RECENT APPLICATIONS OF LOW-RESOLUTION INTERACTIONS

Pierre Arthuis

Funded by
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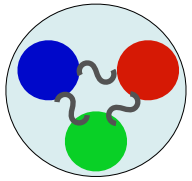
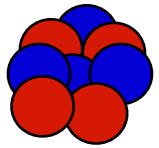
Ab initio many-body scheme



Particle physics

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



Nuclear theory

Interactions anchored in Effective Field Theory

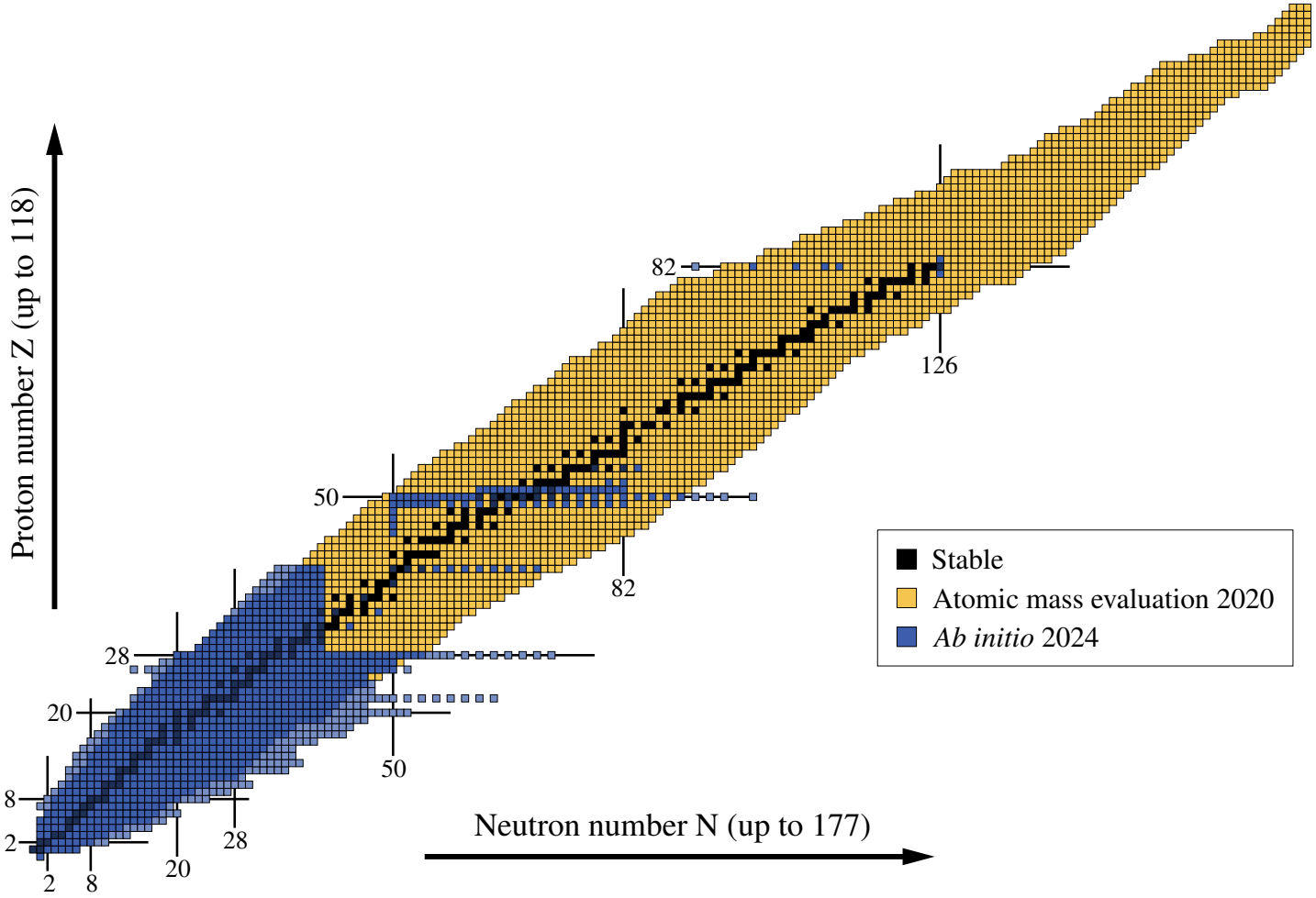
A-body Schrödinger equation

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

Obtain a description that is:

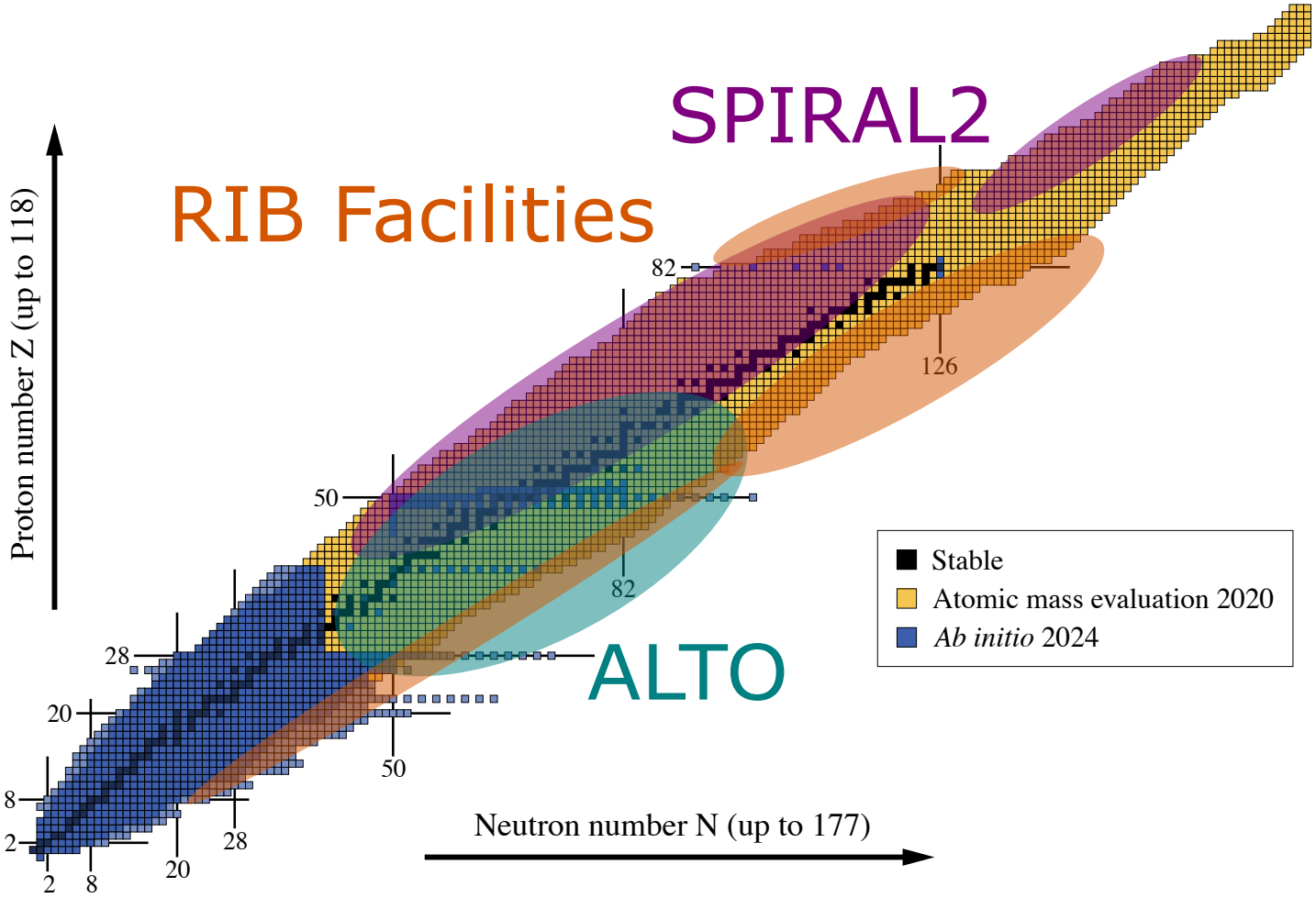
- Consistent
- Systematic
- Accurate enough
- From inter-nucleon interactions
- Rooted in quantum chromodynamics

A look at experimental facilities



Adapted from B. Bally

A look at experimental facilities



Adapted from B. Bally

New era of shared effort

Heaver nuclei

More exotic nuclei

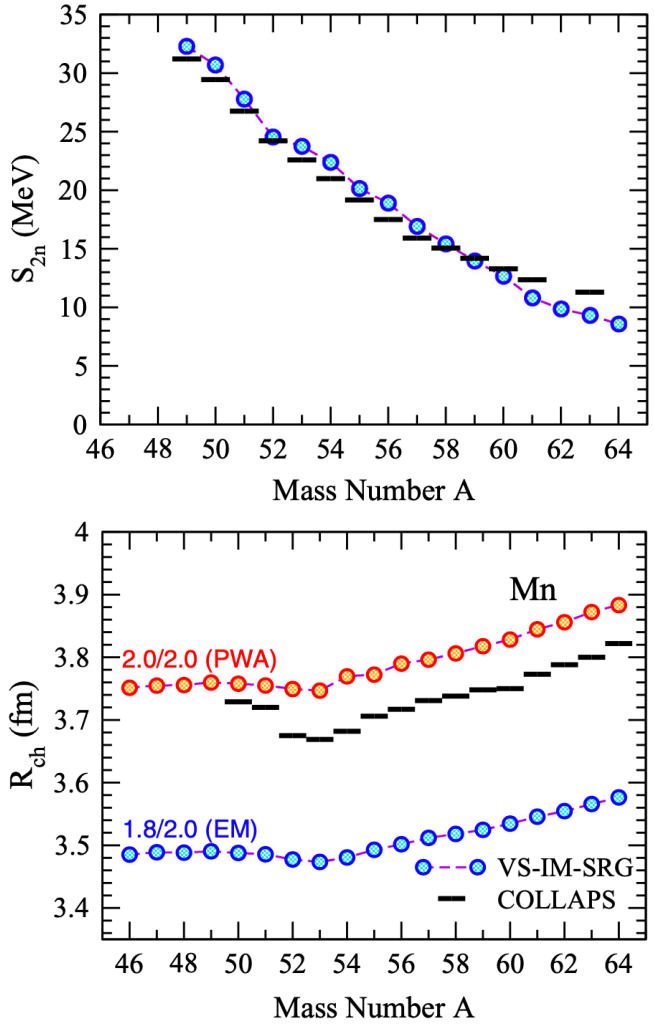
Why low-resolution interactions?

Sufficient to describe bulk properties of nuclei

- Better convergence properties through softened interaction
- Proved successful for binding energies with the 1.8/2.0 (EM)
  [Hebeler *et al.*, *PRC* **83** (2011)]

Revisit the 1.8/2.0 approach

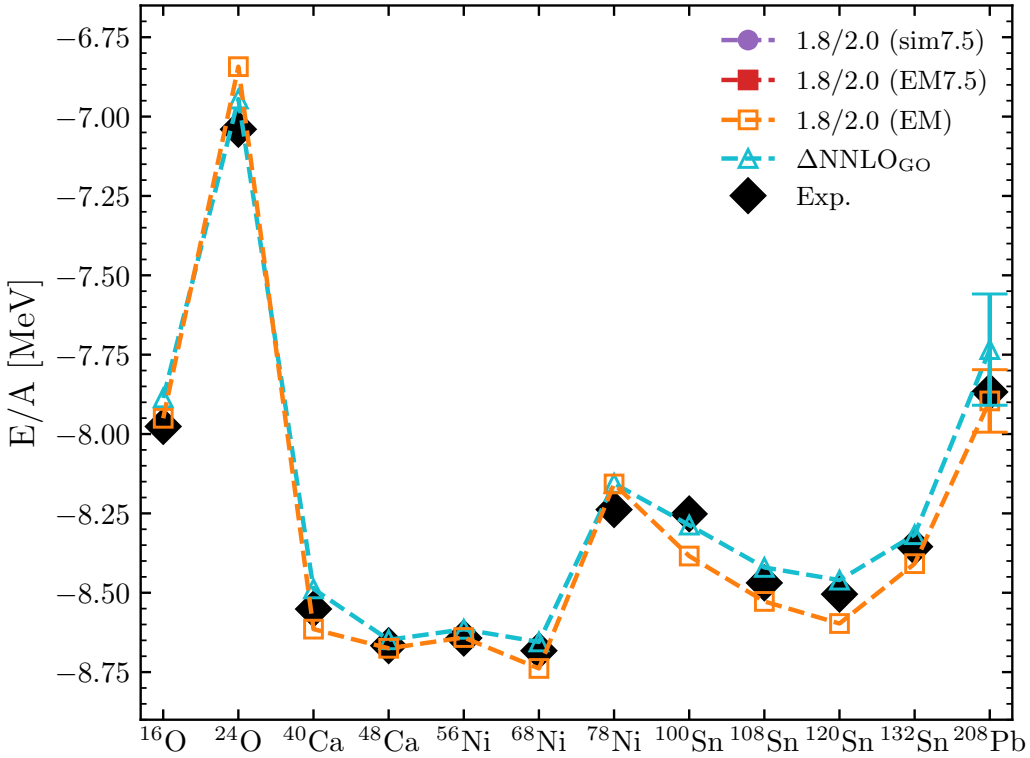
- Goal: Obtain good description of binding energy and radii
- Target: From light to heavy systems

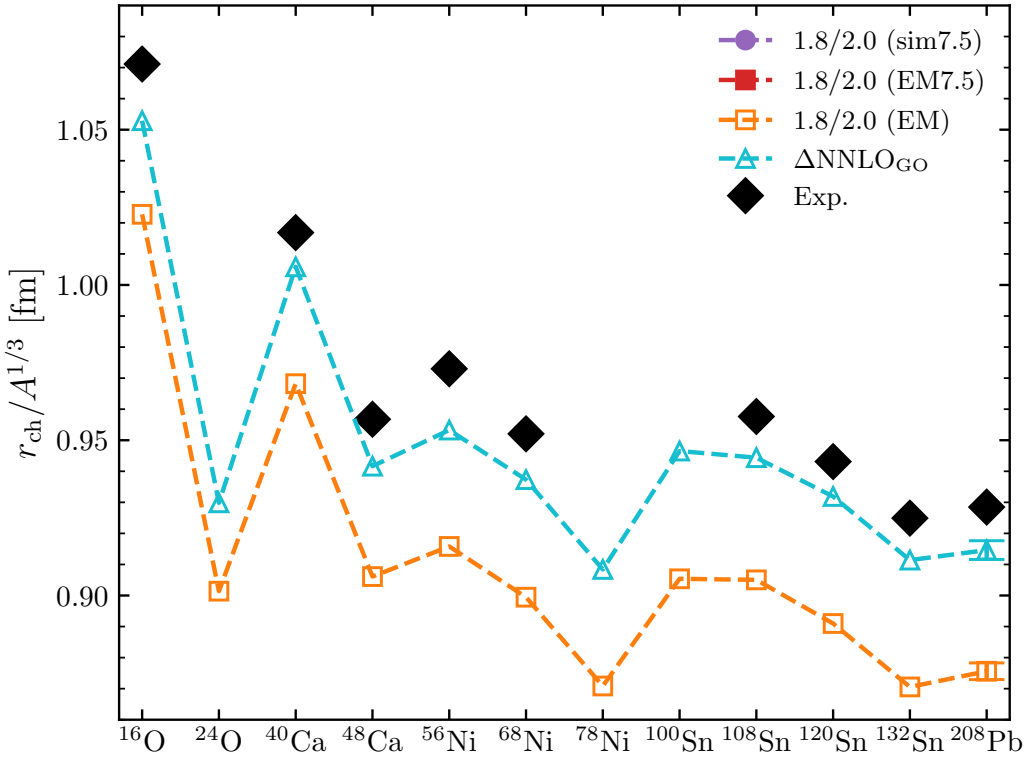


[Simonis *et al.*, *PRC* **96** (2017)]

Ground-state accuracy towards heavy systems

[Arthuis, Hebeler, Schwenk, arxiv:2401.06675]





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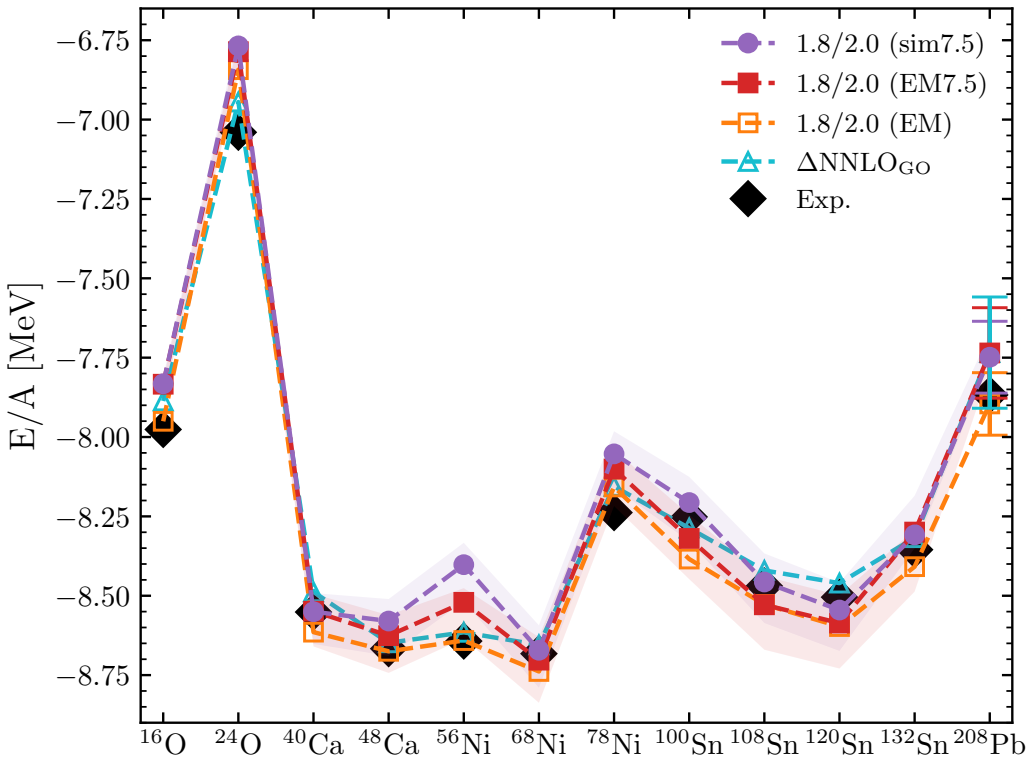
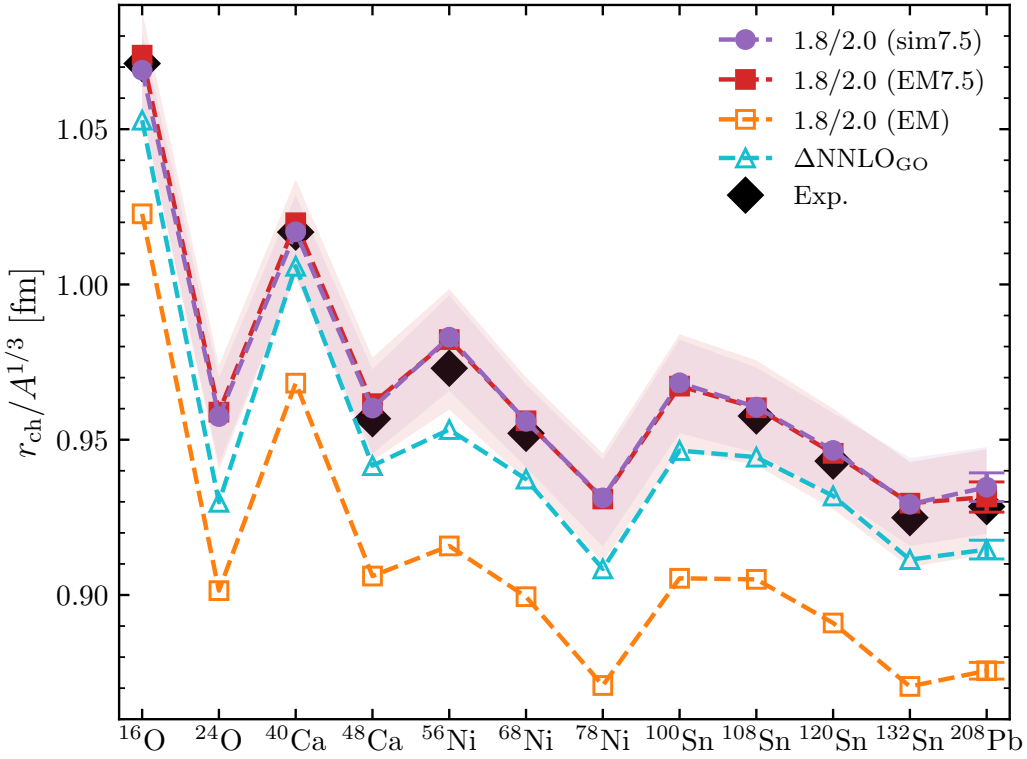




Binding energy

- Reasonable reproduction of experimental values
- Slight improvement for heavy systems w.r.t. 1.8/2.0 (EM)

Charge radius

- Quasi-exact reproduction over complete mass range
- Excellent combined reproduction of charge and mass

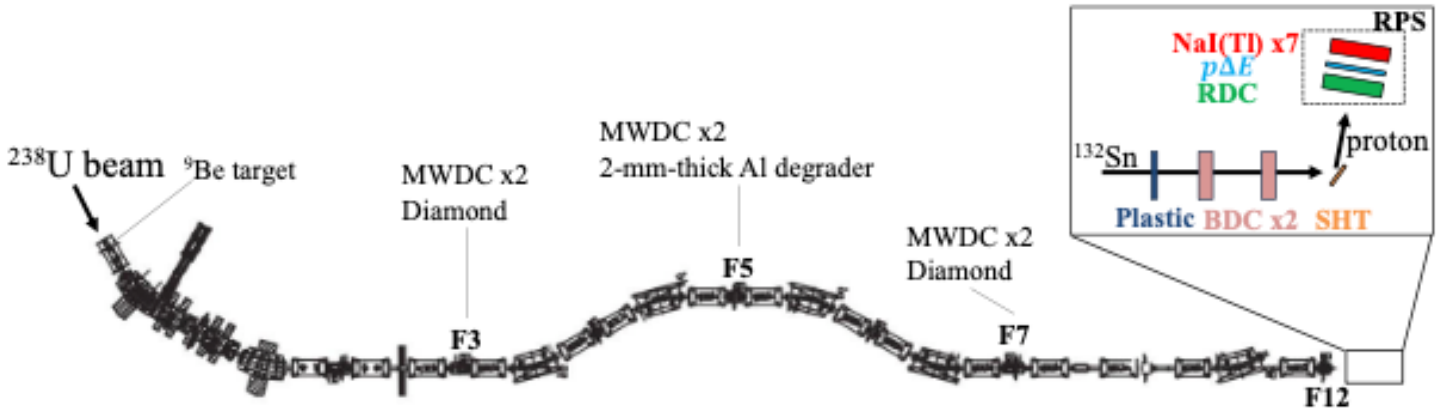
FIRST EXTRACTION OF THE MATTER RADIUS OF ^{132}SN VIA PROTON ELASTIC SCATTERING AT 200 MEV/A

Matter radius of ^{132}Sn

[Hijikata, Zenihiro, … , PA, *et al.*, PTEP in press]

Proton scattering to extract matter distribution

- Complementary to electron scattering for charge distribution
- Experiment at RIBF with a ^{238}U beam
- ^{132}Sn secondary beam selected through BigRIPS

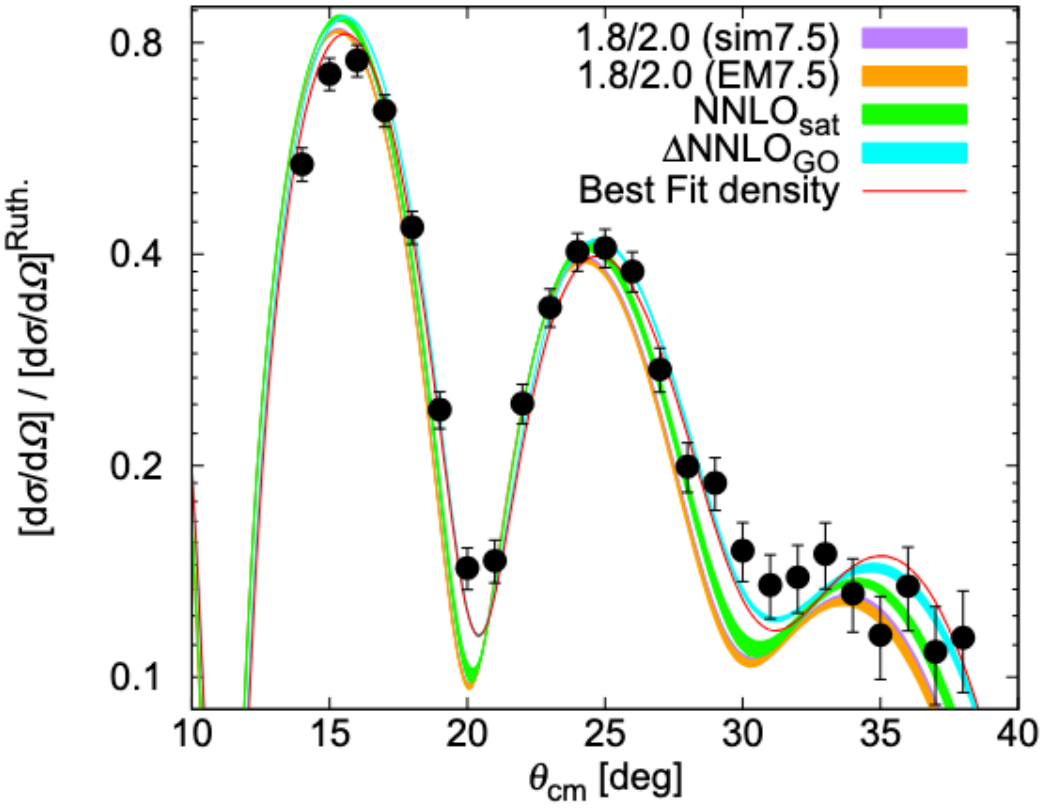


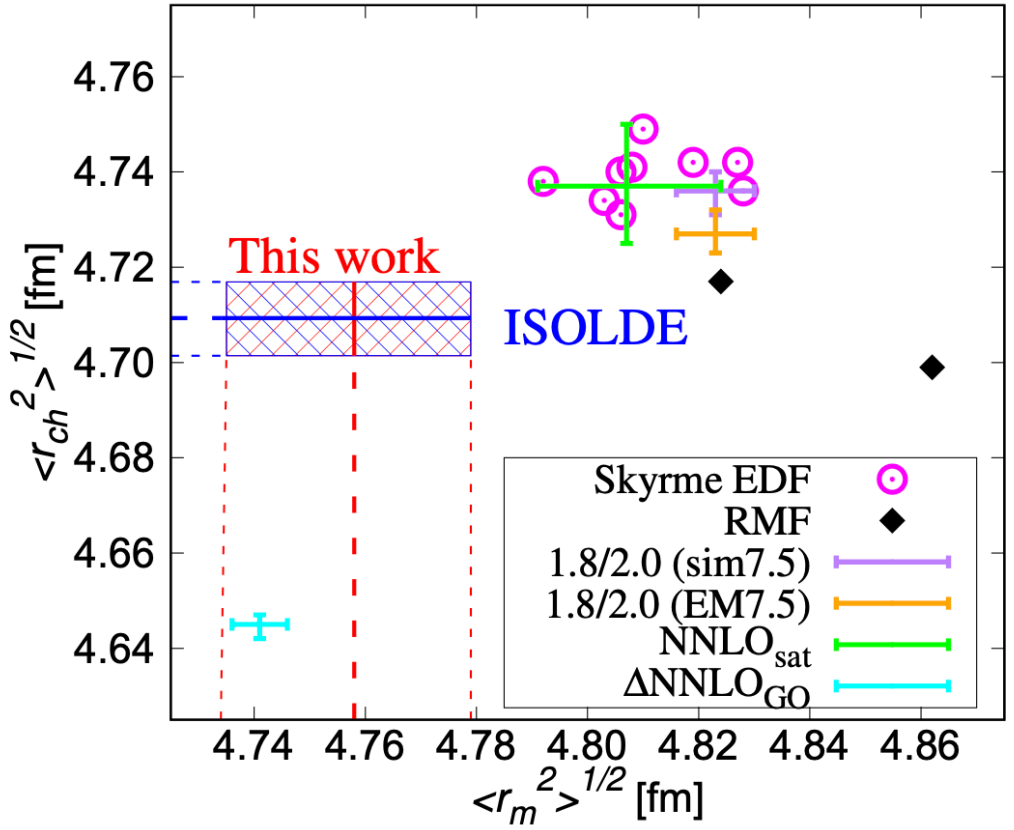
Some notes on the analysis

- Benchmark of different reaction models
- Use of the ISOLDE charge radius value as constraint

Matter radius of ^{132}Sn

[Hijikata, Zenihiro, … , PA, *et al.*, PTEP in press]





Good accuracy of low-resolution interactions

- $\Delta\mathrm{NNLO}_{\mathrm{GO}}$ best fit of cross-section and final radius
- All interactions agree within higher-order uncertainties

~1.5% uncertainty on radii

[Heinz *et al.*, *Phys. Rev. C* 111 (2025)]

CONNECTING RELATIVISTIC DENSITY FUNCTIONAL THEORY TO MICROSCOPIC CALCULATIONS

Ab initio results as pseudodata for RMF fits

[Reed, Heinz, Arthuis, Tews, Schwenk, *PRC* **112** (2025)]

Can chiral forces inform Relativistic Mean Field?

- Several extensions of typical RMF models proposed
- Chiral forces sensitive to different data than RMF
- Start from FSUGold-like Lagrangians

$$\mathscr{L}^{0}_{\text{int}} = \bar{\psi}\left[g_s\phi - \left(g_v W_\mu + \frac{g_\rho}{2}\boldsymbol{\tau}\cdot\boldsymbol{b_\mu} + \frac{e}{2}(1+\tau_3)A_\mu\right)\gamma^\mu\right]\psi - \frac{\kappa}{3!}(g_s\phi)^3 - \frac{\lambda}{4!}(g_s\phi)^4 + \frac{\zeta}{4!}g_v^4(W_\mu W^\mu)^2 + \Lambda_v(g_v^2 W_\mu W^\mu)(g_\rho^2\boldsymbol{b_\mu}\cdot\boldsymbol{b^\mu})$$

Test Lagrangian extension

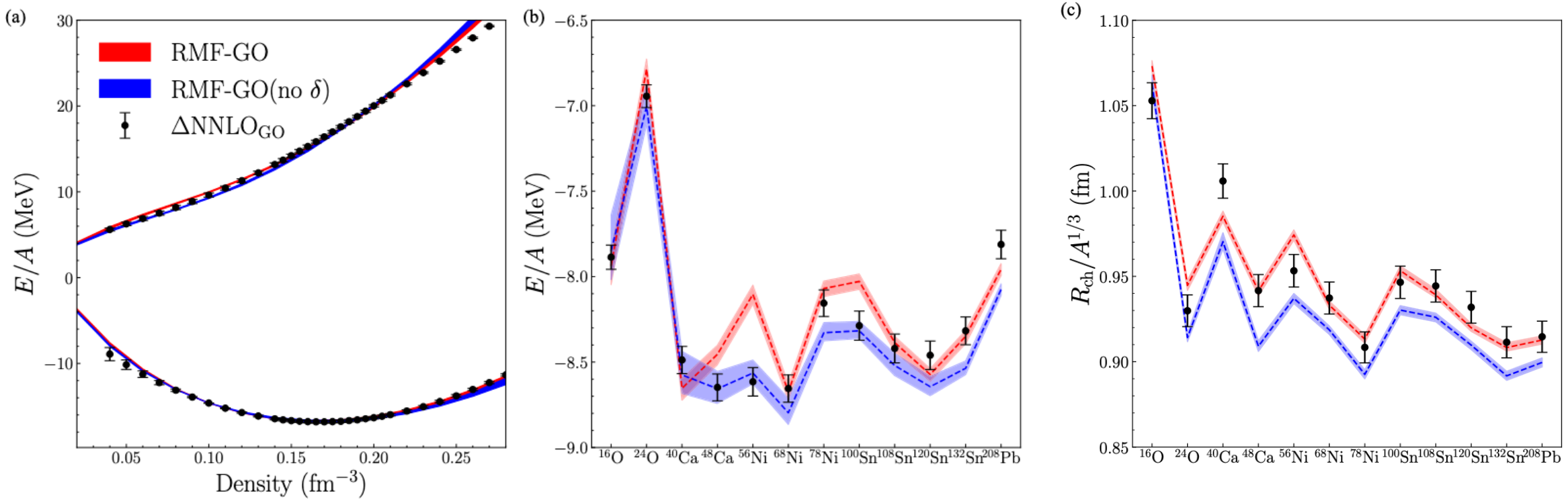
$$\mathscr{L}^{\text{ext}}_{\text{int}} = \bar{\psi}\left[\frac{g_\delta}{2}\boldsymbol{\tau}\cdot\boldsymbol{\delta} - f_v\frac{\sigma^{\mu\nu}}{2M}\partial_\nu W_\mu - f_\rho\frac{\sigma^{\mu\nu}}{2M}\partial_\nu\boldsymbol{b}_\mu\right]\psi$$

Use of ab initio results as pseudodata

- Infinite matter calculations
- Radius of ^{40}Ca, neutron skins of ^{48}Ca and ^{208}Pb

Ab initio results as pseudodata for RMF fits

[Reed, Heinz, Arthuis, Tews, Schwenk, *PRC* **112** (2025)]

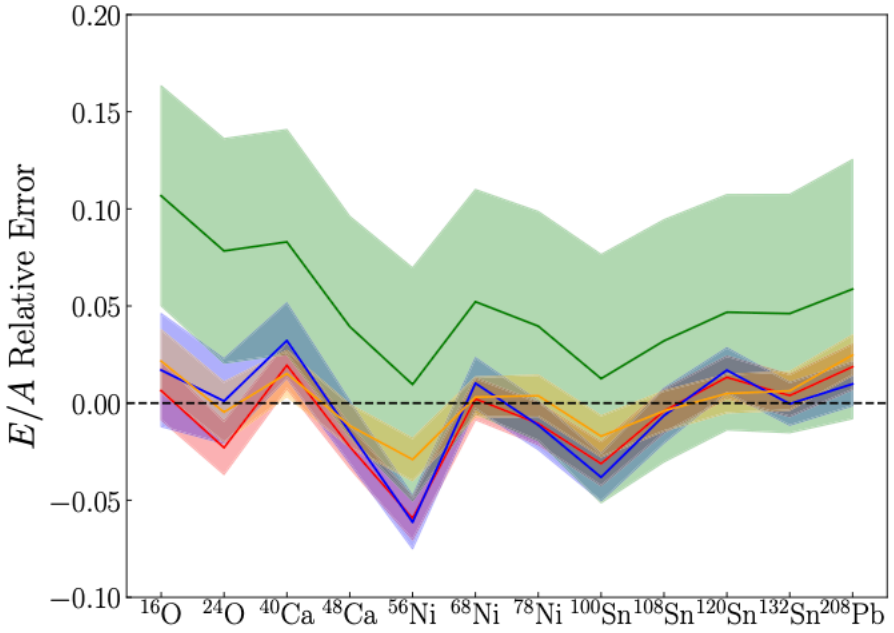


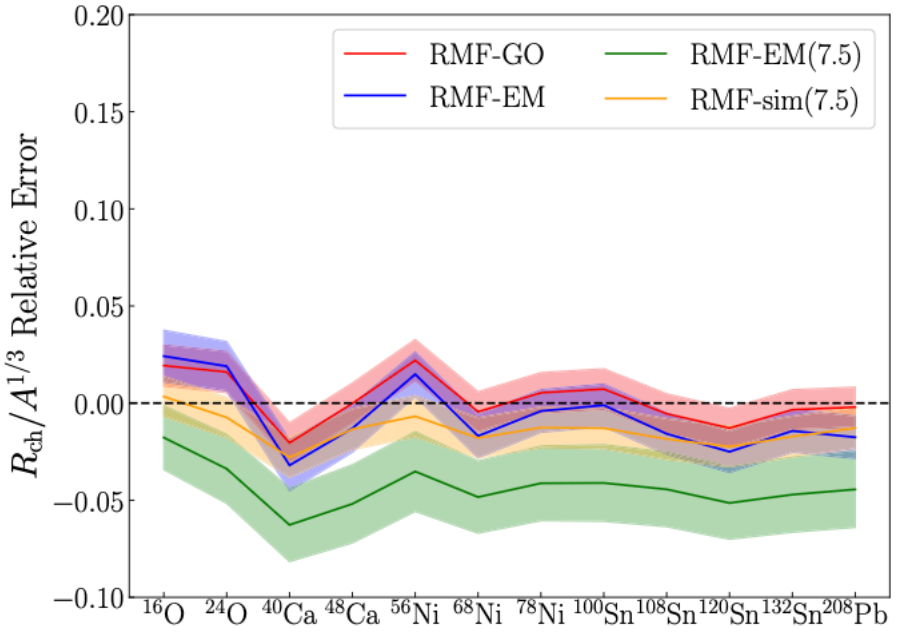
Test with the GO pseudodata

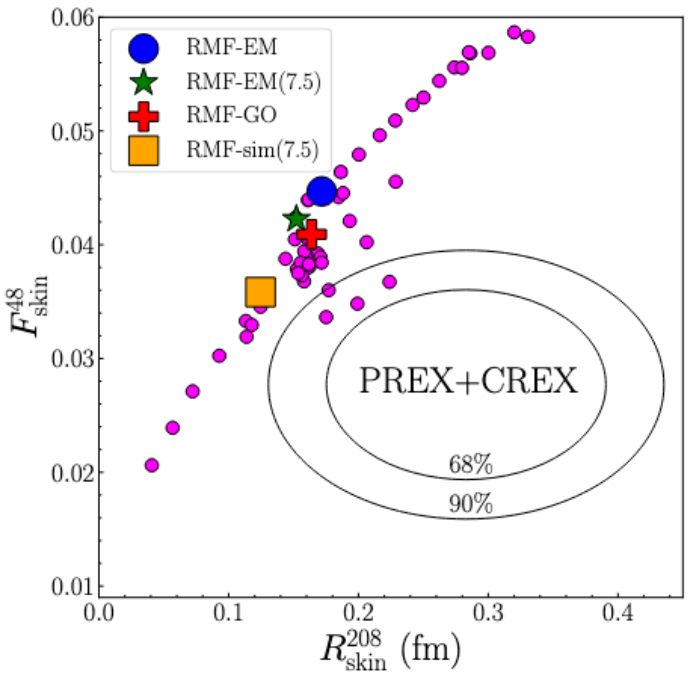
- Extended parametrisation key for heavier nuclei for radii
- Slightly degraded performance for some radii

Ab initio results as pseudodata for RMF fits

[Reed, Heinz, Arthuis, Tews, Schwenk, *PRC* **112** (2025)]







Some key outputs

- Fits on chiral pseudodata does not resolve some known RMF issues
- ”7.5” interactions make for harder reproduction by RMFs

Conclusion and outlook

Extraction of the ^{132}Sn matter radius

- Measurement feasible for unstable nuclei through the ESPRI project
- $\Delta\mathrm{NNLO}_{\mathrm{GO}}$ yields better matter radius but too small charge radius

Ab initio pseudodata for RMF

- New possibilities offered by low-resolution interaction
- Different possible Lagrangian extensions to be envisioned

Acknowledgments

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T. Miyagi

SFB 1245

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