Challenges in nuclear structure theory

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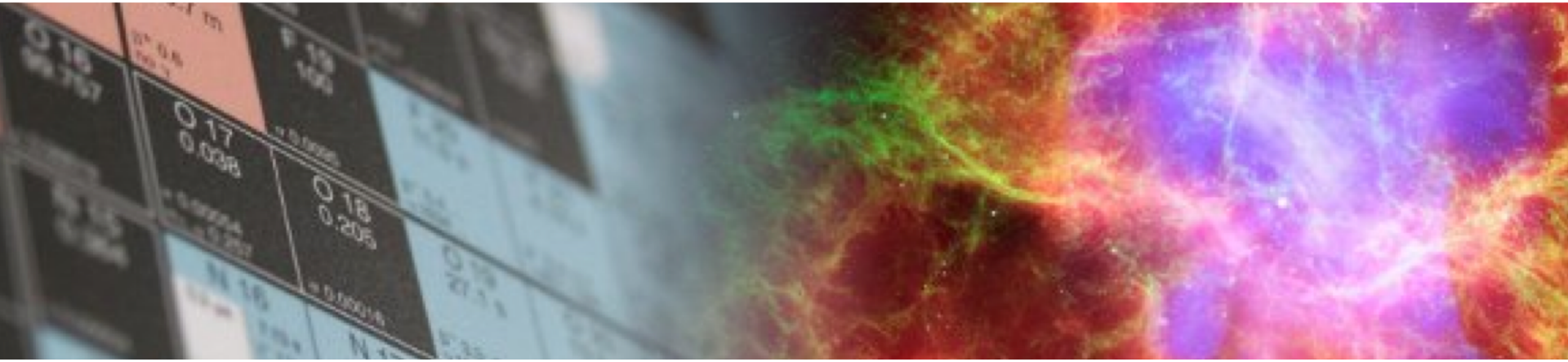

FRIB TA Nuclear Physics Dialogues, Aug. 25, 2020

DFG SFB 1245 erc

Bundesministerium für Bildung und Forschung

HELMHOLTZ ASSOCIATION

Dialogue Topics

Interaction challenges

Ab initio challenges

Tower of EFTs and matching

Consistent electroweak interactions

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Interaction challenges

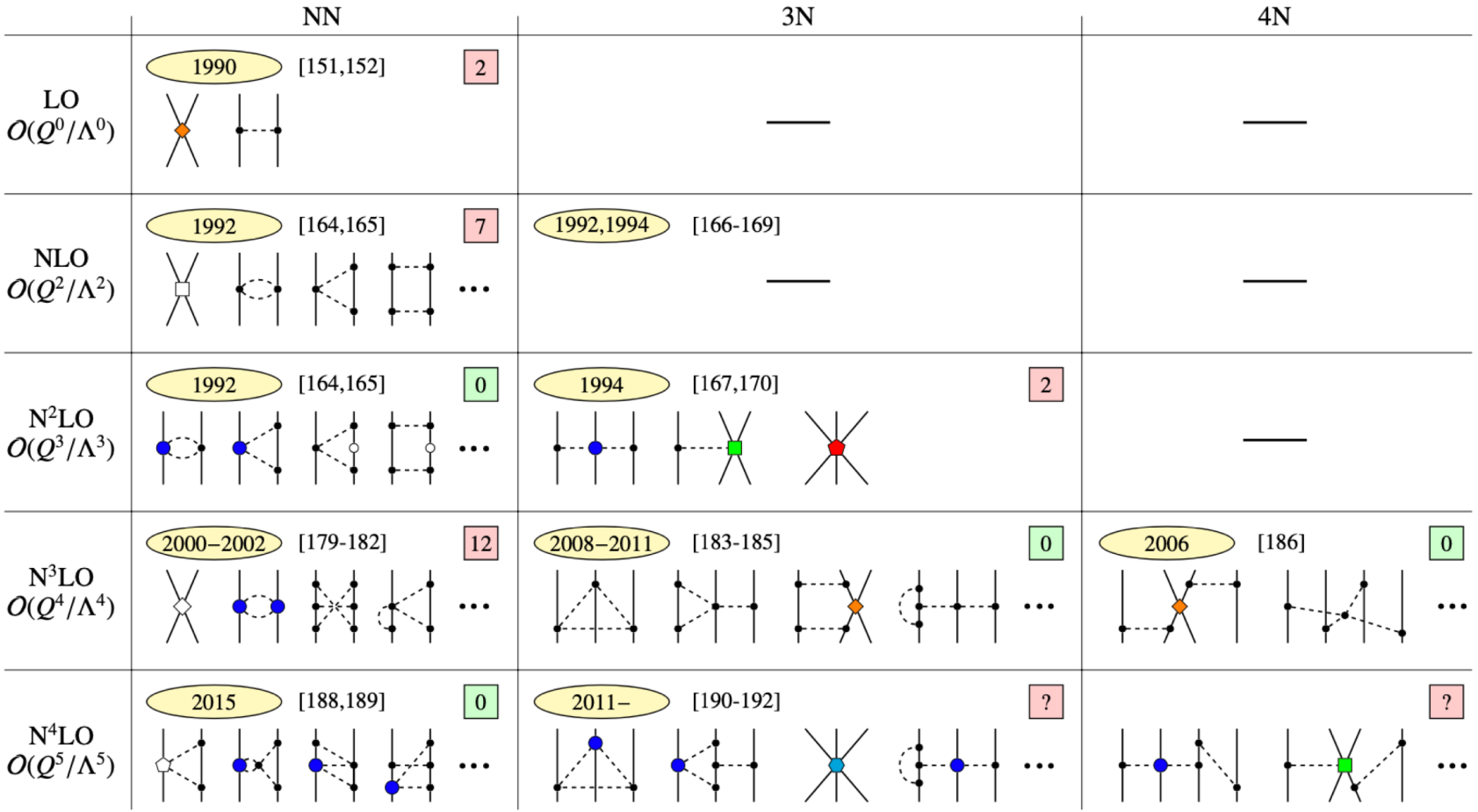
Ab initio challenges

Tower of EFTs and matching

Consistent electroweak interactions

Chiral EFTs

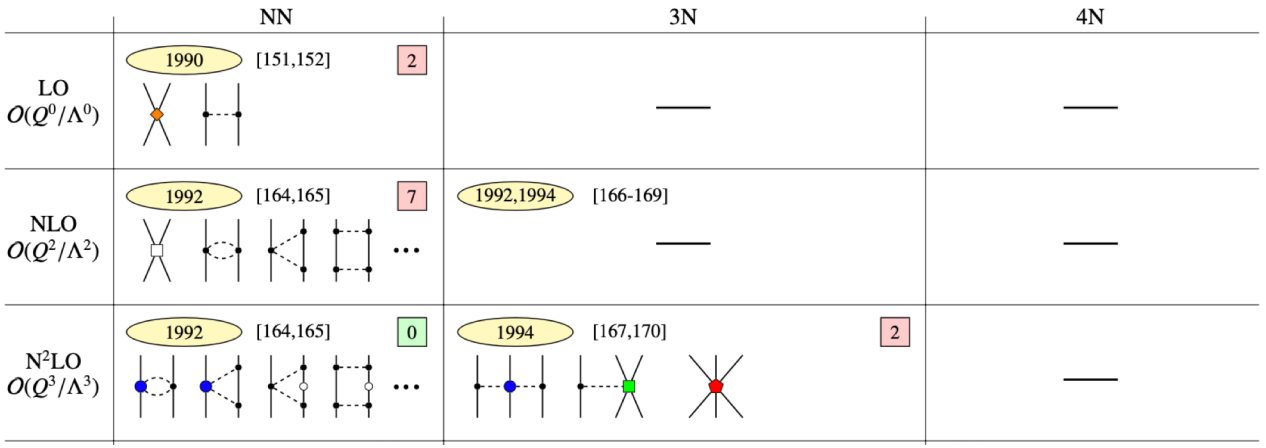
Chiral EFT with Weinberg counting



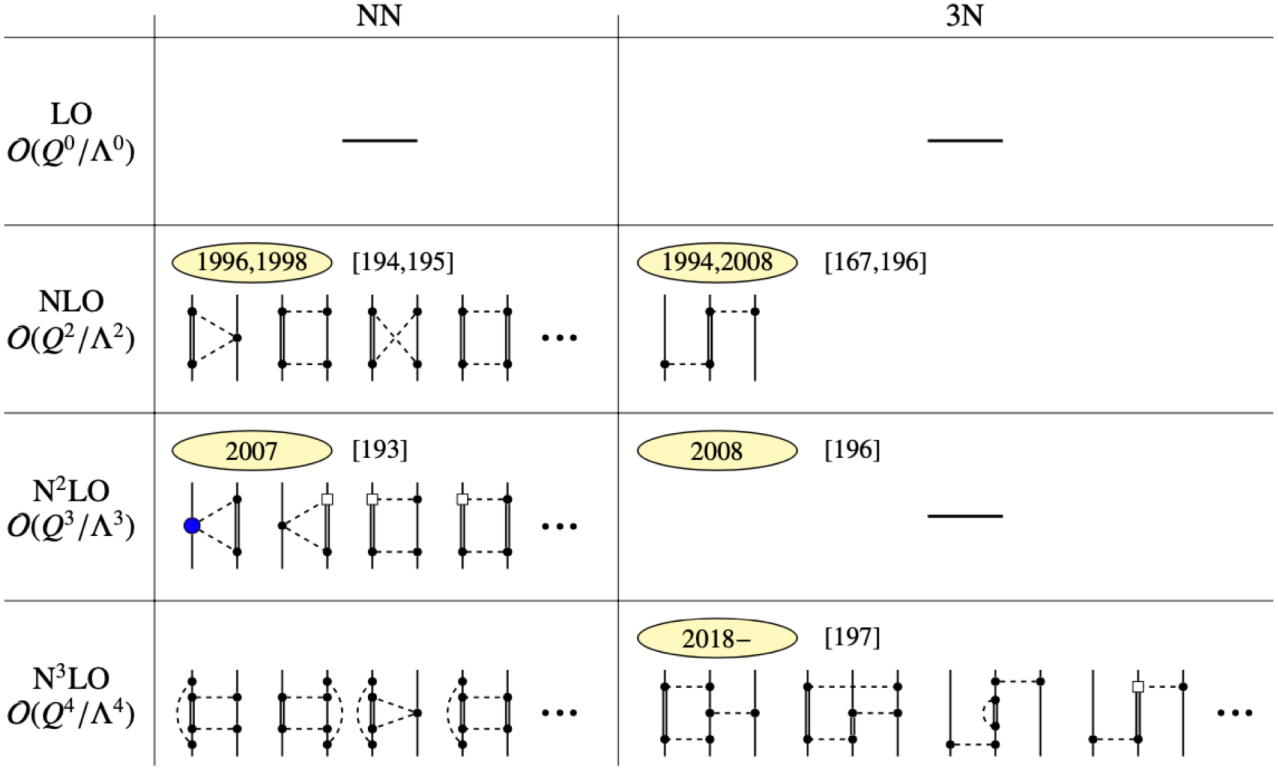
figures from Hebeler

Chiral EFTs

Chiral EFT with Weinberg counting



with explicit Deltas



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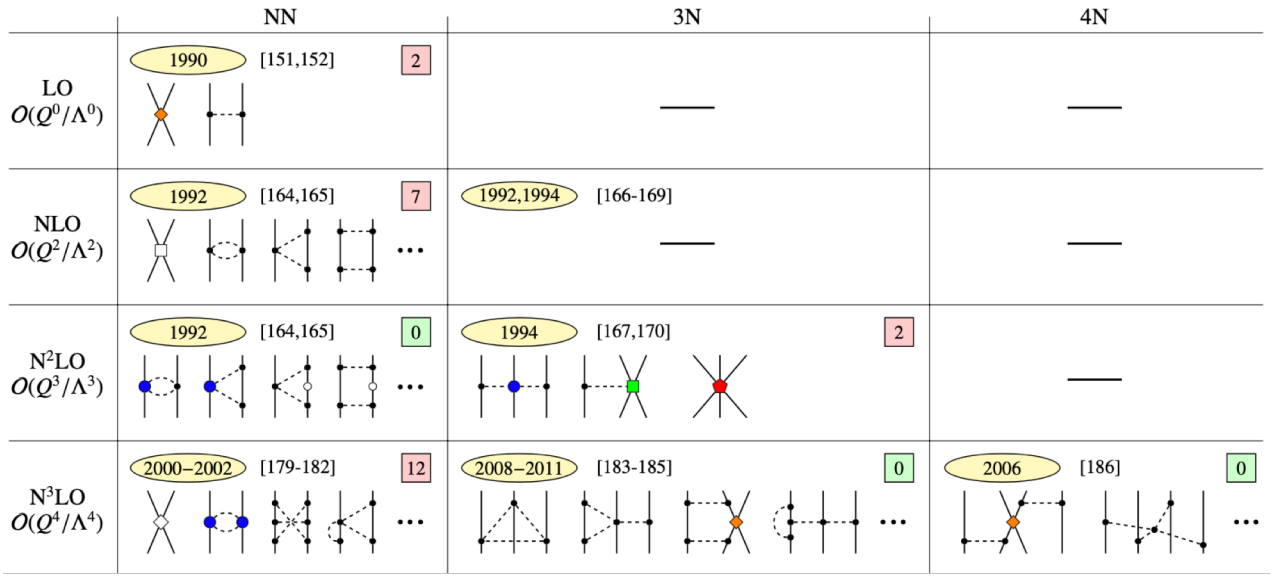
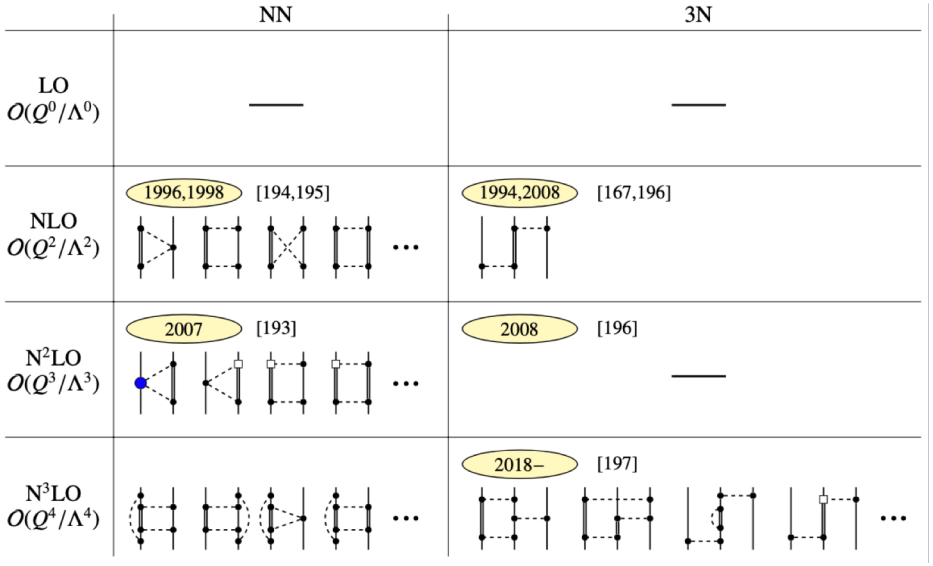
Chiral EFTs

Chiral EFT with Weinberg counting



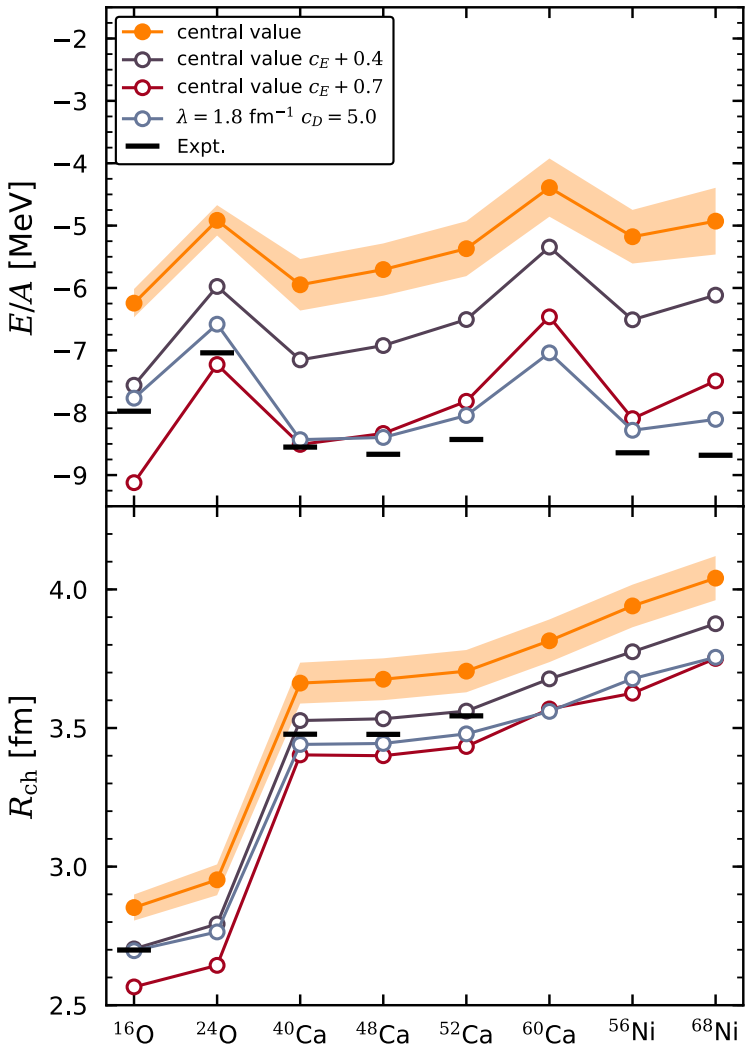
with explicit Deltas



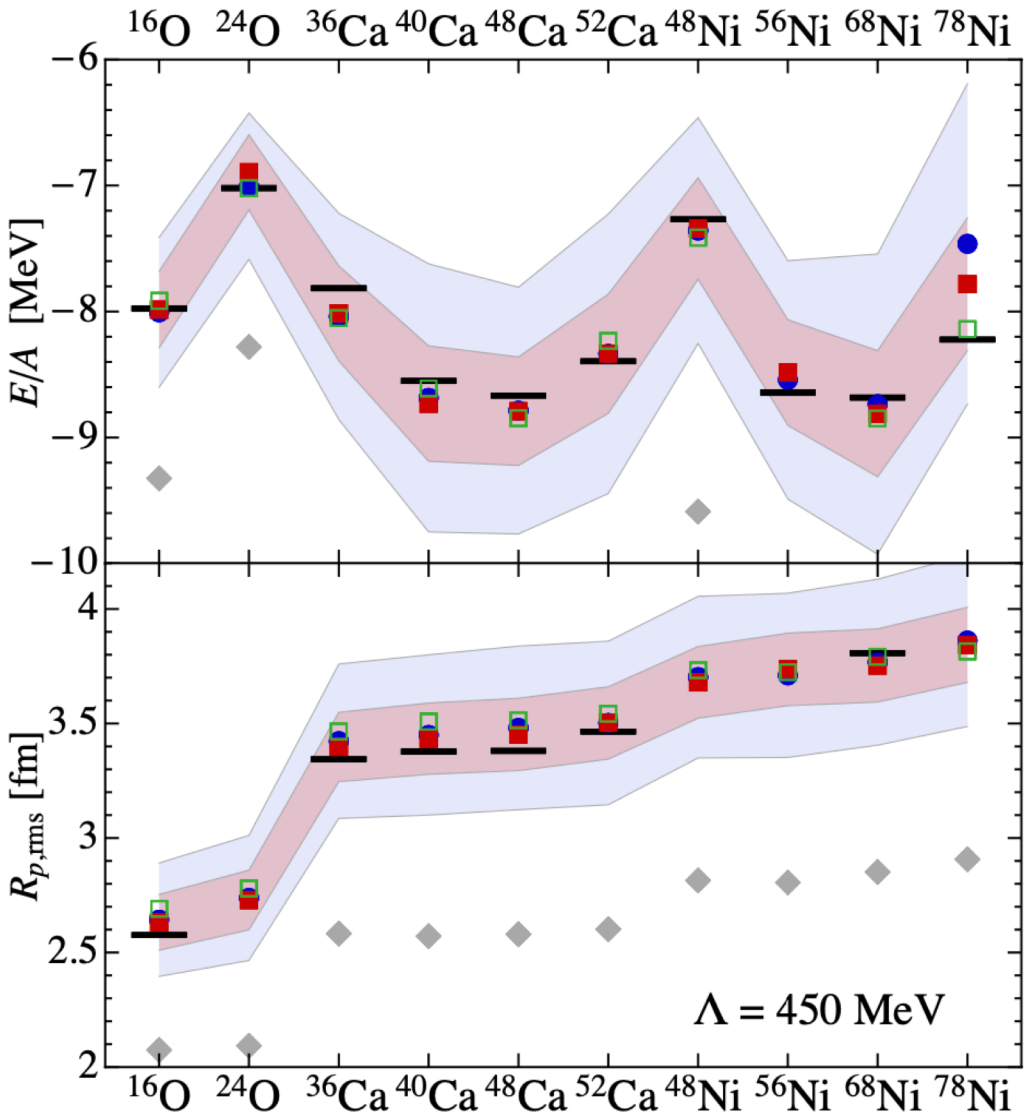
Power counting with RG invariance and improved LO starting point

Chiral EFTs

Chiral EFT with
Weinberg counting



Hoppe et al. (2019)

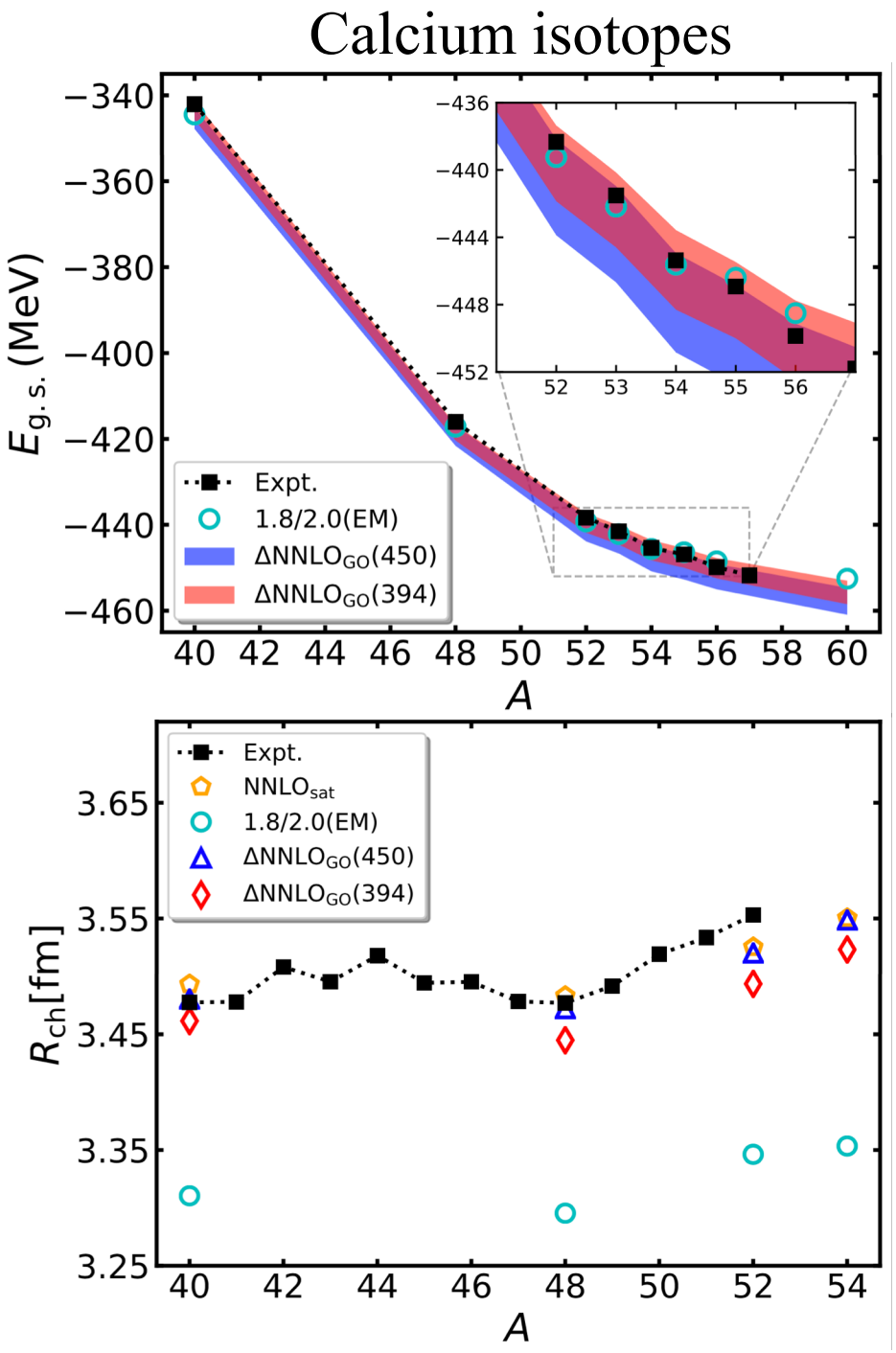


Hüther et al. (2020)

Chiral EFTs

Chiral EFT with Weinberg counting

with explicit Deltas

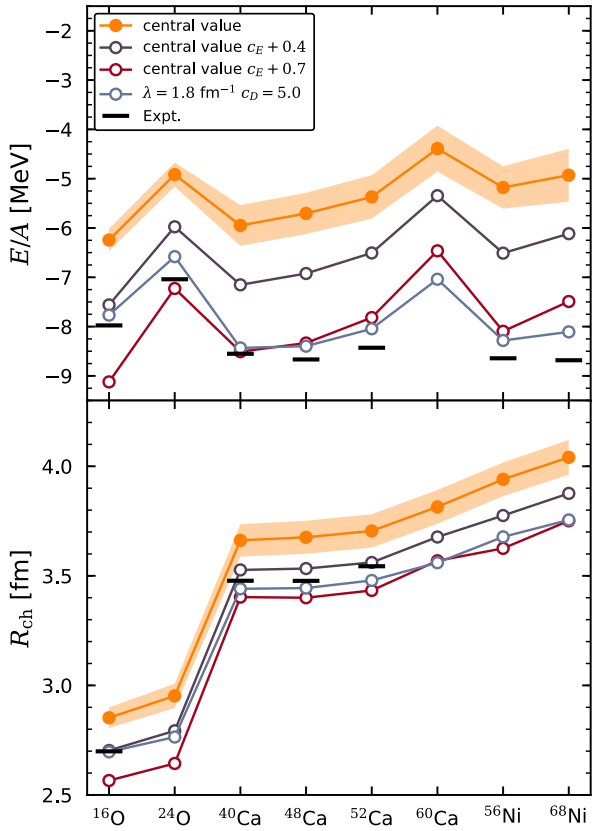


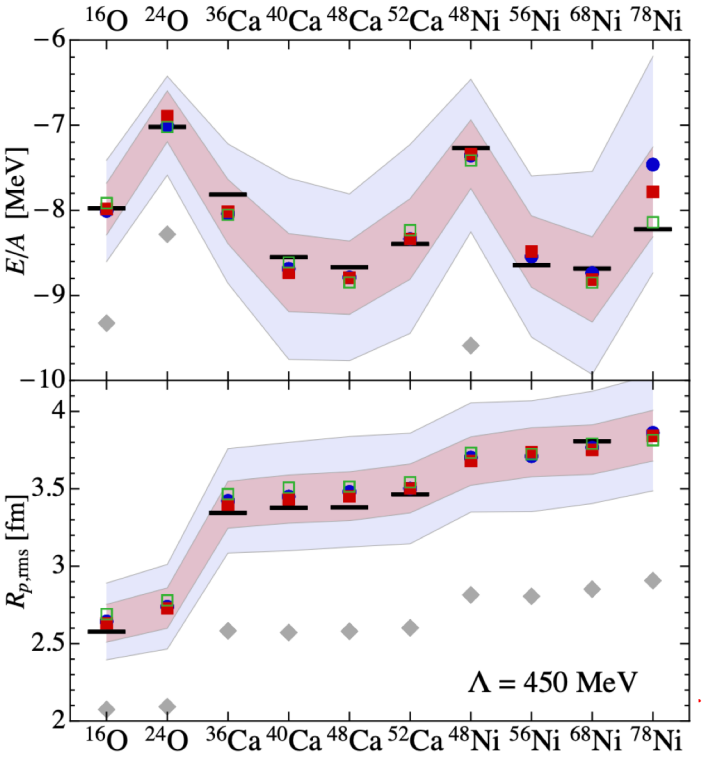
Jiang et al. (2020)

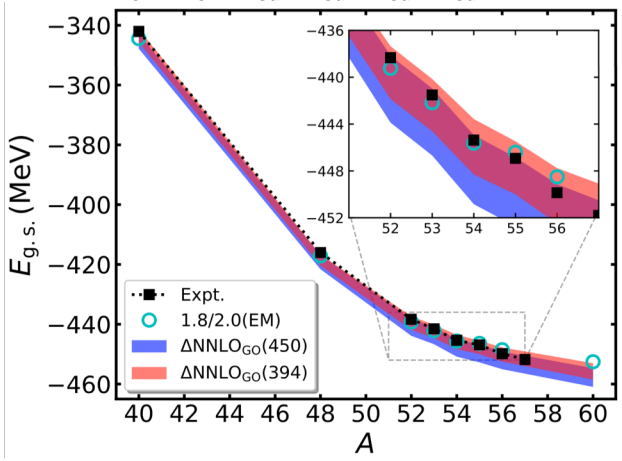
Chiral EFTs

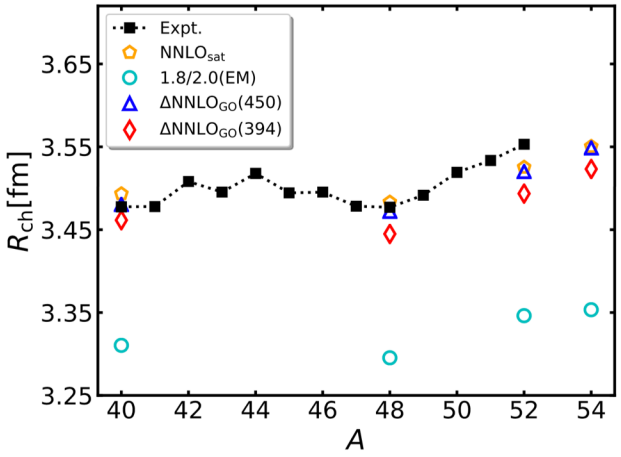
Chiral EFT with Weinberg counting

with explicit Deltas









Power counting with RG invariance and improved LO starting point

Dialogue Topics

Interaction challenges

Which EFT is most effective for medium-mass and heavy nuclei?

Which parts of nuclear forces are most relevant?
How can we better understand/constrain these?

What should be used to constrain the low-energy couplings?
How far can we get with EFTs constrained in few-body systems?

What is the status of EFT uncertainty estimates for nuclei?
What accuracy can we expect?

Dialogue Topics

Interaction challenges

Ab initio challenges

ab initio = systematically improvable solution of the many-body Schrödinger equation (here based on NN+3N interactions)

Tower of EFTs and matching

Consistent electroweak interactions

Dramatic progress in ab initio calculations of nuclei

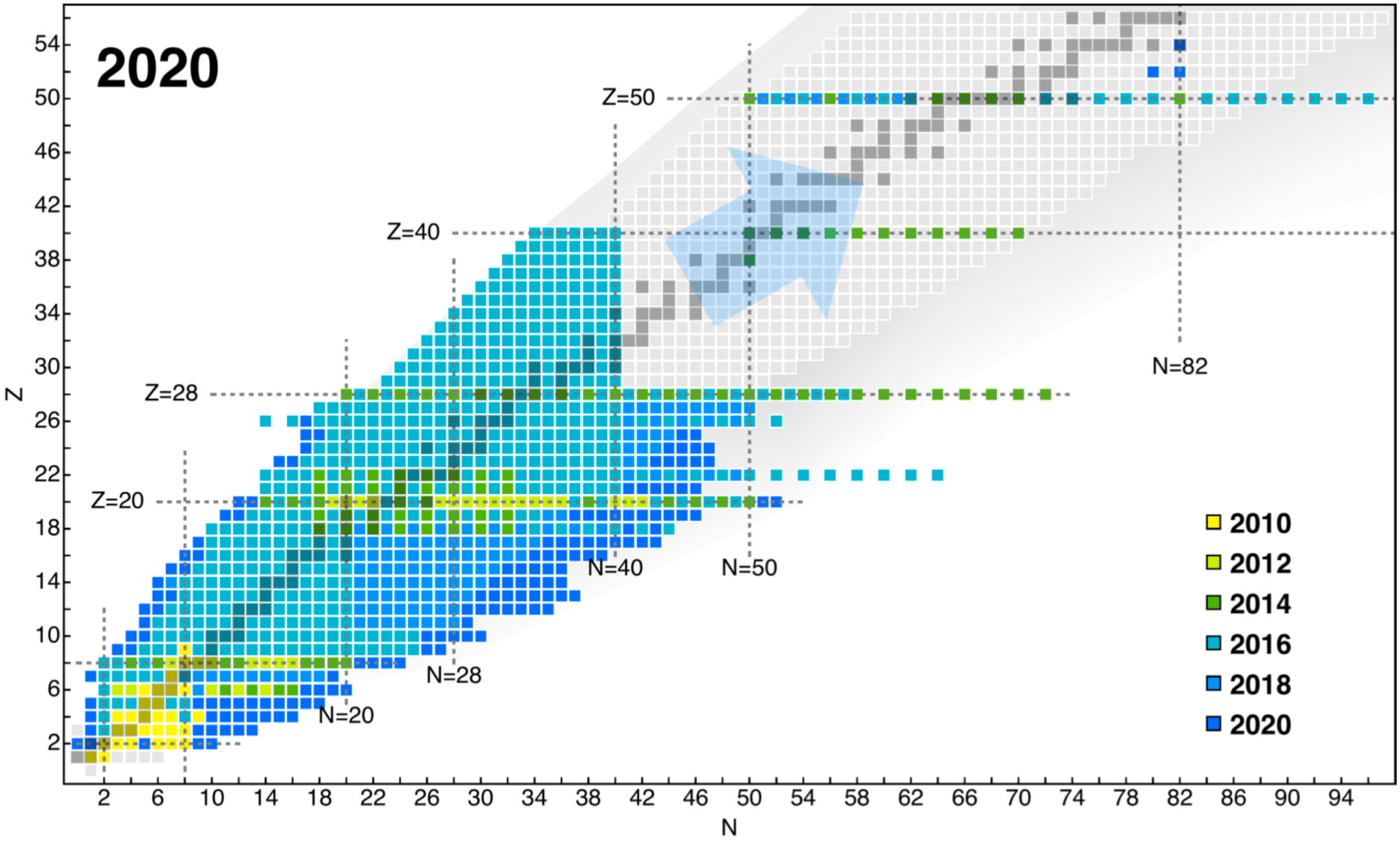
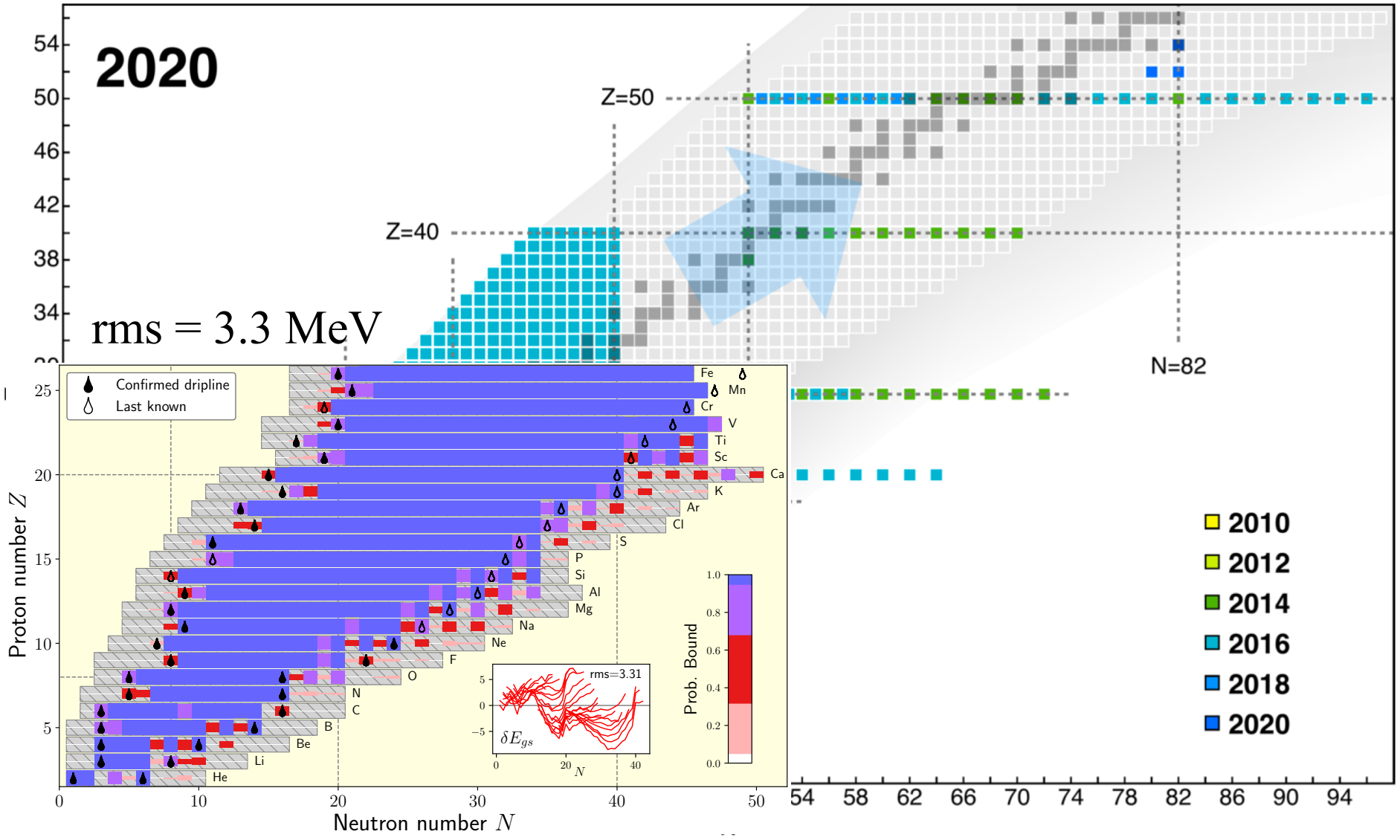


figure from Hergert

Dramatic progress in ab initio calculations of nuclei



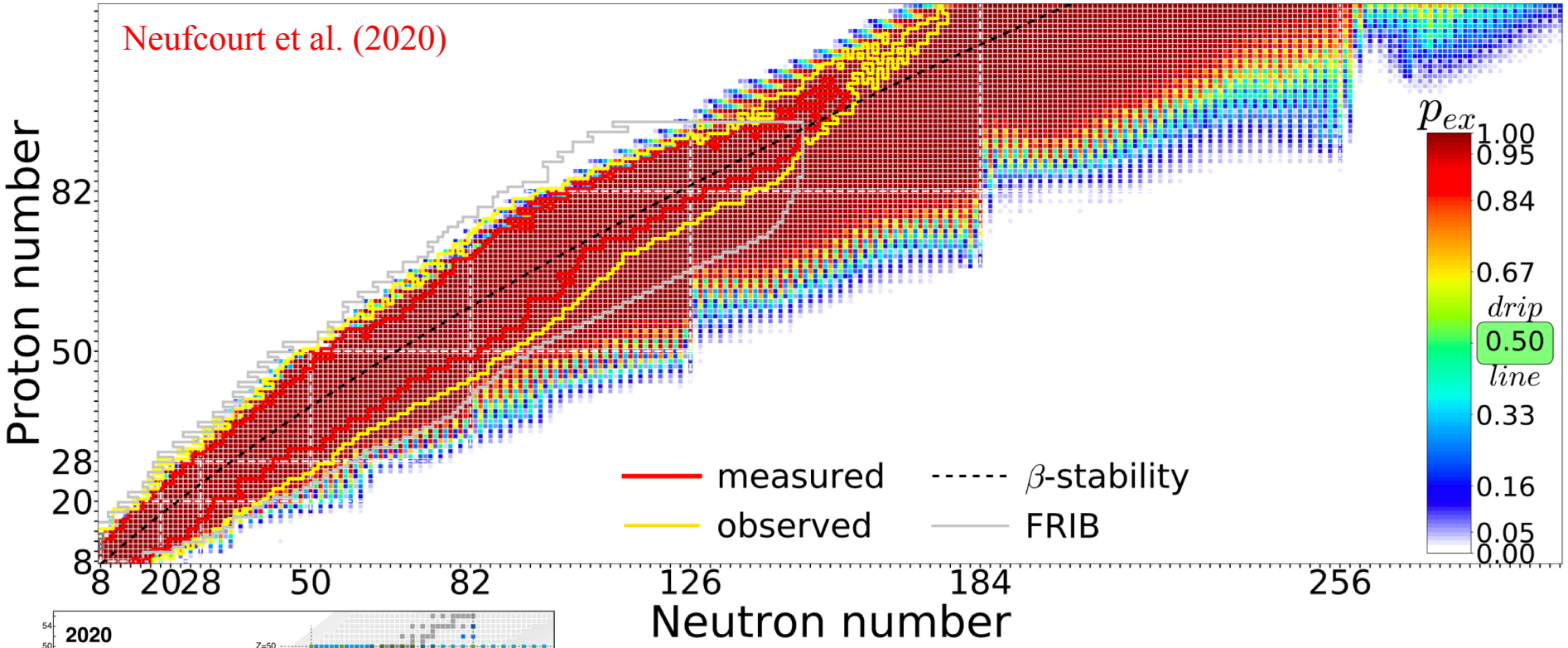
Stroberg et al. (2019/20)

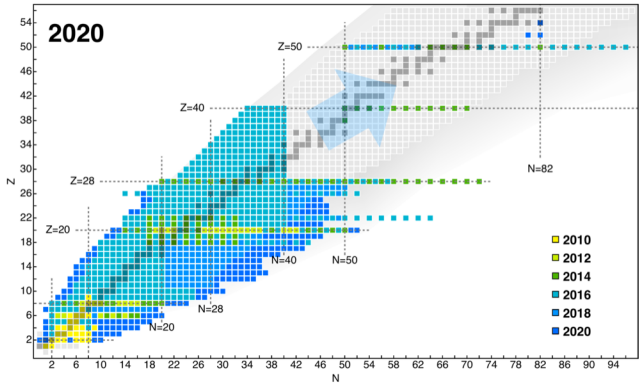
figure from Hergert

Dramatic progress in ab initio calculations of nuclei

Compare to energy-density functionals (EDFs)

Major challenges towards heavy nuclei; expected accuracy and goals?





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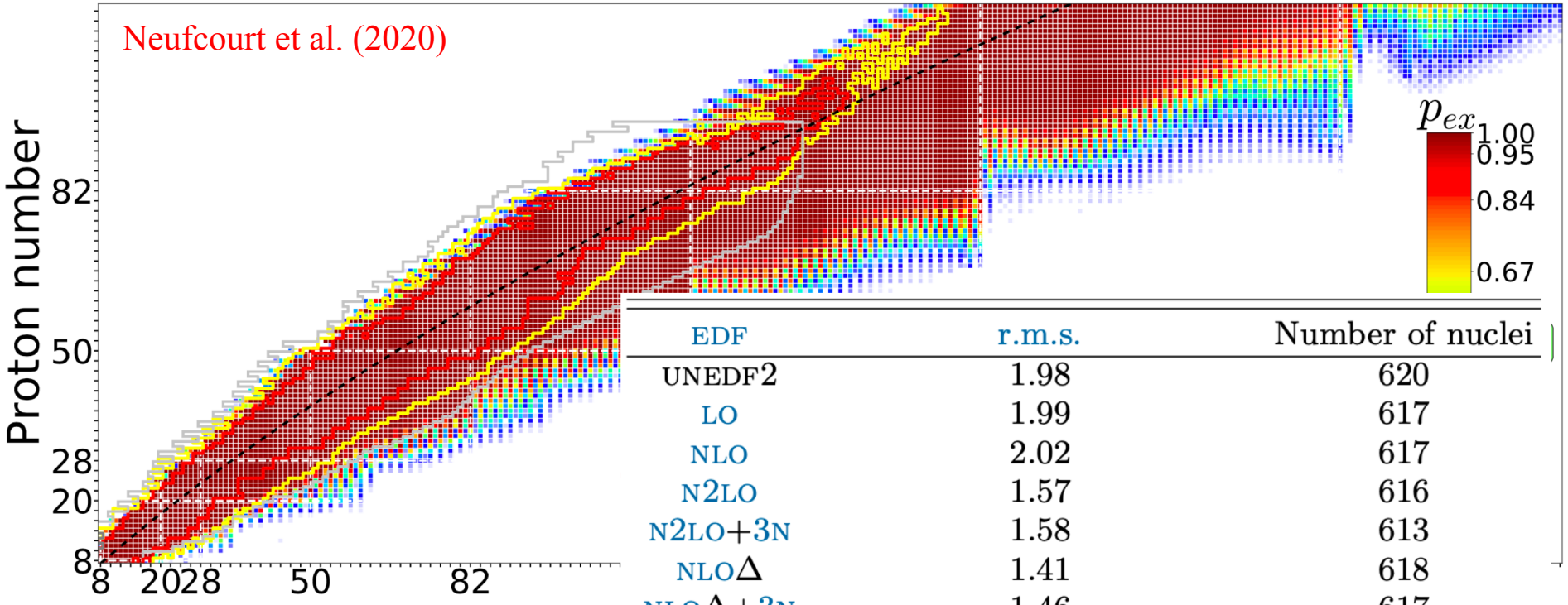
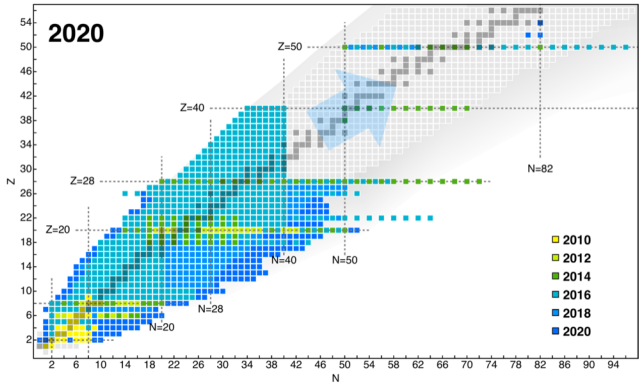


EDF	r.m.s.	Number of nuclei
UNEDF2	1.98	620
LO	1.99	617
NLO	2.02	617
N2LO	1.57	616
N2LO+3N	1.58	613
NLOΔ	1.41	618
NLOΔ+3N	1.46	617
N2LOΔ	1.26	615
N2LOΔ+3N	1.72	617



Navarro Pérez et al. (2018)

Lots of room for matching ab initio and EDFs

Dialogue Topics

Ab initio challenges

Where are the limits of ab initio theory? Both limits in many-body uncertainties and interaction uncertainties?

Does reaching heavy nuclei require fine-tuning of nuclear forces?

What are the largest challenges in ab initio theory?
What the largest deficiencies? What are future key experiments?

What are novel ideas that will revolutionize many-body theory like the past EFT and ab initio developments?

Dialogue Topics

Interaction challenges

Ab initio challenges

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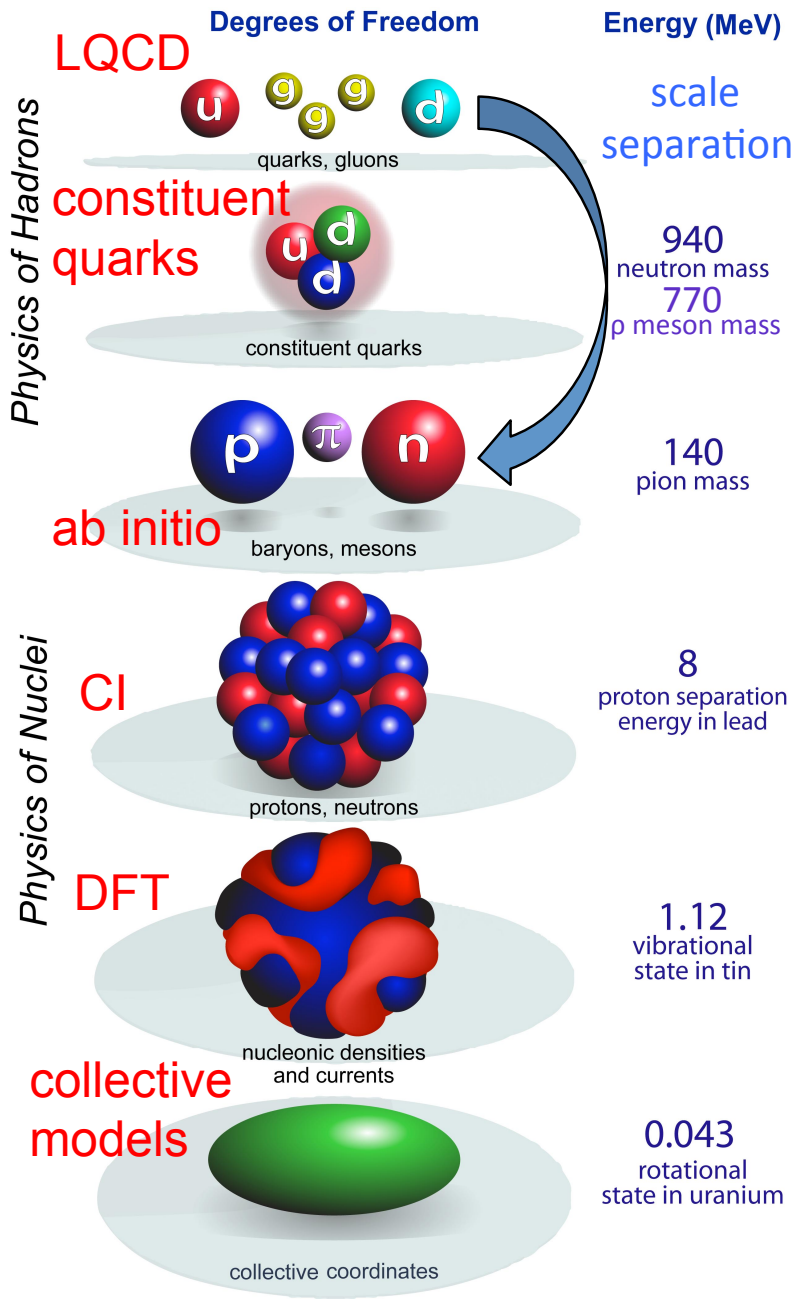


Resolution

Tower of effective field theories

Chiral EFT:
nucleons, pions, Deltas

Pionless EFT: nucleons only (low-energy few-body) or nucleons + clusters (**halo EFT**)

EFT for heavy nuclei:
collective degrees of freedom

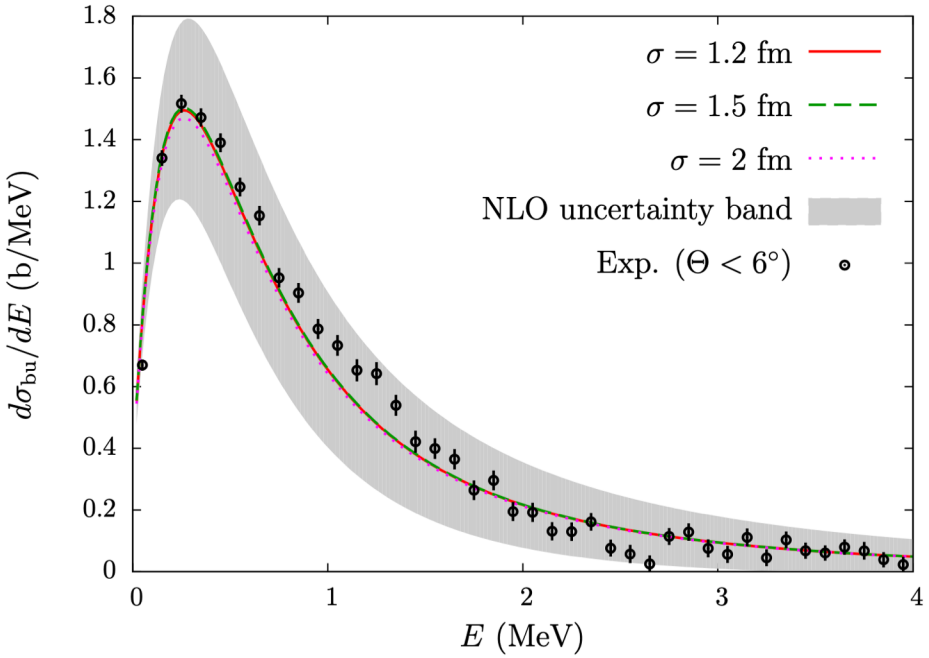
EFT at Fermi surface:
Fermi liquid theory, superconductivity

EFT for nuclear DFT?
densities as degrees of freedom

Halo EFT

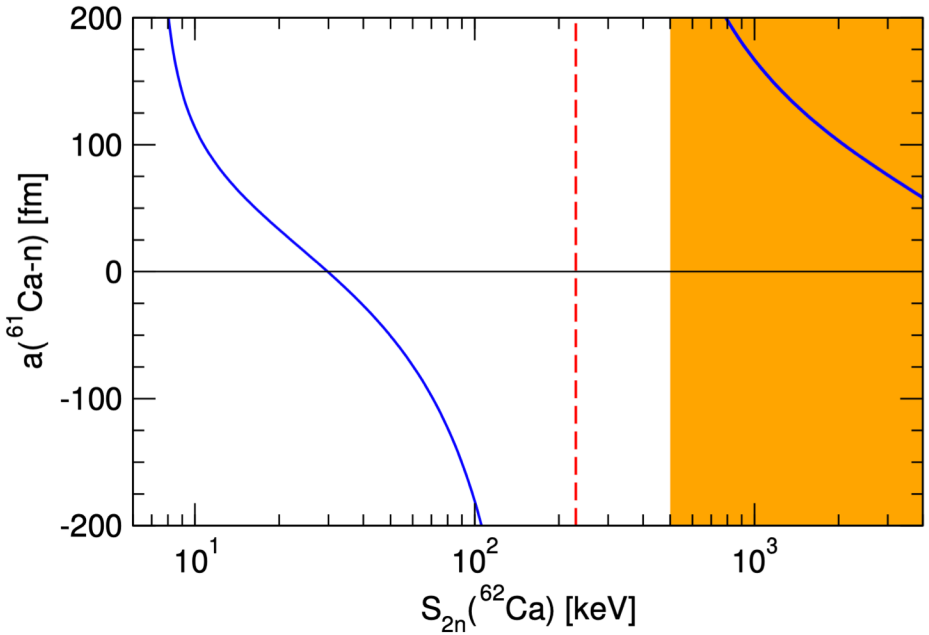
Break-up of ^{11}Be

Capel et al. (2016)



Possible halo nucleus ^{62}Ca?

Hagen et al. (2013)

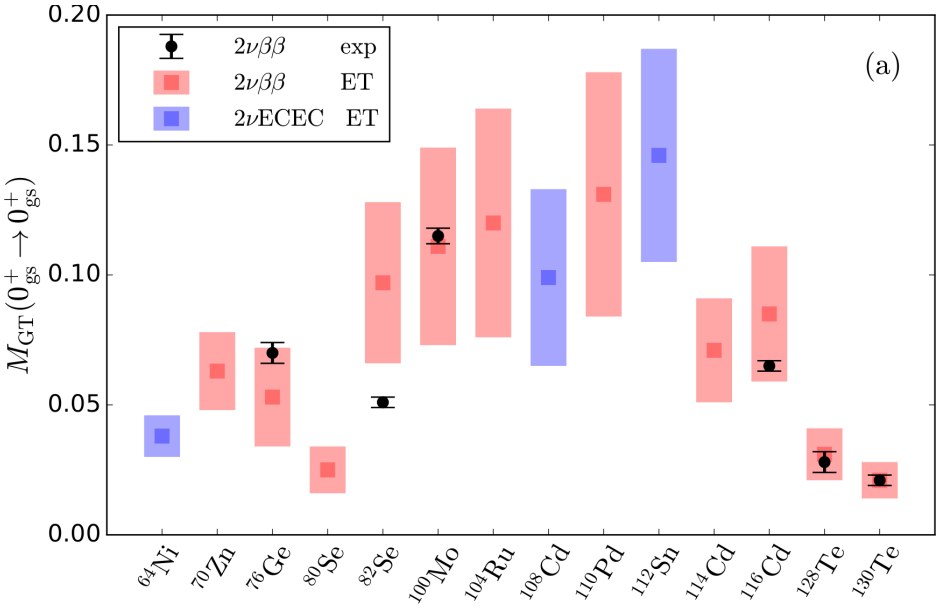


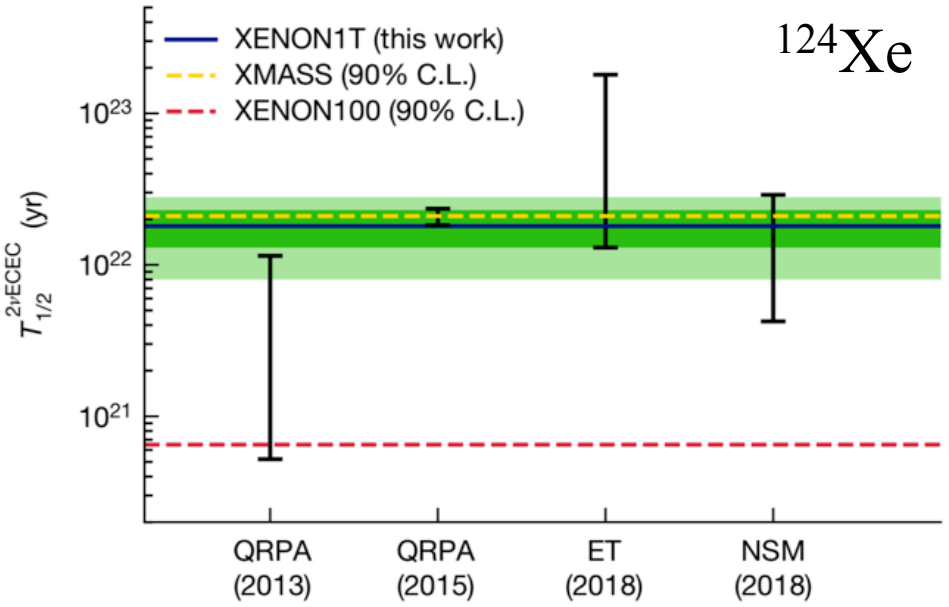
Halo EFT

EFT for heavy nuclei

for 2νββ and 2νECEC decays

Coello Perez, Menéndez et al. (2018, 2019)





Dialogue Topics

Tower of EFTs and matching

Many EFT ideas for many-body physics unexplored.
What is the status of EFT for EDFs?

Can we use EFT to provide EDF uncertainty quantification similar to the Bayesian EFT truncation uncertainties?

Lots of room for new matching calculations from ab initio
to halo EFT,
to EFT for heavy nuclei,
to EDFs.
(all of these have proven higher accuracy for complex nuclei)

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Ab initio challenges

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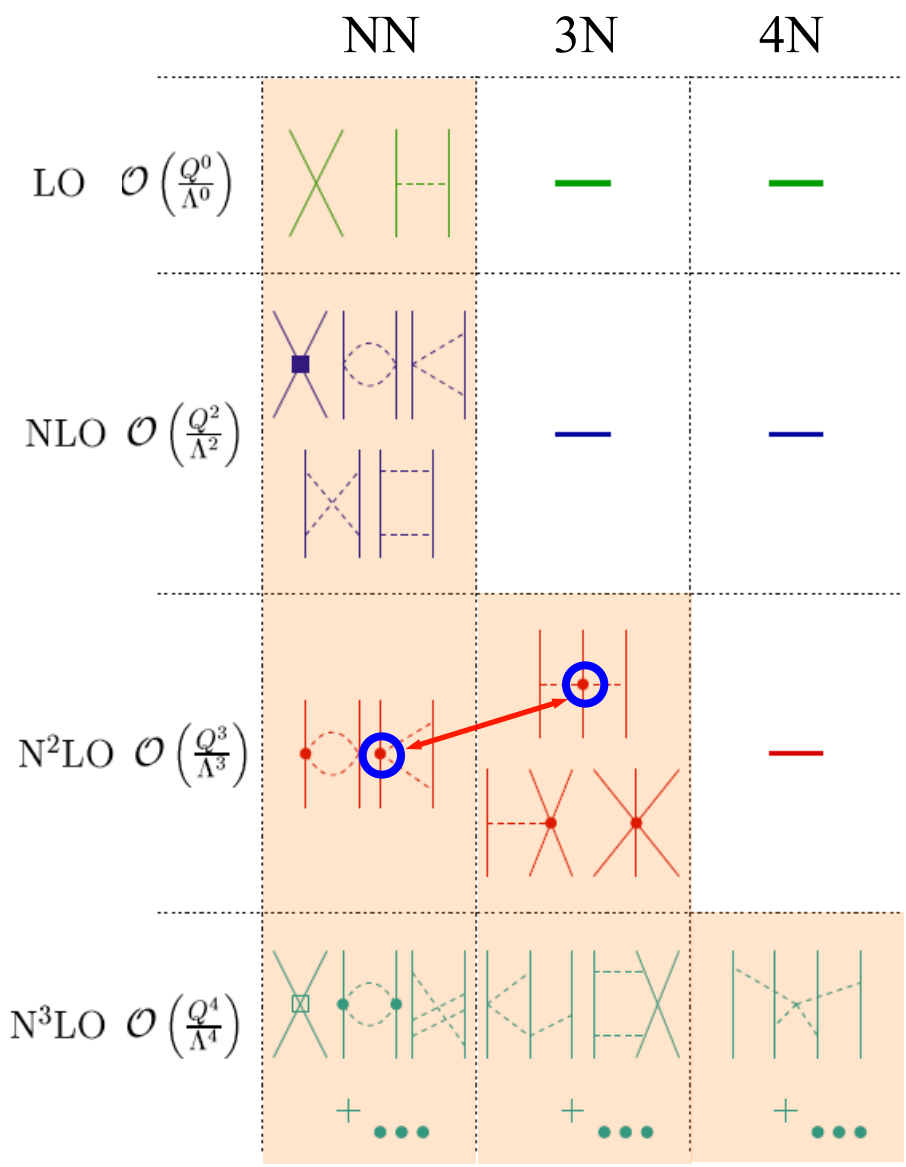
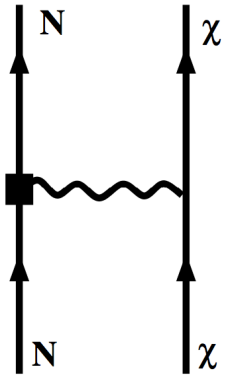
Consistent electroweak interactions

Chiral EFT for coupling to **electroweak interactions**

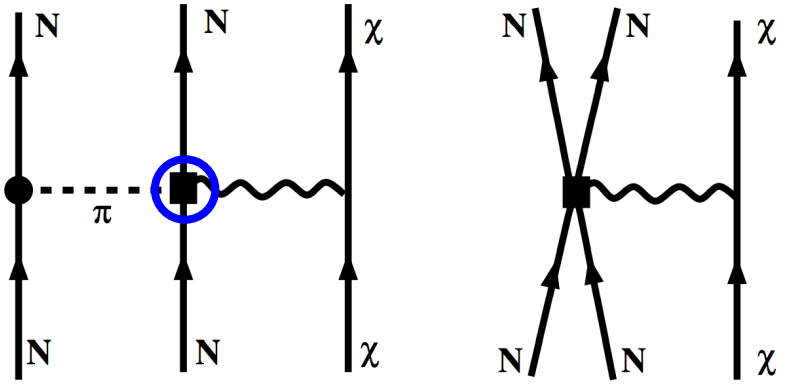


axial-vector currents (beta decays)

one-body currents at Q^0 and Q^2



+ two-body currents at Q^3



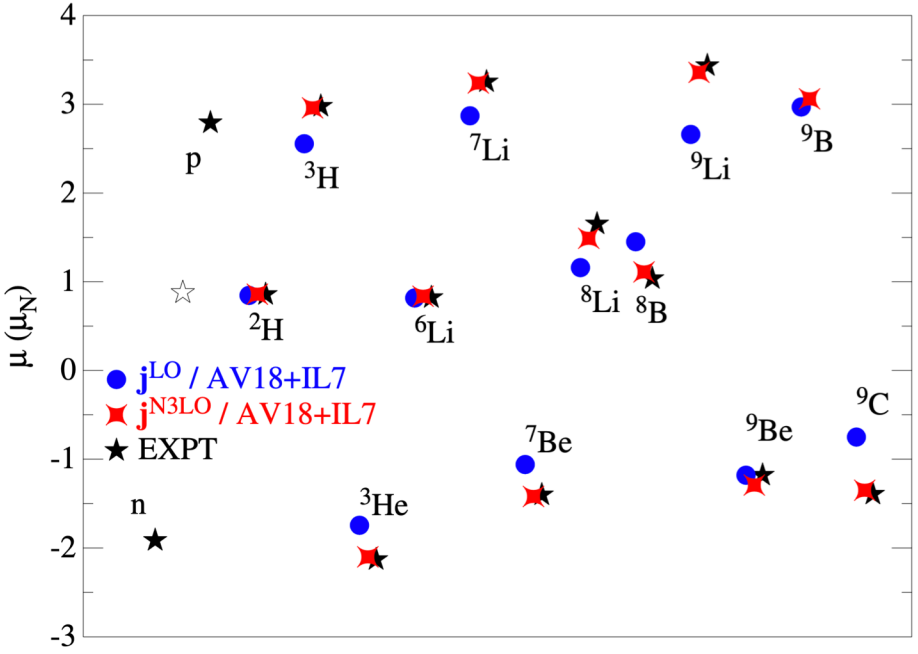
same couplings in forces and currents!

Chiral EFT for coupling to **electroweak interactions**

consistent electroweak one- and two-body currents

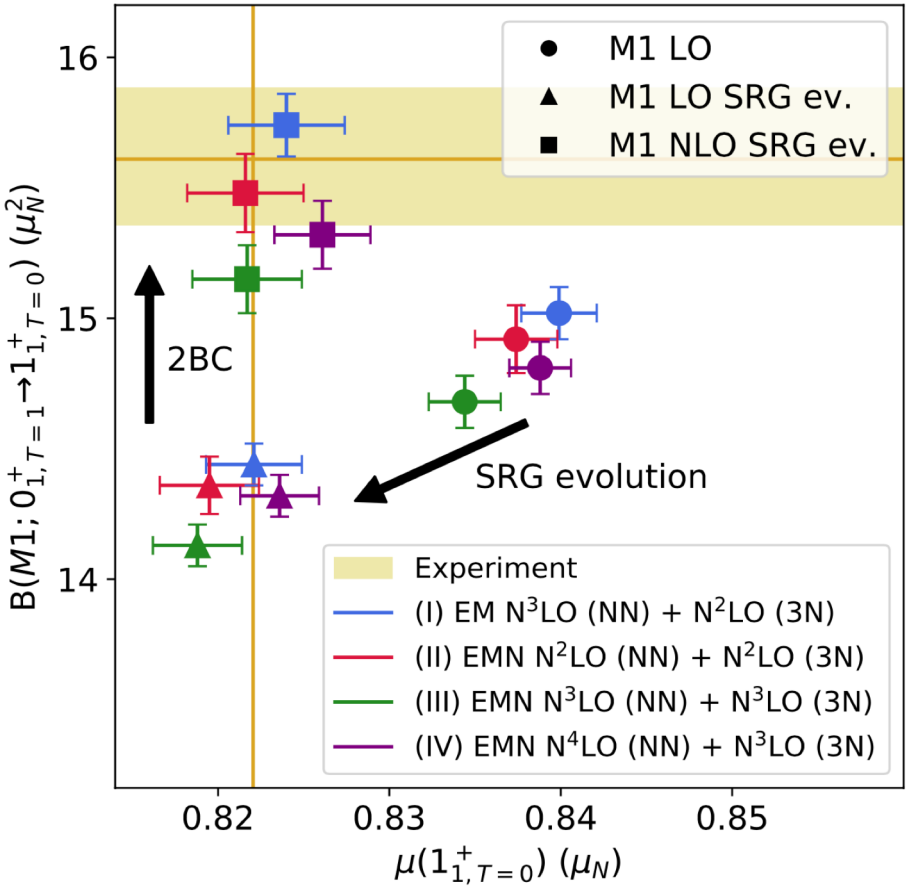
magnetic properties of light nuclei

Pastore et al. (2012-)



B(M1) of ^{6}Li

Friman-Gayer et al. (2020)



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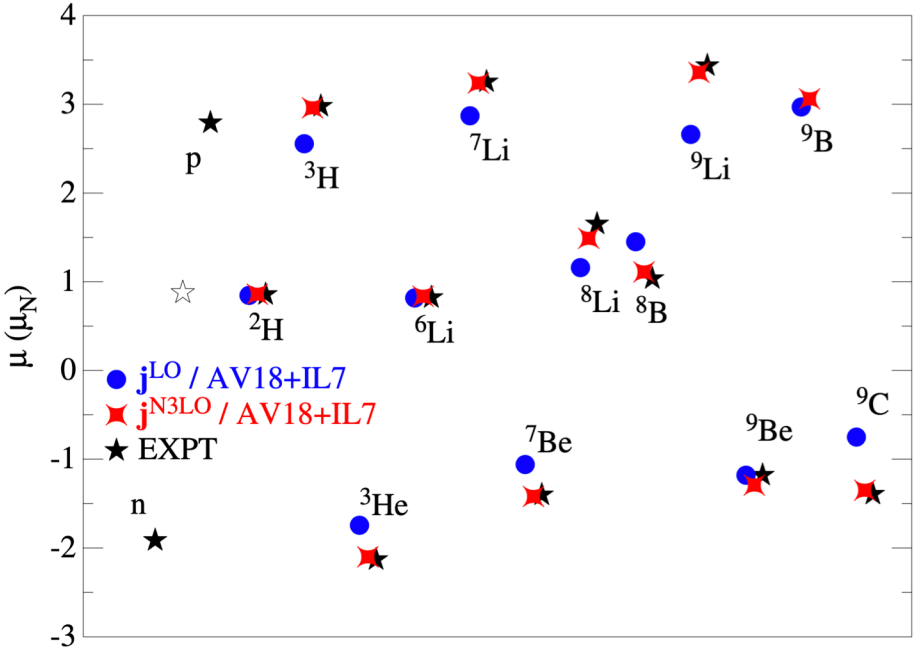
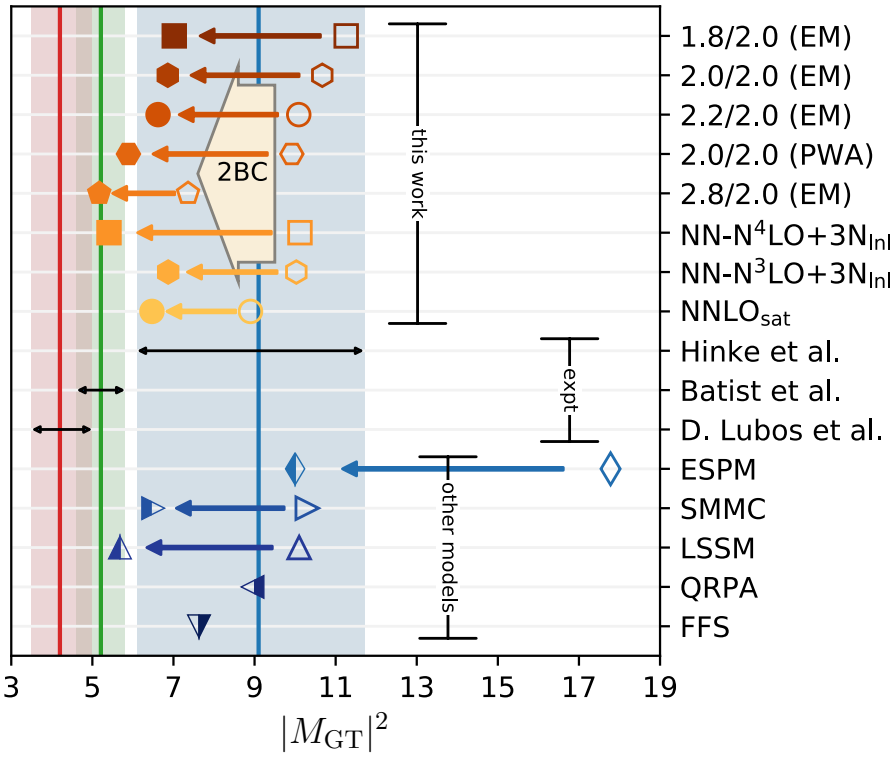


Gamow-Teller beta decay of ^{100}Sn

Gysbers et al., Nature Phys. (2019)



two-body currents (2BC) key for quenching puzzle of beta decays

Dialogue Topics

Consistent electroweak interactions

Consistent order-by-order calculations for electroweak interactions in nuclei are still open challenge.

What are key observables to explore besides quenching puzzle? Impact of two-body currents on charge radii?

What are experimental frontiers here?

Maybe two-body operator contributions will be the first (lattice) QCD constraints for chiral EFT? What is needed to set up matching?

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