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Two-neutrino double beta decay in the DFT-rooted No-Core Configuration Interaction model

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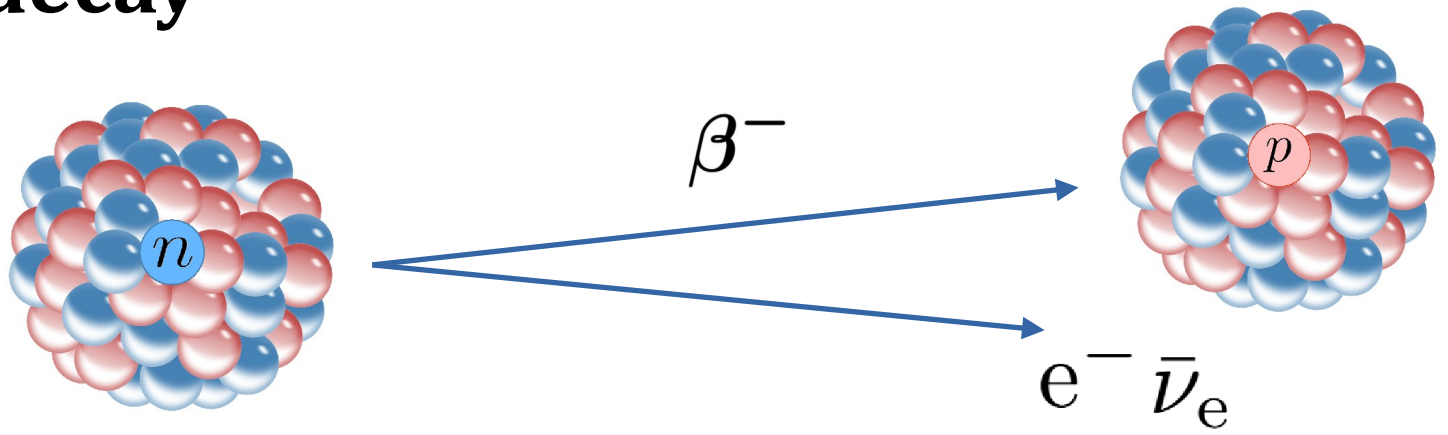
Beta decay

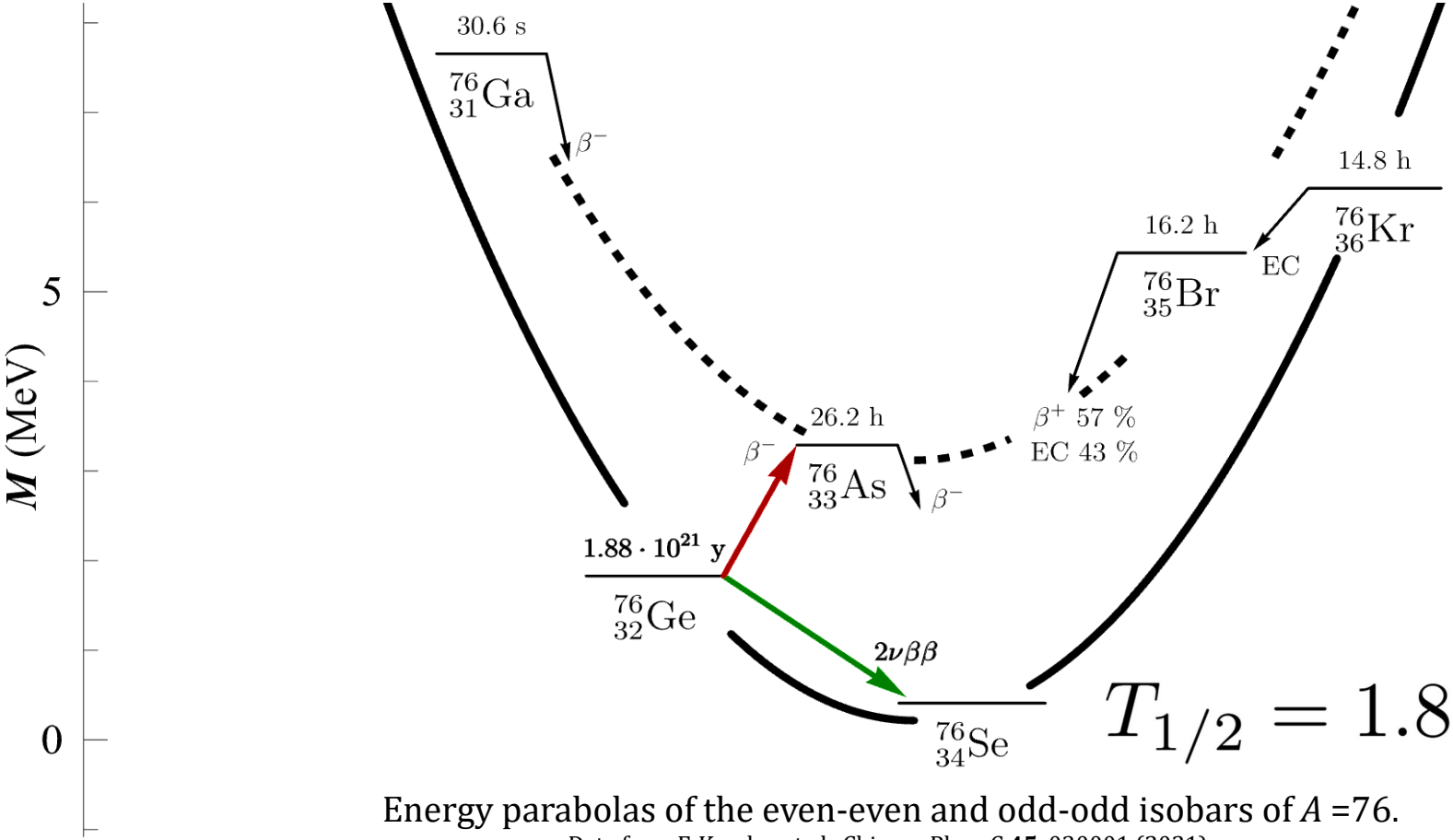


Quantum-wise: $\hat{\mathcal{H}}_\beta = \frac{G_F}{\sqrt{2}} J^{\mu\dagger} j_\mu + \text{h.c.}$

Annihilation-creation of a hadron (p,n)

Annihilation-creation of a lepton (e,ν_e)

Double beta decay



$$T_{1/2} = 1.88 \cdot 10^{21}\text{y. !}$$

Energy parabolas of the even-even and odd-odd isobars of A =76.

Data from F. Kondev et al., Chinese Phys. C **45**, 030001 (2021).

Nuclear matrix element

$$T_{1/2}^{-1} = \underbrace{G_{2\nu\beta\beta}(Z,E)}_{\textit{leptonic part}} \cdot \underbrace{|\mathcal{M}_{2\nu\beta\beta}|^2}_{\textbf{\textit{nuclear matrix element}}}$$

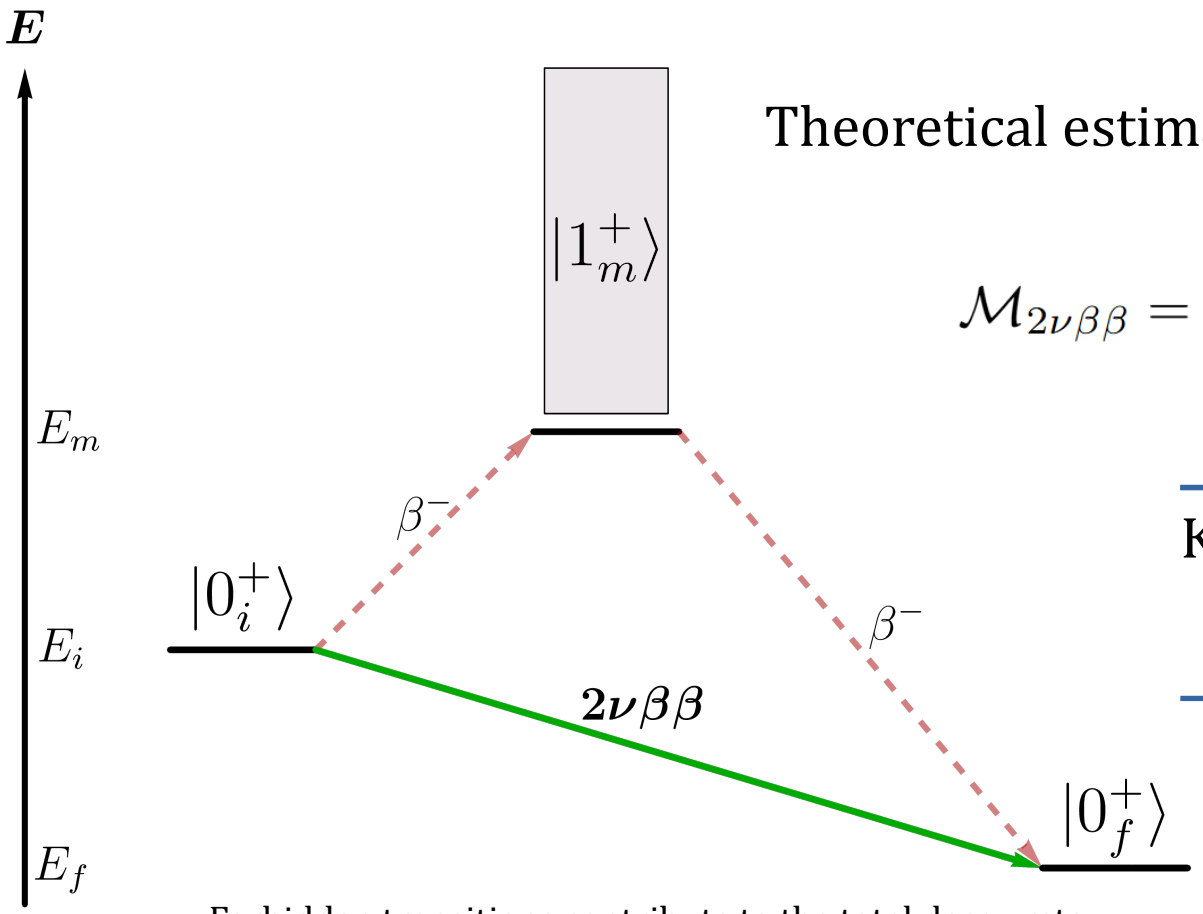
(all nuclear QM)

$$\sim G_F^4$$

Extremely rare!

(only **11** nuclei)

Fermi golden rule of the 2nd order



Theoretical estimation via **virtual** transitions:

$$\mathcal{M}_{2\nu\beta\beta} = \sum_m \frac{\langle 0_f^+ | \hat{H}_\beta | \mathbf{1_m^+} \rangle \langle \mathbf{1_m^+} | \hat{H}_\beta | 0_i^+ \rangle}{\boldsymbol{\Delta E_m} + \frac{1}{2} Q_{\beta\beta} + \Delta M}$$

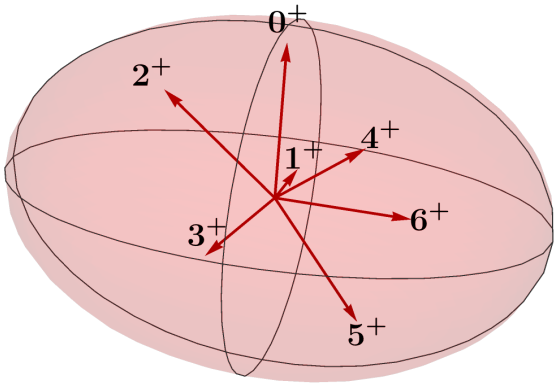
Key difficulty: constructing

$$|0_i^+\rangle, |1_m^+\rangle, |0_f^+\rangle$$

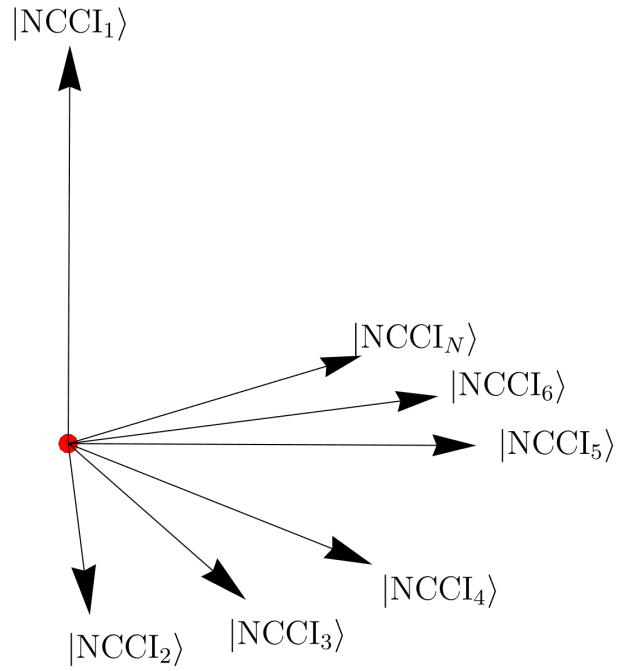
Forbidden transitions contribute to the total decay rate.

NCCI based on Skyrme nuclear density functional

Kohn-Sham $\left|\Psi_i\right\rangle$



$I^\pi(T)$ – projection
configuration mixing
rediagonalization



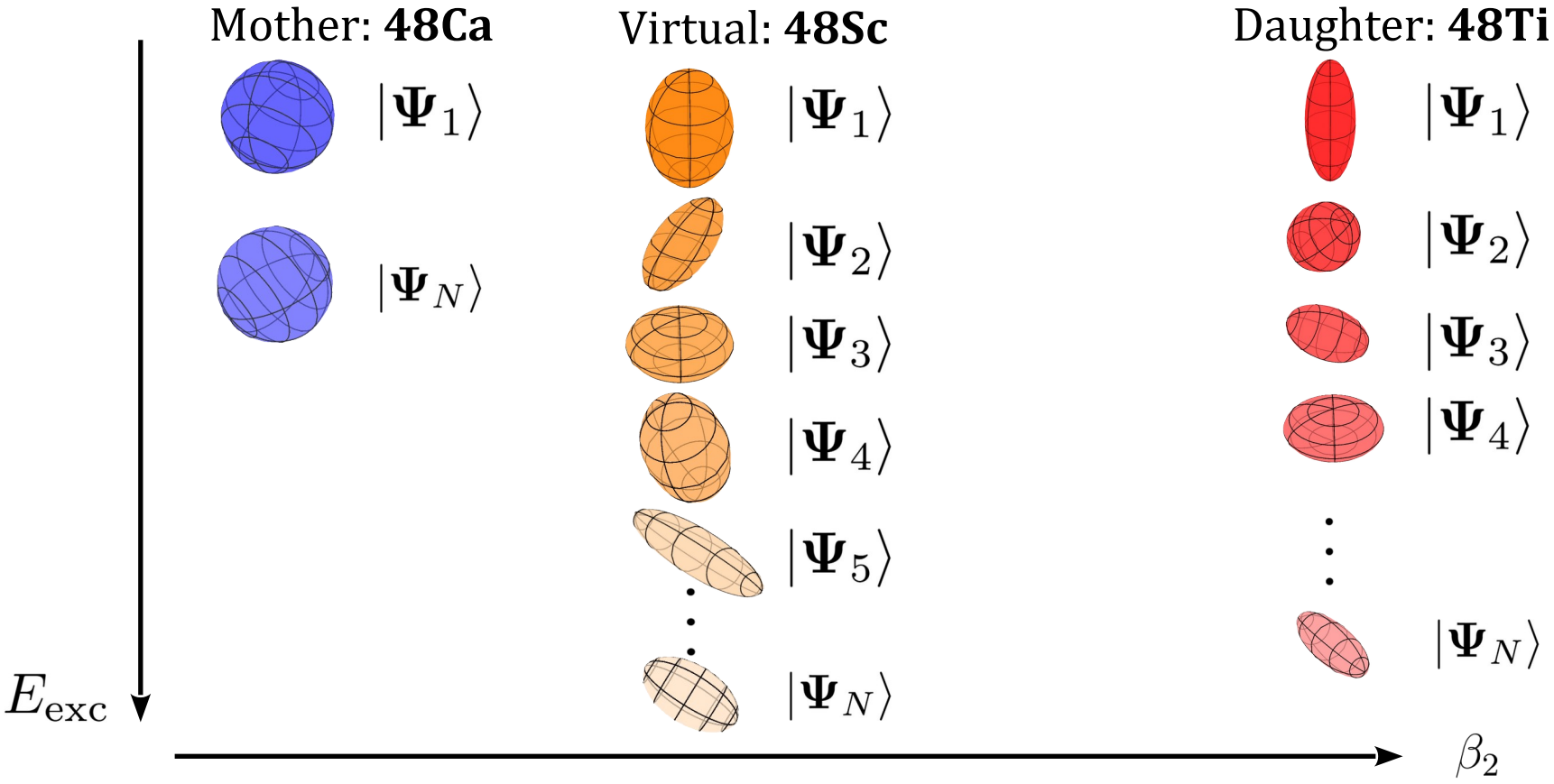
no good quantum numbers
~~γ, β transitions~~

good quantum numbers
γ, β transitions

Ref: W. Satuła et al., Phys. Rev. C ***94****, 024306 – 024319 (2016)*

48Ca → 48Ti case

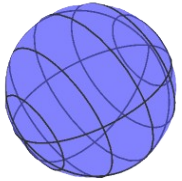
1) Construction of mean-field configurations with Skyrme SV force:



48Ca → 48Ti case

2) I^{π} - projection:

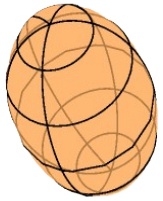
48Ca
$|\Psi_i\rangle$



$\hat{P}^I_{MK}$

$|\Psi_{i1};0^+\rangle$
$\vdots$
$|\Psi_{i\alpha};0^+\rangle$
$\vdots$

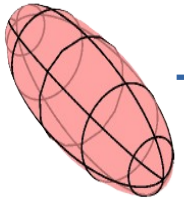
48Sc
$|\Psi_m\rangle$



$\hat{P}^I_{MK}$

$|\Psi_{m1};1^+\rangle$
$\vdots$
$|\Psi_{m\beta};1^+\rangle$
$\vdots$

48Ti
$|\Psi_f\rangle$



$\hat{P}^I_{MK}$

$|\Psi_{f1};0^+\rangle$
$\vdots$
$|\Psi_{f\gamma};0^+\rangle$
$\vdots$

3) Partial Gamow-Teller elements:

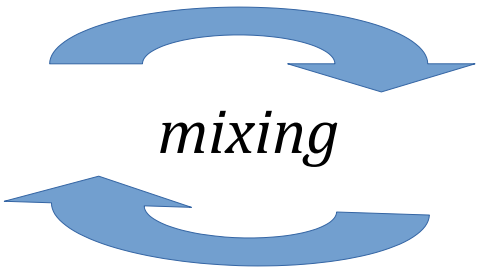
$$\mathcal{M}_{fm} = \langle \Psi_{m\alpha};0^+|\hat{H}_{\mathrm{GT}}|\Psi_{m\beta};1^+\rangle$$

$$\mathcal{M}_{mi} = \langle \Psi_{m\beta};1^+|\hat{H}_{\mathrm{GT}}|\Psi_{i\alpha};0^+\rangle$$

48Ca → 48Ti case

4) Configuration mixing of the projected states:

48Sc: $|\Psi_{m1}; 1^+\rangle$ ⋮ $|\Psi_{m\beta}; 1^+\rangle$ ⋮



$|\mathrm{NCCI}_{m1}; 1^+\rangle$
$|\mathrm{NCCI}_{m2}; 1^+\rangle$
⋮
$|\mathrm{NCCI}_{m\beta}; 1^+\rangle$
⋮

*+ same for **48Ca** and **48Ti***

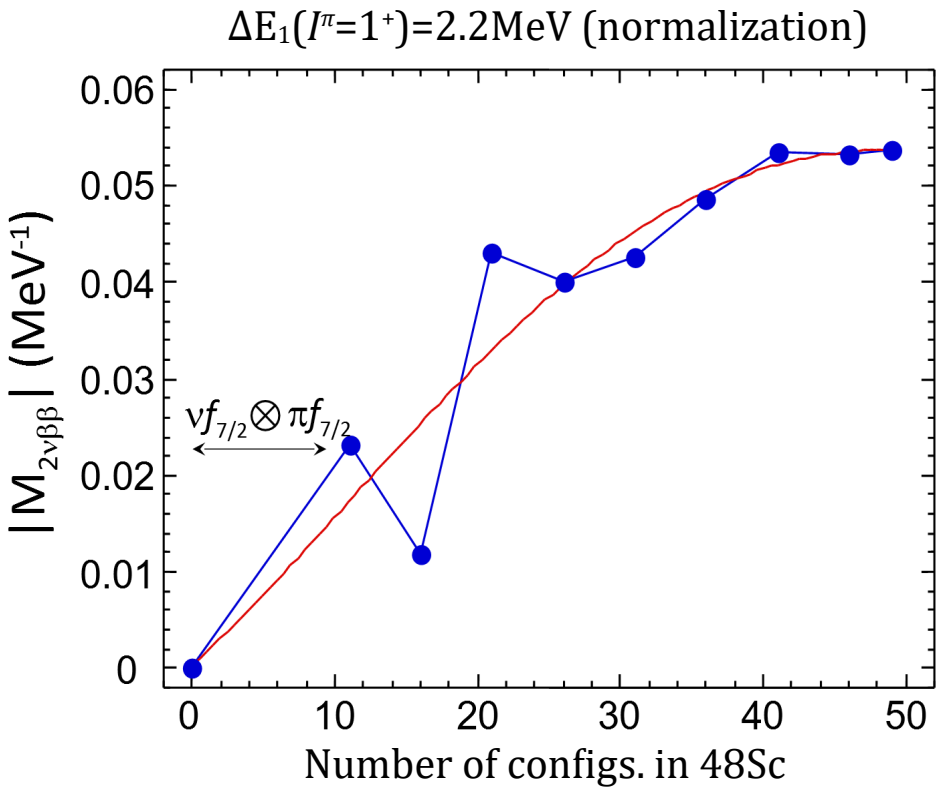
5) Calculation of the cumulative 2*νββ* matrix element :

$$\mathcal{M}_{2\nu\beta\beta} = \sum_m \frac{\langle \mathrm{NCCI}_f | \hat{H}_{\mathrm{GT}} | \mathrm{NCCI}_m \rangle \langle \mathrm{NCCI}_m | \hat{H}_{\mathrm{GT}} | \mathrm{NCCI}_i \rangle}{\underbrace{\Delta E_j + \frac{1}{2} Q_{\beta\beta} + \Delta M}_{\text{taken from experiment}}}$$

*The whole procedure has been performed **numerically** within DFT-based **HFODD** code (open access).*

48Ca → 48Ti case

Resulting cumulative $|\mathcal{M}_{2\nu\beta\beta}|$**:**



saturation at **0.054** (MeV^{-1})

0.027 (dimless)

$qg_A = 1$

SV functional

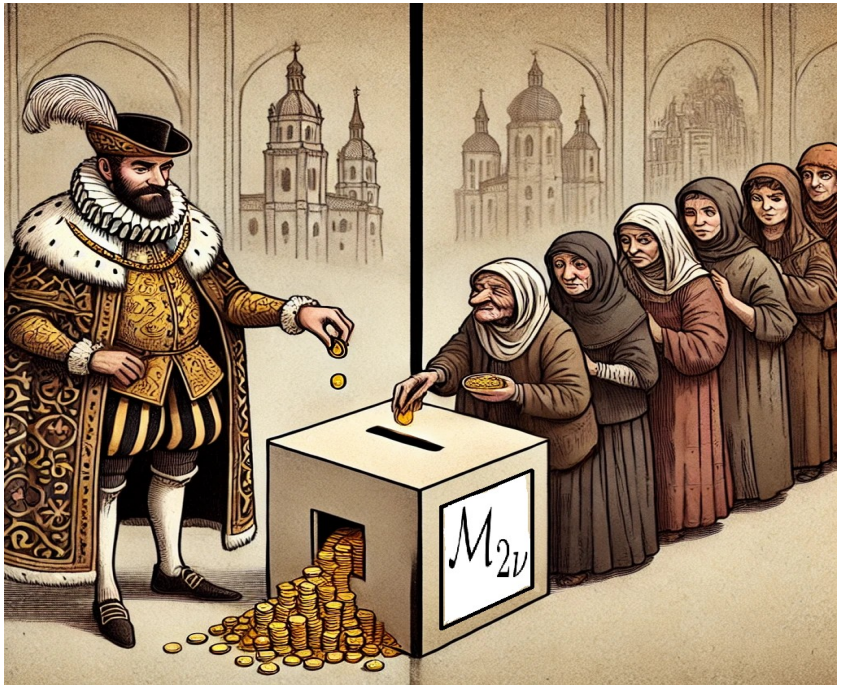
48Ca – 11 configs.

48Ti – 39 configs.

48Ca → 48Ti case

Expectations:

Highest contribution from the strongest partial GTs



Unexpected reality:

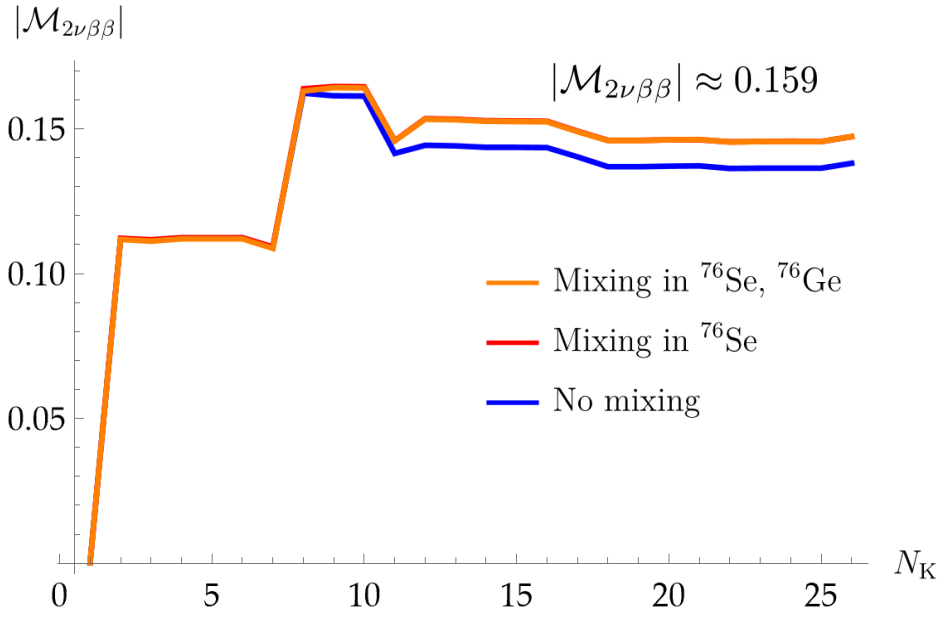
- NCCI mixing of crumble (~0.001) GTs makes up **88%** of the total matrix element!
- Key factor: NCCI mixing in **daughter**

Nuclear widow's mite:
many small contributions > few huge

Exclusive for 48Ca, or a rule for heavier?

Status and future plans for 76Ge and 136Xe

Preliminary estimation for ***76Ge*** *nucleus.*



Summing contributions from $|^{76}\mathrm{As}; 1^+\rangle$ up to saturation. $\Delta E_1(I^\pi=1^+)$=100keV (normalization).

- High triaxiality (γ~27-30°) in each nucleus – little control over single-particle occupancy
- Spectrum highly dependent on the spin-orbit magnitude in Skyrme SV

Status and future plans for 76Ge and 136Xe

136Xe *– initial stage*

- Configuration convergence in progress
- Prolate shape for 136Xe, 136Cs and 136Ba expected as dominant
- Little deformation so far (β~0.03-0.05)

What next?

- Implementation of **neutrinoless** matrix elements into **DFT-NCCI** framework (HFODD)
- Tests of the model on the (hypothetical) $\mathbf{0\nu\beta\beta}$ decay.