Perturbation of transition operators of double-β decay

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0νββ: neutrinoless double-β; 2νββ: two-neutrino double-β
QRPA: quasiparticle random-phase approximation
NME: nuclear matrix element

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1. Purpose and background

To solve the uncertainty problem of the 0νββ NME

J. T. investigated the validity of the QRPA with Skyrme (SkM*) + Coulomb + contact pairing interaction for ^{136}Xe by theoretical self-checks and comparisons with exp. data.
J. T. and Y. Iwata, Phys. Rev. C **100**, 034325 (2019).

The QRPA + those interactions is excellent for ^{136}Xe.

The effective g_A for 2νββ decay is 0.42 << 1.27.

⇒ Need to apply perturbation theory to calculate corrections to the transition matrix elements

Another motivation

It is possible to obtain effective g_A (g_A^{eff}) by referring to the perturbed NME. What is the g_A^{eff} for the 0νββ decay?

2. Extension of NME

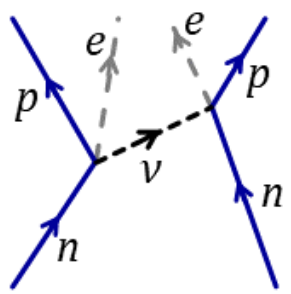
Basic principle ≡ hybrid model of two approaches

- Application of the quantum field theory to leptons
- Application of the Rayleigh-Schrödinger perturbation theory to nucleons

Extension of NME

- Apply the **2nd-order** perturbed wave function for the transition matrix element.
- Set the transition operator and **one** perturbation interaction to the **hadron current**. Set **the other one** to the **residual NN interaction.**
- Suppress the double counting.
- Factorization to the electron and the ν-nuclear sectors (0νββ).
- Choose the terms including only the **perturbation of the transition operator,** referring to diagrams.

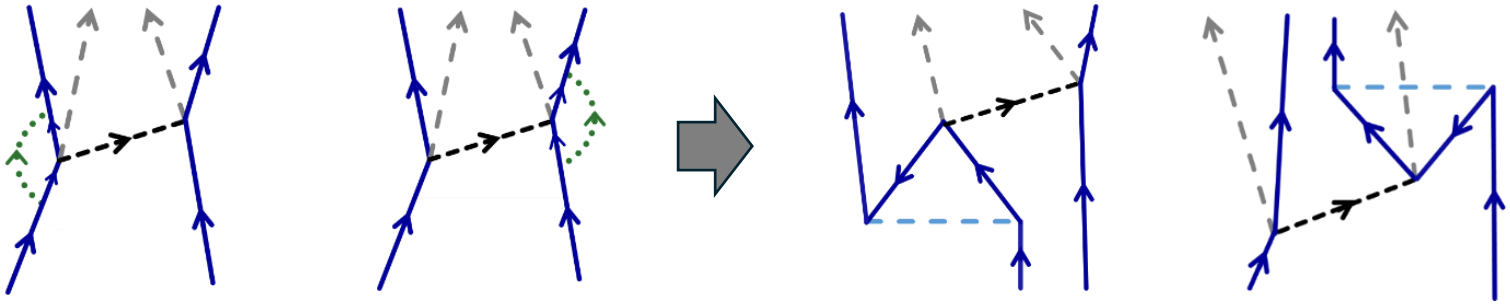
3. Diagrams to calculate 0νββ NME



Leading order with respect to vertex

Incoming → to a vertex : annihilation of nucleon

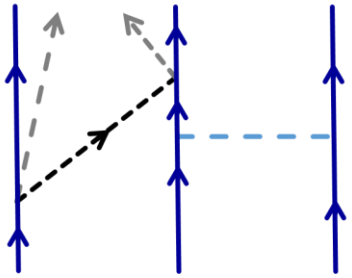
Outgoing → from a vertex : creation of nucleon



Green dots: pion

Vertex correction (VC)

Light blue dashed: NN interaction potential



Two-body current (2BC) correction

4a. Result of calculation, NME

SkM*				
	0νββ NME		2νββ NME	
	GT	Fermi	GT	Fermi
Leading	3.095	–0.467	0.102	–0.00221
VC	1.332	–0.984	0.0545	–0.0328
2BC	–2.731	1.758	–0.192	0.0301
Sum	1.695	0.306	–0.035	–0.00488

- The correction terms are comparable with the leading terms.
- The summed correction has the opposite sign to that of the leading term.
- If g_A = 1.27 is used, leading $M_{0\nu}^{(0)}$ = 3.384,
  with the corrections $M_{0\nu}$ = 1.505.
- 90% of VC and 2BC terms of 2νββ Fermi component; symmetry conserving truncation.

4b. Result of calculation, g_A^{eff}

Four kinds of g_A^{eff} are introduced.

$$\left(g_{A,0\nu}^{\mathrm{eff}}(\mathrm{ld};\mathrm{pert})\right)^2 M_{0\nu}^{\mathrm{GT}(0)} - g_V^2 M_{0\nu}^{\mathrm{Frm}(0)} = g_A^2 M_{0\nu}^{\mathrm{GT}} - g_V^2 M_{0\nu}^{\mathrm{Frm}},$$

The ld implies this g_A^{eff} is used with the leading GT and Fermi comp. The pert implies this g_A^{eff} is deter -mined referring to the perturbed NME (g_A=1.27)

Perturbed (leading+VC+2BC) GT comp. of 0vββ NME

g_A= 1.27, g_V= 1.0.

- Analogous definition for 2vββ NME introduced [$g_{A,2\nu}^{\mathrm{eff}}(\mathrm{ld};\mathrm{pert})$].
- Experimental half-life can be used for the 2vββ g_A^{eff}. That for ^{136}Xe is 2.18×10^{21} y.

$g_{A,2\nu}^{\mathrm{eff}}(\mathrm{ld};\ \mathrm{phen})$ and $g_{A,2\nu}^{\mathrm{eff}}(\mathrm{pert};\ \mathrm{phen})$

phenomenological

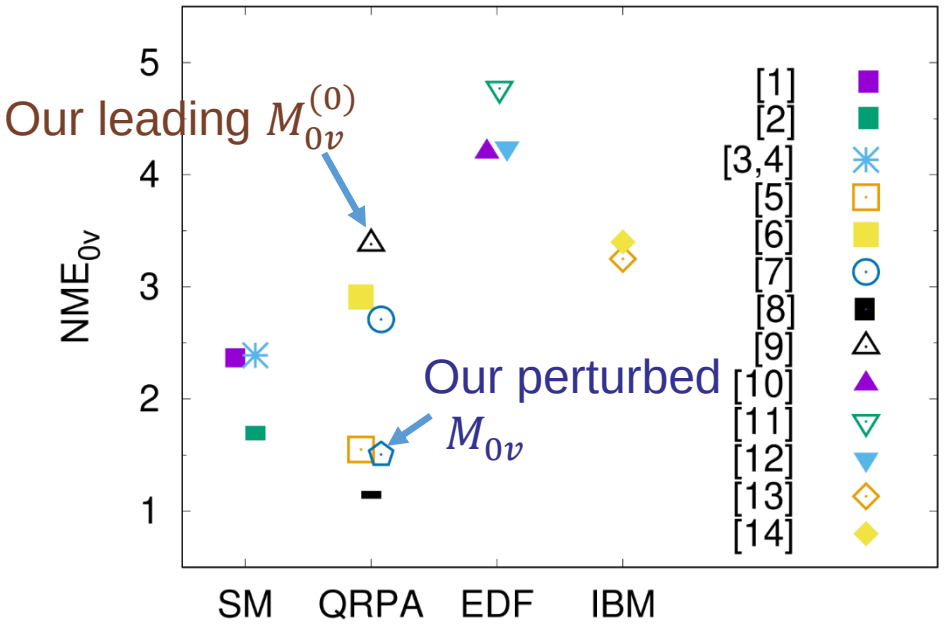
SkM*				
g_A^{eff} by different methods	Decay	Used GT and Fermi components	Reference to reproduce	Value
$g_{A,0\nu}^{\mathrm{eff}}(\mathrm{ld};\ \mathrm{pert})$	0νββ	Leading	Half-life with perturbed NME and bare g_A	0.796
$g_{A,2\nu}^{\mathrm{eff}}(\mathrm{ld};\ \mathrm{pert})$	2νββ	Leading	Half-life with perturbed NME and bare g_A	0.696
$g_{A,2\nu}^{\mathrm{eff}}(\mathrm{ld};\ \mathrm{phen})$	2νββ	Leading	Experimental half-life	0.422
$g_{A,2\nu}^{\mathrm{eff}}(\mathrm{pert};\ \mathrm{phen})$	2νββ	Perturbed	Experimental half-life	0.806

- Three of these g_A^{eff} are close: 0.7– 0.8.

The g_A^{eff} for the 0νββ NME is not quite different from that for the 2νββ NME.

- The smaller g_A^{eff}, the larger perturbation effect.

4c. 0νββ NME with bare g_A for ^{136}Xe of various groups



[1], [2], and [8] show vertical ranges. The other symbols show single values.

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See also I. Shimizu, Int. Conf. Neutrino 2024.

5. Summary

- We calculated the NME of ββ decay with the transition operator perturbed by the nuclear interaction.
- The perturbation effect is significant. The NME is reduced.
- Four g_A^{eff} were calculated depending leading or perturbed and the reference.
- Similarities are found for some of those g_A^{eff}'s including that of the 0νββ NME.

The g_A^{eff} of the 0νββ NME is close to that of 2νββ calculated by the same method.
The 0νββ g_A^{eff} is no longer unknown at all.

We will also calculate other nuclei in the future.