REVISITING CHIRAL LOW-MOMENTUM INTERACTIONS FOR MEDIUM-MASS NUCLEI

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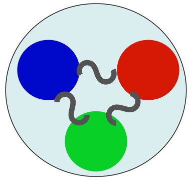
REVISITING CHIRAL LOW-MOMENTUM INTERACTIONS

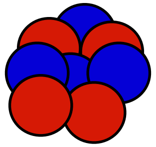
THE PROGRESS OF AB INITIO METHODS

WHAT IS AB INITIO?



Particle physics

No direct application of
quantum chromodynamics
(Lattice QCD only for few nucleons)



Nuclear theory

Effective Field Theory in the A-body sector

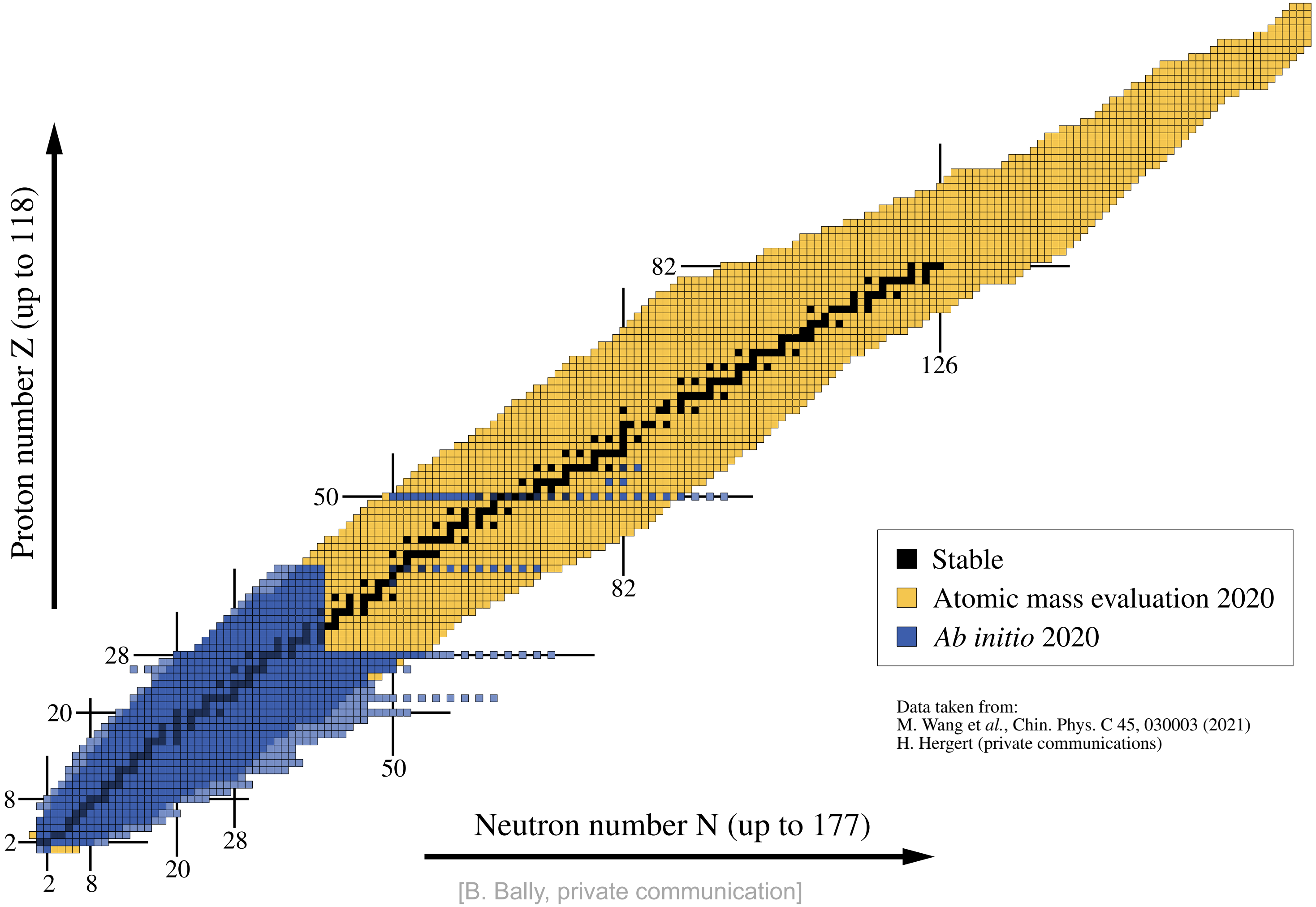
A-body Schrödinger equation

$$H\,|\Psi^{A}\rangle = E^{A}\,|\Psi^{A}\rangle$$

Obtain a description that is:

- Consistent
- Systematic
- Accurate enough
- From inter-nucleon interaction
- Rooted in quantum chromodynamics

FROM THE LIGHTEST NUCLEI…



[B. Bally, private communication]

« Exact » methods (80's)

- GFMC, NCSM, FY, HH

Closed-shell methods (00's)

- CC, DSCGF, IMSRG, MBPT

Open-shell methods (10's)

- BCC, GSCGF, MR-IMSRG, BMBPT

***Ab initio* shell model (2014)**

- SM with interaction from CC, IMSRG

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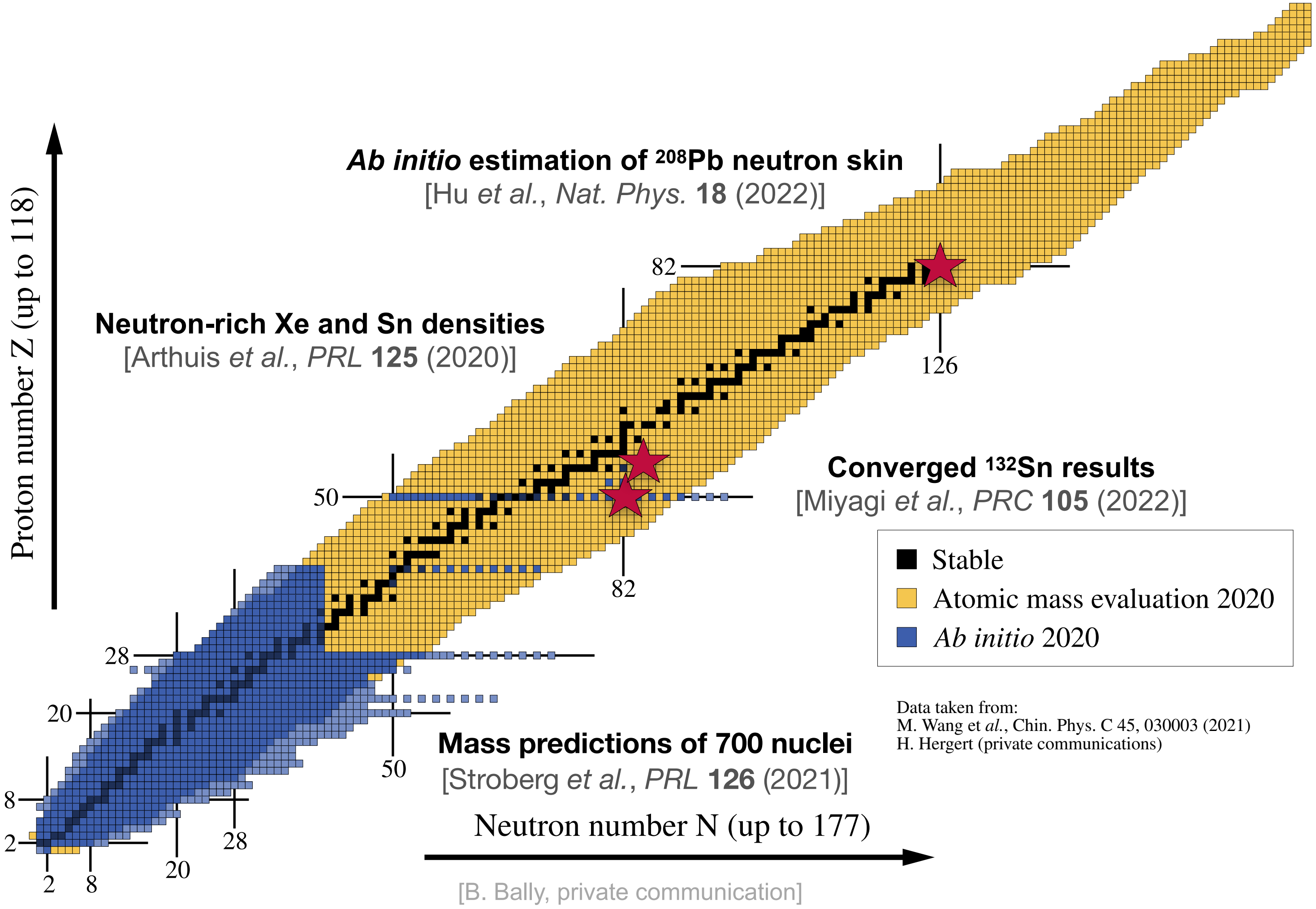
…TOWARDS MEDIUM- AND HEAVY-MASS SYSTEMS



Expansion methods

$$
\begin{aligned}
H\,|\Psi\rangle &= U(\infty)\,|\Phi\rangle \\
&= (U_1 + U_2 + U_3 + \ldots)\,|\Phi\rangle
\end{aligned}
$$

- Build from a simple reference state $|\Phi\rangle$
- Add the correlations on top order by order
- Truncate at the desired order
- Estimate uncertainties from the truncated terms

Controlled expansion & uncertainty

Polynomial cost

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[ARTHUIS, BARBIERI, VORABBI, FINELLI, PRL 125 (2020)]

A LOOK AT TIN AND XENON WITH SCGF

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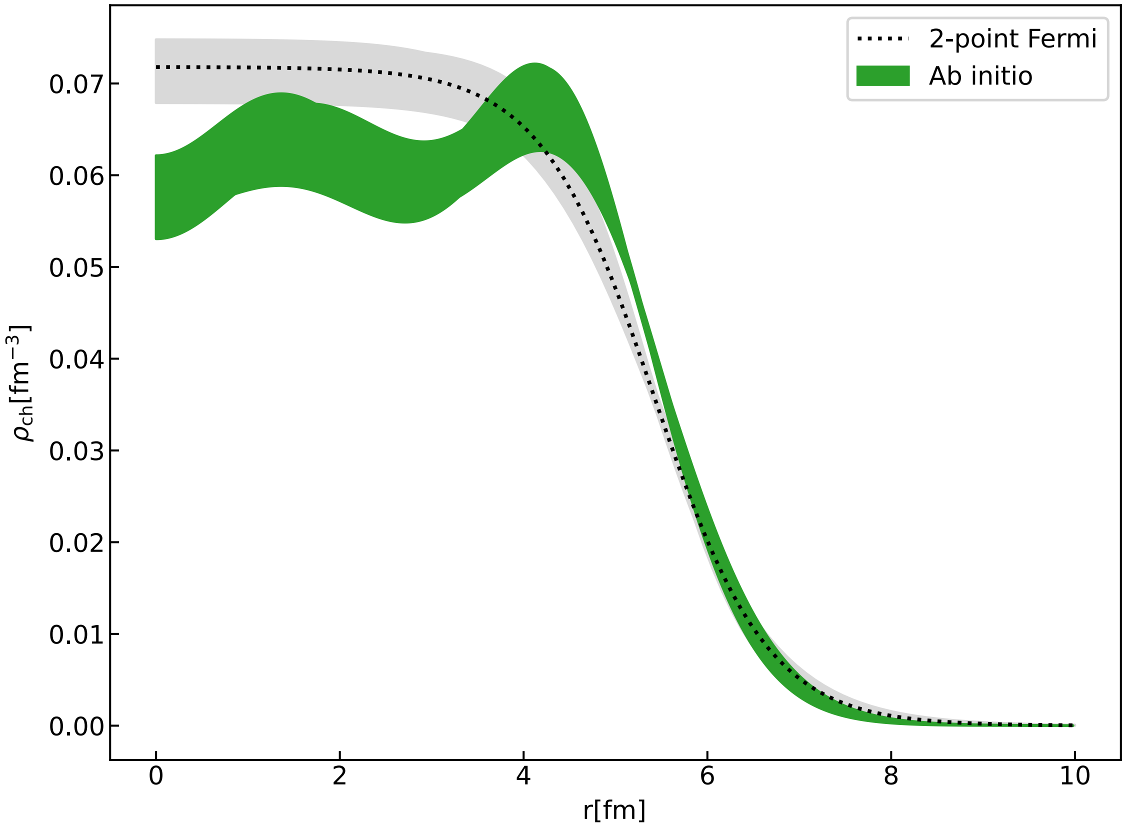
CHARGE DENSITY DISTRIBUTIONS

^{132}Xe charge density distribution with NNLOsat

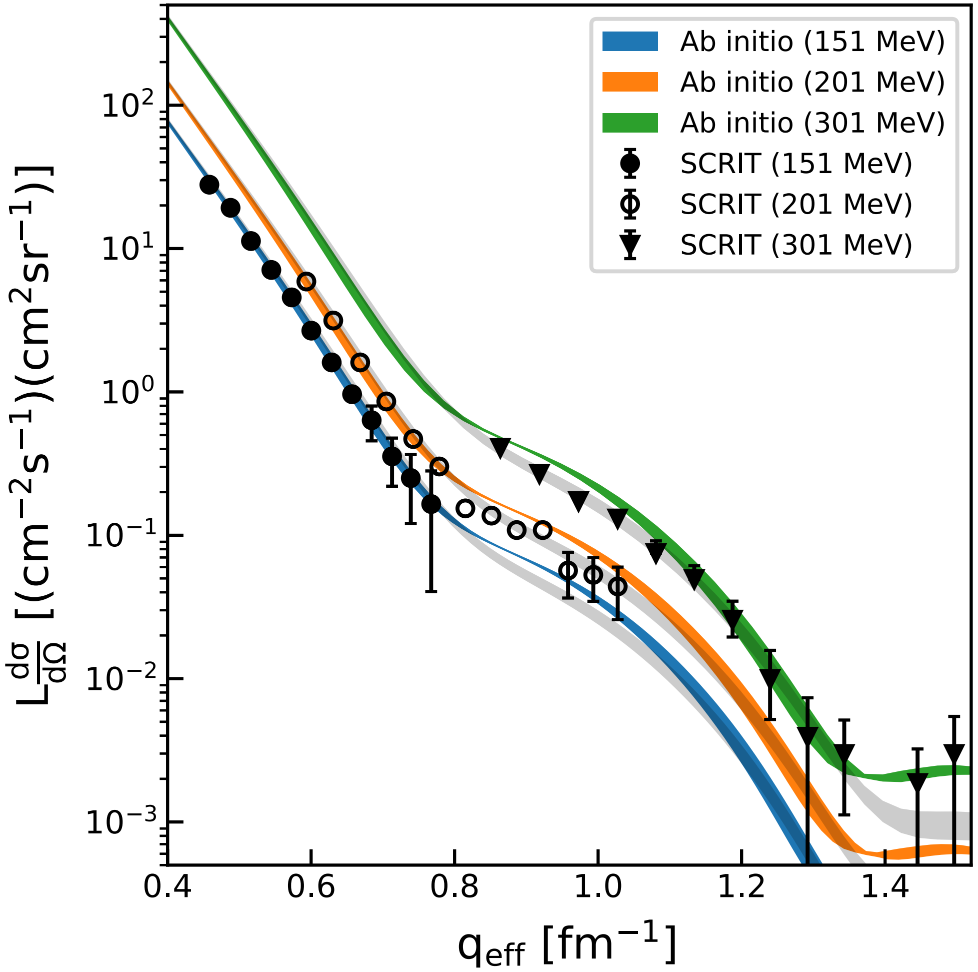
- Radius compatible with experiment: 4.824 ± 0.124 fm
  [Tsukada *et al.*, *PRL* 118 (2017)]: $4.79^{+0.12}_{-0.10}$ fm
- NN+3N(lnl) severely underpredicts: 4.070 ± 0.045 fm
- 2-point Fermi distribution insufficient to describe expected behaviour

Uncertainty band

- Mainly model-space convergence uncertainty (truncated 3NF)
- Many-body method basically converged
- Not included: Chiral EFT uncertainty



ELECTRON SCATTERING OFF 132XE



First *ab initio* calculation past the Sn isotopic line

- Reproduce experimental electron scattering results with NNLOsat
- Unconverged results can be meaningfully compared to exp.
- NN+3N(lnl) fails at reproducing the scattering data

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CHARGE RADII AND NEUTRON SKINS

r [fm]	NNLOsat	SCRIT [1]	Exp [2]
^{100}Sn	4.525 — 4.707		
^{132}Sn	4.725 — 4.956		4.7093
^{132}Xe	4.700 — 4.948	4.69 — 4.91	4.7859
^{136}Xe	4.715 — 4.928		4.7964
^{138}Xe	4.724 — 4.941		4.8279

[1] Tsukada et al., *PRL* **118** (2017)
[2] Angeli & Marinova, *ADNDT* **99** (2013)

Computation of charge radii

- Good reproduction of experimental values with NNLOsat
- NN+3N(lnl) systematically underpredicts radii (not shown)

Ab initio estimation of neutron skins for Sn & Xe

- Compatible within the (large) error bars
- NNLOsat smaller: Known symmetry energy issue
- NN+3N(lnl) more reasonable, but underpredicts radius w.r.t. exp

[fm]	NNLOsat	NN+3N(lnl)
^{100}Sn	-0.079 — -0.096	-0.060 — -0.068
^{132}Sn	0.168 — 0.197	0.183 — 0.275
^{132}Xe	0.103 — 0.128	0.120 — 0.152
^{136}Xe	0.128 — 0.156	0.134 — 0.223
^{138}Xe	0.143 — 0.175	0.152 — 0.251

First converged $E_{g.s.}$ for ^{132}Sn, neutron skin of 0.2202 fm [Miyagi et al., *PRC* 105 (2022)]

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REVISITING CHIRAL LOW-MOMENTUM INTERACTIONS

TOWARDS A BETTER UNDERSTANDING OF INTERACTIONS

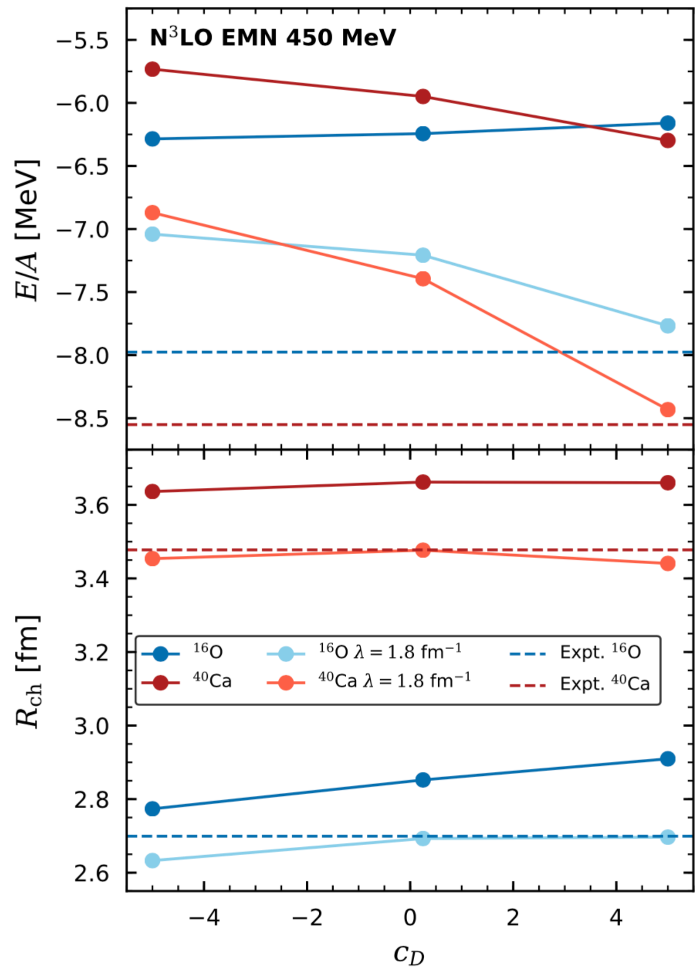
WHY LOW-MOMENTUM INTERACTIONS?

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)]

A NEW LOOK AT THE 1.8/2.0 APPROACH

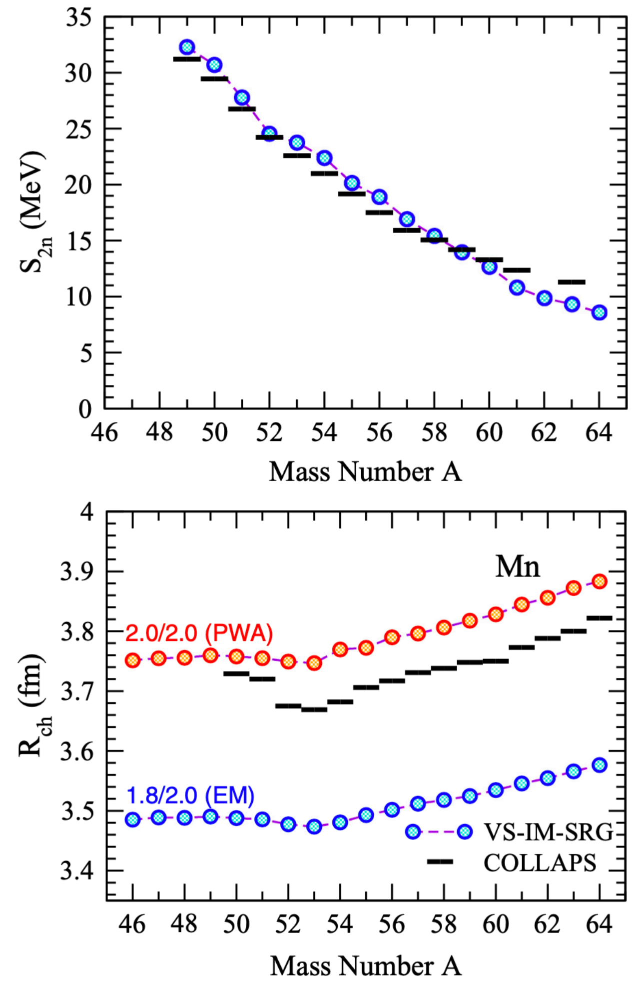
Approach introduced in Hebeler et al., PRC 83 (2011)

- 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	0,000
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

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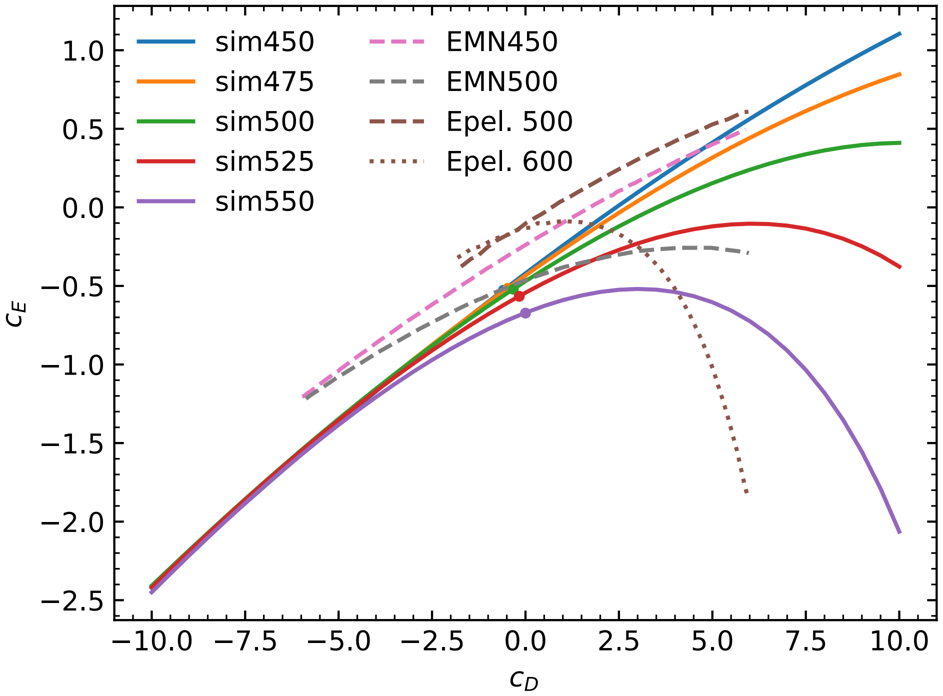
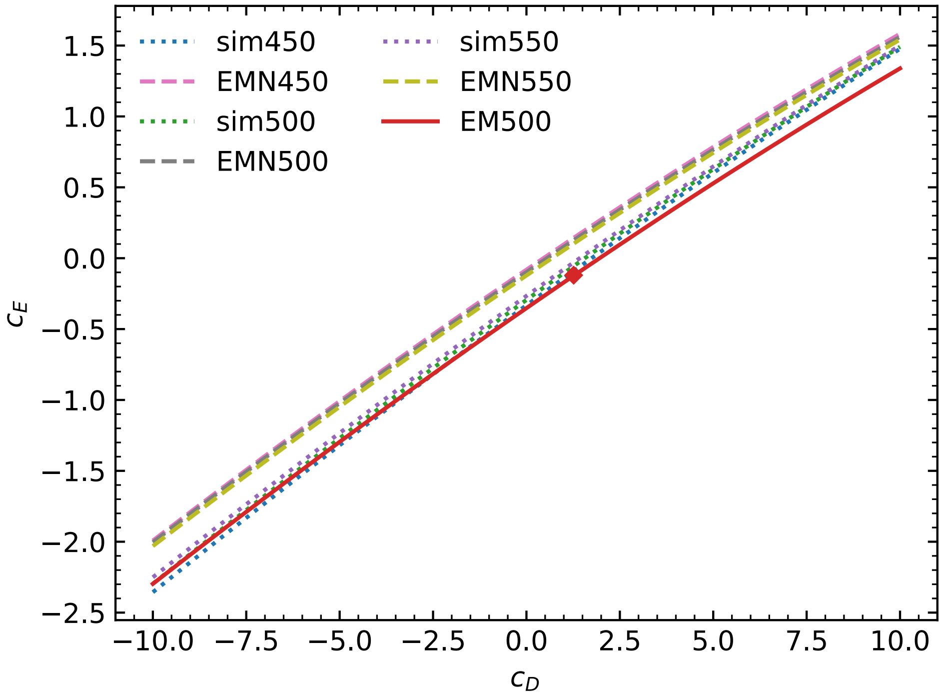
THE 1.8/2.0 AND TRITON BINDING ENERGY



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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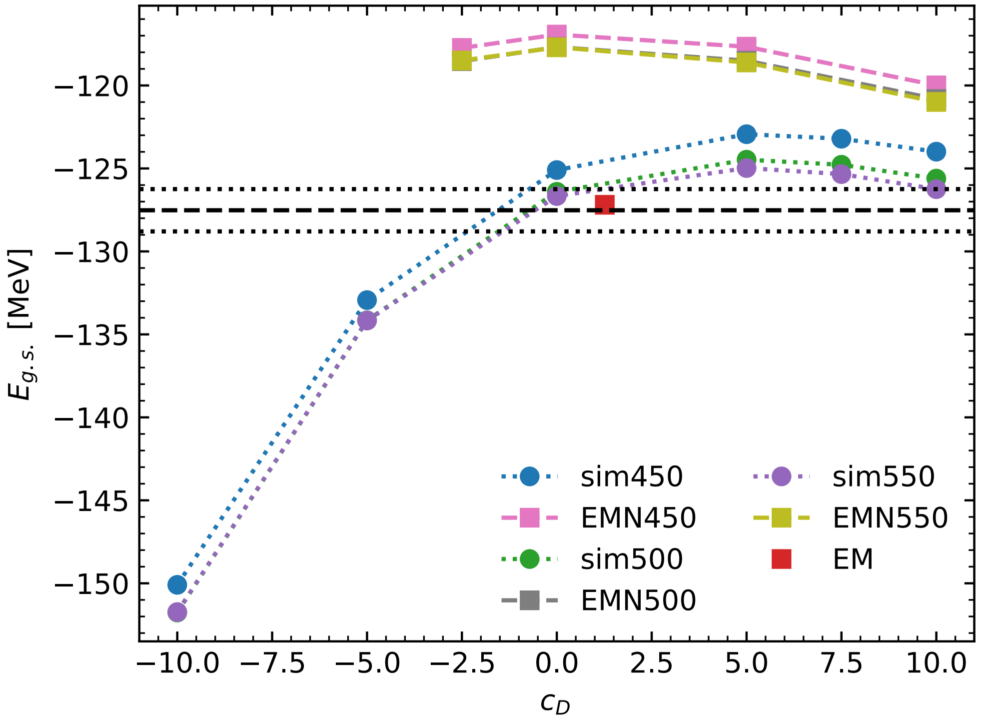
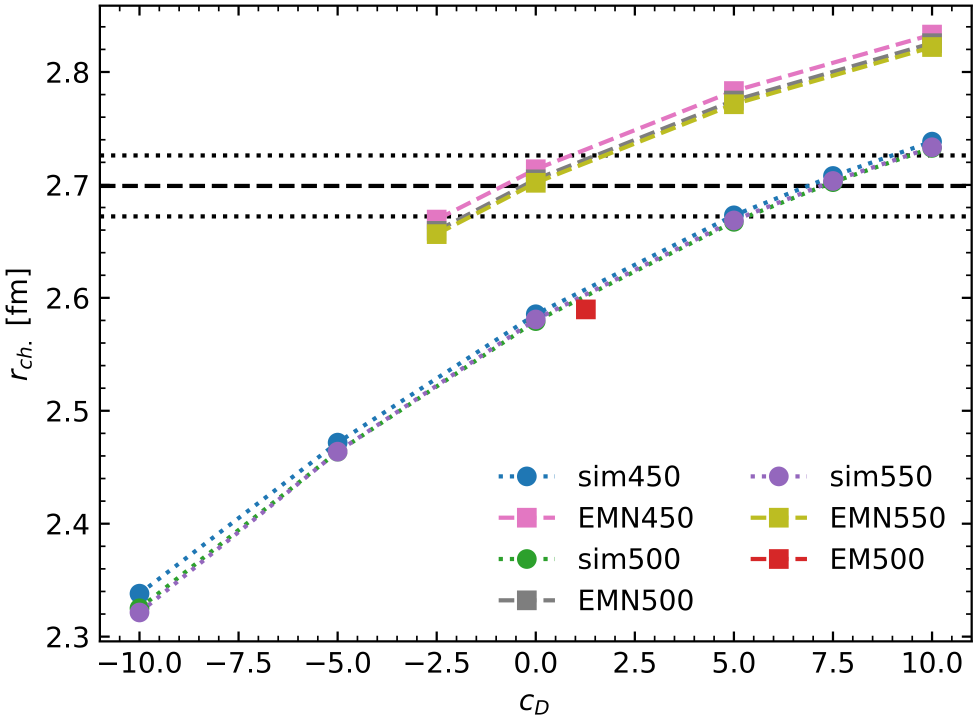
A FIRST CLOSED-SHELL SYSTEM: 16O





- Very distinct behaviours by interaction family
- Two possible working c_D regimes for the sim
- EMN underbinds over the investigated range

- A linear behaviour for the radius
- The sim at large c_D reproduce radius and energy
- Natural c_D regime for sim mimics the EM1.8/2.0

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CONCLUSION AND OUTLOOK

Tremendous progress of ab initio methods

- Now reaching A ~ 100
- Progress driven by formal and numerical developments
- Interactions play a key role in accessing larger mass domains

Current investigations of low-momentum interactions

- Reuse the 1.8/2.0 approach as an investigation tool at low resolution
- Interactions seem to exhibit some level of universal behaviour
- Key differences currently under investigation

Thank your for your attention!

STRONGINT group
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