Chiral 3N Interactions: Local vs. Nonlocal

Thomas Hüther, Klaus Vobig and Robert Roth

TECHNISCHE UNIVERSITÄT DARMSTADT

TRIUMF Workshop 2019

DFG

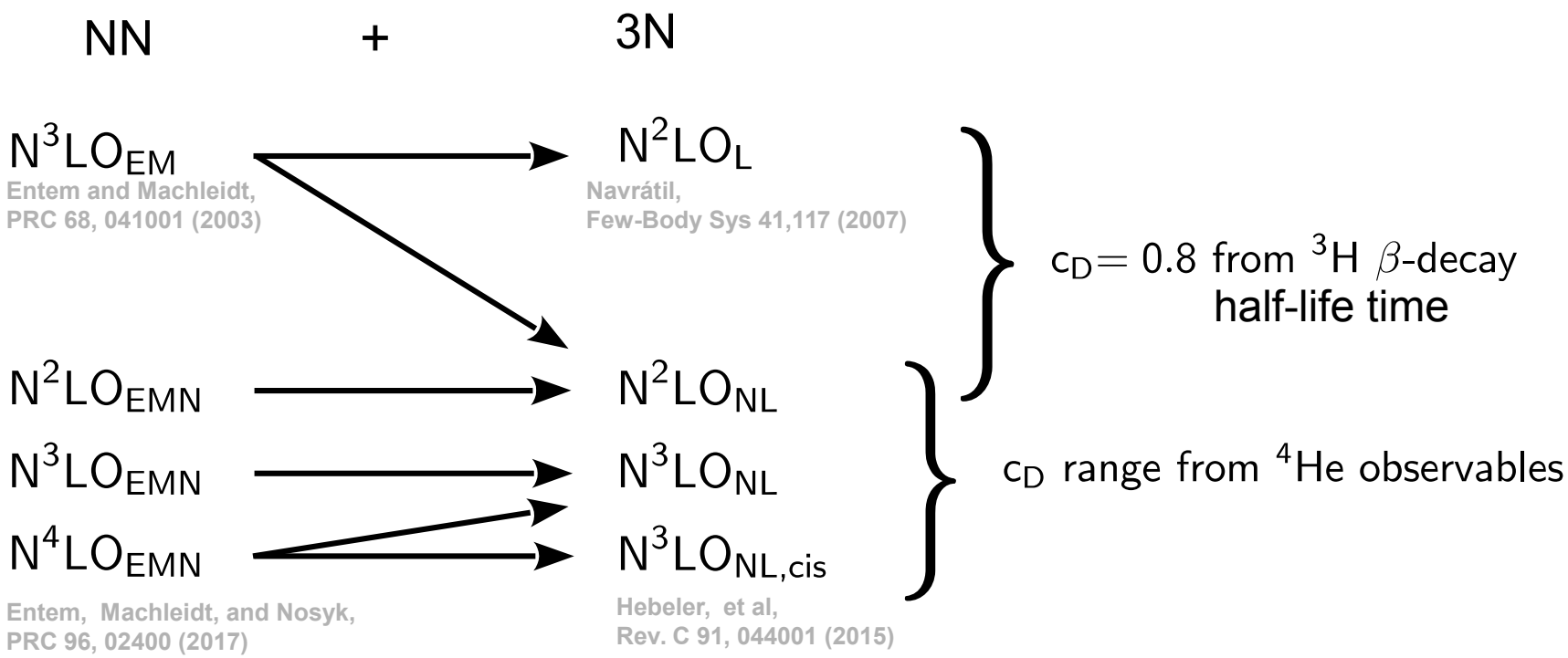
SFB 1245

Hessisches Kompetenzzentrum für Hochleistungsrechnen

Motivation

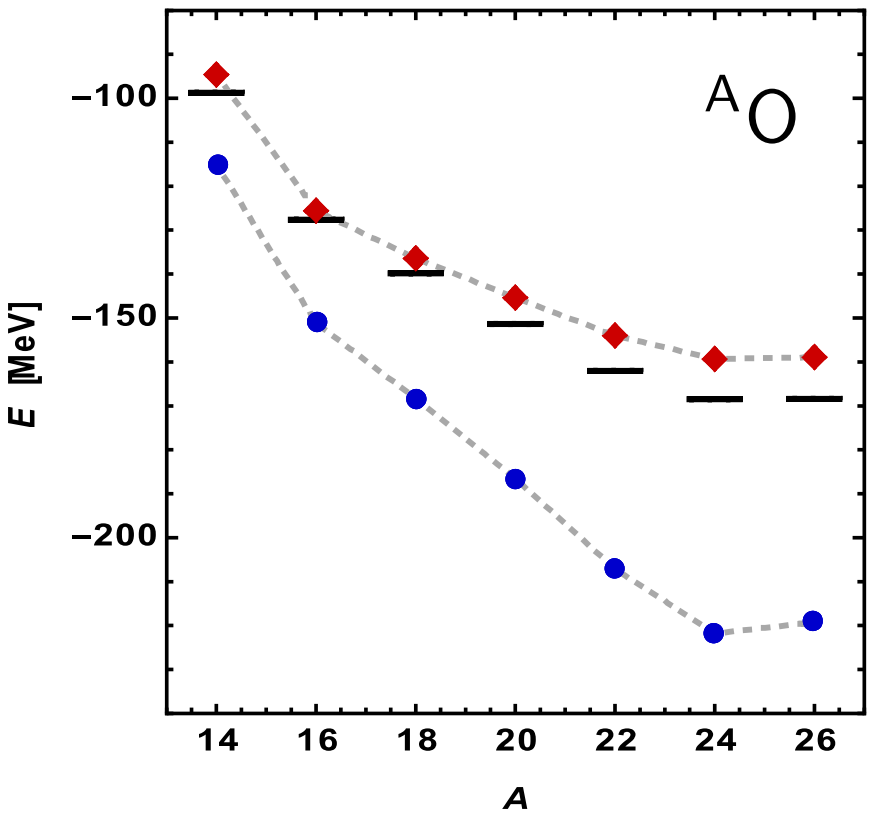
- interactions from chiral effective field theory
  - allow for systematic uncertainty quantification via order-by-order analysis
- combine different NN interactions with 3N interactions
- compare local and nonlocal 3N interactions
- explore 3N interactions ‘consistent’ up to N^3LO

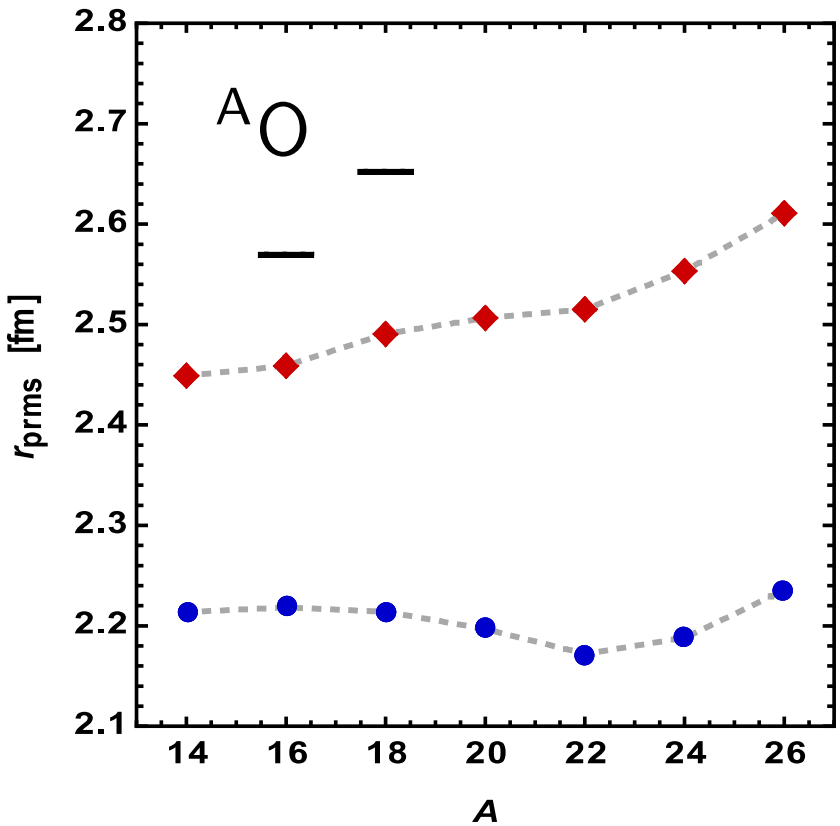
Interactions



- $c_D - c_E$ correlation from ^{3}H ground-state energy
- soften interactions with SRG
- use computational efficient many-body methods: Jacobi-NCSM, NCSM-PT, IM-SRG

Local vs Nonlocal





$N^3LO_{EM} + N^2LO_{NL}$

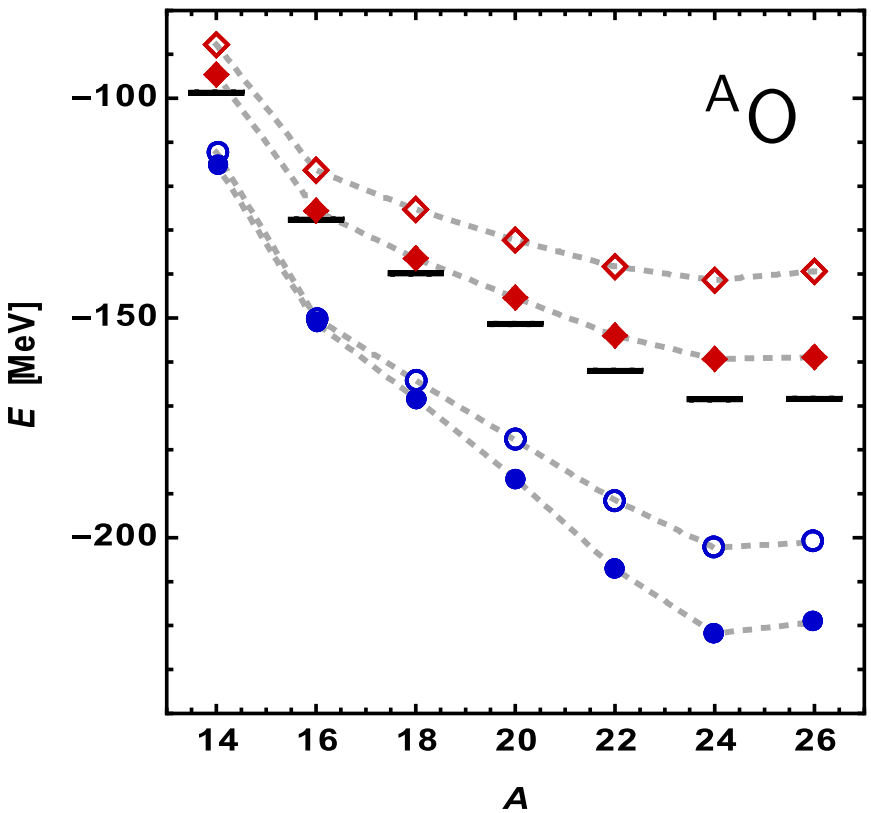
$N^3LO_{EM} + N^2LO_{L}$

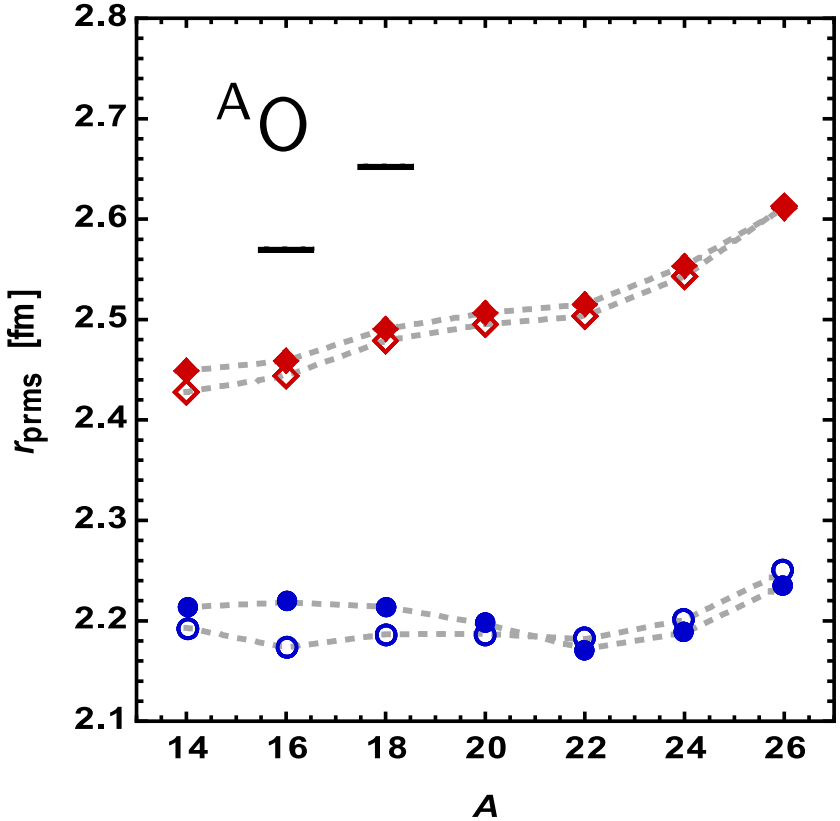
NCSM-PT $\alpha = 0.08\text{fm}^4$

◆ $\Lambda_{3N} = 500\text{MeV}$

● $\Lambda_{3N} = 500\text{MeV}$

Local vs Nonlocal



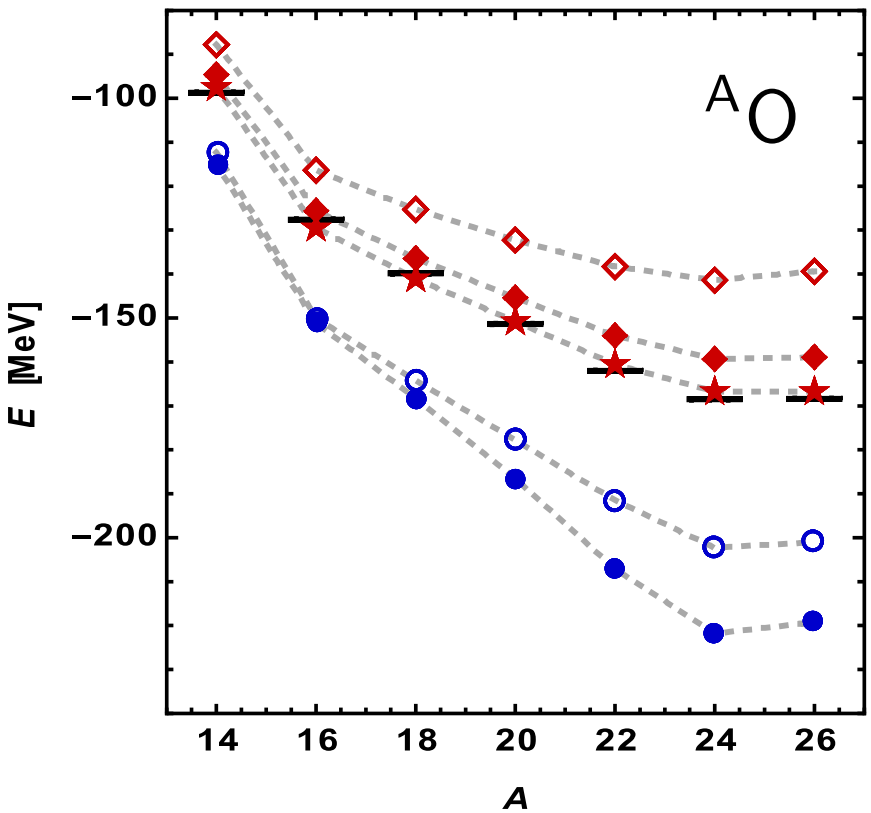


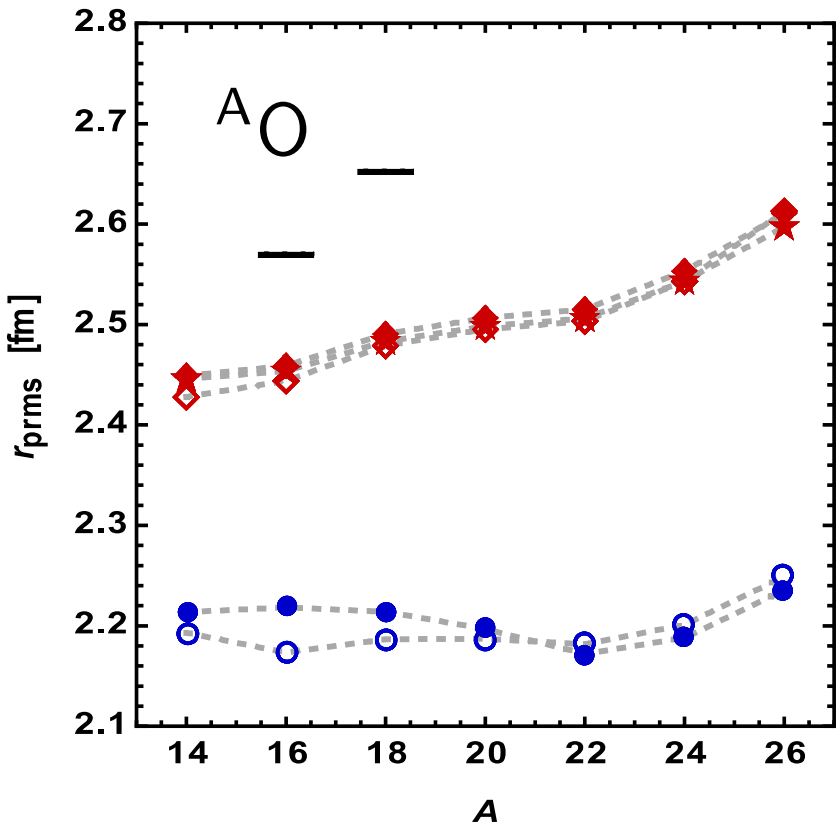
$N^3LO_{EM} + N^2LO_{NL}$ ◇ $\Lambda_{3N} = 400$MeV ◆ $\Lambda_{3N} = 500$MeV

$N^3LO_{EM} + N^2LO_{L}$ ○ $\Lambda_{3N} = 400$MeV ● $\Lambda_{3N} = 500$MeV

NCSM-PT $\alpha = 0.08\text{fm}^4$

Local vs Nonlocal



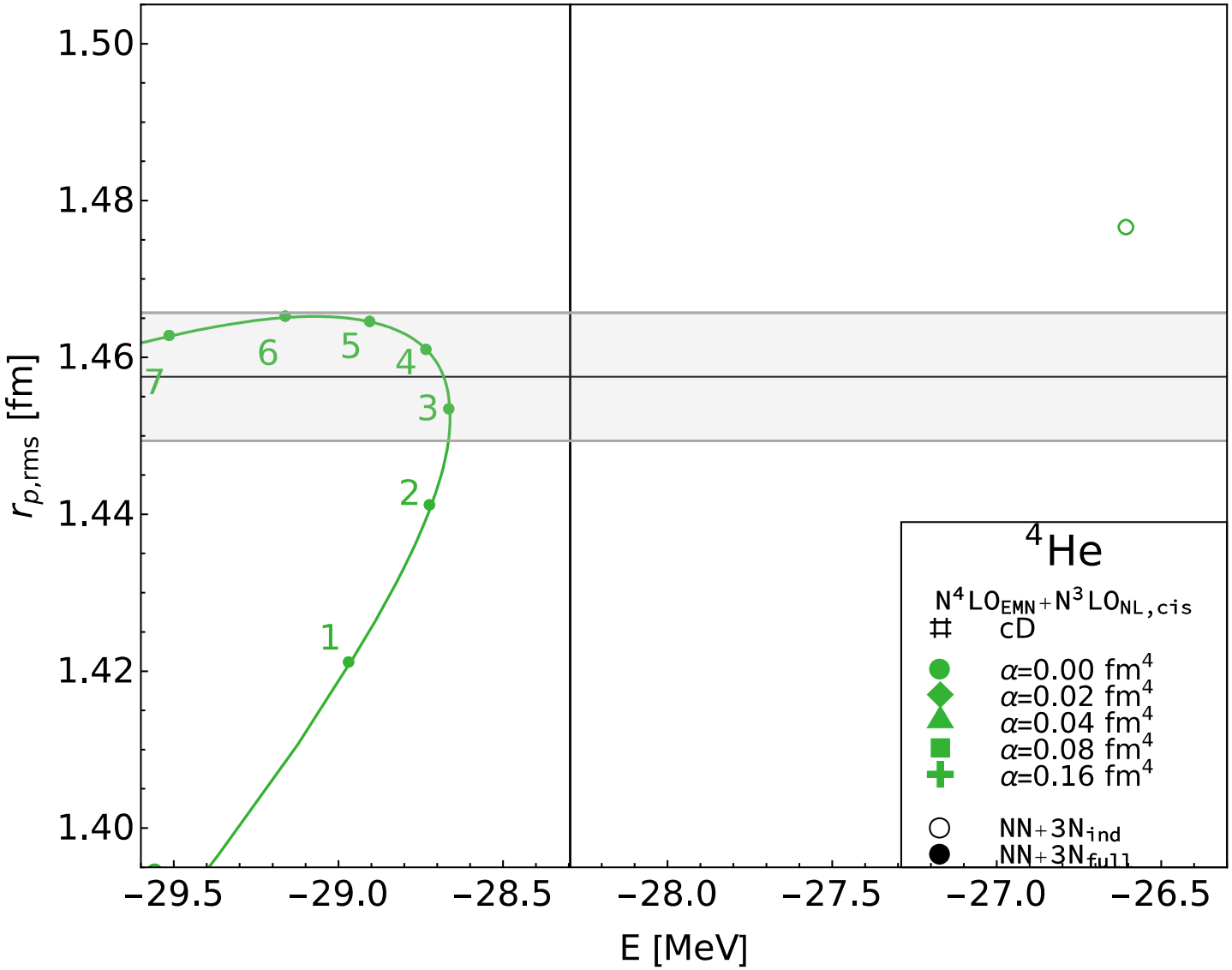


$N^3LO_{EM} + N^2LO_{NL}$ ◇ $\Lambda_{3N} = 400$MeV ◆ $\Lambda_{3N} = 500$MeV ★ $\Lambda_{3N} = 525$MeV

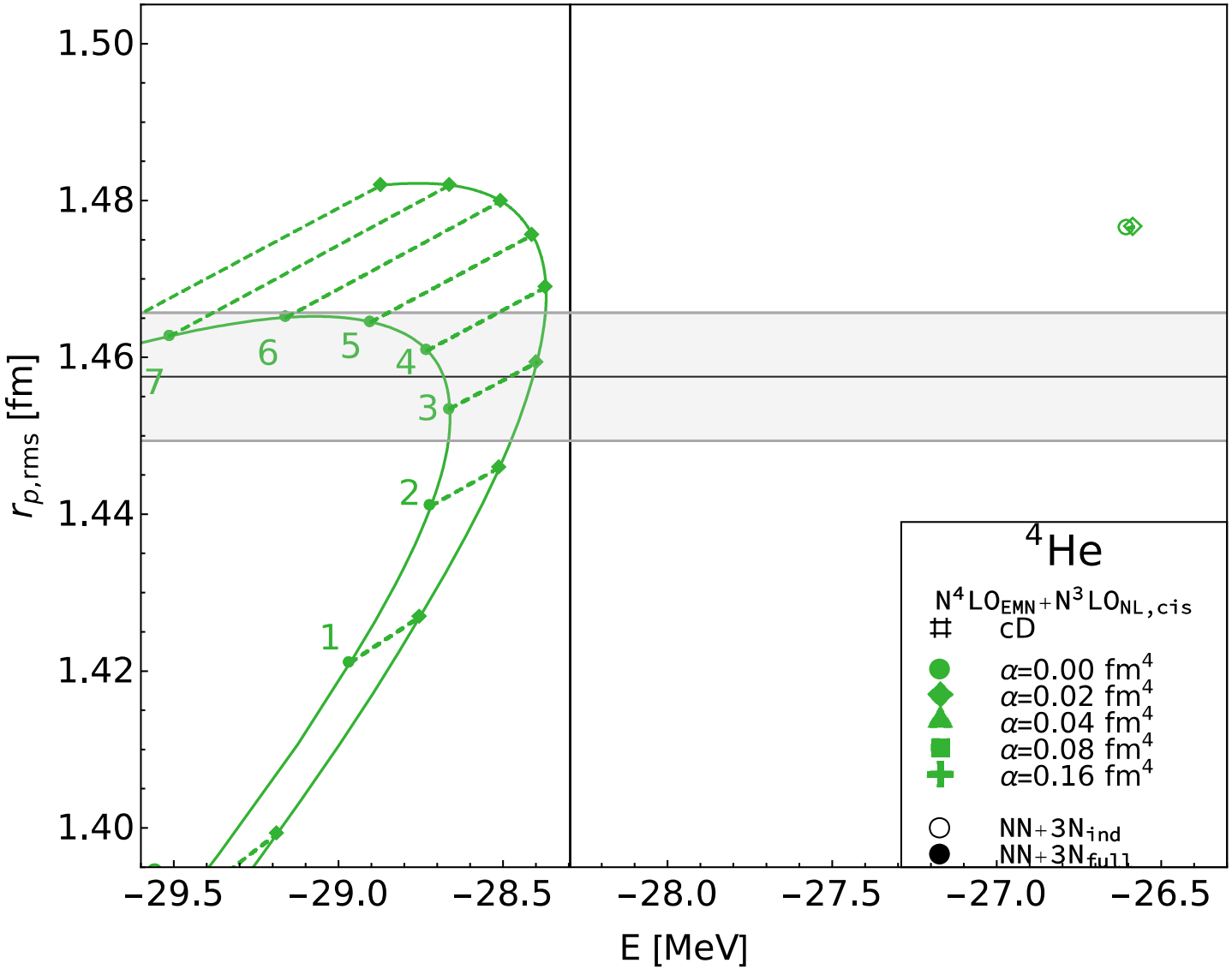
$N^3LO_{EM} + N^2LO_{L}$ ○ $\Lambda_{3N} = 400$MeV ● $\Lambda_{3N} = 500$MeV

NCSM-PT $\alpha = 0.08\text{fm}^4$

^{4}He – Determination of c_D Range



^{4}He – Determination of c_D Range



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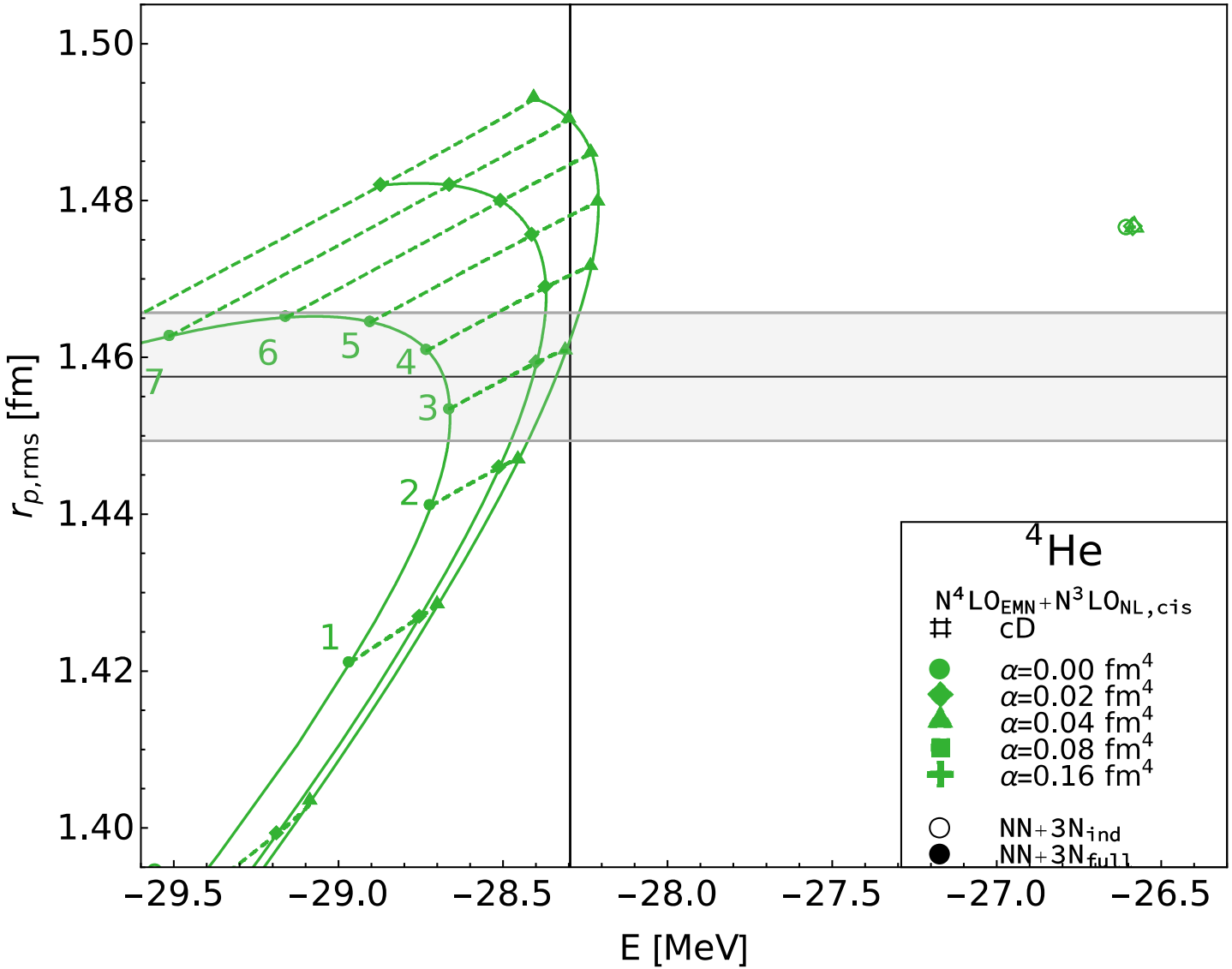
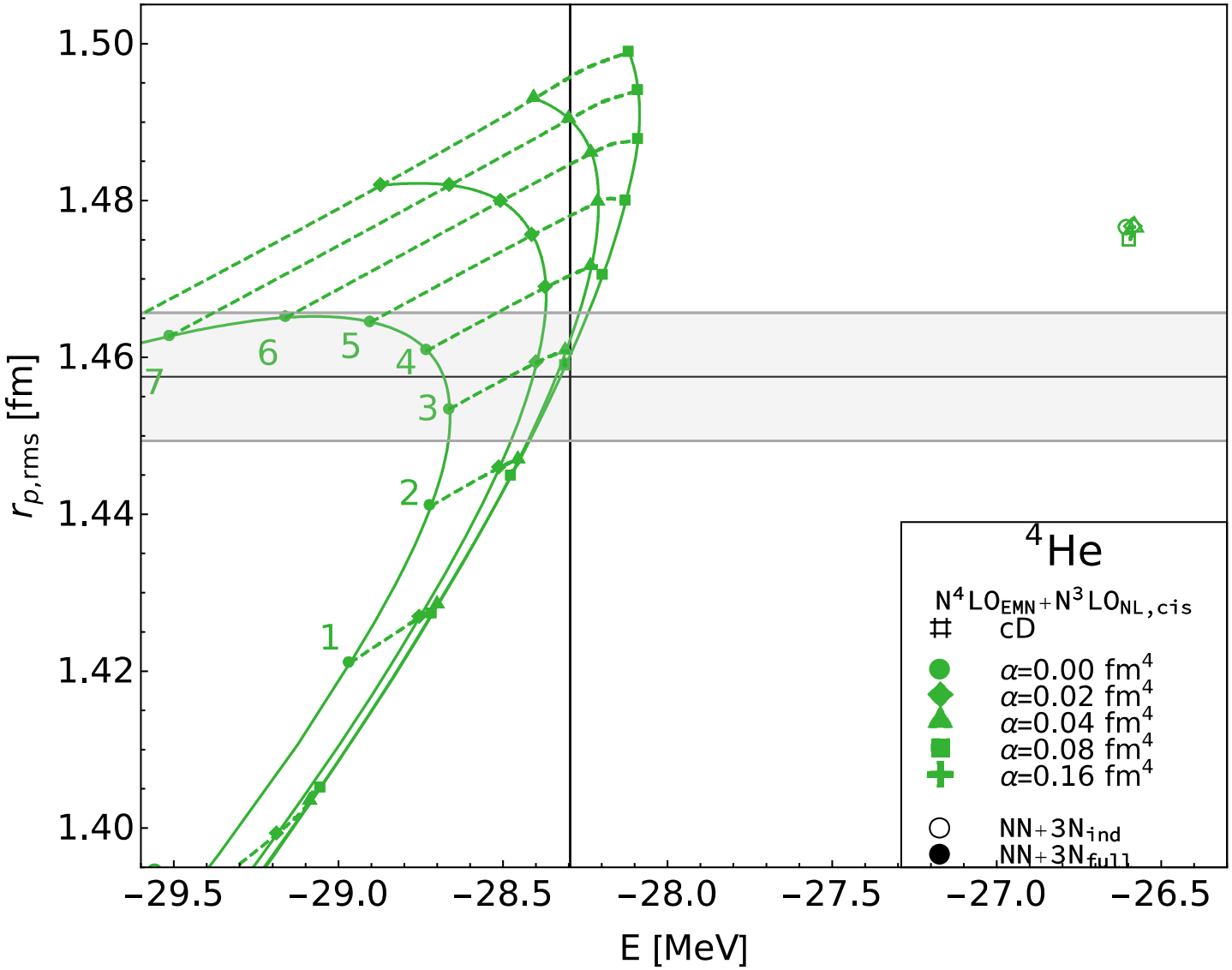


^{4}He – Determination of c_D Range



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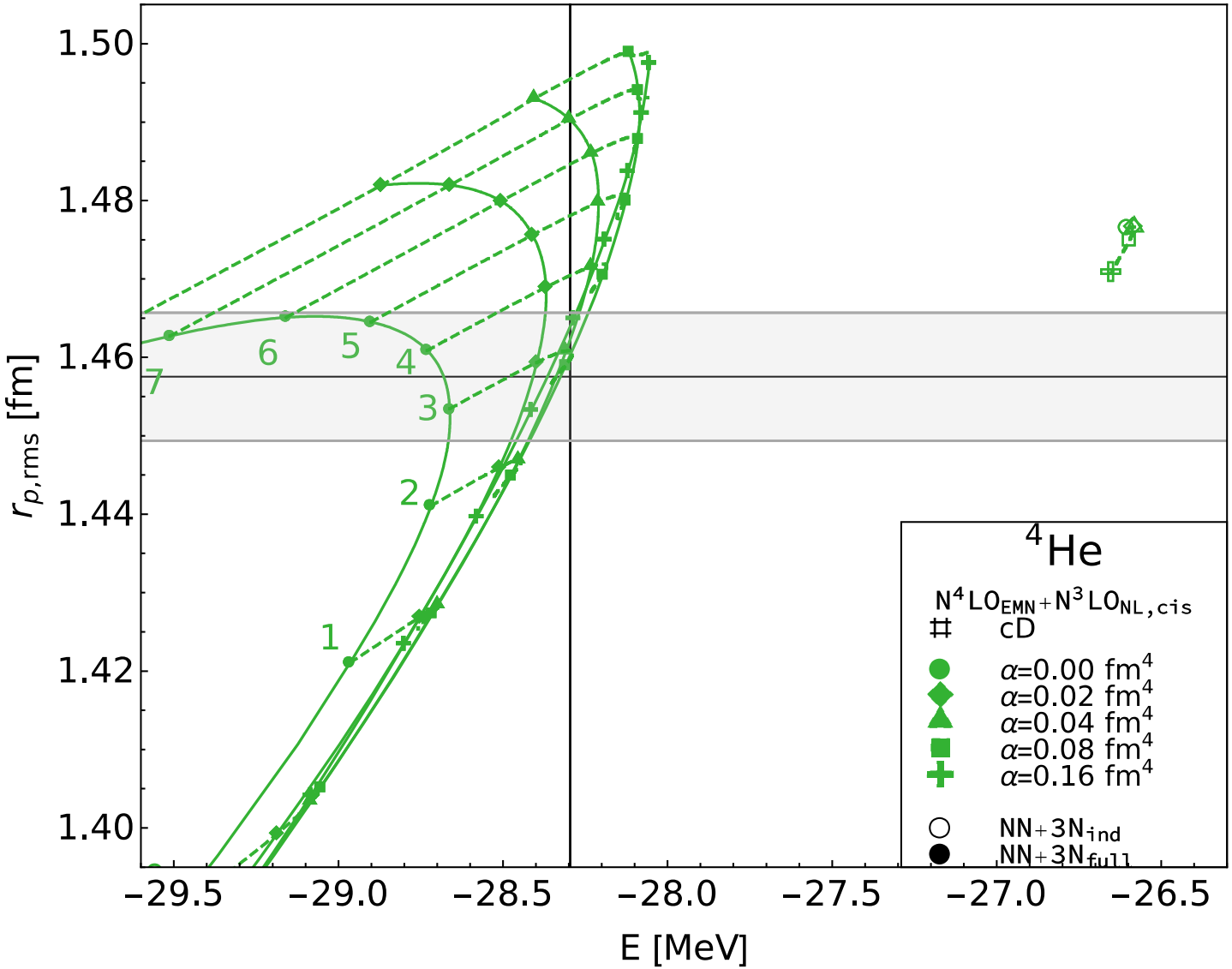
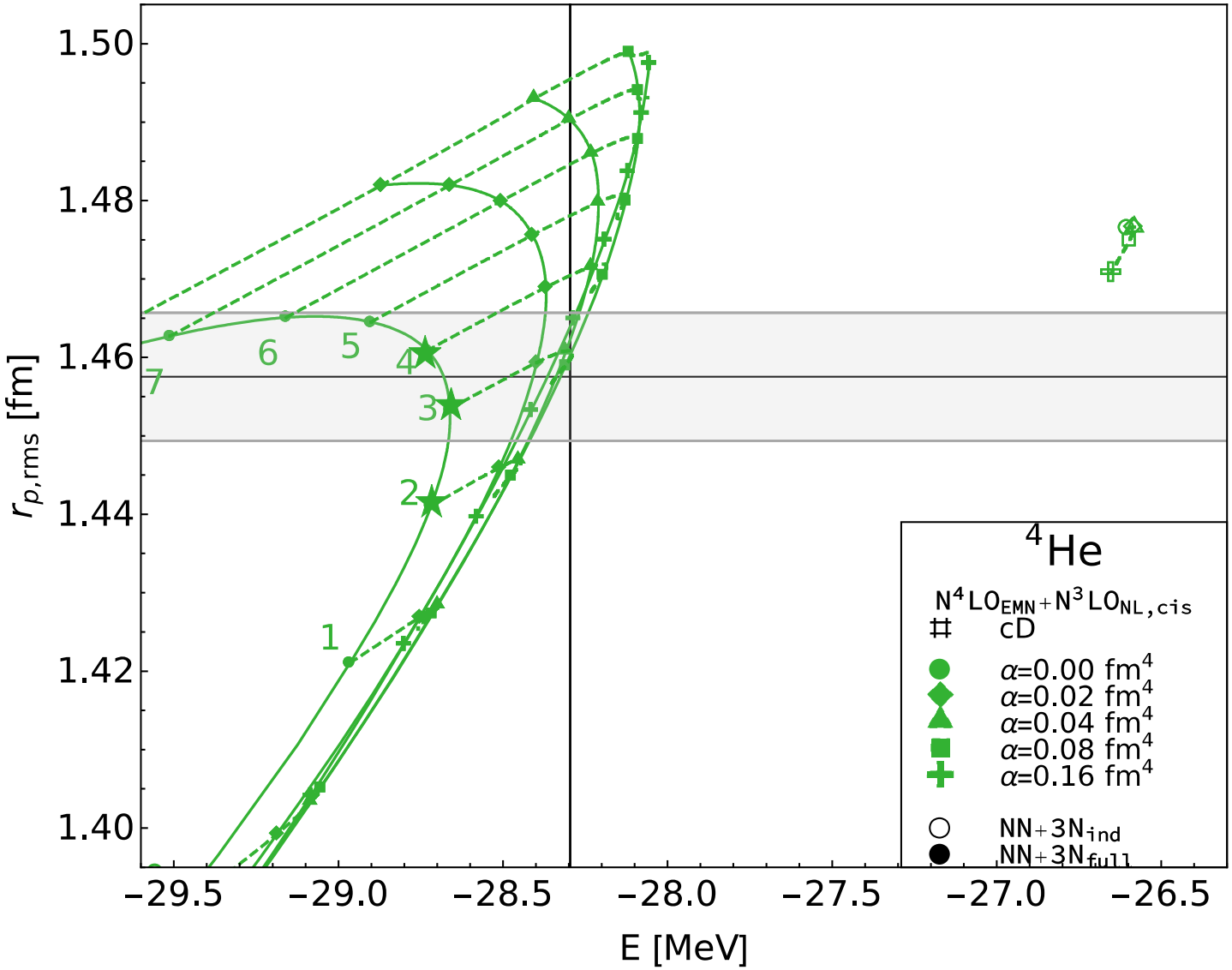
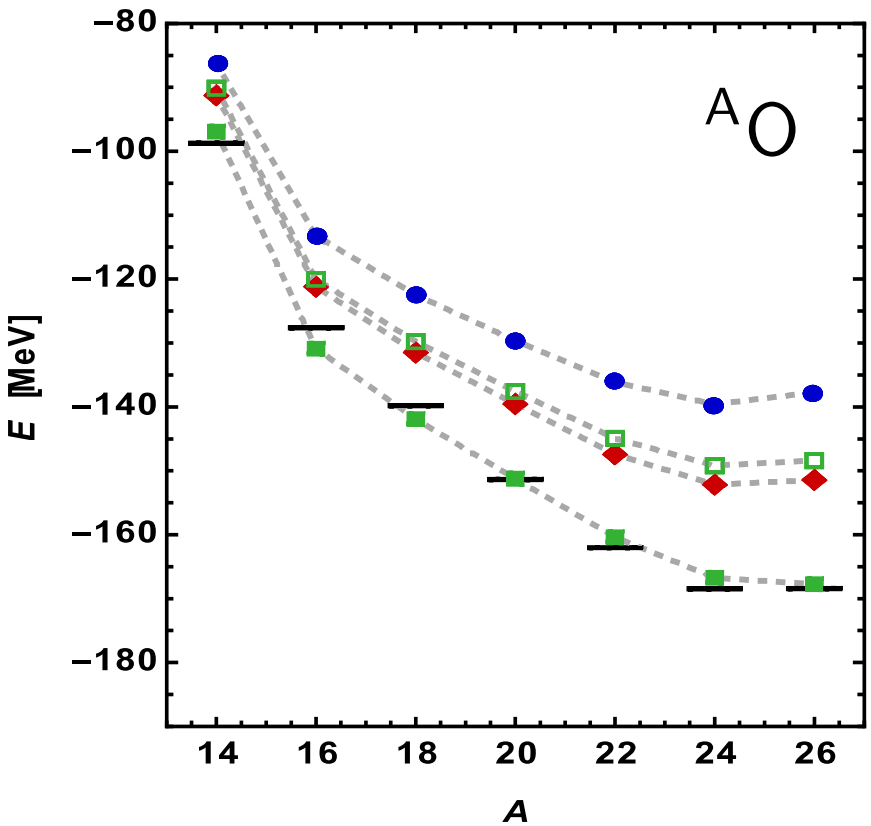
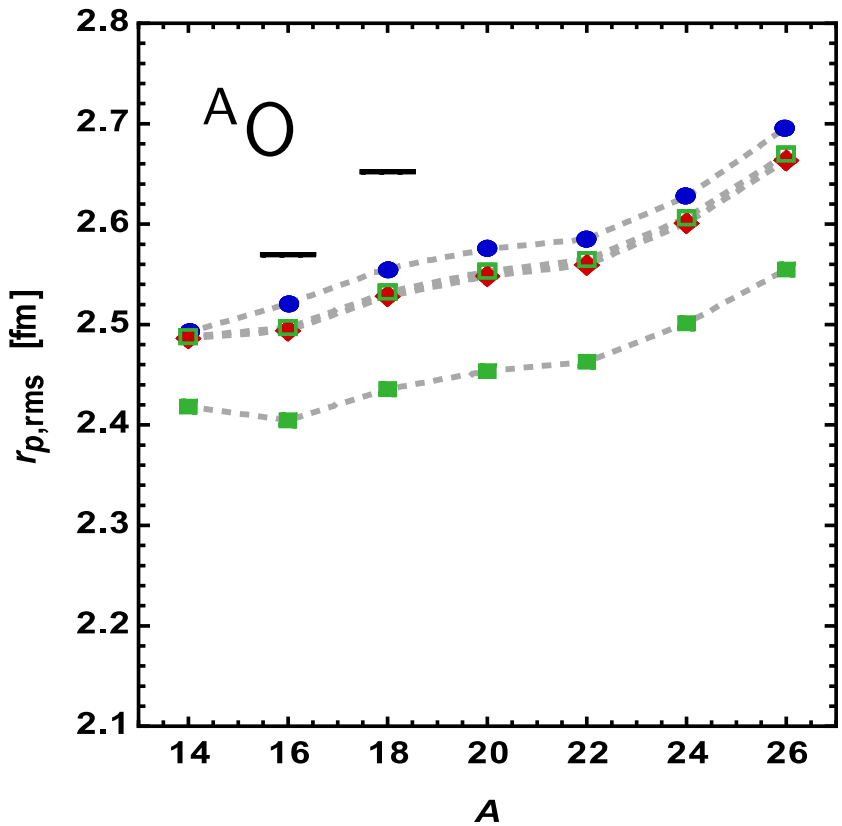


^{4}He – Determination of c_D Range



Oxygen Chain





- $N^2LO_{EMN} + N^2LO_{NL,cD=-1}$
- $N^3LO_{EMN} + N^3LO_{NL,cD=2}$
- $N^4LO_{EMN} + N^3LO_{NL,cD=1}$
- $N^4LO_{EMN} + N^3LO_{NL,cD=3,cis}$

NCSM-PT

$\alpha = 0.08\mathrm{fm}^4$

See you at the Poster

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Chiral 3N Interactions: Local vs Nonlocal

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Motivation

Recent developments in chiral effective field theory (EFT) interactions allow for a systematic uncertainty quantification via order by order analysis and comparison between different regularization schemes and scales.
We explore the effects of different regularizations in the three-body force in nuclear observables, in particular the ground-state energy and radii of various nuclei, since a simultaneous description is hard to achieve.
We combined the N^3LO_{EM} NN interaction [1] with a 3N force at N^2LO with an updated LEC c_D constrained through the beta decay half life of tritium and compare local [2] and nonlocal [3] regularization schemes. Furthermore, we explore 3N forces up to N^3LO in combination with the N^*LO_{EMN} NN interaction family [4].

Similarity Renormalization Group

- unitary transformation of the Hamiltonian to improve convergence in many-body calculations
- prediagonalization of Hamiltonian via continuous flow equation

$$\frac{dH_\alpha}{d\alpha} = [\eta_\alpha, H_\alpha]$$

- antihermitian generator

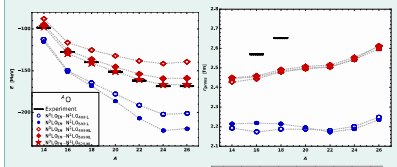
$$\eta_\alpha = (2\mu)^2 [T, H_\alpha]$$

- emergence of induced many-body forces
- perform SRG transformation in NN and 3N space
- the radius operator is consistently evolved in two-body space

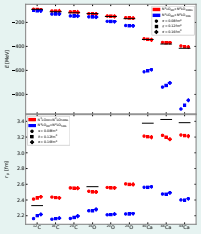
Nuclear Many-Body Problem

- use computational effective methods
- Jacobi-NCSM
  - many-body model-space truncated via total excitation quanta N_{max}
  - relative coordinates make large model spaces accessible
- NCSM-PT [5] with Natural Orbitals Basis [6]
  - use NCSM $N_{max} = 2$ reference state with Natural Orbital Basis
  - second-order perturbative energy corrections
  - radii from $N_{max} = 2$ reference state
- IM-SRG
  - use the SRG flow equation in order to decouple a reference state from the rest of the Hilbert space

N^3LO_{EM} NN with Local and Nonlocal 3N

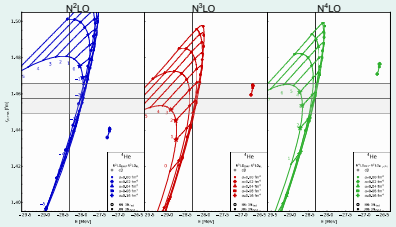


- N^3LO_{EM} NN interaction with local and nonlocal 3N force at N^2LO
- updated c_D= 0.8 from ^{3}H beta decay
- c_D-c_E correlation from ^{3}H ground-state energy
- local force overbindes and radii are far too small
- cutoff variation can improve energy and has small inpact on radii
- small SRG induced many-body contributions

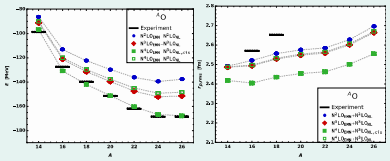


N^*LO_{EMN} NN Interaction with Nonlocal 3N Force

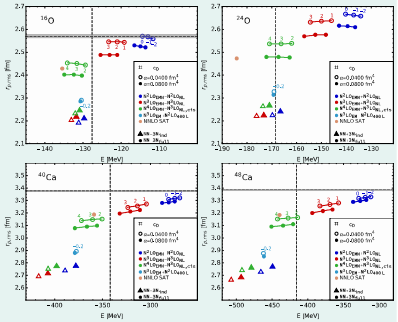
- combine N^*LO_{EMN} NN interaction family with consitent nonlocal 3N forces up to N^3LO and use N^4LO c_i shifts in 3N force
- determine c_D-c_E correlation via tritium ground-state energy and use c_D range motivated through ^{4}He ground-state observables in heavier nuclei



- effect of SRG induced 4N forces increases with increasing c_D



- N^4LO c_i shifts in 3N force inhibits order-by-order convergence
- reproduce experimental ground-state energies with N^4LO interaction



- 3N force increases radii, but c_D choice has small inpact

Technische Universität Darmstadt, Germany

References:
[1] Entem and Machleidt, Phys. Rev. C **68**, 041001 (2003).
[2] Navrátil, Few-Body Systems **41**, 117 (2007).
[3] Hebeler, Krebs, Epelbaum, Gegelia, and Skibiński, Phys. Rev. C **91**, 044001 (2015).
[4] Entem, Machleidt, and Nosyk, Phys. Rev. C **96**, 024004 (2017).
[5] Tichai, Gebrerufael, Vobig, and Roth, Phy Lett. B **786**, 448 (2018).
[6] Tichai, Müller, Vobig, and Roth, arXiv:1809.07571v2 [nucl-th] .

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Epilog

- **Thanks to my group and collaborators**
  - S. Alexa, M. Deuker, **K. Hebeler**, P. Käse, M. Knöll, L. Mertes, T. Mongelli, J. Müller, **R. Roth**, **K. Vobig**, T. Wolfgruber
    Technische Universität Darmstadt
  - R. Wirth
    Michigan State University
  - E. Epelbaum, H. Krebs & the LENPIC Collaboration
    Universität Bochum, ...
- **Thank you for your attention!**

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COMPUTING TIME