

AB INITIO DENSITY DISTRIBUTIONS IN THE TIN SECTOR

Pierre Arthuis

INTRODUCTION

THE PROGRESS OF AB INITIO METHODS

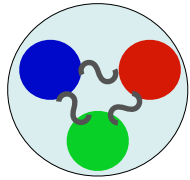
THE PROGRESS OF AB INITIO METHODS

WHAT IS AB INITIO?



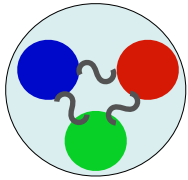
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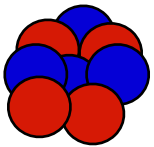


Particle physics

WHAT IS AB INITIO?

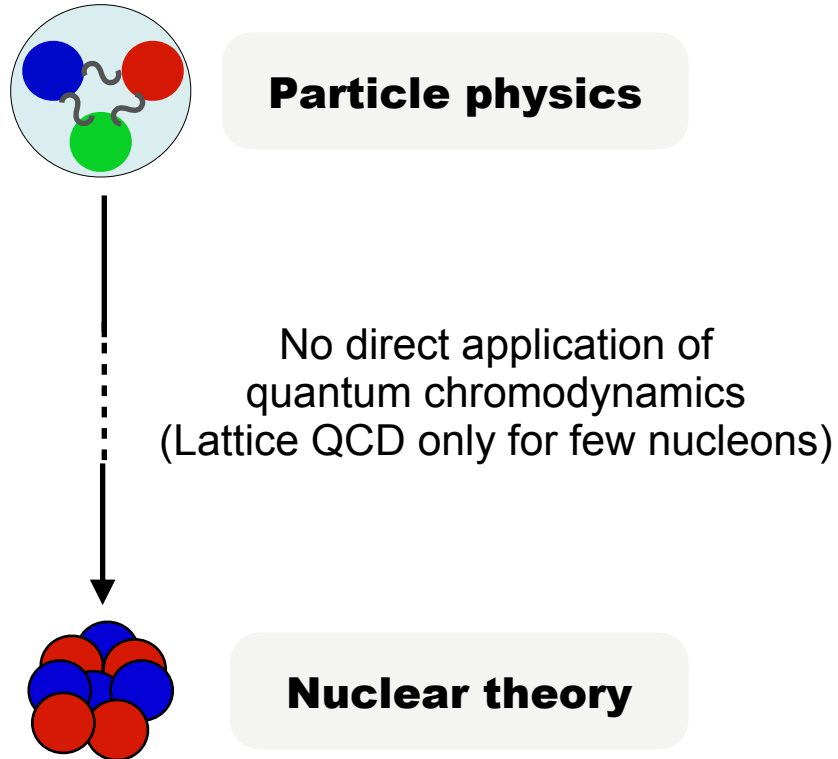


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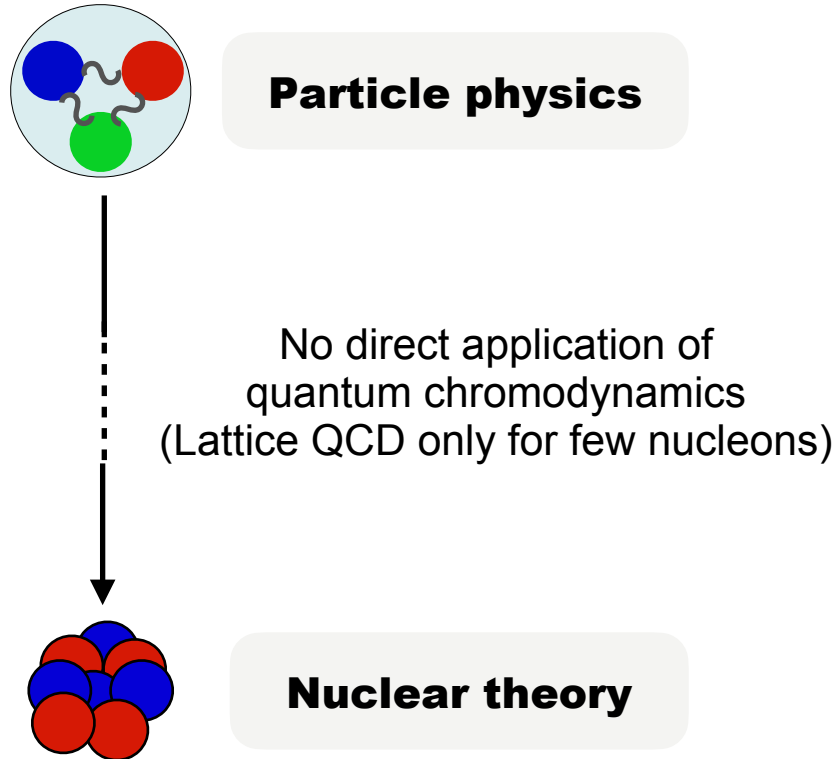


Nuclear theory

WHAT IS AB INITIO?

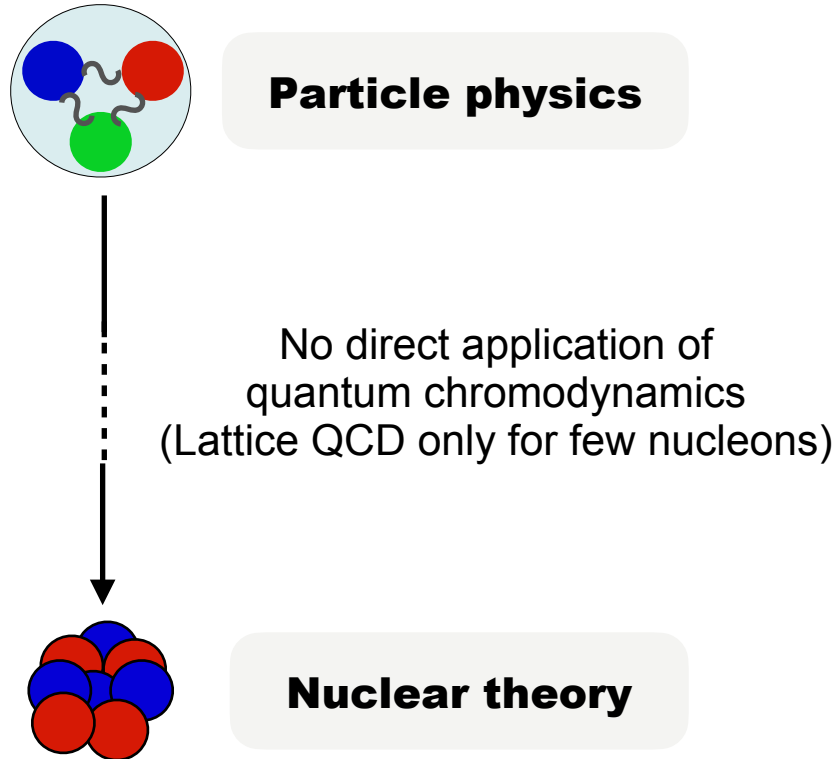


WHAT IS AB INITIO?



Effective Field Theory in the A-body sector

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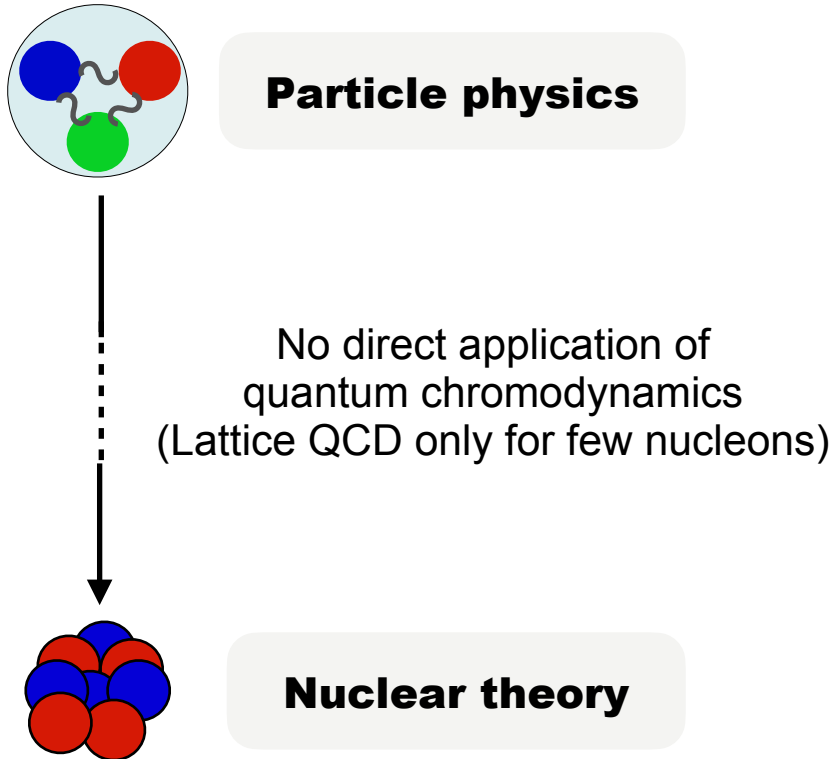


Effective Field Theory in the A-body sector

A-body Schrödinger equation

$$H|\Psi^A\rangle = E^A|\Psi^A\rangle$$

WHAT IS AB INITIO?



Effective Field Theory in the A-body sector

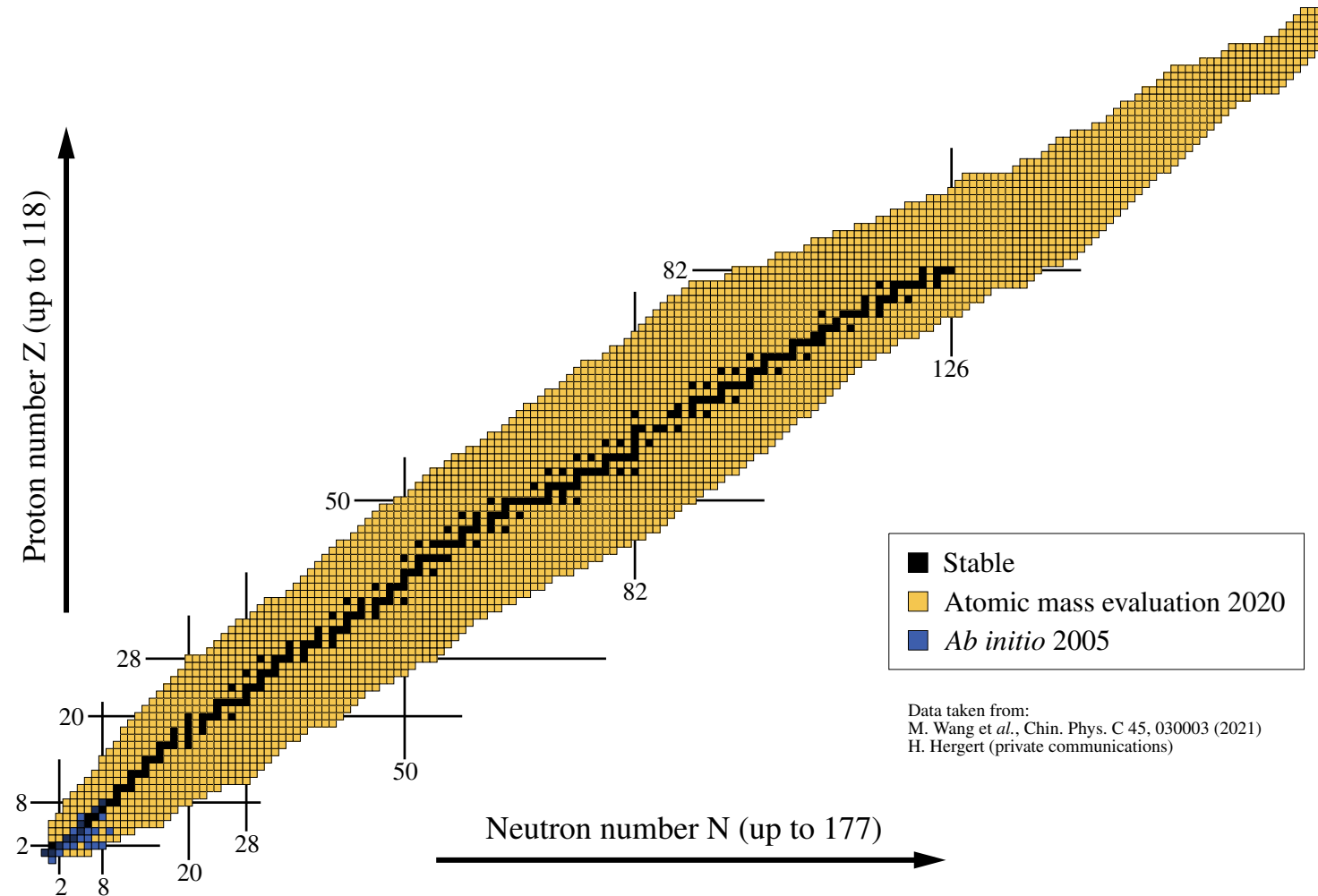
A-body Schrödinger equation

$$H |\Psi^A\rangle = E^A |\Psi^A\rangle$$

Obtain a description that is:

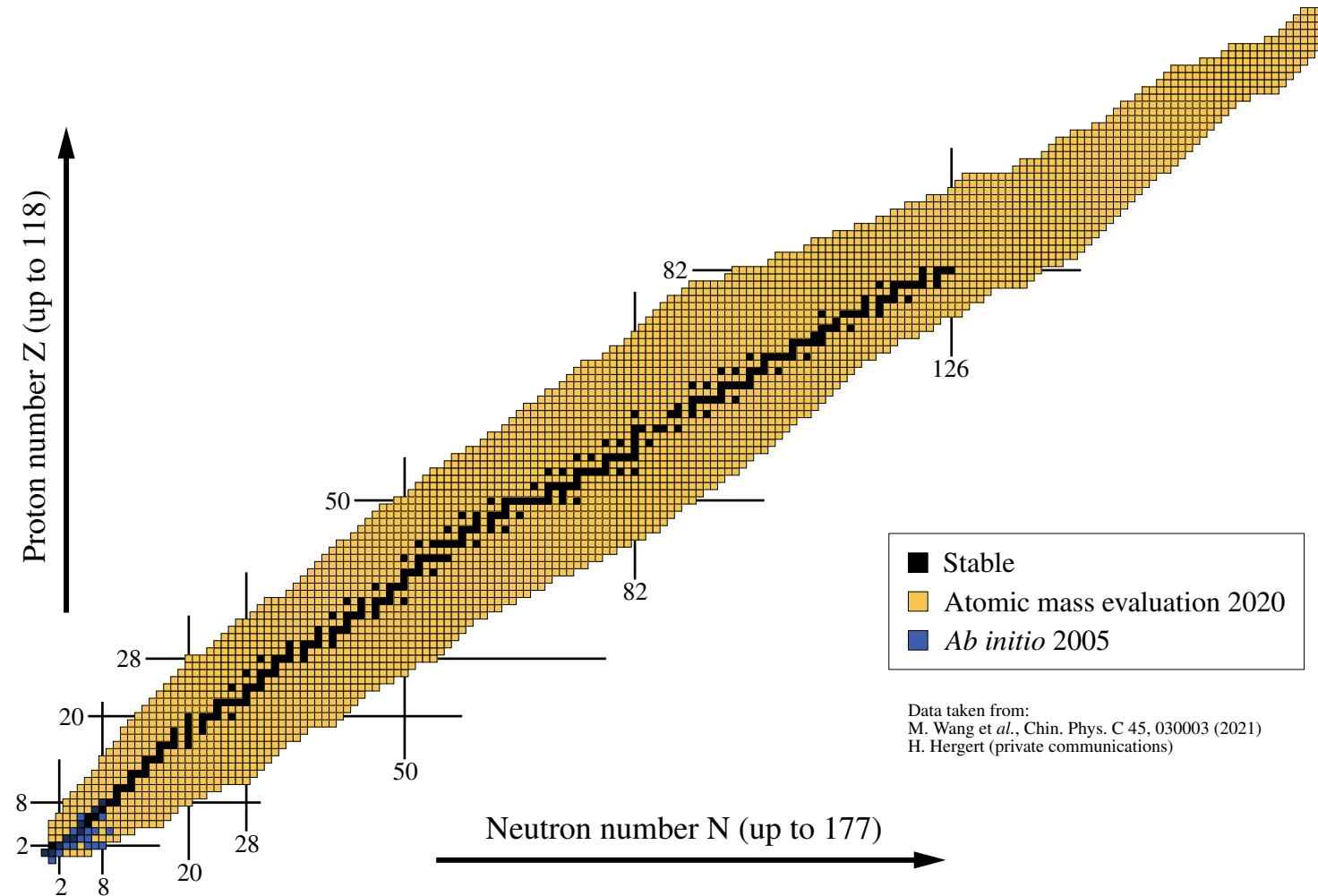
- Consistent
- Systematic
- Accurate enough
- From inter-nucleon interaction
- Rooted in quantum chromodynamics

FROM THE LIGHTEST NUCLEI...



Exact methods (80's)

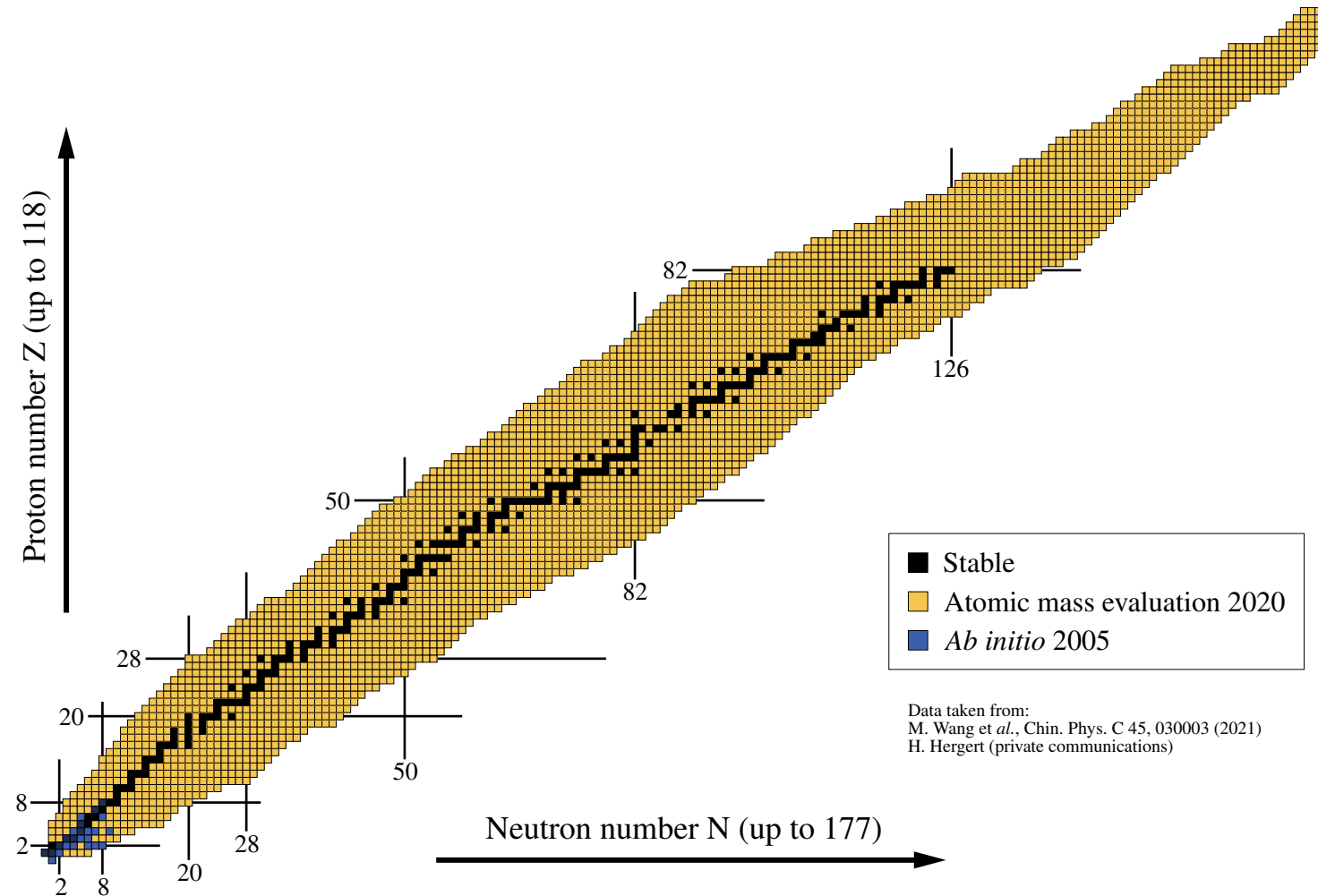
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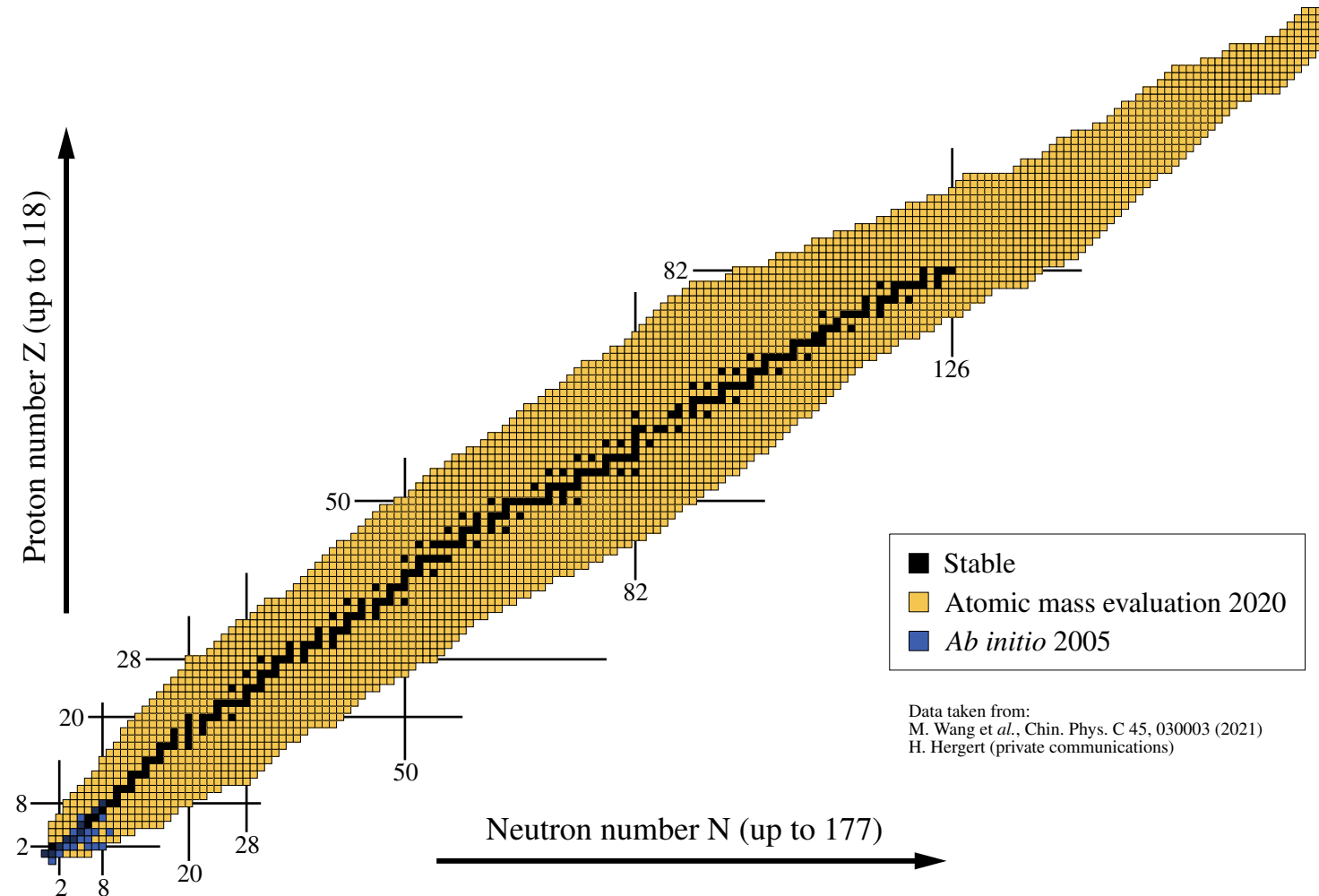


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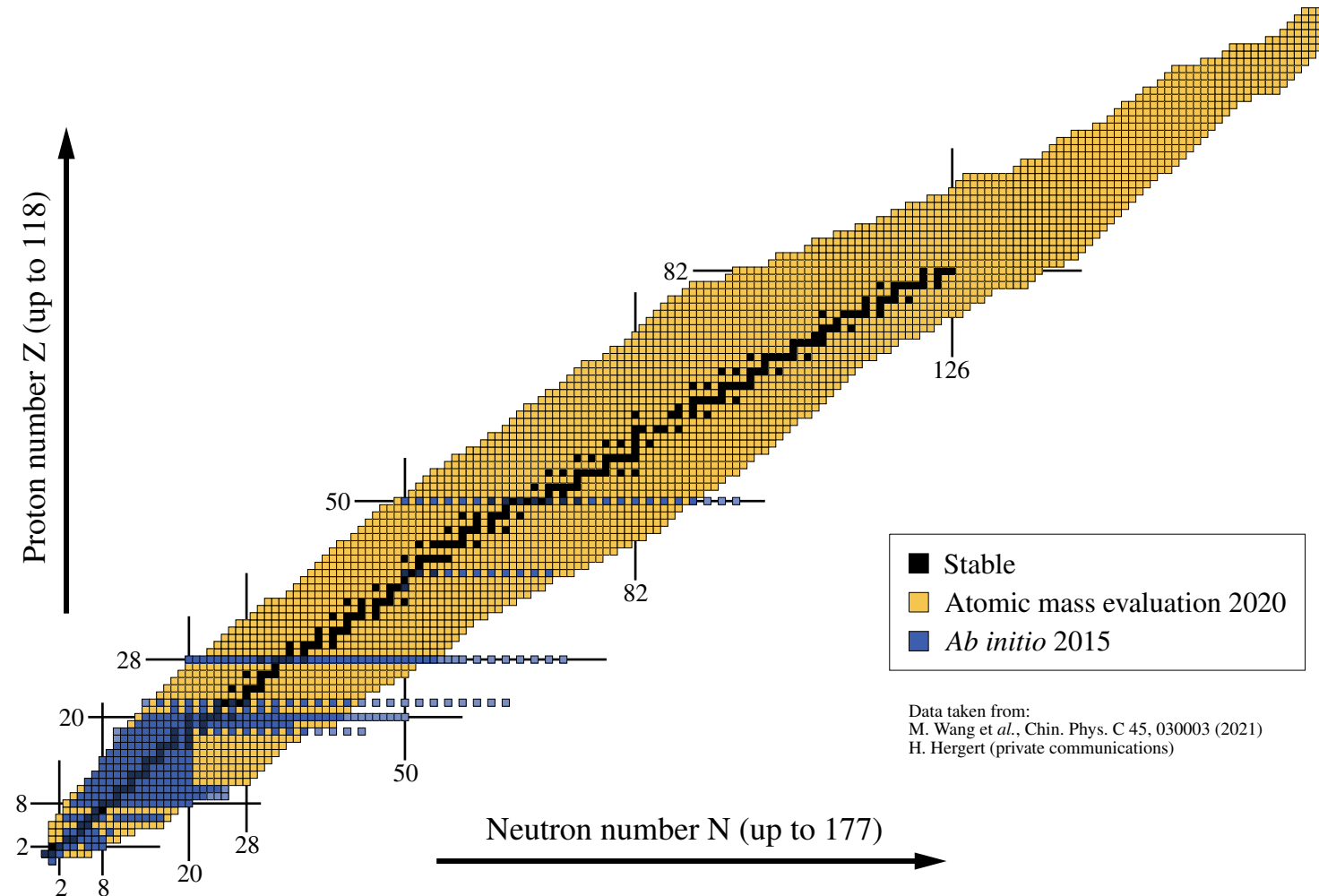
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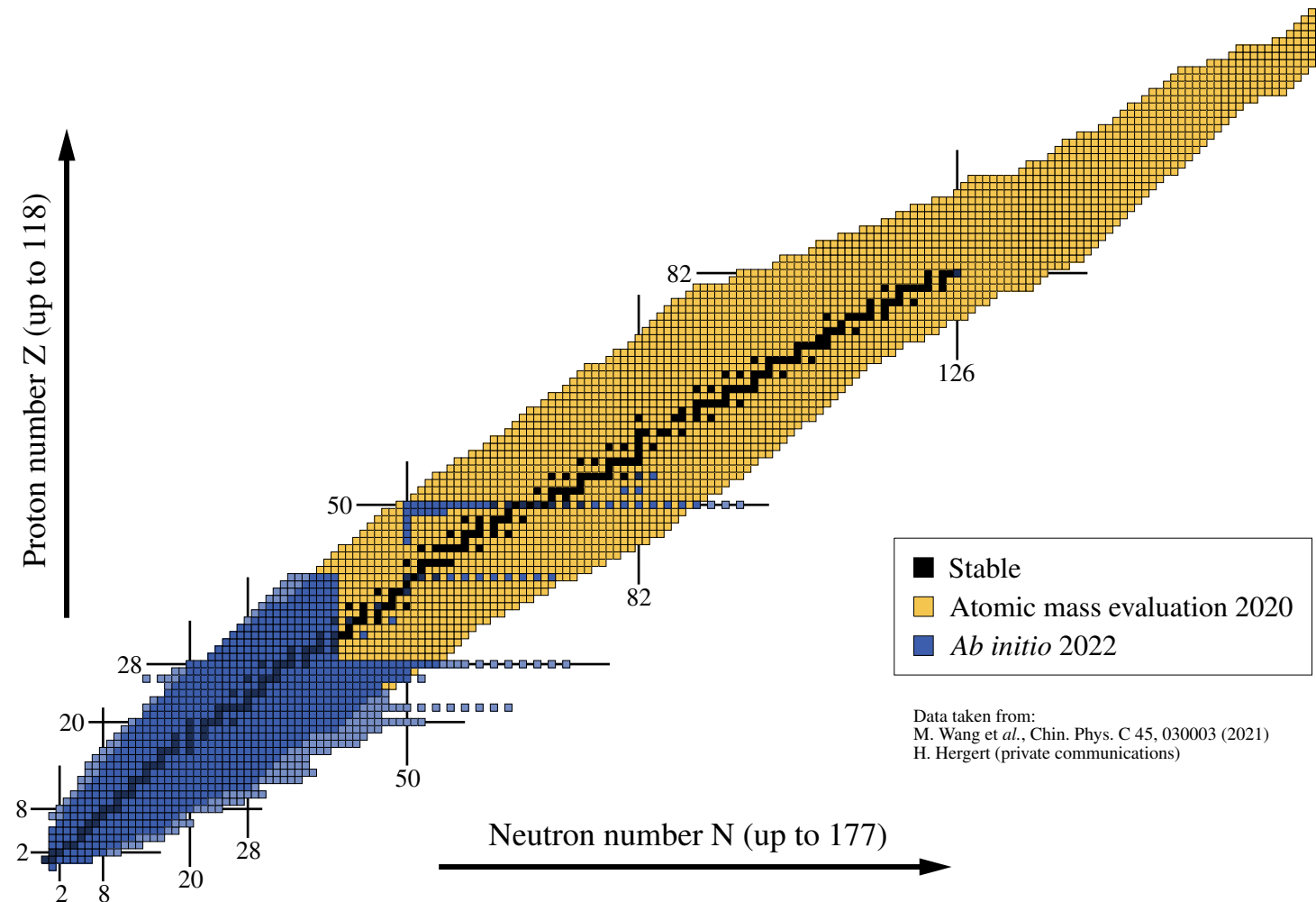
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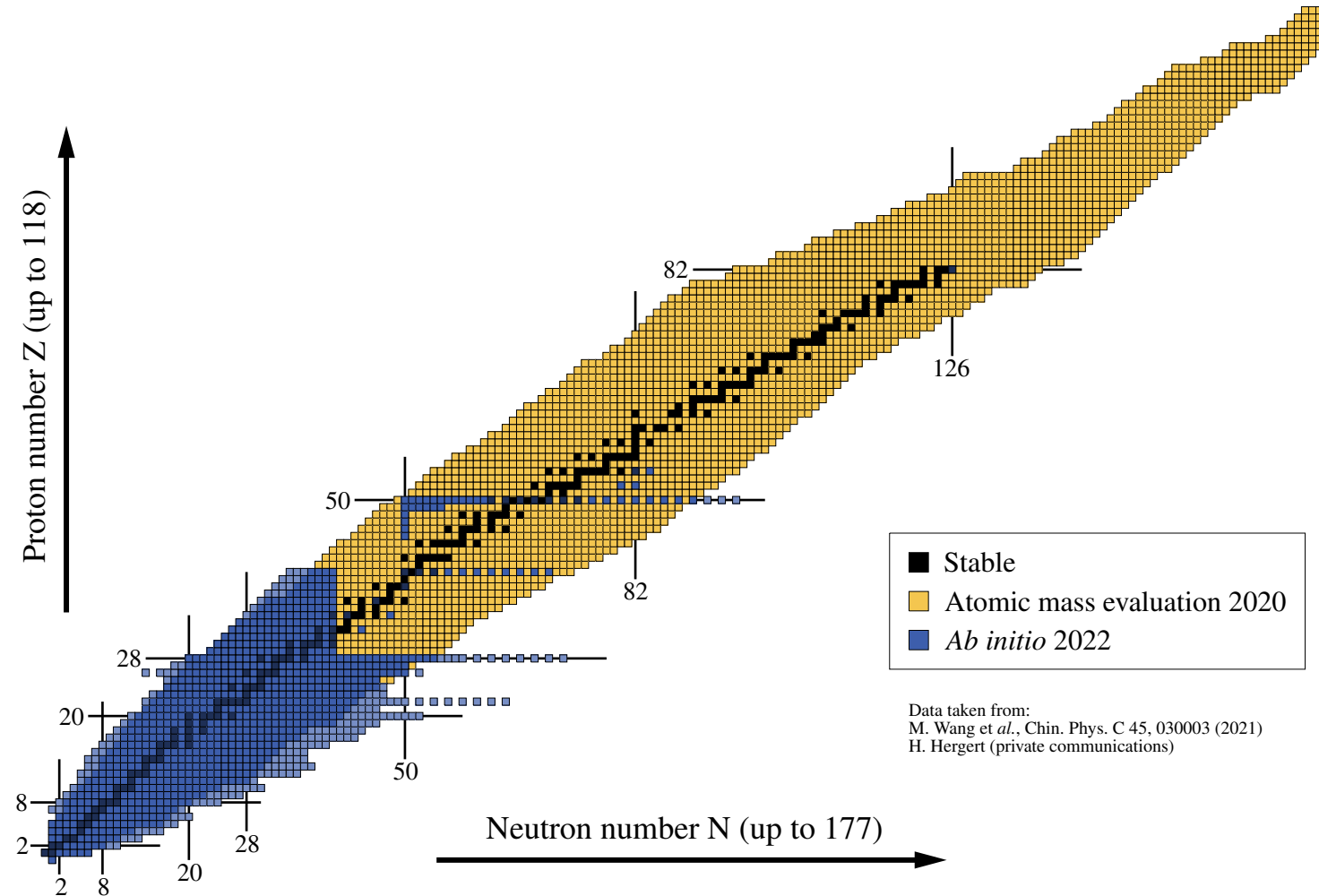
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...TOWARDS MEDIUM- AND HEAVY-MASS SYSTEMS



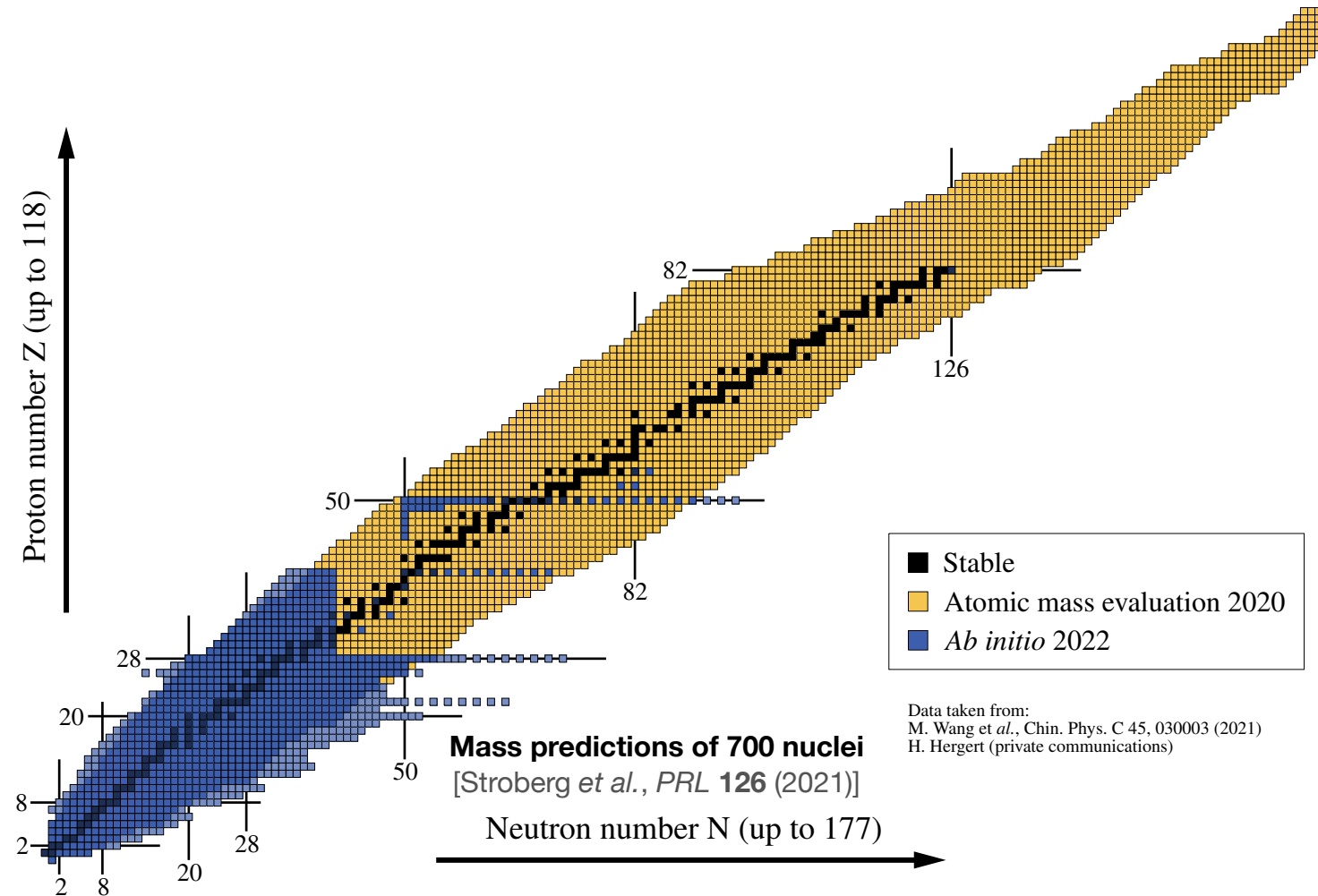
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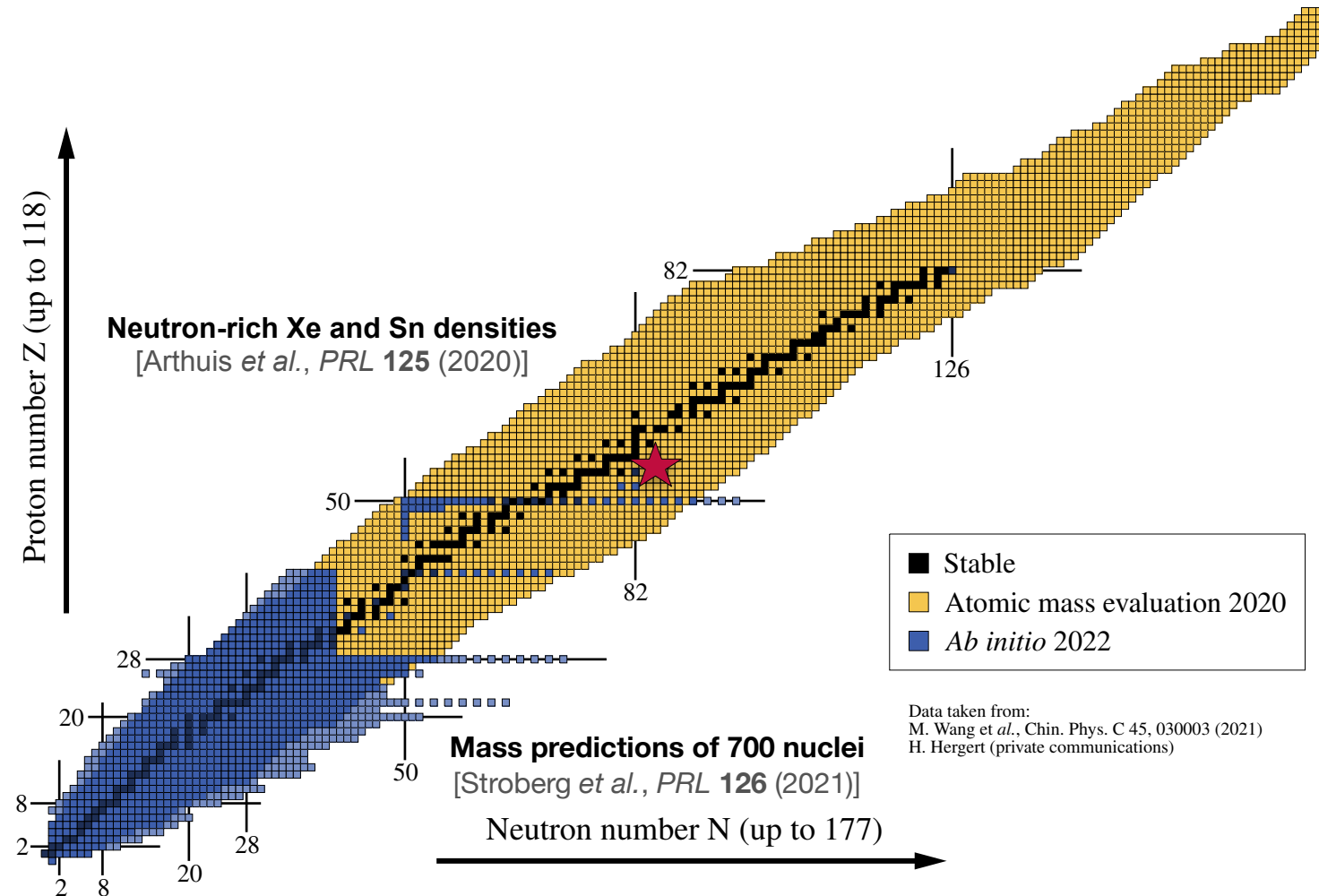
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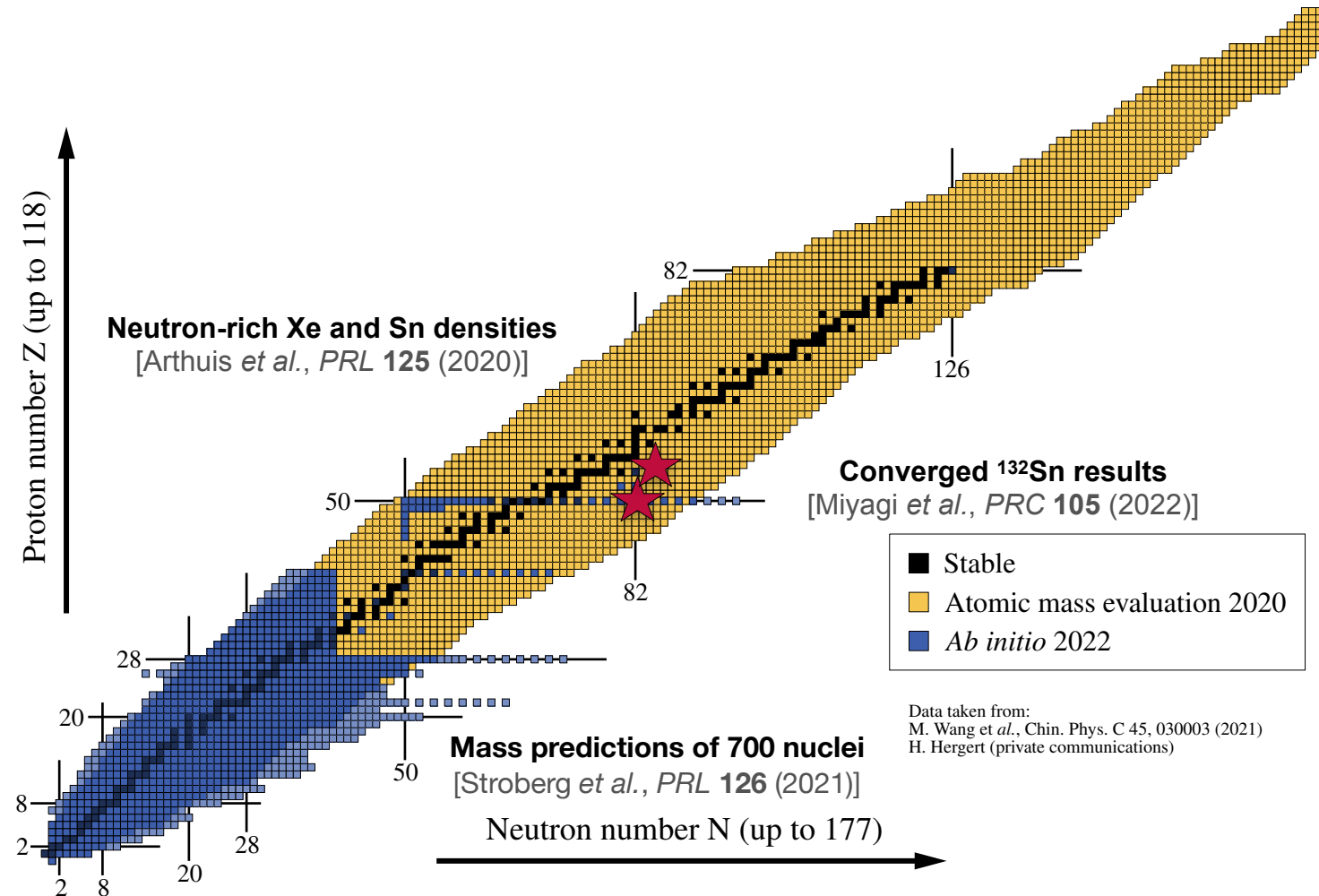
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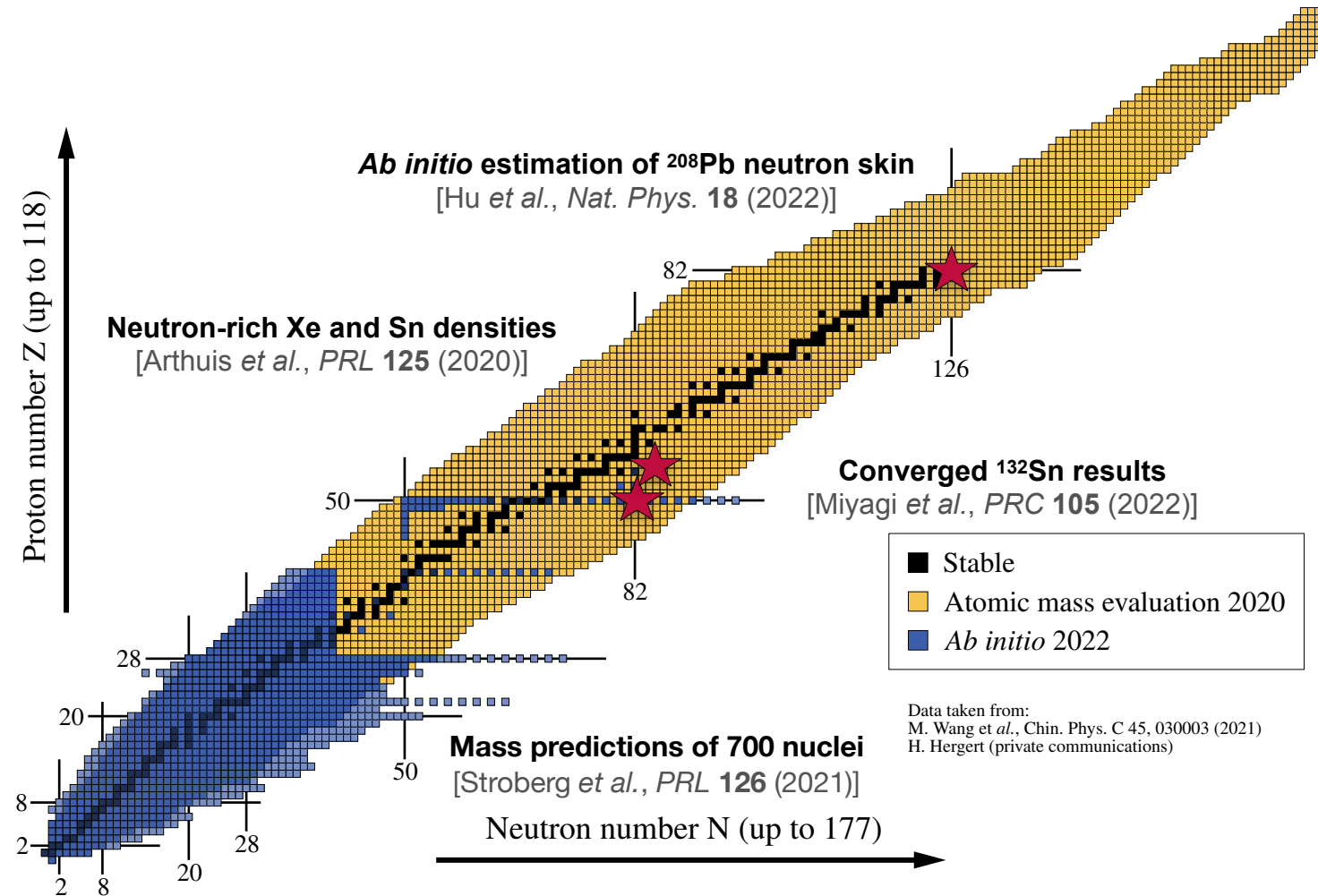
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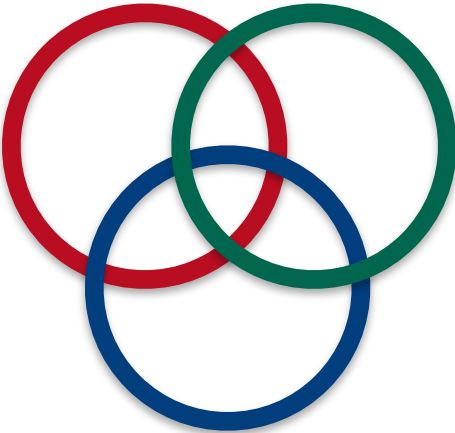
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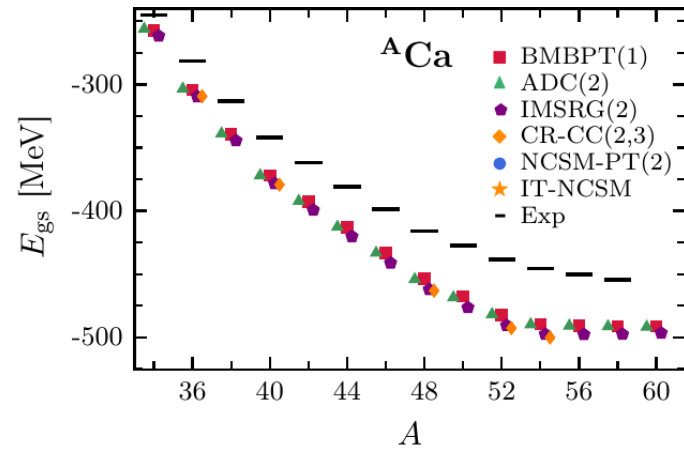
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AB INITIO COMPONENTS

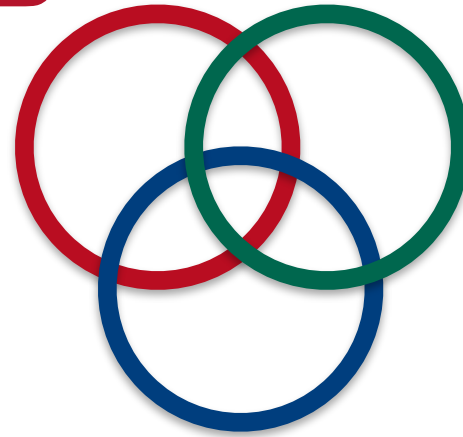


AB INITIO COMPONENTS

Nuclear interaction

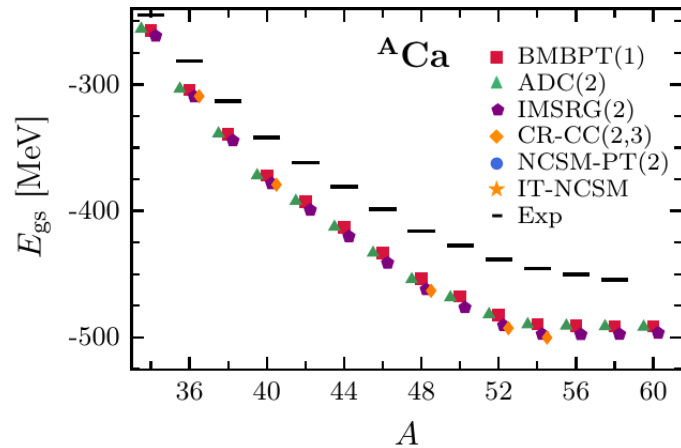


[Tichai, Arthuis *et al.*, *PLB* **786** (2018)]



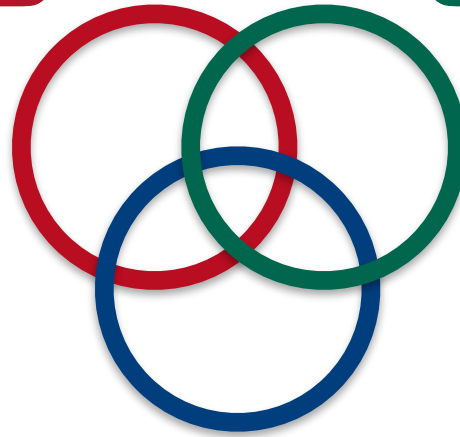
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Many-body method

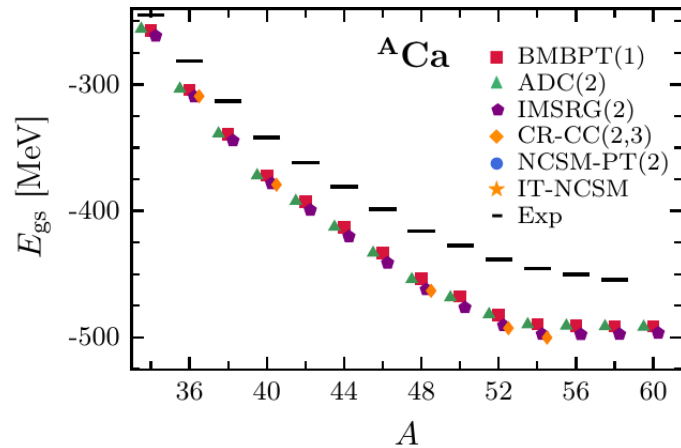


Order	1	2	3	4
# Equations	3	23	396	10,716

[Arthuis *et al.*, *CPC* **240** (2019)]

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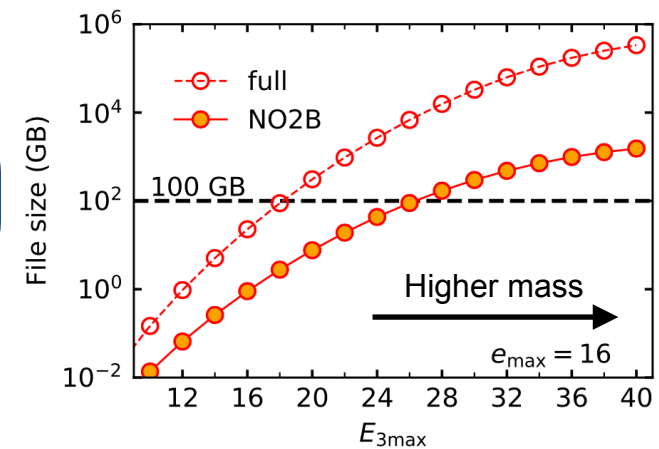
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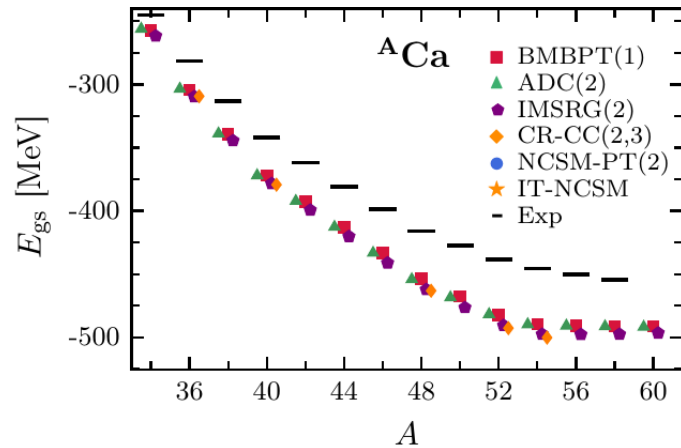
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[Miyagi *et al.*, *PRC* 105 (2022)]

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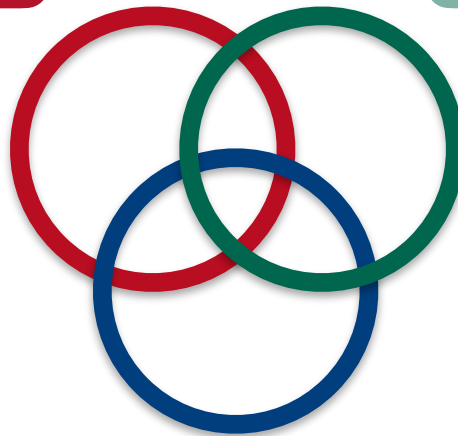


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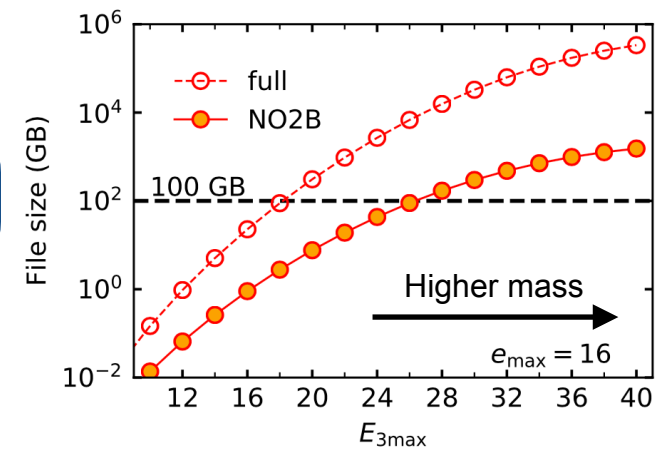
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A 2020 MILESTONE: [ARTHUIS, BARBIERI, VORABBI, FINELLI, PRL 125 (2020)]

FIRST AB INITIO NEUTRON-RICH TIN AND XENON RESULTS

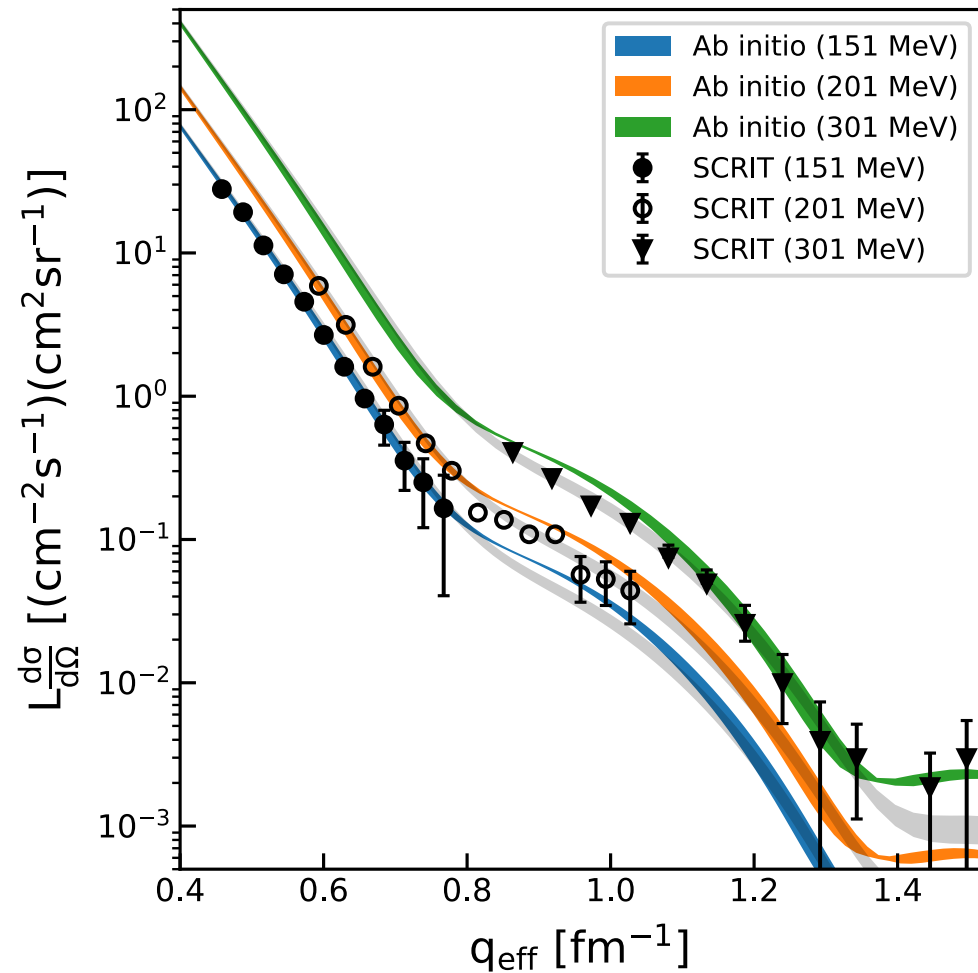
NEUTRON-RICH TIN AND XENON RESULTS [ARTHUIS, BARBIERI, VORABBI, FINELLI, PRL 125 (2020)]

ELECTRON SCATTERING OFF ^{132}Xe @ SCRIT

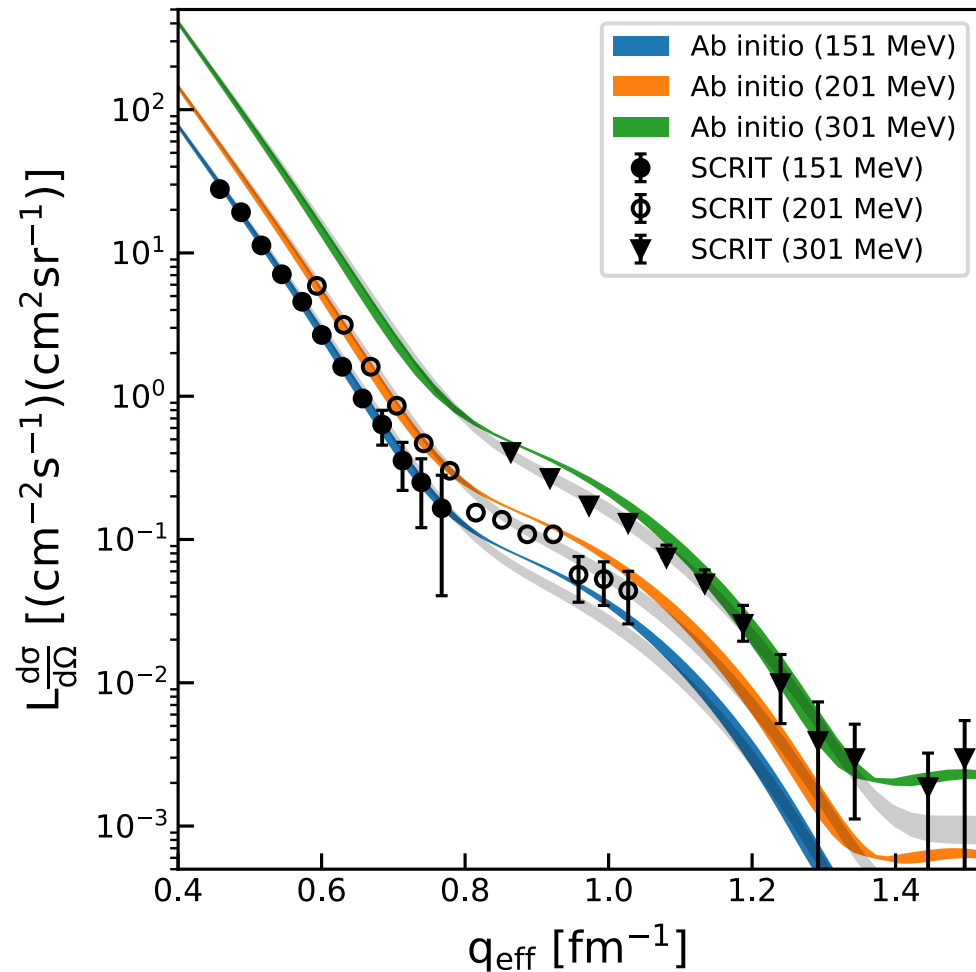


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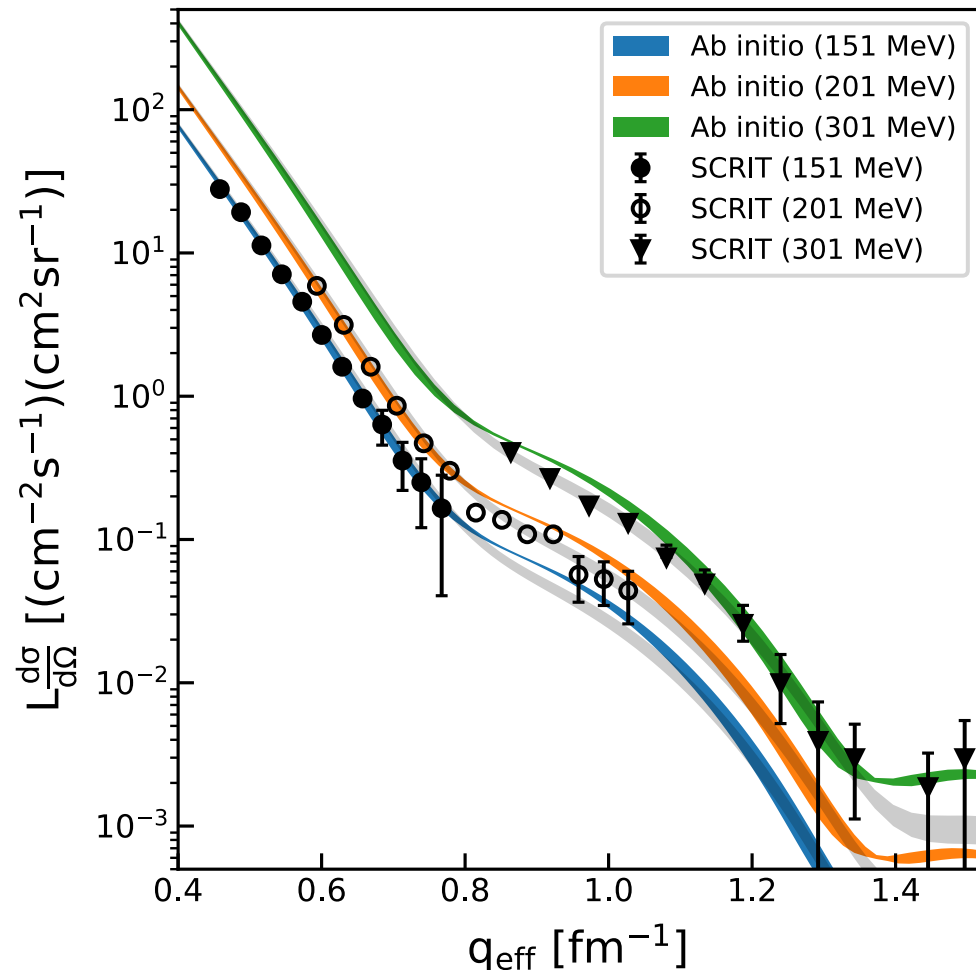
ELECTRON SCATTERING OFF ^{132}Xe @ SCRIT



First *ab initio* calculation past the Sn isotopic line

- Reproduce experimental electron scattering results
- Convergence is not an issue for elastic scattering studies

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r_{ch} [fm]	<i>Ab initio</i>	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
- Uncertainties: 2020's state of the art for heavy systems
- First converged results for ^{132}Sn : Miyagi et al., *PRC* 105 (2022)



REVISITING CHIRAL LOW-RESOLUTION INTERACTIONS [ARTHUIS, HEBELER, SCHWENK (IN PREP.)]

TOWARDS AB INITIO RADII AND DENSITIES OVER THE NUCLEAR CHART

REVISITING CHIRAL LOW-RESOLUTION INTERACTIONS [ARTHUIS, HEBELER, SCHWENK (IN PREP.)]



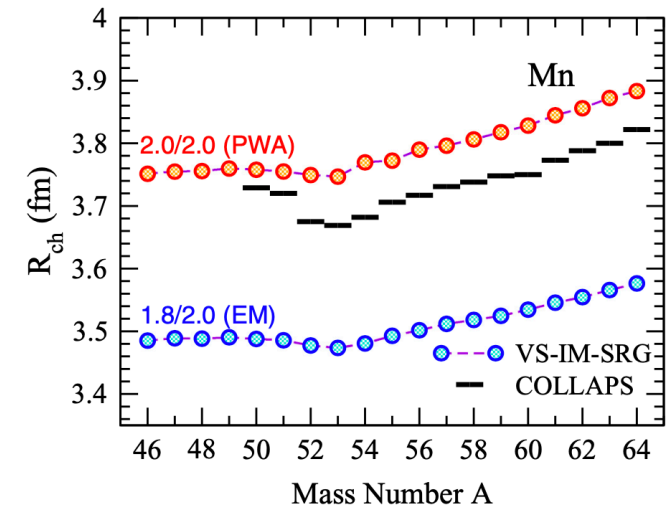
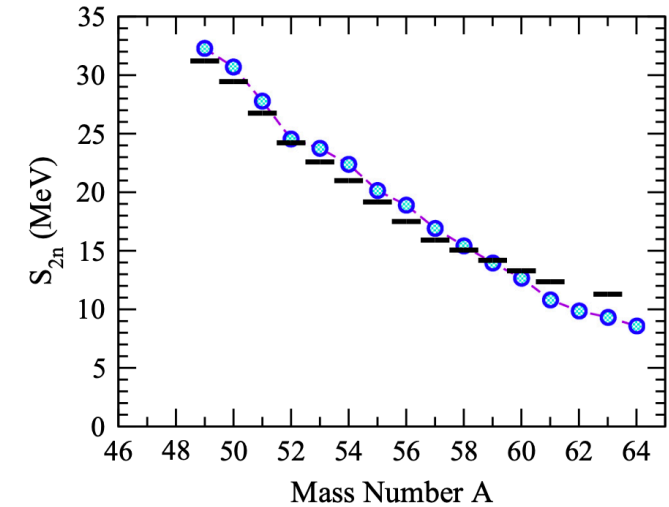
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WHY LOW-RESOLUTION INTERACTIONS?

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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)]



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

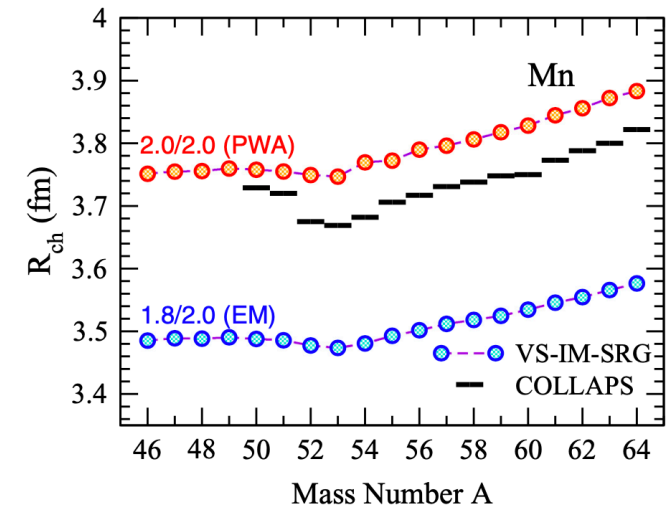
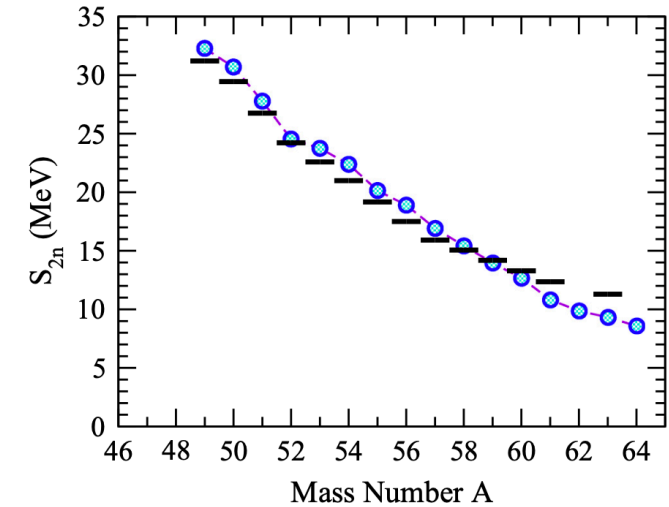
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Revisit this approach

- Goal: Obtain good description of binding energy and radii
- Target: From light to heavy systems ($\sim O$ to $\sim Sn$)
- Make use of progress for matrix element handling



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

WHY LOW-RESOLUTION INTERACTIONS?

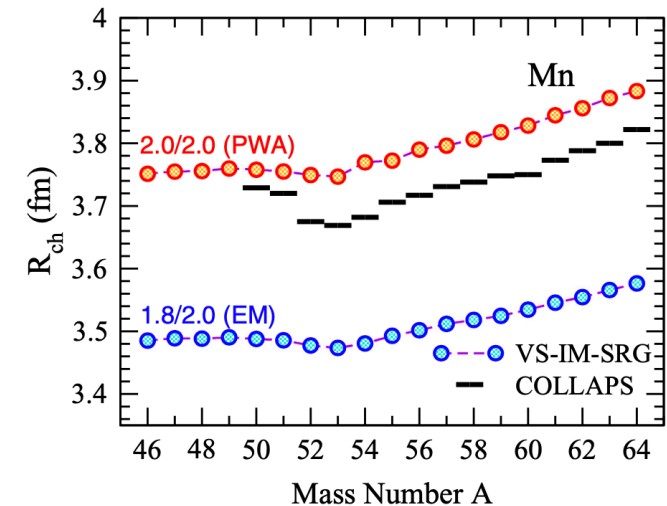
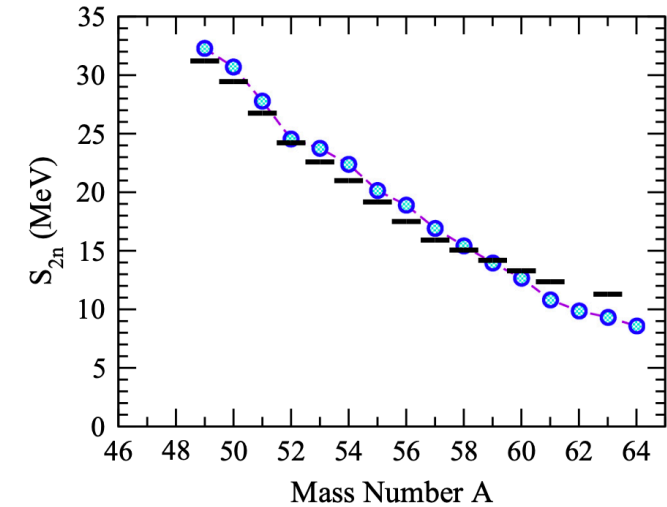
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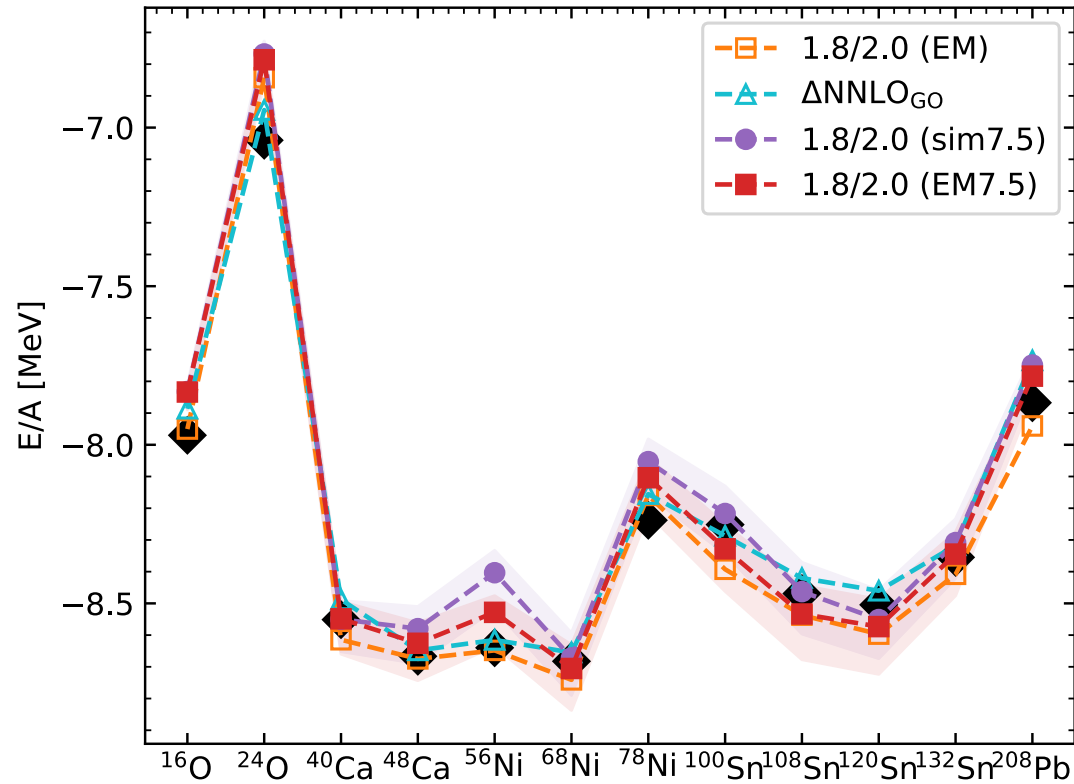
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Two new interactions: Let's test them!



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

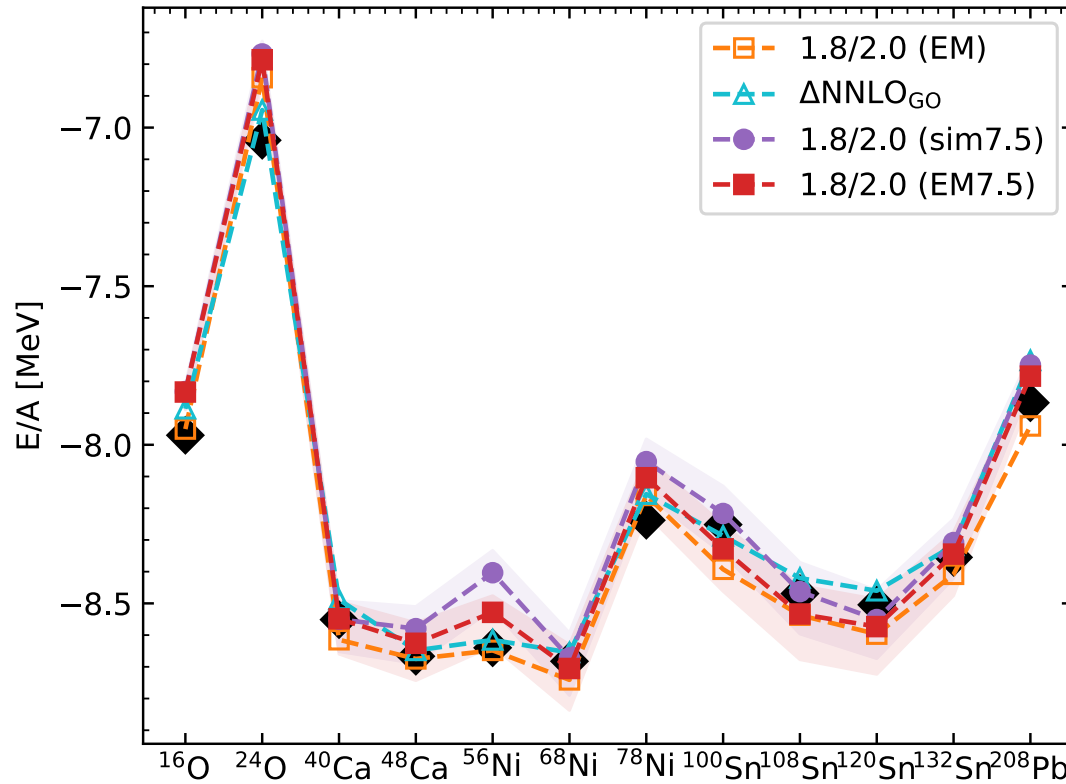
GROUND-STATE ACCURACY TOWARDS HEAVY SYSTEMS



Binding energy

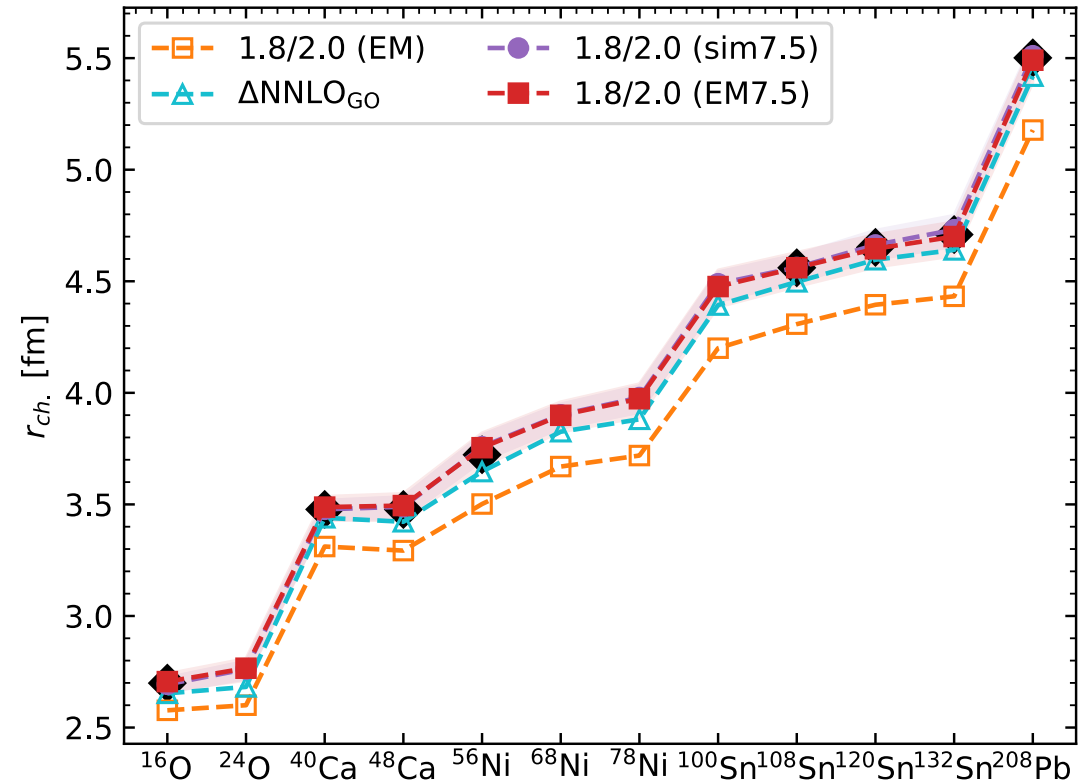
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- Slight improvement for heavy systems w.r.t. 1.8/2.0 (EM)

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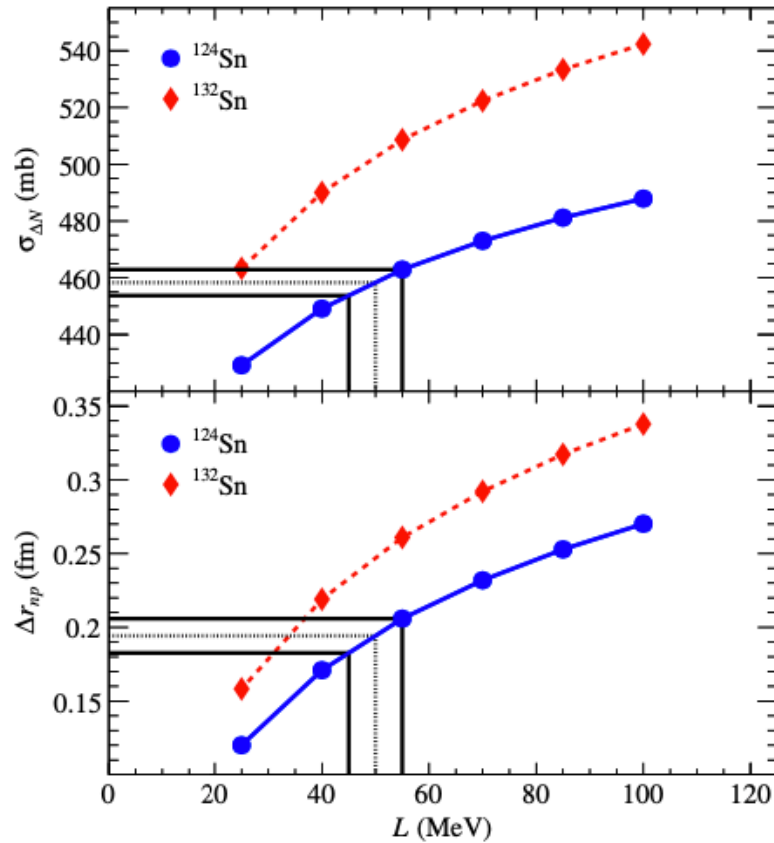
Charge radius

- Quasi-exact reproduction over complete mass range
- Best radius reproduction for low-resolution interactions

NEUTRON SKIN AND INFINITE MATTER

Neutron removal off Sn isotopes @ R3B/GSI

- Access L through the cross-section, compare with our density profiles
- L correlated to neutron skin too: Good benchmark for us

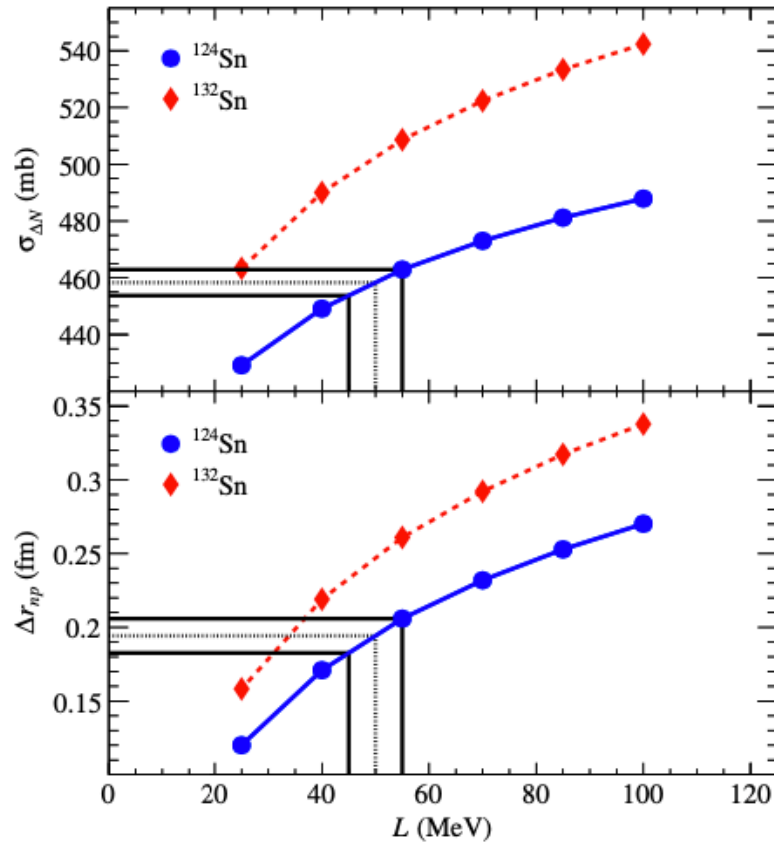


[Aumann *et al.*, *PRL* 119 (2017)]

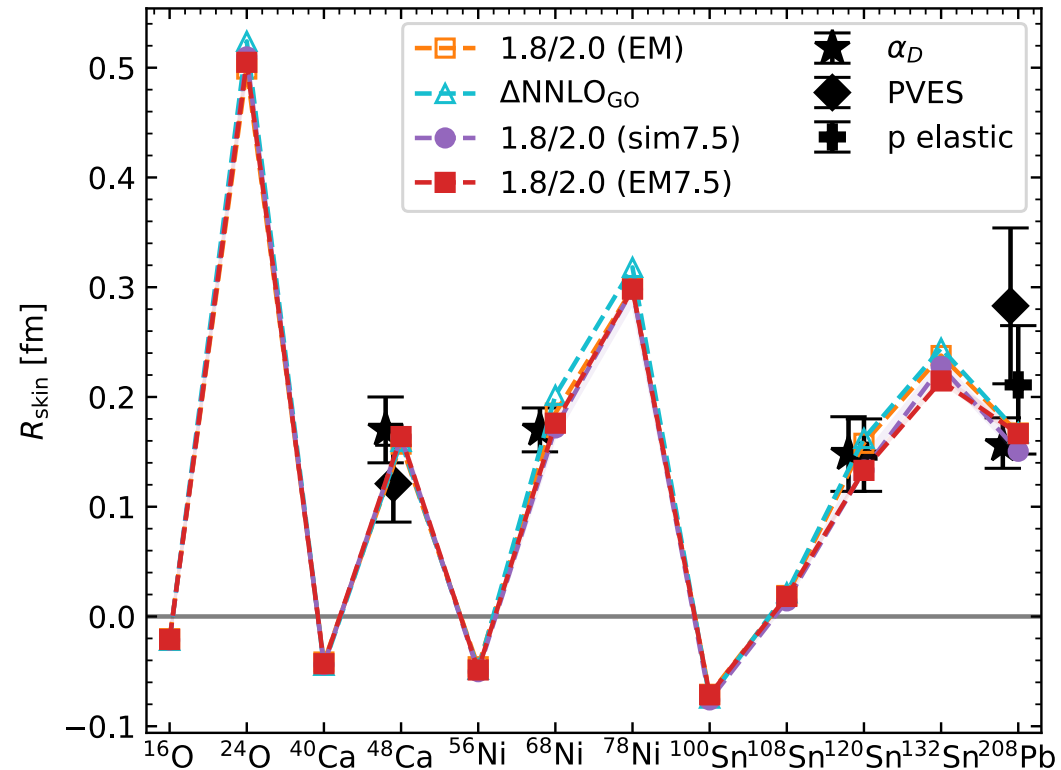
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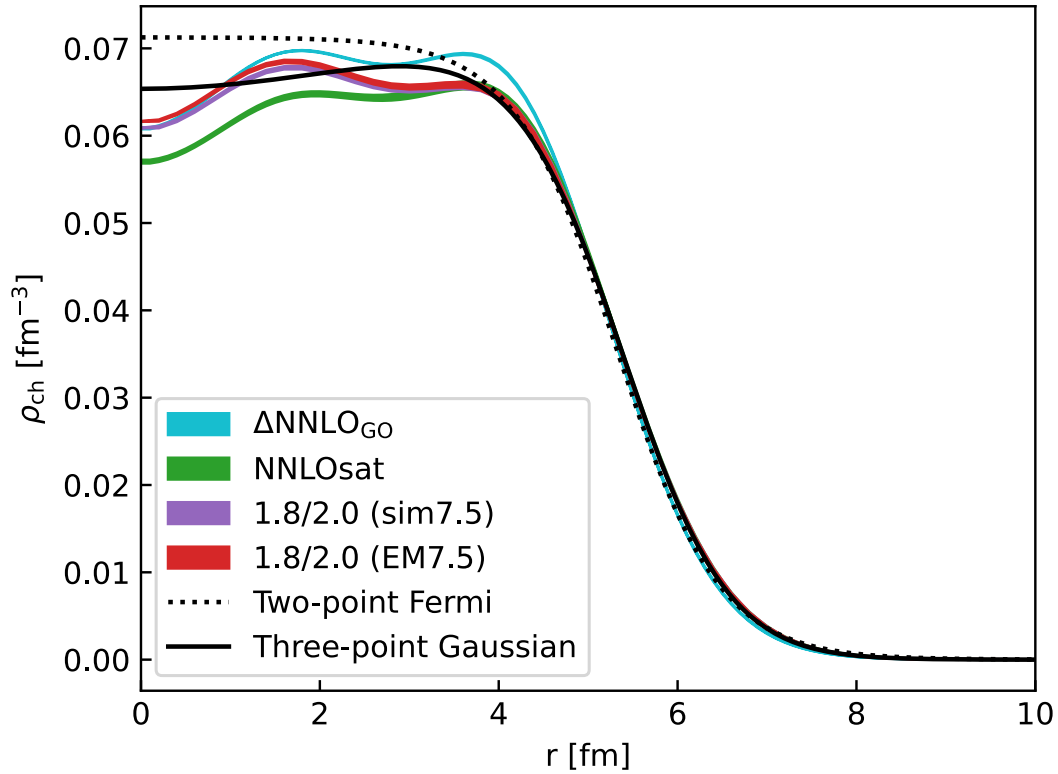
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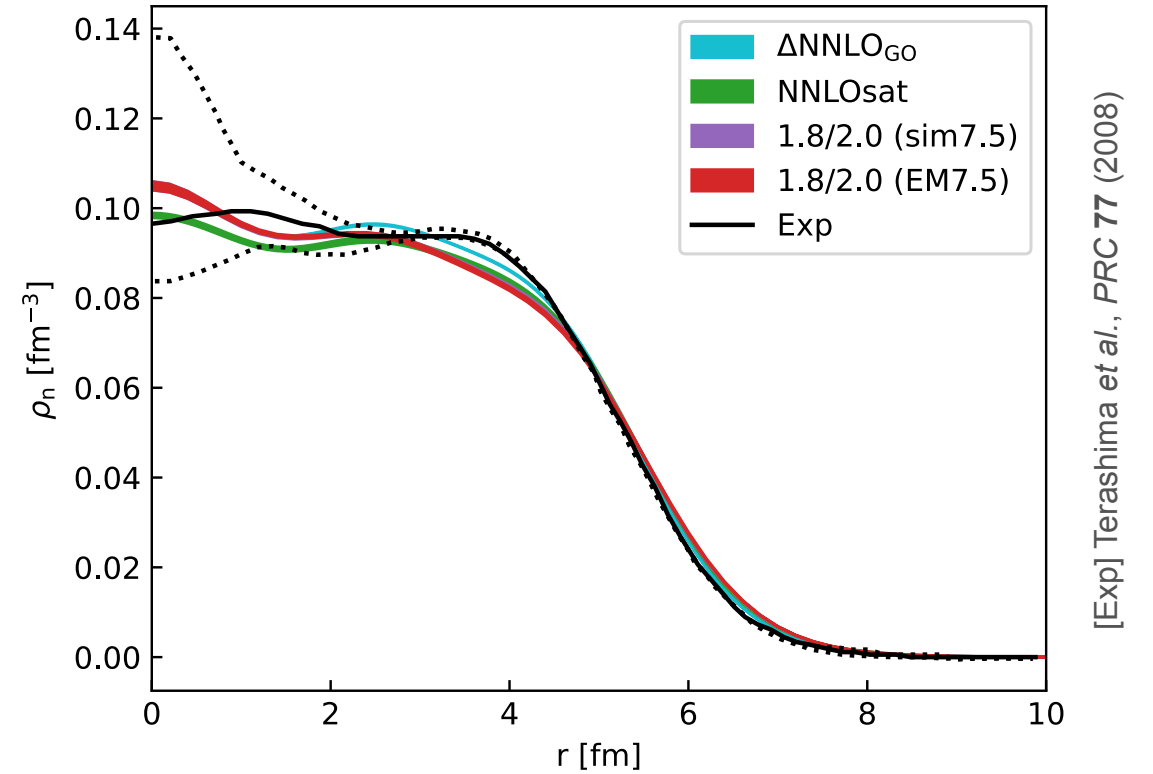
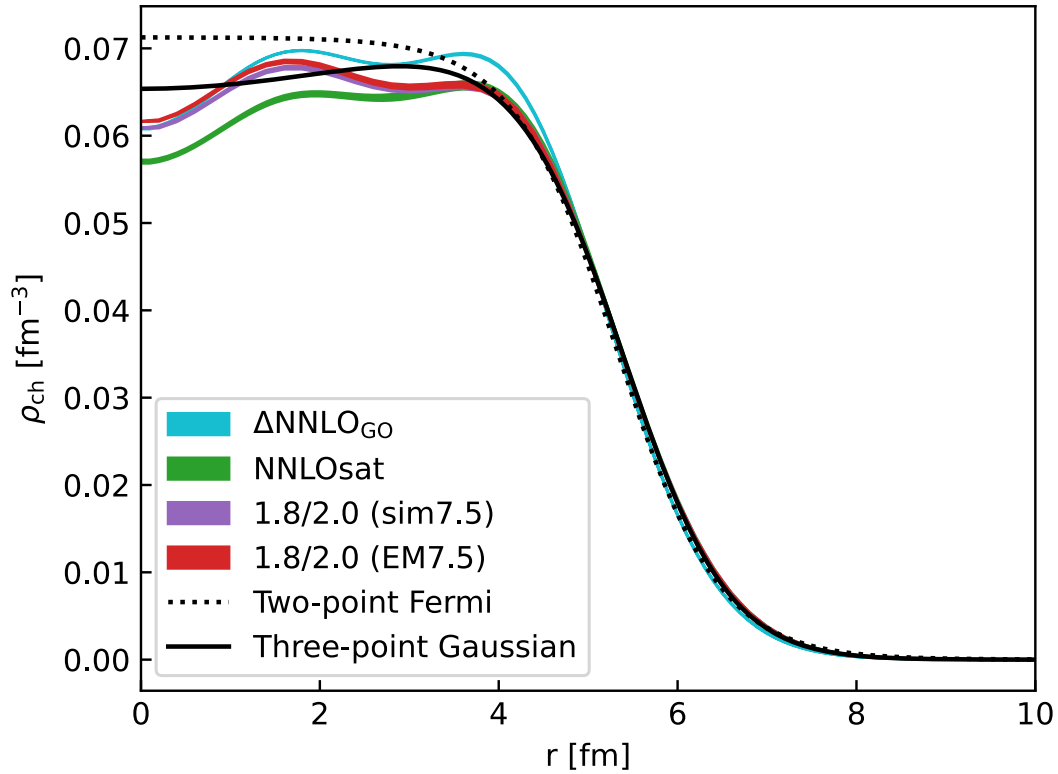


AB INITIO DENSITIES FOR HEAVY SYSTEMS: ^{120}Sn

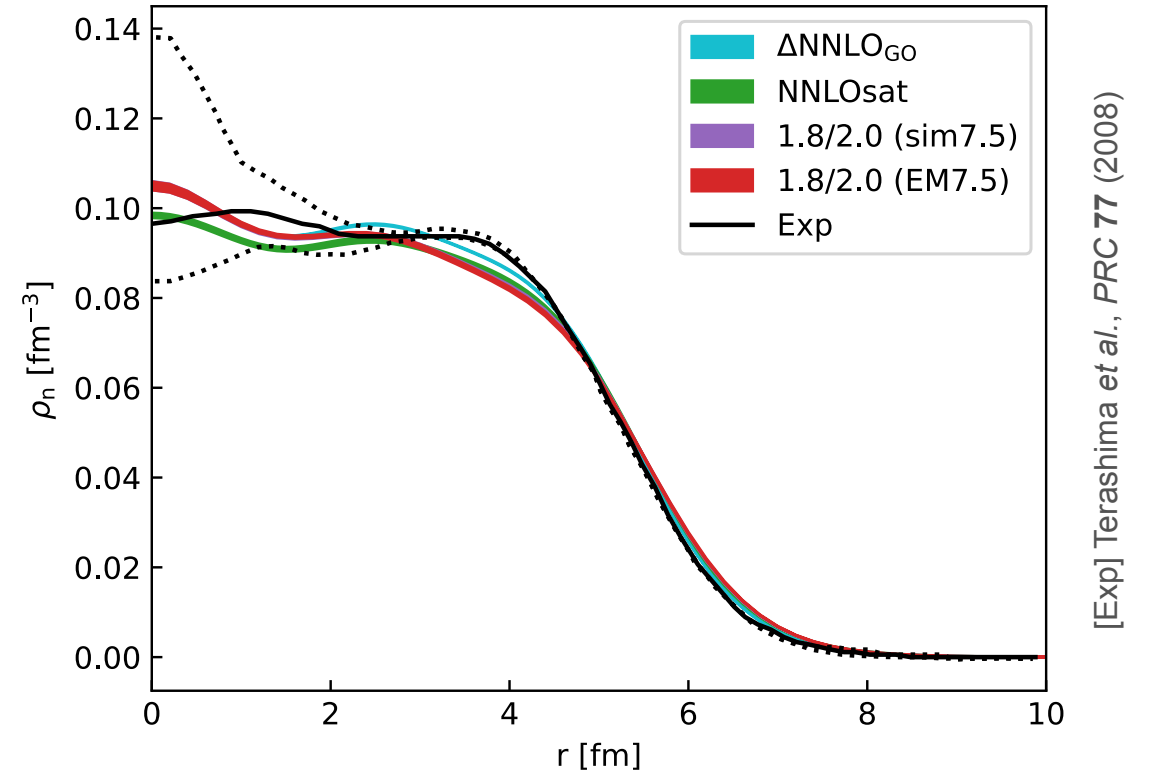
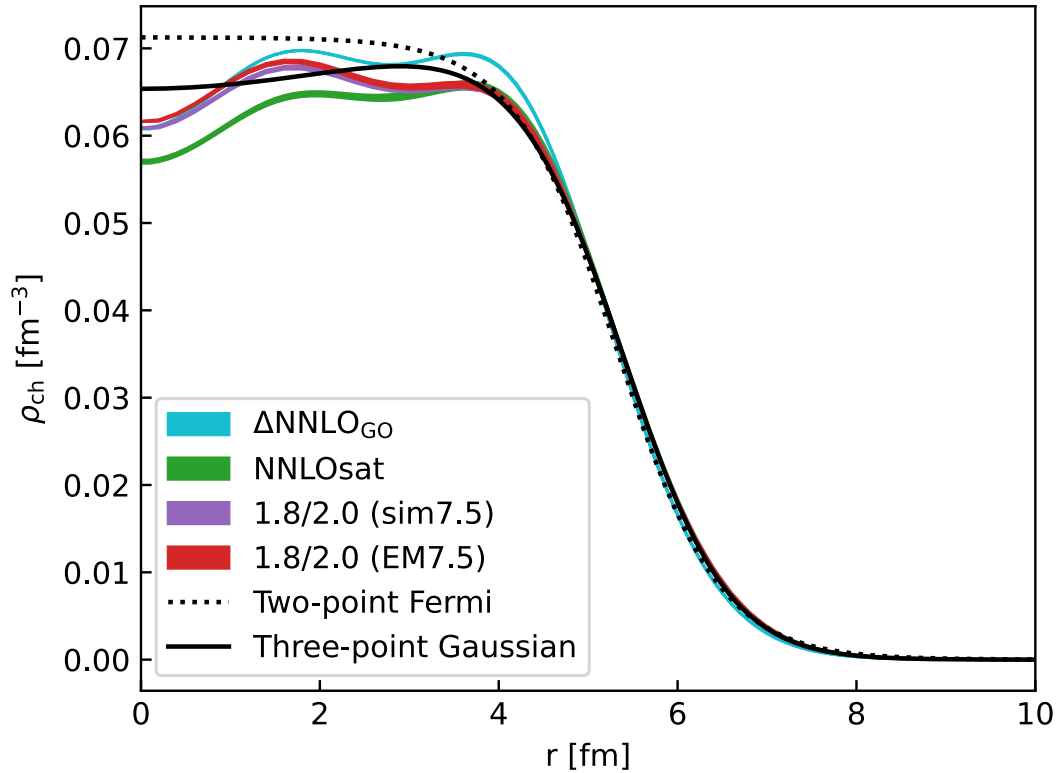


[Exp] Terashima et al., PRC 77 (2008)

AB INITIO DENSITIES FOR HEAVY SYSTEMS: 120SN



AB INITIO DENSITIES FOR HEAVY SYSTEMS: ^{120}Sn



Excellent reproduction of ^{120}Sn densities

- Consistent picture over the different interactions
- Very moderate uncertainties

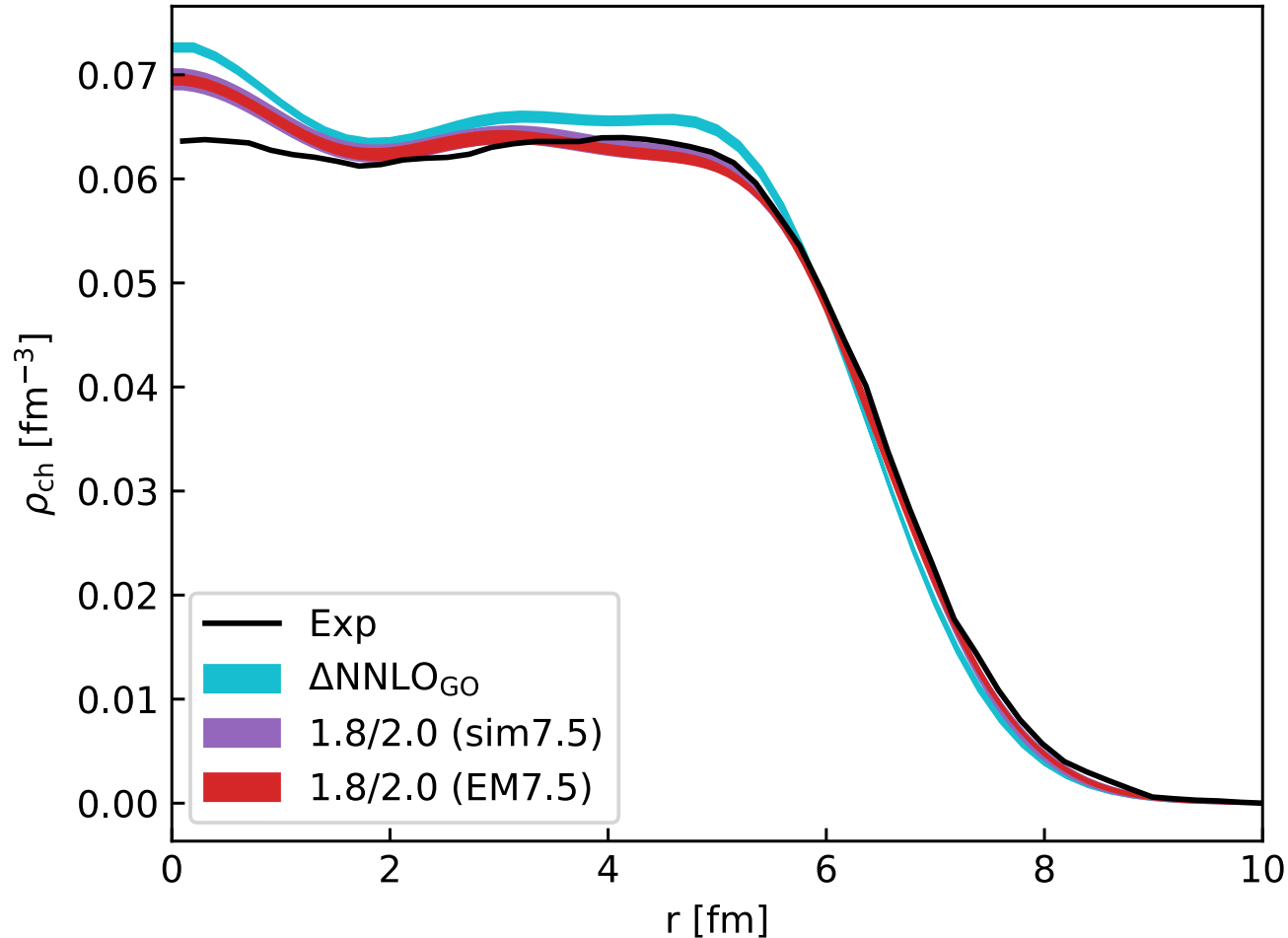
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AB INITIO DENSITIES FOR HEAVIER SYSTEMS: 208PB



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AB INITIO DENSITIES FOR HEAVIER SYSTEMS: 208Pb

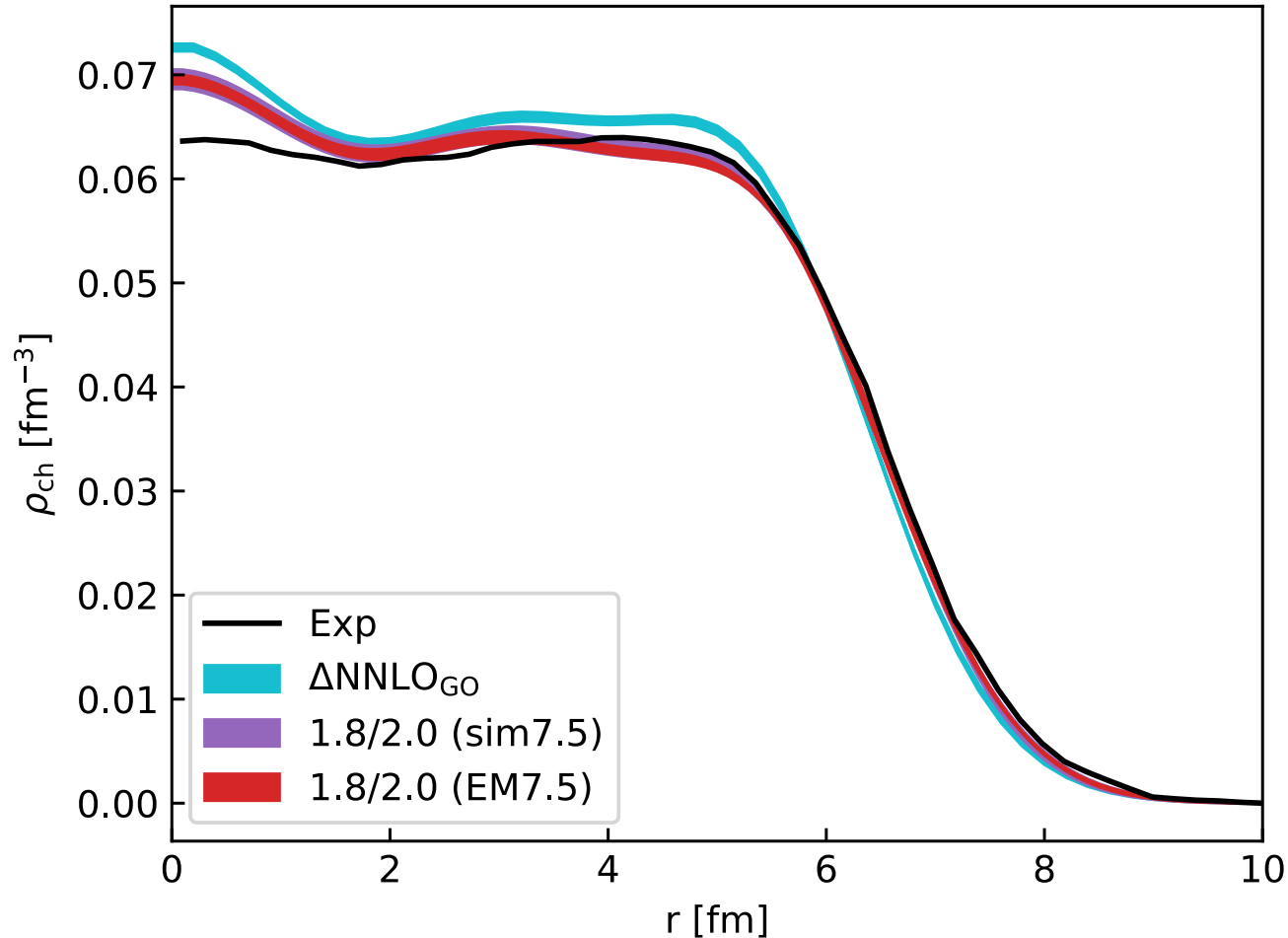


[Exp] Frois & Papanicolas, *ARNPS* 37 (1987)

Very preliminary results for ^{208}Pb

- First *ab initio* density profile for $A > 138$
- Consistent picture over the different interactions
- Further convergence might lead to inner changes

AB INITIO DENSITIES FOR HEAVIER SYSTEMS: 208Pb



[Exp] Frois & Papanicolas, *ARNPS* 37 (1987)

Very preliminary results for ^{208}Pb

- First *ab initio* density profile for $A > 138$
- Consistent picture over the different interactions
- Further convergence might lead to inner changes

New interactions consistent over the nuclear chart

A GLIMPSE AT THE FUTURE

CONCLUSION AND OUTLOOK



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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

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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

Excellent results over the nuclear chart

- Interactions with good convergence properties
- Good reproduction of binding energy, radii, neutron skins
- *Ab initio* densities now well converged and matching experiment

ACKNOWLEDGMENTS



Thank your for your attention!



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STRONGINT group
K. Hebler, M. Heinz, J. Hoppe, T. Miyagi,
A. Schwenk, A. Tichai, L. Zurek

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C. Barbieri



P. Finelli

BROOKHAVEN
NATIONAL LABORATORY



M. Vorabbi