TRIUMF

Canada's national laboratory for particle and nuclear physics
Laboratoire national canadien pour la recherche en physique nucléaire
et en physique des particules

Nonlocal Translationally Invariant Nuclear Density

Michael Gennari, Angelo Calci, Matteo Vorabbi, Petr Navrátil, TRIUMF

Abstract

Nonlocal nuclear density is derived from the no-core shell model (NCSM) [1] one-body densities by generalizing the local density operator to a nonlocal form. The translational invariance (trinv) is generated by exactly removing the spurious center of mass (COM) component from the NCSM eigenstates expanded in the harmonic oscillator (HO) basis [2]. This enables the *ab initio* NCSM nuclear structure to be used in intermediate energy nuclear reactions and density functional theory (DFT). The ground state local and nonlocal density of ^{4}He, ^{6}He, ^{12}C and ^{16}O are calculated to display the effects of COM removal on predicted nuclear structure. We include nonlocal density in calculations of optical potentials [3] and show more accurate theoretical predictions for the differential cross sections for proton scattering on ^{4}He. Additionally, we show amplified effects of COM removal in related DFT quantities like kinetic density [4].

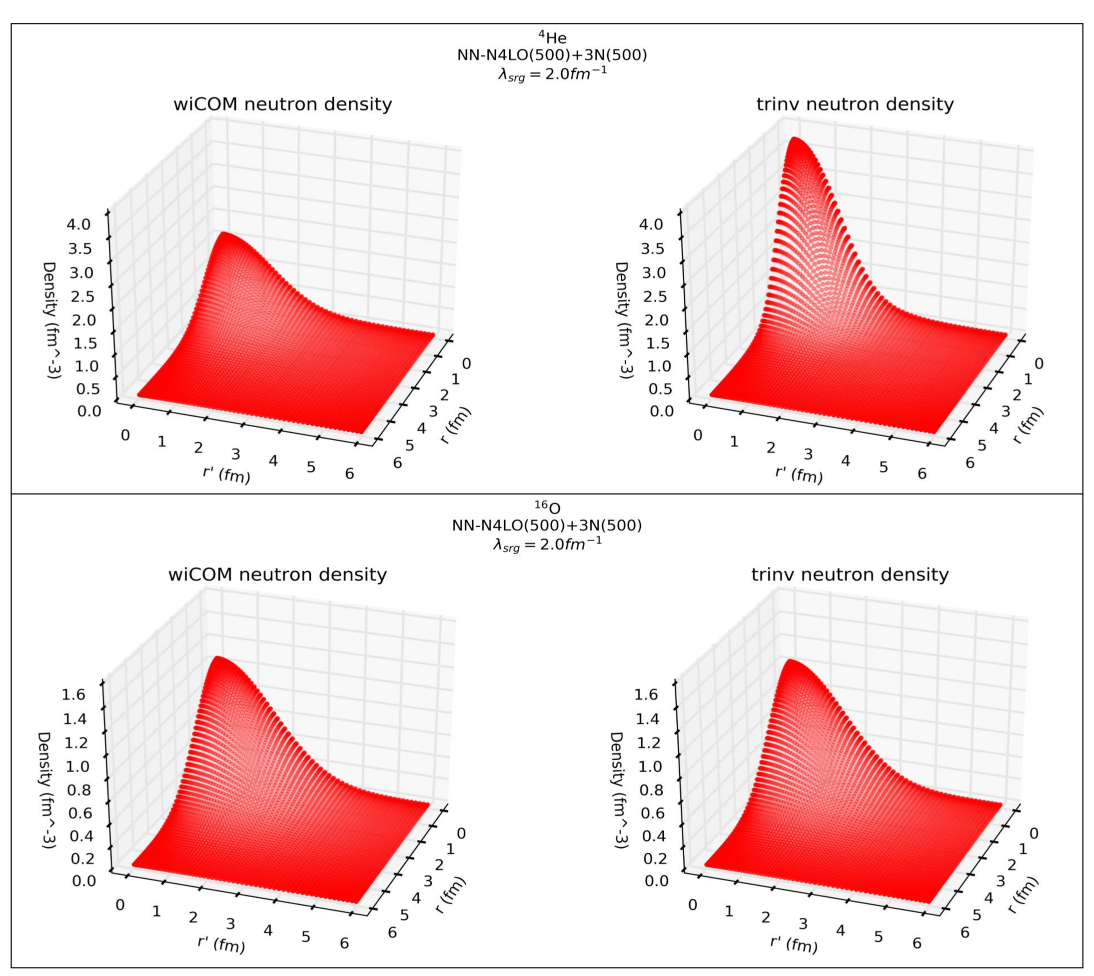
Nonlocal Trinv Nuclear Density

The general nonlocal nuclear density operator is shown below, where r is a coordinate for the final state and r' is a separate coordinate for the initial state.

$$\rho_{op}(\vec{r},\vec{r}') = \sum_{i=1}^{A} \{|\vec{r}\rangle\langle\vec{r}'|\}^i = \sum_{i=1}^{A} \delta(\vec{r}-\vec{r}_i)\delta(\vec{r}'-\vec{r}_i)$$

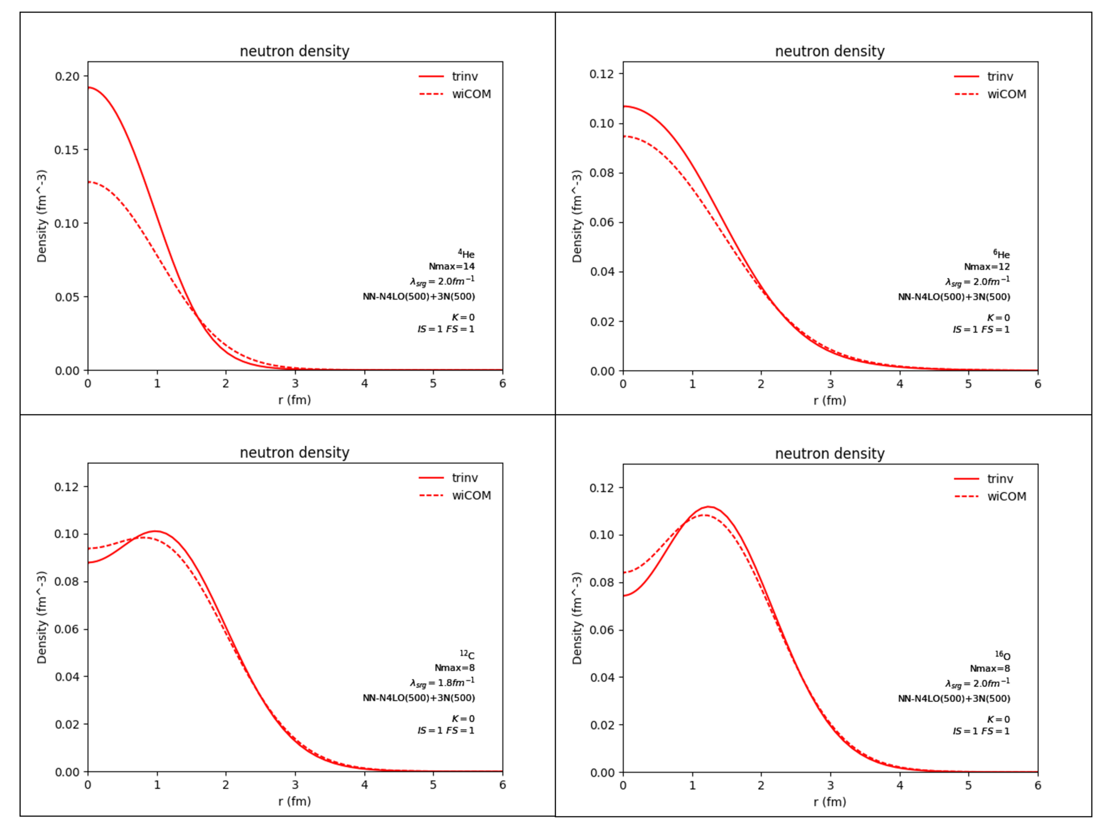
In the NCSM basis, translational invariance of the internal wave function is preserved when the single-particle Slater Determinant (SD) basis is used with N_{max} truncation [1]. The factorization of the Jacobi and SD eigenstates allows us to decouple and remove the ground state COM component from the intrinsic part of the wavefunction [2].

$$\langle\vec{r}_1\cdots\vec{r}_A\vec{\sigma}_1\cdots\vec{\sigma}_A\vec{\tau}_1\cdots\vec{\tau}_A|A\lambda JM\rangle_{SD} = \langle\vec{\xi}_1\cdots\vec{\xi}_{A-1}\vec{\sigma}_1\cdots\vec{\sigma}_A\vec{\tau}_1\cdots\vec{\tau}_A|A\lambda JM\rangle\varphi_{000}(\vec{\xi}_0)$$



Nonlocal Nuclear Density: This figure shows comparisons between COM contaminated and trinv nuclear density for ^{4}He and ^{16}O

We construct the local density [2] by taking the diagonal portion of the nonlocal density ($\vec{r}=\vec{r}'$). The local density provides additional confirmation of the effects of COM removal and is useful for studying convergence patterns of the density.

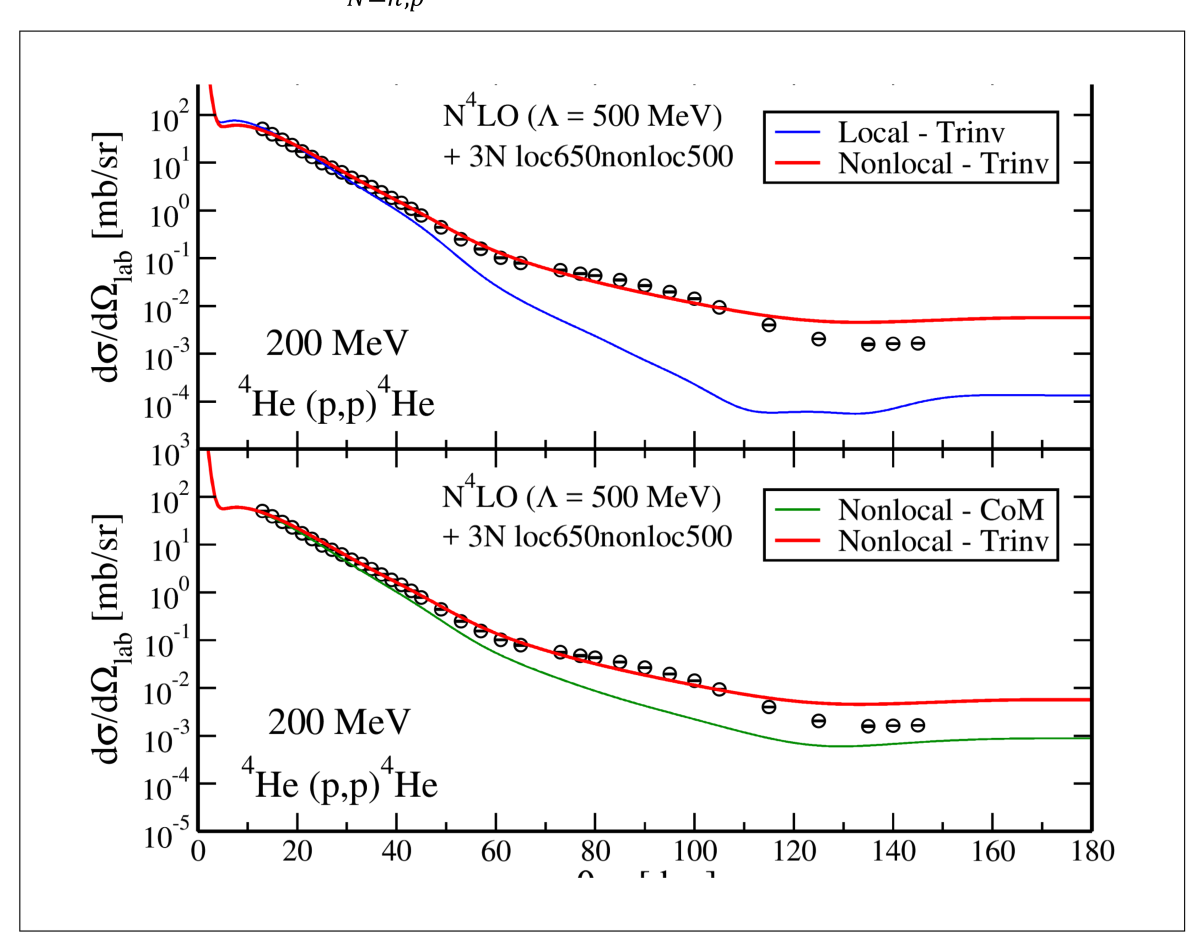


Density Comparison: This figure shows comparisons of local COM contaminated and trinv densities of ^{4}He, ^{6}He, ^{12}C and ^{16}O.

Optical Potentials

Nonlocal nuclear density is an important input for constructing microscopic optical potentials of nuclear reactions at intermediate energy. These are computed by folding the density with the t-matrix computed using modern high precision two and three nucleon interactions [3].

$$U(\vec{q},\vec{K}) = \sum_{N=n,p}\int d\vec{P}\;\eta(\vec{q},\vec{K},\vec{P})\,t_{pN}(\vec{q},\vec{K},\vec{P})\,\rho_N(\vec{q},\vec{P})$$



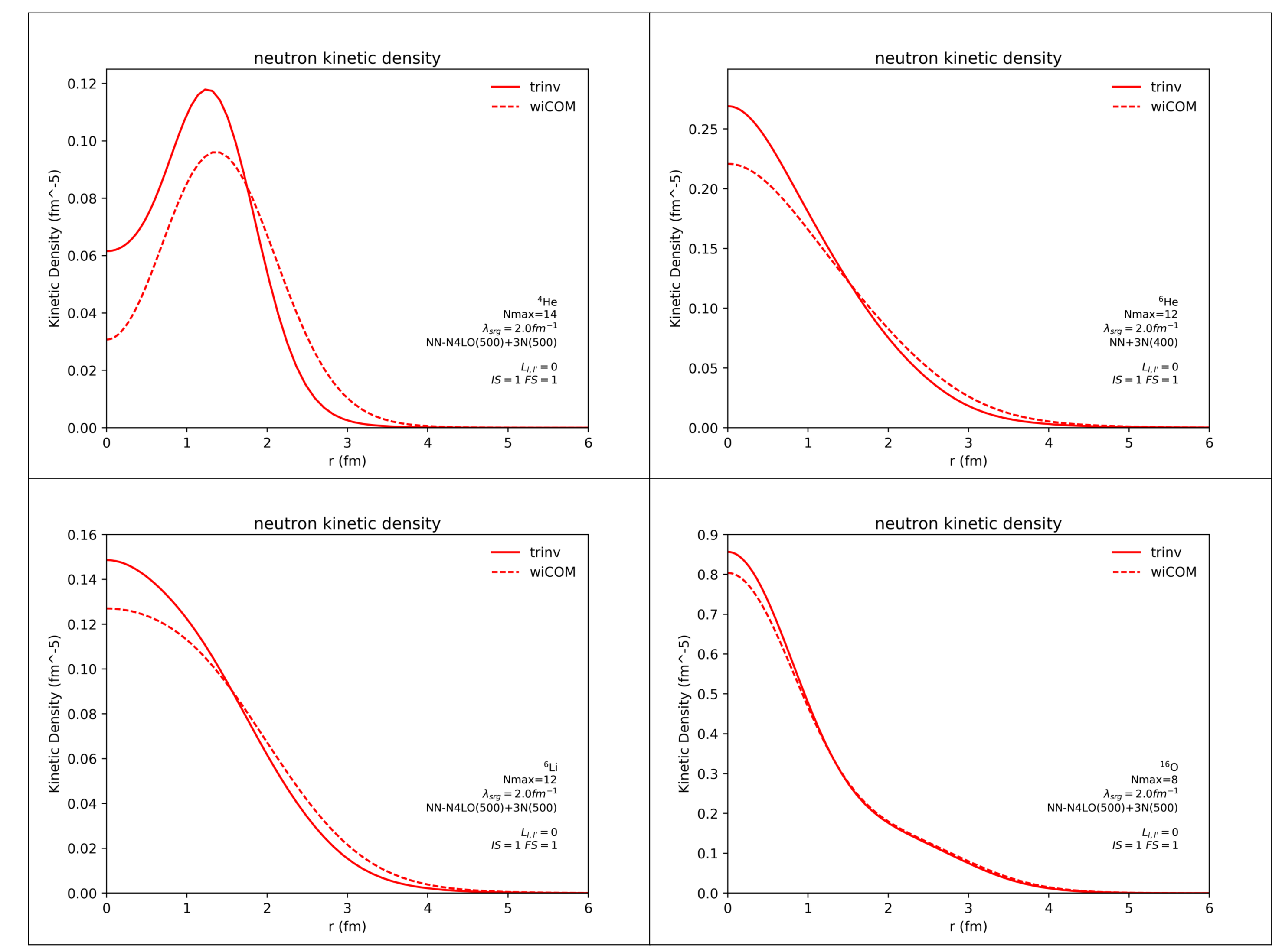
Cross Sections ^{4}He: This figure shows comparisons between the local density approximation and nonlocal density calculations for the differential cross section of ^{4}He, in addition to the effects observed by COM removal

Kinetic Density

The kinetic density is an example of one object in DFT [4] we can now calculate using *ab initio* wavefunctions. Kinetic density is given by the following relation,

$$\tau_T(\vec{r}) = \vec{\nabla}\cdot\vec{\nabla}'\,\rho_T(\vec{r},\vec{r}')|_{\vec{r}=\vec{r}'}$$

The Laplacian-like operator being applied on the nonlocal density should amplify the effects of COM removal, the results of which are shown below.



Nuclei Comparison: This figure shows the comparison between the COM contaminated and trinv kinetic densities, in addition to the effects in higher A-nucleon systems

References

1. B. R. Barrett, P. Navrátil, J.P. Vary, Progress in Particle and Nuclear Physics 69, 131-181 (2013)
2. P. Navrátil, Physical Review C 70, 014317 (2004).
3. M. Vorabbi, P. Finelli, and C. Giusti, Phys. Rev. C 93, 034619 (2016)
4. J.W. Negele, D. Vautherin, Physical Review C 5, 1472 (1972).

Acknowledgments

We would like to acknowledge the NSERC Grant No. SAPIN-2016-00033. TRIUMF receives federal funding via a contribution agreement with the National Research Council of Canada. Computing support came from an INCITE Award on the Titan supercomputer of the Oak Ridge Leadership Computing Facility (OLCF) at ORNL and from Compute Canada.