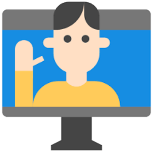
0ν Progress by DBD Collaboration

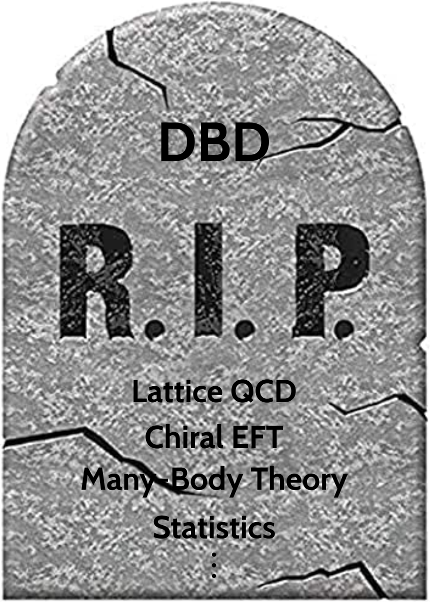
J. Engel

September 21, 2021

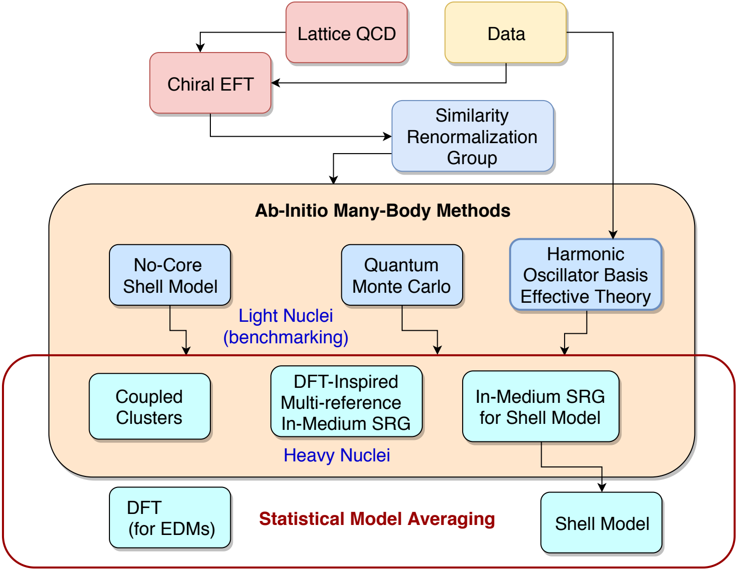


DBD Topical Theory Collaboration

2016-2021



DBD Original Idea



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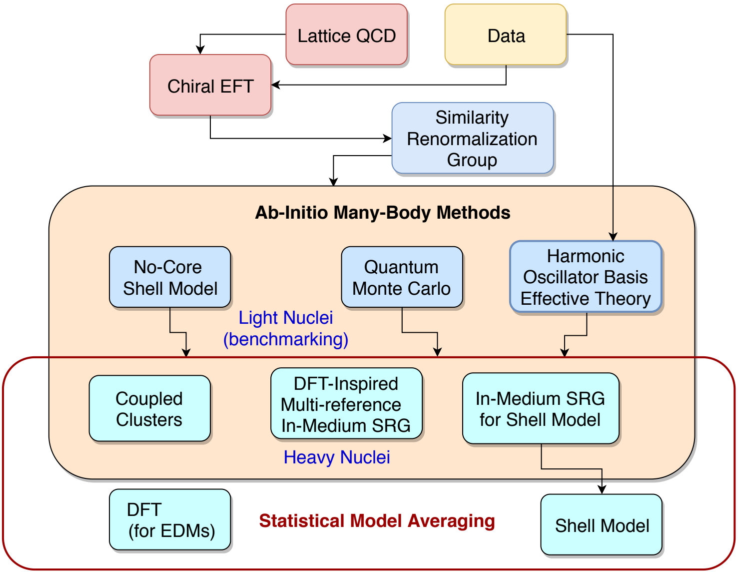
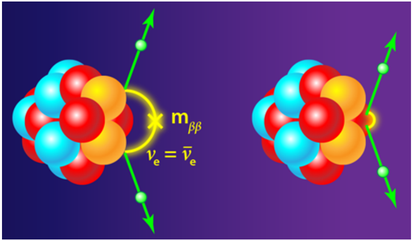


A lot of this actually got done! And other unforeseen things as well!

The Problem

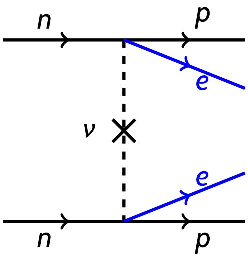


Rate depends on squares of unknown nuclear matrix elements. We need to compute them and assign a believable uncertainty so that experimentalists can

1. plan their experiments
2. draw conclusions from their results

EFT

Example: Light-ν Exchange at Leading Order



Usual long-range exchange

Almost all calculations so far include only this.

EFT

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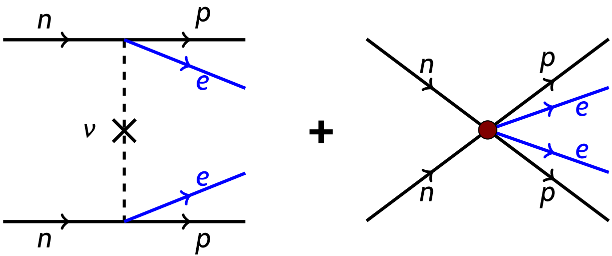


Usual long-range exchange

Almost all calculations so far include only this.

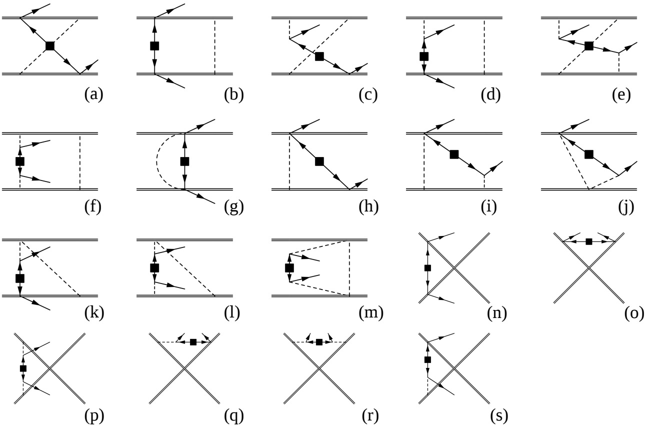
Contact counter term from short short-range exchange at energies beyond breakdown scale of EFT.

Constant in front now estimated.

EFT

N^{2}LO

Corrections of order 10% to standard diagram:



Size of effects confirmed in QMC calculations. Some coefficients still undetermined.

EFT

More...

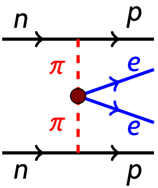
- EFT treatment of decay mediated by heavy-particle exchange
- Examination of effects of sterile neutrinos
- Synthesis of all possible operators and phase-space factors through “master formula”
- ⋮

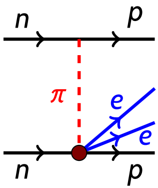
Lattice QCD and Determination of Coefficient in χEFT

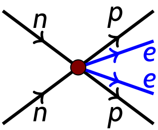
Heavy-Particle Exchange

Effective field theory lists pion-nucleon-level operators and determines their importance.

Lattice QCD can compute dependence of blobs on new particle masses and couplings.







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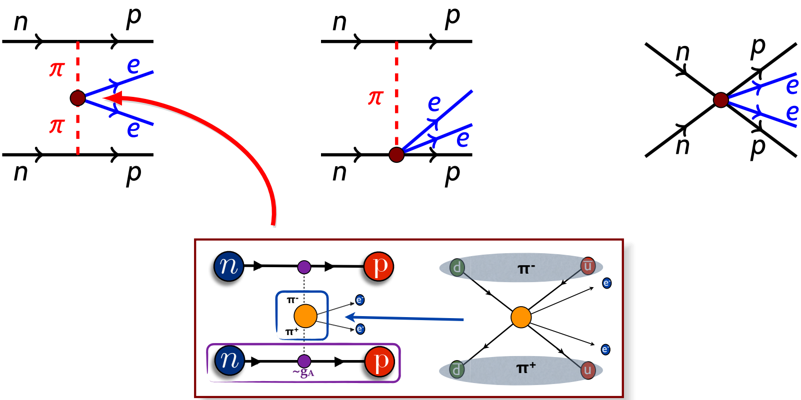

Lattice QCD

Light-ν Exchange

Need

- Development of good two-nucleon operators (needed for heavy-particle exchange as well). Lots of activity here.
- Good treatment of massless fermions on lattice. QED effects can be studied to test methods.
- Lattice χEFT for matching finite-volume LQCD results.

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- Lattice χEFT for matching finite-volume LQCD results.

Lots of progress, but some of this is still a ways off.

Lattice QCD

Related Development

Precise Estimate of g_A

nature

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Letter | Published: 30 May 2018

A per-cent-level determination of the nucleon axial coupling from quantum chromodynamics

C. C. Chang, A. N. Nicholson, E. Rinaldi, E. Berkowitz, N. Garron, D. A. Brantley, H. Monge-Camacho, C. J. Monahan, C. Bouchard, M. A. Clark, B. Joó, T. Kurth, K. Orginos, P. Vranas & A. Walker-Loud

Nature **558**, 91–94 (2018) | Cite this article

Interlude: Light-ν Exchange in a Nucleus

$$[T_{1/2}^{0\nu}]^{-1} = G(Z,N)\,|M_{0\nu}|^2\,\bar{m}_\nu^2$$

$$\boxed{M_{0\nu} = M_{0\nu}^{GT} - \frac{g_V^2}{g_A^2} M_{0\nu}^F + M_{0\nu}^{\text{contact}} + \ldots}$$

with (at leading order in χEFT)

$$M_{0\nu}^{GT} = \langle F| \sum_{i,j} H(r_{ij})\, \boldsymbol{\sigma}_i \cdot \boldsymbol{\sigma}_j\, \tau_i^+ \tau_j^+\ |I\rangle + \ldots$$

$$M_{0\nu}^{F} = \langle F\,| \sum_{i,j} H(r_{ij})\, \tau_i^+ \tau_j^+\ |I\,\rangle + \ldots$$

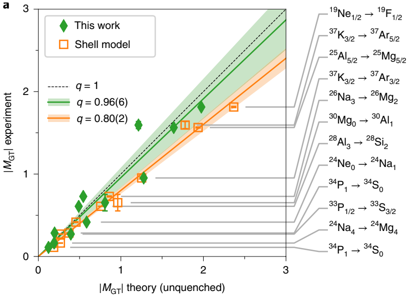
$$H(r) \approx \frac{2R}{\pi r} \int_0^\infty dq \frac{\sin qr}{q - (E_i + E_f)/2} \qquad \text{roughly} \propto 1/r$$

Corrections are from “tensor” term. Higher-order terms in χEFT also add stuff.

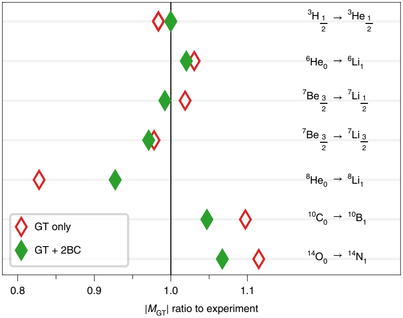
Explorations in Light Nuclei

g_A Quenching, Etc.

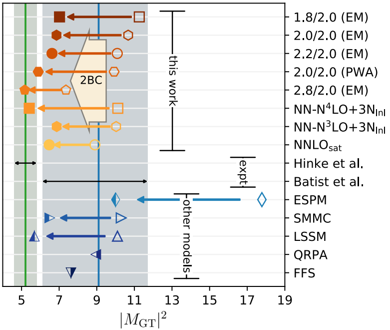
In-Medium SRG (not us)



Quantum Monte Carlo



^{100}Sn in Coupled Clusters



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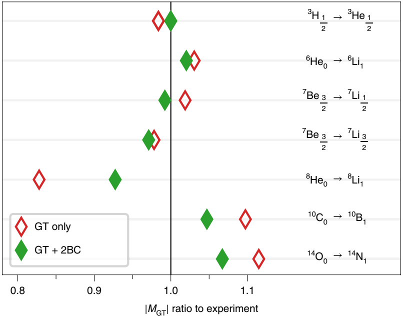

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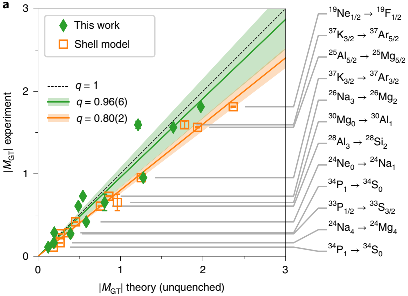

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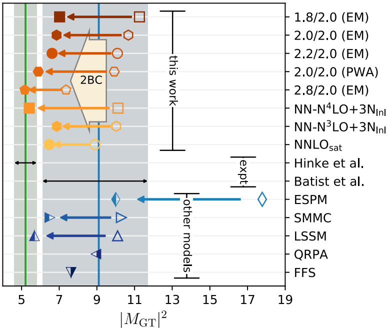

OK, ^{100}Sn is not so light…

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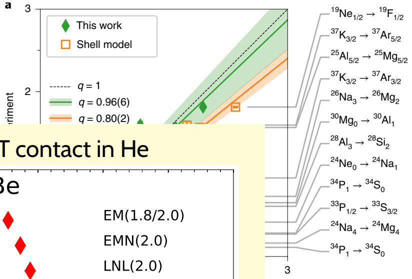

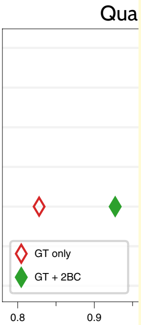

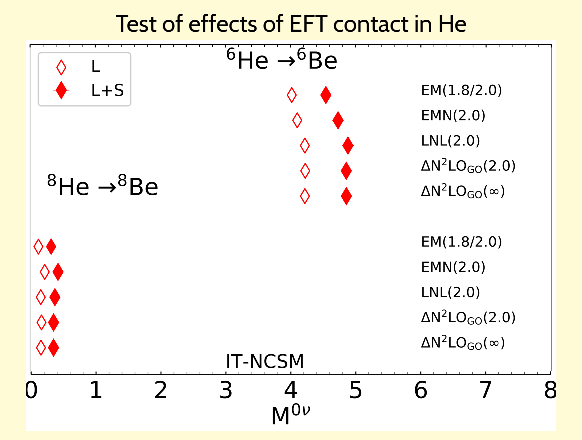

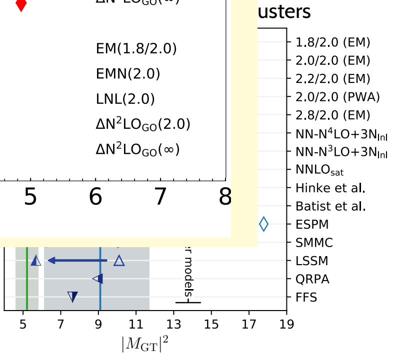

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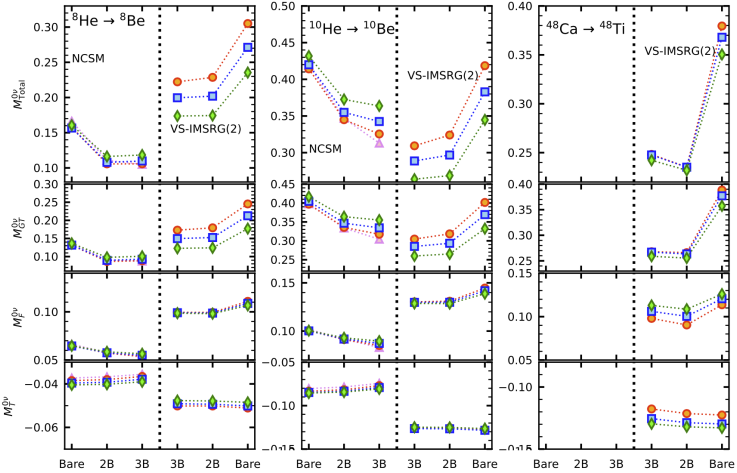
Explorations in Light Nuclei

Softening of Operators with Similarity Renormalization Group

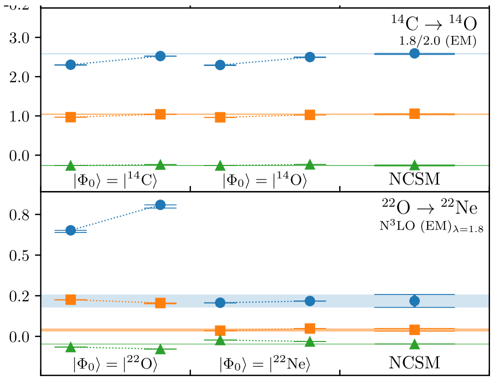
Produces operators for use in truncated single-particle spaces.



Explorations in Light Nuclei

Benchmarking of Methods

Quantum Monte Carlo and No Core Shell Model used to test the *ab initio* methods used in heavy nuclei and the phenomenological Shell Model.

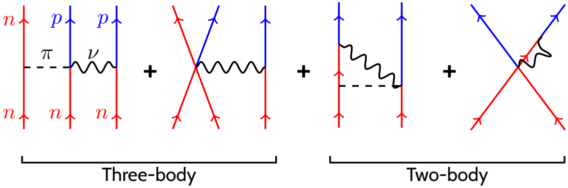


Comparison of Coupled Clusters and NCSM

Phenomenological Shell-Model in Heavy Nuclei

Used to

- Explore effectiveness of Generator Coordinate Method, a mixing of collective mean-field states at the heart of one *ab initio* method.
- Explore heavy-particle exchange in extensions of the Standard Model, opening-angle dependence of decay rates, etc.
- Explore the effects on light-ν exchange of the chiral two-body currents that help quench single-β decay (conclusion: they appear mild but an unknown contact term plays a role).



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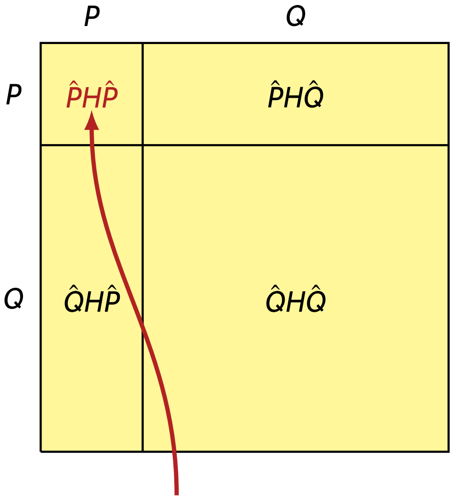
Ab Initio Many-Body Methods for Heavy Nuclei

Partition of Full Hilbert Space



Simpler calculation done here.

P = subspace you want
Q = the rest

Task: Find unitary transformation to make H block-diagonal in P and Q, with H_{eff} in P reproducing most important eigenvalues.

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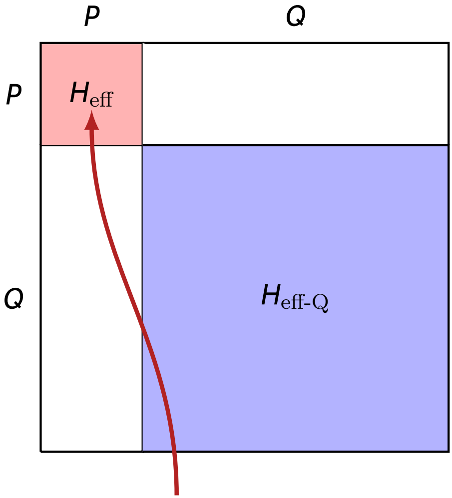

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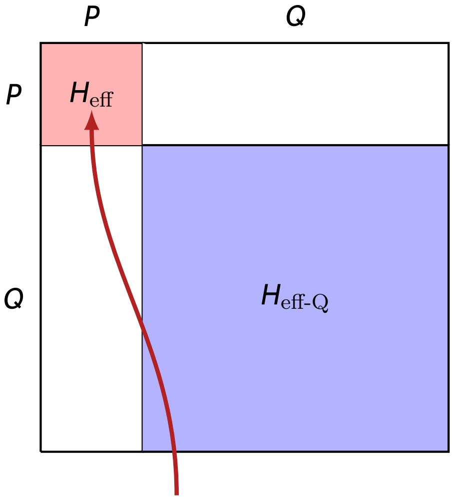

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Must must apply same unitary transformation to transition operator.

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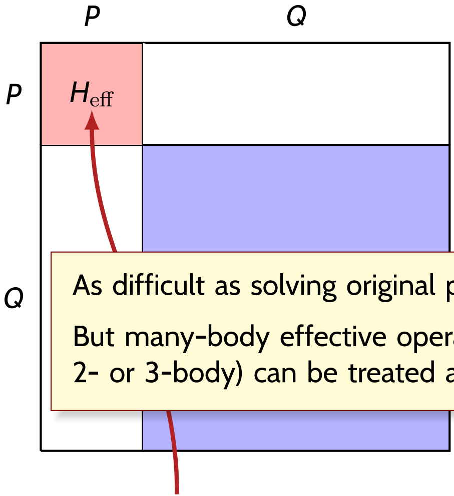

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nvalues.

ly same unitary
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operator.

As difficult as solving original problem.

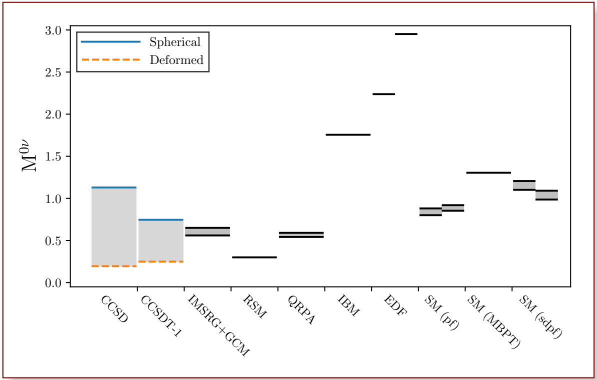
But many-body effective operators (beyond 2- or 3-body) can be treated approximately.

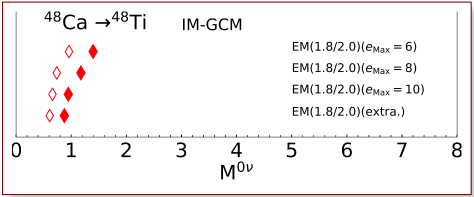
Simpler calculation done here.

Ab Initio Light-ν-Exchange Matrix Elements for ^{48}Ca

In-Medium Generator Coordinate Method and Coupled Clusters

Comparison of all methods



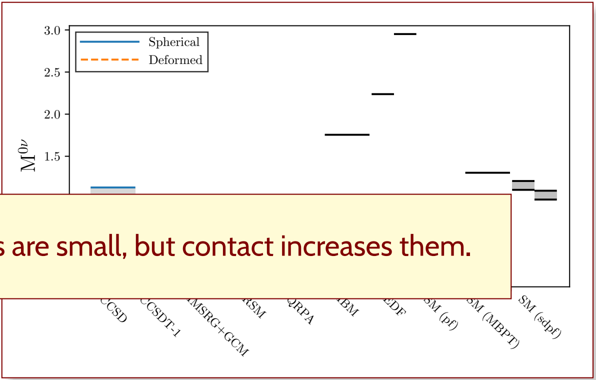


Effect of contact in IM-GCM

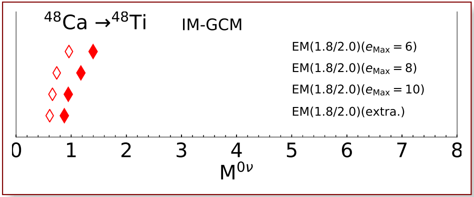
Ab Initio Light-ν-Exchange Matrix Elements for ^{48}Ca

In-Medium Generator Coordinate Method and Coupled Clusters

Comparison of
a



Matrix elements are small, but contact increases them.



Effect of contact in IM-GCM

Heavier Elements

- ^{76}Ge in progress in IM-GCM. Preliminary small-model space results on arXiv; agree pretty well with those of valence-space IMSRG.

- ^{130}Te, ^{136}Xe “in contemplation.”

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Perhaps ^{100}Mo should be next?

Uncertainty Quantification

We met a few times over Zoom towards the end of the collaboration and came up with a procedure that is on the conference website. A few people calculated a few related observables, but we never built up the steam to make a real dent in the problem.

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That's next!