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Translationally Invariant Two-Particle Densities from the NCSM

Marco Knöll

Progress in *Ab Initio* Techniques in Nuclear Physics
TRIUMF 2020

Motivation

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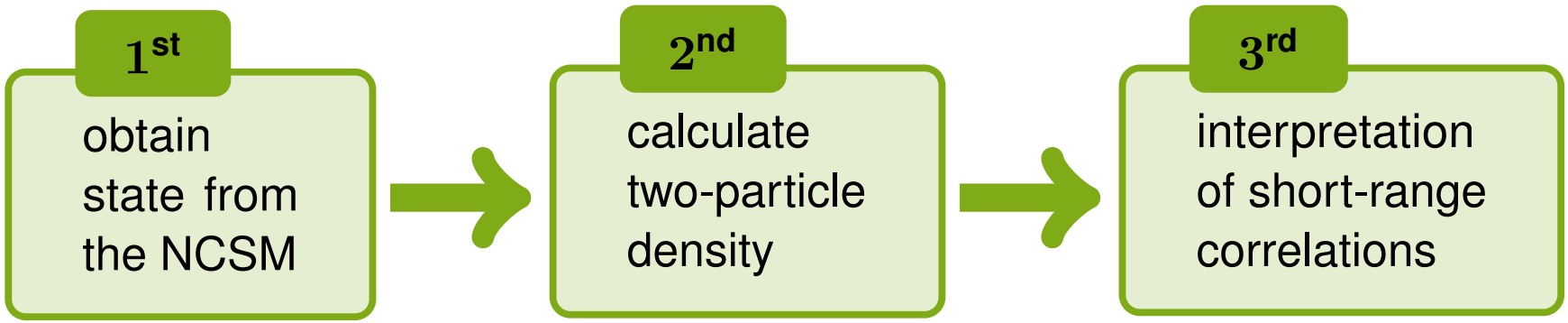
Main goals:

- develop tool to compute **translationally invariant two-particle densities** from NCSM solutions
- investigation of **short-range correlations** for different interactions

Idea:



Two-Particle Density Matrix in Coordinate Representation

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$$\rho^{(2)}_{\{m_t\}}(\vec{x}_1, \vec{x}_2, \vec{x}\,'_1, \vec{x}\,'_2)$$
$$:= \sum_{m_{s1} m_{s2}} \langle \psi | \hat{\Psi}^\dagger_{m_{s1}, m_{t1}}(\vec{x}_1) \hat{\Psi}^\dagger_{m_{s2}, m_{t2}}(\vec{x}_2) \hat{\Psi}_{m_{s2}, m'_{t2}}(\vec{x}\,'_2) \hat{\Psi}_{m_{s1}, m'_{t1}}(\vec{x}\,'_1) | \psi \rangle$$

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$$\rho^{(2)}_{\{m_t\}}(\vec{x}_1, \vec{x}_2, \vec{x}\,'_1, \vec{x}\,'_2) \xrightarrow[\text{transformation}]{\text{Talmi-Moshinski}} \rho^{(2)}_{\{m_t\}}(\vec{r}, \vec{R}, \vec{r}\,', \vec{R}\,')$$

Talmi-Moshinski transformation

$$\varphi_{\alpha_1}(\vec{x}_1)\varphi_{\alpha_2}(\vec{x}_2) = \sum_{\alpha,\beta} \mathcal{M}_{\alpha_1,\alpha_2,\alpha,\beta}\ \varphi_\alpha(\vec{r})\varphi_\beta(\vec{R})$$

Two-Particle Density Matrix in Coordinate Representation

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$$\rho^{(2)}_{\{m_t\}}(\vec{x}_1, \vec{x}_2, \vec{x}\,'_1, \vec{x}\,'_2) \xrightarrow[\text{transformation}]{\text{Talmi-Moshinski}} \rho^{(2)}_{\{m_t\}}(\vec{r}, \vec{R}, \vec{r}\,', \vec{R}\,')$$

translational invariance

$$\int \mathrm{d}\vec{R}\, \varphi^*_\beta(\vec{R})\varphi_{\beta'}(\vec{R}) = \delta_{\beta\beta'}$$

eliminate center of mass

$$\rho^{(2),\text{trinv}}_{\{m_t\}}(\vec{r}, \vec{r}\,')$$

Two-Particle Density Matrix in Coordinate Representation

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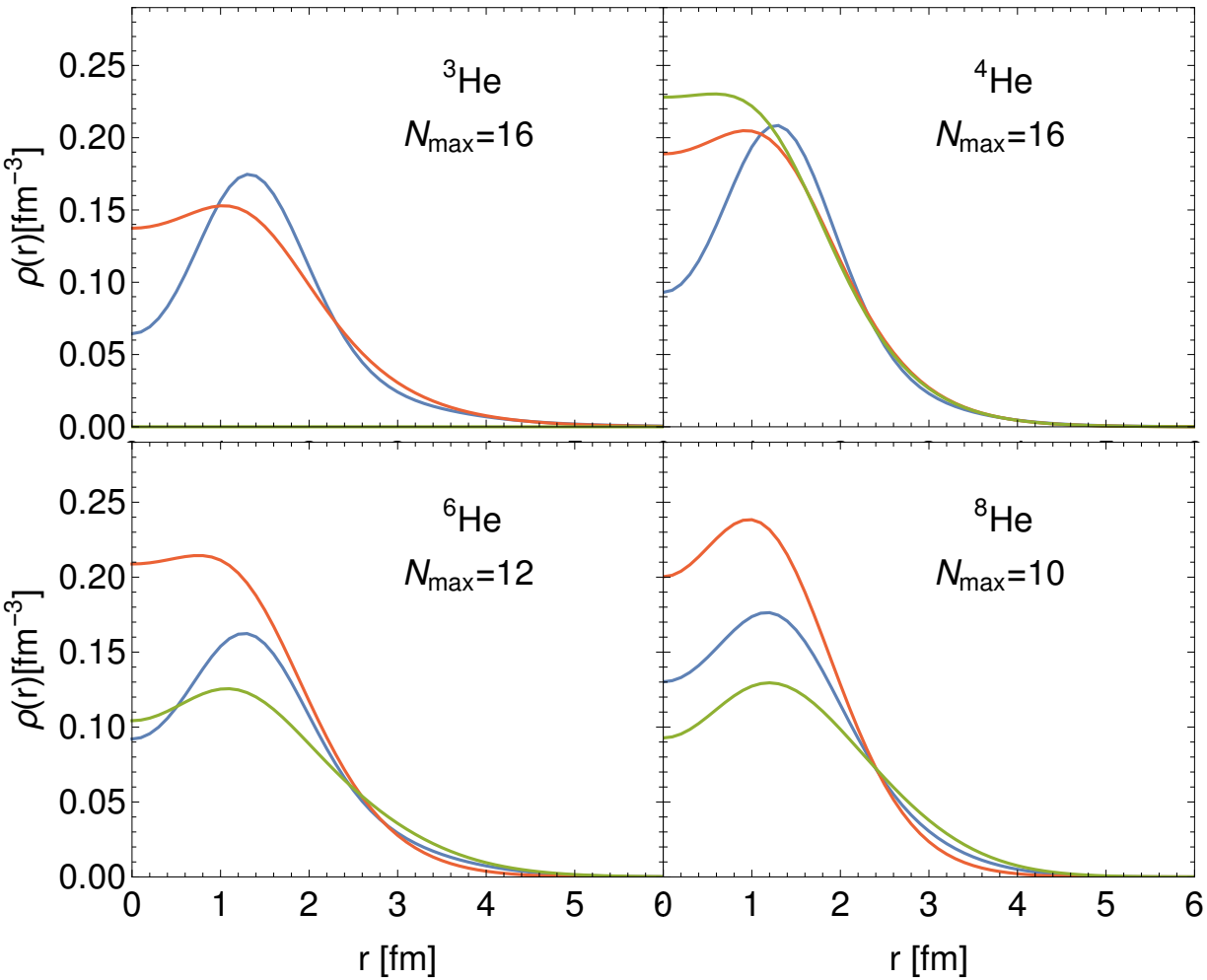
$\rho^{(2)}_{\{m_t\}}(\vec{x}_1, \vec{x}_2, \vec{x}\,'_1, \vec{x}\,'_2)$ —Talmi-Moshinski transformation→ $\rho^{(2)}_{\{m_t\}}(\vec{r}, \vec{R}, \vec{r}\,', \vec{R}\,')$

$\rho^{(2)}_{\{m_t\}}(\vec{r}, \vec{R}, \vec{r}\,', \vec{R}\,')$ —eliminate center of mass→ $\rho^{(2),\text{trinv}}_{\{m_t\}}(\vec{r}, \vec{r}\,')$

$\rho^{(2),\text{trinv}}_{\{m_t\}}(\vec{r}, \vec{r}\,')$ —eliminate angular dependencies→ $\rho^{(2),\text{trinv}}_{\{m_t\}}(r)$

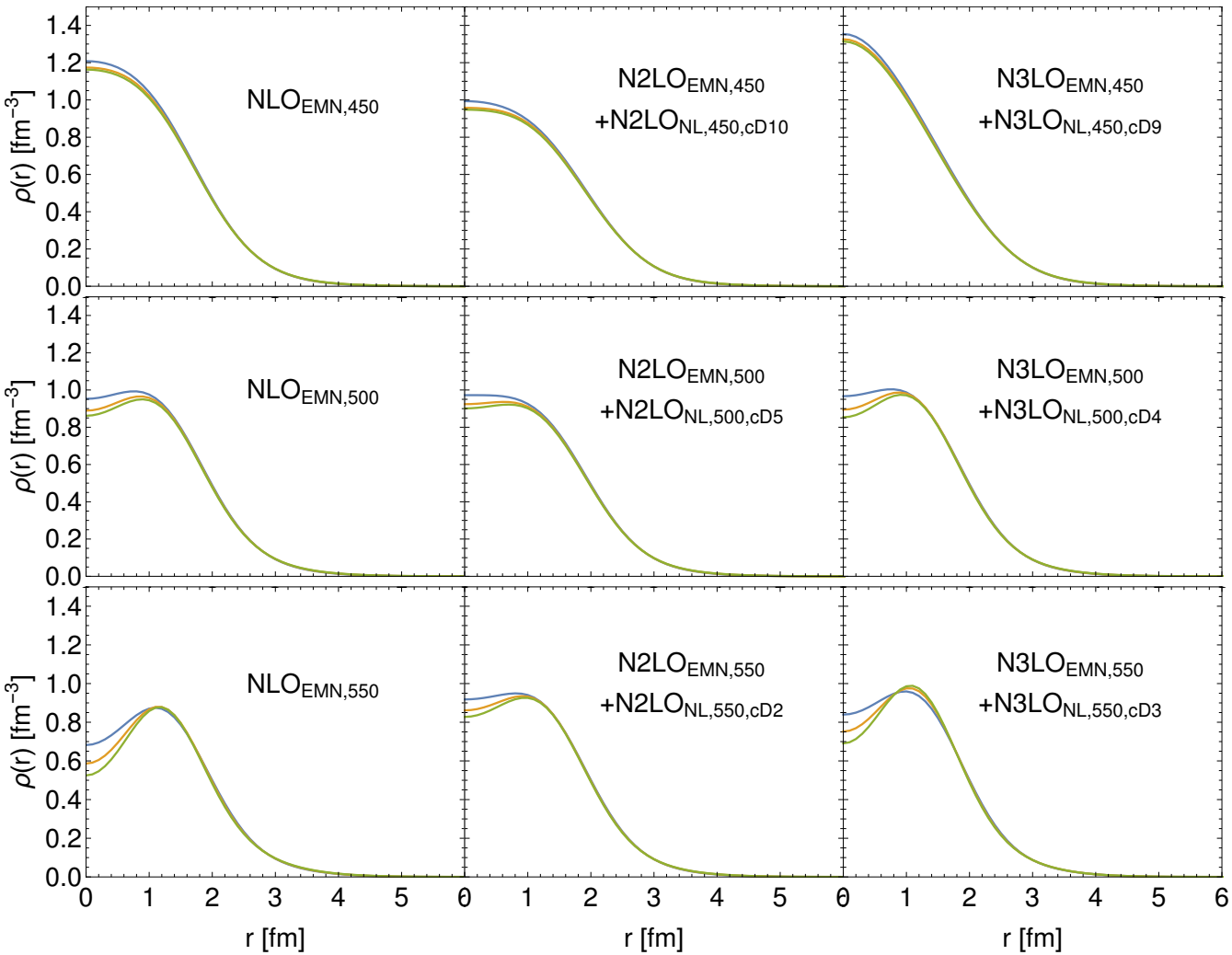
translationally invariant two-particle density matrix in terms of relative distance

Helium Isotopic Chain



- N3LO$_{\mathrm{EMN},500}$
- normalized to 1
- type:
  - np
  - pp
  - nn
- densities strongly depend on isotope

Investigation of nonlocal Interactions



- ^{4}He - np
- $\hbar\omega = 36$ MeV
- $N_{\max}$
  - 8
  - 10
  - 12
- larger cutoffs induce more short-range correlations

Similarity Renormalization Group

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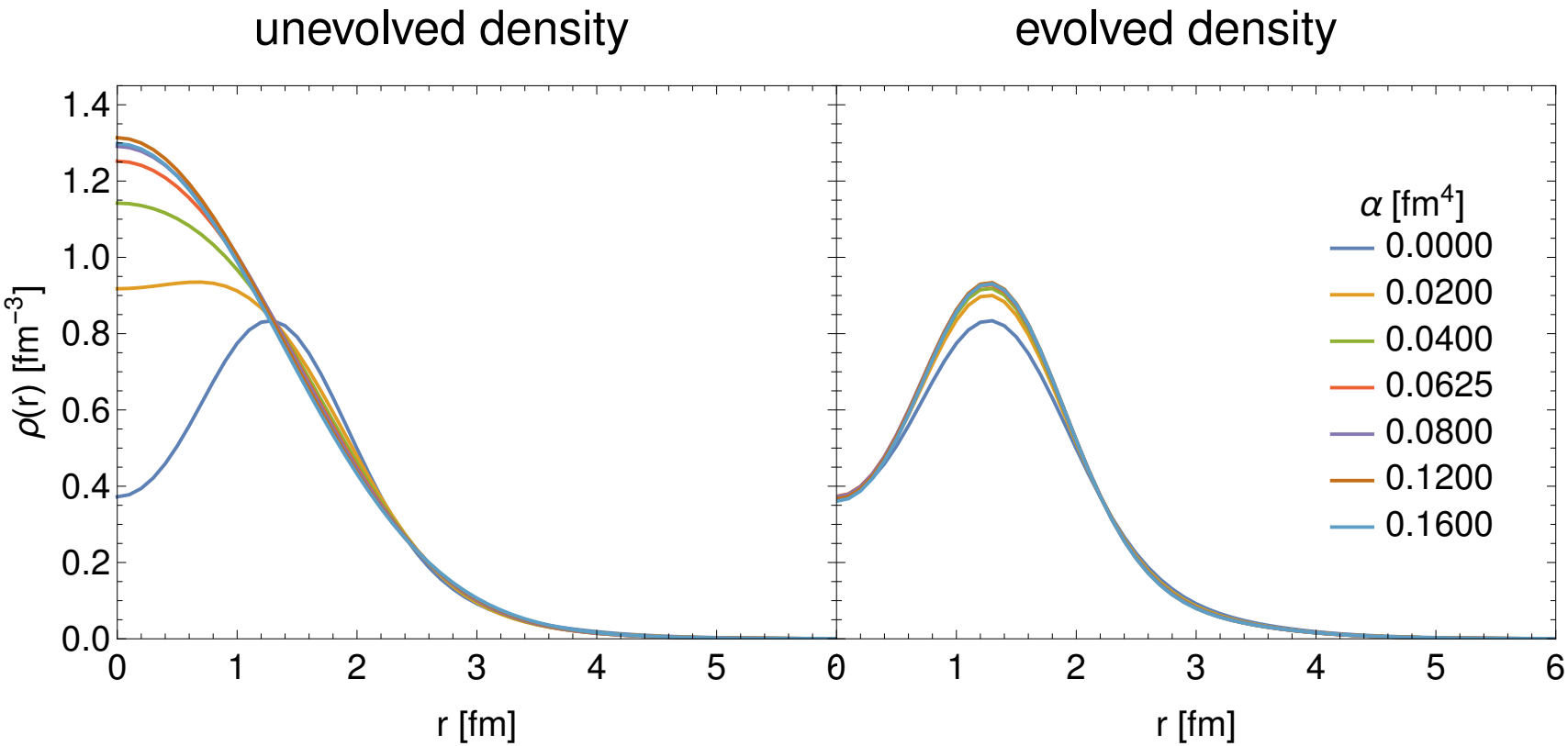
- ^{4}He - np
- $\hbar\omega = 36$MeV
- N3LO$_{\mathrm{EMN},500}$
- $N_{\mathrm{max}} = 12$ (evolved), 16 (bare)



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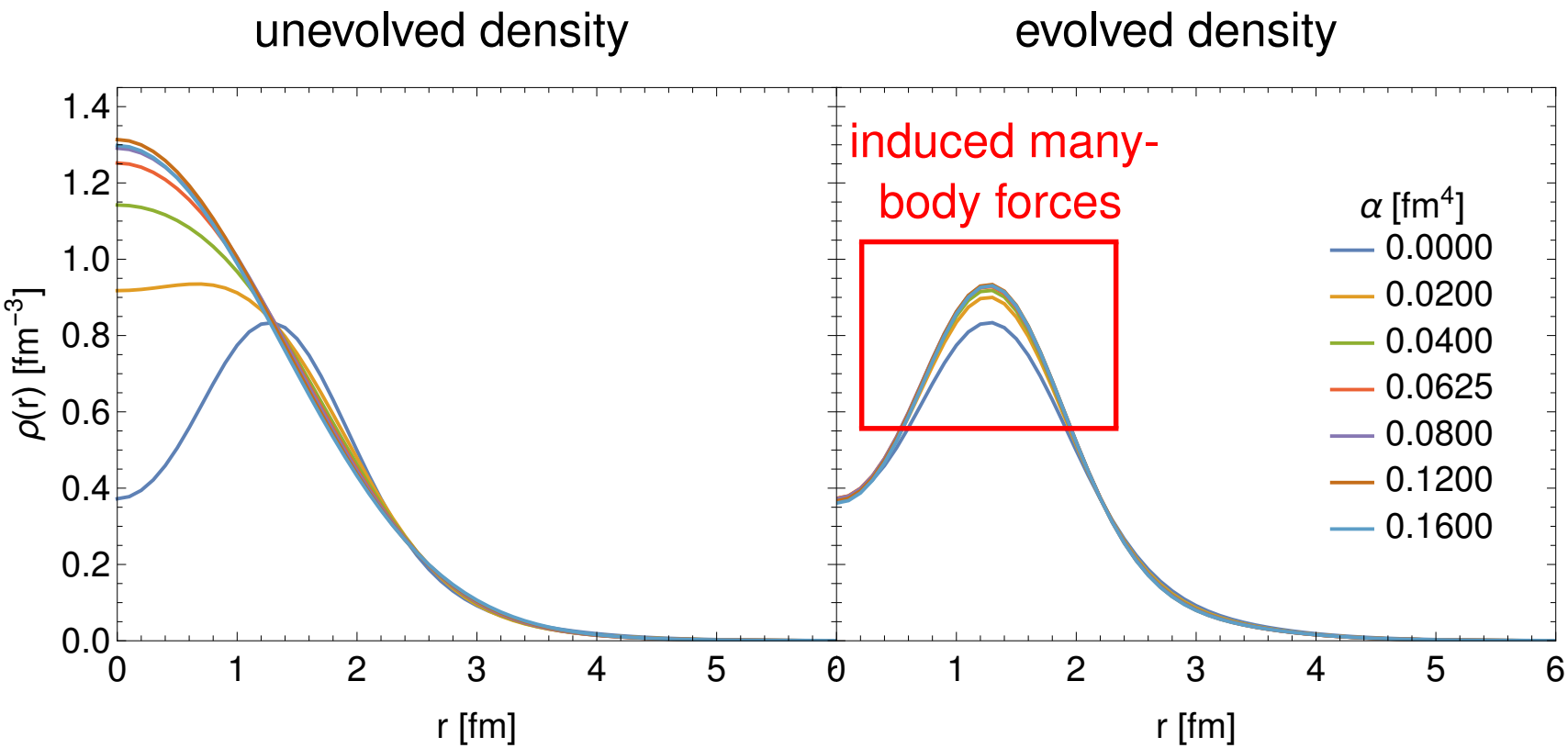
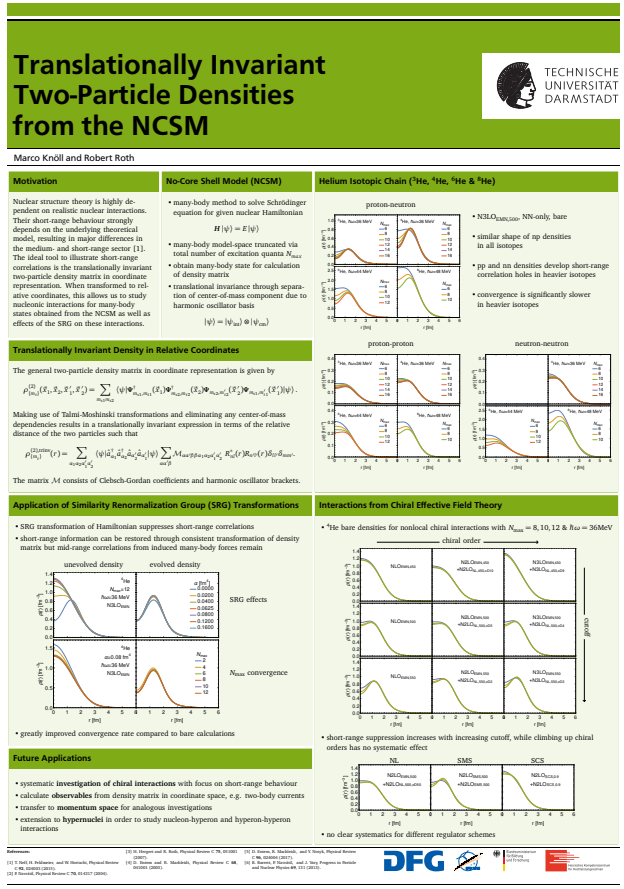


Outlook

- investigation of **chiral interactions**
- **observables** from density matrices
- transfer to **momentum space**
- extension to **hypernuclei**



Thank you for your attention!

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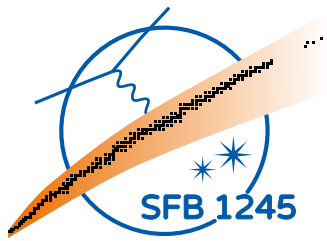
- **thanks to my group and collaborators**

  S. Alexa, T. Hüther, L. Mertes, T. Mongelli,
  J. Müller, **R. Roth**, T. Wolfgruber



Hessisches Kompetenzzentrum
für Hochleistungsrechnen

computing time