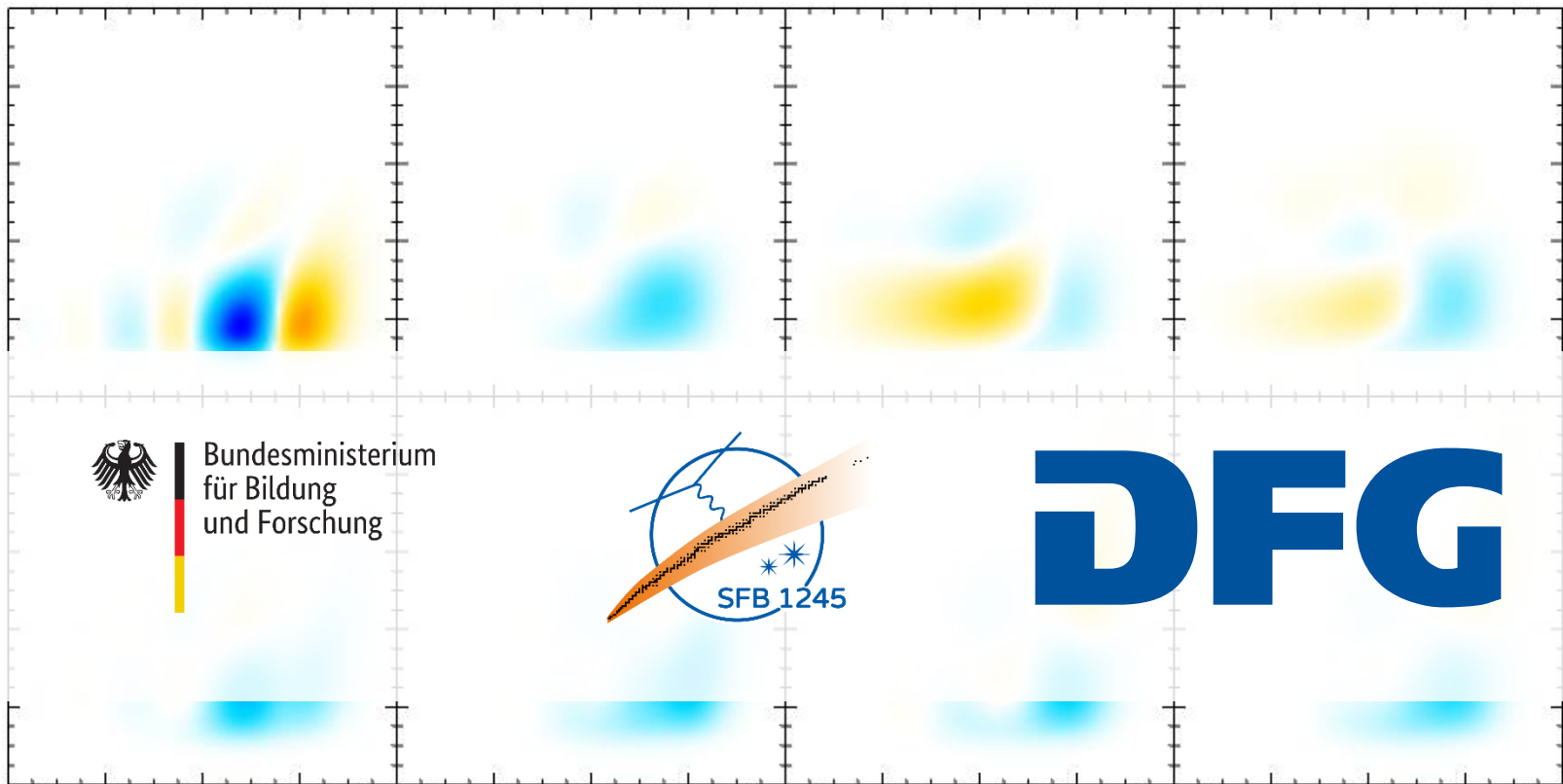


Exploring density-matrix expansions for local chiral interactions



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Lars Zurek, E. A. Coello Pérez, S. K. Bogner, R. J. Furnstahl, A. Schwenk
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Motivation

Energy-density functionals (EDFs) allow for consistent description of nuclei
across entire nuclear chart

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Standard (Skyrme) EDFs may have reached accuracy limit

⇒ More complicated functional forms needed (?) [McDonnell et al., PRL 114, 122501 \(2015\)](#)
[Zhang et al., PRC 98, 064306 \(2018\)](#)

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Employing density-matrix expansion (DME)

⇒ Incorporate exchange contributions from long-range chiral forces explicitly in EDF (parameter-free)

⇒ Semi-phenomenological Skyrme-like EDF with coupling functions instead of coupling constants Navarro Pérez et al., PRC **97**, 054304 (2018)

Motivation

Root-mean square deviations between experimental binding energies and predictions from different EDFs for ~ 620 nuclei:

	EDF	rms deviation [MeV]
Skyrme	UNEDF2	1.98
Skyrme + PSA-DME	+ NN @ LO	1.99
	+ NN @ N ² LO	1.57
	+ NN+ Δ @ N ² LO	1.26
	+ NN+ Δ +3N @ N ² LO	1.72

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Systematics not understood \Rightarrow Revisit DME implementation
 \Rightarrow Is further EDF improvement possible by altering the DME choice?

Density-matrix expansions

DMEs for scalar parts of one-body density matrix (OBDM) of time-reversal invariant systems

$$\rho\left(\mathbf{R} + \frac{\mathbf{r}}{2}, \mathbf{R} - \frac{\mathbf{r}}{2}\right) \approx \sum_{n=0}^{n_{\max}} r^n \Pi_n(k(\mathbf{R})r) \mathcal{P}_n(\mathbf{R})$$

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$\mathcal{P}_n(\mathbf{R})$ are different local densities, e.g.,

$$\rho(\mathbf{R}) = \sum_i |\phi_i(\mathbf{R})|^2, \quad \tau(\mathbf{R}) = \sum_i |\nabla \phi_i(\mathbf{R})|^2$$

Density-matrix expansions

Expansions for scalar parts of OBDM of time-reversal invariant systems

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In this study restrict to $n_{\max} \leq 2$

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Example DME variant: PSA-DME

Gebremariam et al., PRC 82, 014305 (2010)
Gebremariam et al., NPA 851, 17 (2011)

$$\Pi_0(x) = \frac{3j_1(x)}{x}, \quad \Pi_2(x) = \frac{3j_1(x)}{x},$$

$$k(\mathbf{R}) = k_{\text{F}}(\mathbf{R}) = [3\pi^2 \rho(\mathbf{R})]^{1/3}$$

Comparison of density-matrix expansions

Consider 11 closed-shell nuclei with densities from SLy4 EDF calculation

Chabanat et al., NPA 635, 231 (1998),
Erratum: NPA 643, 441 (1998)

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Scalar-isoscalar exchange energy due to regulated Yukawa interaction
(non-self-consistent tests)

Gezerlis et al., PRL 111, 032501 (2013)

$$W_0^{\text{ex}} = -\frac{9}{8} \int d\mathbf{R} d\mathbf{r} \underbrace{\rho_0\left(\mathbf{R} + \frac{\mathbf{r}}{2}, \mathbf{R} - \frac{\mathbf{r}}{2}\right)^2}_{\text{}} V(r)$$

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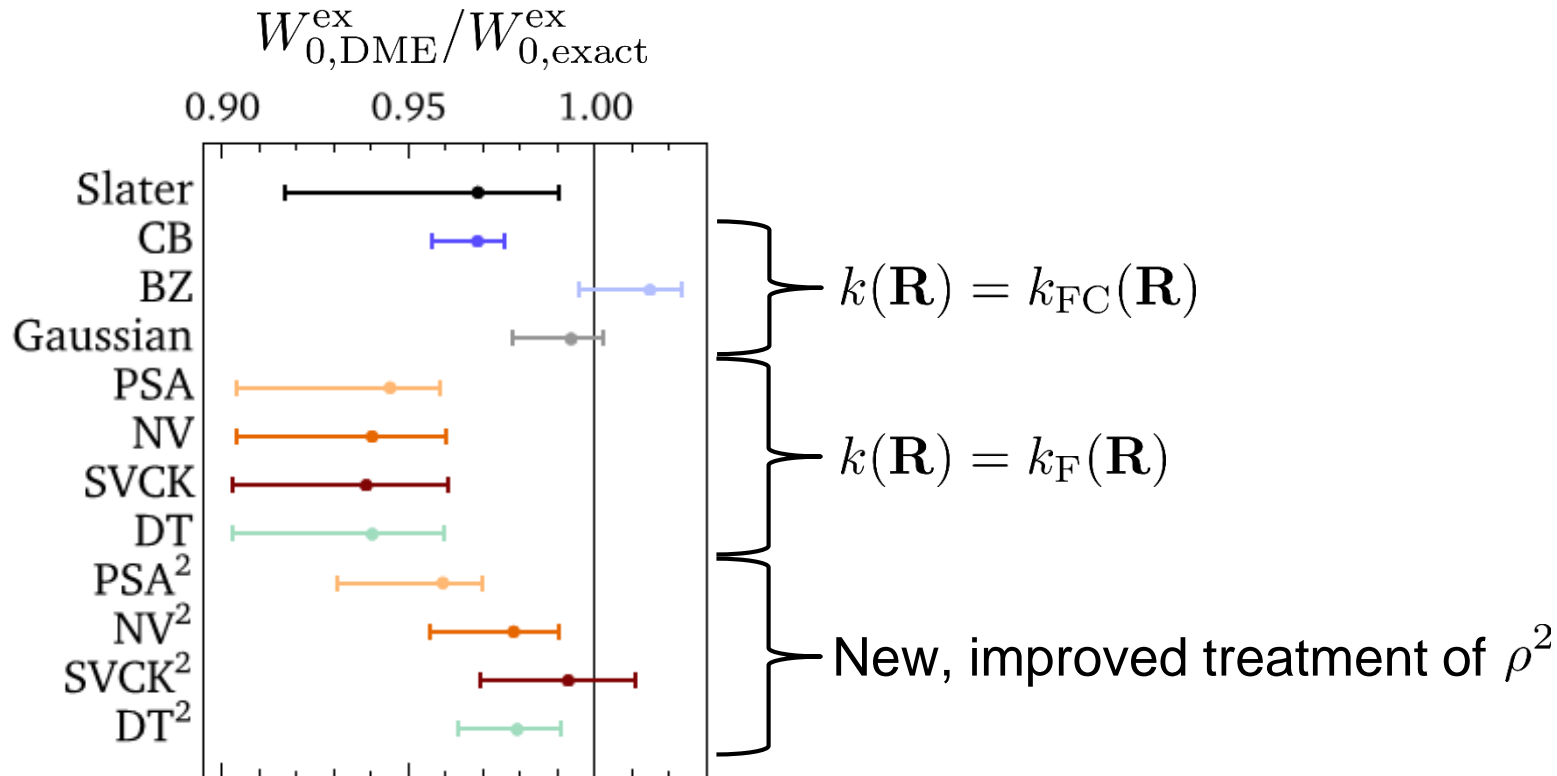
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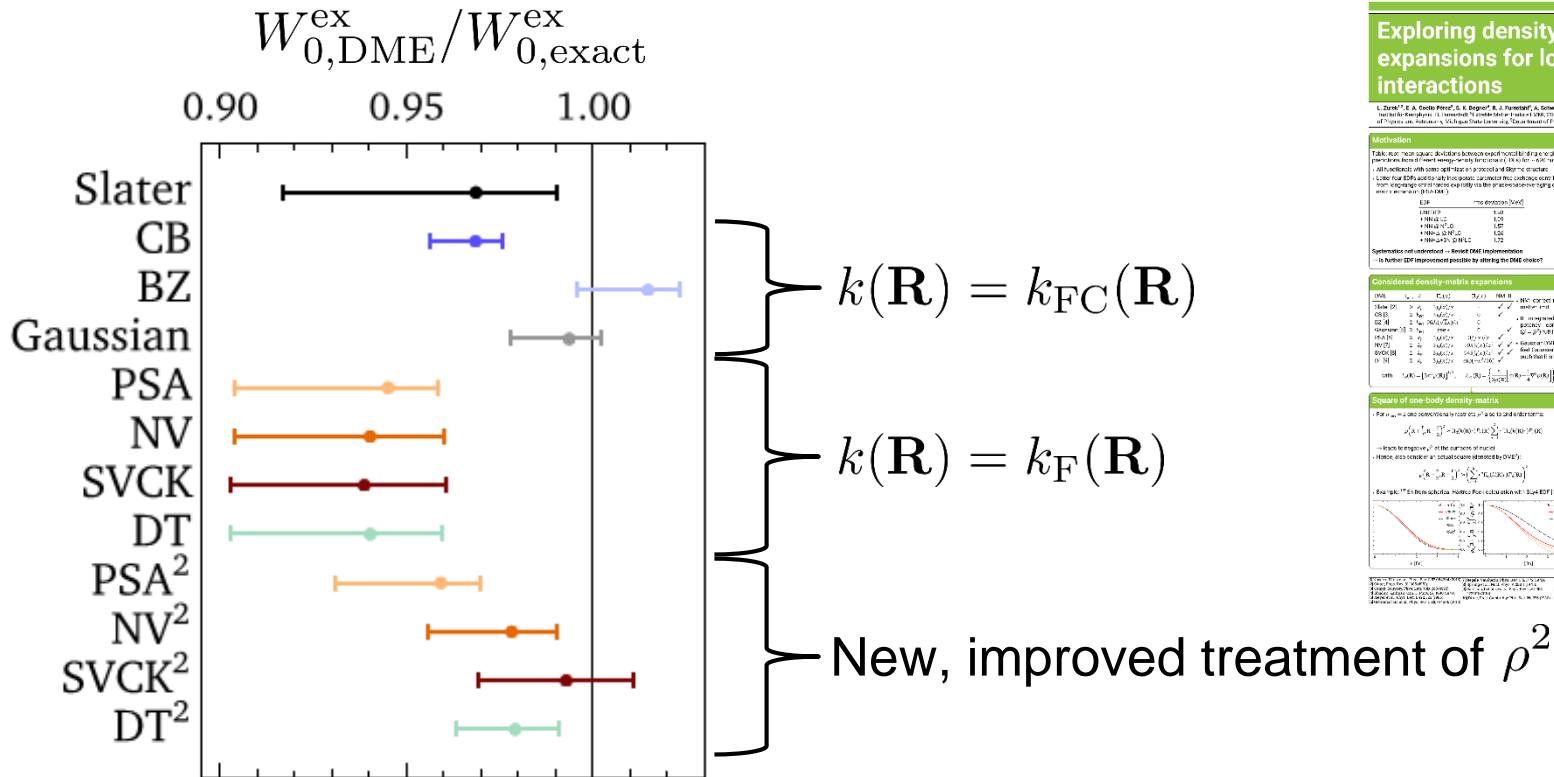
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Comparison of density-matrix expansions



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L. Zurek^{1,2}, A. Giese^{1,2}, P. Pappe^{1,2}, A. Schmitt^{1,2}

¹Institut für Kernphysik, ²Technische Universität Darmstadt, D-64286 Darmstadt, Germany

Abstract

Table-top nuclear physics is a rich field for the study of nuclear structure. The use of density-matrix expansions (DMEs) for the description of nuclear interactions is a powerful tool. In this work, we explore the use of DMEs for the description of local chiral interactions. We compare the results of different DMEs and discuss the impact of the choice of the expansion order on the results. The results are compared with the exact results obtained from the many-body perturbation theory (MBPT) calculations.

Introduction

Table-top nuclear physics is a rich field for the study of nuclear structure. The use of density-matrix expansions (DMEs) for the description of nuclear interactions is a powerful tool. In this work, we explore the use of DMEs for the description of local chiral interactions. We compare the results of different DMEs and discuss the impact of the choice of the expansion order on the results. The results are compared with the exact results obtained from the many-body perturbation theory (MBPT) calculations.

Methodology

The DME is defined as the expansion of the two-body interaction $V(\mathbf{r})$ in terms of the local density $\rho(\mathbf{r})$ and its derivatives. The expansion is truncated at a certain order, and the resulting DME is used to calculate the ground state energy of the nucleus. The results are compared with the exact results obtained from the MBPT calculations.

Results

The results show that the DMEs provide a good approximation to the exact results. The expansion order has a significant impact on the results, and the results converge to the exact results as the expansion order increases. The results are compared with the exact results obtained from the MBPT calculations.

Conclusion

The DMEs provide a good approximation to the exact results. The expansion order has a significant impact on the results, and the results converge to the exact results as the expansion order increases. The results are compared with the exact results obtained from the MBPT calculations.

References

[1] L. Zurek et al., Phys. Rev. Lett. 124, 112501 (2020)

[2] L. Zurek et al., Phys. Rev. Lett. 124, 112501 (2020)

[3] L. Zurek et al., Phys. Rev. Lett. 124, 112501 (2020)

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More details and results at poster

Next up: Investigating DMEs for 3N interactions

