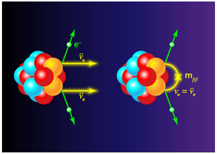
Nuclear physics for neutrinoless double beta decay

M. Grasso (IJClab) , F. Nowacki (IPHC), U. Van Kolck (IJclab)



Atelier “Physique théorique des deux infinis”

IN2P3
Les deux infinis

Nuclear physics and neutrinoless $\beta\beta$ decay

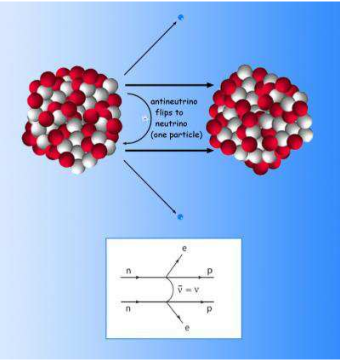
Neutrinos, dark matter studied in experiments using nuclei

Nuclear matrix elements depend on nuclear structure crucial to anticipate reach and fully exploit experiments

$0\nu\beta\beta$ decay: $[T^{0\nu}_{1/2}]^{-1} \propto |M^{0\nu}|^2 \langle m_\nu \rangle^2$

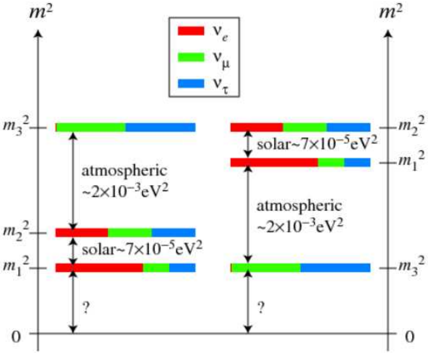
Dark matter: $\frac{d\sigma_{\chi\mathcal{N}}}{dq^2} \propto |\sum_i c_i \zeta_i \mathcal{F}_i|^2$

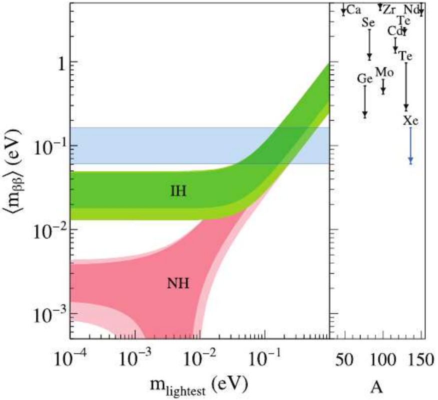
$M^{0\nu}$: Nuclear matrix element
$\mathcal{F}_i$: Nuclear structure factor



Next generation experiments: inverted hierarchy

The decay lifetime is $[T^{0\nu}_{1/2}(0^+ \to 0^+)]^{-1} = G_{0\nu}|M^{0\nu}|^2\langle m_\nu^{\beta\beta}\rangle^2$
sensitive to absolute neutrino masses, $\langle m_\nu^{\beta\beta}\rangle = \sum_i U_{ei}^2 m_i$





KamLAND-Zen, PRL117 082503 (2016)

Matrix elements needed to make sure next generation ton-scale experiments fully explore “inverted hierarchy”

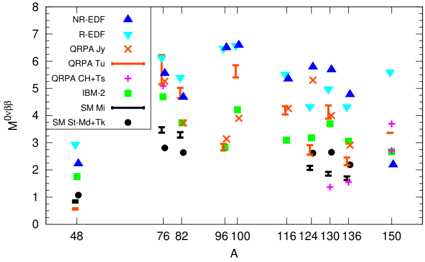
Weak-interaction processes and physics beyond the Standard Model

Reliable nuclear matrix elements needed to plan and fully exploit impressive experiments looking for neutrinoless $\beta\beta$ decay

- **Matrix elements differences between present calculations, factor 2-3 besides additionnal "quenching" ?**

$$[T^{0\nu}_{1/2}(0^+ \to 0^+)]^{-1} = G_{0\nu}|M^{0\nu}|^2|f(m_i, U_{ei}|^2$$

- ^{48}Ca and ^{76}Ge matrix elements in larger configuration space increase $\lesssim$ 30% , missing correlations introduced in IBM, EDF



- Promising Developments with Substracted Second Random Phase Approximation

- - Resolving quenching issues for β decay with Ab-initio calculations and two-body currents, Recent Ab-initio ^{48}Ca matrix elements with CC and IMSRG techniques
- New leading Contribution to $(\beta\beta)_{0\nu}$ mode

Engel, Menendez,
Rep. Prog. Phys. 80 046301 (2017)

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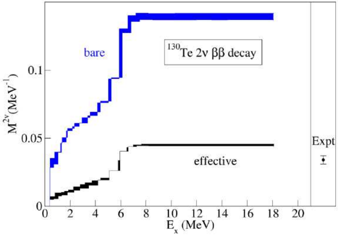
PHYSICAL REVIEW C **100**, 014316 (2019)

Renormalization of the Gamow-Teller operator within the realistic shell model

L. Coraggio,[1] L. De Angelis,[1] T. Fukui,[1] A. Gargano,[1] N. Itaco,[2,1] and F. Nowacki[3,4,2]



Renormalisation of the $(\beta\beta)_{2\nu}$ operator by MBPT
Collaboration IPHC - INFN/Université de Naples

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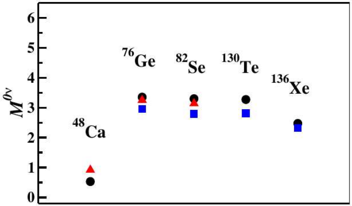
PHYSICAL REVIEW C **101**, 044315 (2020)

Calculation of the neutrinoless double-β decay matrix element within the realistic shell model

L. Coraggio,[1] A. Gargano,[1] N. Itaco,[2,1] R. Mancino,[2,1] and F. Nowacki[3,2]



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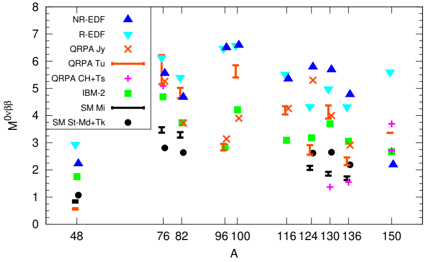

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Towards reliable predictions of NMEs for $(\beta\beta)_{0\nu}$ within SSQRPA

$$[T^{0\nu}_{1/2}(0^+ \to 0^+)]^{-1} = G_{0\nu}|M^{0\nu}|^2\langle m_\nu^{\beta\beta}\rangle^2$$

- A Gamow-Teller (GT)-type term is the dominant contribution in NMEs

- Even if the two processes have of course a different nature,) NMEs predictions would be more trusworthy if the employed many-body model is able to provide GT spectra in agreeement with experiment (well-known problem of the missing strength: the operators are quenched by hand to reproduce data)

- Incoherence and open problem: available many-body models often use by-hand-quenched operators in GT, quenched axial-vector coupling constant g_A value in single β decay, and the bare value of g_A in $(\beta\beta)_{0\nu}$!!

- **Promising direction:** with the Substracted Second Random-Phase Approximation (SSRPA) an important amount of GT strengt is naturally pushed at higher energies in agreement with the data. The experimental spectra are reproduced without altering excitation operator. This model can be safely used for computing NMEs with bare g_A

PHYSICAL REVIEW LETTERS **125**, 212501 (2020)

Gamow-Teller Strength in ^{48}Ca and ^{78}Ni with the Charge-Exchange Subtracted Second Random-Phase Approximation

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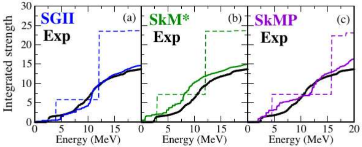
[2]Université Paris-Saclay, CNRS/IN2P3, IJCLab, 91405 Orsay, France
[3]Department of Physics and Astronomy, CB 3255, University of North Carolina, Chapel Hill, North Carolina 27599-3255, USA

Integrated GT Strength up to 20 MeV in ^{48}Ca



For the first time, the GT spectrum of ^{48}Ca is reproduced without resorting to quenching

Collaboration with LNS Catania, Italy and North Carolina University,US

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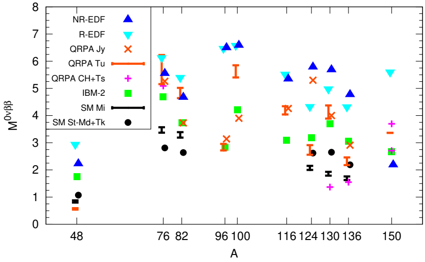
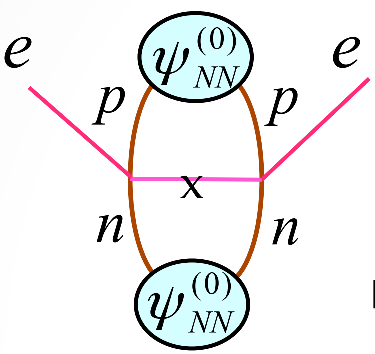


Engel, Menendez,
Rep. Prog. Phys. 80 046301 (2017)

A New Leading Mechanism for Neutrinoless Double-Beta Decay

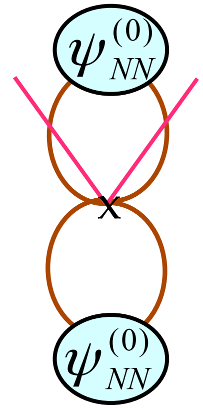
V. Cirigliano, …, U. van Kolck, *Phys. Rev. Lett.* **122** (2019) 143001; *Phys. Rev. C* **100** (2019) 055504

light Majorana neutrino exchange



Chiral Effective Field Theory

renormalization



short-range exchange

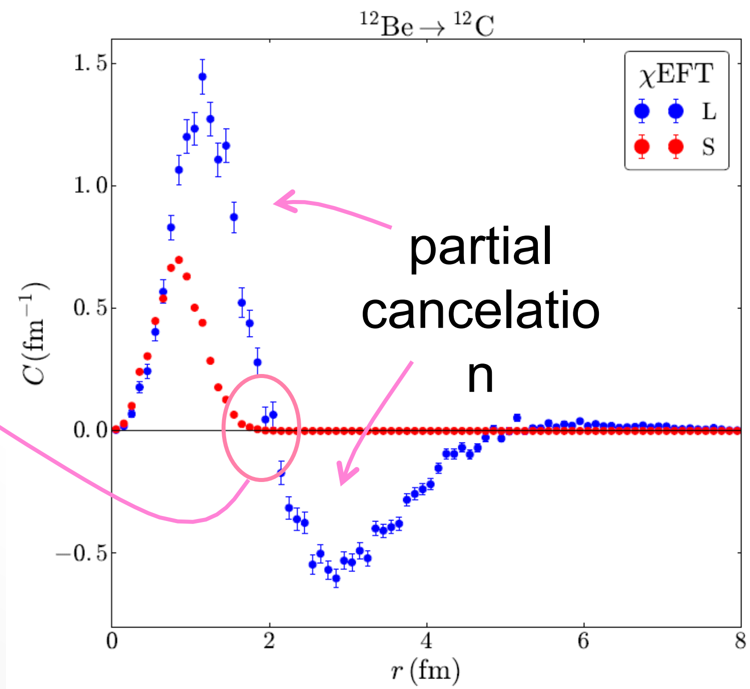
- eventually calculable in lattice QCD
- *estimated* from charge-independence breaking

… but neglected in *all* existing calculations

Variational Monte Carlo

orthogonality initial/final states

feature of realistic transitions



nuclear matrix element:

$$A_{0\nu 2\beta} = \int dr\, C(r)$$

$$\frac{A^{(S)}_{0\nu 2\beta}}{A^{(L)}_{0\nu 2\beta}} \approx 0.8$$

SIGNIFICANT!

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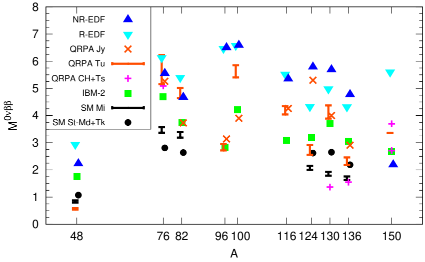

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