Challenges in effective field theory descriptions of nuclei

— Hirschegg 2026, January 20th —

Phys. Rev. C 113, 014317 – Published 20 January, 2026

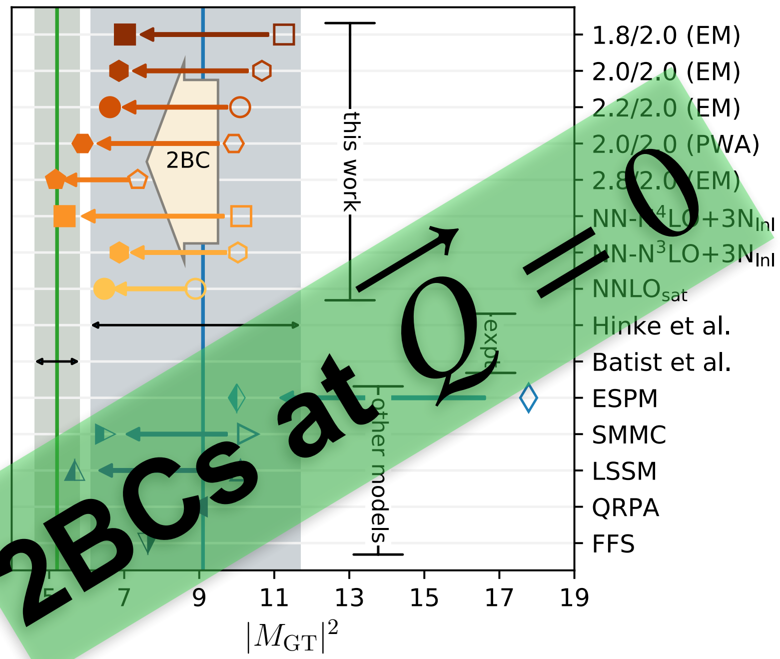
Catharina Brase in collaboration with:

Takayuki Miyagi, Javier Menéndez and Achim Schwenk

2BCs — FINITE MOMENTUM TRANSFER

TECHNISCHE UNIVERSITÄT DARMSTADT

Gysbers et al., Nat. Phys. 15, 428 (2019)

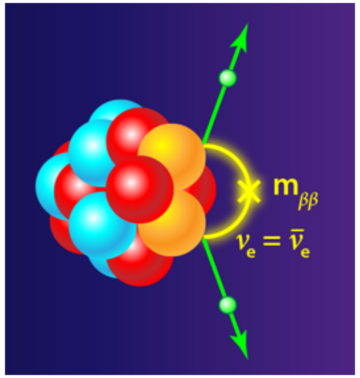


2BCs at $\vec{Q} = 0$

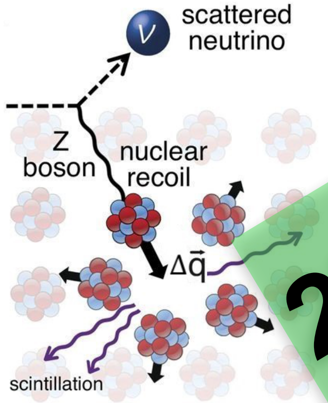
Nuclear theory crucial for extraction of BSM physics

$\longrightarrow$ we need to understand 2BCs at $\vec{Q} \neq 0$

2BCs at $\vec{Q} \neq 0$



Engel and Vogel. Physics 11, 30 (2018)



Del Castello, arXiv:2302.02843 (2023)

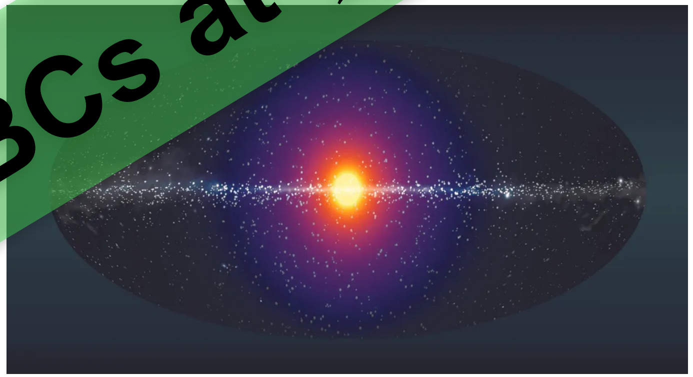
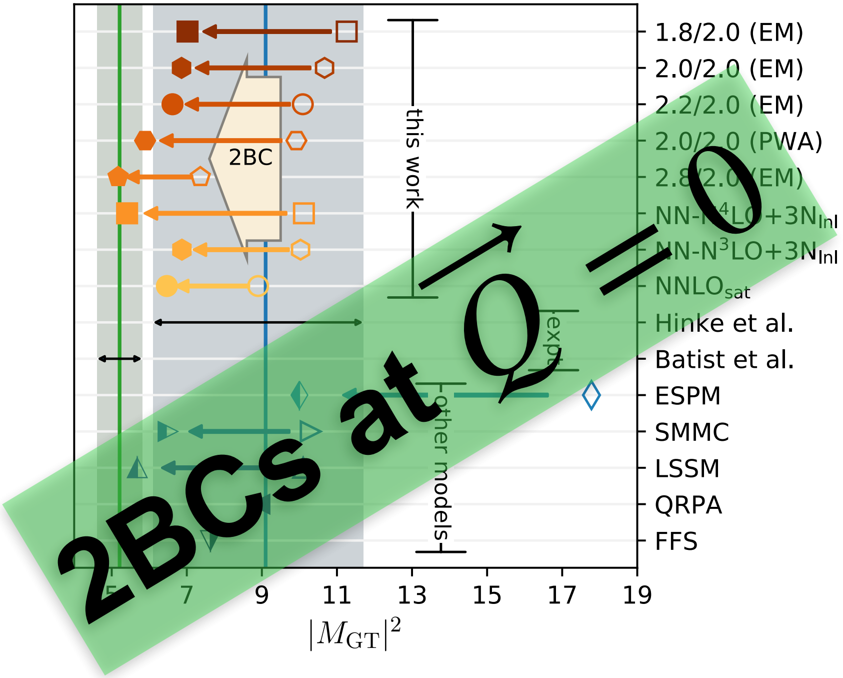


Image credit: Artistic rendering by Christopher Dessert, Nicholas L. Rodd, Benjamin R. Safdi, Zosia Rostomian (Berkeley Lab), based on data from the Fermi Large Area Telescope.
https://www.space.com/dark-matter-haloes-ancient-galaxy-1st-weight-measurements

2BCs — FINITE MOMENTUM TRANSFER

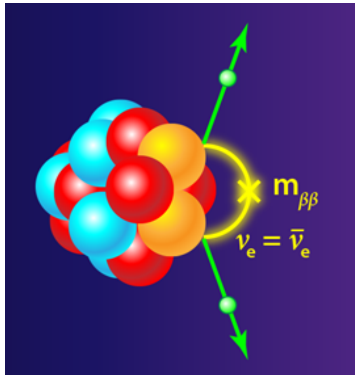
TECHNISCHE UNIVERSITÄT DARMSTADT

Gysbers et al., Nat. Phys. 15, 428 (2019)

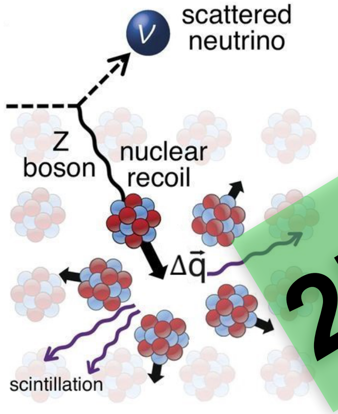


Nuclear theory crucial for extraction of BSM physics

$\longrightarrow$ we need to understand 2BCs at $\vec{Q} \neq 0$



Engel and Vogel. Physics 11, 30 (2018)



Del Castello, arXiv:2302.02843 (2023)

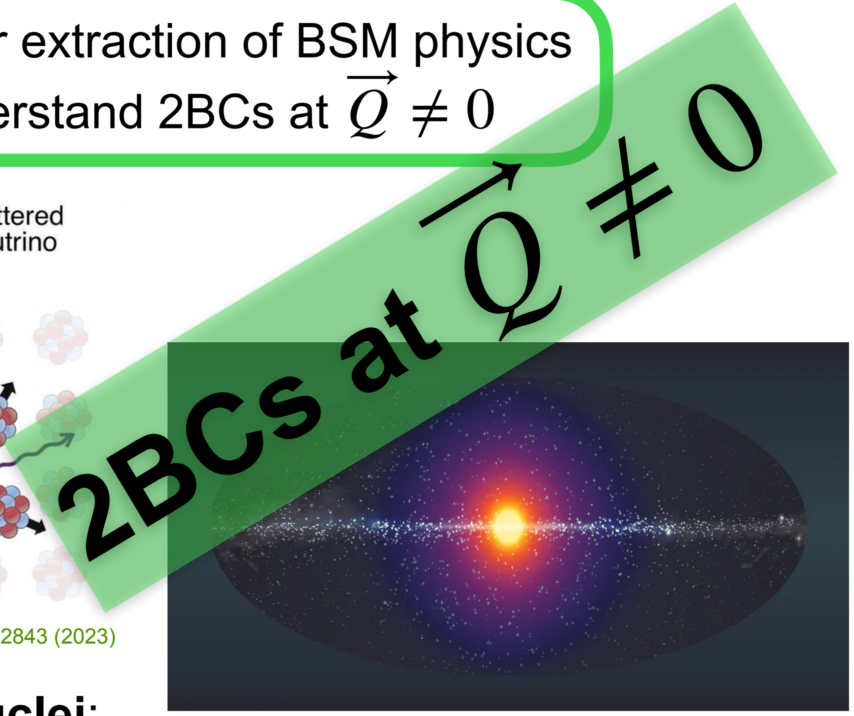


Image credit: Artistic rendering by Christopher Dessert, Nicholas L. Rodd, Benjamin R. Safdi, Zosia Rostomian (Berkeley Lab), based on data from the Fermi Large Area Telescope.
https://www.space.com/dark-matter-haloes-ancient-galaxy-1st-weight-measurements

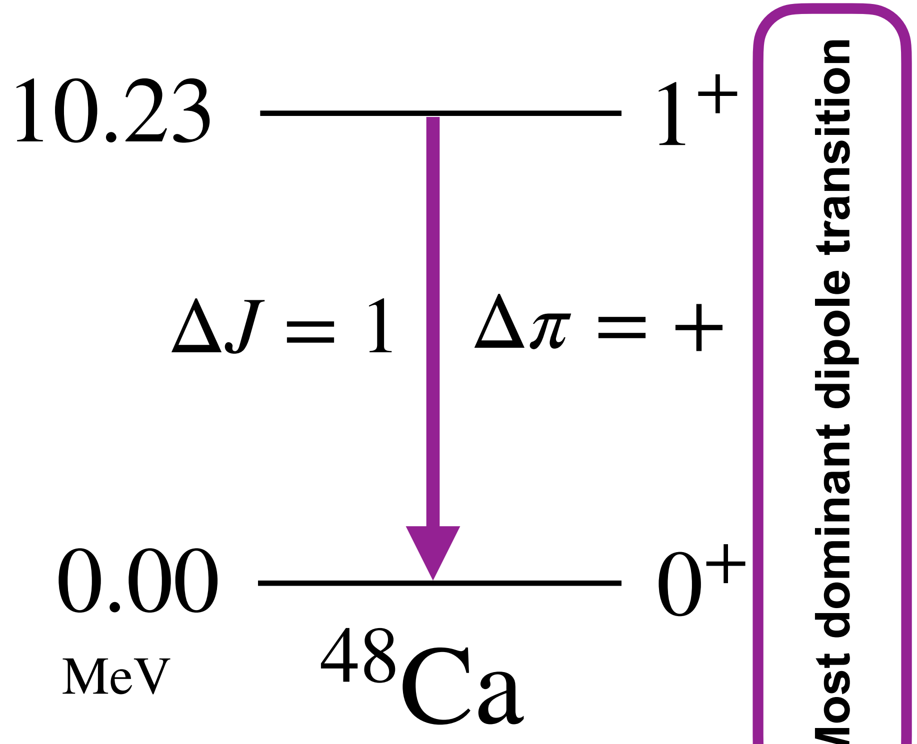
For calculation **without approximating 2BCs** in **medium-mass or heavy nuclei**:
Multipole decomposition of 2BCs helpful

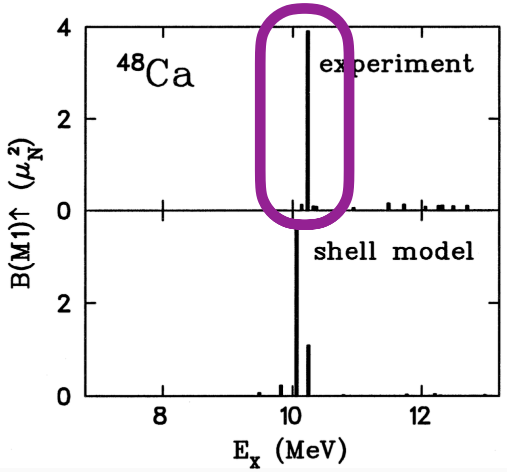
$$\vec{j}(\vec{Q}) = 4\pi \sum_{\lambda\mu} (-i)^{\lambda} \Big(L_{\lambda\mu}(Q)\, \vec{Y}^{*}_{\lambda\mu}(\hat{Q}) + T^{\mathrm{el}}_{\lambda\mu}(Q)\, \vec{\Psi}^{*}_{\lambda\mu}(\hat{Q}) + T^{\mathrm{mag}}_{\lambda\mu}(Q)\, \vec{\Phi}^{*}_{\lambda\mu}(\hat{Q}) \Big)$$

Our work: Takayuki Miyagi derived and implemented multipole decomposed 2BCs for inclusion at finite momentum transfer → first application to M1 transitions
Miyagi et al., Phys. Rev. Lett. 132, 232503 (2024)

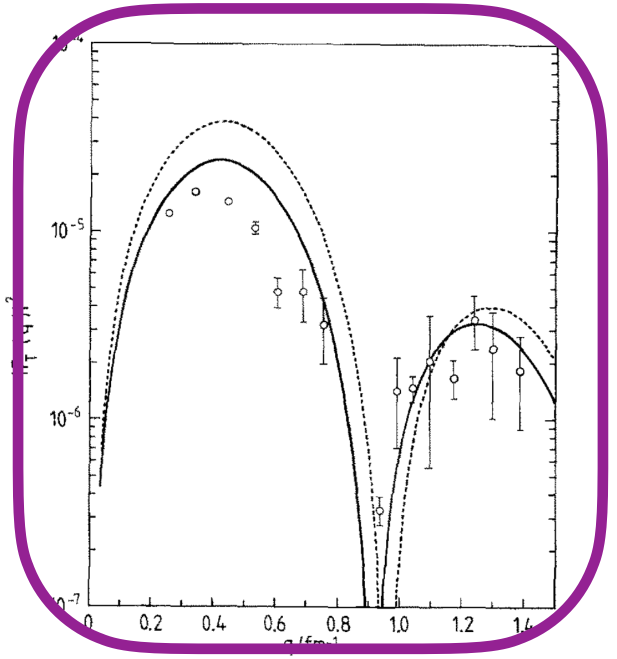
M1 TRANSITION IN ^{48}Ca

- momentum transfer dependence:
  transition form factor
  Steffen et al., Nucl. Phys. A404, 413 (1983)





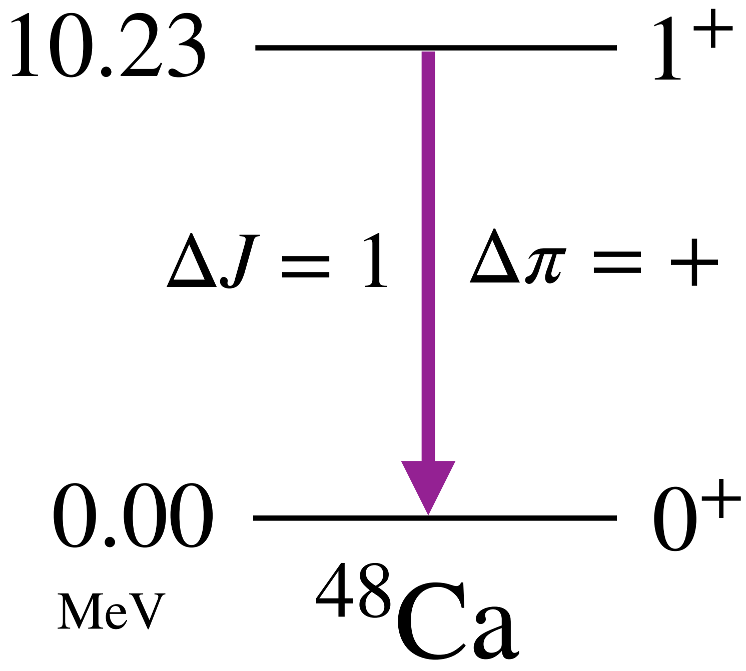
Von Neumann et al., Phys. Lett. B 443, 1 (1998)



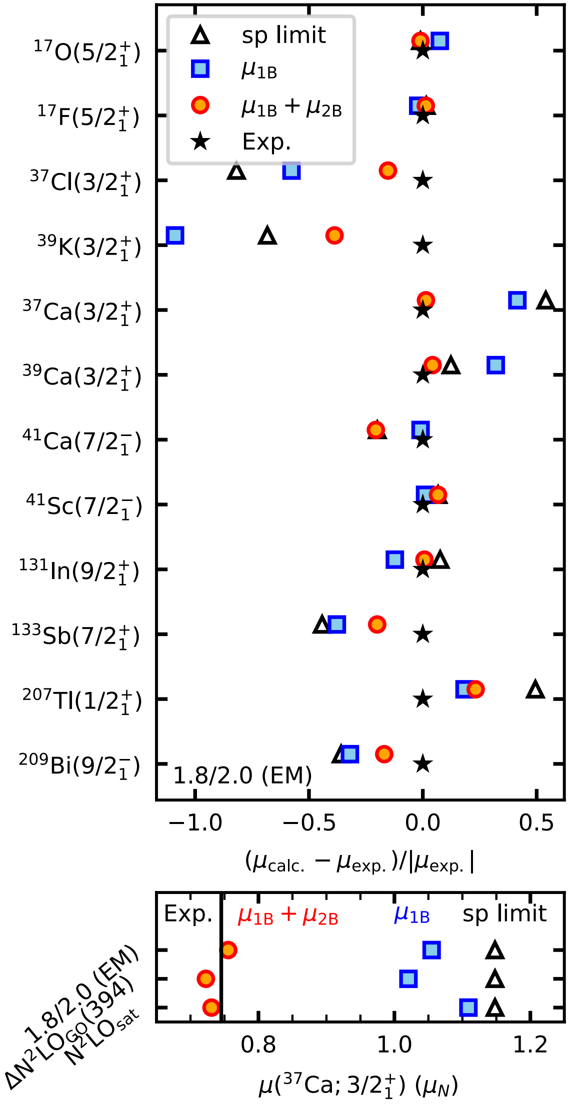
Steffen et al., Nucl. Phys. A404, 413 (1983)

M1 TRANSITION IN ^{48}Ca

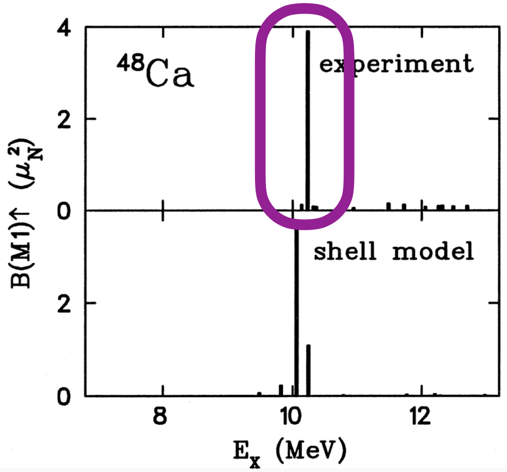
- momentum transfer dependence: transition form factor
  Steffen et al., Nucl. Phys. A404, 413 (1983)
- magnetic moments: inclusion of 2BCs
  → prediction closer to experiment
  Miyagi et al., Phys. Rev. Lett. 132, 232503 (2024)



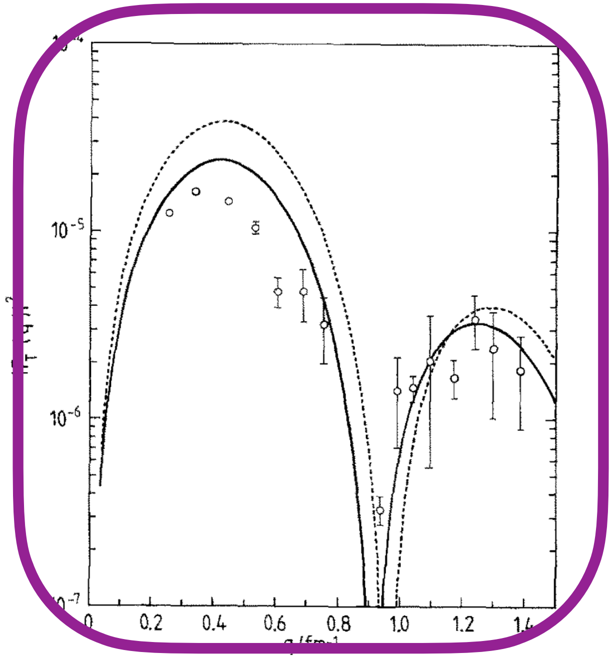
Most dominant dipole transition



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



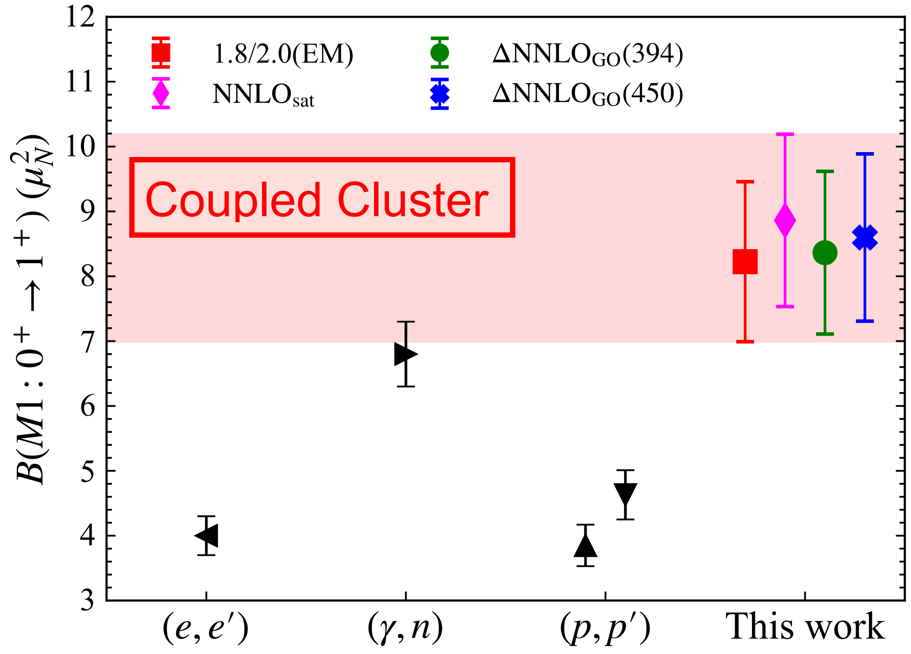
Von Neumann et al., Phys. Lett. B 443, 1 (1998)



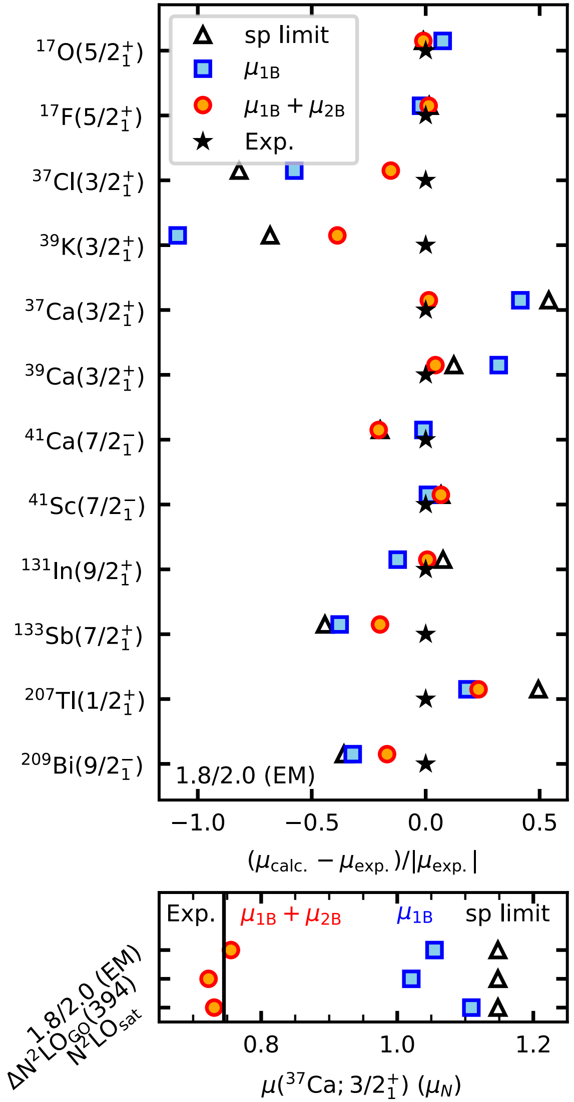
Steffen et al., Nucl. Phys. A404, 413 (1983)

M1 TRANSITION IN ^{48}Ca

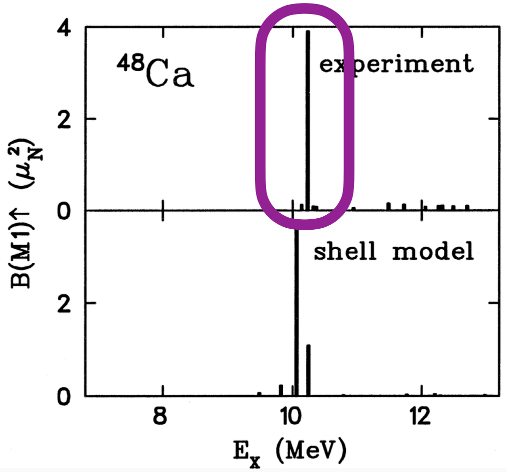
- momentum transfer dependence: transition form factor
  Steffen et al., Nucl. Phys. A404, 413 (1983)
- magnetic moments: inclusion of 2BCs → prediction closer to experiment
  Miyagi et al., Phys. Rev. Lett. 132, 232503 (2024)
- B(M1): experimental discrepancy between (e, e′) and (γ, n) measurement
  Steffen et al., Phys. Lett. B 95, 23 (1980)
  Tompkins et al., Phys. Rev. C 84, 044331 (2011)



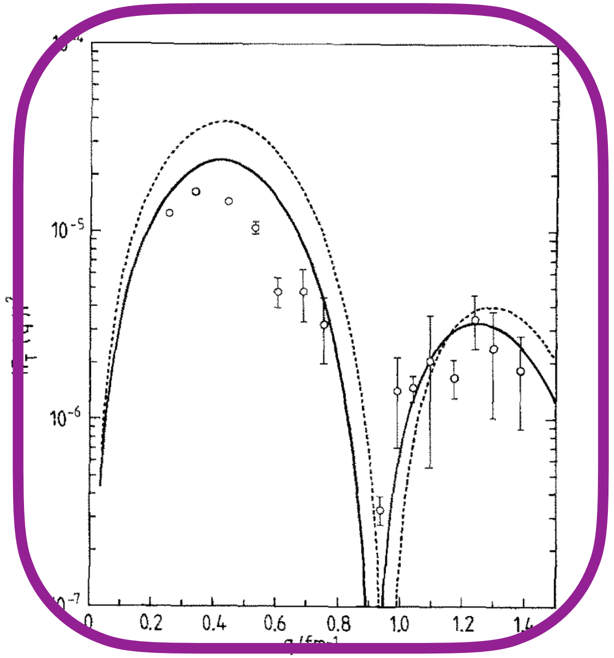
Acharya et al., Phys. Rev. Lett. 132, 232504 (2024)



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



Von Neumann et al., Phys. Lett. B 443, 1 (1998)



Steffen et al., Nuclear Physics A404 413 (1983)

OUR WORK — INPUT AND METHOD

TECHNISCHE UNIVERSITÄT DARMSTADT

Interaction: magic and
34 non-implausible interactions
at ΔNNLO

Operators: With 2BCs
(at finite momentum transfer)

+

Many body method:
VS-IMSRG

=

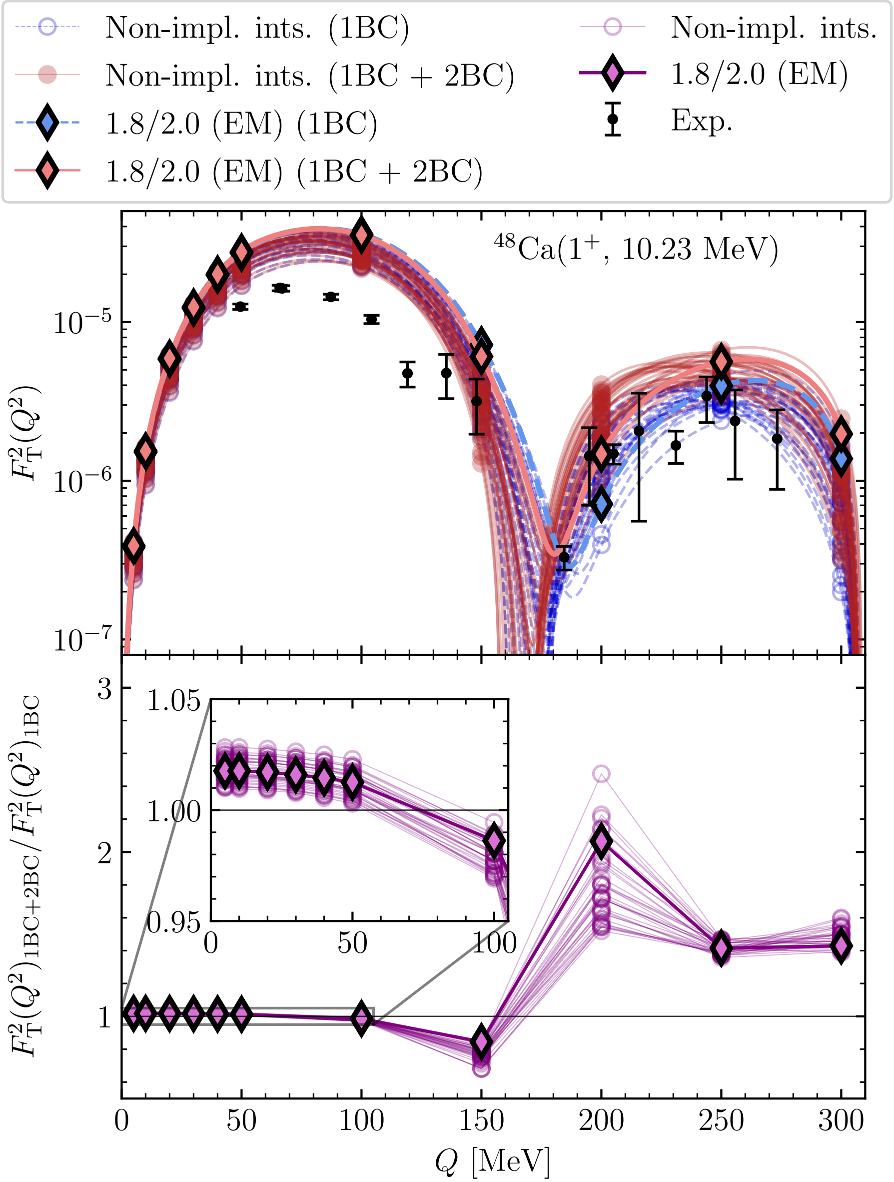
M1 transitions in
$^{48}\mathrm{Ca}$ & $^{48}\mathrm{Ti}$ and their energies

TRANSITION FORM FACTOR COMPARISON TO (e,e') EXPERIMENT

Brase et al., Phys. Rev. C 113, 014317 (2026)

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

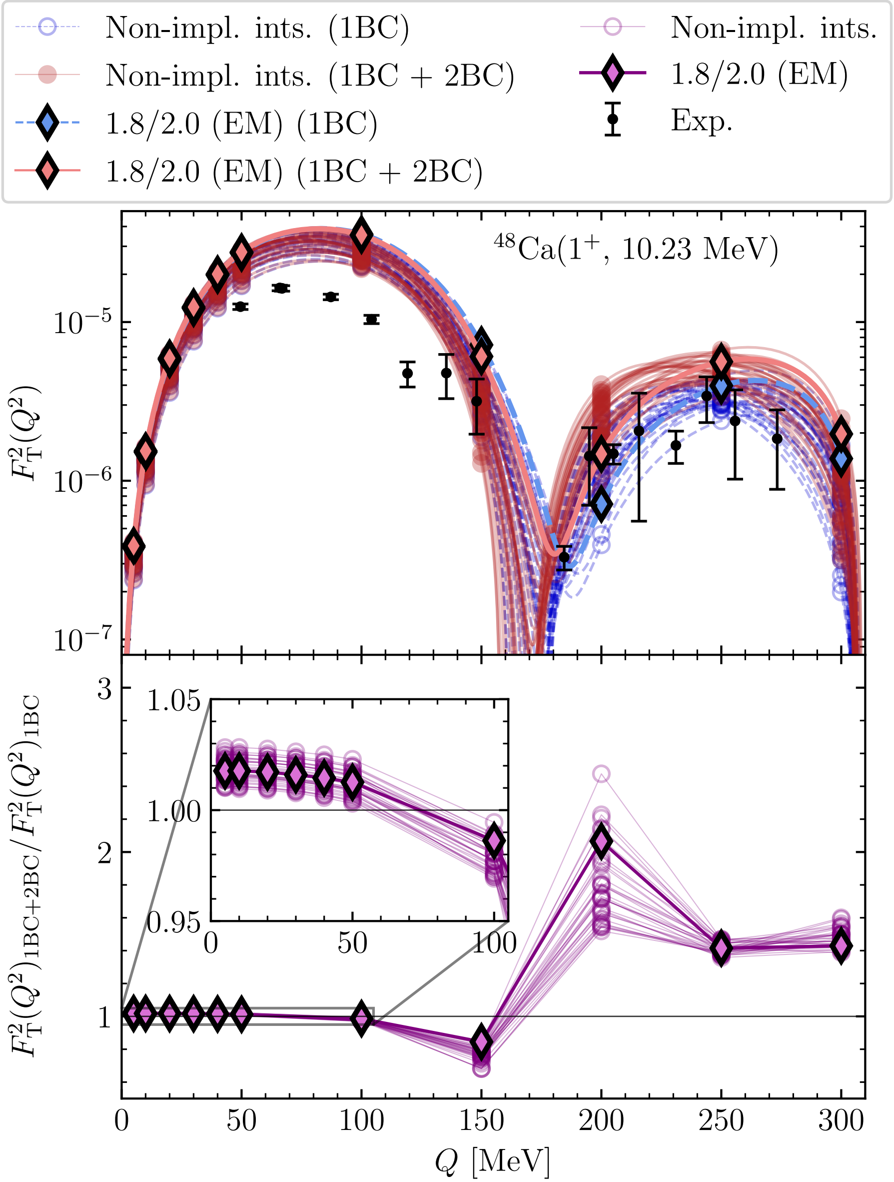
  Hu et al., Nat. Phys. 18, 1196 (2022)
  Miyagi, Eur. Phys. J. A 59, 150 (2023)
  Stroberg, github.com/ragnarstroberg/imsrg.git



TRANSITION FORM FACTOR COMPARISON TO (e,e') EXPERIMENT

Brase et al., Phys. Rev. C 113, 014317 (2026)

- non-implausible interactions using VS-IMSRG with 1BC and with 1BC+2BC
  Hu et al., Nat. Phys. 18, 1196 (2022)
  Miyagi, Eur. Phys. J. A 59, 150 (2023)
  Stroberg, github.com/ragnarstroberg/imsrg.git
- small 2BC contribution for small momentum transfer Q
- cancellation between 2BCs, seagull and pion-in-flight



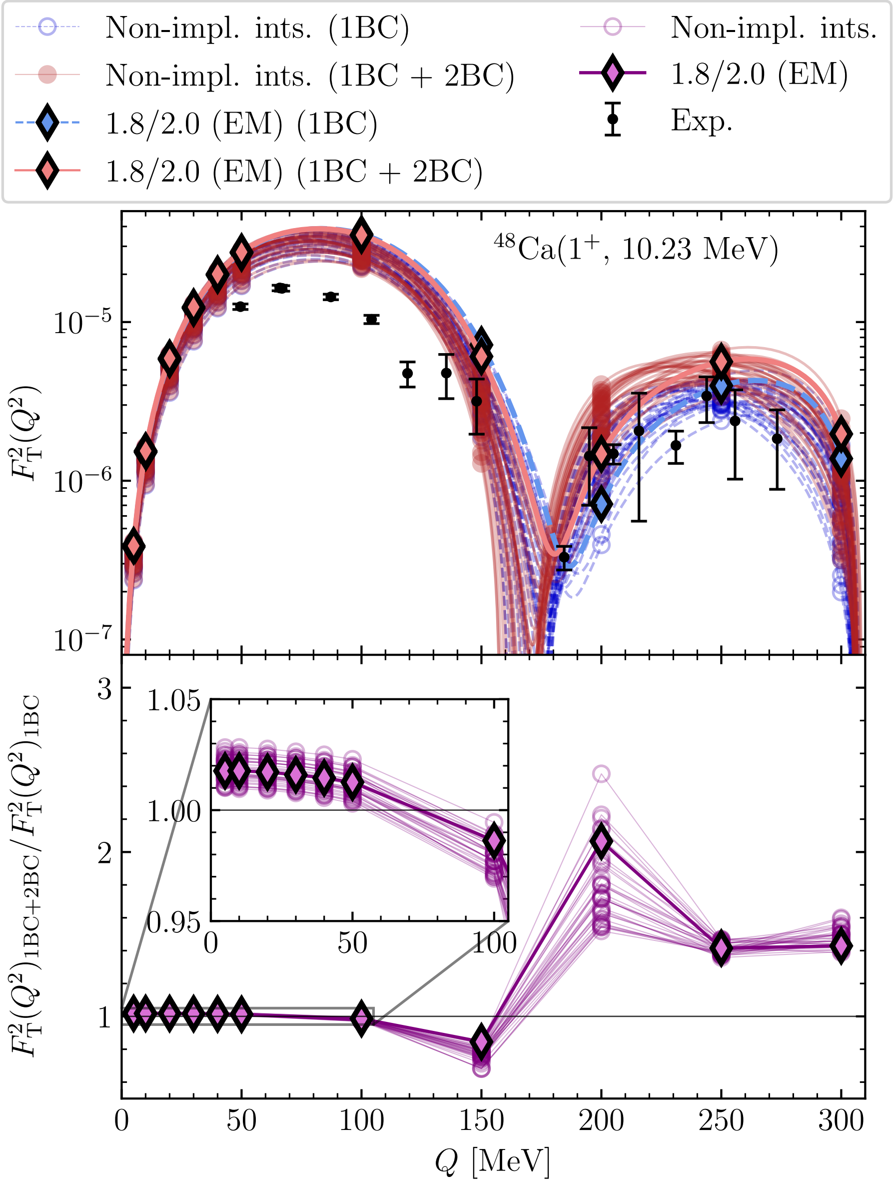
TRANSITION FORM FACTOR COMPARISON TO (e,e') EXPERIMENT

Brase et al., Phys. Rev. C 113, 014317 (2026)

- non-implausible interactions using VS-IMSRG with 1BC and with 1BC+2BC
  Hu et al., Nat. Phys. 18, 1196 (2022)
  Miyagi, Eur. Phys. J. A 59, 150 (2023)
  Stroberg, github.com/ragnarstroberg/imsrg.git
- small 2BC contribution for small momentum transfer Q
- cancellation between 2BCs, seagull and pion-in-flight

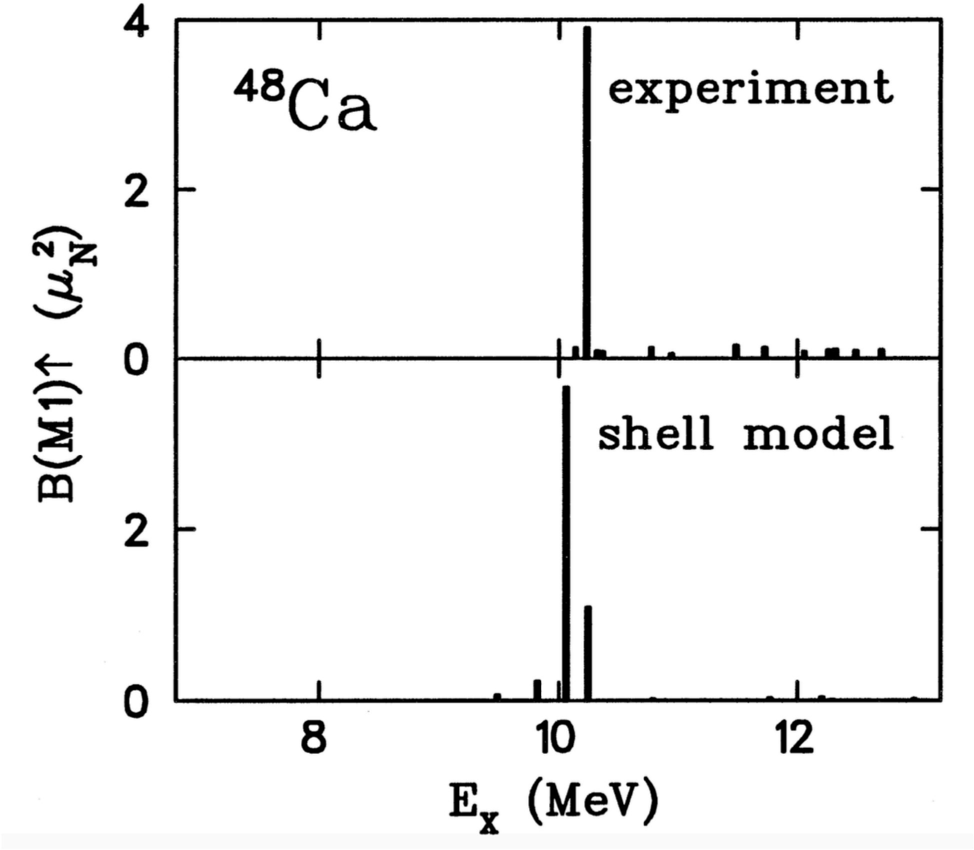
For ^{48}Ca: higher-order currents relevant?

strong cancellation not found in other nuclei

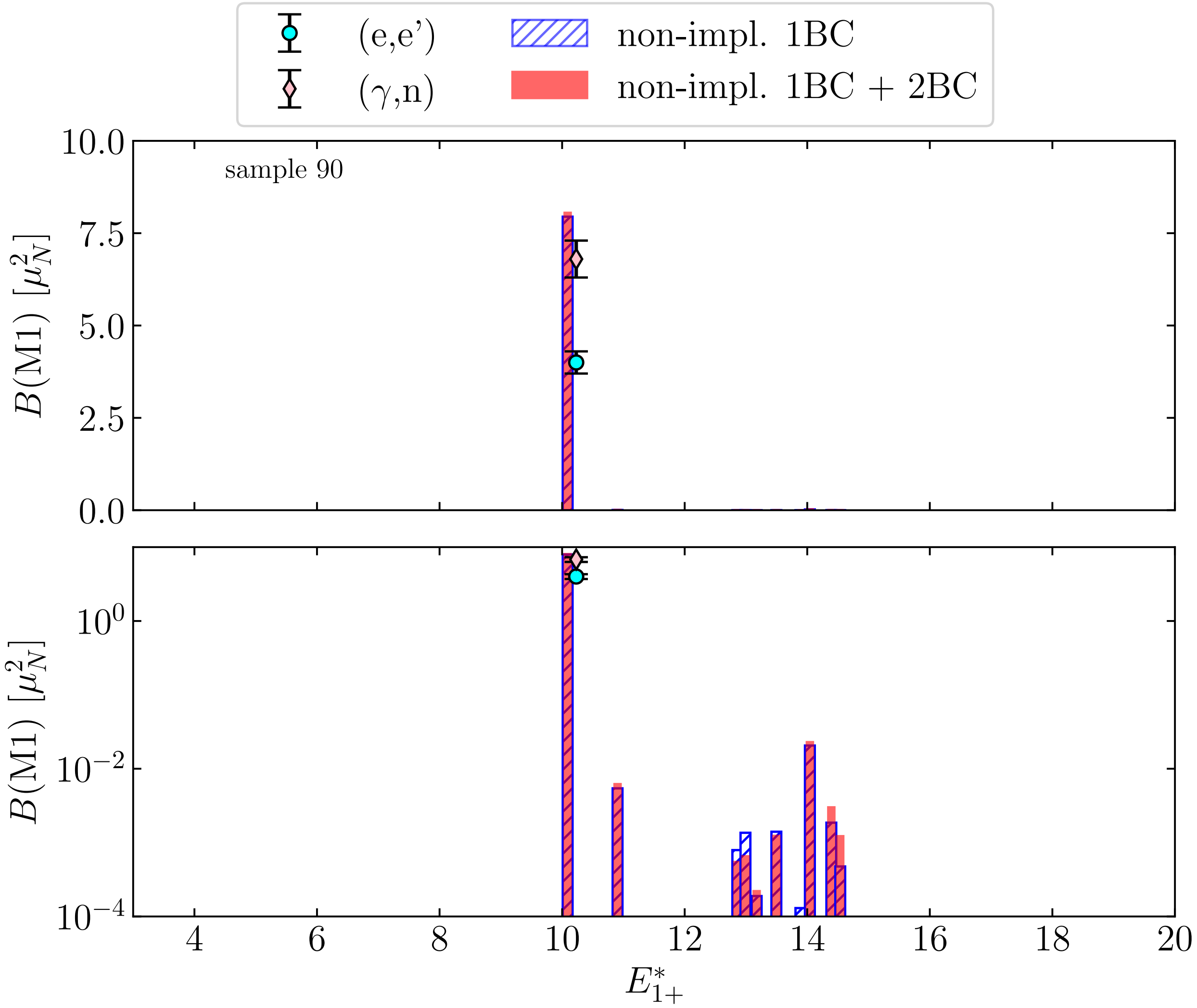


M1 STRENGTH DISTRIBUTION

Main experimental feature of one dominant transition is reproduced in our calculations

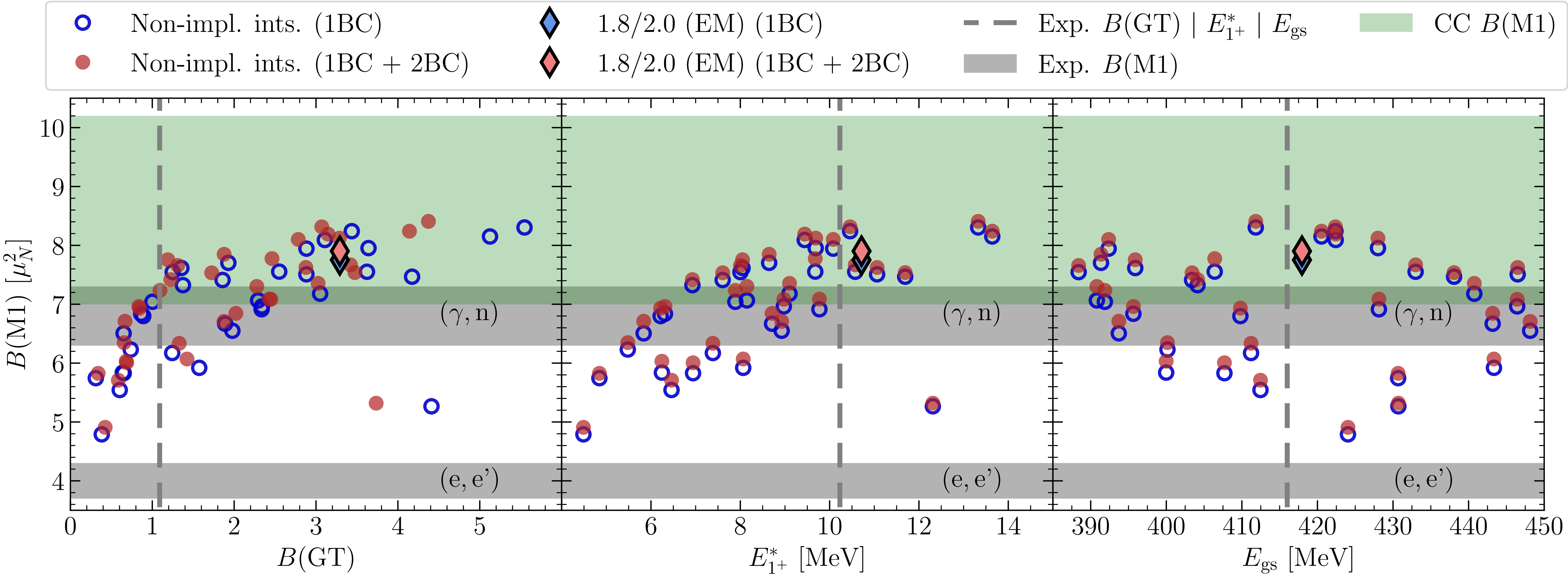


Von Neumann et al., Phys. Lett. B 443, 1 (1998)



CORRELATIONS — ^{48}Ca
2BCs IN M1- AND GT-STRENGTH

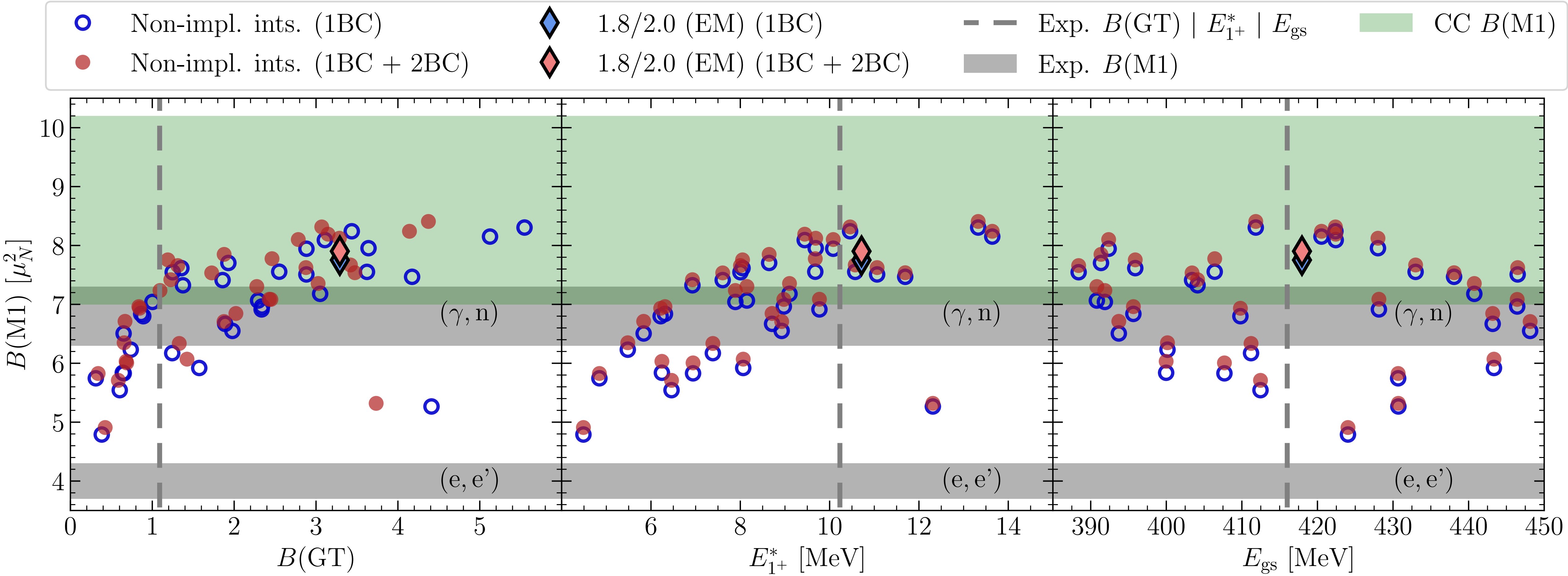
TECHNISCHE UNIVERSITÄT DARMSTADT



Brase et al., Phys. Rev. C 113, 014317 (2026)

CORRELATIONS — ^{48}Ca
2BCs IN M1- AND GT-STRENGTH

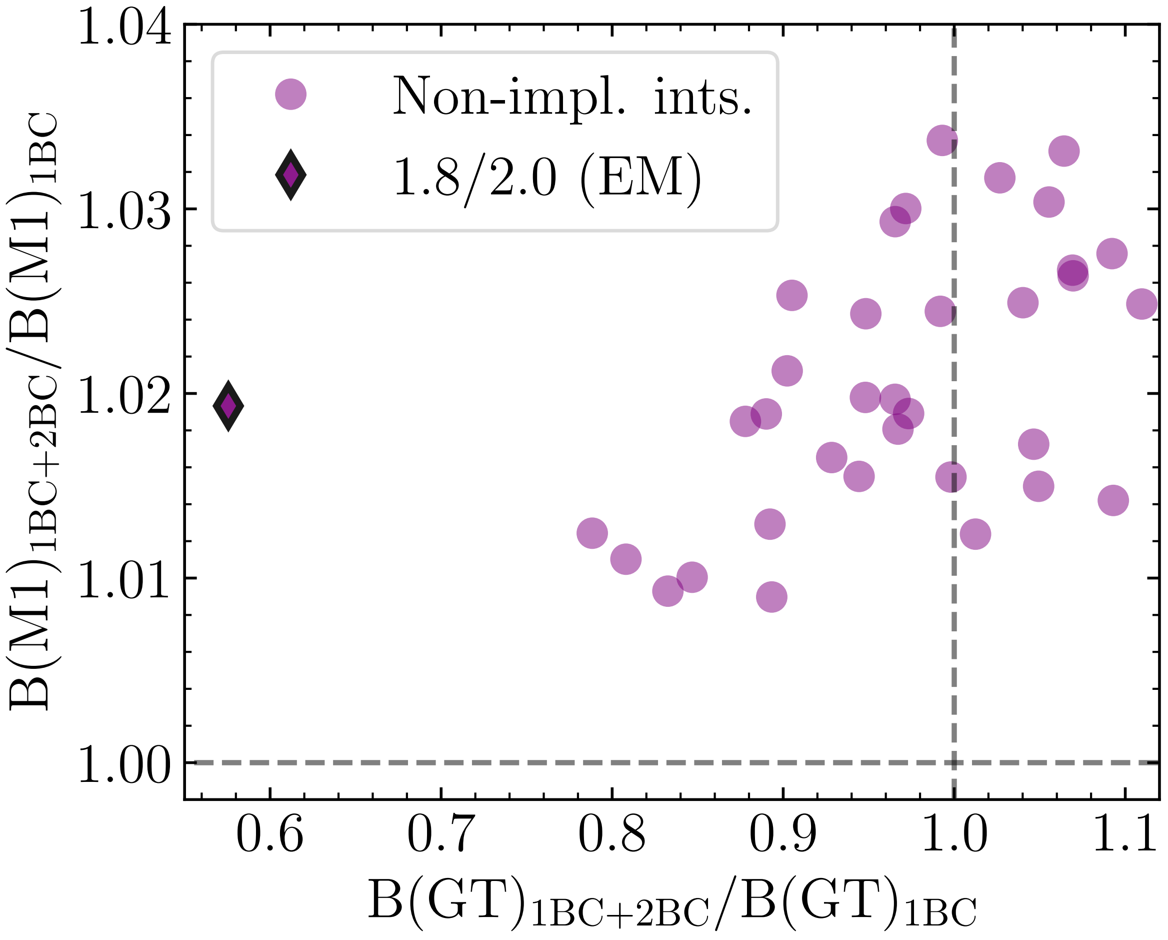
TECHNISCHE UNIVERSITÄT DARMSTADT



our work: B(M1) increases with 2BC - favors (γ, n) results → closer look into impact from 2BCs

Brase et al., Phys. Rev. C 113, 014317 (2026)

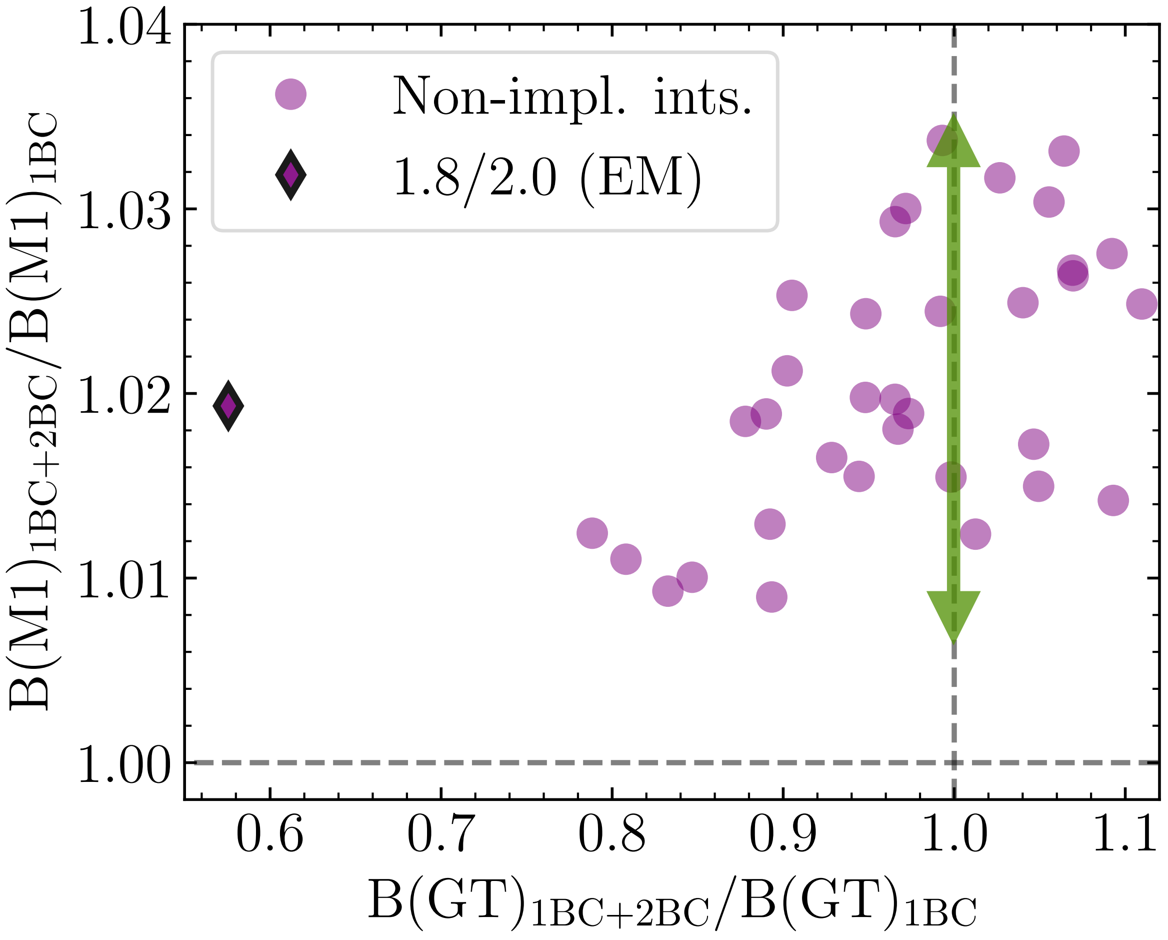
2BCs IN B(GT) VS B(M1)?



- no correlation between behavior of 2BCs in M1 and GT strength
- *B*(M1) — vector 2BCs: mainly increase M1 strength
  - increase between 0.8 and 3.6%
- *B*(GT) — axial-vector 2BCs: more complex behaviour
  - reduction up to ~ 22%
  - increase up to ~ 12%

Brase et al., Phys. Rev. C 113, 014317 (2026)

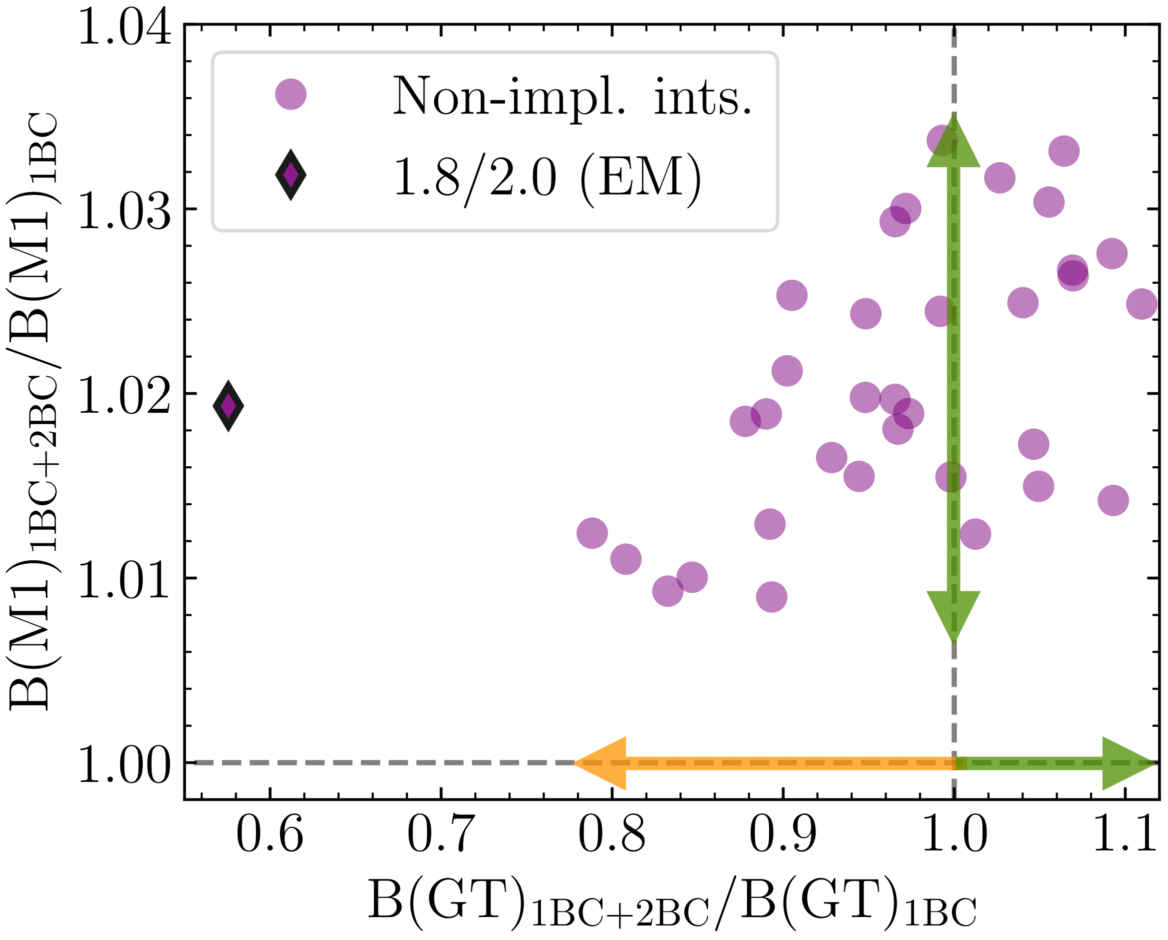
2BCs IN B(GT) VS B(M1)?



- no correlation between behavior of 2BCs in M1 and GT strength
- *B*(M1) — vector 2BCs: mainly increase M1 strength
  - ▸ increase between 0.8 and 3.6%
- *B*(GT) — axial-vector 2BCs: more complex behaviour
  - ▸ reduction up to ~ 22%
  - ▸ increase up to ~ 12%

Brase et al., Phys. Rev. C 113, 014317 (2026)

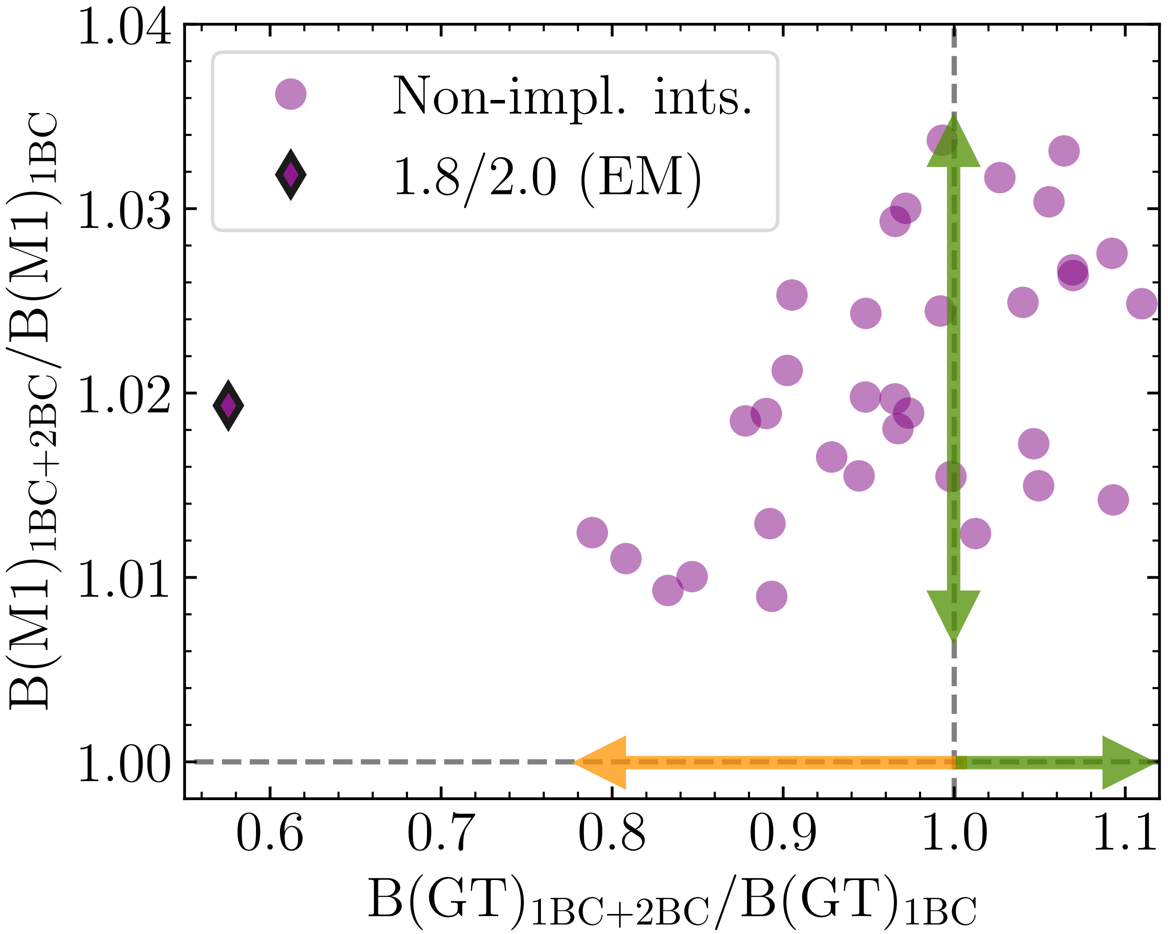
2BCs IN B(GT) VS B(M1)?



- no correlation between behavior of 2BCs in M1 and GT strength
- *B*(M1) — vector 2BCs: mainly increase M1 strength
  - ▸ increase between 0.8 and 3.6%
- *B*(GT) — axial-vector 2BCs: more complex behaviour
  - ▸ reduction up to ~ 22%
  - ▸ increase up to ~ 12%

Brase et al., Phys. Rev. C 113, 014317 (2026)

2BCs IN B(GT) VS B(M1)?



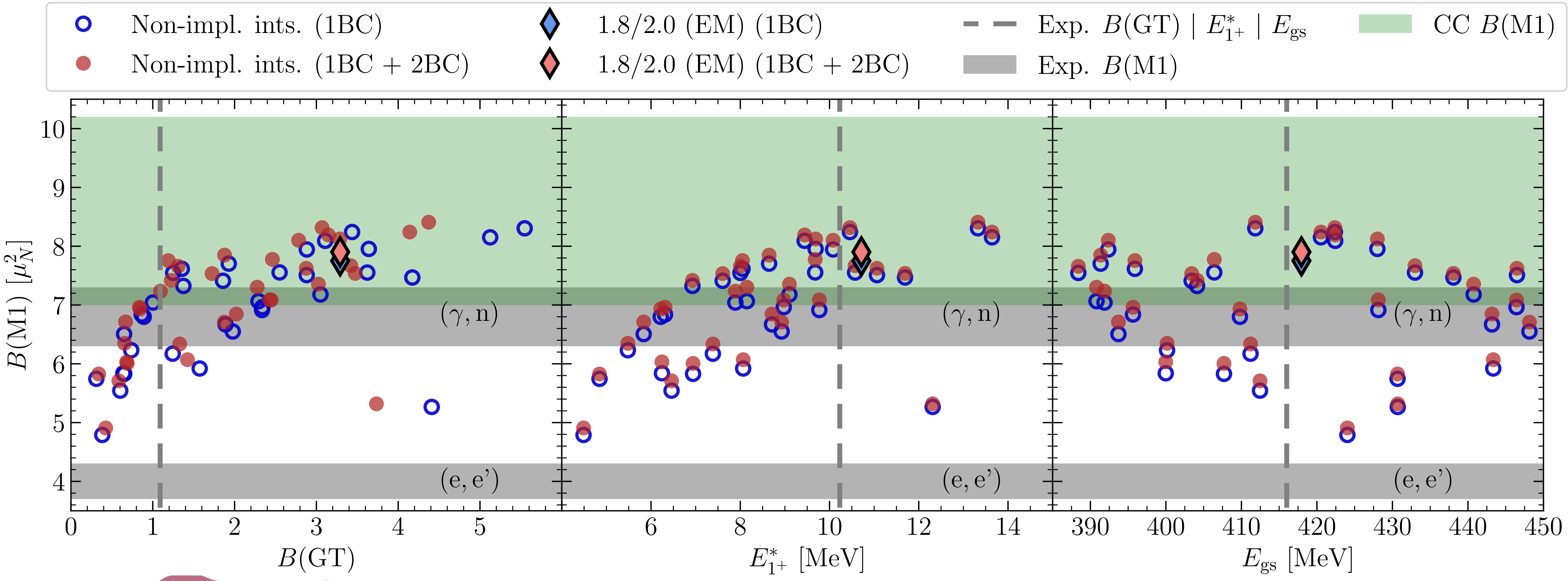
- no correlation between behavior of 2BCs in M1 and GT strength
- *B*(M1) — vector 2BCs: mainly increase M1 strength
  - ▸ increase between 0.8 and 3.6%
- *B*(GT) — axial-vector 2BCs: more complex behaviour
  - ▸ reduction up to ~ 22%
  - ▸ increase up to ~ 12%

We find: vector and axial-vector currents → very different behavior

Brase et al., Phys. Rev. C 113, 014317 (2026)

CORRELATIONS — ^{48}Ca
2BCs IN M1- AND GT-STRENGTH

TECHNISCHE UNIVERSITÄT DARMSTADT

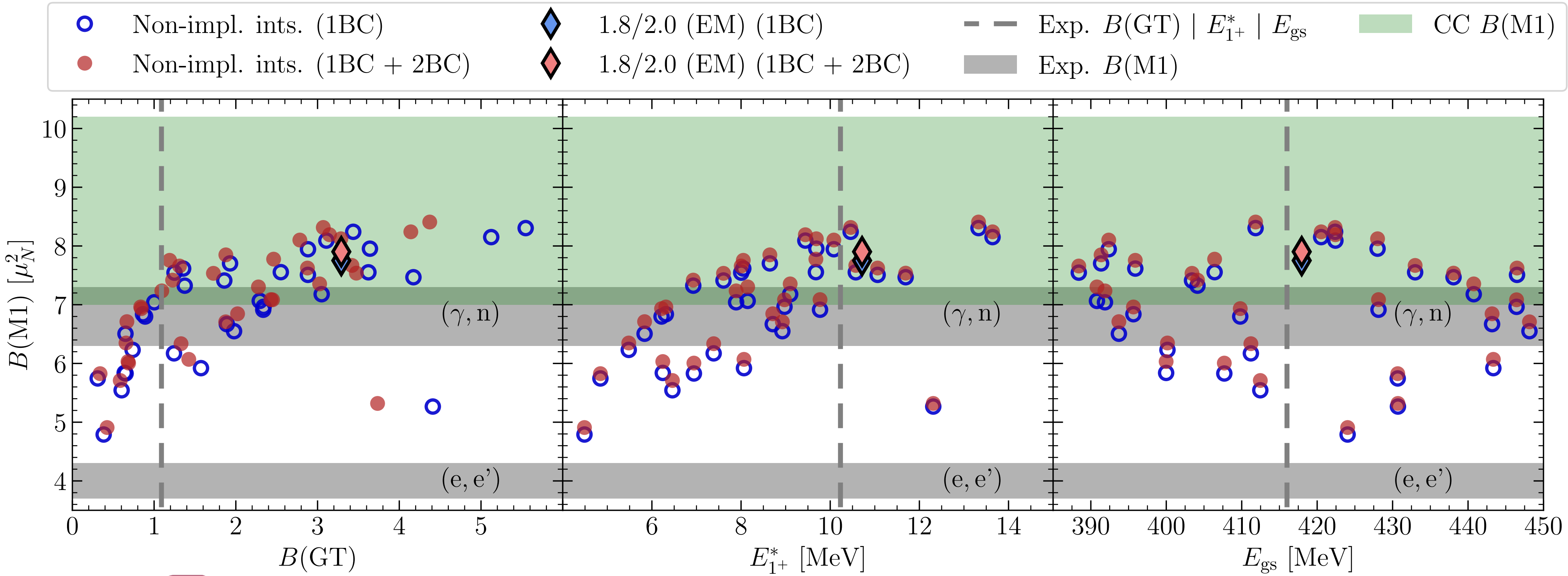


B(M1) increases with 2BC - favors (γ, n) results; consistent with CC calculation

Brase et al., Phys. Rev. C 113, 014317 (2026)

CORRELATIONS — ^{48}Ca
2BCs IN M1- AND GT-STRENGTH

TECHNISCHE UNIVERSITÄT DARMSTADT



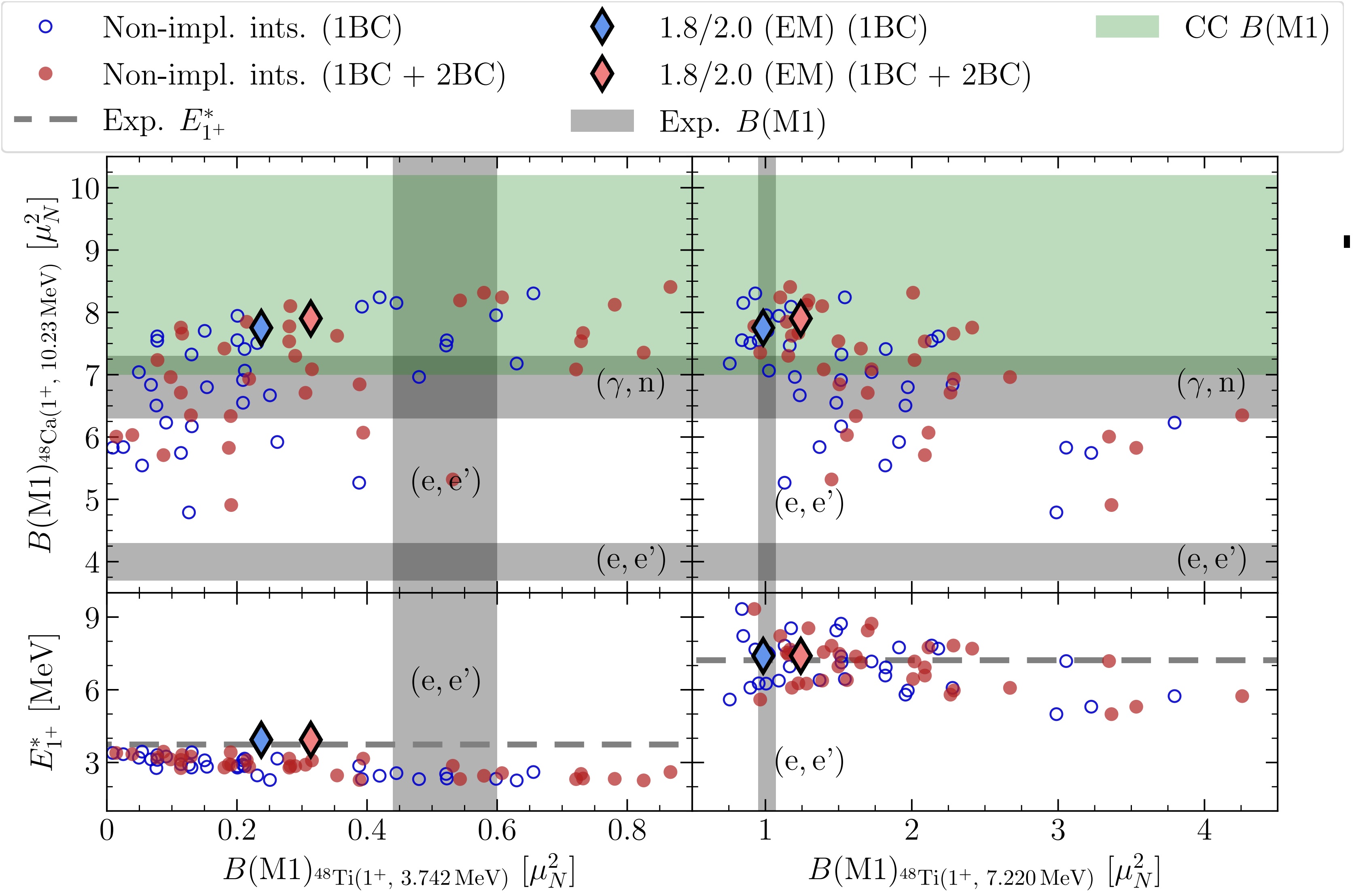
B(M1) increases with 2BC - favors (γ, n) results; consistent with CC calculation

What about another nucleus and its M1 strengths? $\longrightarrow$ ^{48}Ti

Brase et al., Phys. Rev. C 113, 014317 (2026)

WHAT ABOUT ANOTHER NUCLEUS?

TECHNISCHE UNIVERSITÄT DARMSTADT



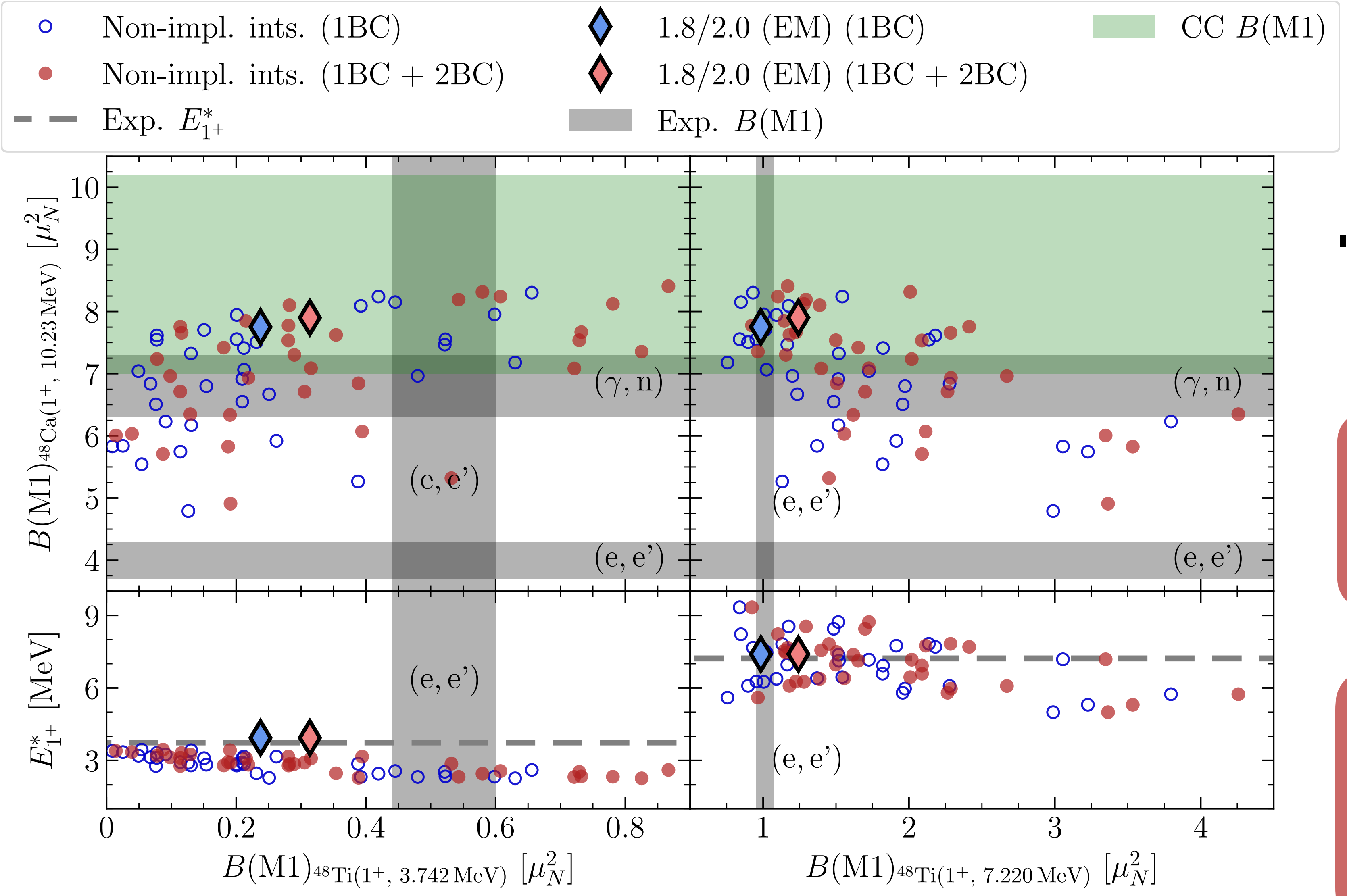
^{48}Ti vs ^{48}Ca

- Non-implausible interactions cover both M1 strengths in ^{48}Ti

Brase et al., Phys. Rev. C 113, 014317 (2026)

WHAT ABOUT ANOTHER NUCLEUS?

TECHNISCHE UNIVERSITÄT DARMSTADT



^{48}Ti vs ^{48}Ca

- Non-implausible interactions cover both M1 strengths in ^{48}Ti

Exp. M1 strengths in ^{48}Ti lie in predicted distribution

In ^{48}Ti: inclusion of 2BCs bigger impact compared to ^{48}Ca

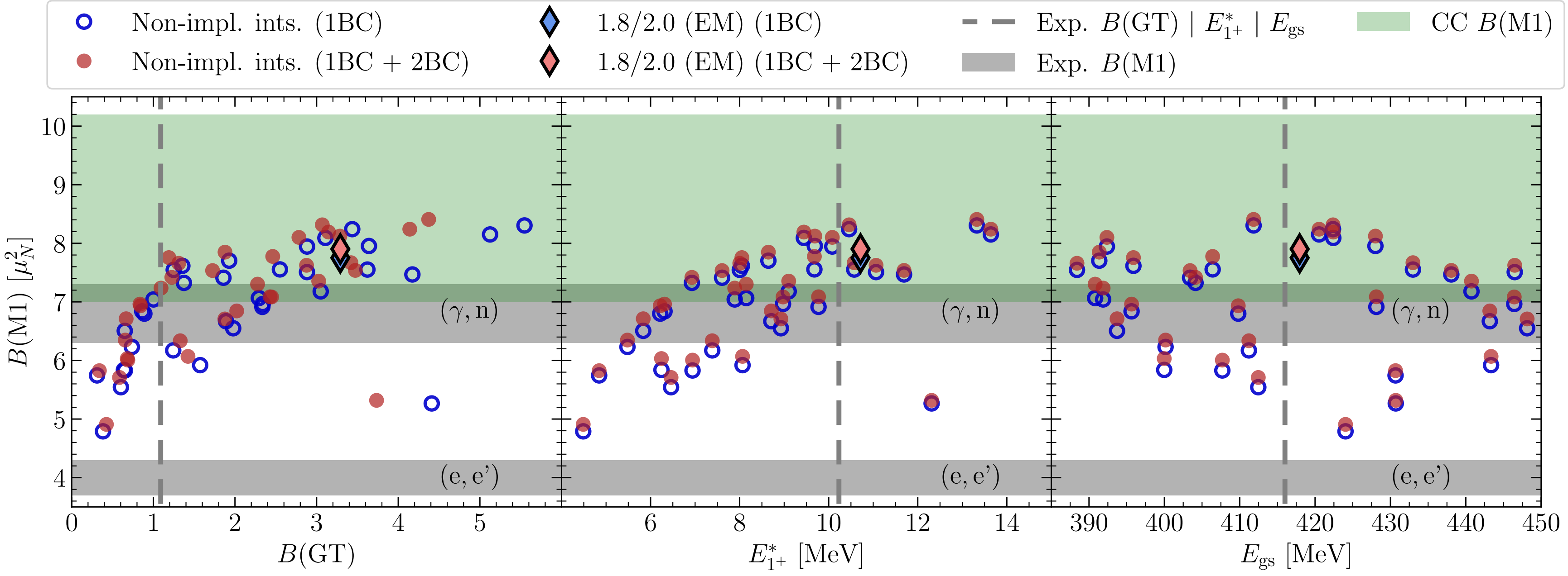
Brase et al., Phys. Rev. C 113, 014317 (2026)

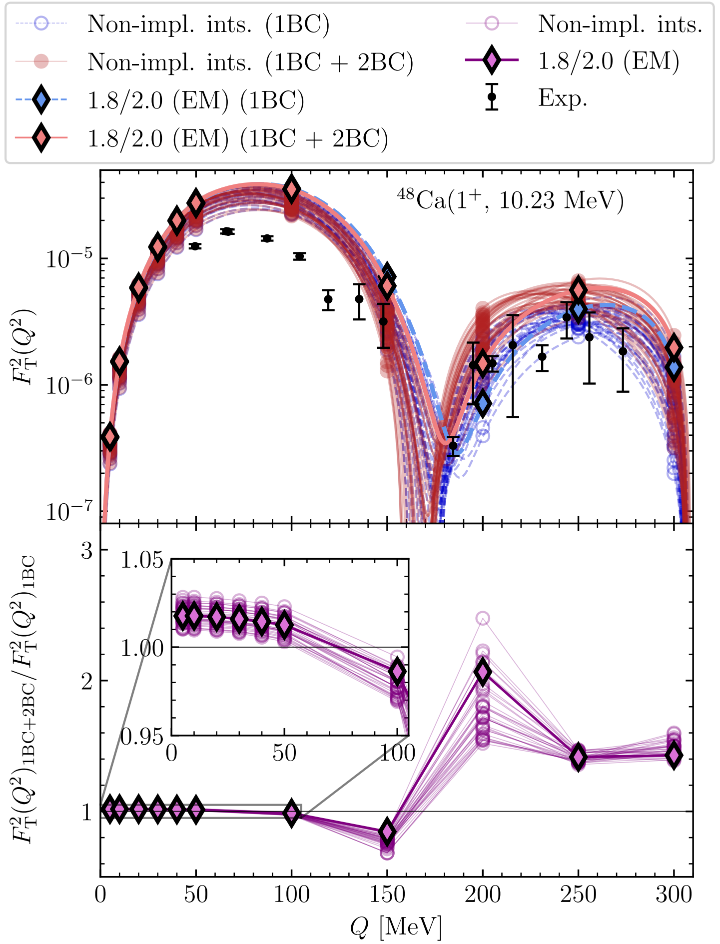
SUMMARY

Brase et al., Phys. Rev. C 113, 014317 (2026)

TECHNISCHE
UNIVERSITÄT
DARMSTADT

Multipole decomposition of 2BCs for inclusion at finite momentum transfer in heavier nuclei



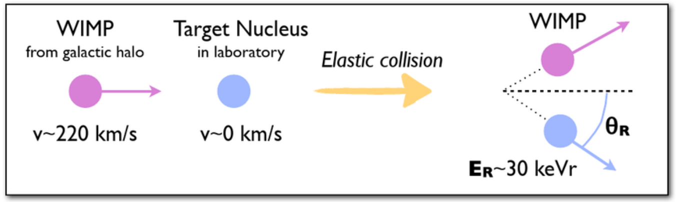


***B*(M1) increases with 2BC** — in ^{48}Ca: favors (γ, n) results

2BCs sensitive on interaction and momentum transfer

Vector and axial-vector 2BCs, very different contributions

OUTLOOK



Cooley, SciPost Phys. Lect. Notes 55 (2022)

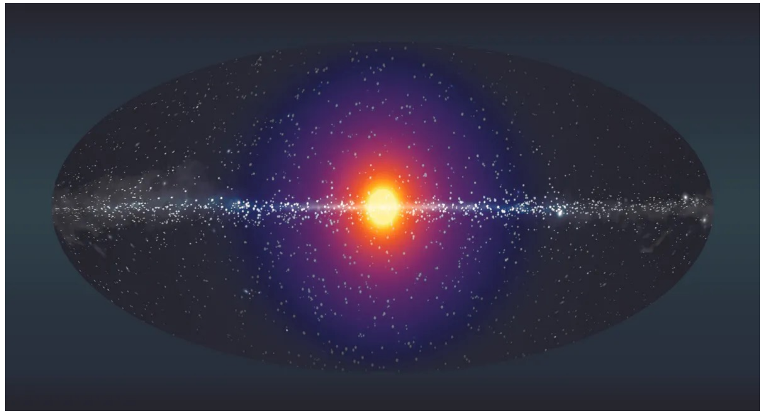
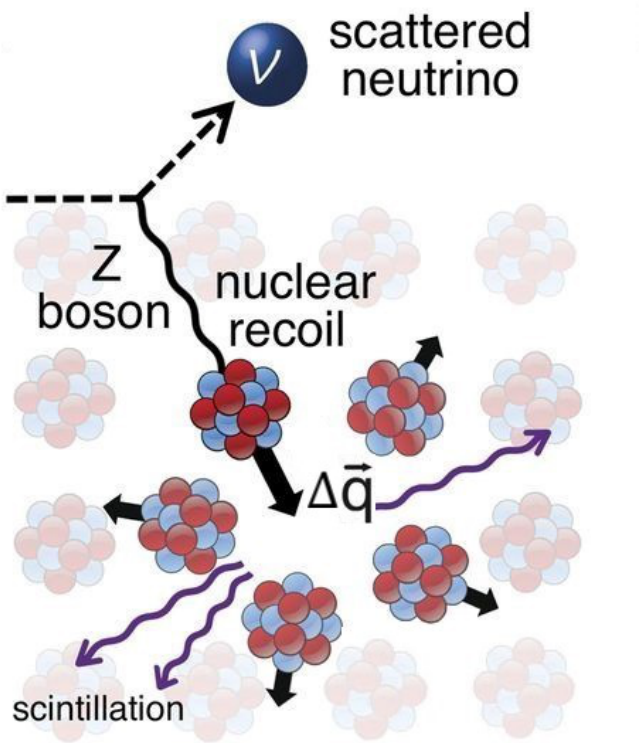
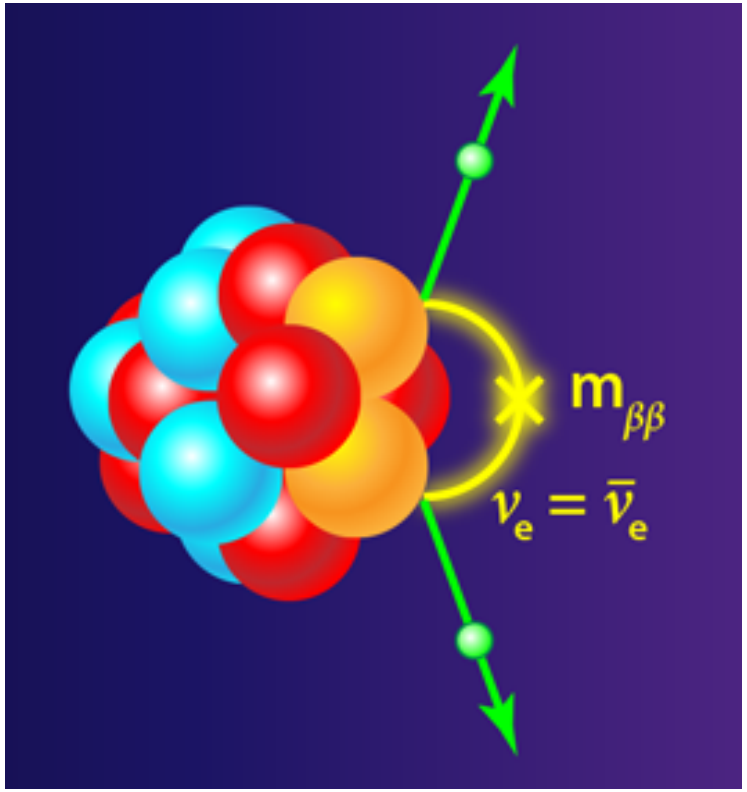


Image credit: Artistic rendering by Christopher Dessert, Nicholas L. Rodd, Benjamin R. Safdi, Zosia Rostomian (Berkeley Lab), based on data from the Fermi Large Area Telescope.
https://www.space.com/dark-matter-haloes-ancient-galaxy-1st-weight-measurements



Del Castello, arXiv:2302.02843 (2023)



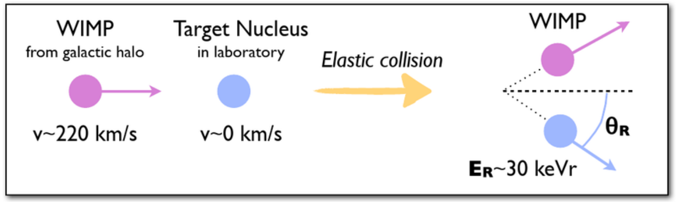
Engel and Vogel. Physics 11, 30 (2018)

Apply multipole decomposed 2BCs at finite momentum transfer to heavier nuclei

→ **WIMP-nucleus scattering (work in progress with Li, Chiba, Miyagi, Menéndez and Schwenk)**, neutrino-nucleus scattering, $0\nu\beta\beta$ decay, ….

OUTLOOK

Thank you for your attention!



Cooley, SciPost Phys. Lect. Notes 55 (2022)

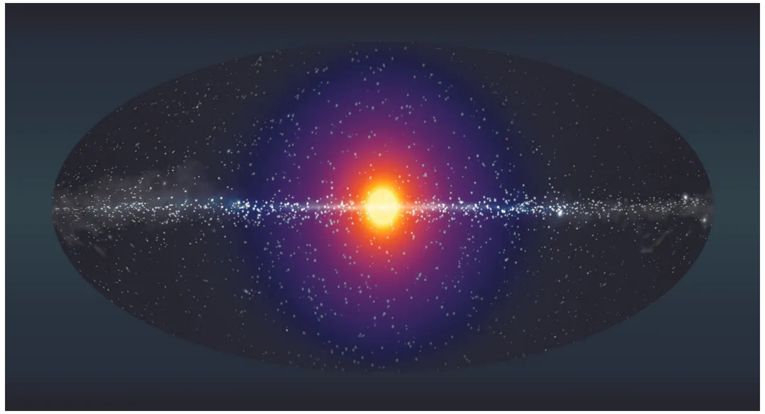
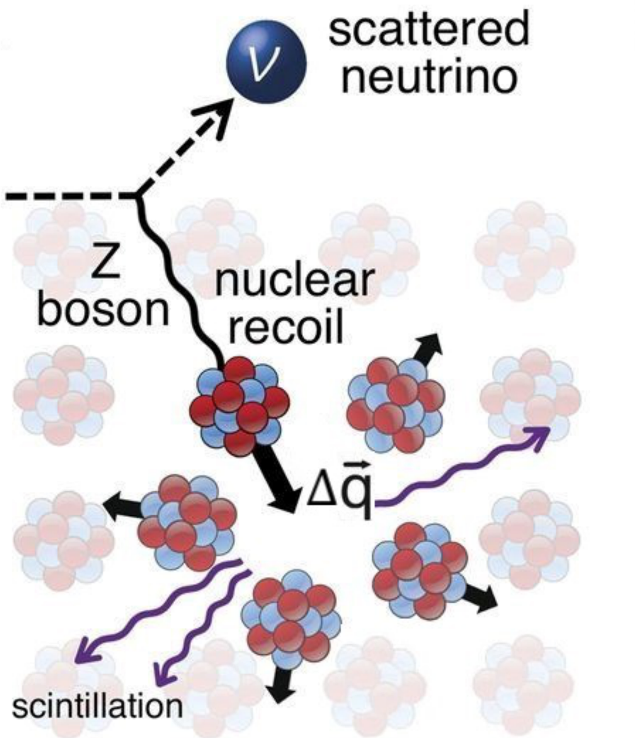
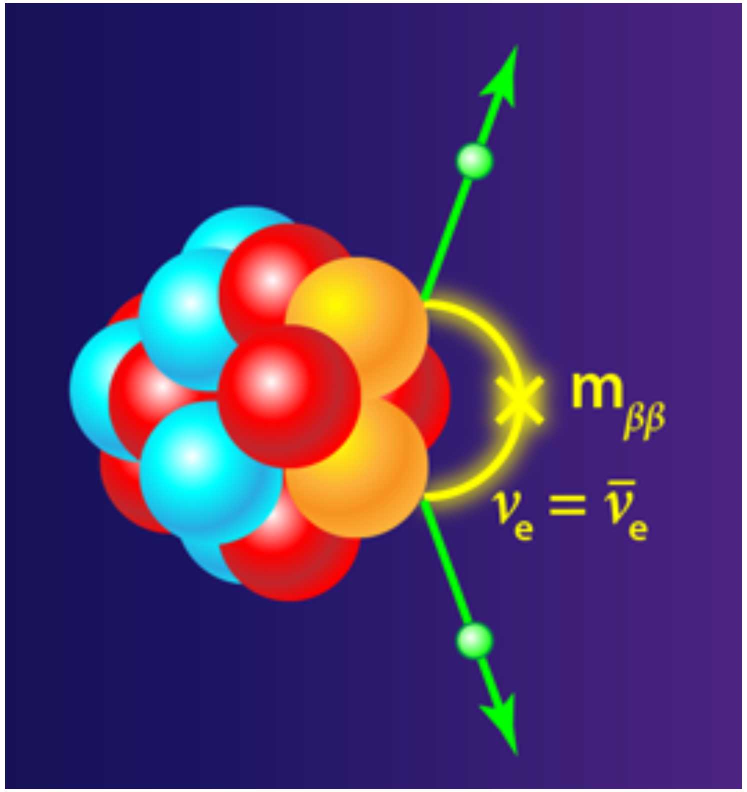


Image credit: Artistic rendering by Christopher Dessert, Nicholas L. Rodd, Benjamin R. Safdi, Zosia Rostomian (Berkeley Lab), based on data from the Fermi Large Area Telescope. https://www.space.com/dark-matter-haloes-ancient-galaxy-1st-weight-measurements



Del Castello, arXiv:2302.02843 (2023)



Engel and Vogel. Physics 11, 30 (2018)

Apply multipole decomposed 2BCs at finite momentum transfer to heavier nuclei

→ **WIMP-nucleus scattering (work in progress with Li, Chiba, Miyagi, Menéndez and Schwenk)**,

neutrino-nucleus scattering, $0\nu\beta\beta$ decay, ….