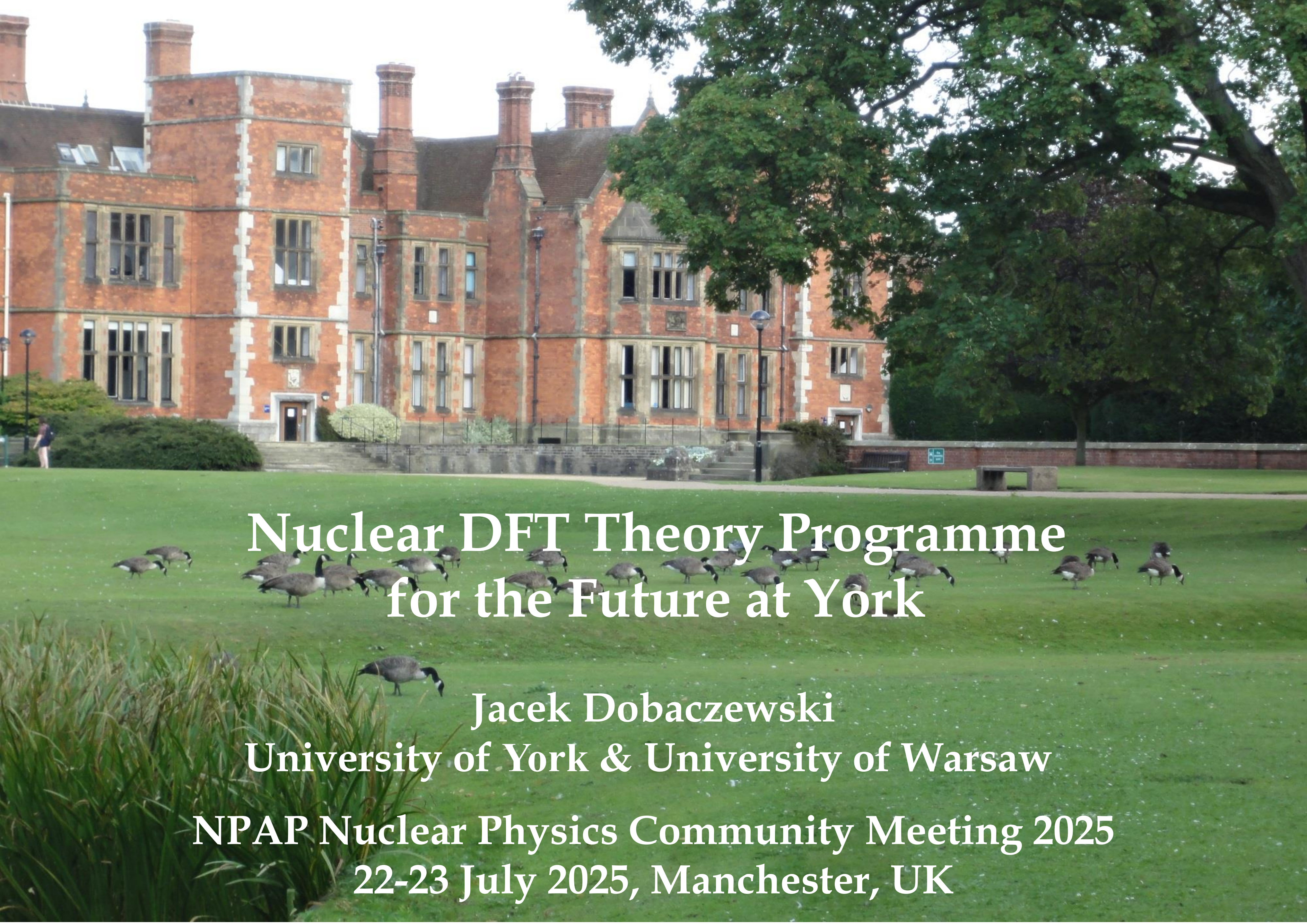

Nuclear DFT Theory Programme for the Future at York

Jacek Dobaczewski
University of York & University of Warsaw

NPAP Nuclear Physics Community Meeting 2025
22-23 July 2025, Manchester, UK

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Outline:

1. Past
2. Present
3. Future

Published projects in 2022-2025

1. **Nuclear DFT determination of radii and electric quadrupole and magnetic dipole moments in nuclei:**
   Nature **607** (2022) 260,
   Phys. Lett. B827 (2022) 136930,
   J. Phys. G: Nucl. Part. Phys. **49** (2022) 11LT01,
   Phys. Lett. **B843** (2023) 138014,
   Phys. Lett. **B847** (2023) 138268,
   Phys. Rev. Lett. 131 (2023) 022502,
   Phys. Lett. **B848** (2024) 138352,
   Nature Physics **20** (2024) 1719,
   J. Phys. G: Nucl. Part. Phys. **52** (2025) 065104,
   Phys. Rev. Lett. 134 (2025) 252501
2. **Nuclear DFT determination of the nuclear anapole moments in nuclei**:
   Rep. Prog. Phys. **87** (2024) 084301.
3. **Nuclear DFT determination of the nuclear Schiff moments in nuclei and the electric-dipole-moment searches for fundamental interactions:**
   Eur. Phys. J. **A59** (2023) 116,
   arXiv:2507.05208, submitted to Nature Physics.
4. **Collective excitations in nuclei:**
   Acta Phys. Pol. B Proc. Ser. **18** (2025) 2A7,
   Phys. Lett. **B868** (2025) 139685
5. **Isospin symmetry breaking in nuclei:**
   arXiv:2505.15375, submitted to Physical Review C.
6. **Nuclear fission studied within the two-centre model:**
   Eur. Phys. J. **A61** (2025) 138

Theory @ York 2025: Workforce

1. PDRAs (until September 2027):

   a. Xuwei Sun
   b. Herlik Wibowo

2. PhD students (until June 2026):

   a. Betânia Tumelero Backes
   b. Anu Nagpal

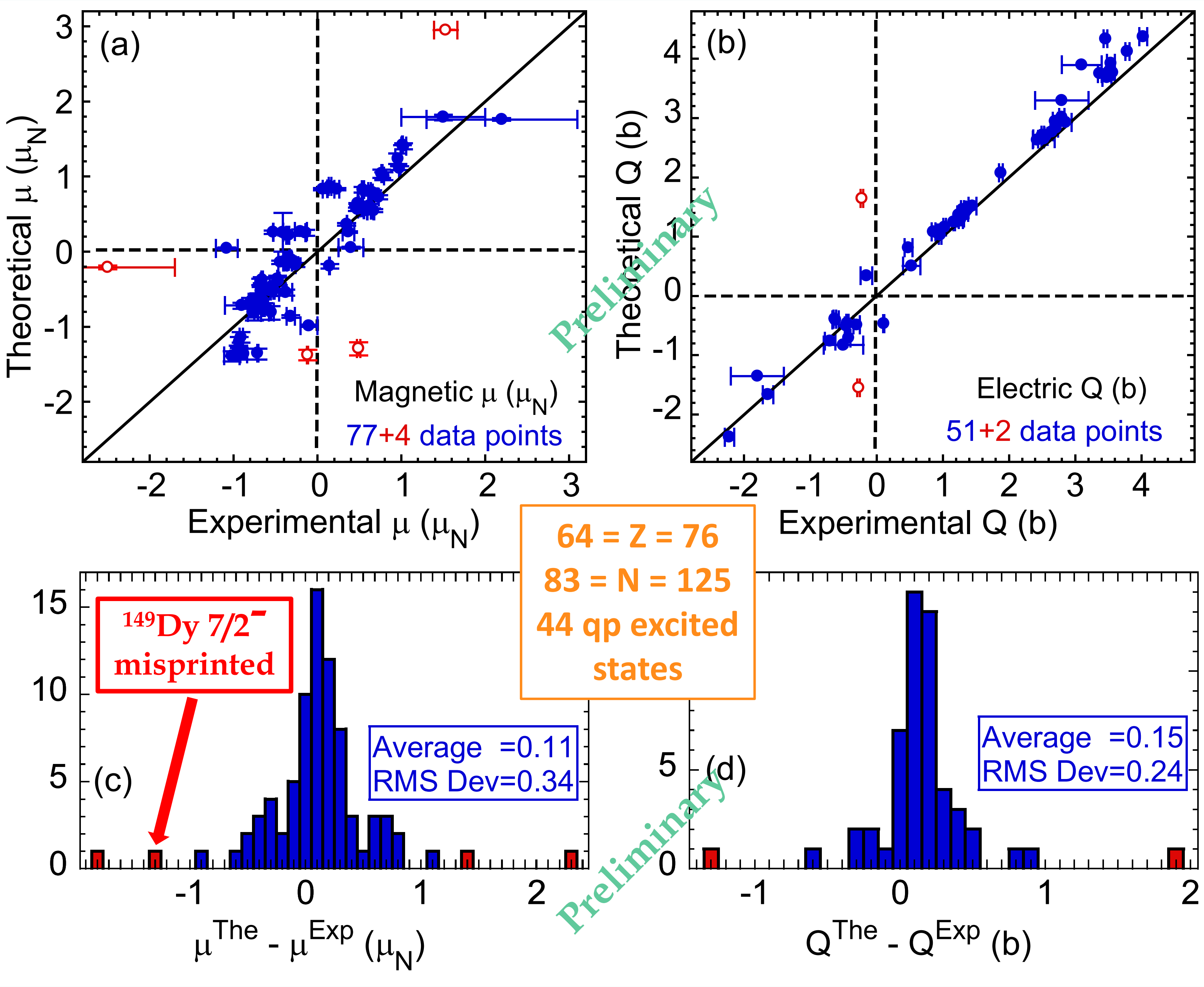
3. Self-funded MSc by research students (until December 2025):

   a. Alejandro Restrepo Giraldo
   b. Luka Buttigan

4. Two academics to be hired, planned for 2022-2023, current timeline not specified.

5. J.D. will retire from the University of York in September 2025.

Summary of results obtained in Gd – Os isotopes



64 = Z = 76
83 = N = 125
44 qp excited states

J.D., P.L. Sassarini, A.E. Stuchbery, K. Bennaceur, G. Danneaux, A. Nagpal, and H. Wibowo, to be published (2025)

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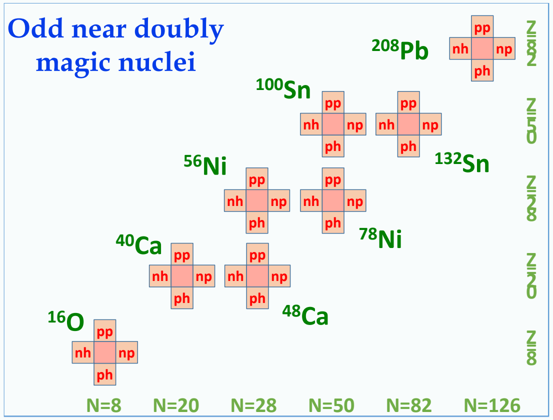
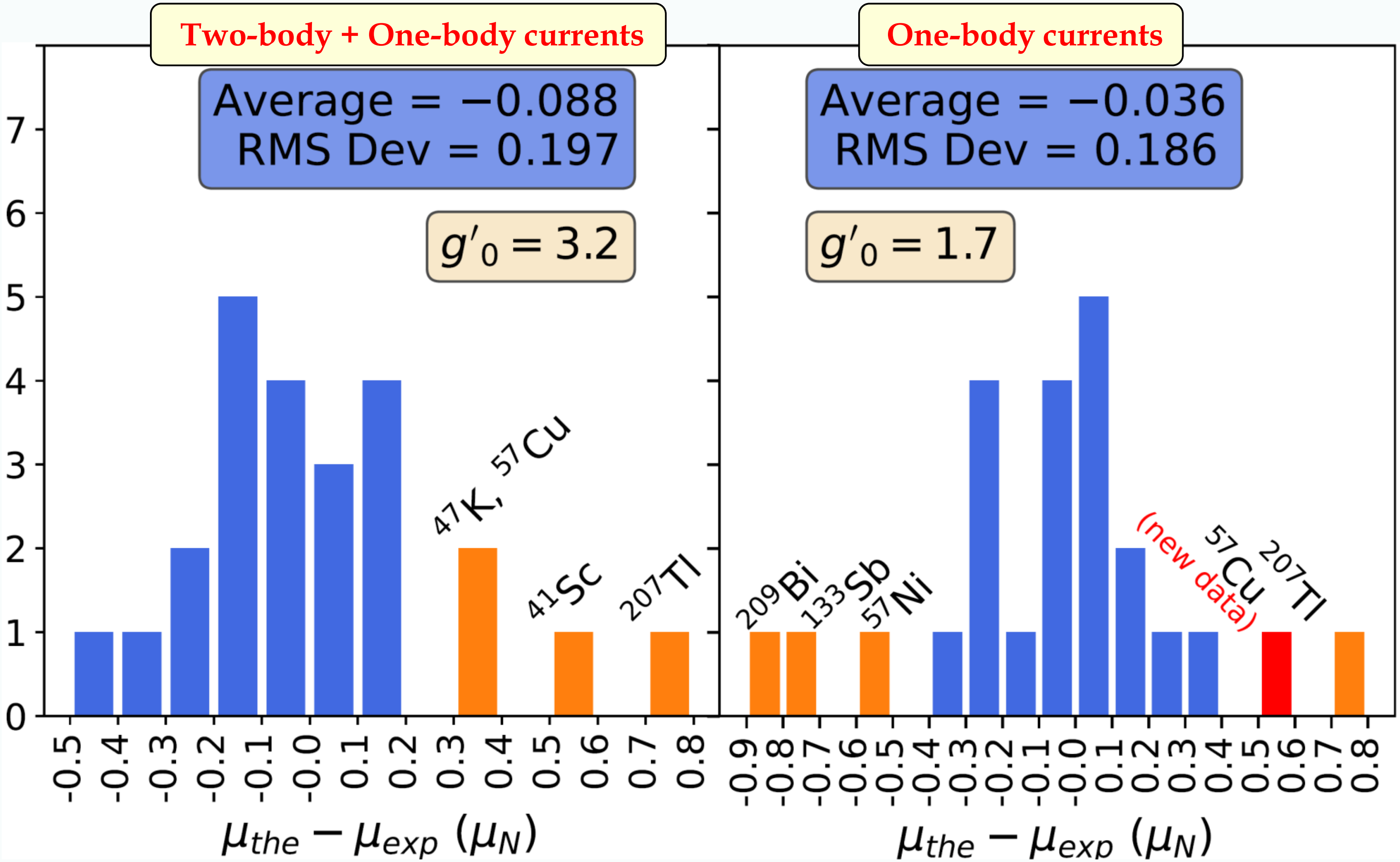
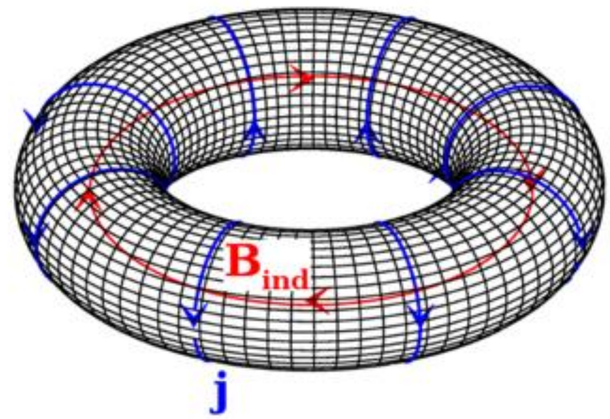
Corrections to magnetic moments due to two-body meson exchange currents





H. Wibowo, R. Han, B. C. Backes, G. Danneaux, J.D., W.C. Haxton, W. Jiang, and M. Kortelainen, to be published (2025)

Anapole moments in nuclei

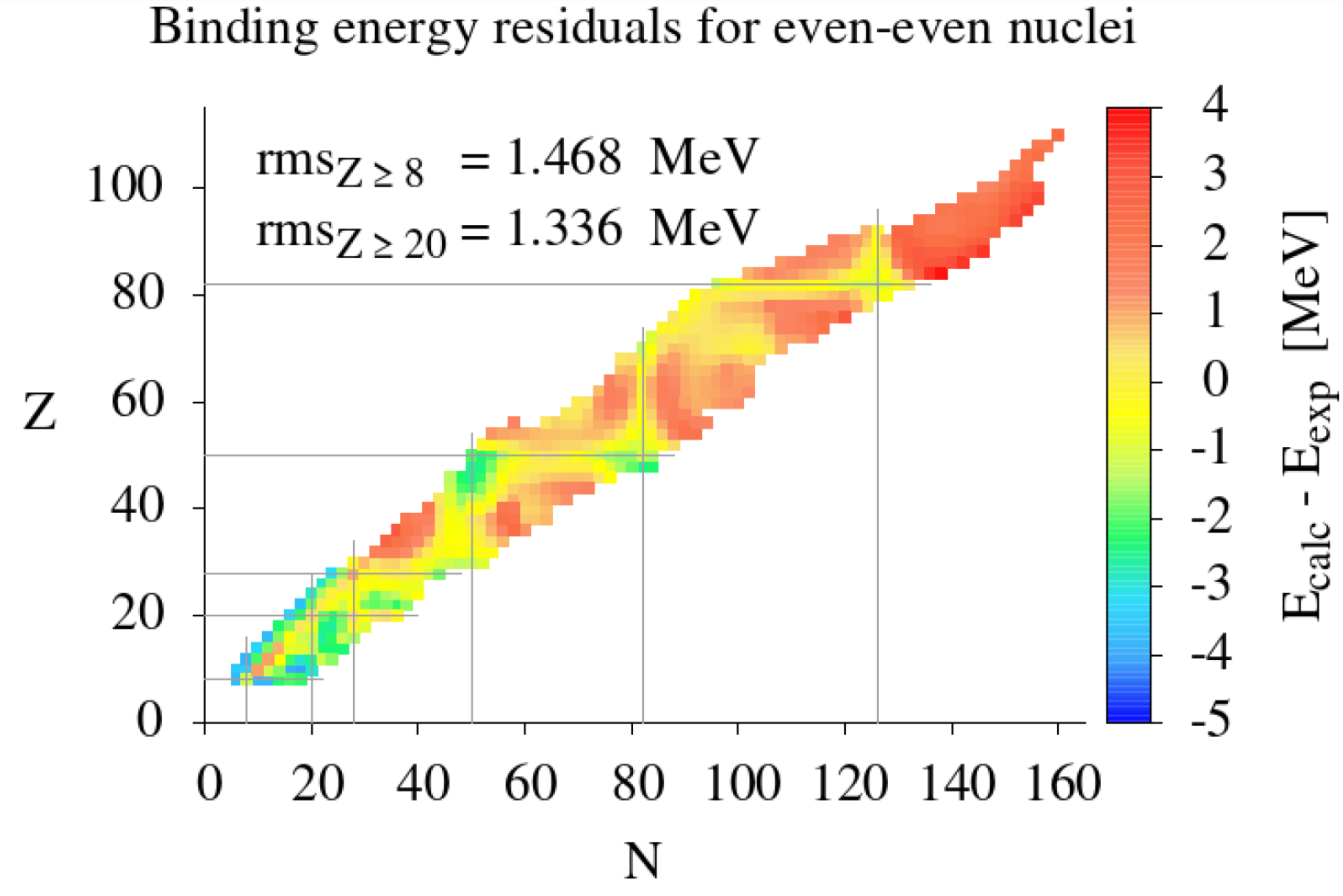


$$
\begin{aligned}
\hat{V}^{\text{PNC}}_{\text{DDH}}(\mathbf{r}) = & \; i\frac{h^1_\pi g_{\pi NN}}{\sqrt{2}}\left(\frac{\hat{\boldsymbol{\tau}}_1 \times \hat{\boldsymbol{\tau}}_2}{2}\right)_z (\hat{\boldsymbol{\sigma}}_1 + \hat{\boldsymbol{\sigma}}_2) \cdot \left[\frac{\hat{\mathbf{p}}_1 - \hat{\mathbf{p}}_2}{2M}, \omega_\pi(r)\right] \\
& - g_\omega\left(h^0_\omega + h^1_\omega\left(\frac{\hat{\boldsymbol{\tau}}_1 + \hat{\boldsymbol{\tau}}_2}{2}\right)_z\right)(\hat{\boldsymbol{\sigma}}_1 - \hat{\boldsymbol{\sigma}}_2) \cdot \left\{\frac{\hat{\mathbf{p}}_1 - \hat{\mathbf{p}}_2}{2M}, \omega_\omega(r)\right\} \\
& - i g_\omega(1+\chi_S)\left(h^0_\omega + h^1_\omega\left(\frac{\hat{\boldsymbol{\tau}}_1 + \hat{\boldsymbol{\tau}}_2}{2}\right)_z\right)(\hat{\boldsymbol{\sigma}}_1 \times \hat{\boldsymbol{\sigma}}_2) \cdot \left[\frac{\hat{\mathbf{p}}_1 - \hat{\mathbf{p}}_2}{2M}, \omega_\omega(r)\right] \\
& - g_\omega h^1_\omega \left(\frac{\hat{\boldsymbol{\tau}}_1 - \hat{\boldsymbol{\tau}}_2}{2}\right)_z (\hat{\boldsymbol{\sigma}}_1 + \hat{\boldsymbol{\sigma}}_2) \cdot \left\{\frac{\hat{\mathbf{p}}_1 - \hat{\mathbf{p}}_2}{2M}, \omega_\omega(r)\right\} \\
& - g_\rho\left(h^0_\rho \hat{\boldsymbol{\tau}}_1 \cdot \hat{\boldsymbol{\tau}}_2 + h^1_\rho\left(\frac{\hat{\boldsymbol{\tau}}_1 + \hat{\boldsymbol{\tau}}_2}{2}\right)_z + h^2_\rho \frac{(3\hat{\tau}_{1z}\hat{\tau}_{2z} - \hat{\boldsymbol{\tau}}_1 \cdot \hat{\boldsymbol{\tau}}_2)}{2\sqrt{6}}\right) \\
& \times\left((\hat{\boldsymbol{\sigma}}_1 - \hat{\boldsymbol{\sigma}}_2) \cdot \left\{\frac{\hat{\mathbf{p}}_1 - \hat{\mathbf{p}}_2}{2M}, \omega_\rho(r)\right\} + i(1+\chi_V)(\hat{\boldsymbol{\sigma}}_1 \times \hat{\boldsymbol{\sigma}}_2) \cdot \left[\frac{\hat{\mathbf{p}}_1 - \hat{\mathbf{p}}_2}{2M}, \omega_\rho(r)\right]\right) \\
& + g_\rho h^1_\rho \left(\frac{\hat{\boldsymbol{\tau}}_1 - \hat{\boldsymbol{\tau}}_2}{2}\right)_z (\hat{\boldsymbol{\sigma}}_1 + \hat{\boldsymbol{\sigma}}_2) \cdot \left\{\frac{\hat{\mathbf{p}}_1 - \hat{\mathbf{p}}_2}{2M}, \omega_\rho(r)\right\} \\
& - g_\rho h^{1\prime}_\rho i \left(\frac{\hat{\boldsymbol{\tau}}_1 \times \hat{\boldsymbol{\tau}}_2}{2}\right)_z (\hat{\boldsymbol{\sigma}}_1 + \hat{\boldsymbol{\sigma}}_2) \cdot \left[\frac{\hat{\mathbf{p}}_1 - \hat{\mathbf{p}}_2}{2M}, \omega_\rho(r)\right],
\end{aligned}
$$

The Desplanques, Donoghue, and Holstein (DDH) potential
[Wick C. Haxton and Barry R. Holstein, Prog. Part. Nucl. Phys. 71, 185 (2013)]

H. Wibowo, A. Borschevsky, J.D., R.F. Garcia Ruiz, W.C. Haxton, to be published (2026)

Higher-order and semi-contact pseudopotentials



K, Bennaceur, J.D., *et al.*, to be published (2025)

Two-body particle densities in nuclei

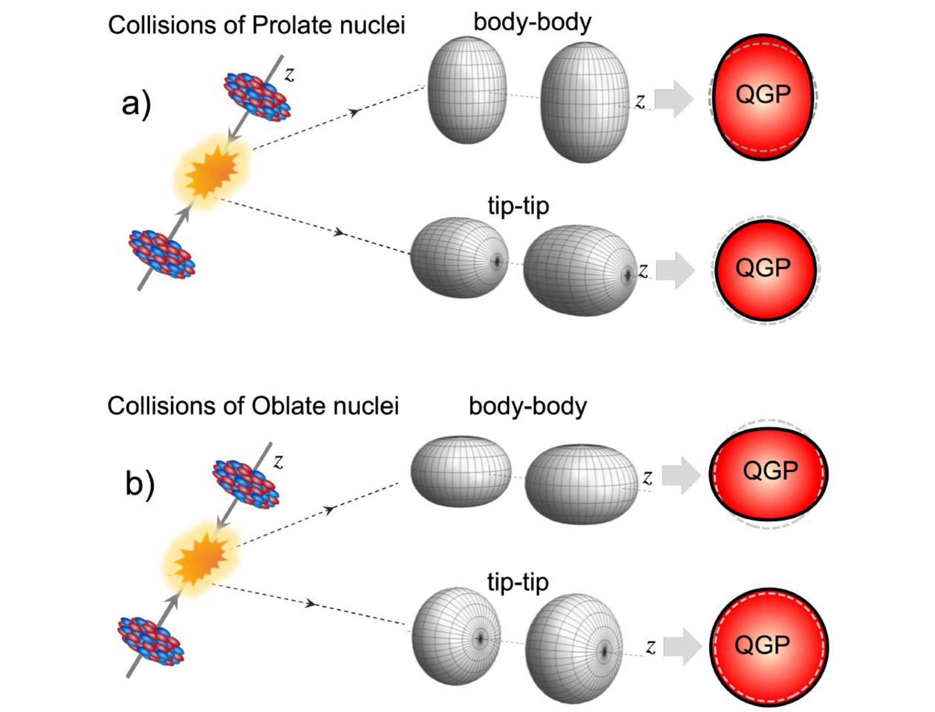


FIG. 1: Illustration of how collision geometry and collective expansion are impacted by quadrupole deformation in collisions of prolate (**a**) and oblate (**b**) nuclei. The configurations vary between body-body and tip-tip. The negative (positive) correlation between ellipticity and inverse size in (**a**) ((**b**)) drives the negative (positive) correlation between elliptic flow and radial flow in the final state, highlighting the potential of constraining the triaxiality. The dashed grey circles represent the baseline shape of the QGP for spherical nuclei.

***Imaging nuclear shape through anisotropic and radial flow in high-energy heavy-ion collisions*, The STAR Collaboration, arXiv:2506.17785v1 [nucl-ex] 21 Jun 2025**

A naive interpretation of ultra-relativistic heavy-ion collisions was presented in numerous RHIC and LHC publications (eight PRLs and one Nature) and has been recently criticised by:
J.D., A. Gade, K. Godbey, R.V.F. Janssens, and W. Nazarewicz, arXiv:2507.05208v2 [nucl-th], 7 Jul 2025.

Advanced calculations of two-body particle densities in symmetry-conserving nuclear states are mandatory for the correct analysis of RHIC and LHC data.

J.D., X. Sun, W. Nazarewicz, to be published (2025)

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Precision physics with nuclear charge distributions in muonic atoms

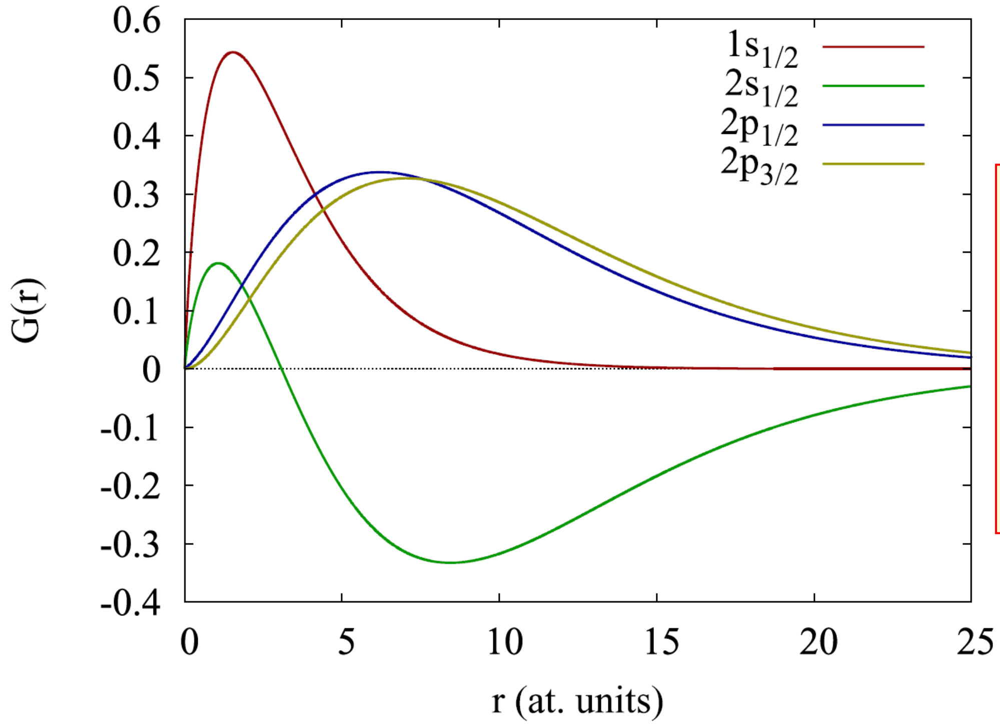

Fig. 1. The G component of electronic radial wave function (5) calculated with the homogeneously charged nuclear model is plotted for four lowest lying states for hydrogen-like ${}^{185}_{75}$Re.

B.S.M. Patoary and N.S. Oreshkina, Eur. Phys. J. D 72 (2018) 54

Significant overlaps between muon and nuclear charge distributions in heavy nuclei require self-consistent treatment of the combined Coulomb fields.

Ante Ravlić, Andrzej Czarnecki, J.D., Kyle Godbey, Witold Nazarewicz, Xuwei Sun, to be published (2025)

Evaluation and measurement of Bohr-Weisskopf corrections

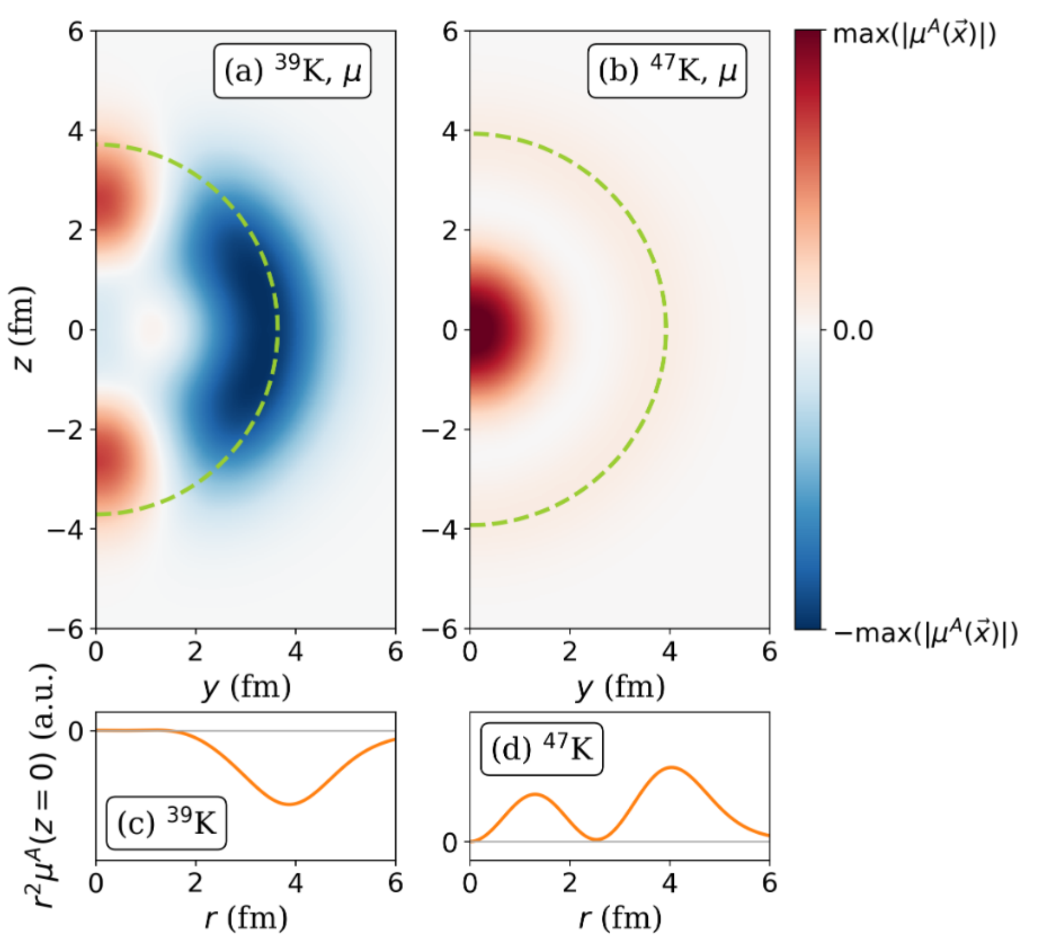

FIG. 4. Calculated magnetization distributions in ^{39}K (a) and ^{47}K (b). The dashed line indicates nuclear surface, that is, matter density of 0.08 fm^{-3}. Distributions are rotationally symmetric around the z-axis, and the scale is normalized separately for both nuclei. Panels (c) and (d) show magnetization distribution along the $z = 0$ line, multiplied by r^2, for ^{39}K and ^{47}K, respectively.

M. L. Bissell, M. Jankowski, A. Antusek, N. Azaryan, B. C. Backes, M. Baranowski, M. Chojnacki, K. Dziubinska-Kuehn, R. Han, A. Hurajt, B. Karg, I. Michelon, M. Pesek, M. Piersa-Silkowska, B. Roberts, G. Sanamyan, L. Vasquez, H. Wibowo, T. Treczoks, D. Zakoucky, M. Znava, M. Kortelainen, J. Dobaczewski, J. Ginges, M. Kowalska, to be published (2025)

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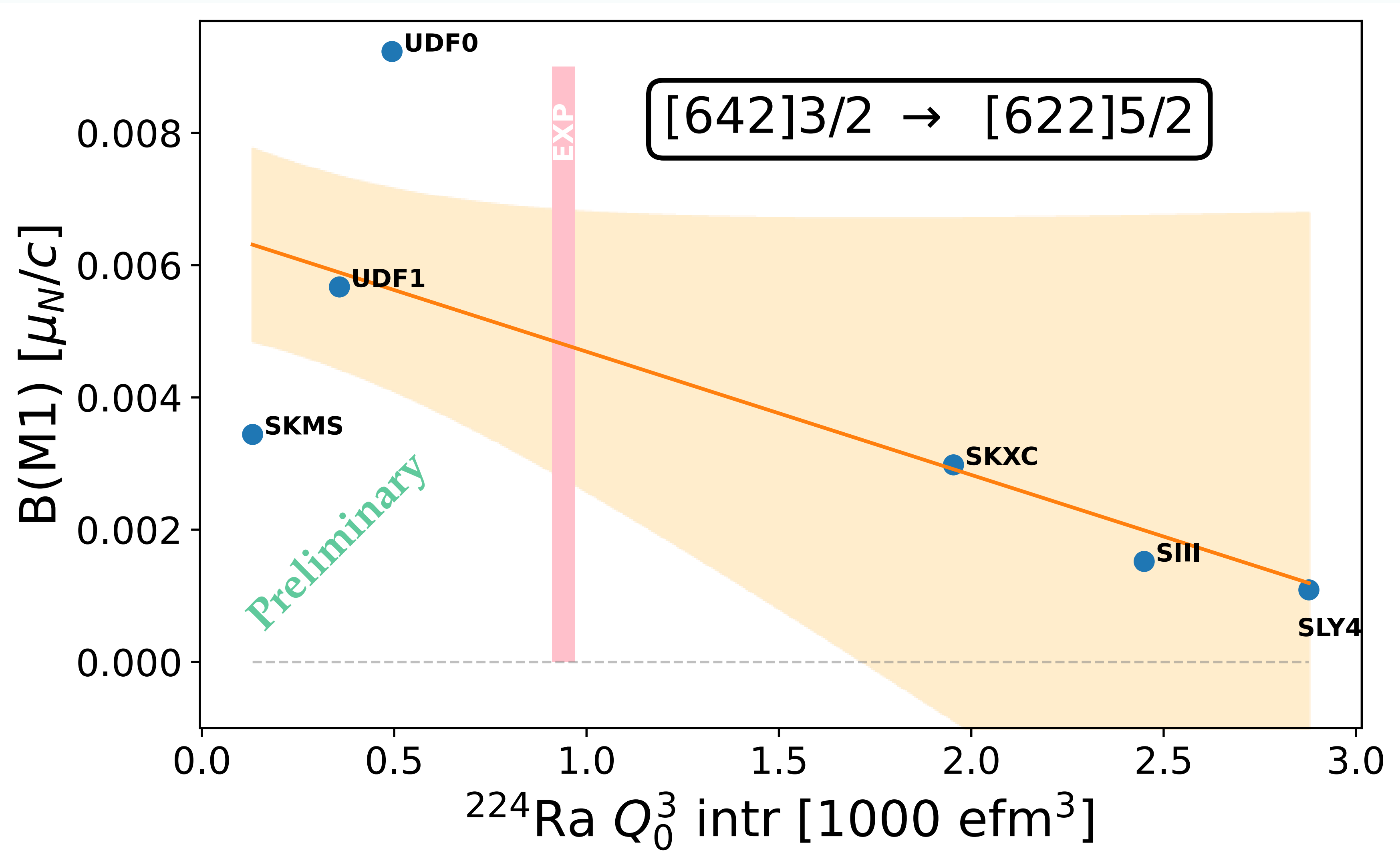
Radiative decay rate of the ^{229}Th isomer



A. Restrepo-Giraldo, J.D. J. Bonnard, P. Becker, A. Pastore, to be published (2025)

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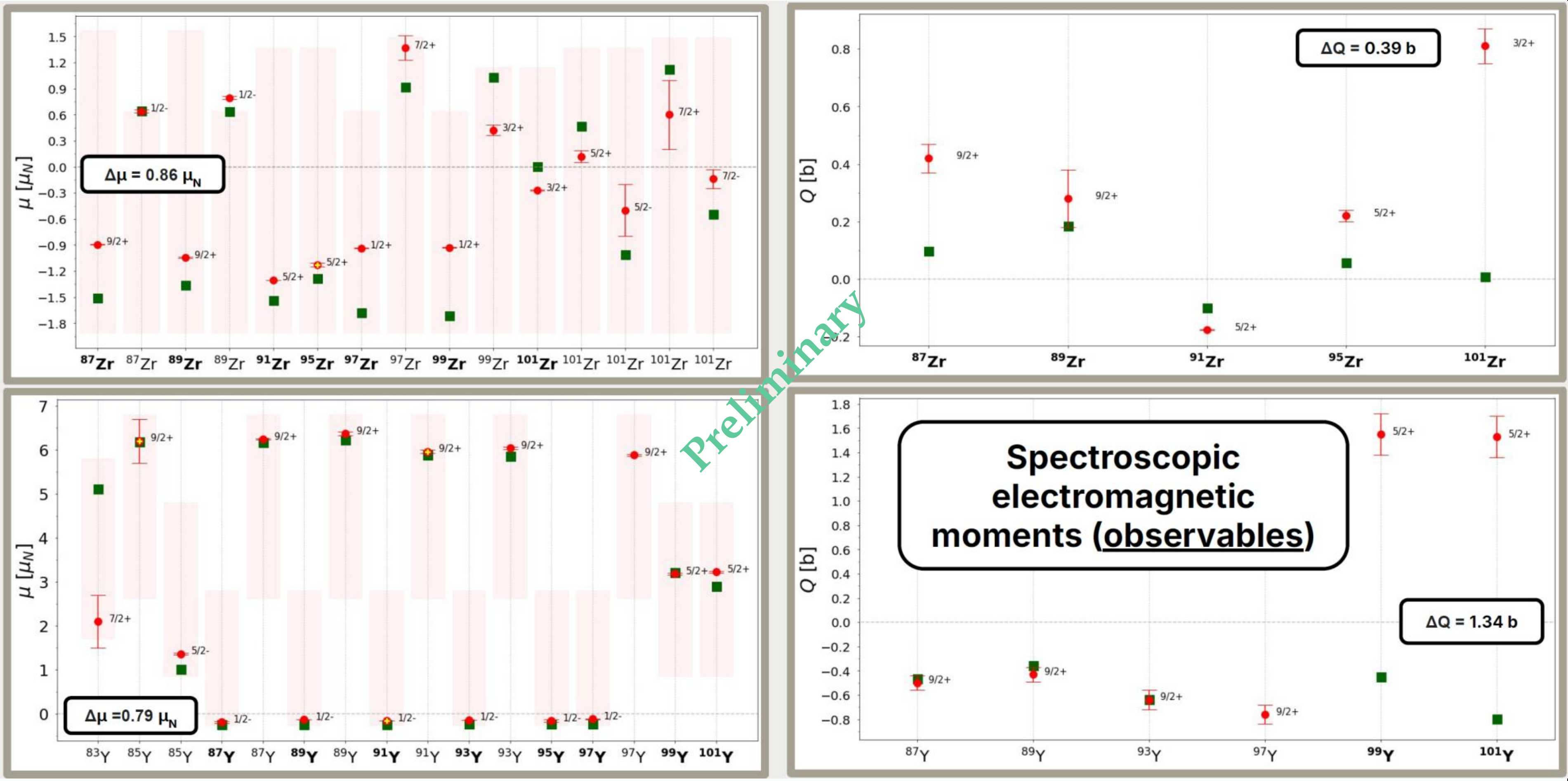
Isomeric transitions in Zr and Y isotopes

Zr

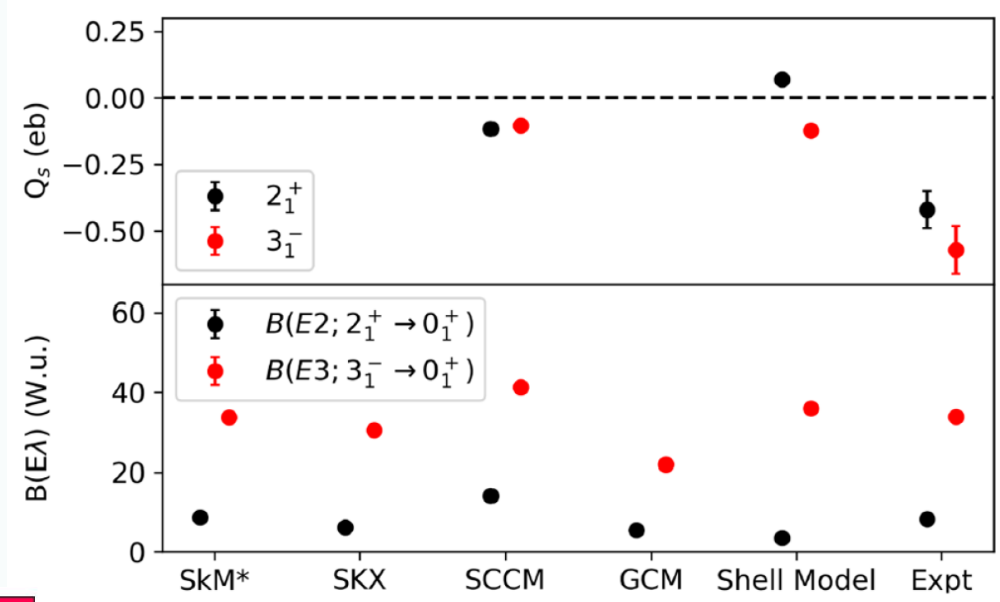
Y



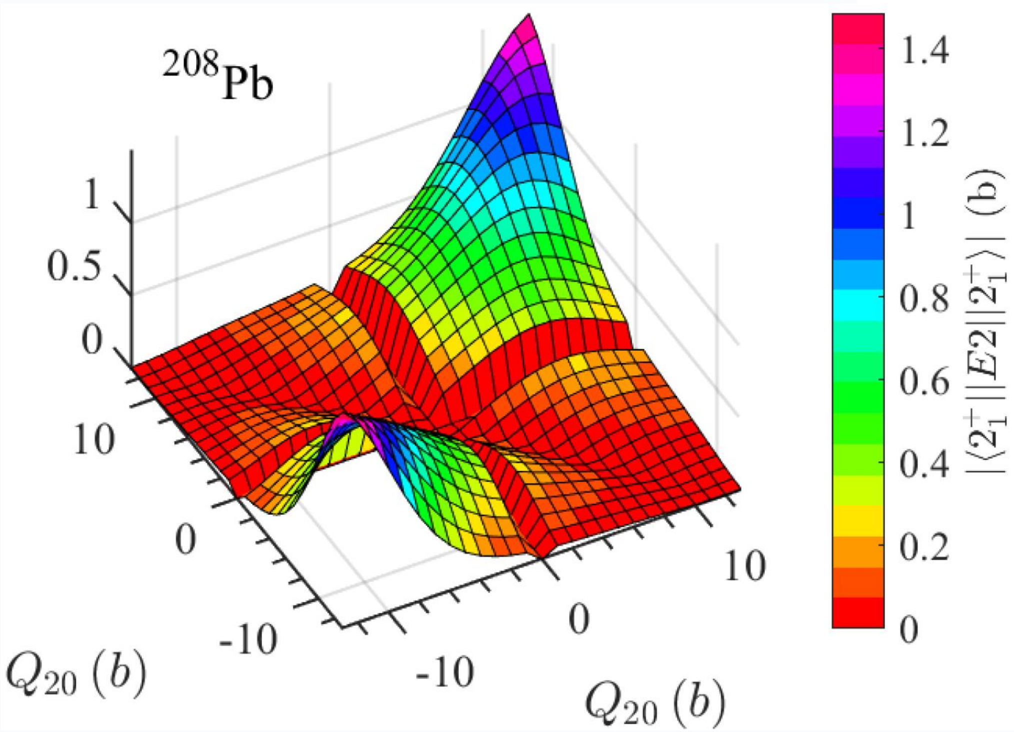
Alejandro Restrepo-Giraldo, J.D., Lee Morgan, Aaron Stott, to be published (2025)

Electromagnetic moments of excited states, ^{208}Pb

Experimental data yield a negative value for the reduced quadrupole matrix element of the first 2+ state in 208Pb, indicating a positive intrinsic deformation of that state.



J. Henderson et al., PRL 134, 062502 (2025)



Calculations yield almost perfect prolate-oblate symmetry of that matrix element, which implies a spherical intrinsic shape of the first 2^+ state in ^{208}Pb.

X. Sun, J.D., W. Nazarewicz, *et al.*, to be published (2025)

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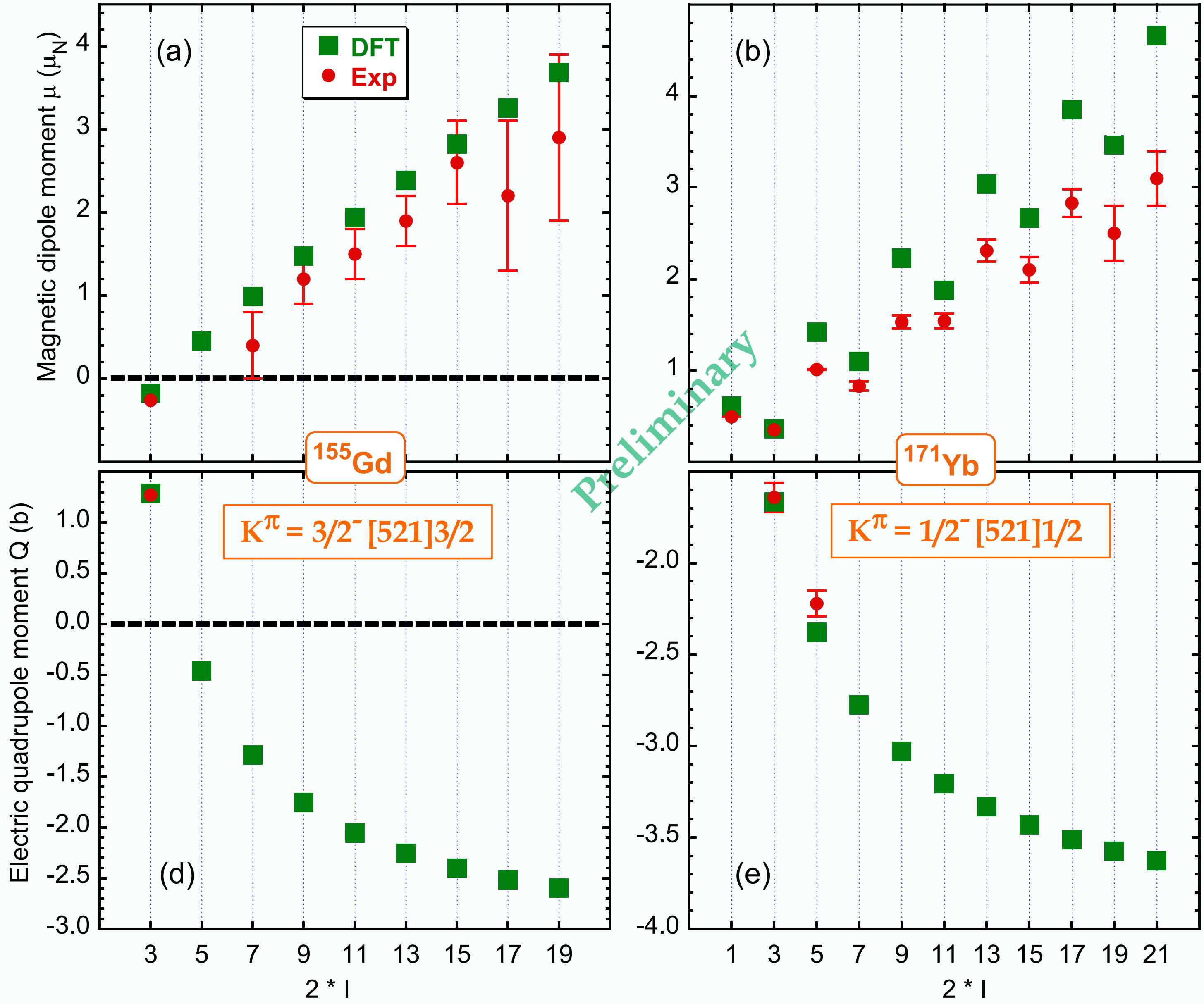
Magnetic μ and electric Q moments, and B(M1) and B(E2) transitions, in rotational bands



L. Buttigan, J.D., A.E. Stuchbery, *et al.*, to be published (2025)

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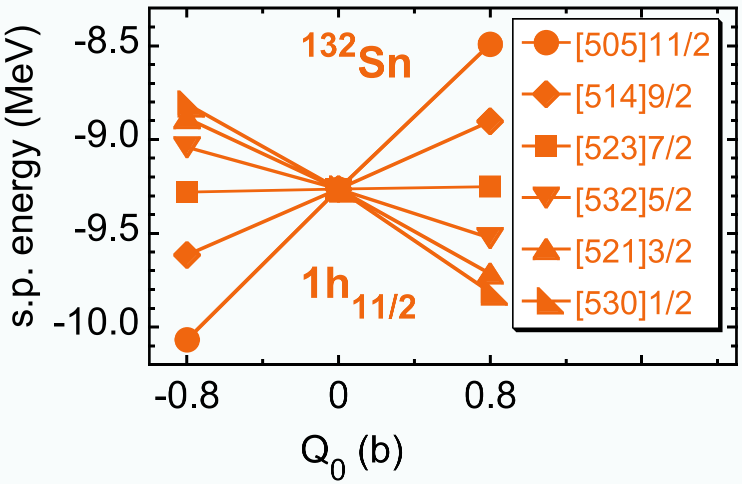
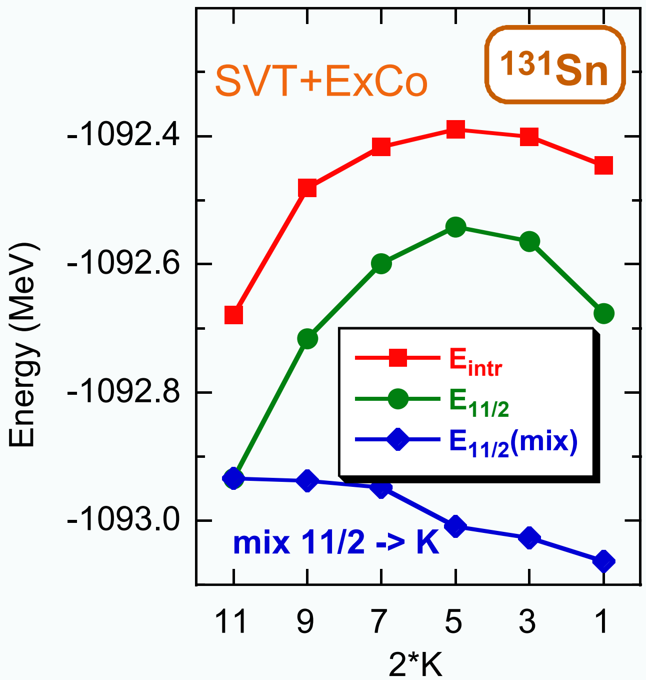
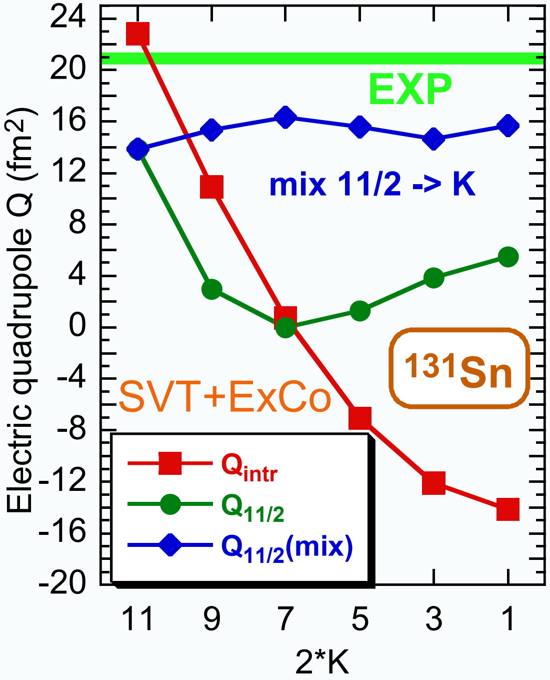
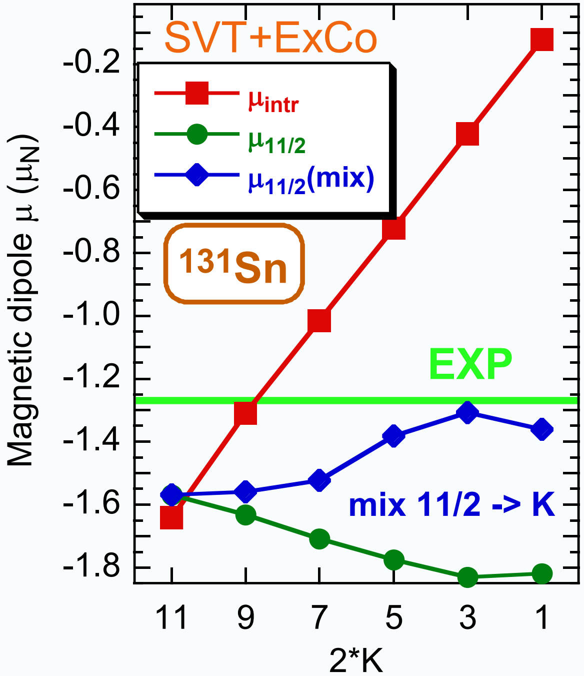
K-mixing in nuclei



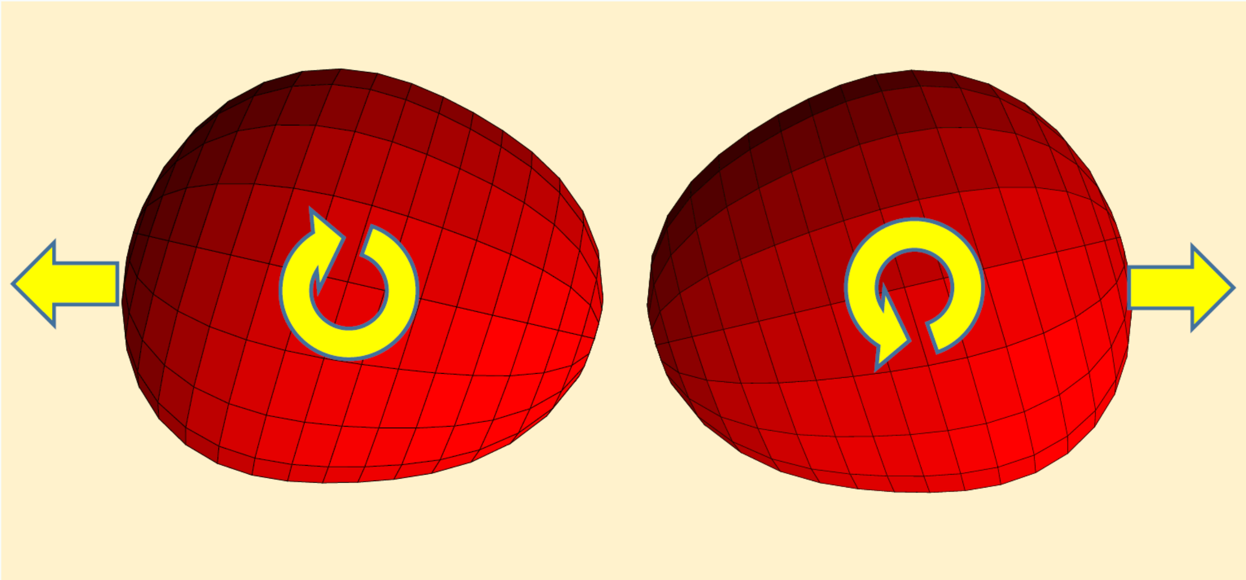






J.D., M. Bender, J. Bonnard, W. Nazarewicz, W. Satuła, X. Sun, H. Wibowo, to be published (2025)

Non-axial and non-co-axial fission in the two-centre model



1. Angular-momentum generation in fission
2. Particle-number distributions in fission products

Adrián Sánchez-Fernández, J.D. *et al.*, to be published (2026)

Thank you