HFHF Helmholtz Forschungsakademie Hessen für FAIR

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SFB 1245

REVISITING CHIRAL LOW-MOMENTUM INTERACTIONS FOR MEDIUM-MASS NUCLEI

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REVISITING CHIRAL LOW-MOMENTUM INTERACTIONS

INTERACTIONS AND AB INITIO METHODS

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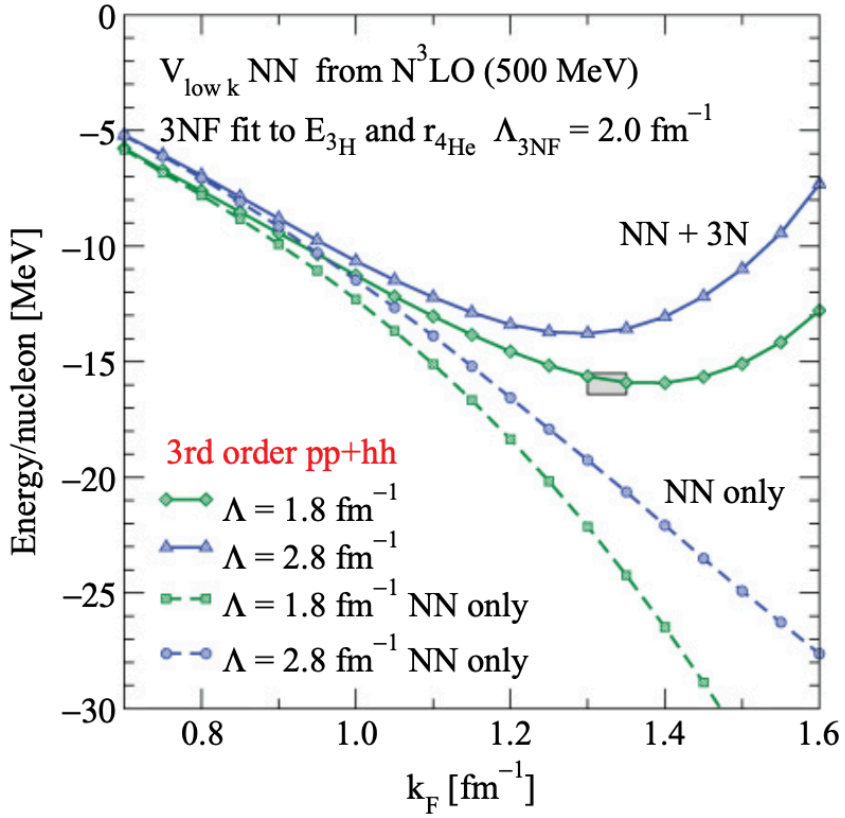
THE IMPORTANCE OF GOOD INTERACTIONS

Driver of the ab initio progress

- Accurate results now available over the nuclear chart
- EFT paradigm enables uncertainty quantification

Key importance of three-body forces

- Needed for good description of driplines, saturation…



[Hebeler *et al.*, *PRC* **83** (2011)]

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CURRENT LIMITATIONS

Simultaneous description of nuclear properties

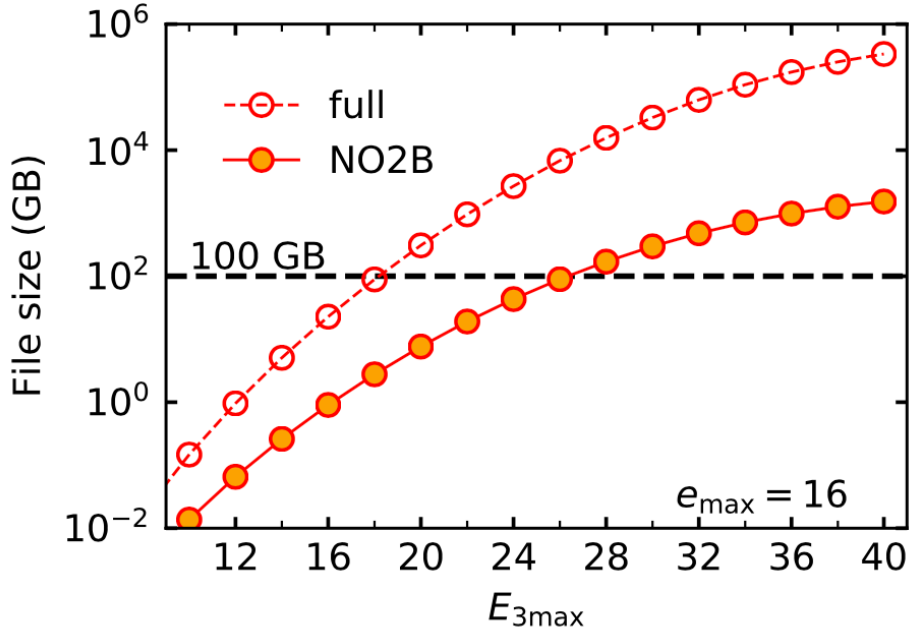
- Difficulty reproducing all the phenomenology with one Hamiltonian
- Trade-off between energies, radii…

Importance of softness for larger masses

- Hard interactions kill the numerical convergence
- Issue of e.g. contributions at larger $e_{\max}/E3_{\max}$

Storage

- Hardware limitations prevent large $e_{\max}/E3_{\max}$ ME storage
- A lot of progress recently but need for even more agressive savings



[Miyagi *et al.*, *PRC* **105** (2022)]

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REVISITING CHIRAL LOW-MOMENTUM INTERACTIONS

EXPOSING THE LOW-RANK STRUCTURE OF NUCLEAR INTERACTIONS

[Tichai, Arthuis, Hebeler, Heinz, Hoppe, Schwenk, *PLB* **821** (2021)]
[Tichai, Arthuis, Hebeler, Heinz, Hoppe, Schwenk, Zurek, *PRC* **106** (2022)]

[Tichai, Arthuis, Hebeler, Heinz, Hoppe, Schwenk, *PLB* **821** (2021)]

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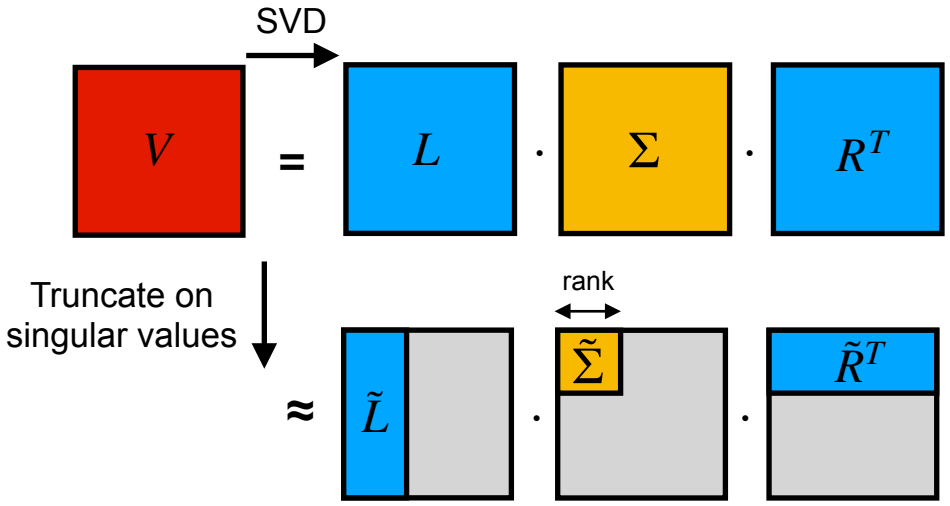
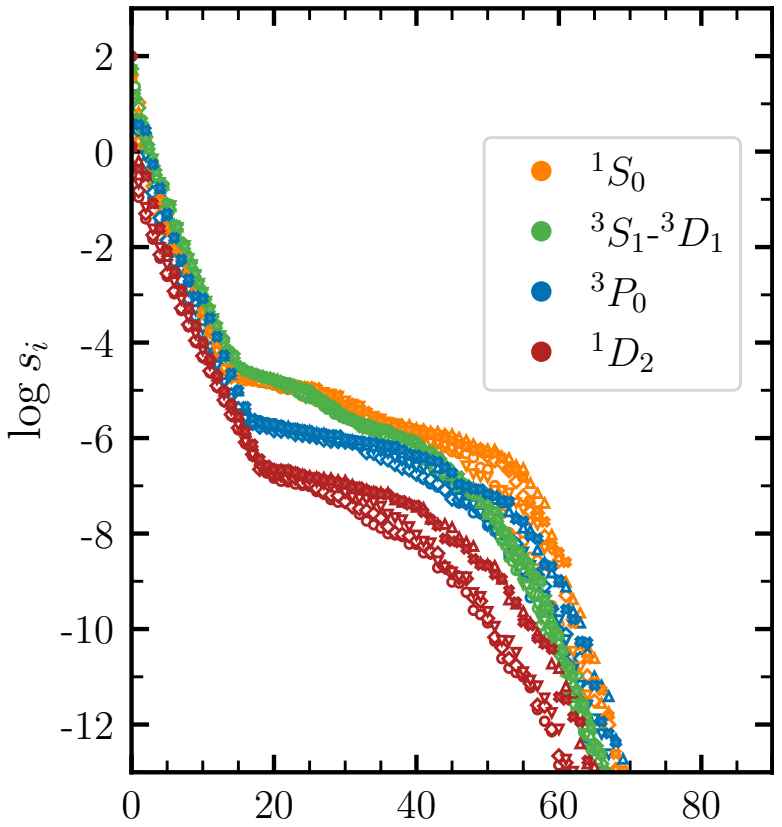
SVD DECOMPOSITION OF NN HAMILTONIANS

Matrix element storage

- Sizable but manageable for NN part
- 3N force is responsible for the *ab initio* range limit

Can we do something about it?





Can we exploit this rapid fall-off?

[Tichai, Arthuis, Hebeler, Heinz, Hoppe, Schwenk, *PLB* **821** (2021)]

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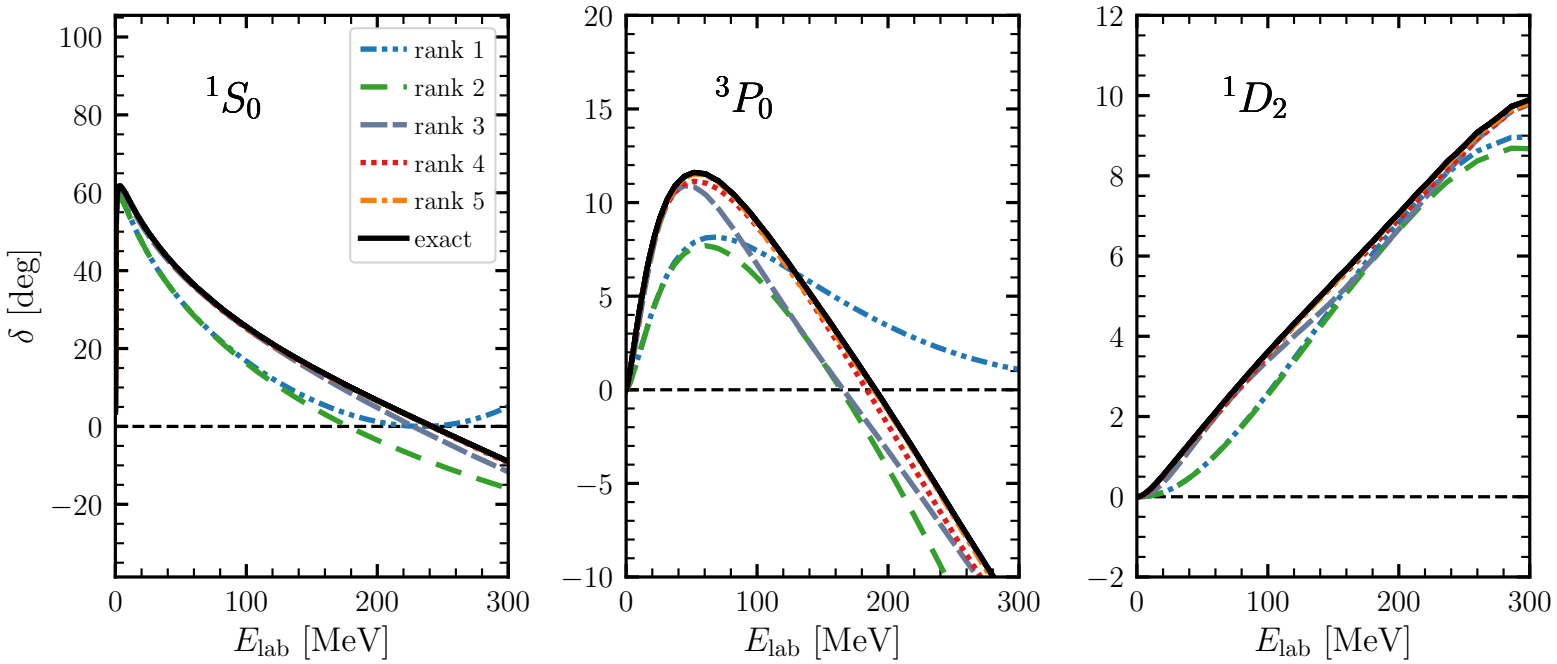
SVD DECOMPOSITION OF NN HAMILTONIANS

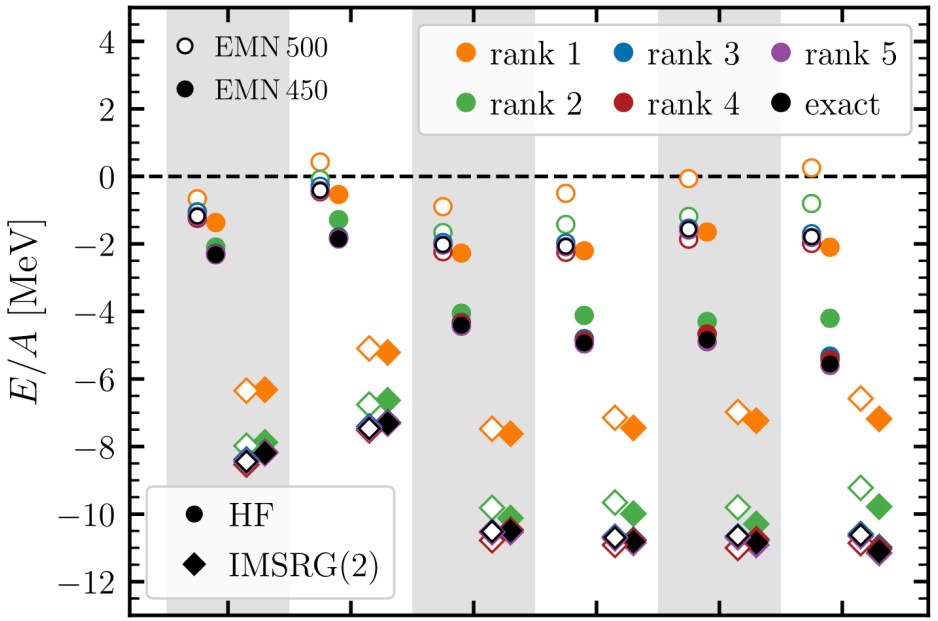
Reproduction of the phaseshifts

- Each rank improves convergence
- Virtually exact by rank 5



99% accuracy with 5% of the data

- Systematic convergence w.r.t. rank
- Quality independent of mass number



See also [Zhu *et al.*, *PRC* 104 (2021)]

[Tichai, Arthuis, Hebeler, Heinz, Hoppe, Schwenk, Zurek, *PRC* **106** (2022)]

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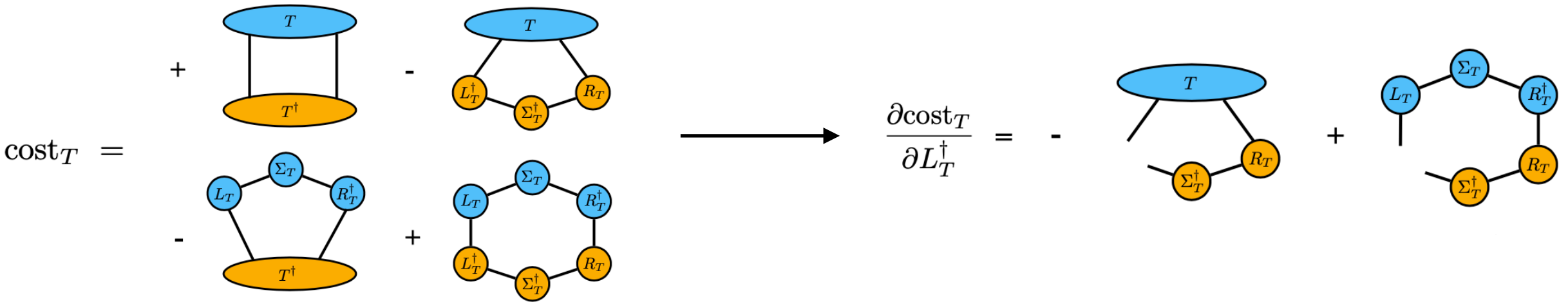
LEVERAGING THE FACTORIZATION

Factorized form of an equation

$$T = f(T, V, \dots)$$

Measure the distance to the exact form

Minimum reached when derivatives vanish



[Tichai, Arthuis, Hebeler, Heinz, Hoppe, Schwenk, Zurek, *PRC* **106** (2022)]

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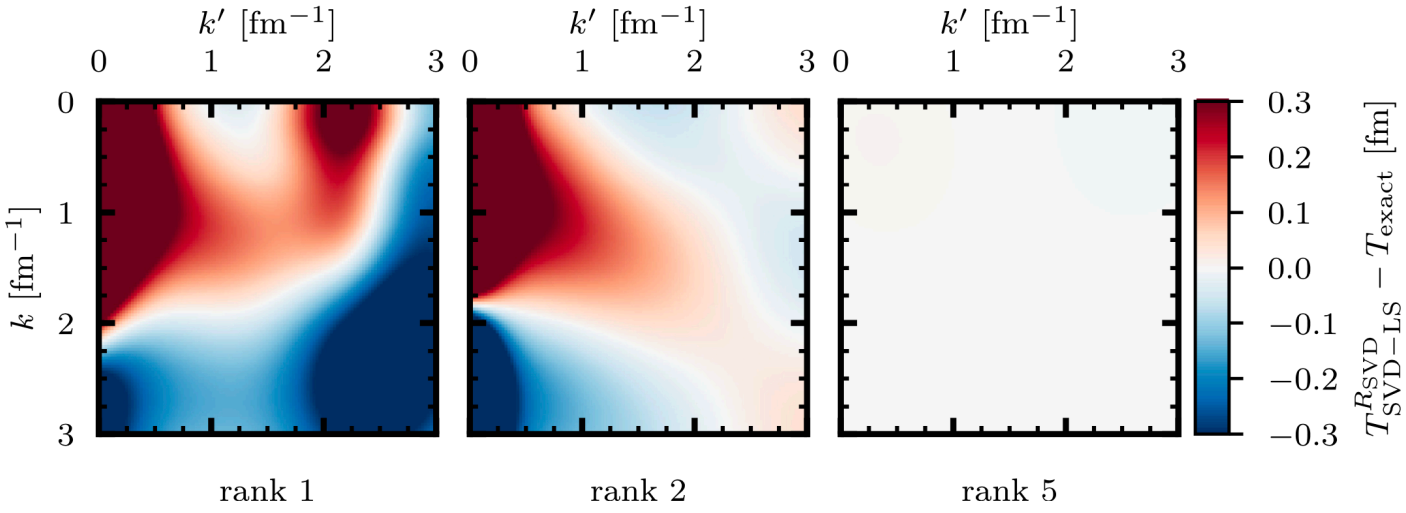
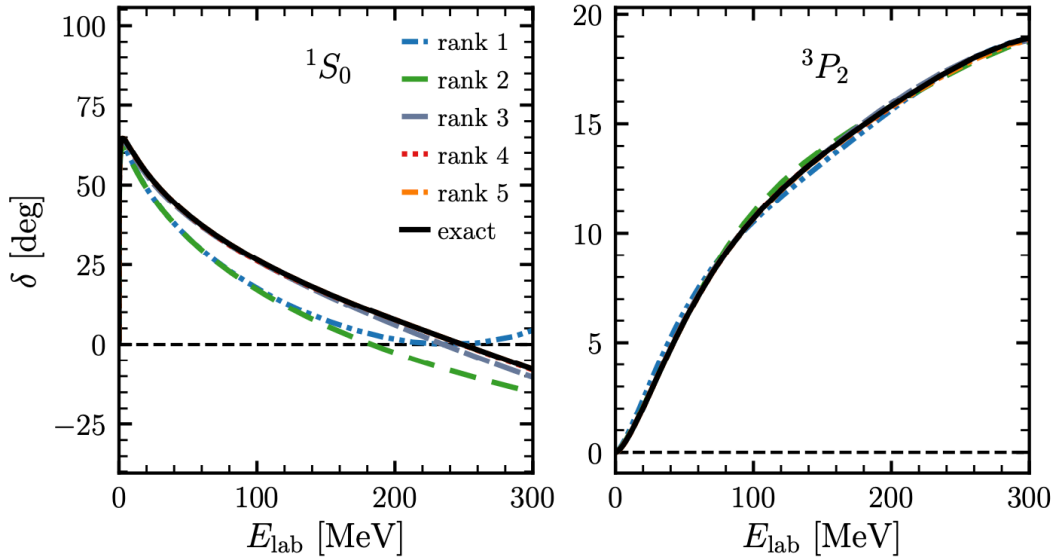
LEVERAGING THE FACTORIZATION





T-matrix reproduction

- Each rank improves convergence
- Virtually exact by rank 5

Reproduction of the phaseshifts

- Now from factorised T-matrix
- Completely factorised toolchain

First step towards factorised many-body methods

TOWARDS A BETTER UNDERSTANDING OF INTERACTIONS

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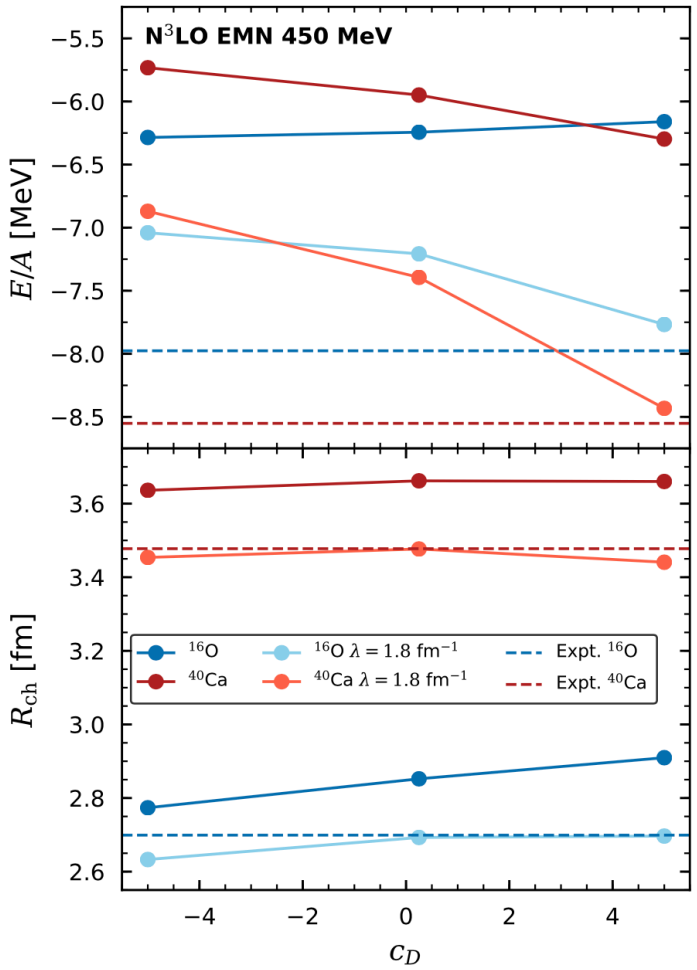
WHY LOW-MOMENTUM INTERACTIONS?

Make sense of interactions

- Difficulty reproducing all the phenomenology with one Hamiltonian
- But low-momentum interactions like 1.8/2.0(EM) proved successful
- Can we get a better understanding?

Insights from recent studies

- Low-cutoff fits can work even without initial SRG
  [Jiang *et al.*, *PRC* **102** (2020)]
- SRG evolution enhances LEC sensitivity
  [Hüther *et al.*, *PLB* **808** (2019), Hoppe *et al.*, *PRC* **100** (2019)]



[Hoppe *et al.*, *PRC* **100** (2019)]

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A NEW LOOK AT THE 1.8/2.0 APPROACH

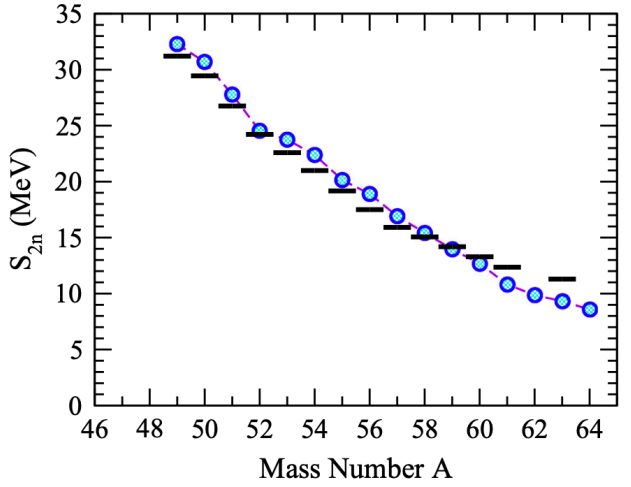
Approach introduced in Hebeler et al., PRC 83 (2011)

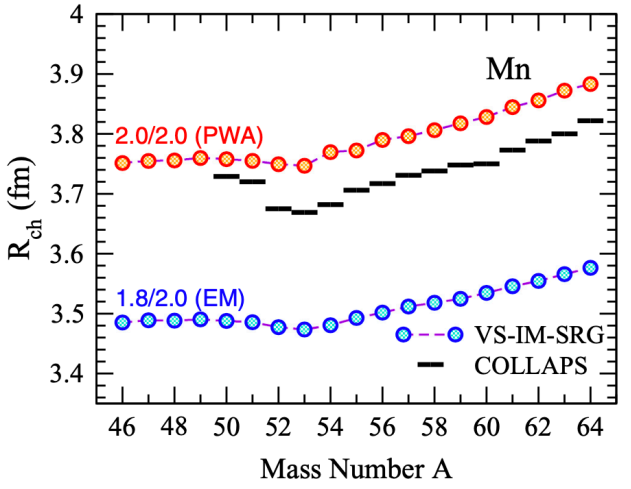
- NN force SRG-evolved to 1.8 fm^{-1}
- 3N force fitted with a cutoff of 2.0 fm^{-1}

Application to medium-mass nuclei

- Particularly successful for energies starting from the EM500 [Entem & Machleidt, *PRC* **68** (2003)]
- But underpredicted radii

Can we meaningfully revisit this from other interactions?





[Simonis *et al.*, *PRC* **96** (2017)]

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OUR STARTING INTERACTIONS

EMN NNLO and the sim family

- Different initial fitting strategies
- Wide range of cutoffs
- Different powers for the regulator

EMN: [Entem *et al.*, *PRC* **96** (2017)]
Sim: [Carlsson *et al.*, *PRX* **6** (2016)]

Three-body force regulator

$$\exp\left[-\left(\frac{4p^2+3q^2}{4\Lambda^2}\right)^n\right]$$

LEC	EMN NNLO	sim450	sim475	sim500	sim525	sim550
c_D		-0.594	-0.471	-0.325	-0.166	0
c_E		-0.528	-0.515	-0.521	-0.566	-0.673
c_1	-0.74	-0.05	0.11	0.22	0.28	0.27
c_3	-3.61	-3.45	-3.51	-3.56	-3.58	-3.56
c_4	2.44	4.235	4.092	3.933	3.781	3.644

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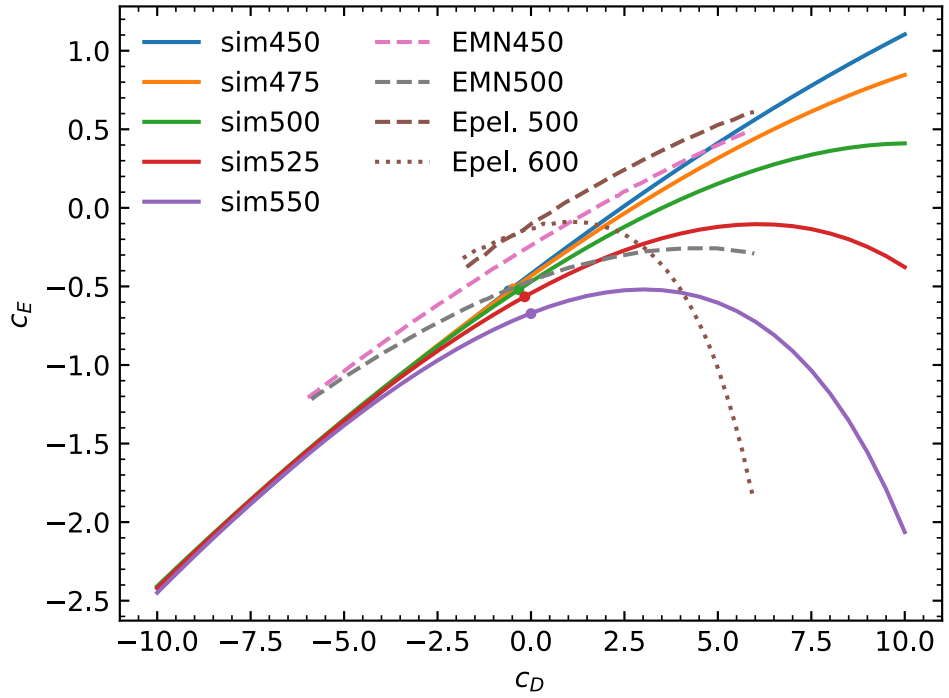
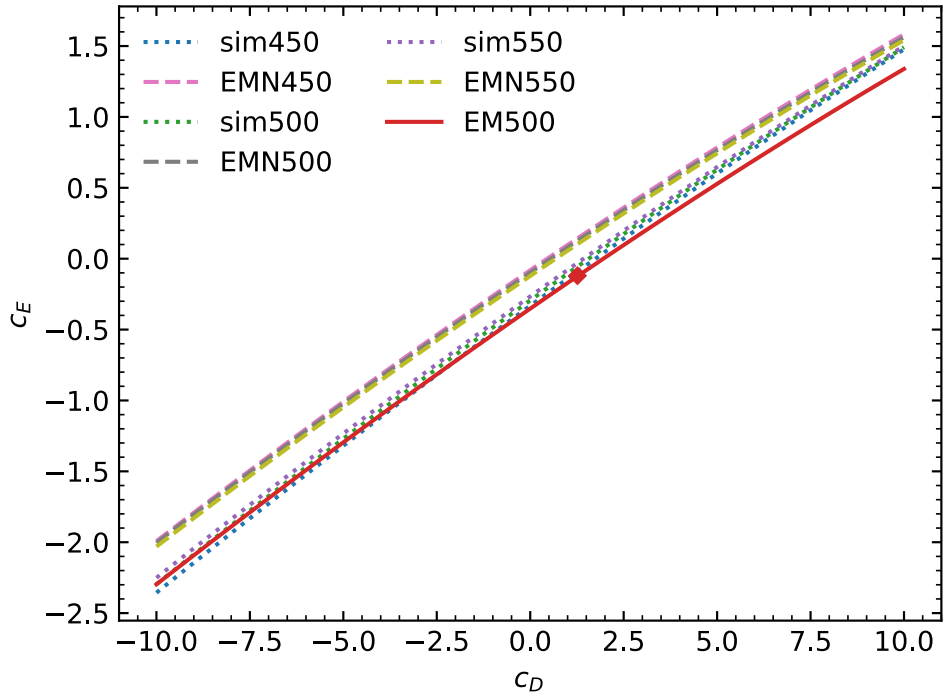
THE 1.8/2.0 AND TRITON BINDING ENERGY



Epel. data: [Epelbaum et al., *PRC* **66** (2002)]



Bare interactions

- Similar parabolic curves
- Larger cutoff means stronger bend

‘1.8/2.0’ interactions

- Very similar, quasi-linear dependence
- Mild dependence on original LECs

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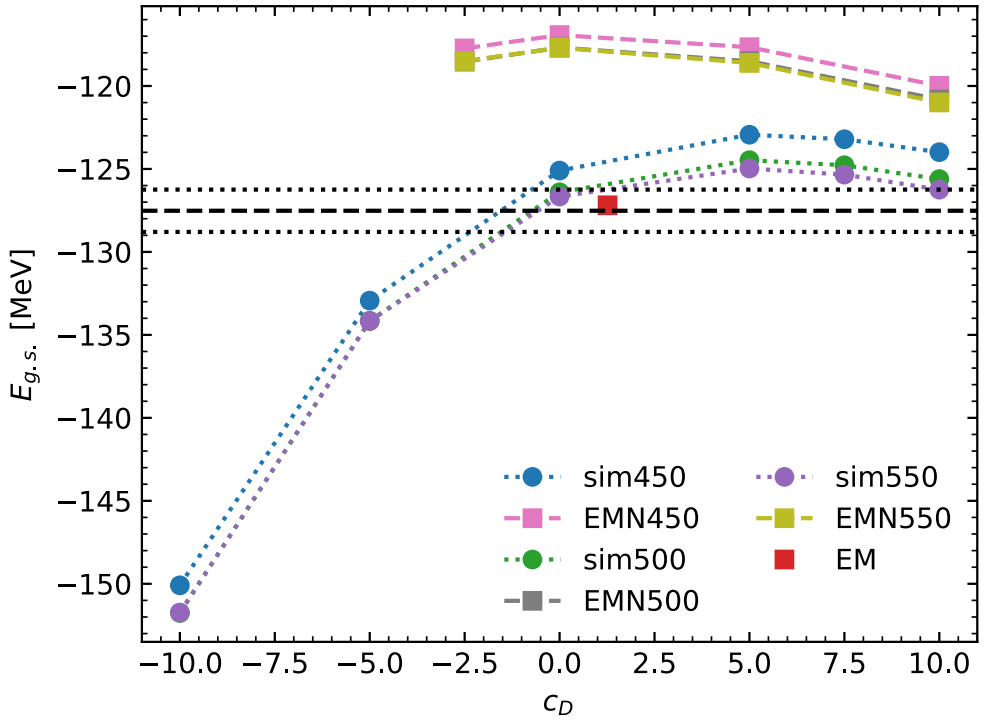
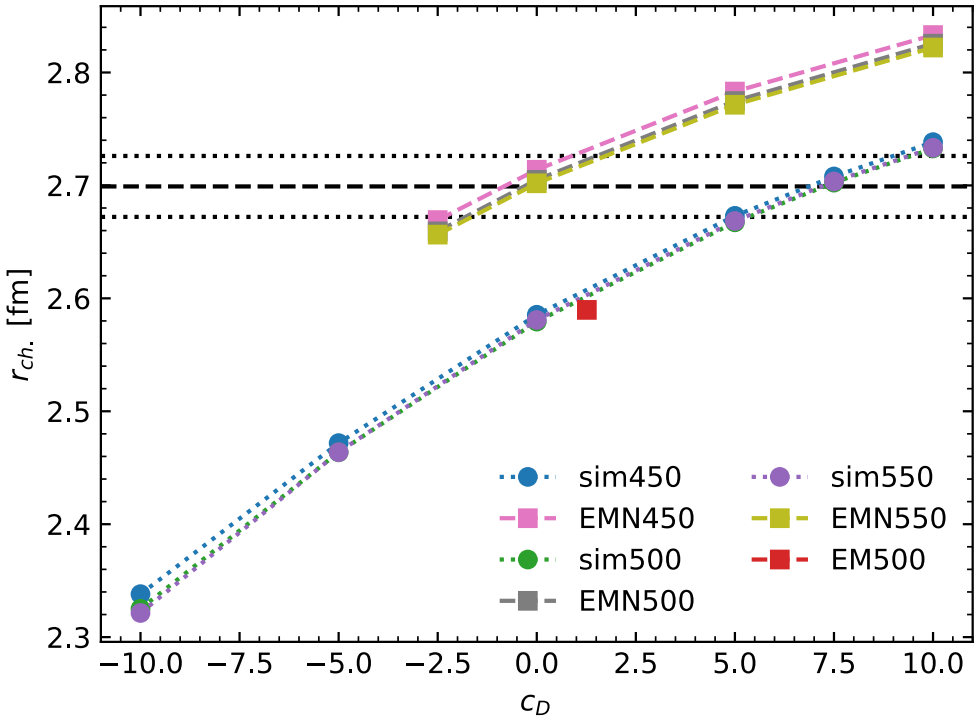
A FIRST CLOSED-SHELL SYSTEM: 16O





- Distinct behaviours in EMN and NNLOsim
- Two possible working c_D regimes for the sim
- EMN underbinds over the investigated range

- Linear dependence on c_D
- NNLOsim at large c_D reproduce radius and energy
- Natural c_D regime for sim mimics 1.8/2.0(EM)

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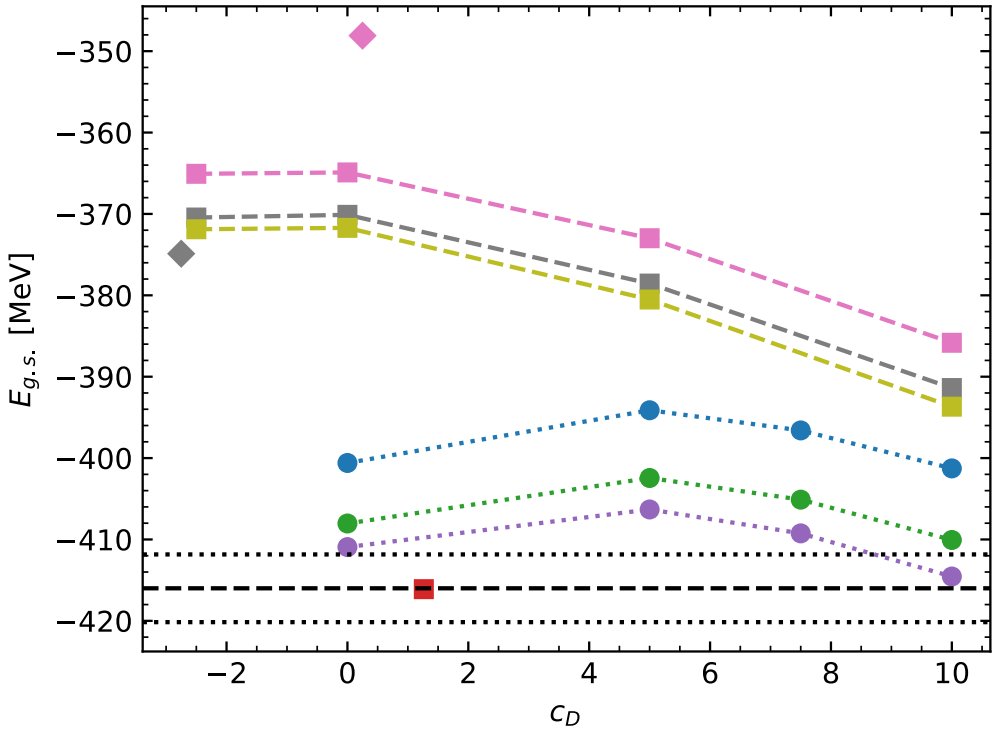
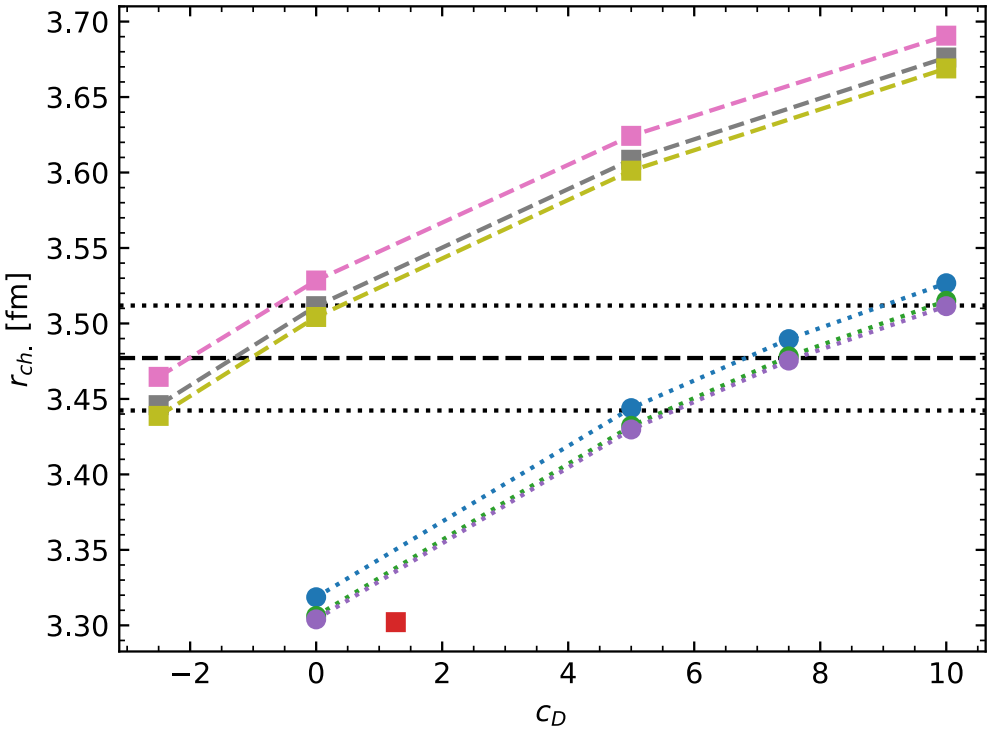
THE MEDIUM-MASS SECTOR: 48CA





Similar picture in the medium-mass domain

- EMN-based 1.8/2.0 underbinds
- 1.8/2.0 give roughly same energies as consistently-evolved forces

What is missing in the EMNs?

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BACK TO THE ORIGINAL LECS

LEC	EMN NNLO	sim450	sim475	sim500	sim525	sim550
c_D		-0.594	-0.471	-0.325	-0.166	0.000
c_E		-0.528	-0.515	-0.521	-0.566	-0.673
c_1	-0.74	-0.05	0.11	0.22	0.28	0.27
c_3	-3.61	-3.45	-3.51	-3.56	-3.58	-3.56
c_4	2.44	4.235	4.092	3.933	3.781	3.644

Differences in the 3N LECs

- Similar values for c_3
- More variation in terms of c_1 and c_4

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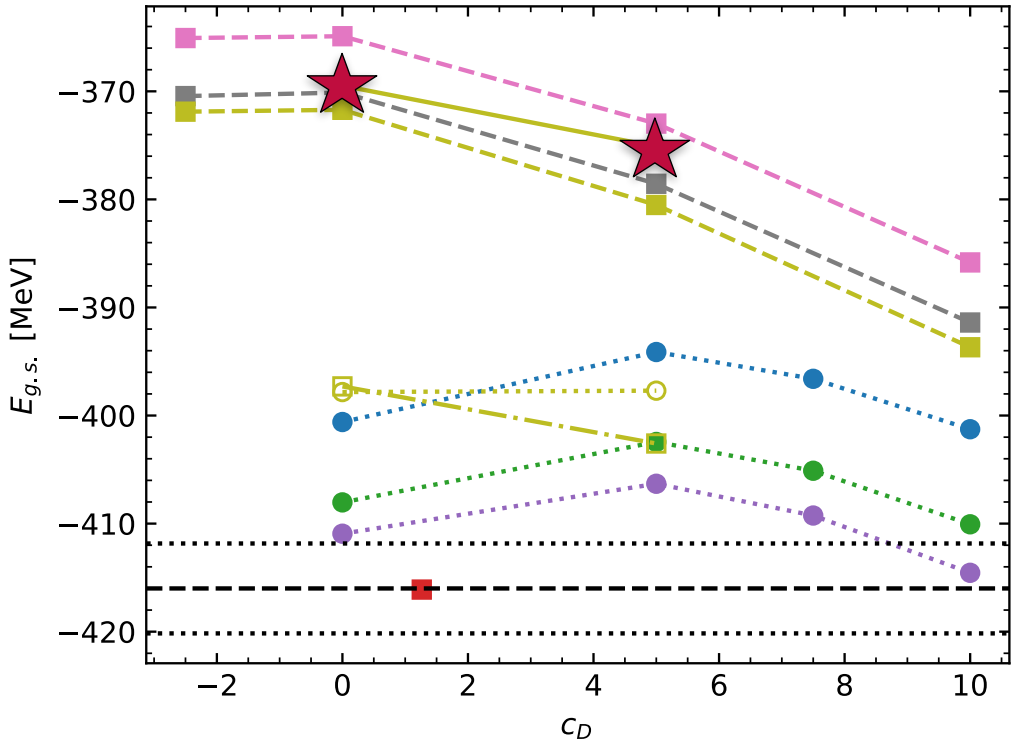
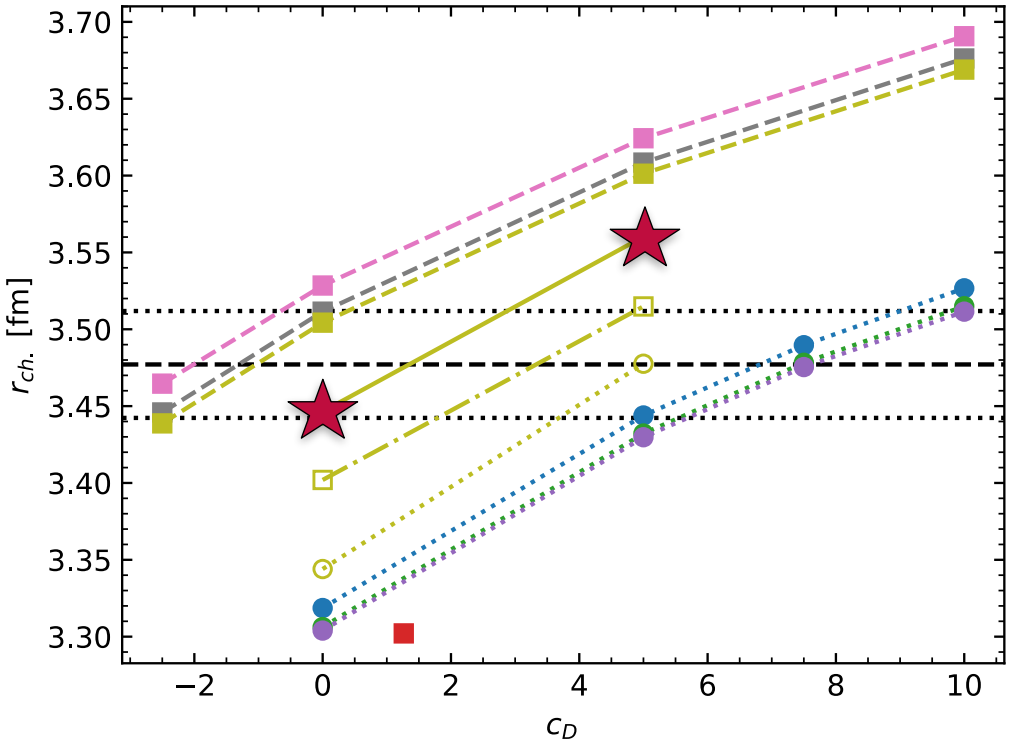
EXPLORE THE SPACE OF LEC VALUES





Shifted c_4

- Change the slope for $E_{g.s.}$
- More compact radius

Shifted c_1

- Brings a lot of binding
- More compact radius

Shifting both

- Additive effect of the shifts
- ‘sim-like’ 1.8/2.0(EMN)

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TAKE-AWAY ON THE 1.8/2.0 APPROACH (SO FAR…)

Similar behaviour for the starting interaction families

- More linear $c_D - c_E$ trajectory for the triton binding energy
- Similar evolution with c_D for both radius and energy

1.8/2.0 as a tool

- NN universality underlines the choice of 3N LECs
- Perturbativeness makes for quasi-linear dependence on LECs for finite nuclei
- Diagnosis tool / way to test and try sets of LECs
- Proximity with consistently SRG-evolved interaction results

The investigation goes on…

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CONCLUSION AND OUTLOOK

Tremendous progress of ab initio methods

- Rely on recent development in terms of interactions
- Current developments pave the way to huge storage savings for MEs

Re-exploration of low-momentum interactions

- Reuse the 1.8/2.0 approach as an investigation tool at low resolution
- Key differences between EMN- and NNLOsim-based forces
- Small shifts in 3N LECs seem to combine linearly

ACKNOWLEDGMENTS

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Thank your for your attention!

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STRONGINT group

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