Status of beta-decay calculations and quenching from ab-initio

Stefano Gandolfi

Los Alamos National Laboratory (LANL)

Precise beta decay calculations for searches for new physics,
April 8-12, 2019, ECT*, Trento, Italy

LDRD

www.computingnuclei.org

Outline

- The "g_A quenching" puzzle
- The nuclear Hamiltonian and currents
- Evidence of the importance of two-body currents in electron scattering
- β-decay in light nuclei
- Medium/heavy nuclei
- Conclusions

Motivation

At "nuclear" energies, understanding neutrino-nucleus interactions very challenging and important!

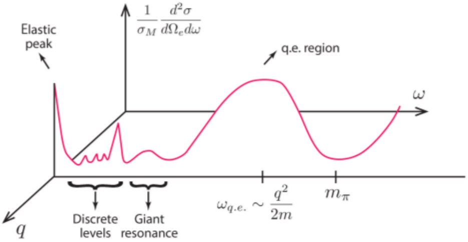
Understanding Nuclei:

- Nuclear interactions and structure
- Exotic nuclei - neutron rich
- Electroweak processes

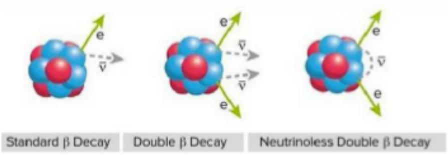
Relevance:

- Neutrino scattering in nuclei (neutrino oscillation experiments)
- Neutrinoless Double Beta Decay
- Neutrino interactions in supernovae and neutron stars, nucleosynthesis

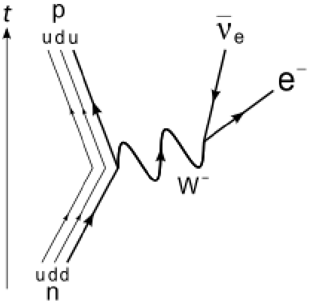
We need a coherent picture of ν-nucleus interactions

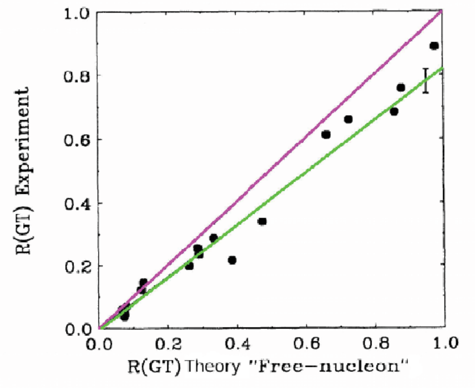


- $\omega \approx$ few MeV, $q \approx 0$: $\beta-$ and $\beta\beta-$decays
- $\omega \approx$ few MeV, $q \approx 10^2$ MeV: Neutrinoless $\beta\beta-$decays
- $\omega \leq$ tens MeV: Astrophysics
- $\omega \approx 10^2$ MeV: Accelerator neutrinos, ν-nucleus scattering



The "quenching"-g_A problem





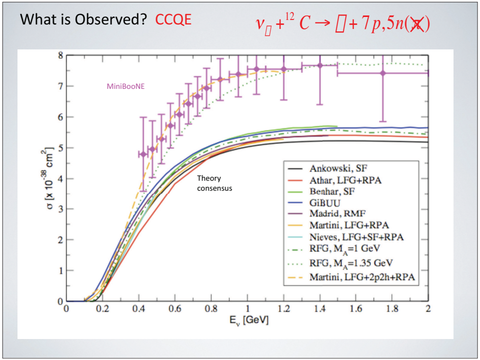
$$g_A^{\text{eff}} \simeq 0.70\, g_A$$

Chou et al., PRC 47, 163 (1993)

What's the origin (or is there a **need**) of g_A quenching?

Charge-change quasi-elastic cross-section in ^{12}C

Experimental vs theory disagreement:



Alvarez-Ruso arXiv:1012.3871

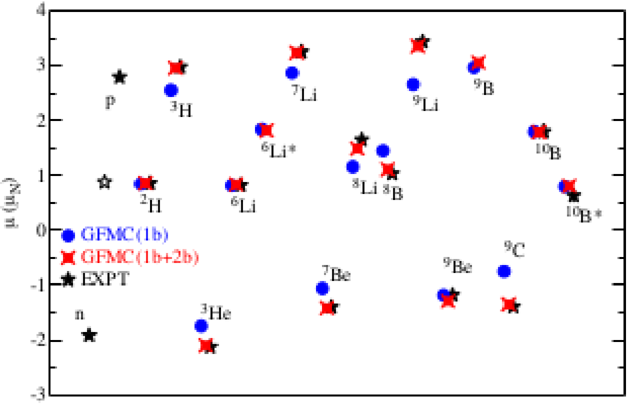
Currents inconsistent with the Hamiltonian.

Nucleon-nucleon correlations and two-body processes approximately accounted for.

Need of g_A "unquenching"???

Electromagnetic two-body processes

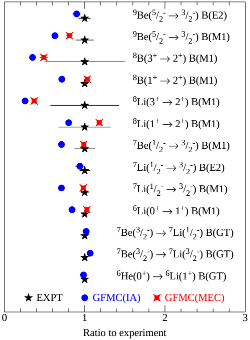
Magnetic moments in light nuclei:



Pastore *et* al, PRC 2013

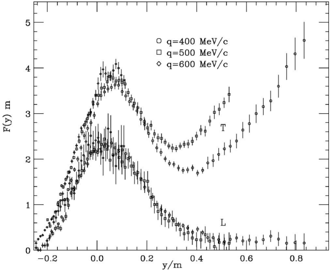
Electromagnetic two-body processes

Low-momentum, transitions:



Pastore *et* al, PRC 2014

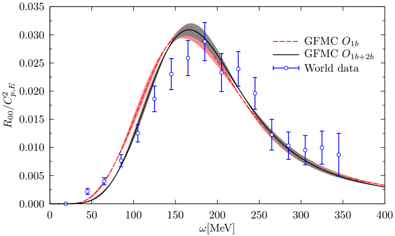
High-momentum, e^{-} scattering: rescaled longitudinal vs transverse electromagnetic response in ^{12}C

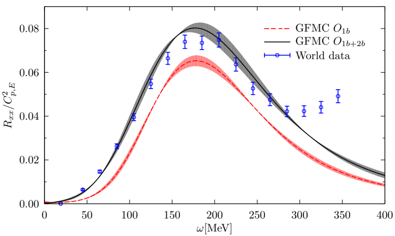


Benhar, Day, Sick, RMP (2008)

Without two-body processes, the longitudinal and transverse response is about the same

Electromagnetic longitudinal and transverse response functions of ^{12}C (q=570 MeV)

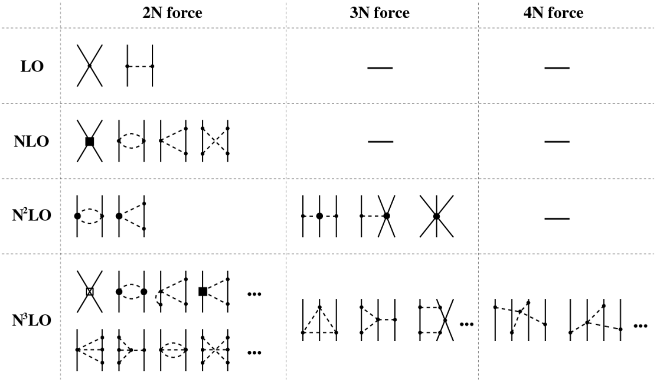




Lovato et al., PRL (2016).

Role of two-body currents very important (as expected).

Nuclear Hamiltonian (only pions)



Expansion in powers of Q/Λ, Q$\sim$100 MeV, Λ $\sim$1 GeV.

Long-range physics given by pion-exchanges (no free parameters).

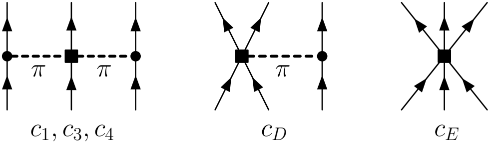
Short-range physics: contact interactions (LECs) to fit.

Operators need to be regulated $\rightarrow$ cutoff dependency!

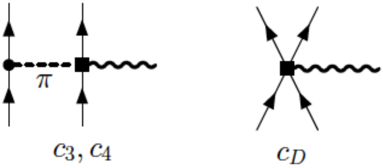
Order's expansion provides a way to quantify uncertainties!

Three-body forces and currents

Chiral three-body forces at N^{2}LO:



Chiral two-body currents:



NN and NNN often use different regulators and cutoffs (local vs non-local, or a mix).

Hamiltonian-currents consistency?

Various many-body methods (with various approximations):

- Shell-model
- Quantum Monte Carlo (QMC)
- Coupled-cluster (CC)
- In-Medium SRG (IMSRG)
- No-core Shell model (NCSM)
- ...

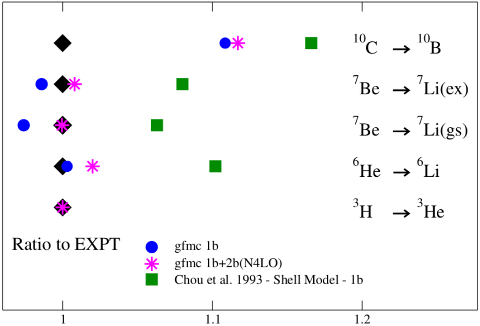
Caveats:

- Regulators in Hamiltonian and currents
- Cutoff in Hamiltonian and currents
- SRG of Hamiltonian and currents
- Normal ordering (NNN to NN and 2BC to 1BC)
- Chiral order expansion consistency, i.e. NN vs NNN vs 2BC?

More discussions and details later this week.

β-decays in light nuclei

QMC calculations using a correlated wave function compared to shell-model calculations using the AV18+IL7 Hamiltonian and chiral currents.

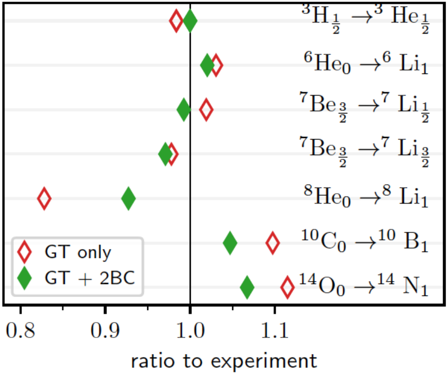


Pastore, et al., PRC 97, 022501 (2018).

The effect of correlations in the nuclear wave function is critical!

β-decays in light nuclei

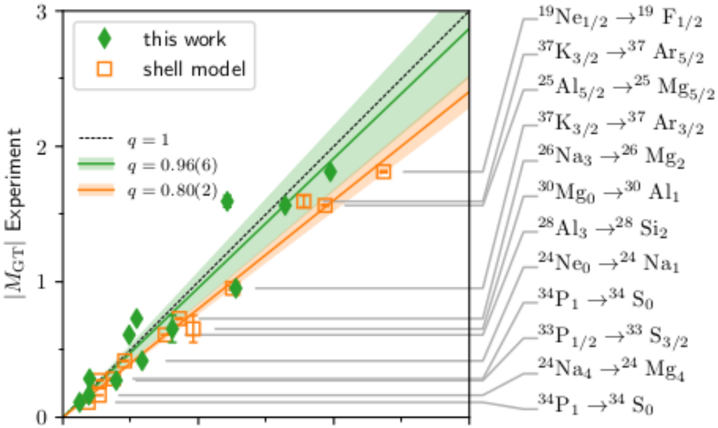
NCSM calculations using NN-N^{4}LO+3N$_{lnl}$



Gysbers et al., Nature Physics (2019).

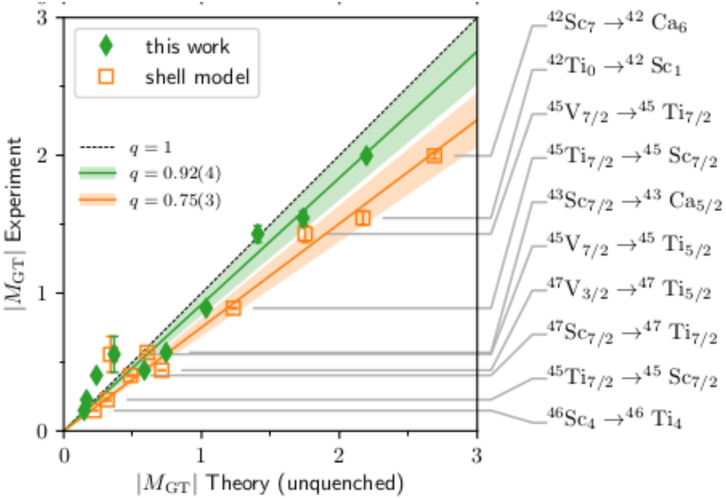
β-decays in *sd*-shell nuclei

VS-IMSRG calculations using NN-N^{4}LO+3N$_{lnl}$



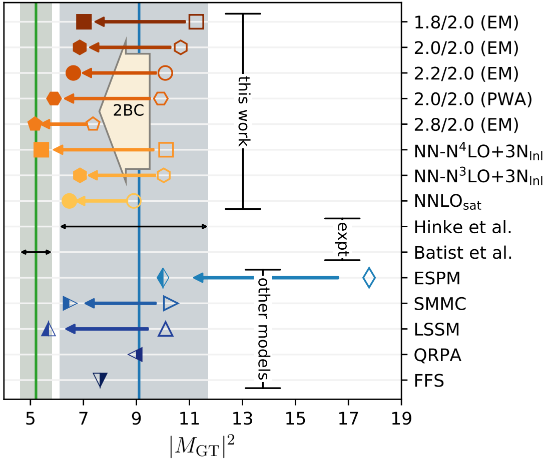
Gysbers et al., Nature Physics (2019).

VS-IMSRG calculations using NN-N^{4}LO+3N$_{lnl}$



Gysbers et al., Nature Physics (2019).

β-decay in ^{100}Sn



ESPM: Extreme Single Particle Model

SMMC: Shell Model MC

LSSM: Large Space Shell Model

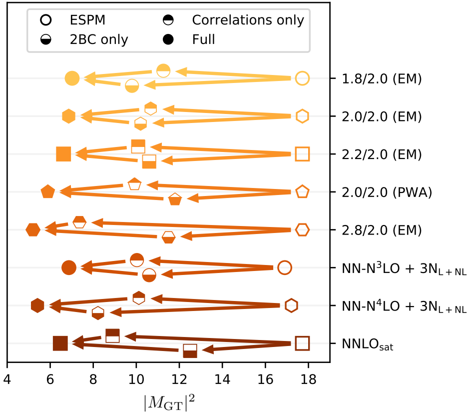
QRPA: quasiparticle random phase approximation

FFS: finite Fermi systems

Gysbers et al., Nature Physics (2019).

β-decay in ^{100}Sn

Role of correlations vs 2BC



Gysbers et al., Nature Physics (2019).

Summary and future work

Conclusions:

- Role of two-body currents essential in electromagnetic transitions.
- Role of strong correlations in the nuclear wave function critical.
- "Quenching" of g_A *maybe* understood.

Open questions:

- Role of regulators, cutoff, regulator&cutoff to be understood.
- Consistency of Hamiltonian and currents?
- Additional approximations, i.e. SRG, normal-ordering, etc???
- Theoretical Uncertainties?