

GAMOW-TELLER RESONANCE AND DOUBLE-BETA DECAY OF ^{48}Ca WITHIN THE STDA FRAMEWORK

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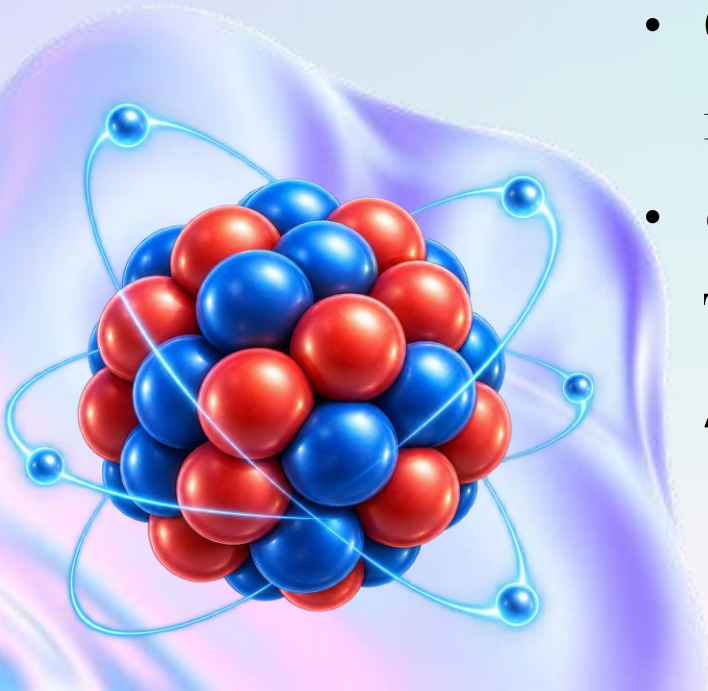
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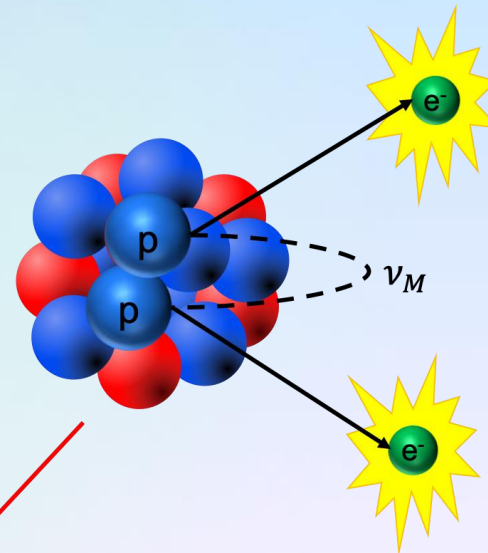
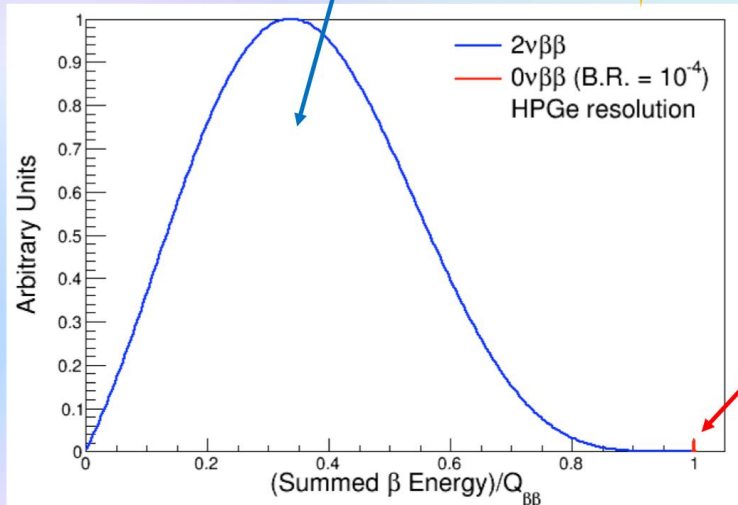
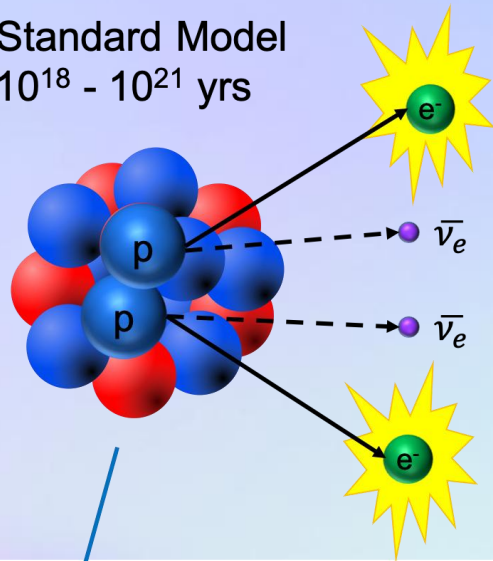
Motivation

- ^{48}Ca is one of the key nuclei for studies of double-beta decay.
- Both Gamow–Teller response and $2\nu\beta\beta$ decay are governed by the spin–isospin operator.
- Standard 1p1h descriptions reproduce the collective GT resonance only partially; experimentally, the GT strength is fragmented and quenched.
- Coupling to more complex configurations, particularly 2p2h excitations, can redistribute GT strength and introduce correlations relevant for $\beta\beta$ decay.
- *Goal:* investigate GT strength and double-beta decay within the Second Tamm–Dancoff Approximation (STDA) using a chiral $\Delta\text{NNLO}_{\text{GO}}$ (394), $\Delta\text{NNLO}_{\text{GO}}$ (450), $\text{N}^3\text{LO}_{\text{Texas}}$, NNLO_{opt} interactions.



Theoretical background

$2\nu\beta\beta$ – Standard Model
 $\tau_{1/2} = 10^{18} - 10^{21}$ yrs



$0\nu\beta\beta$ – New Physics!
 $\tau_{1/2} > 10^{26}$ yrs

$$\left(T_{1/2}^{2\nu}\right)^{-1} = G^{2\nu} g_A^4 m_e^2 \left| M_{GT} - \frac{M_F}{g_A^2} \right|^2$$

Experimental 2ν decay half-lives

Parent / transition	Mode	$T_{1/2}^{2\nu}$ [yr]
$^{48}\text{Ca} \rightarrow ^{48}\text{Ti}$	$2\nu\beta\beta$	$5.3(+1.2/-0.8) \times 10^{19}$
$^{76}\text{Ge} \rightarrow ^{76}\text{Se}$	$2\nu\beta\beta$	$(1.88 \pm 0.08) \times 10^{21}$
$^{82}\text{Se} \rightarrow ^{82}\text{Kr}$	$2\nu\beta\beta$	$0.87(+0.02/-0.01) \times 10^{20}$
$^{96}\text{Zr} \rightarrow ^{96}\text{Mo}$	$2\nu\beta\beta$	$(2.3 \pm 0.2) \times 10^{19}$
$^{100}\text{Mo} \rightarrow ^{100}\text{Ru (g.s.)}$	$2\nu\beta\beta$	$7.06(+0.15/-0.13) \times 10^{18}$
$^{100}\text{Mo} \rightarrow ^{100}\text{Ru (0}_1^+)$	$2\nu\beta\beta$	$6.7(+0.5/-0.4) \times 10^{20}$
$^{116}\text{Cd} \rightarrow ^{116}\text{Sn}$	$2\nu\beta\beta$	$(2.69 \pm 0.09) \times 10^{19}$
$^{128}\text{Te} \rightarrow ^{128}\text{Xe}$	$2\nu\beta\beta$	$(2.25 \pm 0.09) \times 10^{24}$
$^{130}\text{Te} \rightarrow ^{130}\text{Xe}$	$2\nu\beta\beta$	$(7.91 \pm 0.21) \times 10^{20}$
$^{136}\text{Xe} \rightarrow ^{136}\text{Ba}$	$2\nu\beta\beta$	$(2.18 \pm 0.05) \times 10^{21}$
$^{150}\text{Nd} \rightarrow ^{150}\text{Sm (g.s.)}$	$2\nu\beta\beta$	$(9.34 \pm 0.65) \times 10^{18}$
$^{150}\text{Nd} \rightarrow ^{150}\text{Sm (0}_1^+)$	$2\nu\beta\beta$	$1.2(+0.3/-0.2) \times 10^{20}$
$^{238}\text{U} \rightarrow ^{238}\text{Pu}$	$2\nu\beta\beta$	$(2.0 \pm 0.6) \times 10^{21}$
$^{78}\text{Kr} \rightarrow ^{78}\text{Se}^{(b)}$	ECEC (2ν)	$1.9(+1.3/-0.8) \times 10^{22}$
$^{124}\text{Xe} \rightarrow ^{124}\text{Te}^{(b)}$	ECEC (2ν)	$(1.8 \pm 0.5) \times 10^{22}$
$^{130}\text{Ba} \rightarrow ^{130}\text{Xe}$	ECEC (2ν)	$(2.2 \pm 0.5) \times 10^{21}$

Nuclear matrix element

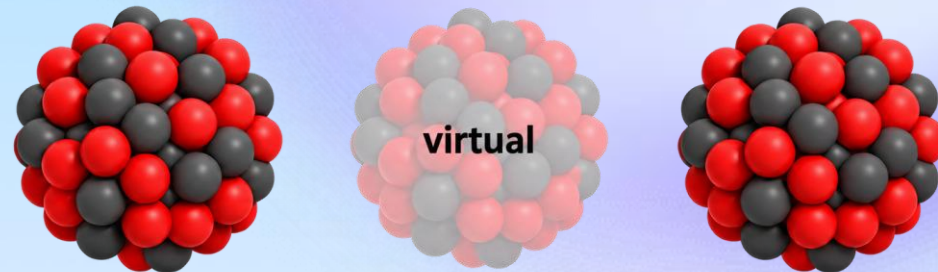
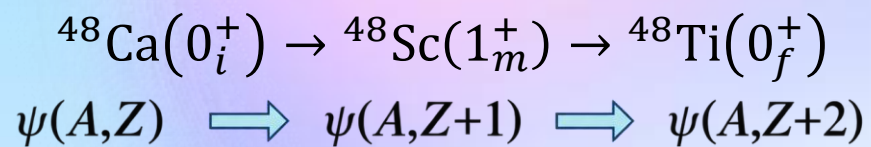
$$M_{F,GT}^{2\nu} = \sum_n \frac{\langle f \| \hat{O}_{F,GT} \| J_n^+ \rangle \langle J_n^+ \| \hat{O}_{F,GT} \| i \rangle}{E_n - (E_i + E_f)/2}$$

Fermi operator

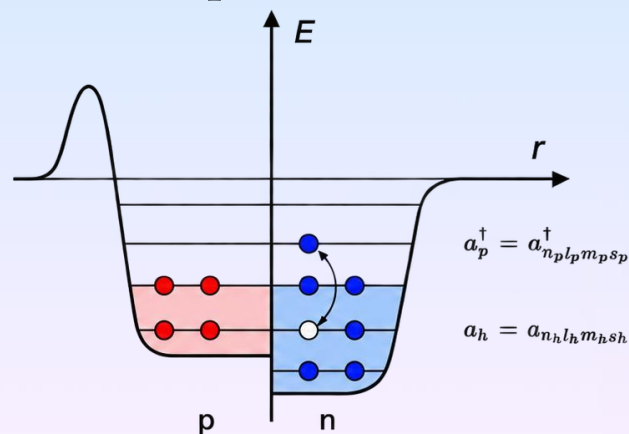
$$\hat{O}_F = \sum_{k=1}^A \tau_k^+$$

Gamow-Teller operator

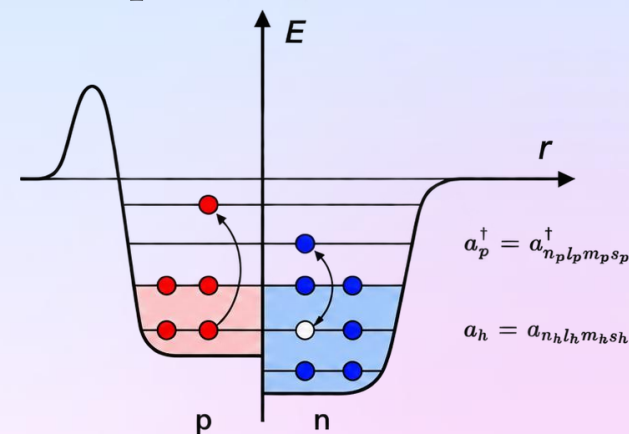
$$\hat{O}_{GT} = \sum_{k=1}^A \sigma_k \tau_k^+$$



1p-1h excitations



2p-2h excitations



The GT^- transition strength

$$B(GT; i \rightarrow f) = \frac{1}{2J_i + 1} \left\| \left\langle f \left\| \sum_k \boldsymbol{\sigma}(k) \tau_k^\pm \right\| i \right\rangle \right\|^2$$

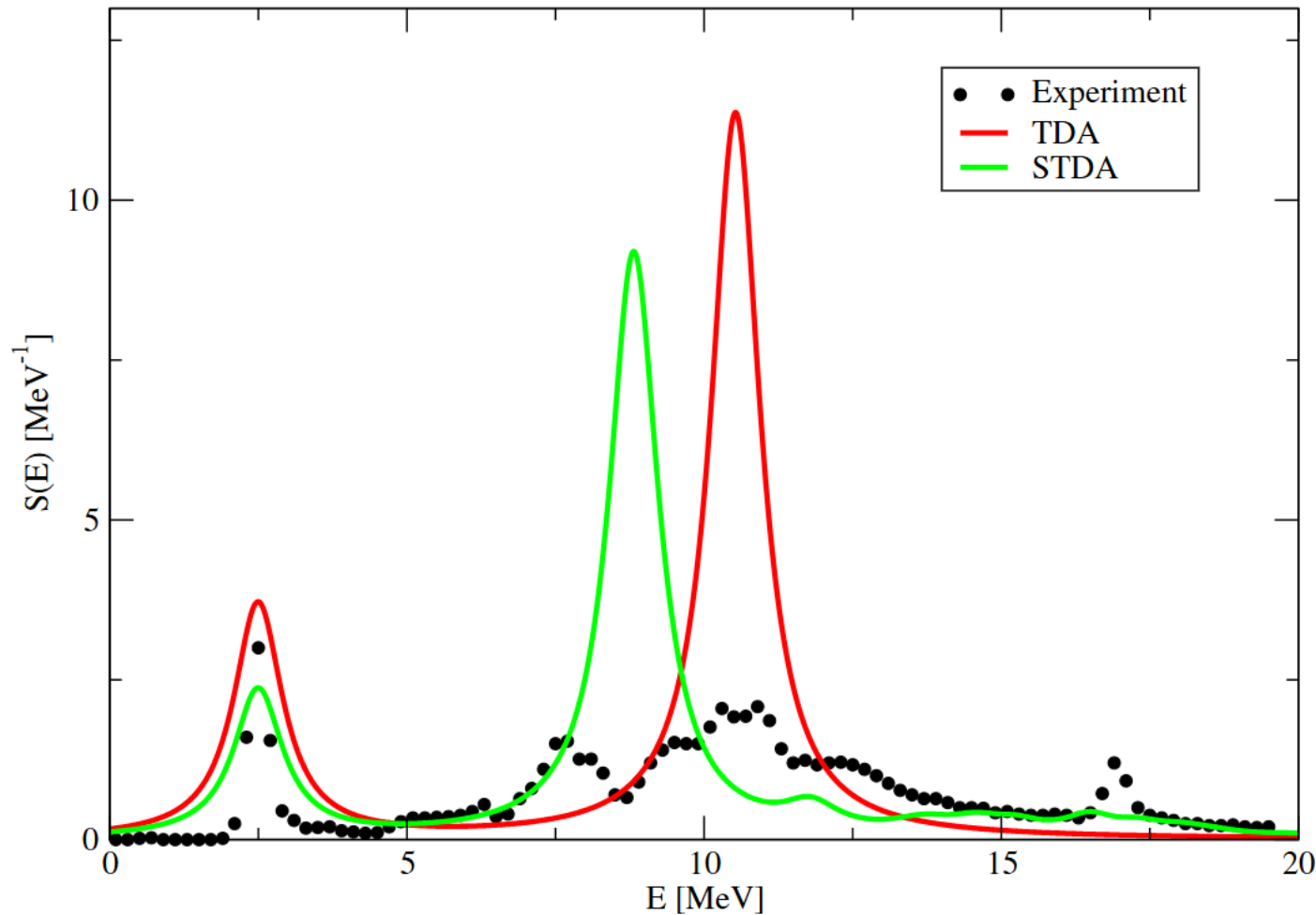
Strength function

$$S(E) = \sum_\lambda |\langle \Psi_\lambda | \hat{O}_{GT} | \Psi_i \rangle|^2 \zeta_\Delta(E - E_\lambda)$$

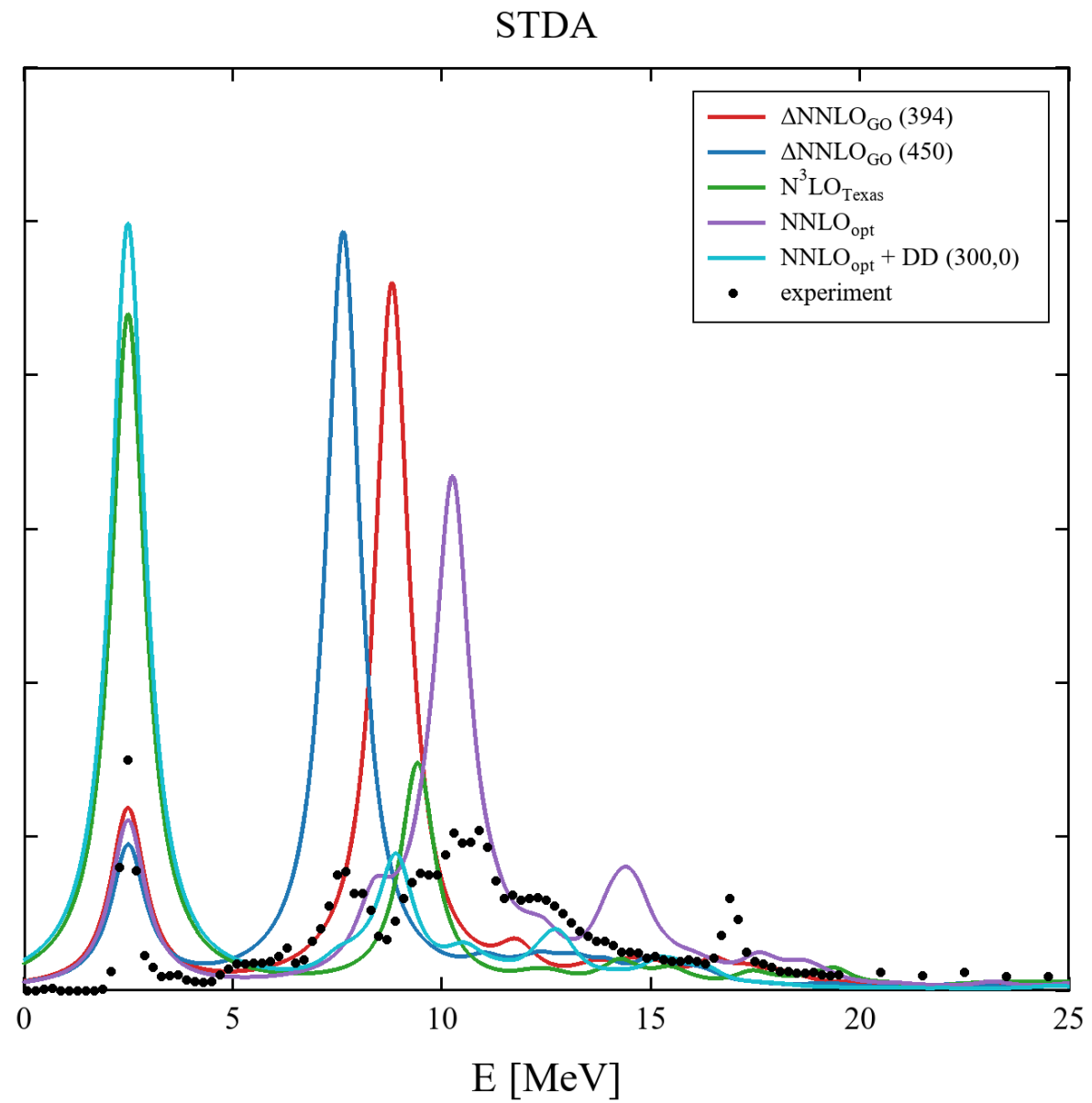
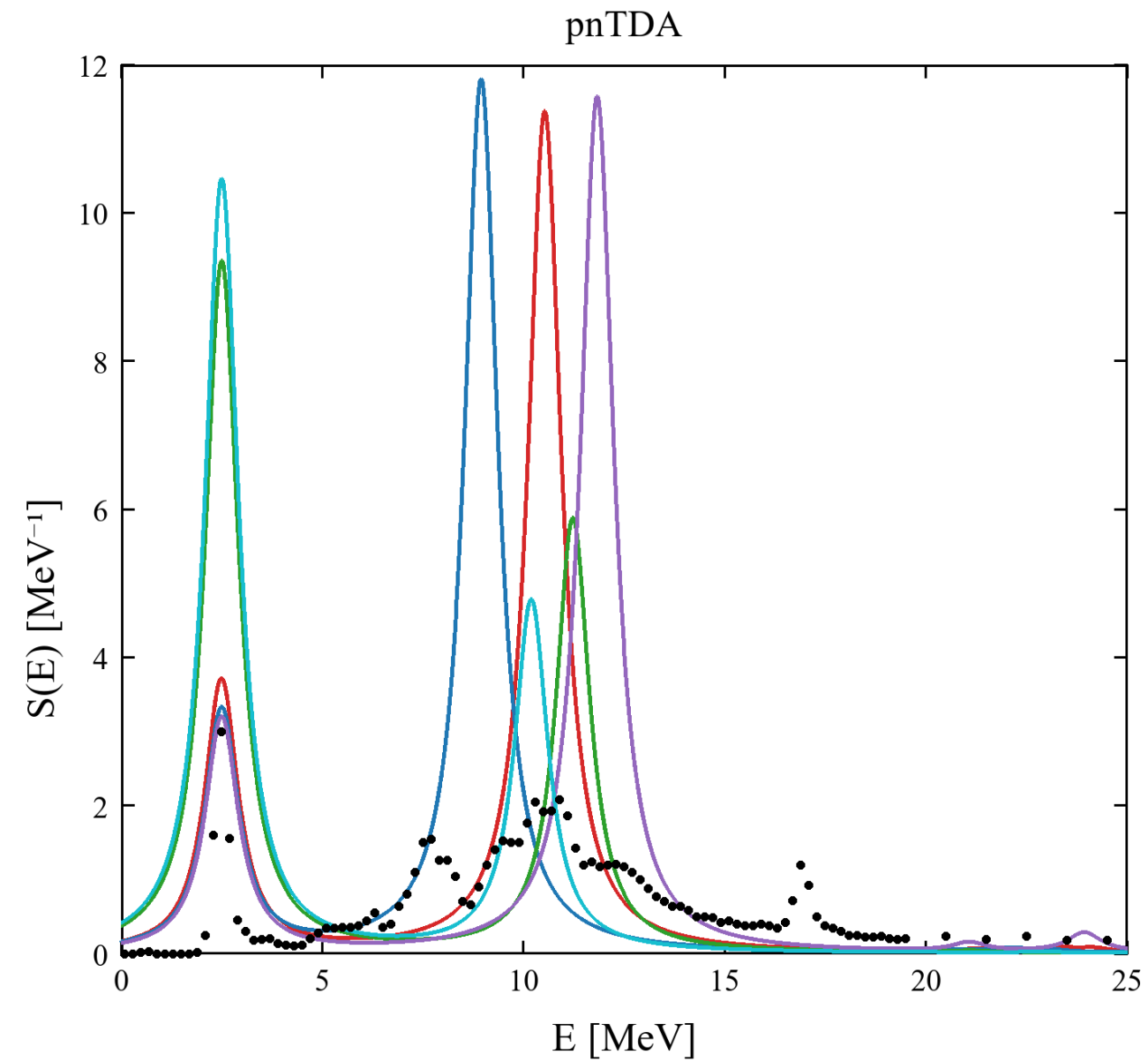
Lorentzian curve of width Δ

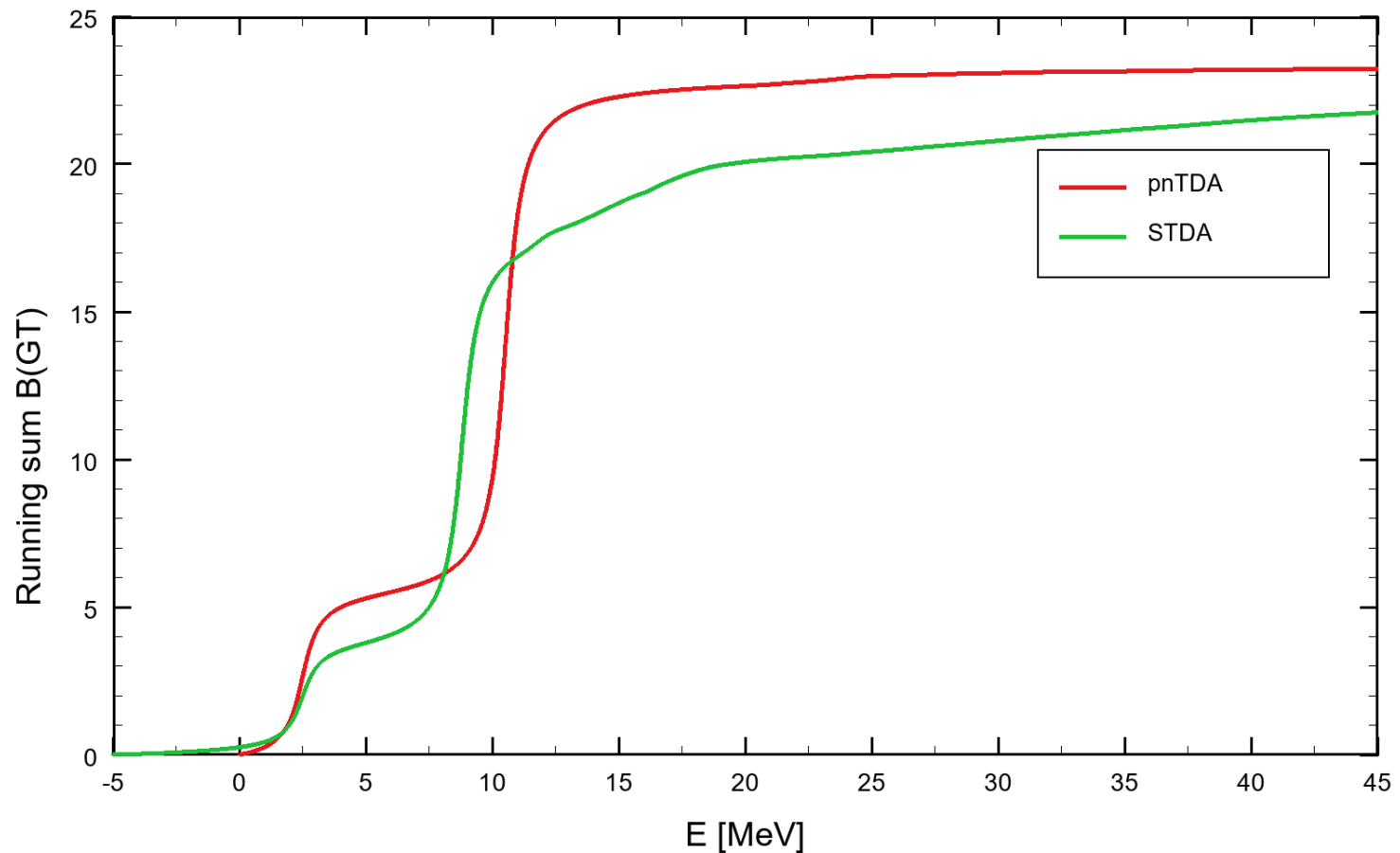
$$\zeta_\Delta = \frac{1}{2\pi} \frac{\Delta}{(E - E_\lambda)^2 + (\Delta/2)^2}$$

Results



- TDA, and STDA, strength functions of GT⁻ transitions from ⁴⁸Ca to ⁴⁸Sc compared to the experimental points extracted from the measurement of ⁴⁸Ca(p,n)⁴⁸Sc.
- Δ NNLO_{GO} (394) interaction was used.
- Experimental data from: K. Yako, et al., Phys. Rev. Lett. 103, (2009) 012503





Ikeda Sum Rule

$$\Sigma_{\text{Ikeda}}(^{48}\text{Ca}) = 3(N - Z) = 24.$$

$\Delta\text{NNLO}_{\text{GO}}$ (394) interaction was used.

The dependence of Fermi M_F^I , M_F^{II} , and Gamow-Teller M_{GT}^I , M_{GT}^{II} , NMEs of $2\nu\beta\beta$ -decay depending on the applied potentials $\Delta NNLO_{GO}$ (394), $\Delta NNLO_{GO}$ (450), and N^3LO_{Texas} .

Potential	$\Delta NNLO_{GO}$ (394)	$\Delta NNLO_{GO}$ (450)	N^3LO_{Texas}
M_F^I (MeV ⁻¹)	2.302×10^{-2}	3.357×10^{-2}	3.311×10^{-2}
M_{GT}^I (MeV ⁻¹)	-0.1316	-0.0963	-0.0151
M_F^{II} (MeV ⁻¹)	1.435×10^{-2}	1.917×10^{-2}	1.791×10^{-2}
M_{GT}^{II} (MeV ⁻¹)	-0.1024	-0.0765	-0.0098
Interaction	$T_{1/2}^{2\nu, I}$ (yr)	$T_{1/2}^{2\nu, II}$ (yr)	
$\Delta NNLO_{GO}$ (394)	4.45×10^{18}	7.64×10^{18}	
$\Delta NNLO_{GO}$ (450)	6.90×10^{18}	1.21×10^{19}	
Experiment	5.3×10^{19}	5.3×10^{19}	

Conclusions

- TDA and STDA were applied to study the Gamow-Teller resonance and $2\nu\beta\beta$ decay of ^{48}Ca using the realistic chiral $\Delta\text{NNLO}_{\text{GO}}(394)$, $\Delta\text{NNLO}_{\text{GO}}(450)$, $\text{N}^3\text{LO}_{\text{Texas}}$, NNLO_{opt} interactions.
- Inclusion of 2p2h configurations in ^{48}Sc improves the description of the GT resonance and gives better agreement with experiment.
- 2p2h correlations also improve the calculated $2\nu\beta\beta$ NME and move the predicted half-life closer to the experimental value, although it remains underestimated.
- The Fermi NME is small but non-zero, indicating a weak breaking of isospin symmetry.
- *Future work*: restoration of isospin symmetry using projection techniques and extension of the formalism toward RRPA with additional correlations.

THANK YOU

