Institute for Basic Science HQ, Daejeon, Korea

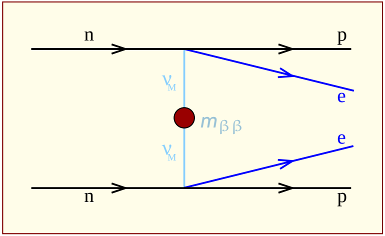
Ab-Initio Theory and ββ Decay

조나단 엥겔

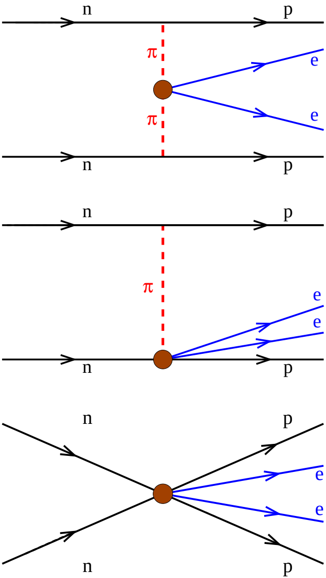
July 2, 2018

Review of $0\nu\beta\beta$ Decay

Standard operator



Other possibilities



Forbidden in Standard Model.

New physics inside blobs.

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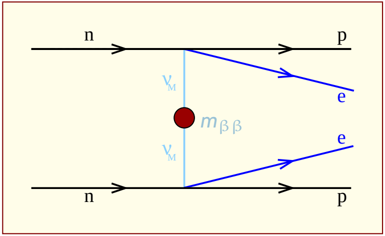

I'll focus on this one.

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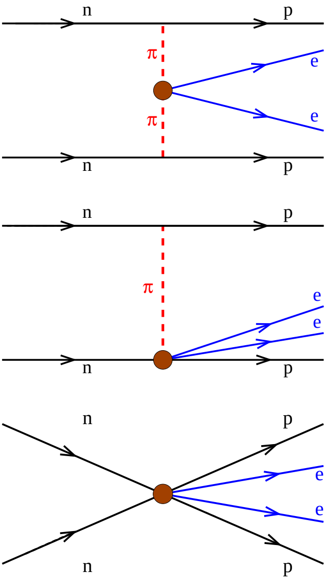

Nuclear Matrix Element (Simplified)

$$\boxed{M^{0\nu} = g_A^2\, M_{GT}^{0\nu} - g_V^2\, M_F^{0\nu} + \ldots}$$

Dominant piece

with

$$M_{GT}^{0\nu} = \langle f | \sum_{a,b} H_{GT}(r_{ab}) \vec{\sigma}_a \cdot \vec{\sigma}_b \tau_a^+ \tau_b^+ \, | i \rangle$$

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But the idea that there is a single "g_A in medium" is too much of a simplification.

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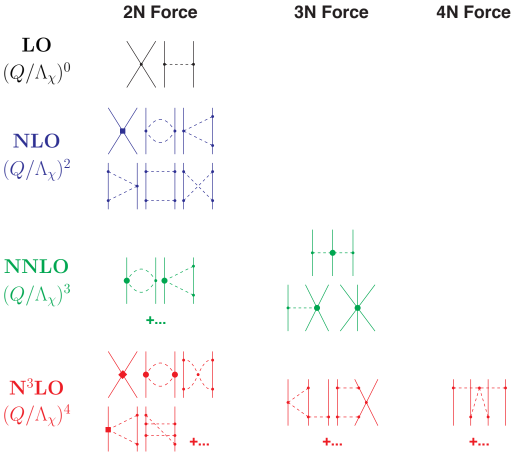
Ab Initio Nuclear Structure

Often starts with chiral effective-field theory

Nucleons, pions sufficient below chiral-symmetry breaking scale.
Expansion of operators in powers of Q/Λ_χ.

$Q = m_\pi$ or typical nucleon momentum.



Many-Body Methods

All require many CPU-hours.

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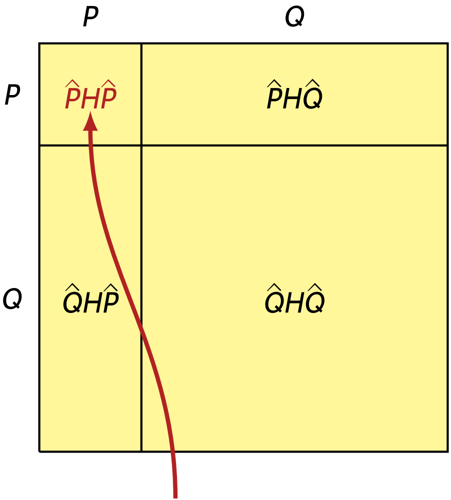
Ab Initio Shell Model

Partition of Full Hilbert Space



Shell model done here.

P = valence space
Q = the rest

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

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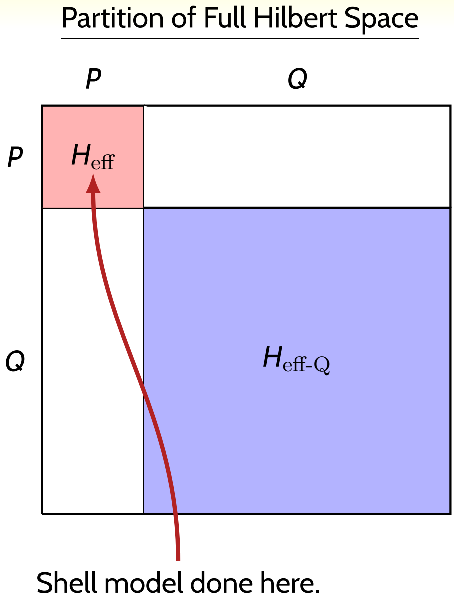

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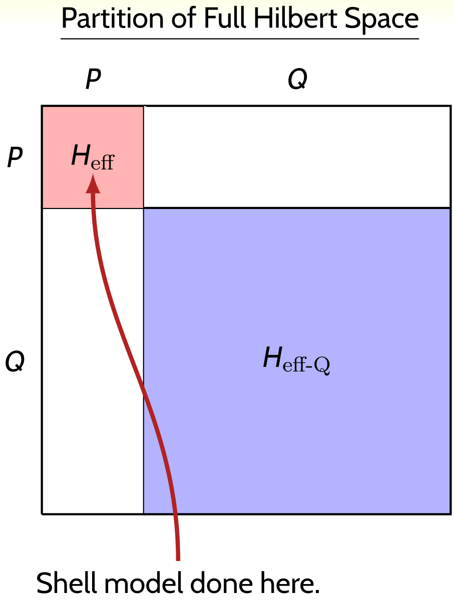

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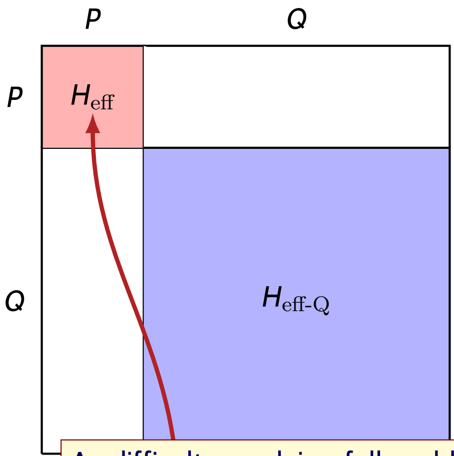

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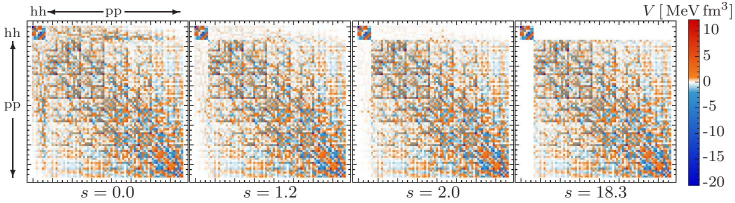
As difficult as solving full problem. But idea is that N-body effective operators beyond N >2 or 3 can be treated approximately.

Shell model done here.

In-Medium Similarity Renormalization Group

One way to determine the transformation

Flow equation for effective Hamiltonian.
Gradually decouples shell-model space.



Hergert et al.

Trick is to keep all 1- and 2-body terms in *H* at each step *after normal ordering* (approximate treatment of 3-, 4- …terms.

If shell-model space contains just a single state, approach yields ground-state energy. If it is a typical valence space, result is effective interaction and operators.

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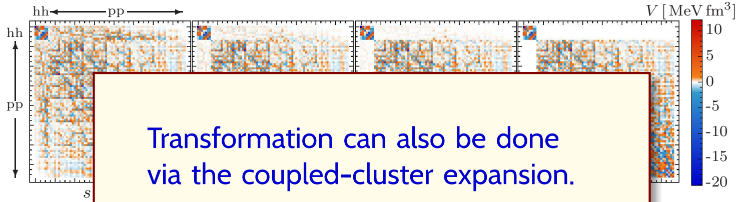

Transformation can also be done via the coupled-cluster expansion.

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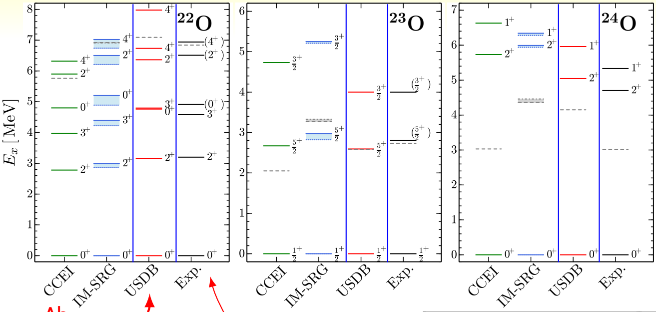
Ab Initio Calculations of Spectra



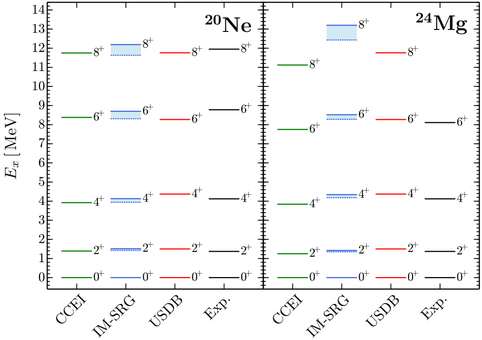
Ab initio

Phenom.

Expt.

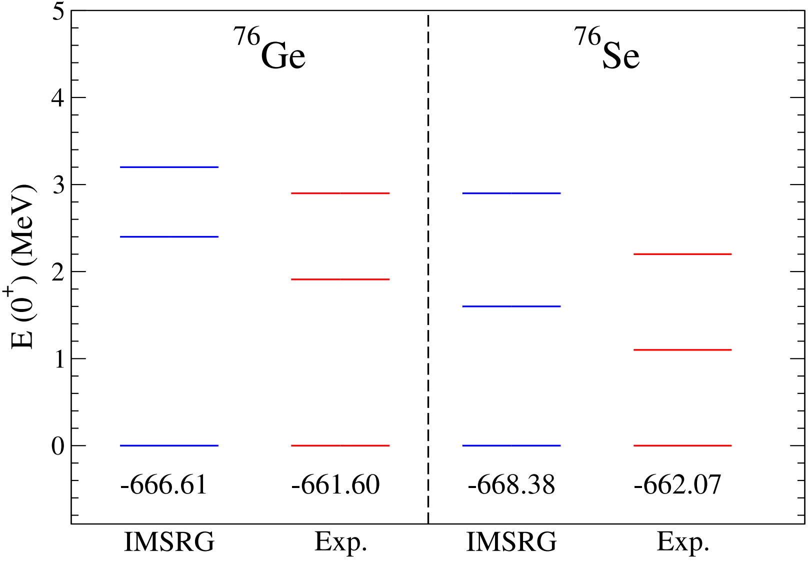
Neutron-rich oxygen isotopes

Deformed nuclei



Ab Initio ^{76}Ge and ^{76}Se

Stroberg, Holt, et al.

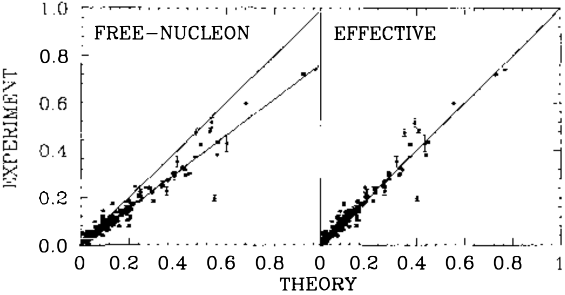


Gamow-Teller β Decay

Leading order decay operator is $\vec{\sigma}\tau_+$.

50-Year-Old Problem: Effective g_A needed in all calculations of shell-model (or related) type.

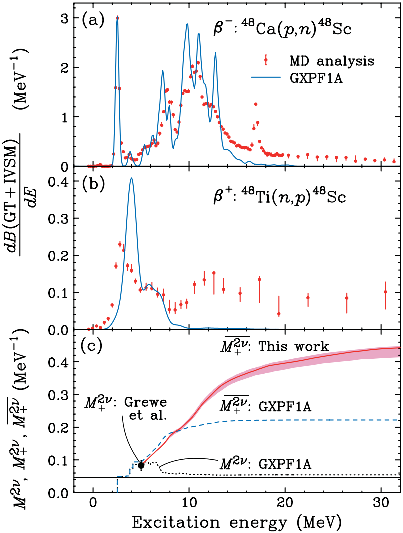
Brown & Wildenthal



Many suggestions about the cause but, until recently, no consensus.

Other Tests of $\vec{\sigma}\tau$ Strength Also Show Suppression

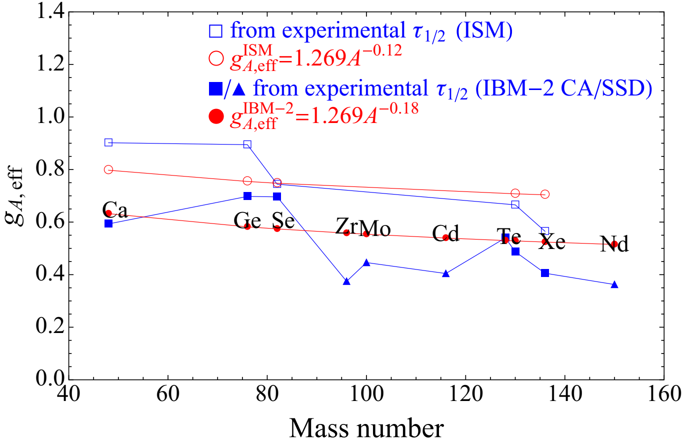
From Yako et al., PRL 103, 012503 (2009)



Only about 2/3 of theoretically expected strength observed.

And 2νββ Decay…

From F. Iachello



And $2\nu\beta\beta$ Decay…

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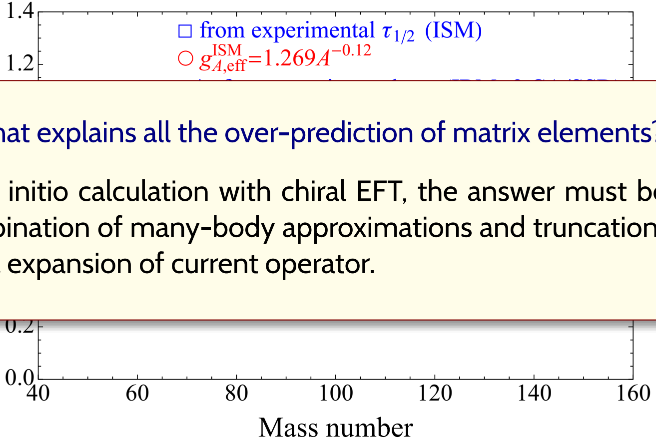


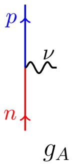
What explains all the over-prediction of matrix elements?

In ab initio calculation with chiral EFT, the answer must be a combination of many-body approximations and truncation of chiral expansion of current operator.

Axial Weak Current in Chiral EFT

β Decay (simplified) with electron lines omitted

Leading order:



Usual β-decay current.

Finite-momentum corrections at next order.

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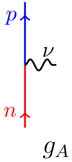

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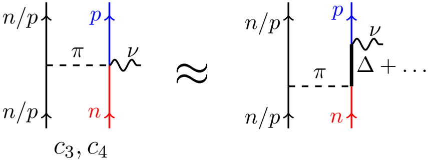
Higher order:



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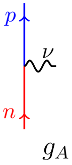

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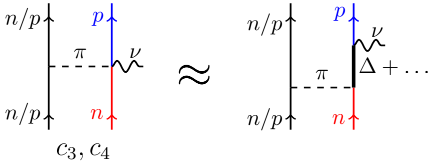
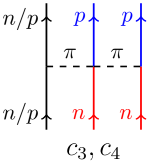
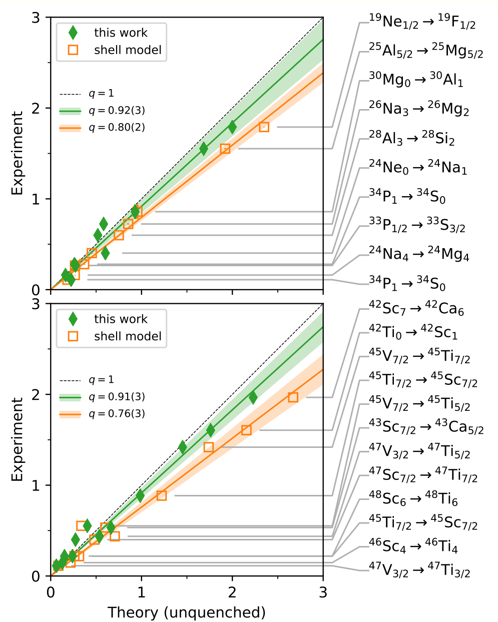
Higher order:

Coefficients same as in three-body interaction:





Quenching in the *sd* and *pf* Shells



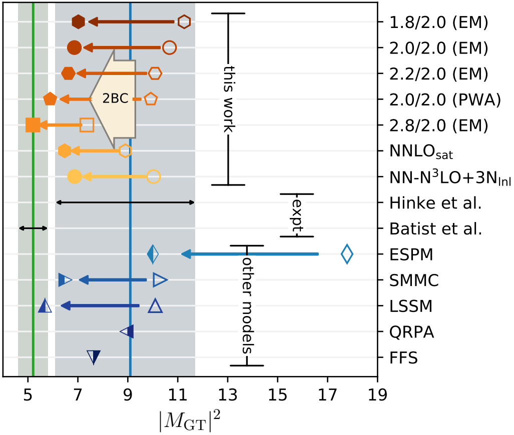
IMSRG calculation, Holt et al, preliminary

Shell model seems to include most correlations. Bulk of quenching comes from two-body current.

. . . And in ^{100}Sn

Coupled-Cluster Calculation of β Decay

Hagen et al, unpublished

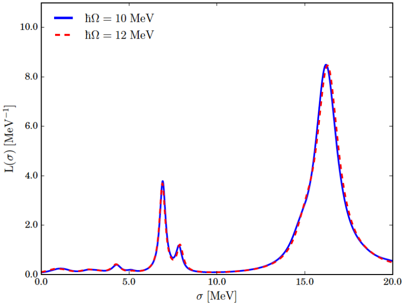


Again, good part of the quenching accounted for by two-body current.

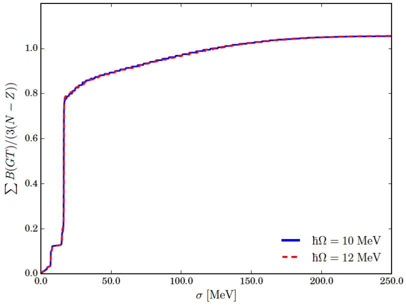
Quenching increases with mass, at least up to Sn.

Spectator nucleons contribute coherently to two-body current.

Gamow-Teller Strength in ^{132}Sn



Strength vs. energy



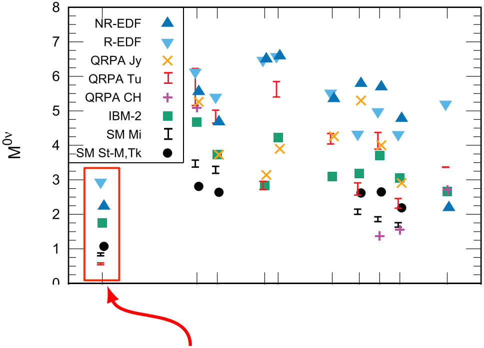
Running sum

Almost 20% of strength above 30 MeV and 10% above 50 MeV.

And $0\nu\beta\beta$ Decay?

Preliminary results in ^{48}Ca

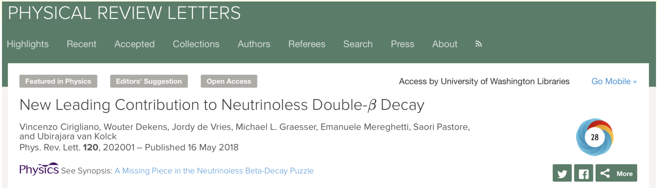
Two-body currents not yet included, but preliminary indications are that their effects are not as large as in β decay.



Coupled -clusters result is red bar at bottom.

But ^{48}Ca is not typical. ^{76}Ge coming soon.

Small Fly in the Ointment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New Leading Contribution to Neutrinoless Double-β Decay

Vincenzo Cirigliano, Wouter Dekens, Jordy de Vries, Michael L. Graesser, Emanuele Mereghetti, Saori Pastore, and Ubirajara van Kolck

Phys. Rev. Lett. **120**, 202001 – Published 16 May 2018

Physics See Synopsis: A Missing Piece in the Neutrinoless Beta-Decay Puzzle

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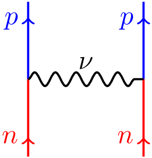
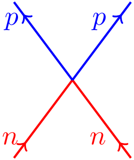
More

Usual light neutrino exchange:



must be supplemented, at same order in chiral EFT, by short-range operator (representing high-energy ν exchange):



Coefficient of this term is unknown.

Looking for ways to fit to, e.g., pion double-charge exchange

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