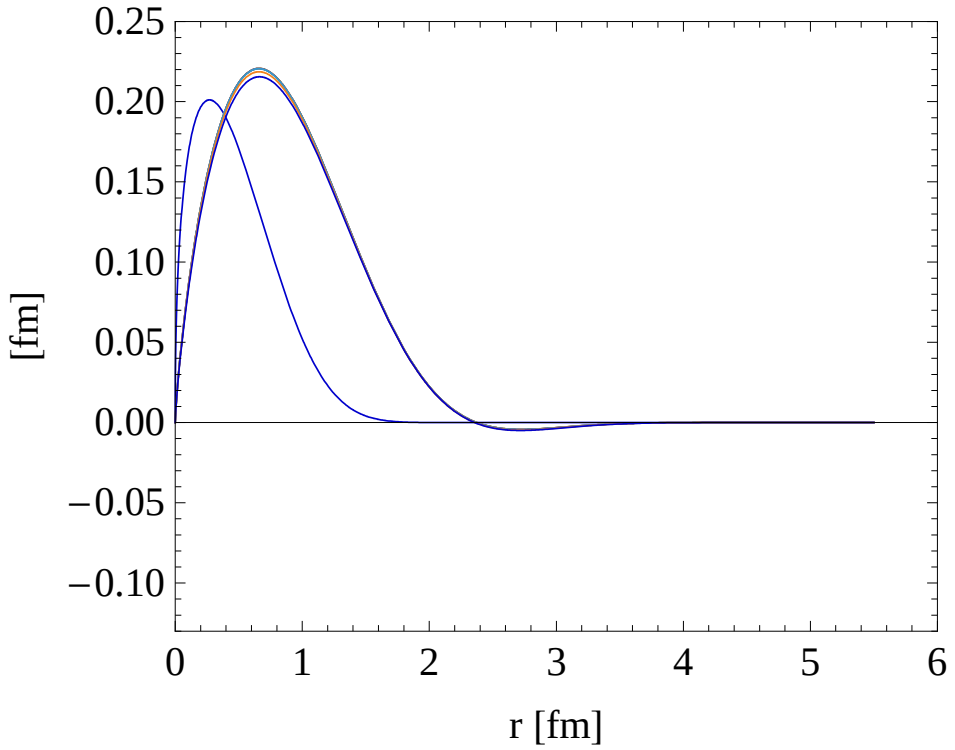
Tensor Correlation Functions



- short-range behavior for central correlator: OK
- SRG-generated correlation functions: long-ranged oscillations
- tensor correlator: double-peak at short distances

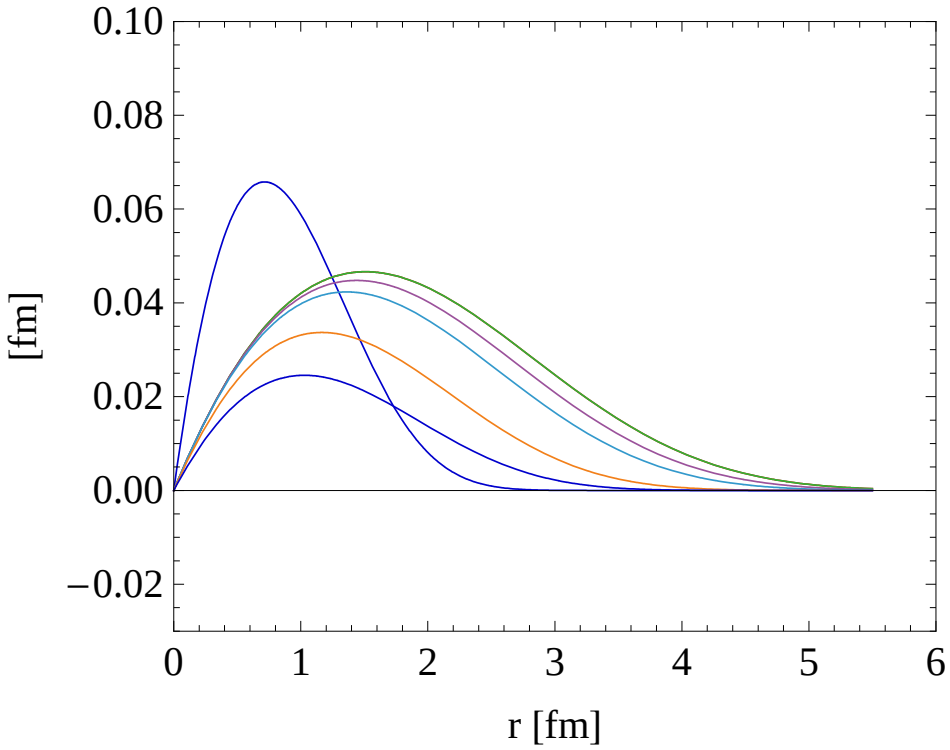
SRG

Correlation Functions



energy minimization
for AV18 and N3LO

Tensor Correlation Functions



- small negative contribution for N3LO in central correlator
- N3LO: longer range of correlators
- shift of peaks towards larger radii

Three-Body Interaction

Ideal World

- use chiral EFT interaction including three-body terms
- perform UCOM/SRG transformation consistently for two- and three-body forces
- calculate three-body matrix elements...

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Pragmatic Approach

- computationally not feasible for reasonable model space sizes
- include effective three-body interaction
  - regularized contact interaction
  - finite-range interaction

Three-Body Interaction

Contact Interaction

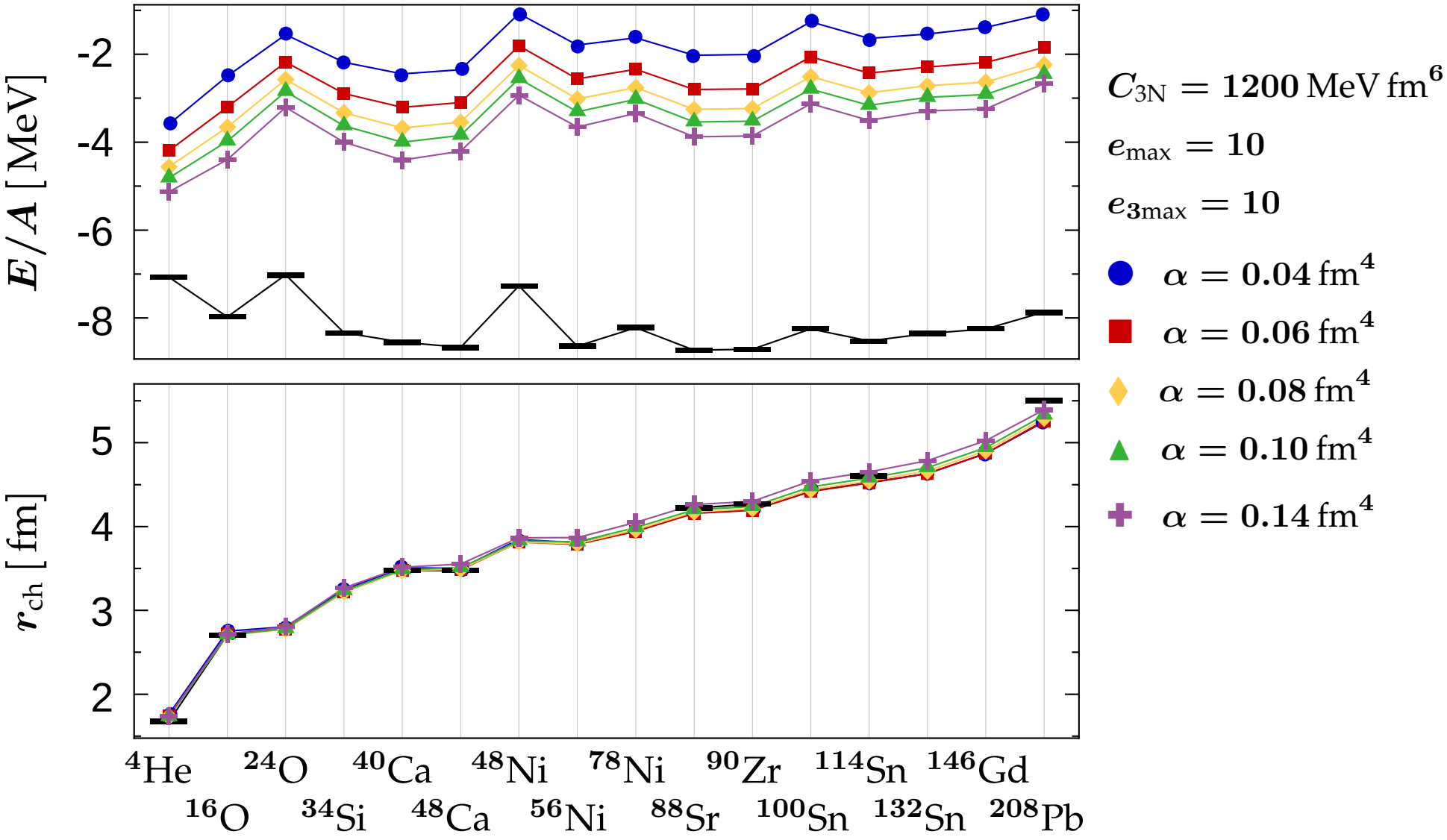
- repulsive three-body interaction
  $\longrightarrow$ increased charge radii
  $\longrightarrow$ decreased binding energies
- simplest ansatz: contact interaction:

$$\mathbf{V}_{\mathrm{3N}} = C_{\mathrm{3N}}\, \boldsymbol{\delta}^{(3)}(\mathbf{x_1} - \mathbf{x_2})\, \boldsymbol{\delta}^{(3)}(\mathbf{x_1} - \mathbf{x_3})$$

- calculation of matrix elements in harmonic-oscillator basis
- regularization via cut-off for three-body states:

$$e_1 + e_2 + e_3 \leq e_{3\mathrm{max}} \qquad (e = 2n + l)$$

Hartree-Fock Results

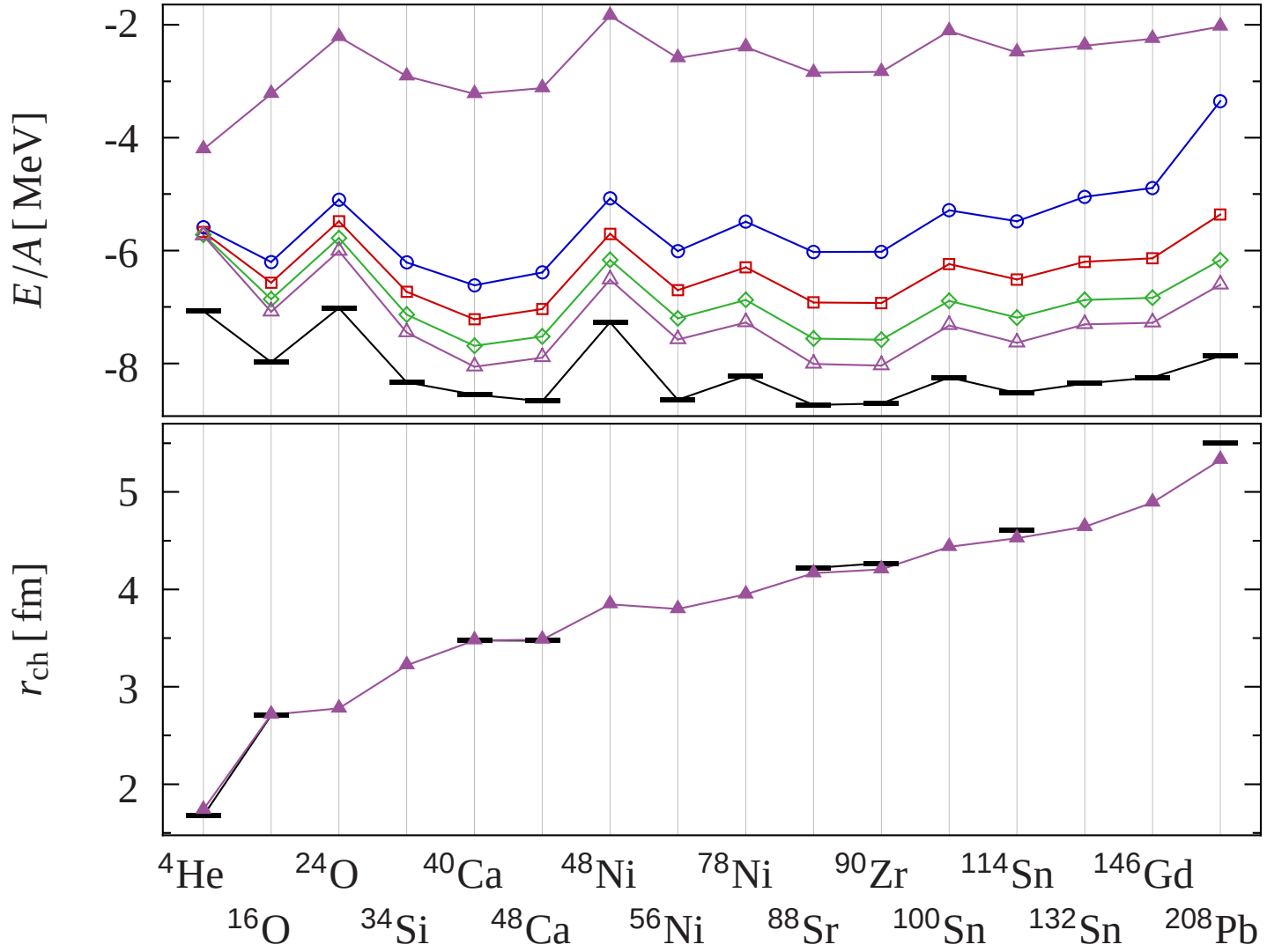


Many-Body Perturbation Theory

Formulation

- no long-range correlations with Hartree-Fock
- many-body perturbation theory
  - second order energy correction
- computationally demanding:
  - need to calculate three-body matrix elements
  - sums over unoccupied states are time-consuming

Many-Body Perturbation Theory



$C_{3N} = 1200\,\mathrm{MeV\,fm^6}$

$\alpha = 0.06\,\mathrm{fm^4}$

$e_{3\mathrm{max}} = 10$

Hartree-Fock:

● $e_{\mathrm{max}} = 14$

Perturbation Theory:

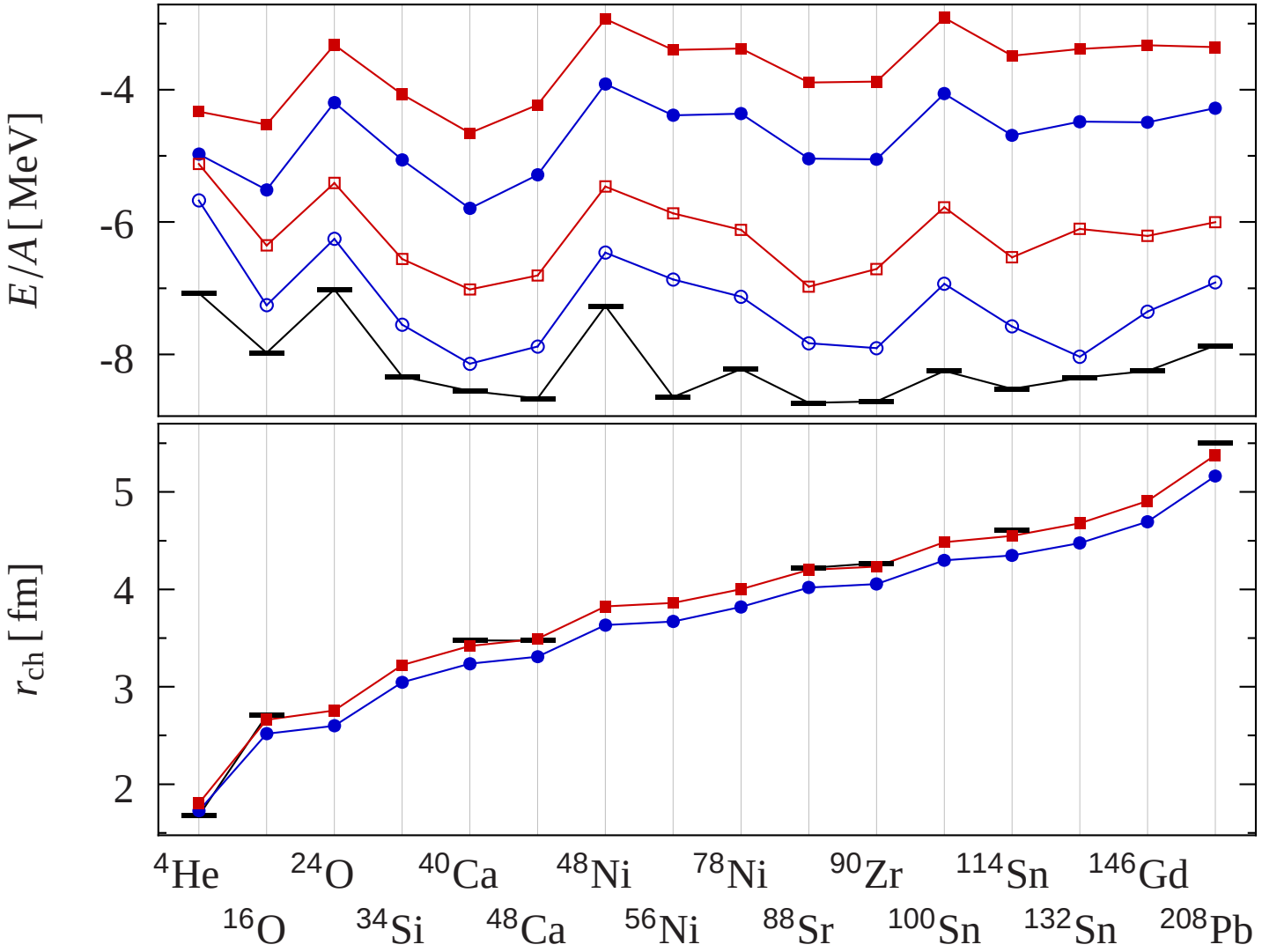
❍ $e_{\mathrm{max}} = 8$

□ $e_{\mathrm{max}} = 10$

◇ $e_{\mathrm{max}} = 12,\ l_{\mathrm{Max}} = 10$

△ $e_{\mathrm{max}} = 14,\ l_{\mathrm{Max}} = 10$

Outlook: N3LO Interaction



$e_{\max} = 12$

$e_{3\max} = 10$

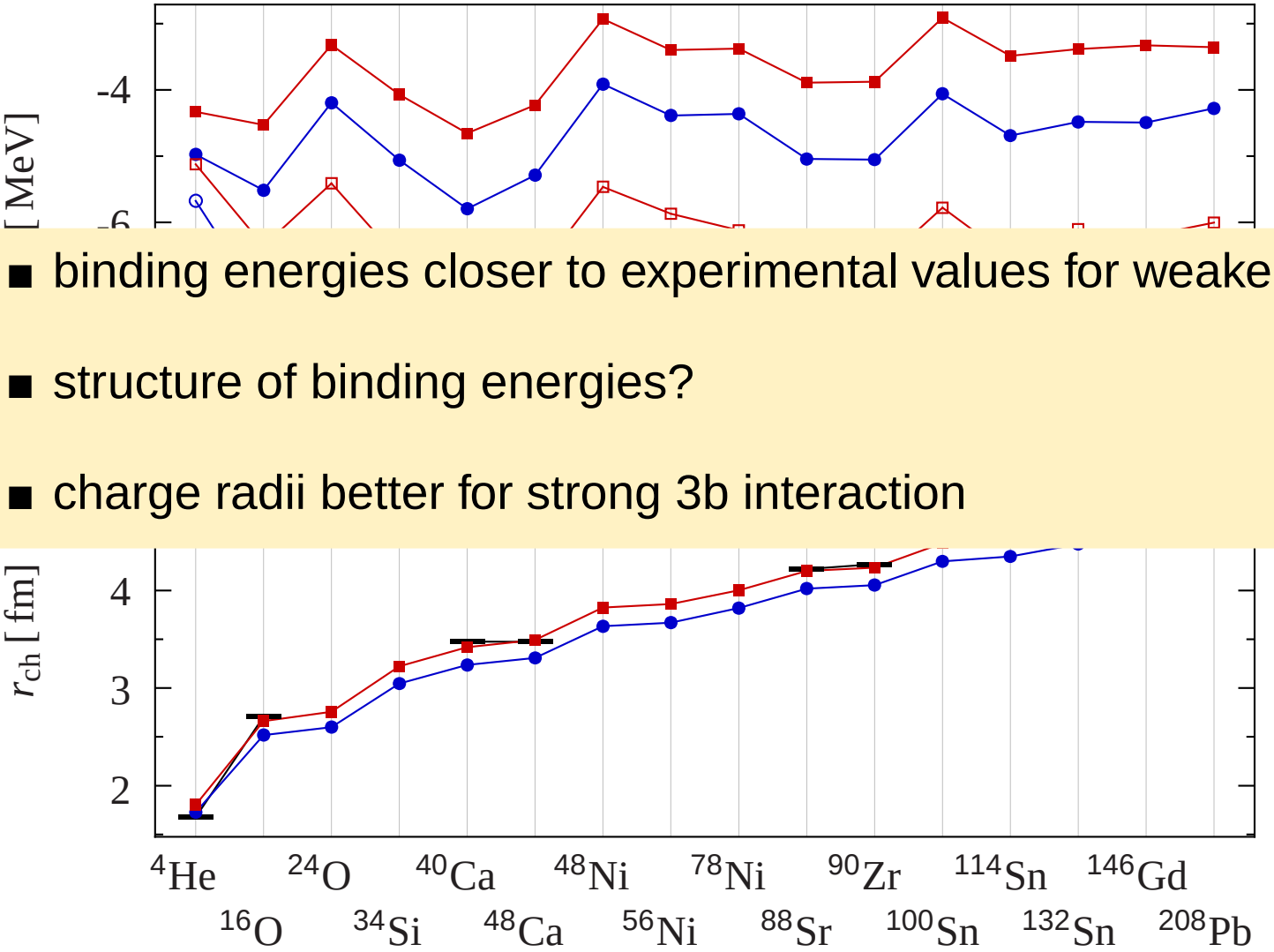
Hartree-Fock:

- ● $C_{3N} = 1500\,\mathrm{MeV\,fm^6}$
- ■ $C_{3N} = 2500\,\mathrm{MeV\,fm^6}$

Perturbation Theory:

- ❍ $C_{3N} = 1500\,\mathrm{MeV\,fm^6}$
- □ $C_{3N} = 2500\,\mathrm{MeV\,fm^6}$

Outlook: N3LO Interaction



$e_{\max} = 12$

$e_{3\max} = 10$

Hartree-Fock:

fm^6

fm^6

fm^6

□ $C_{3N} = 2500\,\mathrm{MeV\,fm}^6$

- binding energies closer to experimental values for weaker 3b interaction
- structure of binding energies?
- charge radii better for strong 3b interaction

Summary

Summary

- SRG-generated UCOM correlators
  - correlation functions
- effective three-body interaction
  - contact interaction with regularization
  - Hartree-Fock for different flow parameters
  - Many-Body Perturbation Theory
- calculations with N3LO interaction
- alternative: finite-range three-body interaction