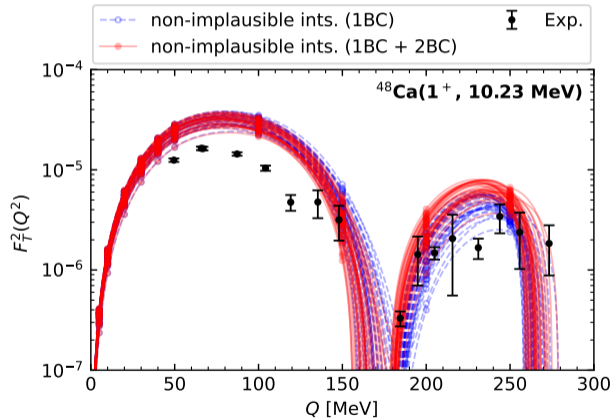


Two-body currents at finite momentum transfer and applications to M1 transition

Catharina Brase

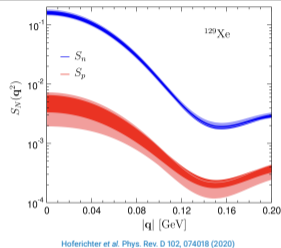
in collaboration with:

T. Miyagi, J. Menéndez and A. Schwenk



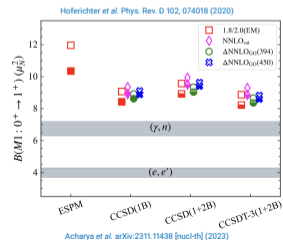
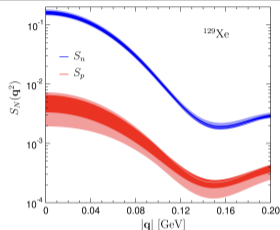
Motivation: 2BCs at finite momentum transfer

- quenching for $0\nu\beta\beta$ decay [Menéndez, Gazit, and Schwenk, Phys. Rev. Lett. 107, 062501 \(2011\)](#)
- neutrinos scattering off nuclei [Hoferichter, Menéndez, and Schwenk, Phys. Rev. D 102, 074018 \(2020\)](#)
- weakly interacting massive particles scattering off nuclei
[Klos, Menéndez, Gazit, and Schwenk, Phys. Rev. D 88 \(2013\)](#)
- in medium-mass/heavy nuclei: only approximately included
[Menéndez, Gazit, and Schwenk, Phys. Rev. Lett. 107, 062501 \(2011\)](#)
- **multipole decomposition** for inclusion of two-body currents



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- **multipole decomposition** for inclusion of two-body currents
- first applications to well studied **M1 transition in ^{48}Ca** [Acharya et al., arXiv:2311.11438 \[nucl-th\] \(2023\)](#)
- momentum transfer dependence of transition form factor [Steffen et al., Nucl. Phys. A404, 413 \(1983\)](#)
- $B(\text{M1})$: experimental discrepancy between (e, e') and (γ, n) measurement [Steffen et al., Phys. Lett. B 95, 23 \(1980\)](#), [Tompkins et al., Phys. Rev. C 84, 044331 \(2011\)](#)



^{48}Ca many-body convergence

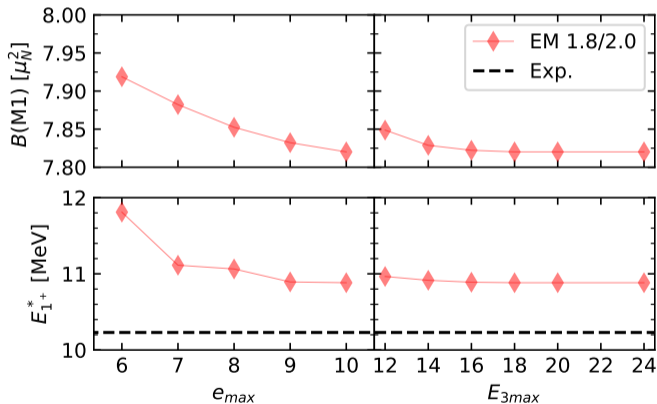
- VS-IMSRG convergence checked with EM 1.8/2.0 for $B(M1)$ and $E_{1^+}^*$

Miyagi, Eur. Phys. J. A 59, 150 (2023)

Stroberg, <https://github.com/ragnarstroberg/imsrg.git>

Hebeler et al., Phys.Rev.C 83 031301 (2011)

- $E_{3\text{max}} = 24$ for e_{max} variation
- $e_{\text{max}} = 10$ for $E_{3\text{max}}$ variation
- for further calculations:
 $e_{\text{max}} = 12$ and $E_{3\text{max}} = 24$



Multipole decomposed vector current

$$\vec{j}(\vec{Q}) = 4\pi \sum_{\lambda\mu} (-i)^\lambda \left(L_{\lambda\mu}(Q) \vec{Y}_{\lambda\mu}^*(\hat{Q}) + T_{\lambda\mu}^{\text{el}}(Q) \vec{\Psi}_{\lambda\mu}^*(\hat{Q}) + T_{\lambda\mu}^{\text{mag}}(Q) \vec{\Phi}_{\lambda\mu}^*(\hat{Q}) \right)$$

summing over rank λ and its projection μ using the following definitions

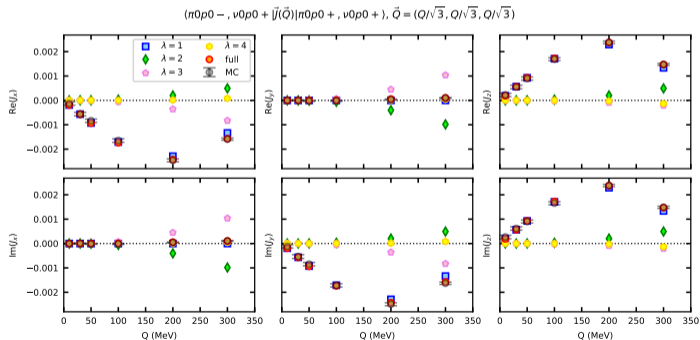
$$\vec{Y}_{LM}(\hat{\vec{X}}) = \hat{\vec{X}} Y_{LM}(\hat{\vec{X}}), \quad \vec{\Psi}_{LM}(\hat{\vec{X}}) = \sqrt{\frac{1}{L(L+1)}} \mathbf{x} \nabla Y_{LM}(\hat{\vec{X}}), \quad \vec{\Phi}_{LM}(\hat{\vec{X}}) = \vec{Y}_{L,L,M}$$

$$\text{with } \vec{Y}_{JLM}(\theta, \phi) = \sum_{M_{\text{sum}}=-L}^L \sum_{\lambda=-1}^1 Y_{L,M}(\theta, \phi) C_{LM_{\text{sum}}1\lambda}^{JM} \vec{e}_\lambda$$

Benchmark for vector 2BC at finite momentum transfer: seagull and pion-in-flight (sum in figure)

$$\vec{j}(\vec{Q}) = 4\pi \sum_{\lambda\mu} (-i)^\lambda \left(L_{\lambda\mu}(Q) \vec{Y}_{\lambda\mu}^*(\hat{Q}) + T_{\lambda\mu}^{\text{el}}(Q) \vec{\Psi}_{\lambda\mu}^*(\hat{Q}) + T_{\lambda\mu}^{\text{mag}}(Q) \vec{\Phi}_{\lambda\mu}^*(\hat{Q}) \right)$$

multipole decomposed & Monte-Carlo integral results: agreement for all matrix elements studied



Transition for factor – Comparison to (e, e') data

Steffen et al., Nucl. Phys. A404, 413 (1983)

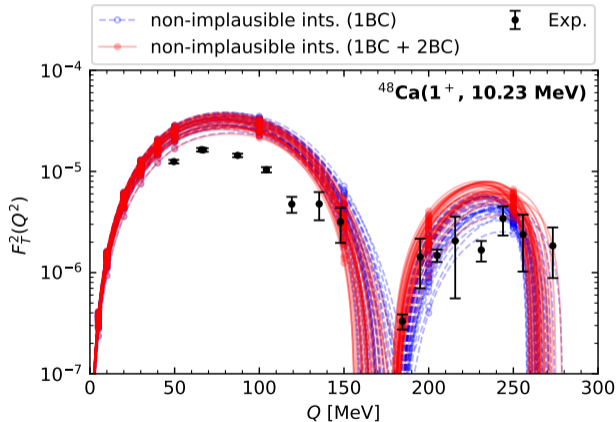
- non-implausible interactions using VS-IMSRG with 1BC and with 1BC+2BC

B. Hu et al., Nat. Phys. 18, 1196 (2022)

Miyagi, Eur. Phys. J. A 59, 150 (2023)

Stroberg, <https://github.com/ragnarstroberg/imsrg.git>

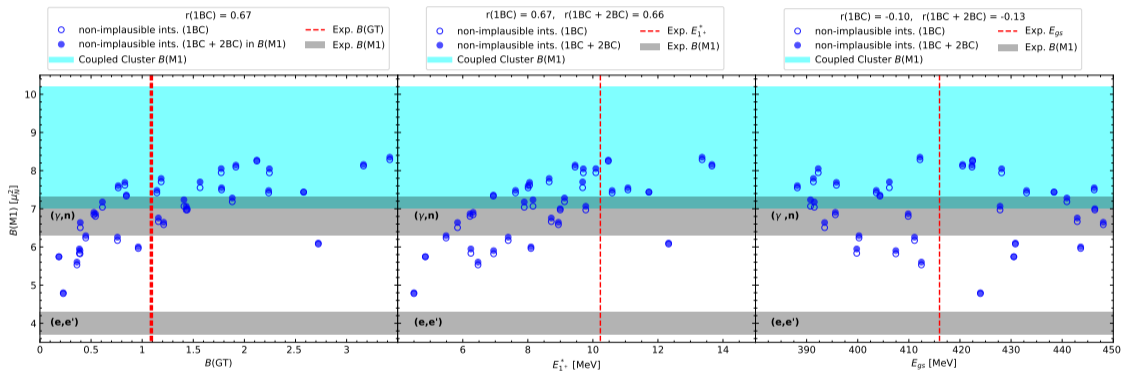
- small 2BC contribution
- similar to $B(M1)$
- $Q \rightarrow 0$ limit consistent with $B(M1)$



Correlations

Acharya et al., arXiv:2311.11438 [nucl-th] (2023), <https://www.nndc.bnl.gov/nudat3/>

Steffen et al., Phys. Lett. B 95, 23 (1980), Tompkins et al., Phys. Rev. C 84, 044331 (2011)

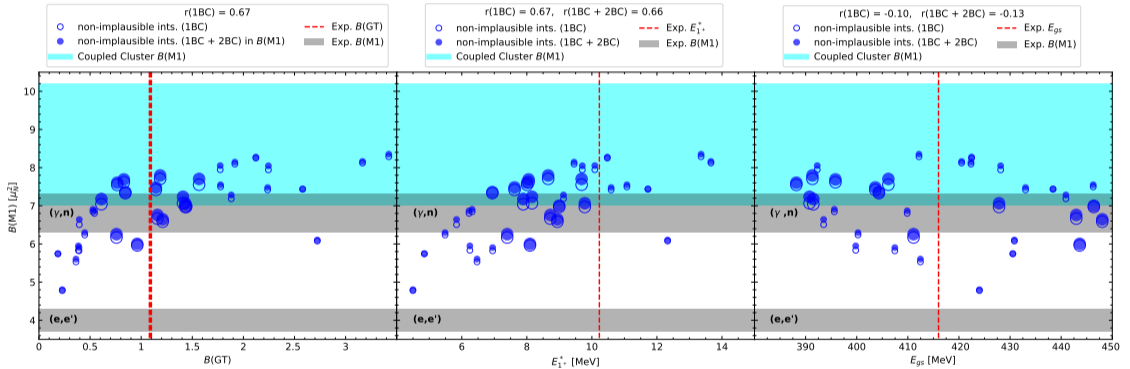


non-implausible interactions favor $B(M1)$ from (γ, n) exp. and show partial overlap with Coupled Cluster calculation

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I want to thank my collaborators, Takayuki, Javier and Achim. Thank you for your attention and check out my poster

Two-body currents at finite momentum transfer and applications to M1 transition

C. Brase^{1,2}, T. Miyagi^{3,4}, J. Menéndez⁵, and A. Schwenk^{1,2}



¹Institut für Kernphysik, TU Darmstadt, ²Exzellente Materie Institute EXMI, GS, ³Max-Planck-Institut für Kernphysik, Heidelberg, ⁴Departament de Física Quàntica i Astrofísica, Universitat de Barcelona, ⁵Institut de Ciències del Cosmos, Universitat de Barcelona

Motivation

- two-body currents at finite momentum transfer in medium-mass and heavy nuclei only approximately included [1]
- multiple decomposition for inclusion of two-body currents
- applications to well studied M1 transition in ⁴⁸Ca, see also [2]
- momentum transfer dependence of transition form factor [3]
- experimental discrepancy between μ_N [4] and μ_N [5] measurement

⁴⁸Ca many-body convergence

- VS-MSRG [6, 7] convergence checked with EM 1.8/2.0 [4] for $B(1\pi)$ and F_T
- $E_{\text{max}} = 20$ for μ_N variation
- $E_{\text{max}} = 10$ for F_T variation
- for further calculations: $E_{\text{max}} = 22$ and $E_{\text{max}} = 20$

Correlations with $B(1\pi)$

Correlations for ⁴⁸Ca: $B(1\pi)$, $B(2\pi)$, and $B(3\pi)$

- non-implausible interactions [8] using VS-MSRG with 1BC and with 1BC+2BC
- 2BC increase $B(1\pi)$ for all non-implausible interactions

Note: Calculation of $B(1\pi)$ for ^{48}Ca only with 1BC

Correlation:

- $B(1\pi)$ and F_T no correlation
- $B(1\pi)$ and $B(2\pi)$ show very similar behaviour $\phi \rightarrow 0$

Non-implausible interactions favor DUMI: from [9] exp. and show partial overlap with Coupled Cluster calculation [2]

Multipole decomposition of 2BC

$$J(\vec{q}) = \sum_{\lambda} \sum_{\mu} \langle J_{\lambda\mu} \rangle \mathcal{Y}_{\lambda\mu}(\hat{q}) + \sum_{\lambda} \sum_{\mu} \langle J_{\lambda\mu} \rangle \mathcal{Y}_{\lambda\mu}(\hat{q})$$

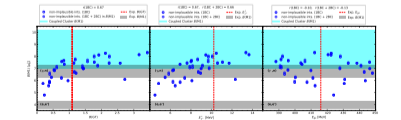
- checked for vector 2BC: μ_N and pion-in-flight (sum in figure)
- comparison between: multiple decomposed (full) and Monte-Carlo (MC) integral results
- good agreement for all matrix elements studied

Transition form factor F_T

Comparison to μ_N data [2]

Up to minimum:

- 2BCs reduce transition form factor
- small 2BC contribution, similar to $B(1\pi)$
- 2BCs enhance F_T^2
- $Q \rightarrow 0$ limit consistent with $B(1\pi)$



[1] Menéndez, Pastar and Schwenk, Phys. Rev. Lett. 102, 042501 (2009)
 [2] Schwenk et al., arXiv:2008.03883 [nucl-th] (2020)
 [3] Schwenk et al., Phys. Lett. B 692, 21 (2010)
 [4] T. Miyagi et al., Phys. Rev. C 84, 044302 (2011)
 [5] T. Miyagi et al., Phys. Rev. C 84, 044302 (2011)
 [6] J. Menéndez et al., Phys. Rev. Lett. 102, 042501 (2009)
 [7] J. Menéndez et al., Phys. Rev. Lett. 102, 042501 (2009)
 [8] J. Menéndez et al., Phys. Rev. Lett. 102, 042501 (2009)
 [9] J. Menéndez et al., Phys. Rev. Lett. 102, 042501 (2009)