

# Ab initio radii and density distributions for Sn and Xe isotopes



Pierre Arthuis

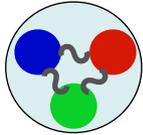


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# ***Ab initio* many-body scheme**

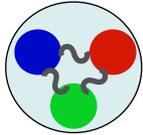
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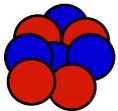


Particle physics

# *Ab initio* many-body scheme

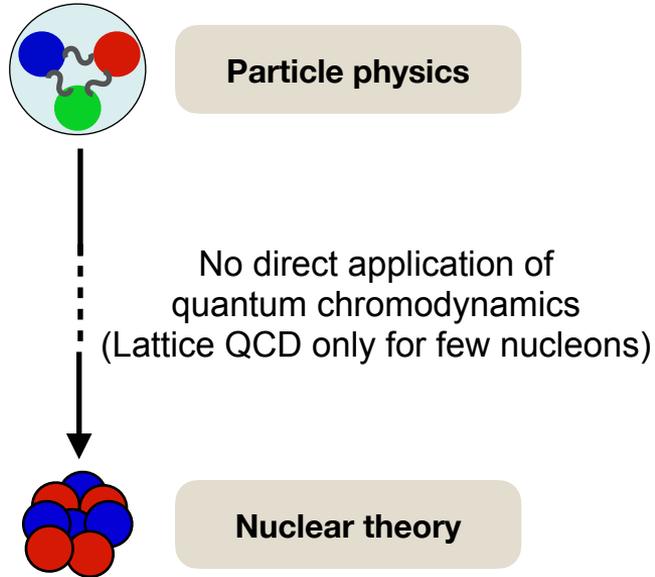


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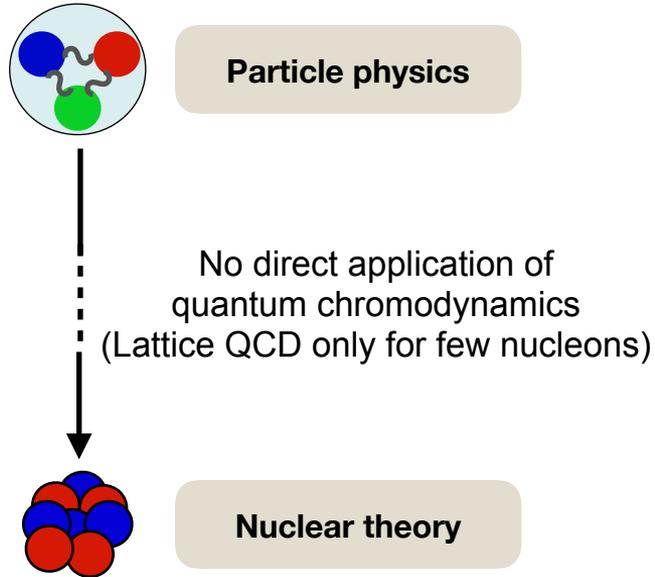


Nuclear theory

# *Ab initio* many-body scheme

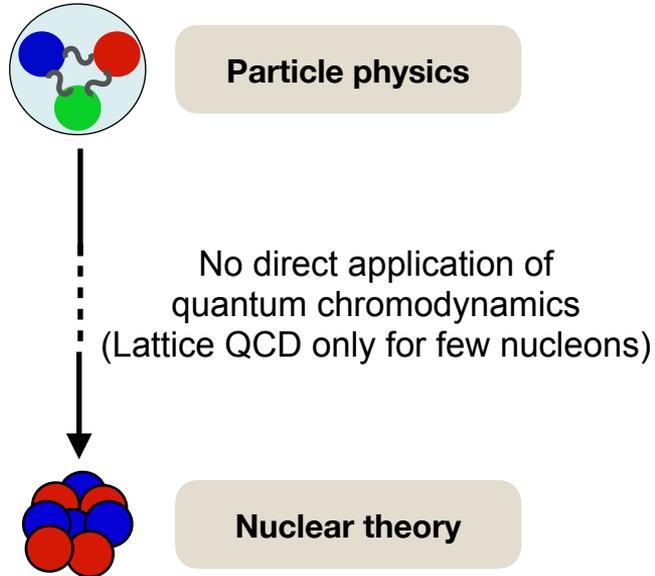


# *Ab initio* many-body scheme



Effective Field Theory in the A-body sector

# Ab initio many-body scheme

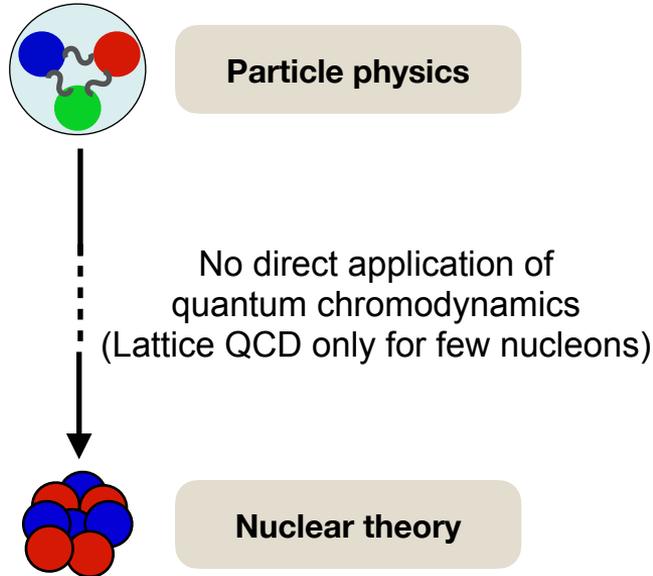


**Effective Field Theory in the A-body sector**

**A-body Schrödinger equation**

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

# Ab initio many-body scheme



## Effective Field Theory in the A-body sector

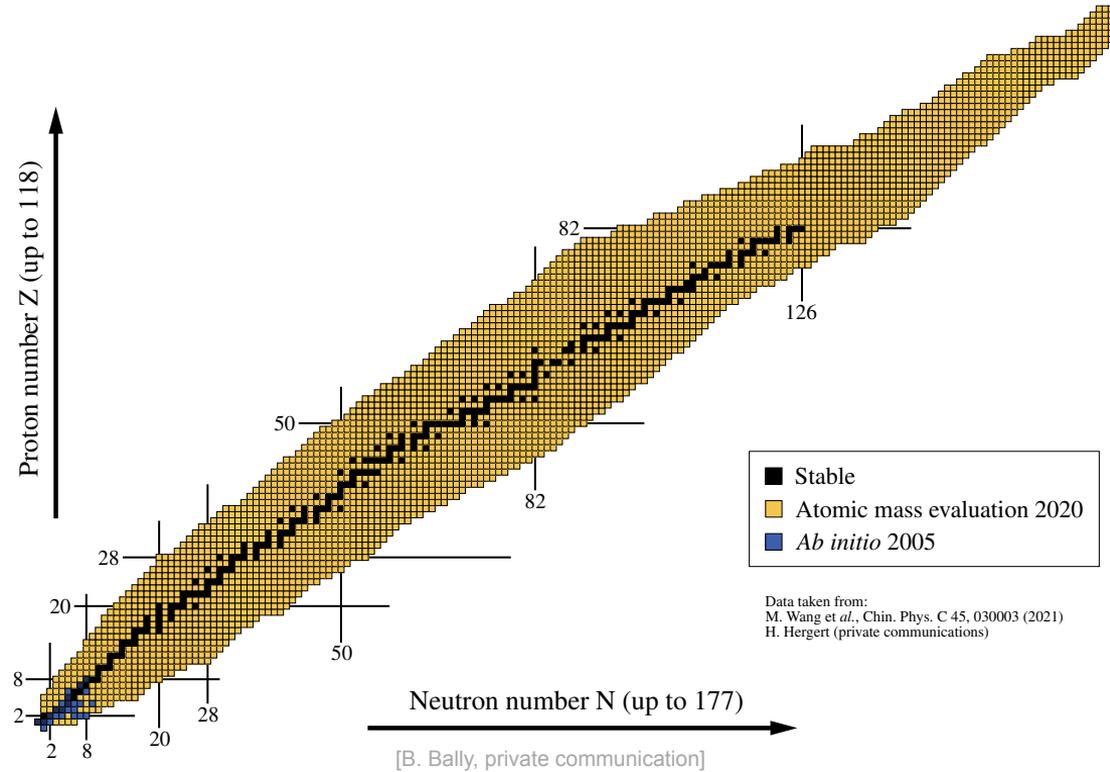
### A-body Schrödinger equation

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

### Obtain a description that is:

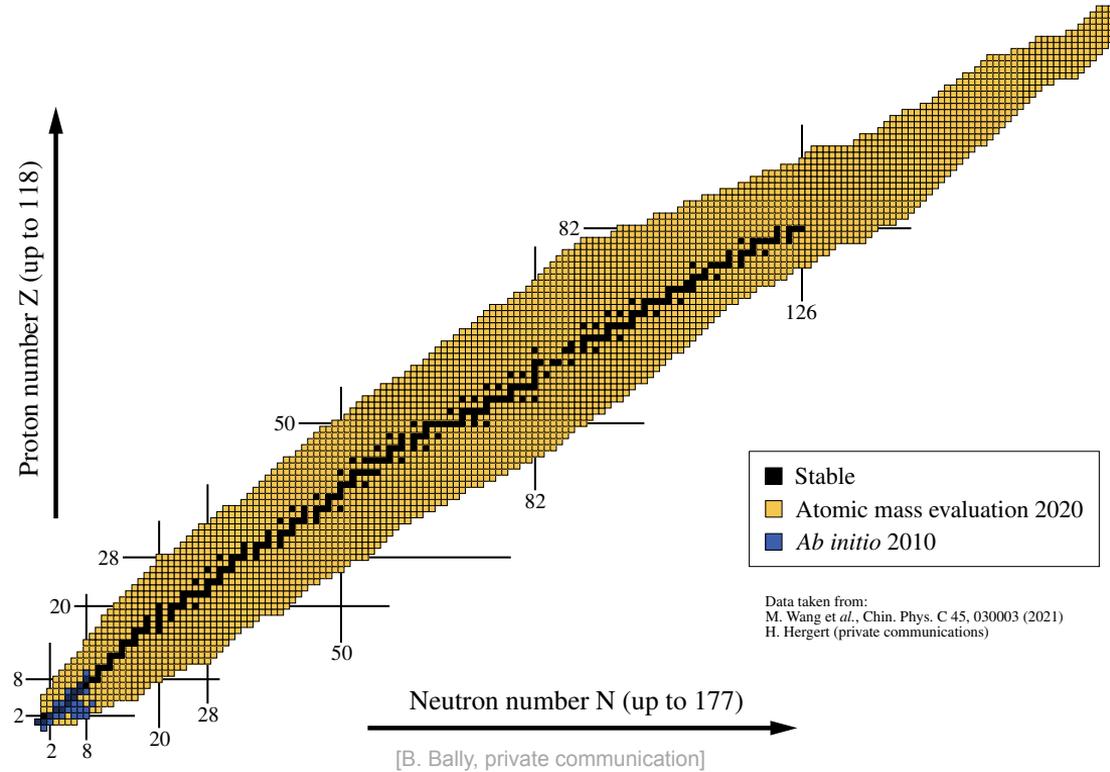
- Consistent
- Systematic
- Accurate enough
- From inter-nucleon interaction
- Rooted in quantum chromodynamics

# The progress of *ab initio* methods



« Exact » methods (80's)

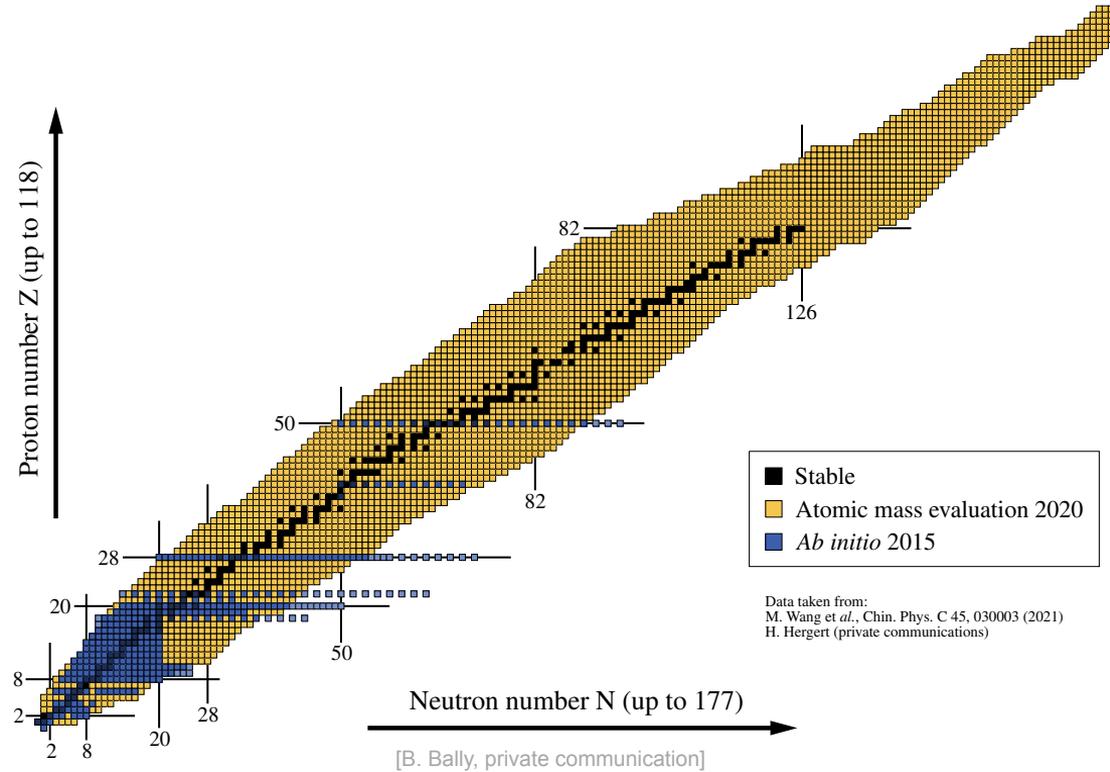
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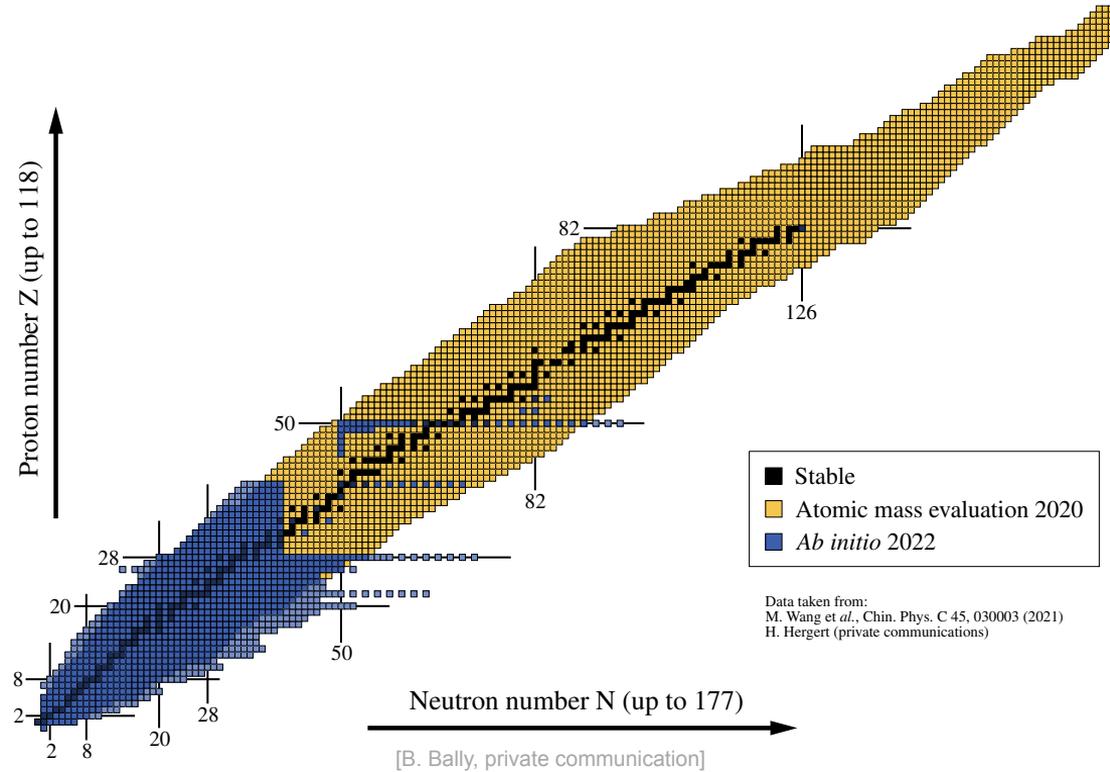
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Closed-shell methods (00's)

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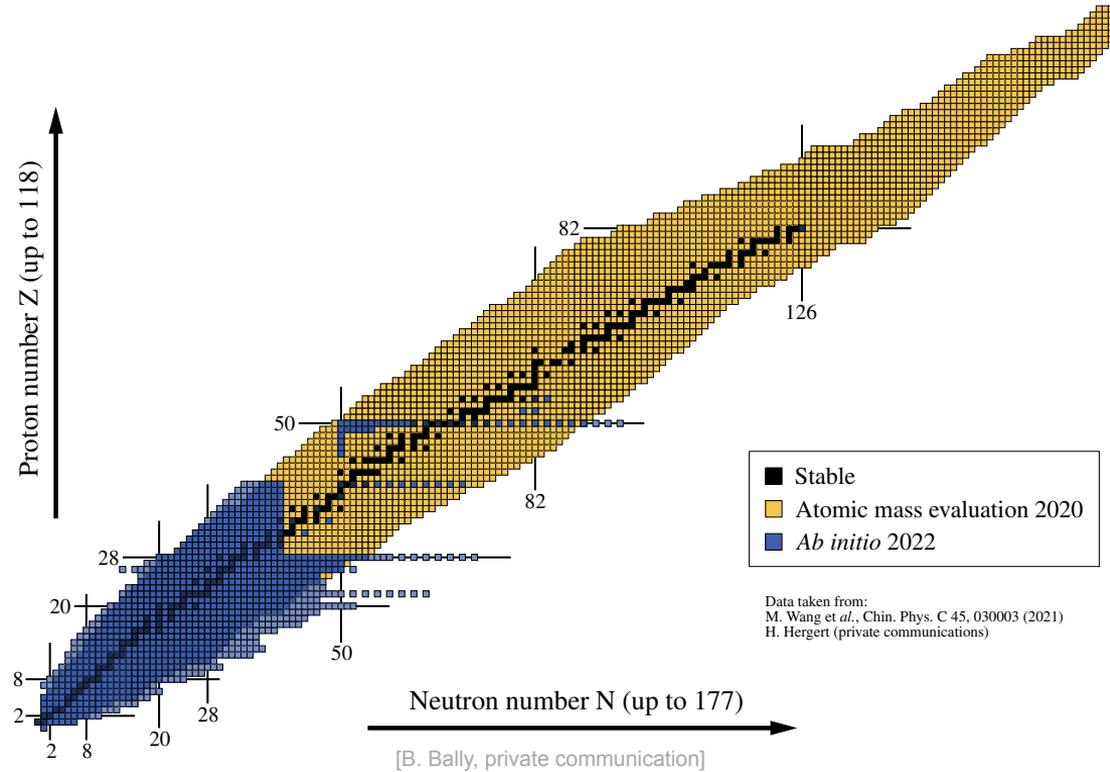
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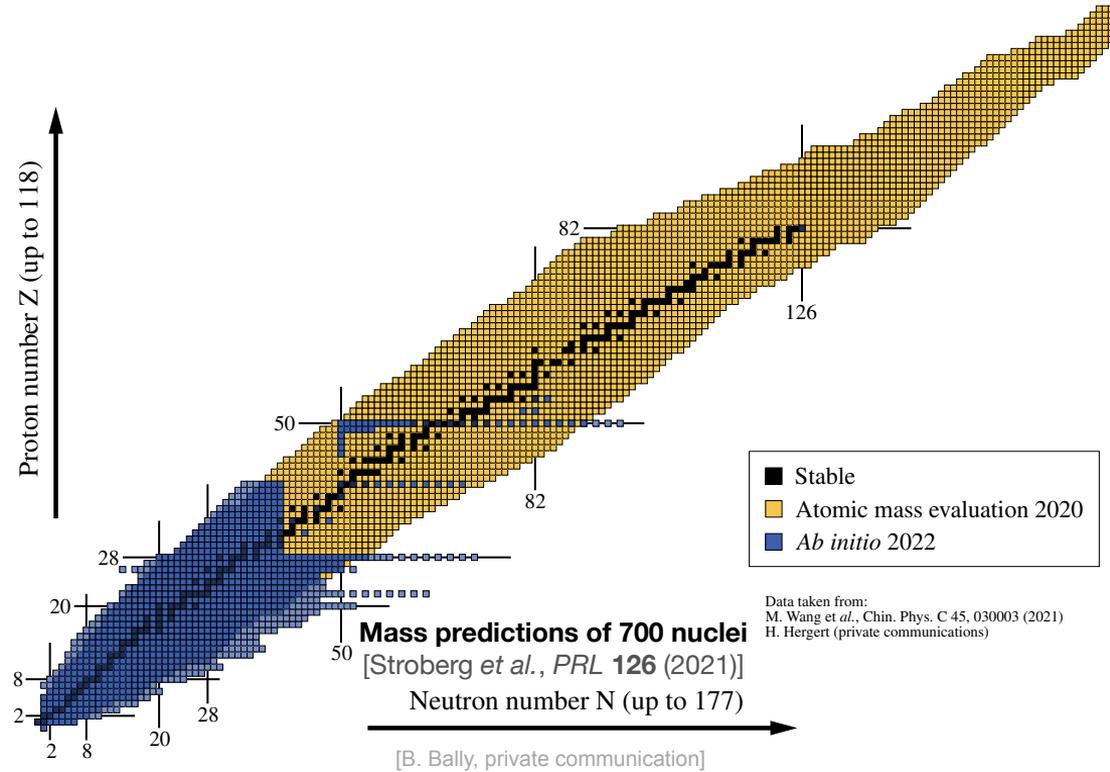
Open-shell methods (10's)

*Ab initio* shell model (2014)

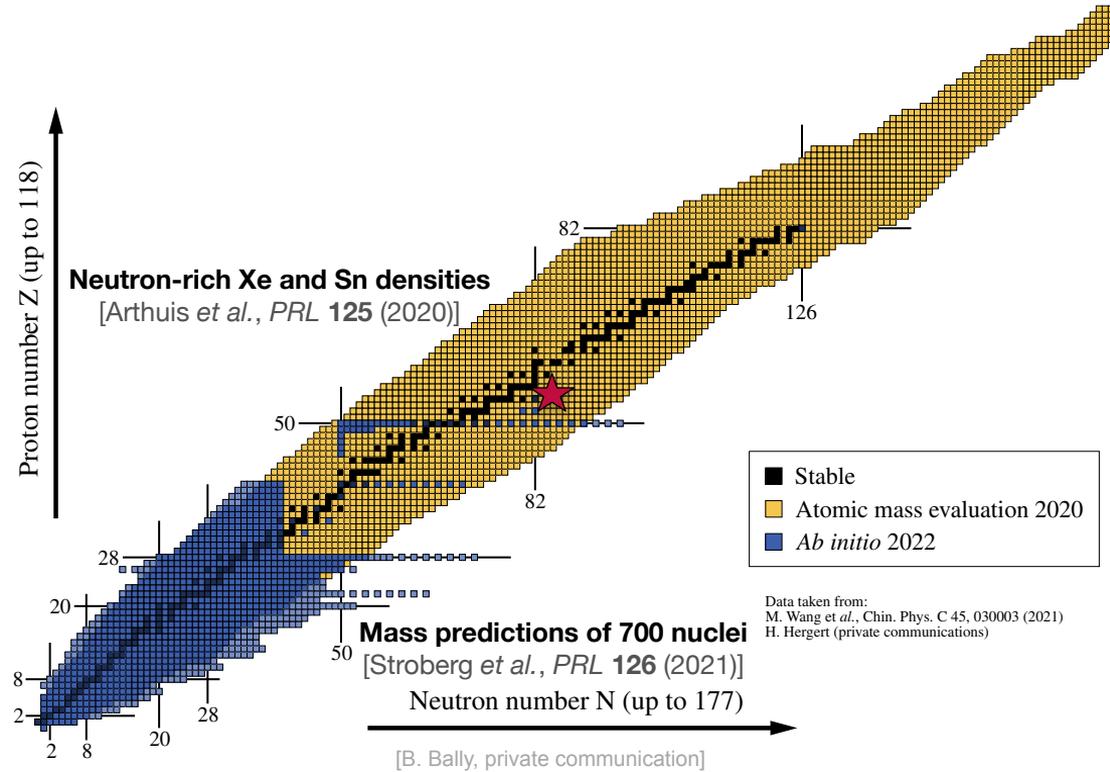
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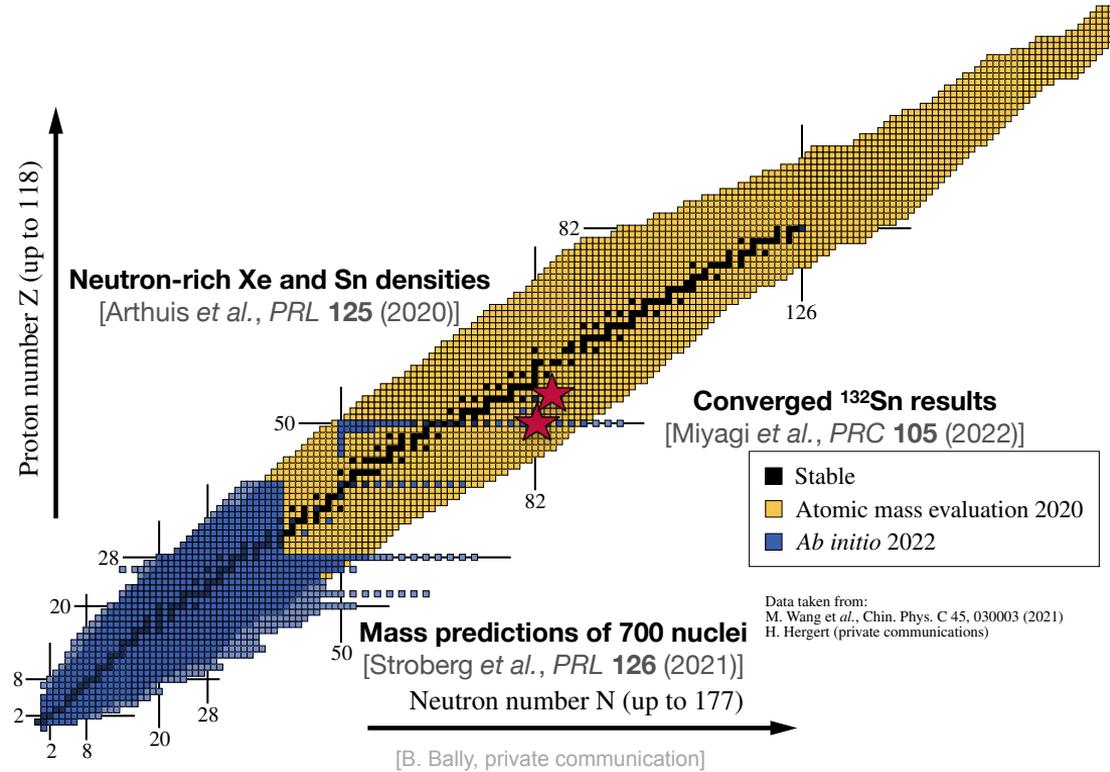
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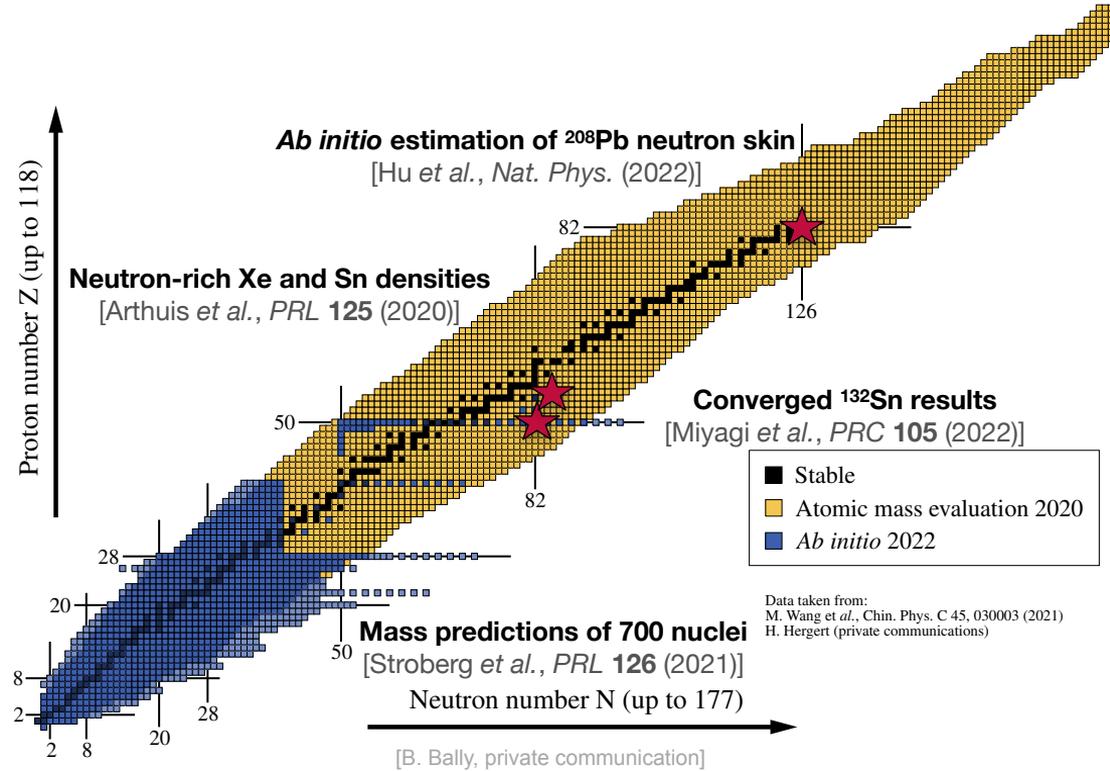
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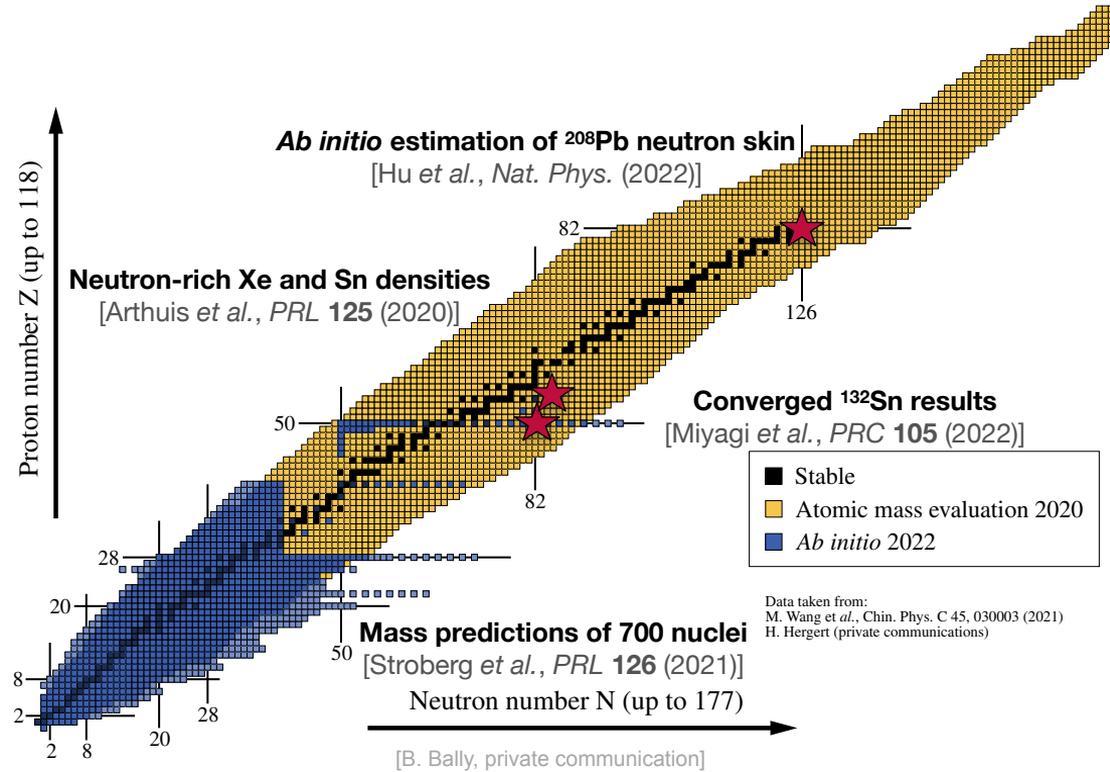
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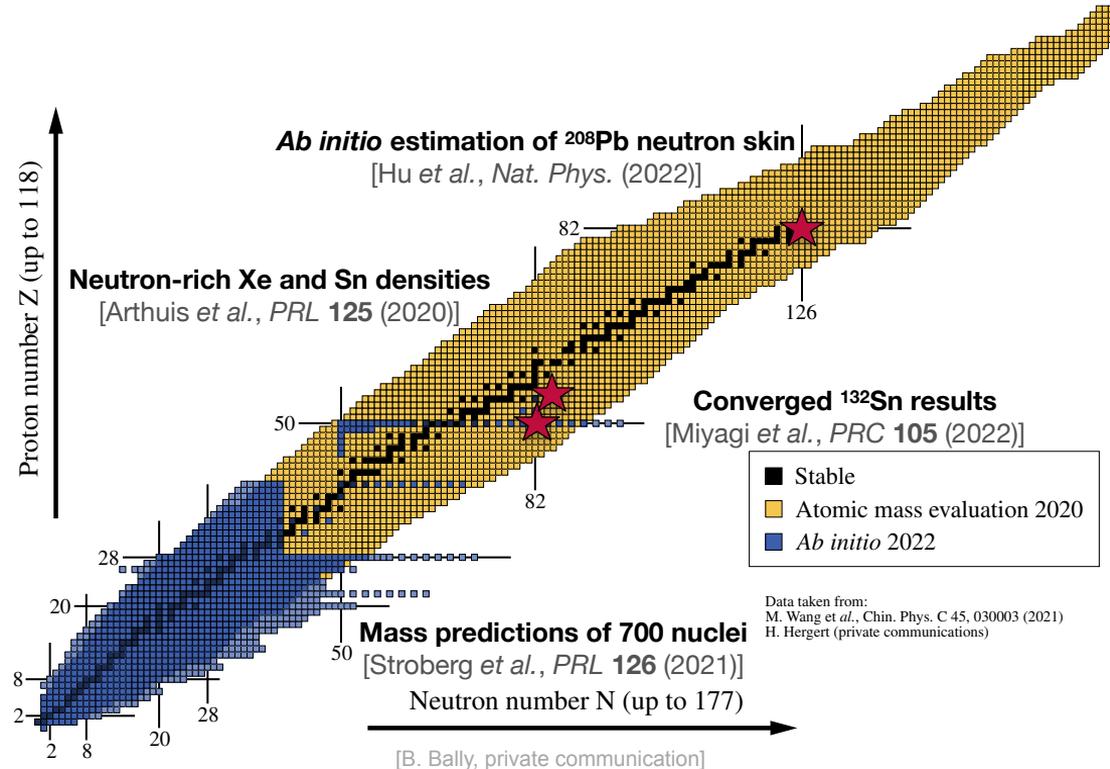


## Expansion methods

$$H|\Psi\rangle = U(\infty)|\Phi\rangle$$
$$= (U_1 + U_2 + U_3 + \dots)|\Phi\rangle$$

- 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

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**Controlled expansion & uncertainty**  
**Polynomial cost**

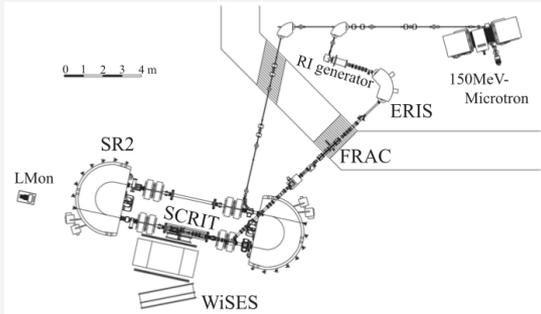
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# Applications to the heavy sector

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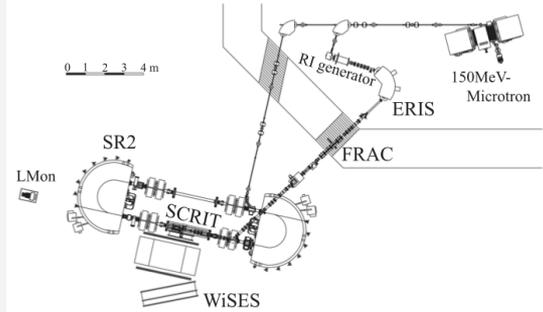
## Electron scattering off exotic nuclei



[Tsukada *et al.*, *PRL* 118 (2017)]

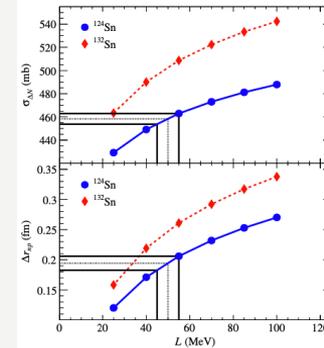
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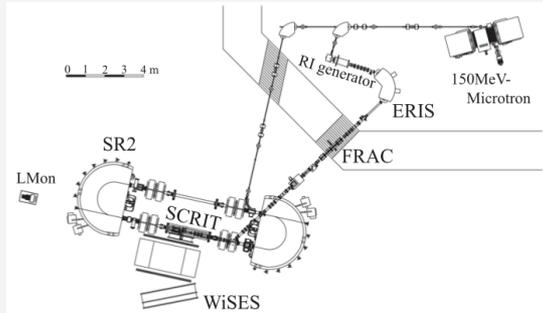
## Neutron removal cross-sections



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

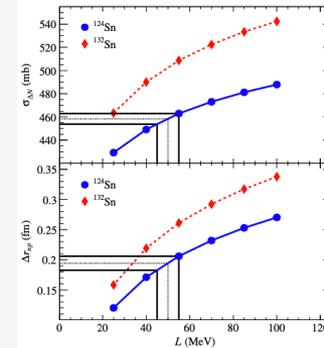
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## Our setup

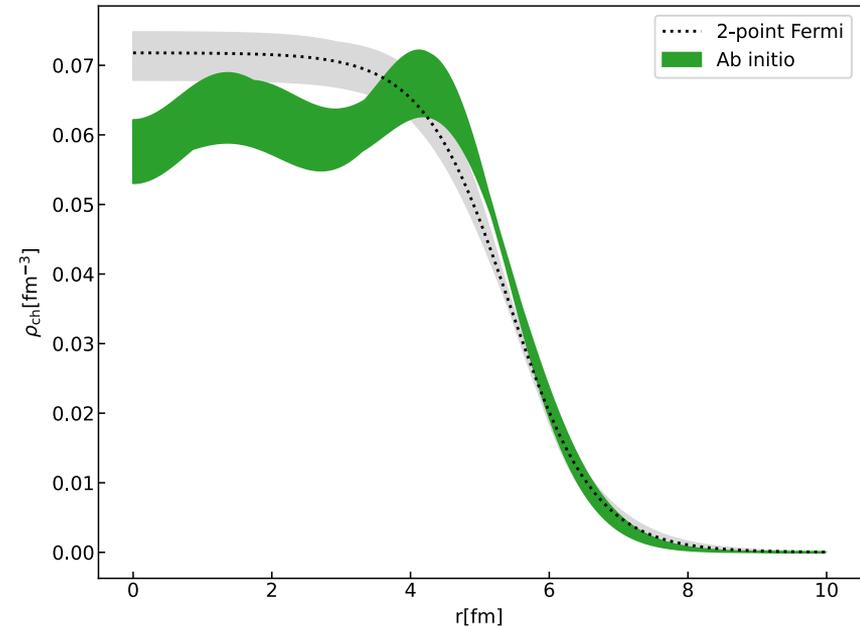
- Dyson/Gorkov Self-Consistent Green's Functions
- NNLOsat / NN+3N(Inl) interactions

# Charge density distributions

[Arthuis, Barbieri, Vorabbi, Finelli, *PRL* 125 (2020)]

## $^{132}\text{Xe}$ charge density distribution with NNLOsat

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



# Charge density distributions

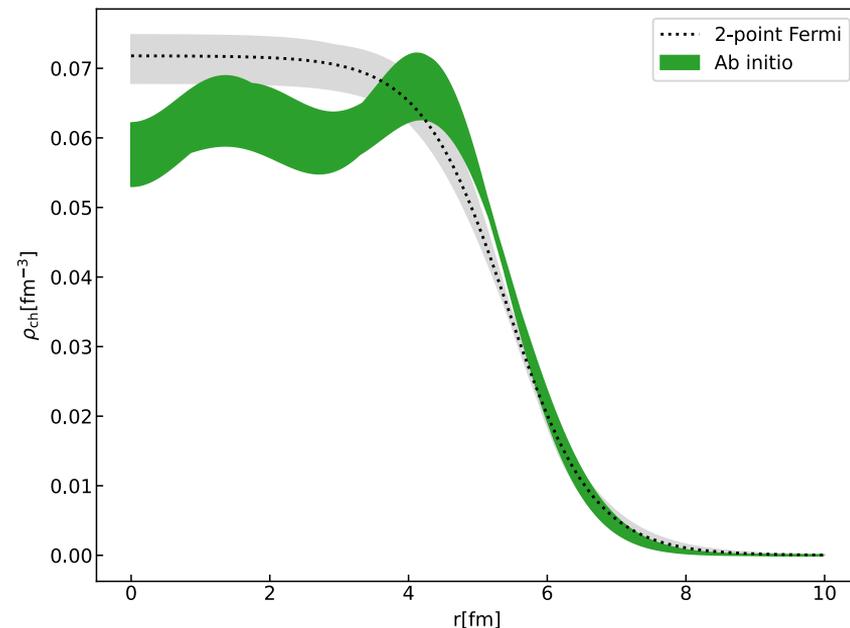
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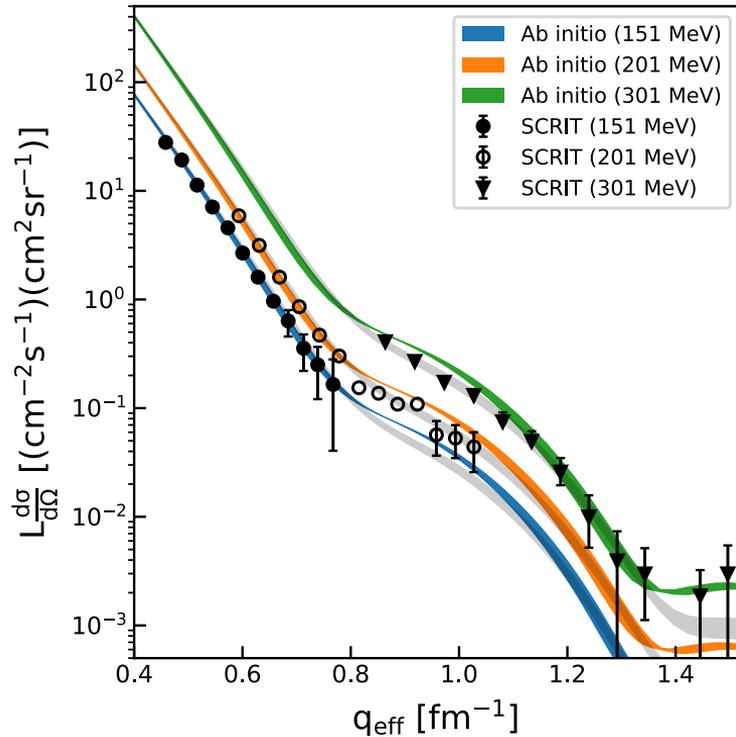
## Uncertainty band

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



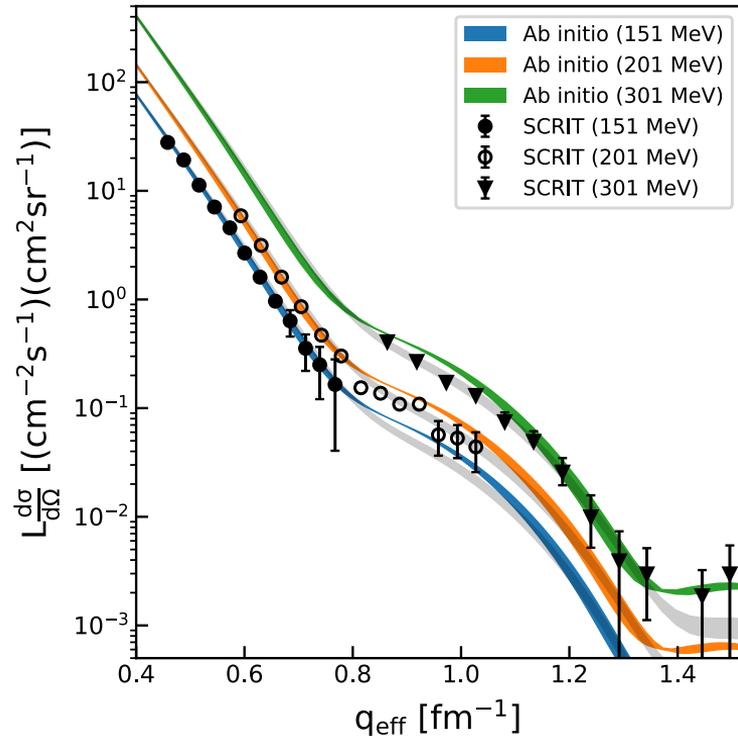
# Electron scattering on $^{132}\text{Xe}$ at SCRIT

[Arthuis, Barbieri, Vorabbi, Finelli, *PRL* **125** (2020)]



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**First *ab initio* calculation past the Sn isotopic line**

- Reproduce experimental electron scattering results
- Results meaningful for exp. despite moderate convergence

# Charge radii and neutron skins

[Arthuis, Barbieri, Vorabbi, Finelli, *PRL* **125** (2020)]

r [fm]	NNLOsat	SCRIT [1]	Exp [2]
<sup>100</sup> Sn	4.525 – 4.707		
<sup>132</sup> Sn	4.725 – 4.956		4.7093
<sup>132</sup> Xe	4.700 – 4.948	4.69 – 4.91	4.7859
<sup>136</sup> Xe	4.715 – 4.928		4.7964
<sup>138</sup> Xe	4.724 – 4.941		4.8279

[1] Tsukada et al., *PRL* **118** (2017)

[2] Angeli & Marinova, *ADNDT* **99** (2013)

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## Computation of charge radii

- Good reproduction of experimental values with NNLOsat
- NN+3N(Inf) systematically underpredicts radii (not shown)
- First prediction of <sup>100</sup>Sn radius

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## Computation of charge radii

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## First *ab initio* estimation of neutron skins for Sn and Xe

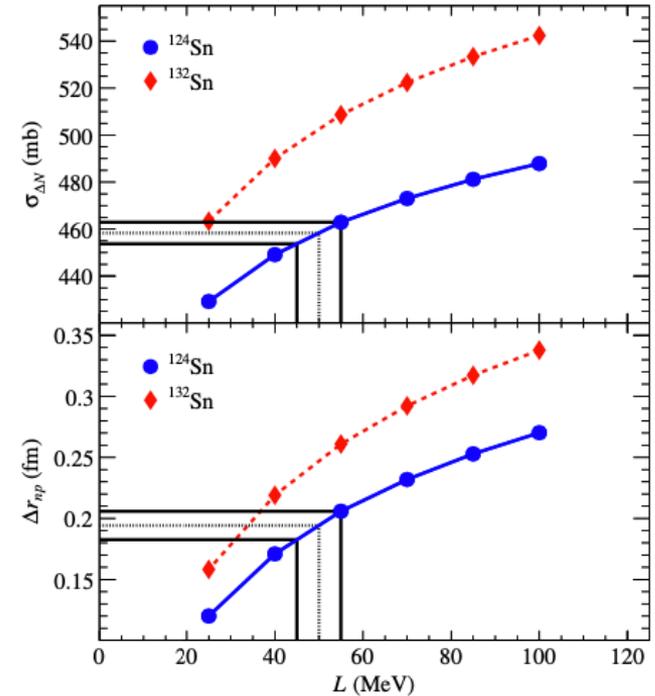
- Compatible within the error bars
- NNLOsat smaller: Known symmetry energy issue
- NN+3N(Inl) more reasonable, but underpredicts charge radius

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

# Neutron radius and neutron skin in the Sn region

## Why investigate such systems and observables

- Slope parameter  $L$  accessible through neutron removal
- Need for neutron density distributions
- $L$  correlated to neutron skin as well



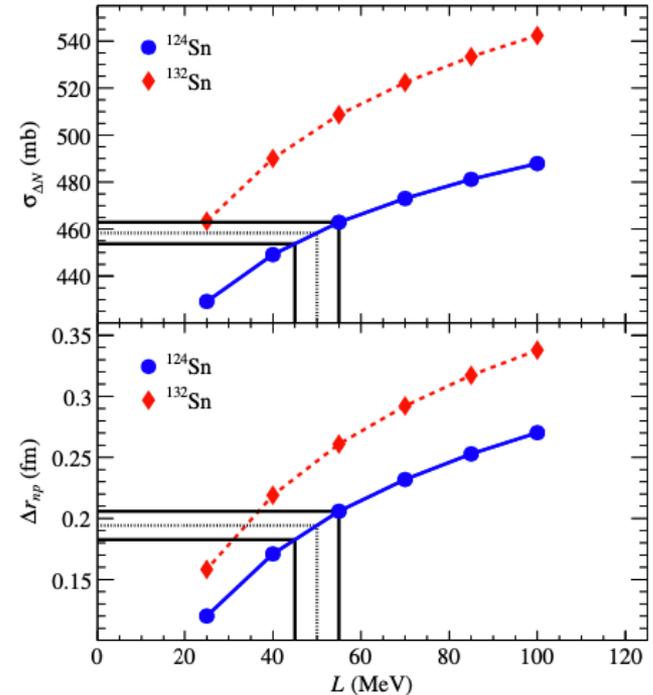
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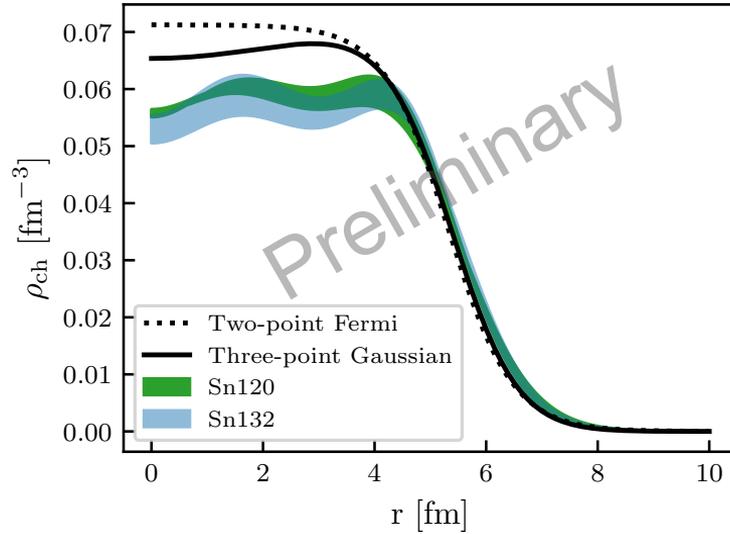
Start by revisiting  $^{132}\text{Sn}$  and explore  $^{120}\text{Sn}$



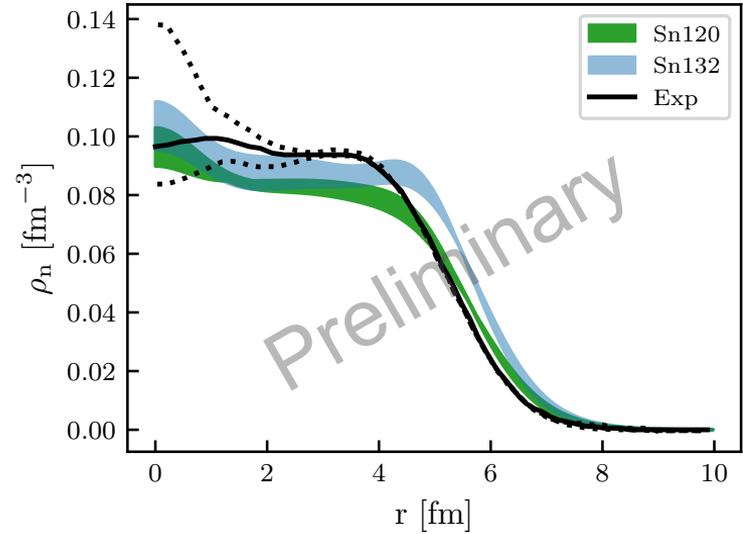
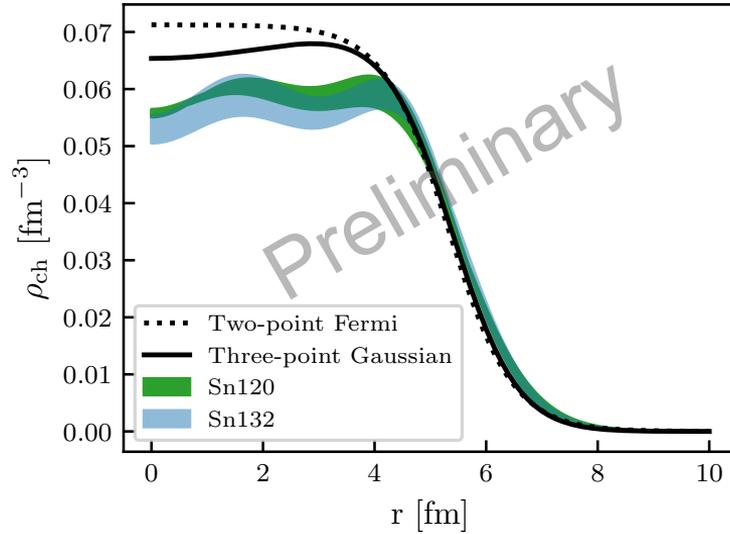
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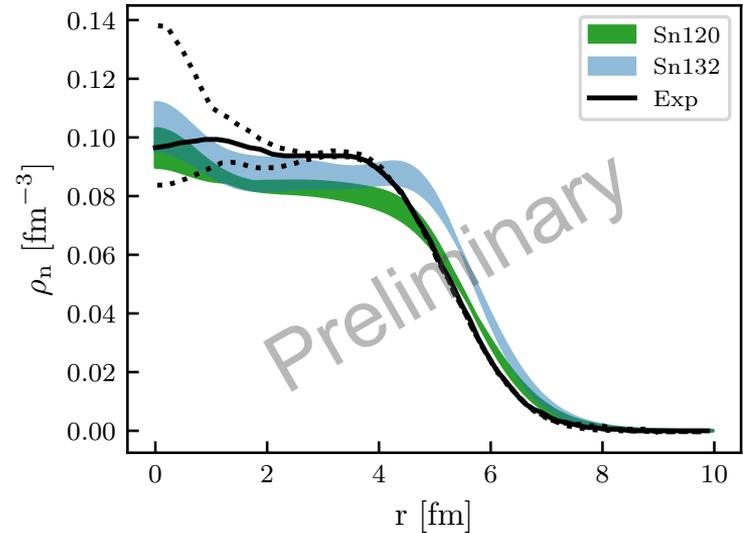
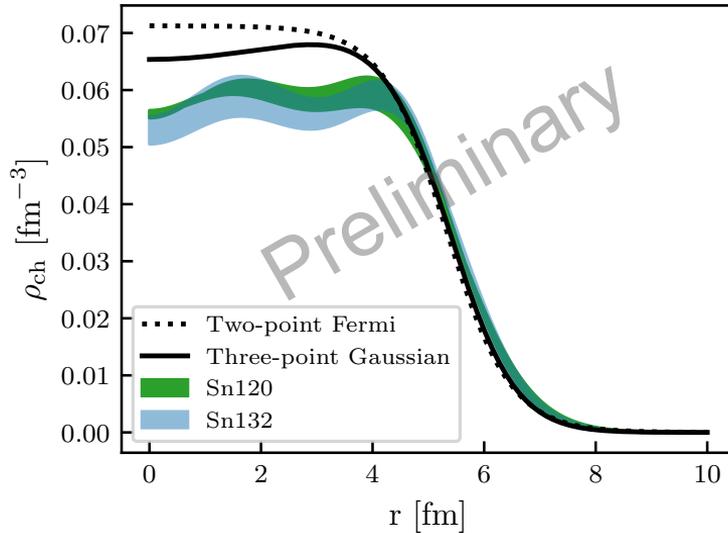


# Charge and neutron density distributions for $^{120}\text{Sn}$



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

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## Results consistent with previous systems

- Reasonable picture, similar to  $^{132}\text{Sn}$
- Slightly too large charge radius, underpredicted internal densities

# Revisiting charge radii and neutron skins

[fm]	NNLOsat	Exp [1]
$^{100}\text{Sn}$	4.525 – 4.707	
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## New results for $^{120}\text{Sn}$

- Slightly overestimated charge radius
- Neutron skin probably underpredicted, from previous experience

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- New formal developments, better interactions, numerical progress
- Results spanning up to  $^{208}\text{Pb}$

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## Increasing relevance for heavy-mass experiments

- Radii and densities for exotic nuclei
- Access to neutron skin and the symmetry energy

# Thank your for your attention!



TECHNISCHE  
UNIVERSITÄT  
DARMSTADT

## **STRONGINT group**

K. Hebeler, M. Heinz, J. Hoppe, T. Miyagi,  
A. Schwenk, A. Tichai, L. Zurek



UNIVERSITÀ  
DEGLI STUDI  
DI MILANO



C. Barbieri



P. Finelli



M. Vorabbi