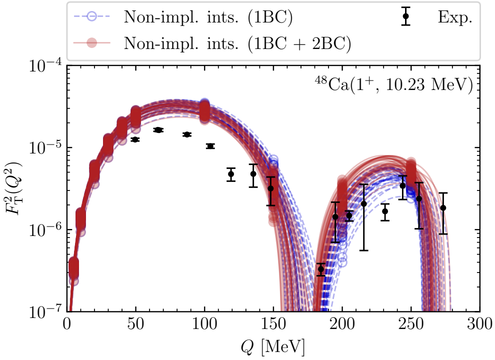
Two-body currents at finite momentum transfer and applications to M1 transition

TECHNISCHE UNIVERSITÄT DARMSTADT

... in preparation

Catharina Brase in collaboration with:
T. Miyagi, K. Hebeler, J. Menéndez and A. Schwenk

European Research Council
Established by the European Commission



International School of Nuclear Physics 45th Course
Nuclei in the Laboratory and in Stars
Erice-Sicily, September 16-22, 2024

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)

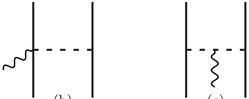
- in medium-mass/heavy nuclei: approximately included Menéndez, Gazit, and Schwenk, Phys. Rev. Lett. 107, 062501 (2011)
- **multipole decomposition** for inclusion of two-body currents (2BCs)

- multipole decomposed matrix elements $L_{\lambda\mu}(Q)$, $T^{\mathrm{el}}_{\lambda\mu}(Q)$ and $T^{\mathrm{mag}}_{\lambda\mu}(Q)$
- apply expansion equation

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

summing over rank λ and its projection μ

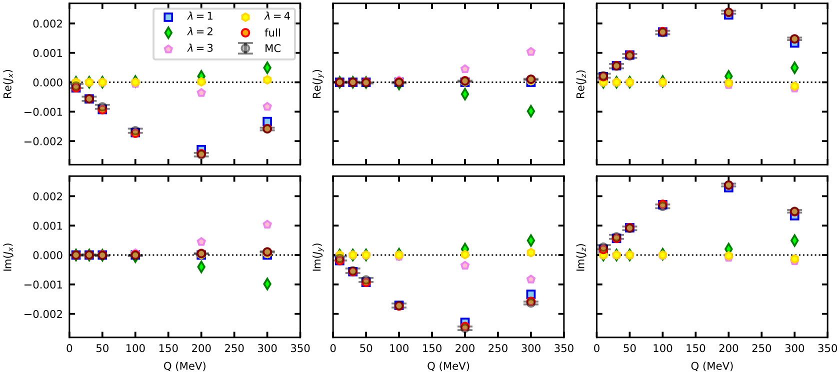
Benchmark for vector 2BC at finite momentum transfer: seagull (b) and pion-in-flight (c) (sum in figure)



(b) (c)

R. Seutin, TU Darmstadt,
doi.org/10.26083/tuprints-00014649

$\langle \pi 0p0-, \nu 0p0+ | \vec{J}(\vec{Q}) | \pi 0p0+, \nu 0p0+ \rangle, \ \vec{Q} = (Q/\sqrt{3}, Q/\sqrt{3}, Q/\sqrt{3})$

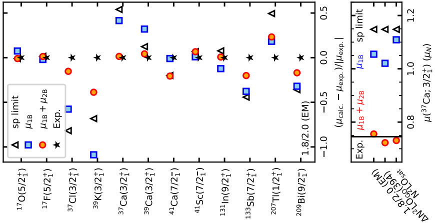


multipole decomposed and Monte-Carlo integral results: agreement for all matrix elements studied

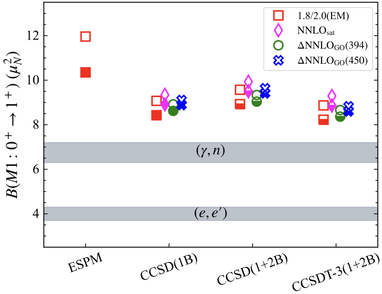
2BCs at finite momentum transfer – first applications to important M1 transition in ^{48}Ca

Acharya *et al.*, Phys. Rev. Lett. 132, 232504 (2024)

- momentum transfer dependence of transition form factor
  Steffen *et al.*, Nucl. Phys. A404, 413 (1983)
- $B(\mathrm{M1})$: 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)
- magnetic moments: inclusion of 2BCs
  $\rightarrow$ prediction closer to experiment Miyagi *et al.*, Phys. Rev. Lett. 132, 232503 (2024)



Miyagi *et al.*, Phys. Rev. Lett. 132, 232503 (2024)

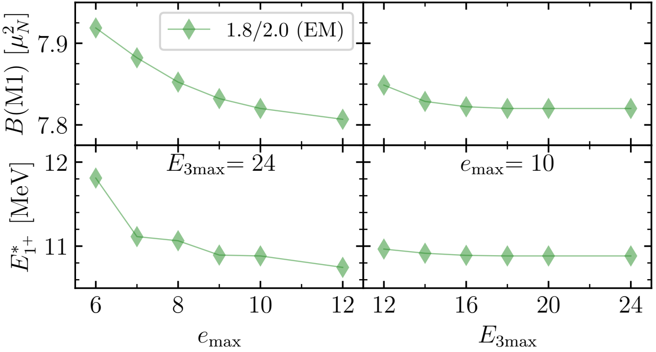


Acharya *et al.* Phys. Rev. Lett. 132, 232504 (2024)

Ab initio VS-IMSRG using 1.8/2.0 (EM) interaction for ^{48}Ca – Many-body convergence

- convergence checked for $B(\mathrm{M1})$ 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)

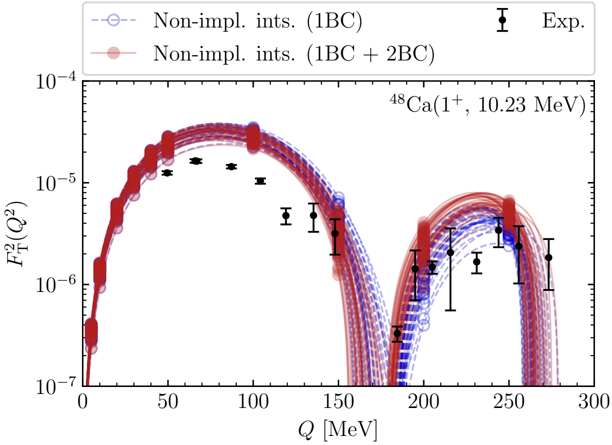
- for further calculations:
  $\mathrm{e}_{\mathrm{max}} = 12$ and $E_{3\mathrm{max}} = 24$



Transition form factor – Comparison to (e, e') experiment

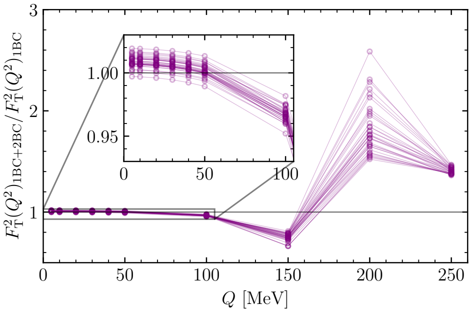
Steffen *et al.*, Nucl. Phys. A404, 413 (1983)

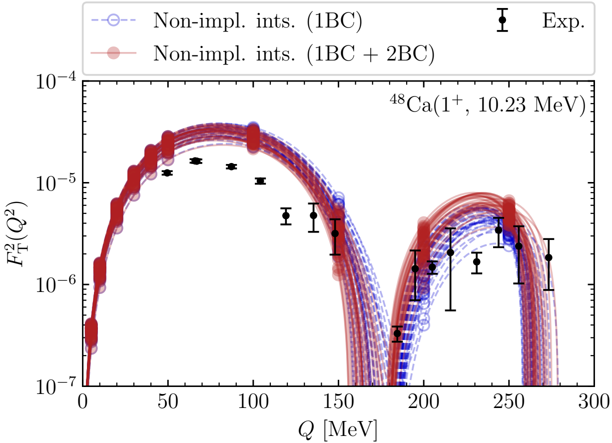
- non-implausible interactions using VS-IMSRG with 1BC and with 1BC+2BC
  B. Hu *et al.*, Nat. Phys. 18, 1196 (2022)
  Miyagi, Eur. Phys. J. A 59, 150 (2023)
  Stroberg, https://github.com/ragnarstroberg/imsrg.git
- small 2BC contribution for small momentum transfer Q
- $Q \to 0$ limit consistent with $B(M1)$



Transition form factor –
Comparison to (e, e') experiment

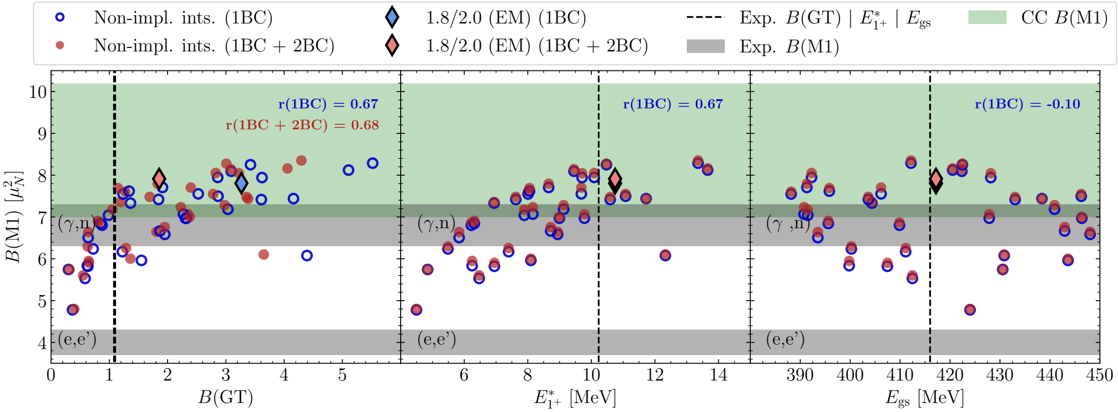
Steffen *et al.*, Nucl. Phys. A404, 413 (1983)





Correlations - ^{48}Ca: 2BCs in M1- and GT-strength

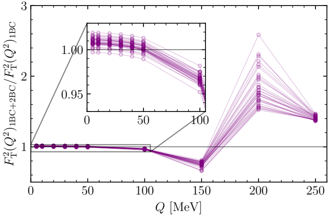
Hebeler *et al.*, Phys. Rev. C 83, 031301(R) (2011) Steffen *et al.*, Phys. Lett. B 95, 23 (1980) https://www.nndc.bnl.gov/nudat3/
Tompkins *et al.*, Phys. Rev. C 84, 044331 (2011) Acharya *et al.*, Phys. Rev. Lett. 132, 232504 (2024)

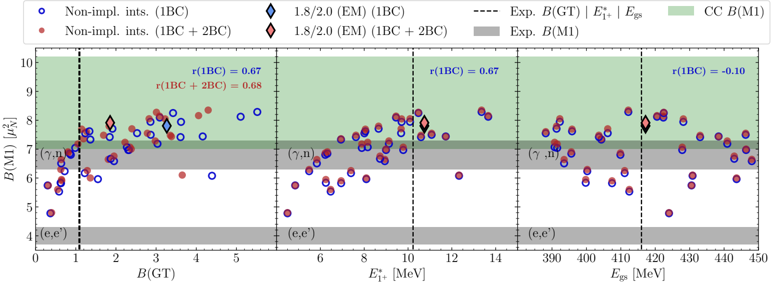


our calculations: *B*(M1) increases with 2BC - favor bigger values

Summary for M1 transition in ^{48}Ca

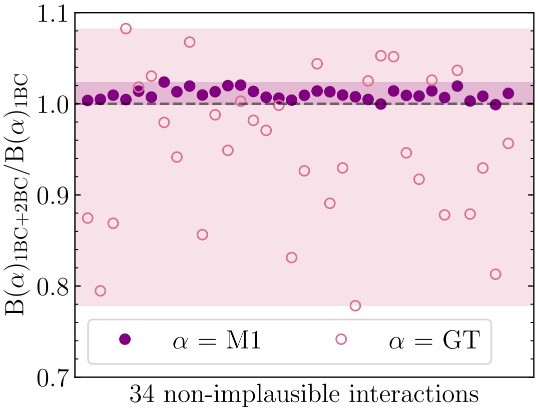
- 2BC contribution to transition form factor varies in size and sign over momentum transfer
- weak correlation between M1- and GT-strength from non-impl. ints (w/ and w/o 2BC)
- GT-strength closer to experiment with 2BC
- the inclusion of 2BCs does not reduce strength to overlap with (e,e') experiment
- our results seem to favor larger values, same as the CC results





Outlook: WIMP-nucleus scattering with 2BCs at finite momentum transfer

Ratio B(M1) with and without 2BC



M1-strength

- for 32 out of 34 interactions: B(M1) is enhanced by 2BCs (in agreement with CC result)
- 2BC effect range: 0.999 - 1.024

GT-strength

- for all interactions: reduction
- 2BC effect range: 0.785 - 1.085
- much wider spread

Multipole decomposed (vector/axial-vector) current

- multipole decomposed matrix elements $L_{\lambda\mu}(Q)$, $T^{\mathrm{el}}_{\lambda\mu}(Q)$ and $T^{\mathrm{mag}}_{\lambda\mu}(Q)$
- apply expansion equation

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

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

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

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