Two-body currents in magnetic dipole moments based on nuclear DFT

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Outline

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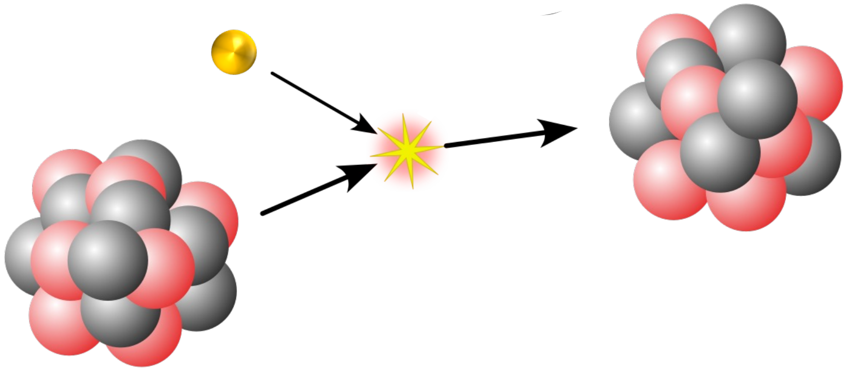
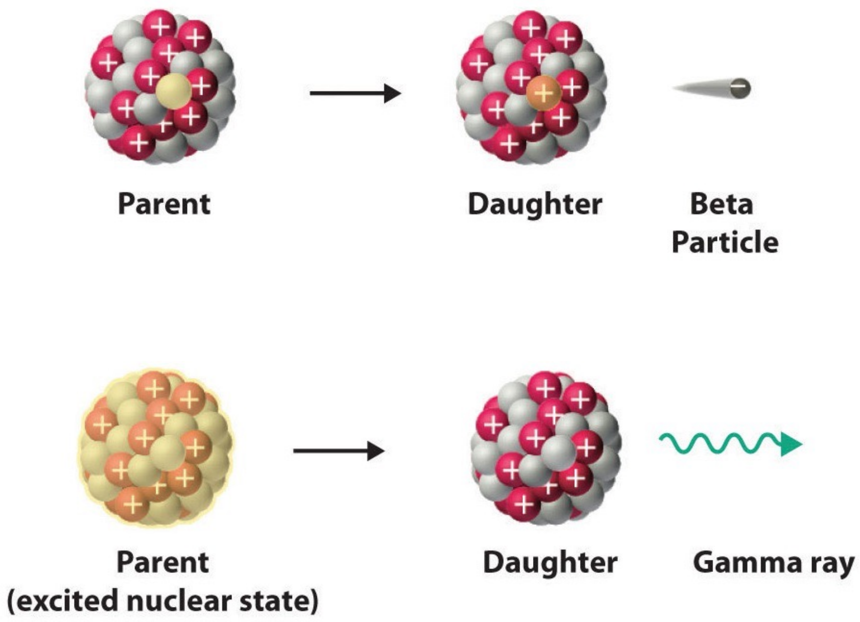
  - ➢ Deviation between theory and experiment
  - ➢ Higher-order corrections
  - ➢ Nuclear Density Functional Theory (DFT)
- **2BC in nuclear DFT**
- **Preliminary results**
- **Summary & outlook**

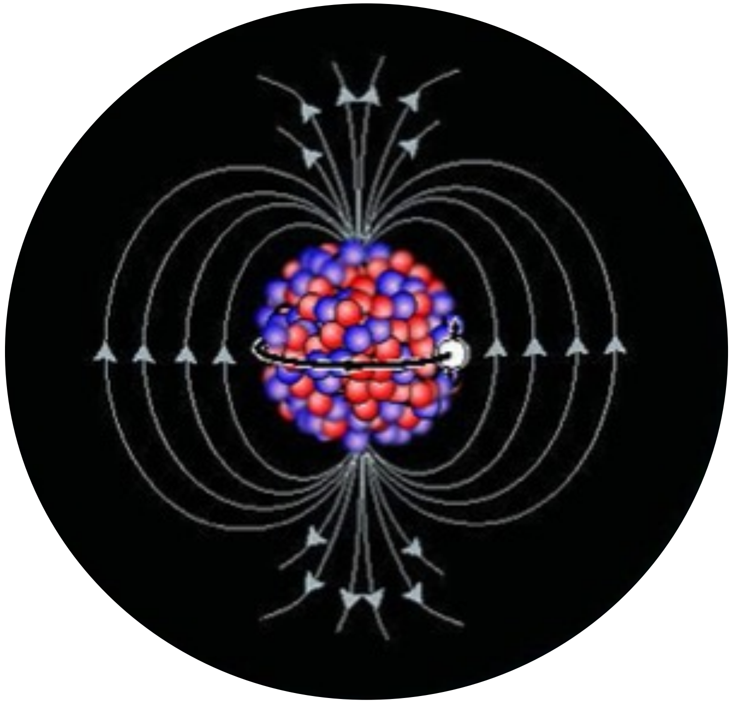


Introduction – Transition and moment

- The transitions and moments are sensitive to nuclear forces and wave functions, which are powerful tools to explore the microscopic structure of nucleus, nuclear forces and even physics beyond the standard model.
- Higher requirements for the precision of transitions and moments are raised both experimentally and theoretically.



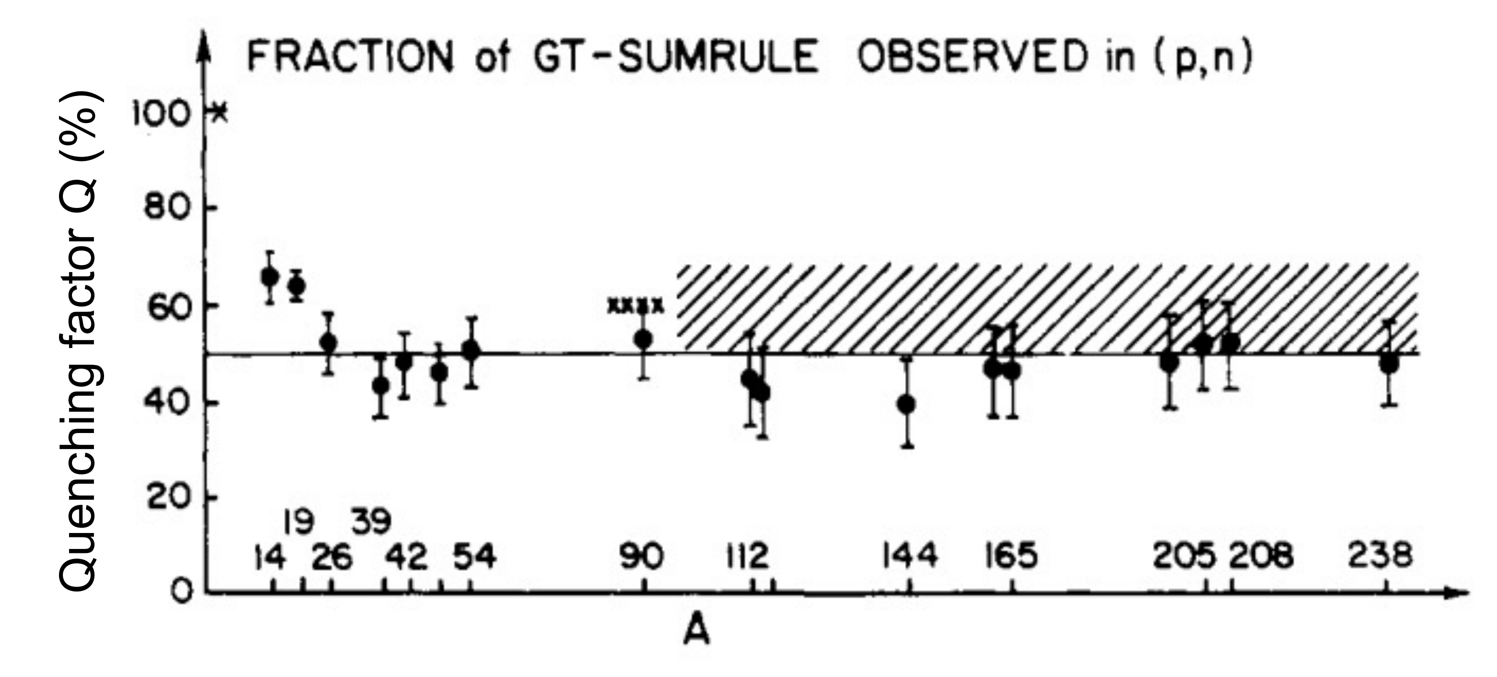
transitions



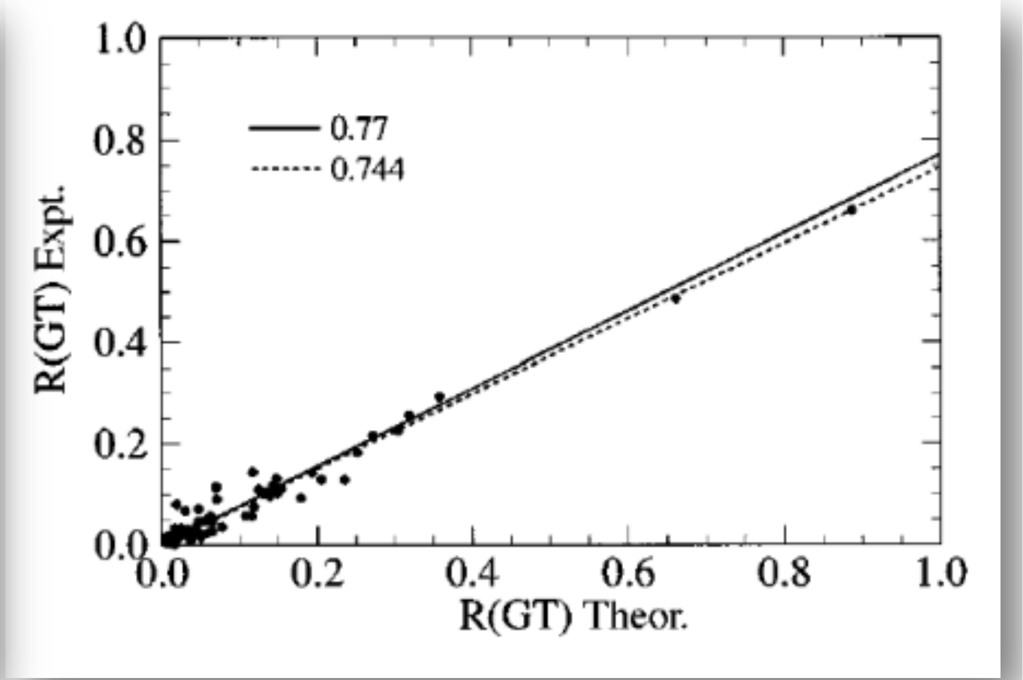
magnetic dipole moment

Introduction – Deviation between theory and experiment

Long-standing problem: Quenching of Gamow-Teller strength in nuclei



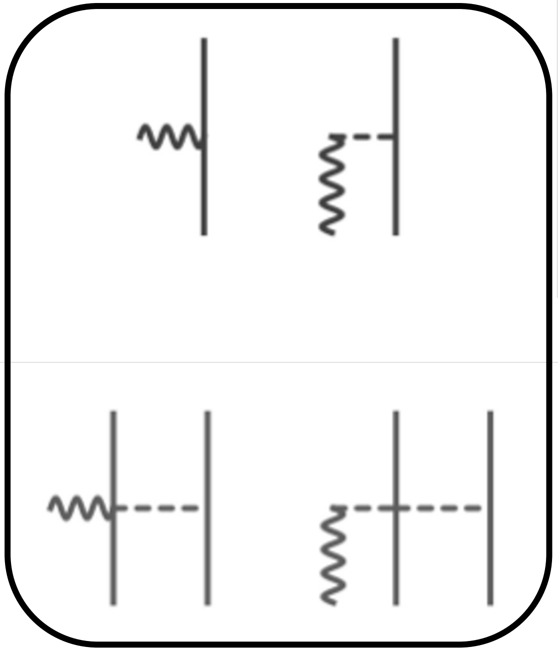
C. Gaarde, Phys. Scr. T5, 55 (1983)



G. Martinez-Pinedo et al, Phys. Rev. C 53, R2602 (1996)

Introduction – Higher-order corrections

E.g. transitions/moments operators



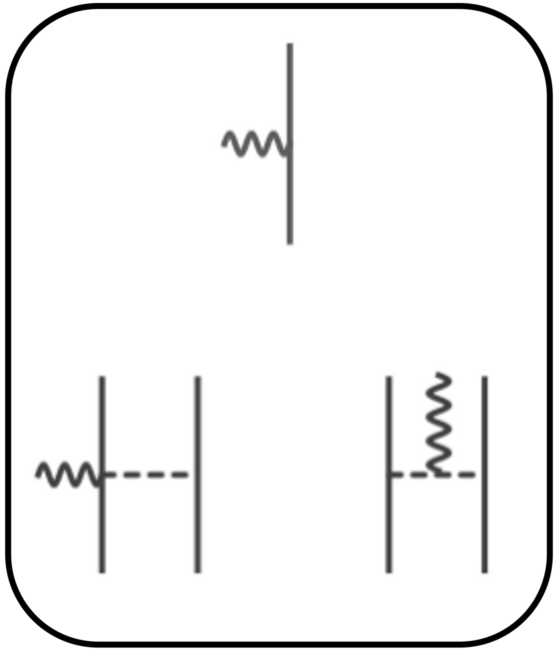
What we used to do

One body current operator at LO

Higher-order correction

Two-body current operator at NLO

one-pion-exchange

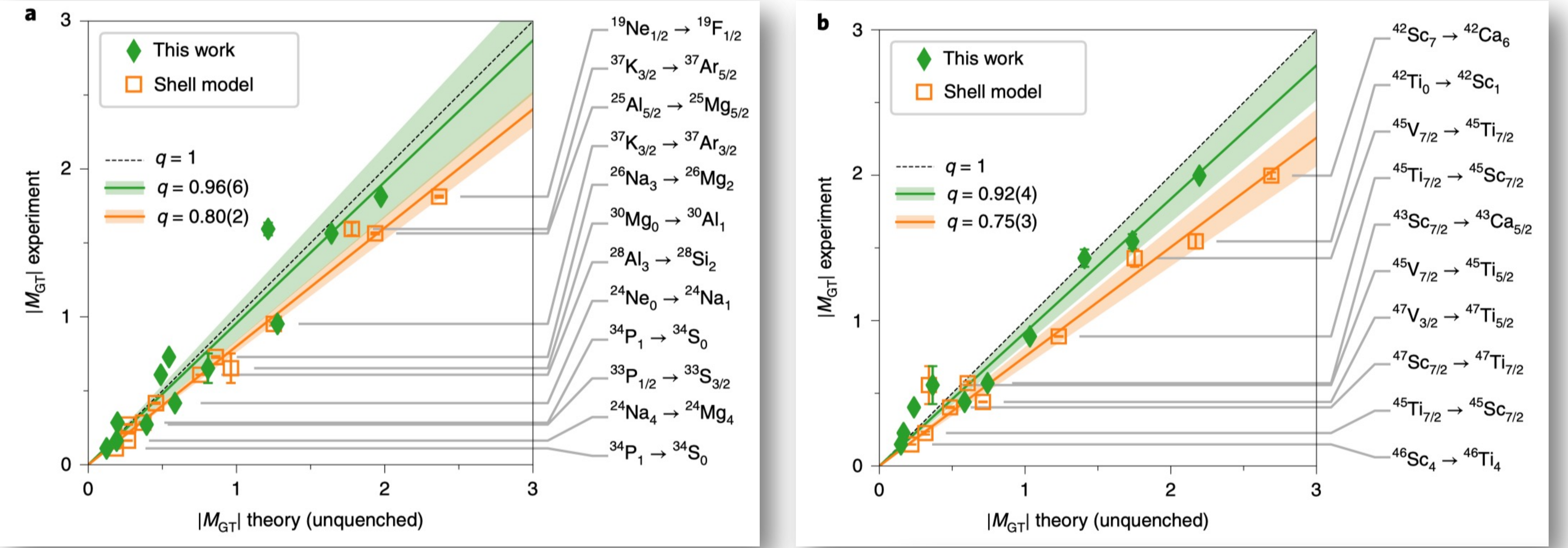


GT transition, …

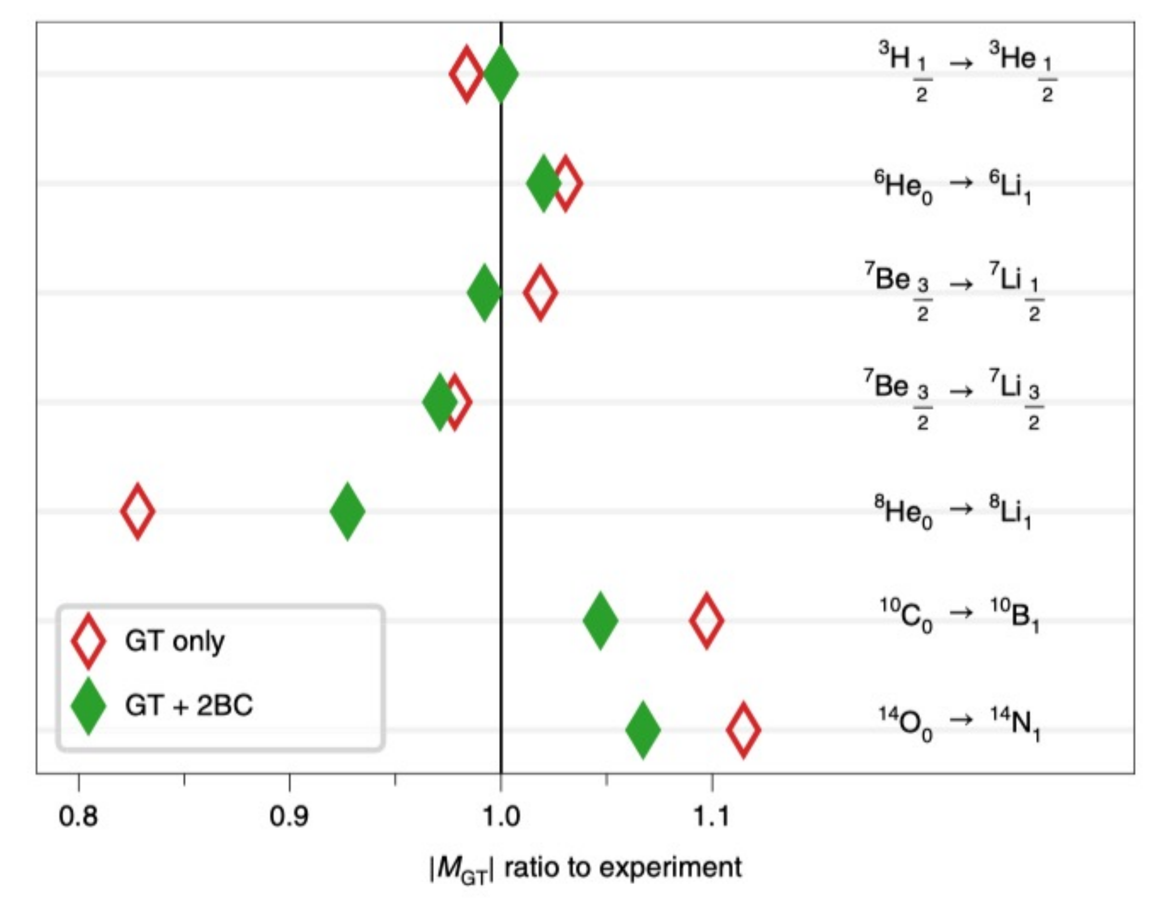
EM observables, …

E. Epelbaum, arXiv:1908.09349 (2019)

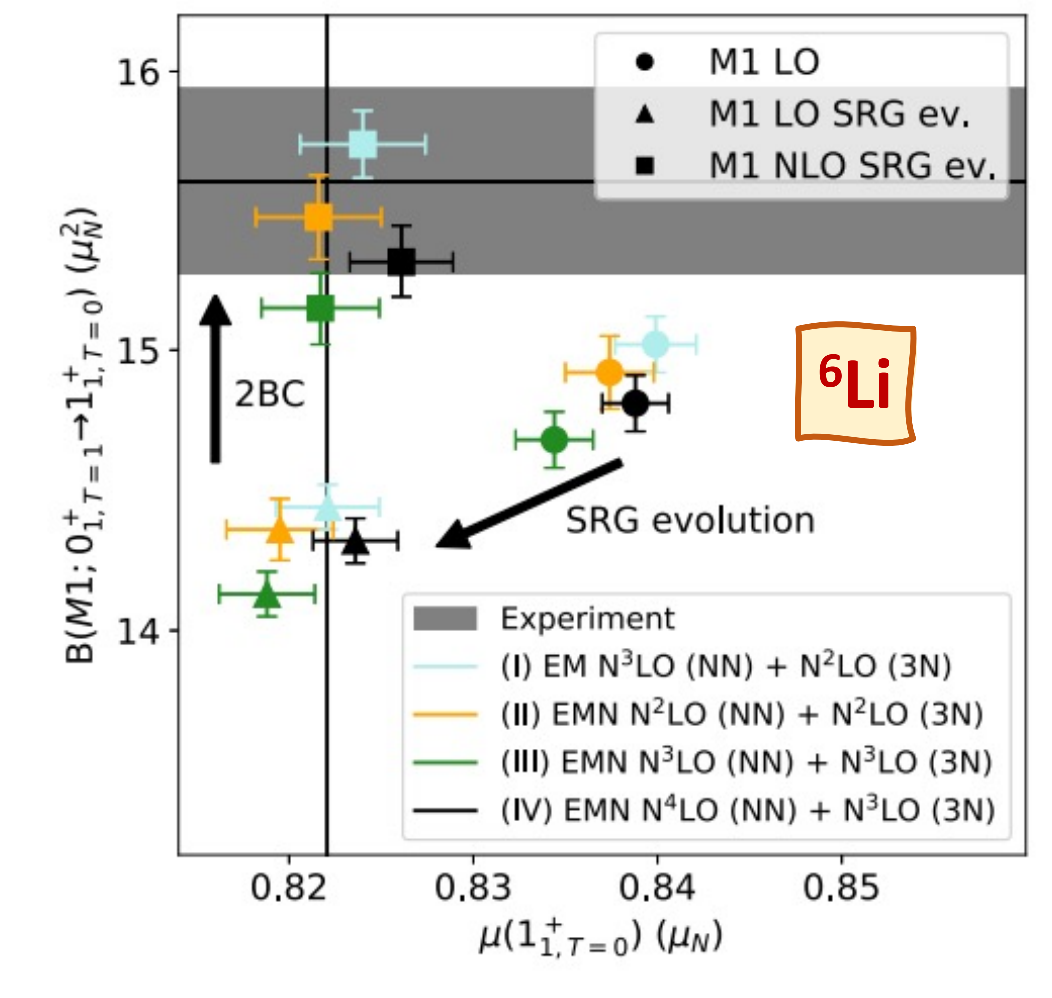
Introduction – Higher-order corrections



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

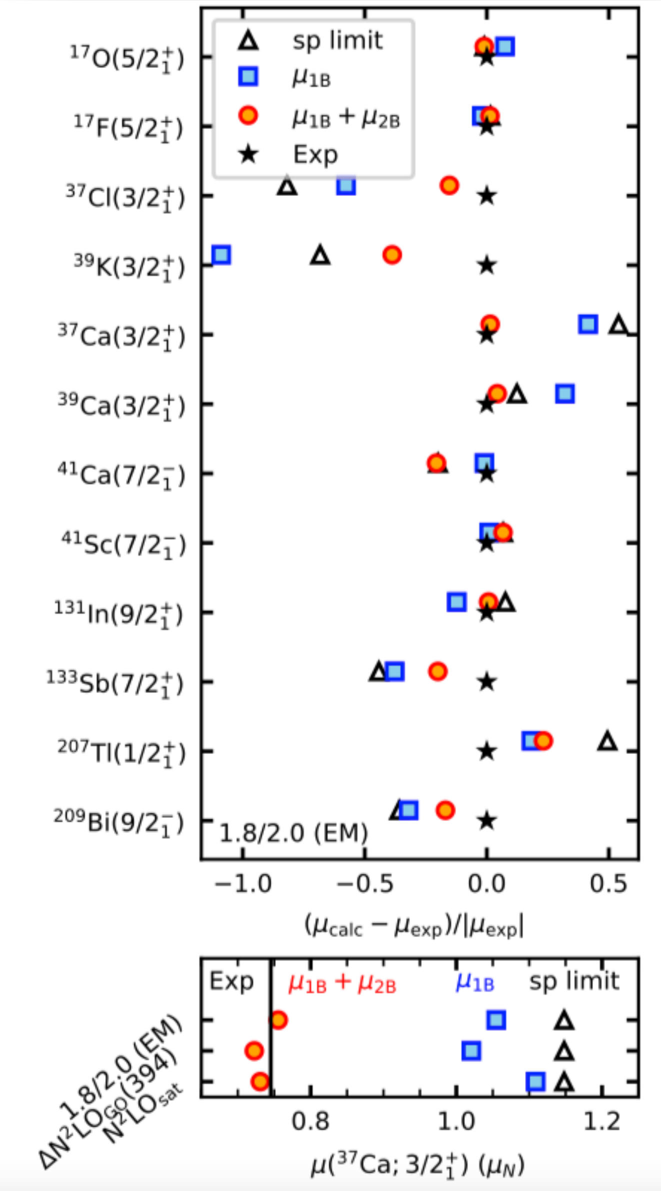


P. Gysbers et al., Nat. Phys. 15, 428 (2019)



U. Friman-Gayer et al., Phys. Rev. Lett. 126, 102501 (2021)

Introduction – Higher-order corrections



- The above configuration interaction calculations suggest that the NLO corrections could improve the description of transitions and moments.

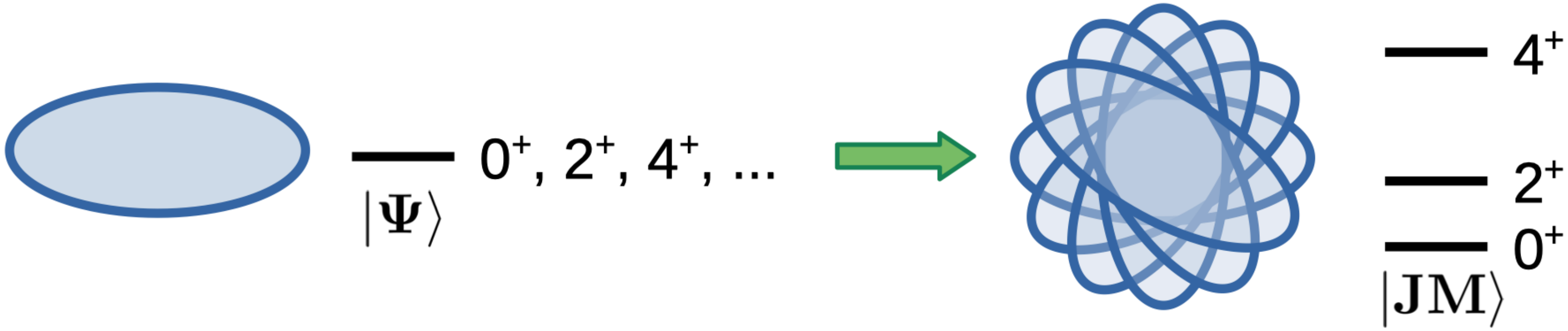
T. Miyagi et al., Phys. Rev. Lett. 132, 232503 (2024)

- DFT: Density matrix, variational theorem
- HFB equation (Bogoliubov-de Gennes equations):

$$\begin{pmatrix} h & \Delta \\ -\Delta^* & -h^* \end{pmatrix} \begin{pmatrix} U_\alpha \\ V_\alpha \end{pmatrix} = \begin{pmatrix} U_\alpha \\ V_\alpha \end{pmatrix} E_\alpha$$

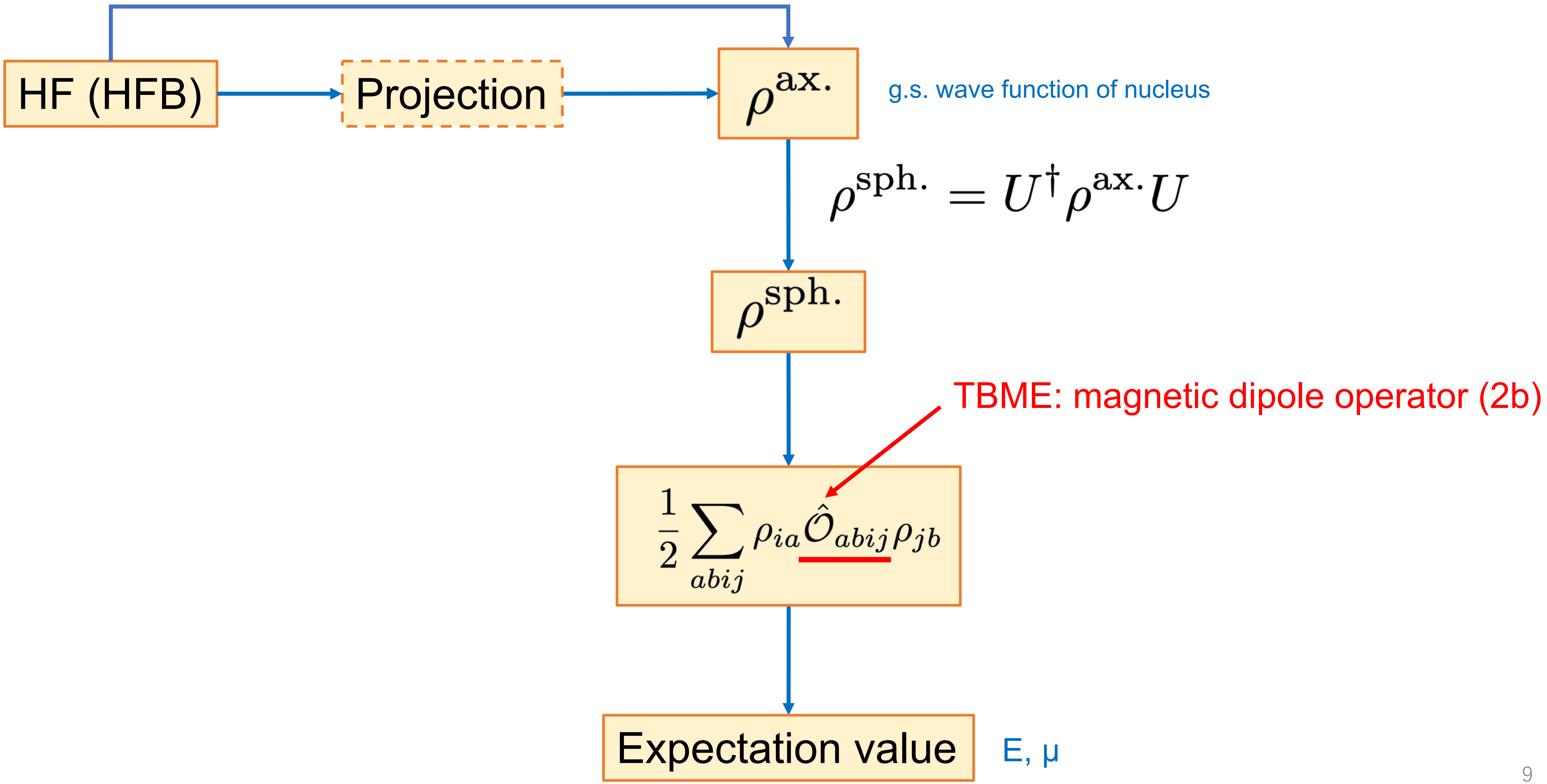
- Collective mode, large deformation, heavy nuclei.

- Angular momentum projection (PAV):

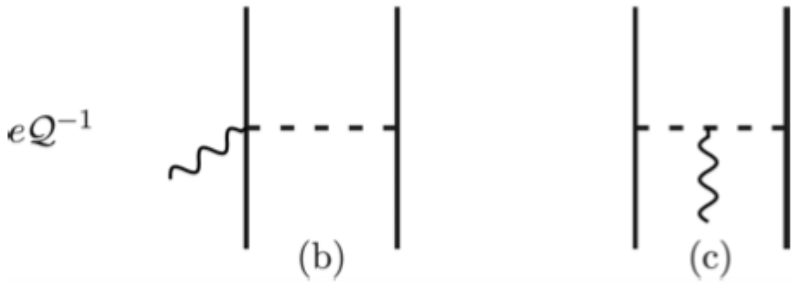


Markus Kortelainen's poster

2BC in nuclear DFT



2BC in nuclear DFT – magnetic dipole moment operators



"seagull" π-in-flight

R. Seutin et al., Phys. Rev. C 108, 054005 (2023)

$$\boldsymbol{j}^{\mathrm{NLO}}_{\mathrm{seagull}}(\boldsymbol{q}_1,\boldsymbol{q}_2) = -ie\frac{g_A^2}{F_\pi^2}G_E^V(Q^2)\,(\boldsymbol{\tau}_1\times\boldsymbol{\tau}_2)_z\,\boldsymbol{\sigma}_1\frac{\boldsymbol{\sigma}_2\cdot\boldsymbol{q}_2}{\omega_{q_2}^2} + 1 \leftrightharpoons 2,$$

$$\boldsymbol{j}^{\mathrm{NLO}}_{\pi-\mathrm{in}-\mathrm{flight}}(\boldsymbol{q}_1,\boldsymbol{q}_2) = ie\frac{g_A^2}{F_\pi^2}G_E^V(Q^2)\,(\boldsymbol{\tau}_1\times\boldsymbol{\tau}_2)_z\,\frac{\boldsymbol{q}_1-\boldsymbol{q}_2}{\omega_{q_1}^2\omega_{q_2}^2}\boldsymbol{\sigma}_1\cdot\boldsymbol{q}_1\boldsymbol{\sigma}_2\cdot\boldsymbol{q}_2,$$

$$\boldsymbol{\mu}^{\mathrm{NLO}}_{\mathrm{2b}} = \boldsymbol{\mu}^{\mathrm{NLO,int}}_{\mathrm{2b}} + \boldsymbol{\mu}^{\mathrm{NLO,Sachs}}_{\mathrm{2b}}$$

$$\boldsymbol{\mu}^{\mathrm{NLO,int}}_{2b,ij}(\boldsymbol{r}_{ij}) = -\frac{g_A^2 m_\pi}{32\pi F_\pi^2}(\boldsymbol{\tau}_i\times\boldsymbol{\tau}_j)_z\{f(r_{ij})\,[(\boldsymbol{\sigma}_i\times\boldsymbol{\sigma}_j)\cdot\hat{\boldsymbol{r}}_{ij}]\,\hat{\boldsymbol{r}}_{ij} - (\boldsymbol{\sigma}_i\times\boldsymbol{\sigma}_j)\}\,e^{-m_\pi r_{ij}}$$

Only depends on intrinsic coordinate

$$\boldsymbol{\mu}^{\mathrm{NLO,Sachs}}_{2b,ij}(\boldsymbol{r}_{ij},\boldsymbol{R}_{ij}) = -\frac{1}{2}(\boldsymbol{\tau}_i\times\boldsymbol{\tau}_j)_z V_{1\pi}(\boldsymbol{r}_{ij})\boldsymbol{R}_{ij}\times\boldsymbol{r}_{ij}$$

Contains c.o.m. dependence

Preliminary results

without AMP, UNEDF1, HF, Nsh=7

Nucleus	State	μ2b_intr (μ_N)	μ2b_sach (μ_N)	μ2b (μ_N)
3He	1/2+	-0.061823	0	-0.061823
5He	3/2-	0.006372	-0.021636	-0.015264
17O	5/2+	0.015166	-0.05781	-0.042644
39K	3/2+	0.025387	0.088248	0.113635
41Ca	7/2+	0.020146	-0.100212	-0.080066
131In	9/2+	-0.030637	0.229622	0.198985
133Sb	7/2+	0.01435	0.159426	0.173776

39K: with AMP, UNEDF1, Nsh=6
μ_exp = $0.391\mu_N$
μ _cal (1b) = $0.125834\ \mu_N$
μ _cal (1b+2b) = $0.231247\mu_N$

Summary & outlook

- Introduce the implementation of 2BC based on nuclear DFT to explore the contribution of higher-order corrections to magnetic dipole moments.

- 2BC corrections improve the magnetic dipole moment generally.

- Outlook:

  - Improve the computational efficiency and compute in larger shells and heavier nuclei.

  - Transitions: e.g. M1 transitions.

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- TU Darmstadt: T. Miyagi

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[7] U. Friman-Gayer et al., Phys. Rev. Lett. 126, 102501 (2021).

[8] A. Vernon et al., Nature 607, 260 (2022).

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