Ab initio correlations between neutrinoless and two-neutrino double-beta decays in ^{48}Ca

X. Lian[1]

Collaborators: C. R. Ding[2,3] · C. L. Bai[1] · J. M. Yao[2,3,4]

1 College of Physics, Sichuan University, Chengdu, China

2 School of Physics and Astronomy, Sun Yat-sen University, Zhuhai, China

3 Guangdong Provincial Key Laboratory of Quantum Metrology and Sensing, Sun Yat-sen University

4 Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto, Japan

Roadmap

01 **Double-beta decay and the NME challenge**

Why neutrino physics needs reliable nuclear matrix elements

02 **IM-NCCI with chiral nuclear forces**

Workflow, nuclear states and weak matrix elements

03 ^{48}Ca **numerical results and NME correlations**

Gamow–Teller strength, two-neutrino decay and neutrinoless predictions

04 **Conclusions and next steps**

Ab initio findings, improved currents and other candidate nuclei

Why neutrinoless double-beta decay matters

Probe lepton-number violation and the Majorana nature of neutrinos.

$$(A, Z) \longrightarrow (A, Z+2) + 2e^-$$

A discovery would reveal physics beyond the Standard Model.

It could also shed light on the origin of the matter–antimatter asymmetry.

For light-Majorana-neutrino exchange:

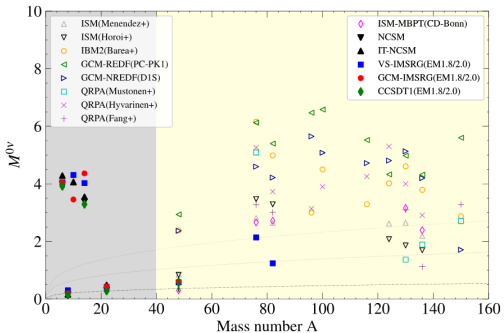
$$[T^{0\nu}_{1/2}]^{-1} = G_{0\nu} g_A^4 \, |M^{0\nu}|^2 \left| \frac{\langle m_{\beta\beta} \rangle}{m_e} \right|^2$$

Reliable NMEs connect measured decay rates to neutrino-mass information.

Engel and Menéndez, Rep. Prog. Phys. 80, 046301 (2017).

From NME uncertainties to experimental constraints

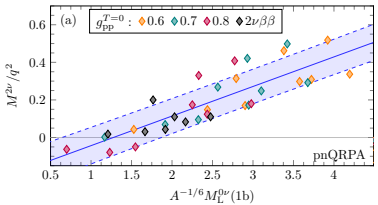
NME spread across methods



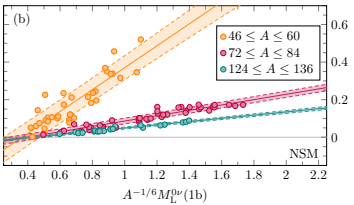
Yao et al., PPNP 126, 103965 (2022).

Phenomenological correlations

pnQRPA: restricted many-body correlations



NSM: limited valence space



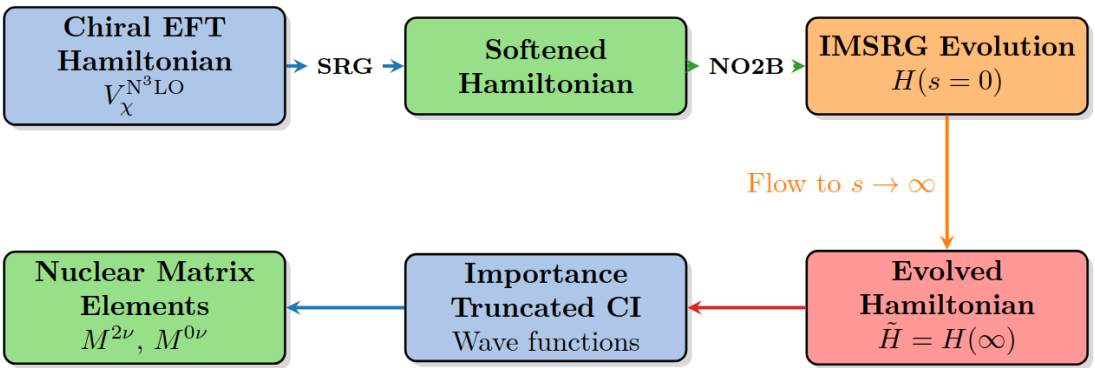
Jokiniemi et al., PRC 107, 044305 (2023).

Test the correlation in an ab initio framework for both decay modes.

Use measured two-neutrino decay to **constrain** the neutrinoless NME.

IM-NCCI: nuclear states and transition operators

In-medium no-core configuration interaction



Nuclear input	Chiral two- and three-nucleon forces.
Normal ordering	Retain normal-ordered terms through two-body rank (NO2B).
IMSRG evolution	Transform the Hamiltonian and decay operators together.
Configuration interaction	Calculate nuclear states in an importance-selected CI space.

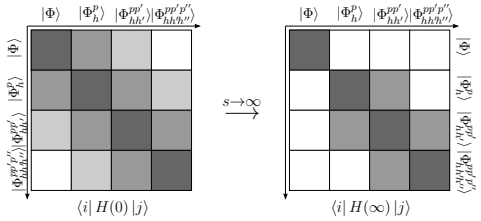
IMSRG and importance-truncated CI

In-medium similarity renormalization group

$$\frac{dX(s)}{ds} = [\eta(s), X(s)], \qquad X = H, O$$

Decouple the reference state.

Evolve H and O consistently.



No-core CI with importance truncation

$$|\Psi\rangle = \sum_{\nu\in\mathcal{M}} C_\nu |\Phi_\nu\rangle$$

$$\kappa_\nu = \sum_k \left| \frac{\langle\Phi_\nu|H|\Psi_k^{\mathrm{ref}}\rangle}{\epsilon_\nu - E_k^{(0)}} \right|$$

All nucleons are active.
The CI space grows rapidly.

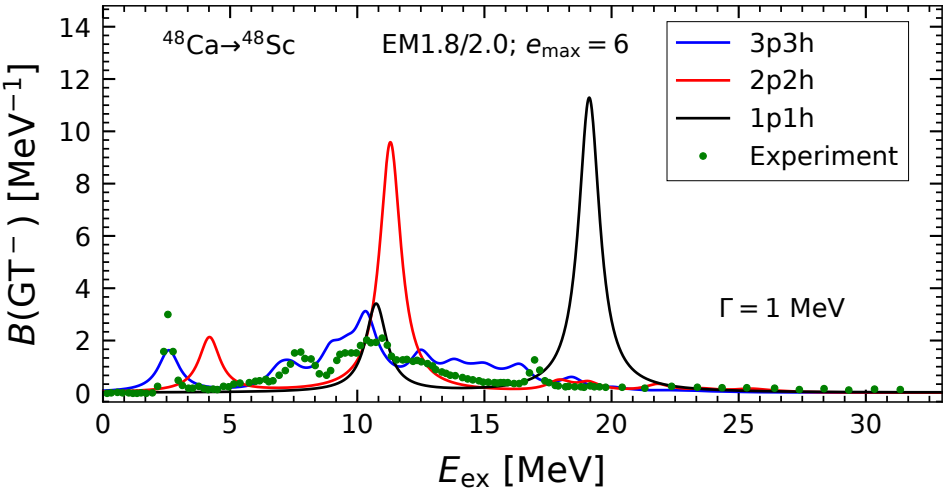
Select → diagonalize → expand.

Nuclear states and evolved operators determine weak matrix elements.

Hergert et al., Phys. Rep. 621, 165 (2016); Roth, PRC 79, 064324 (2009).

Gamow–Teller strength

$$B_m(\mathrm{GT}^-) = |\langle 1^+_m || O_{\mathrm{GT}} || 0^+_i \rangle|^2$$

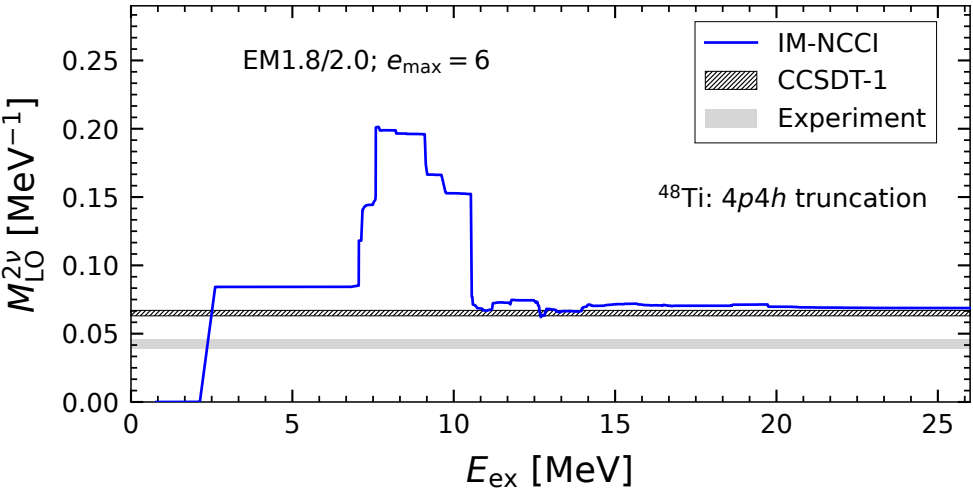


The 3p3h calculation reproduces the main peak positions near 3, 8 and 11 MeV.

X. Lian et al., arXiv:2605.19479 (2026).

Two-neutrino decay: the cumulative NME

$$M^{2\nu}_{\mathrm{LO}} = \sum_m \frac{\langle 0^+_f \| O_{\mathrm{GT}} \| 1^+_m \rangle \langle 1^+_m \| O_{\mathrm{GT}} \| 0^+_i \rangle}{E_m - (E_i + E_f)/2}$$

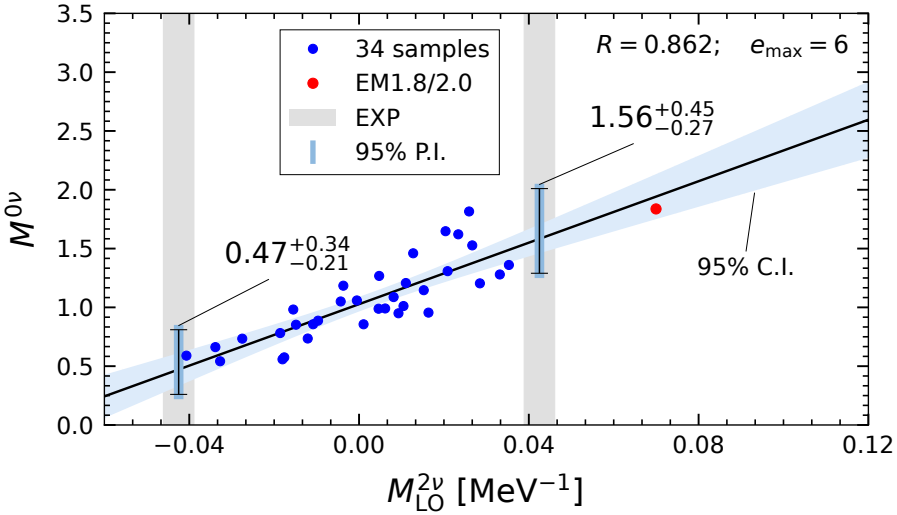


Opposite-sign contributions produce strong high-energy cancellations.

X. Lian et al., arXiv:2605.19479 (2026).

NME correlation and prediction

$$M^{0\nu} = M^{0\nu}_{\mathrm{GT}} + M^{0\nu}_{F} + M^{0\nu}_{T} + M^{0\nu}_{\mathrm{CT}}$$



The correlation turns two-neutrino data into a neutrinoless NME prediction.

X. Lian et al., arXiv:2605.19479 (2026).

Conclusions and next steps

1 **A novel many-body framework for nuclear weak decays**

IM-NCCI treats nuclear states and weak operators in one framework.

2 **Benchmarks of the many-body description**

The GT strength distribution tests the method; the two-neutrino NME is close to CCSDT-1.

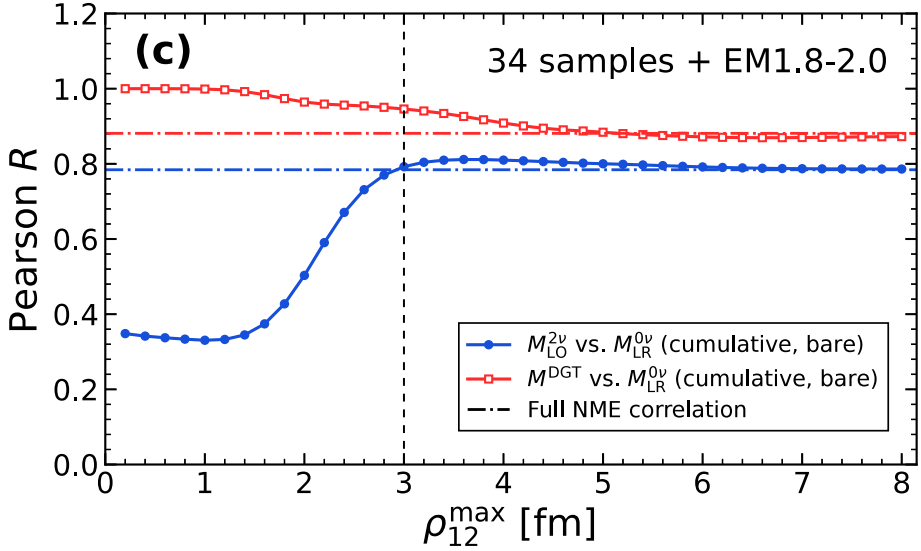
3 **An ab initio correlation with experimental input**

Two-neutrino measurements constrain the predicted neutrinoless NME.

Next steps Larger spaces, improved weak currents and joint uncertainty estimates; extension to other candidate nuclei.

Thank you!

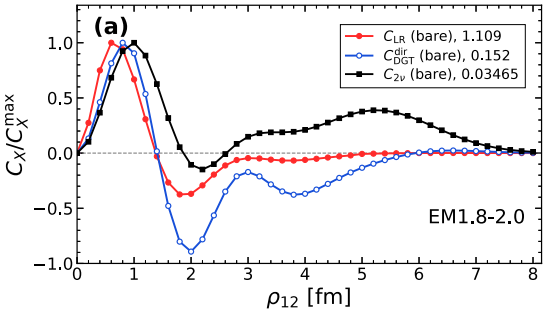
Where is the correlation established?

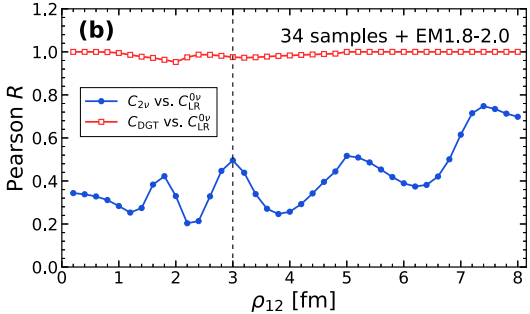


The correlation is largely established by nucleon pairs within about 3 fm.

X. Lian et al., arXiv:2605.19479 (2026).

Why does two-neutrino decay retain a long tail?



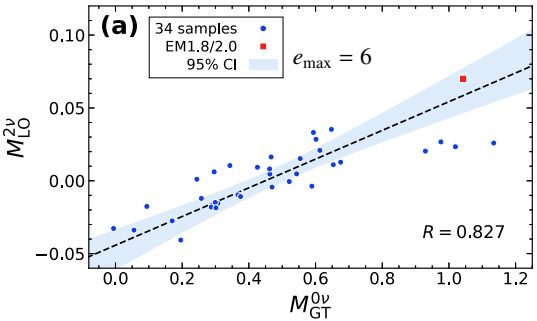


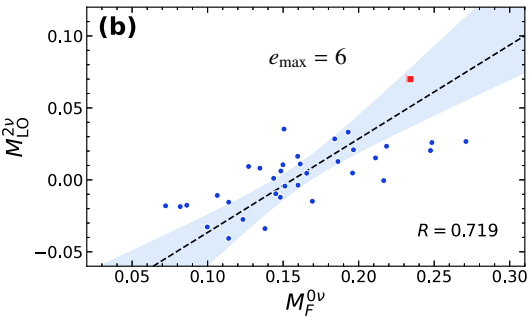
$$M^X = \int d\rho_{12}\, C_X(\rho_{12})$$

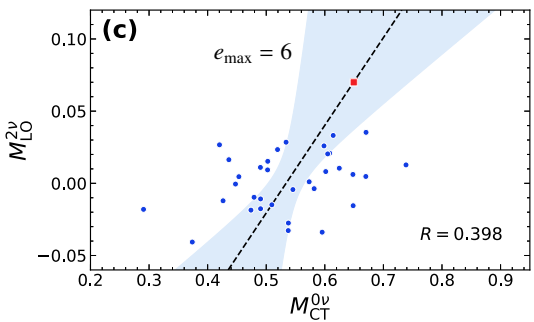
The two-neutrino NME retains about 50–60% of its contribution beyond 3 fm.

X. Lian et al., arXiv:2605.19479 (2026).

Which components track the correlation?





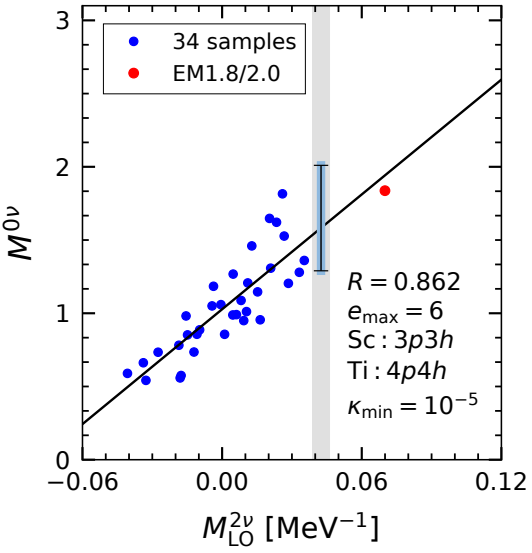


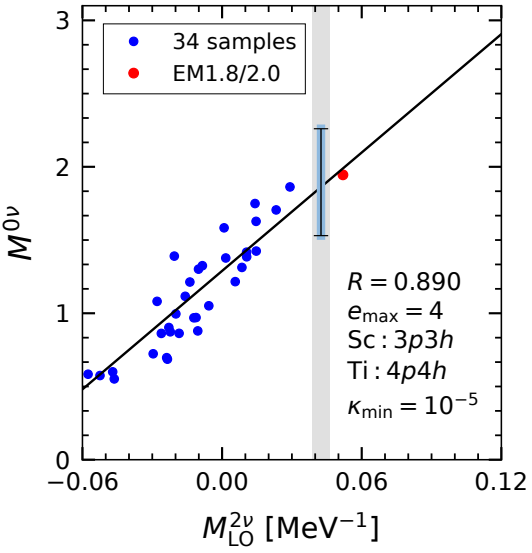
The long-range GT sector shows the strongest correlation.

The contact term shows a weaker correlation.

X. Lian et al., arXiv:2605.19479 (2026).

Does the correlation survive basis truncation?

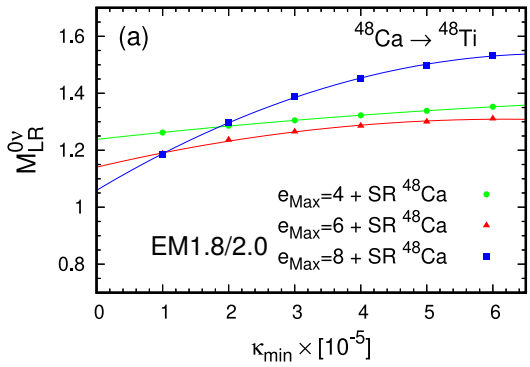


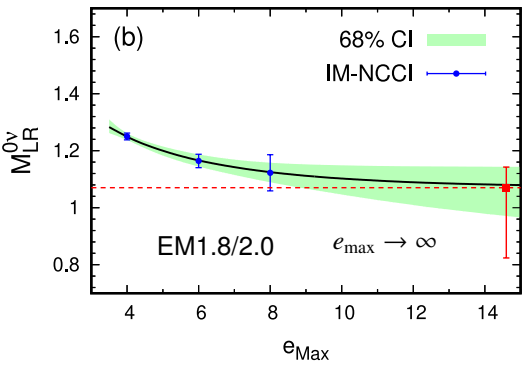


The correlation remains strong, while the absolute NME calibration shifts.

X. Lian et al., arXiv:2605.19479 (2026).

How are the numerical truncations assessed?



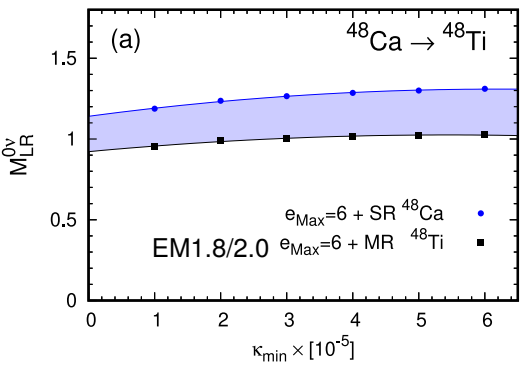


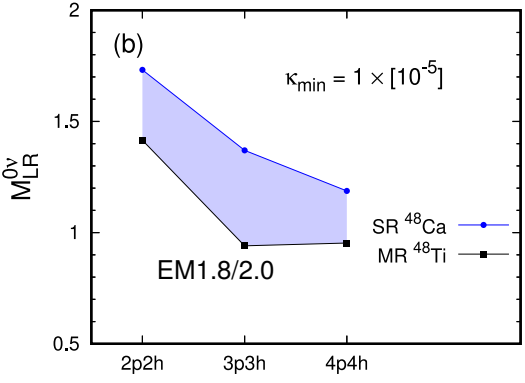
First extrapolate the importance threshold; then examine single-particle basis dependence.

These bands estimate numerical truncation effects, rather than the full theory uncertainty.

X. Lian et al., arXiv:2605.19479 (2026).

How large are reference and excitation-rank effects?



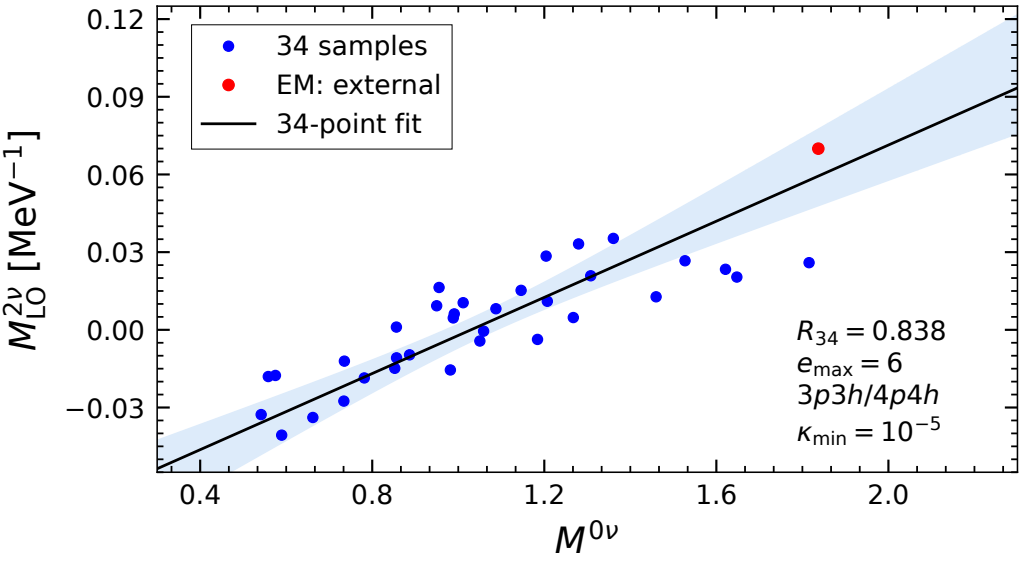


Reference-state and excitation-rank dependence remain visible at the working truncations.

They are additional many-body systematics beyond the threshold and basis extrapolations.

X. Lian et al., arXiv:2605.19479 (2026).

Does Hamiltonian selection control the trend?



Filtering strengthens the trend; removing EM still gives R = 0.838.

X. Lian et al., arXiv:2605.19479 (2026).

How do weak currents enter the inference?

Published estimates motivate a comparison of both decay processes.

$$\delta M^{2\nu}/M^{2\nu}_{\mathrm{LO}} \sim -(30\text{–}40)\%$$

Phenomenological estimates for neutrinoless decay can be comparable in size.

The neutrinoless correction remains **difficult to quantify** beyond normal ordering.

Both corrections are omitted; equal effects or exact cancellation are not assumed.

Menéndez et al., PRL 107 (2011); Jokiniemi et al., PRC 107 (2023); Wang et al., PRC 98 (2018).

What do the bands and sign branches mean?

$$M^{0\nu} = kM^{2\nu}_{\mathrm{LO}} + b + \epsilon$$

$$M^{0\nu}_{+} = 1.56^{+0.45}_{-0.27}, \qquad M^{0\nu}_{-} = 0.47^{+0.34}_{-0.21}$$

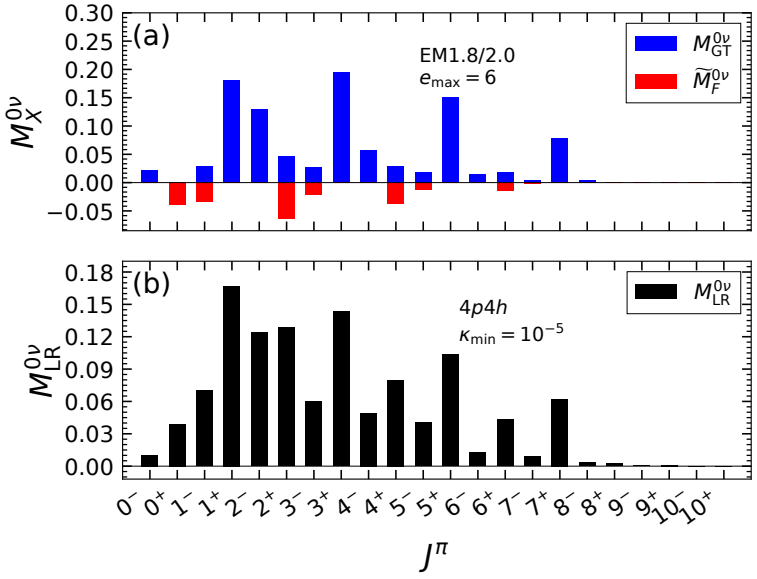
95% prediction intervals include experimental uncertainty and residual ensemble scatter.

They do not include a complete covariance model for nuclear theory uncertainties.

The half-life fixes the magnitude of the two-neutrino NME, not its sign.

X. Lian et al., arXiv:2605.19479 (2026).

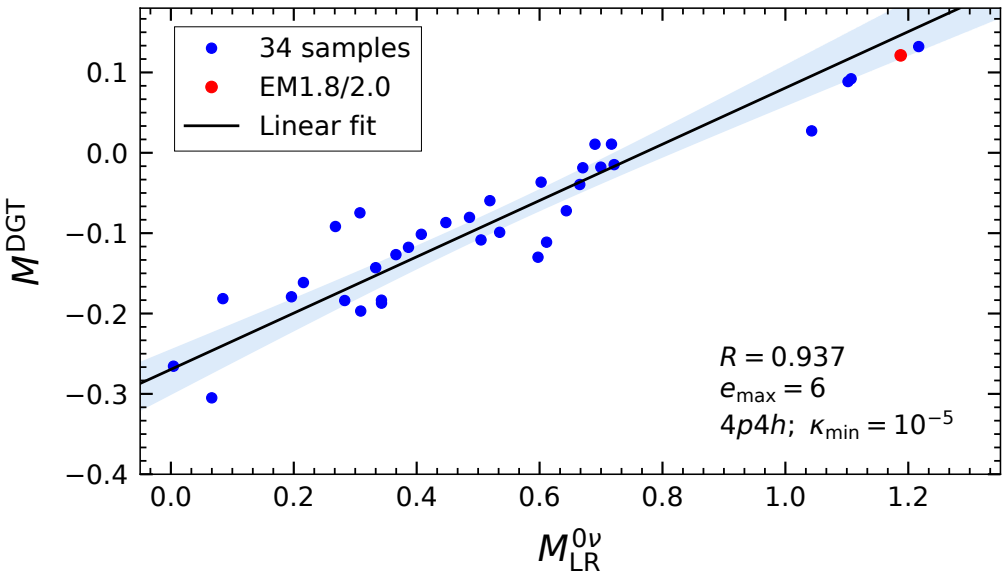
Why are channels beyond 1^+ important?



Several particle–hole channels contribute to the long-range neutrinoless NME.

X. Lian et al., arXiv:2605.19479 (2026).

Why is the DGT correlation stronger?



DGT offers a complementary probe of the long-range spin–isospin structure.

X. Lian et al., arXiv:2605.19479 (2026).