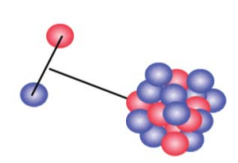
Separable Nucleon-Nucleus Optical Potentials

L. Hlophe, V. Eremenko, Ch. Elster
INPP, Department of Physics and Astronomy, Ohio University
F. Nunes (MSU), J. E. Escher & I. J. Thompson (LLNL), G. Arbanas (ORNL)

MOTIVATION

- Deuteron stripping (d, p) reactions are a tool to investigate the structure of exotic nuclei
- (d, p) reactions can be treated as a three-body problem with effective two-body interactions:
  - neutron-proton
  - neutron-nucleus } optical potential
  - proton-nucleus



- Three-body problem: Faddeev techniques in momentum space with separable two-body interactions
- Current calculations are limited up to calcium isotopes (Z= 20) due to numerical complications in treating the Coulomb force via screening techniques

OBJECTIVE

- Develop separable effective interactions
- Show that they reproduce two-body observables
- No screening of the Coulomb force

SUMMARY

- Starting from a Woods-Saxon type phenomenological optical (complex) potentials
  - analytic and numeric Fourier transform to momentum space
  - generalized Ernst-Shakin-Thaler (EST) to

    (a) complex potentials
    (L. Hlophe, Ch. Elster, et. al., Phys.Rev. **C88**, 064608 (2013).)

    (b) charged particles
    (L. Hlophe, V. Eremenko , et. al., arXiv: 1409.4012)
  - succeeded in calculating Coulomb distorted form factors in momentum space
    (N. Upadhyay, V. Eremenko, et. al., Phys. Rev. **C90,** 014615 (2014).)
- Ingredients are ready for implementation in three-body calculations

RESULTS

Form factors

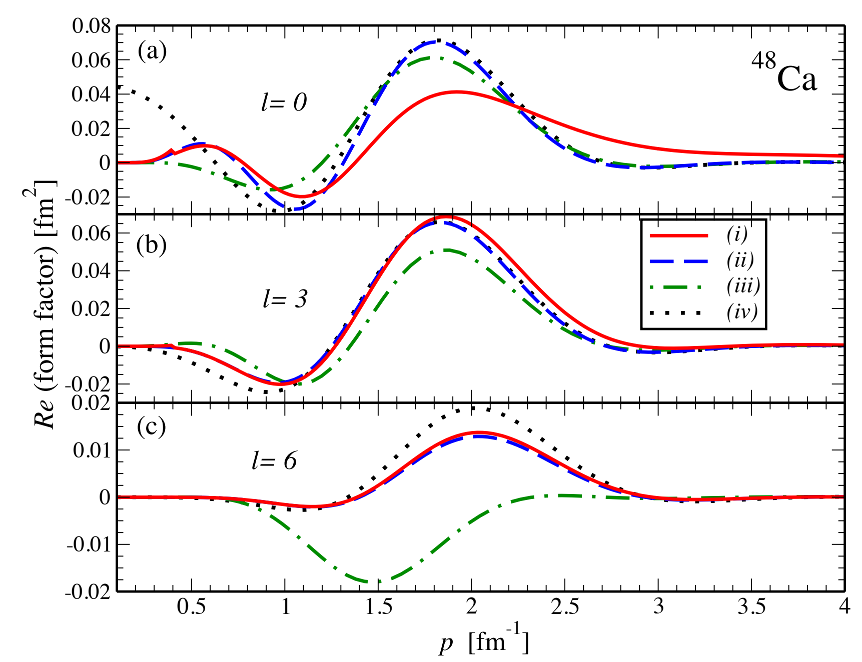


FIG. 2. (Color online) The real parts of the partial wave proton-nucleus form factor for ^{48}Ca as function of the momentum p for selected angular momenta l: (a) $l = 0$, (b) $l = 3$, and (c) $l = 6$. The form factors are calculated at $E_{c.m.} = 36$ MeV and based on the CH89 global optical potential: full calculations (i) are compared to those omitting the short range Coulomb (ii), the neutron-nucleus form factor (iii) and the Coulomb distorted neutron-nucleus form factor (iv).

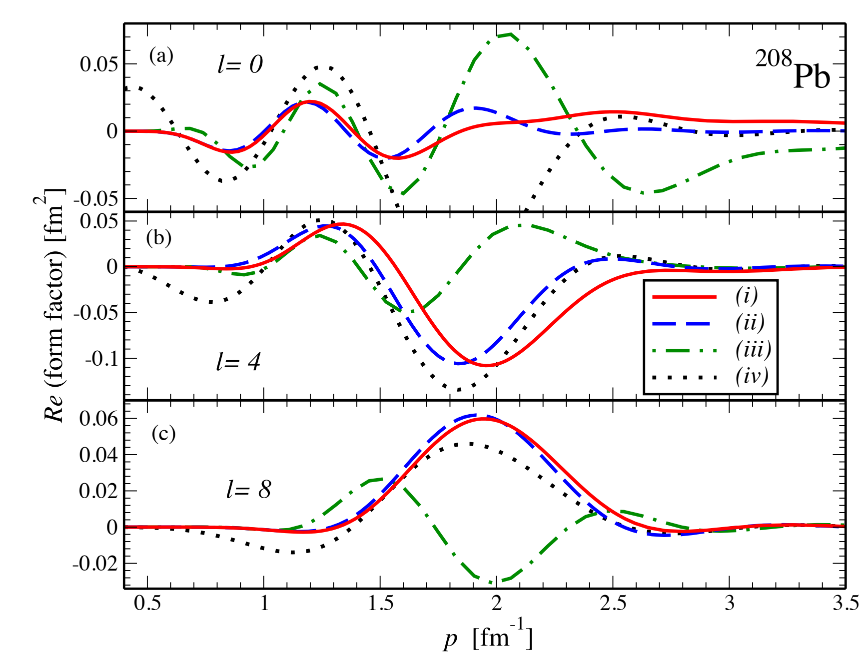


FIG. 3. (Color online). Same as Fig. 2 but for ^{208}Pb. The form factors for $l = 0$ (a) and $l = 4$ are calculated at $E_{c.m.} = 21$ MeV but for $l = 8$ (c) these are calculated at $E_{c.m.} = 36$ MeV.

Off-shell transition matrix

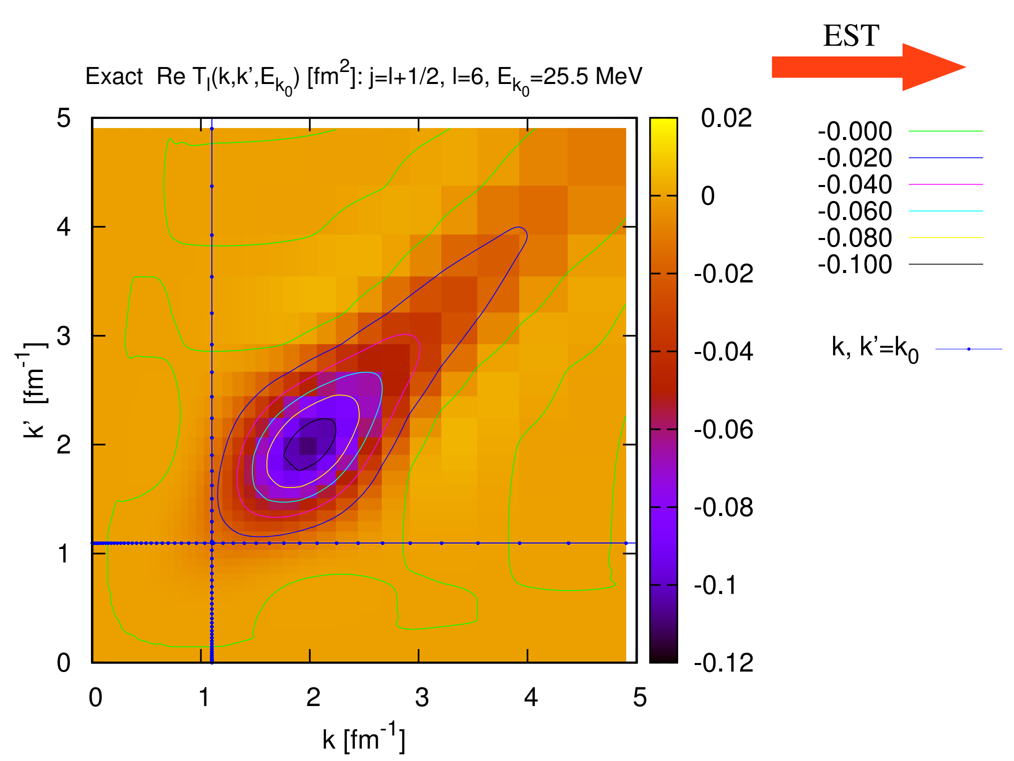


FIG. 4. Real part of the off-shell t-matrix calculated using the exact CH89 potential. This t-matrix is symmetric and exhibits high components along the diagonal.

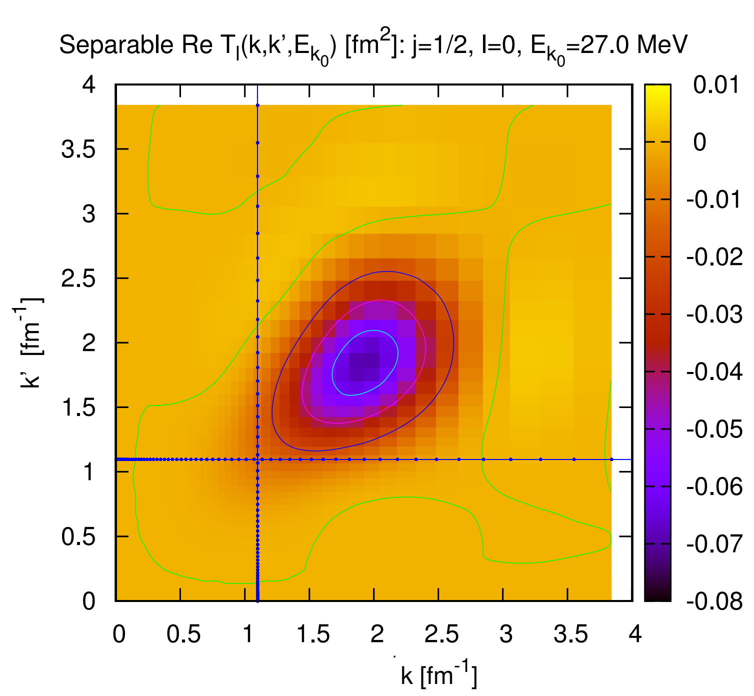


FIG. 5. Separable representation of the real part of the off-shell t-matrix calculated using the exact CH89 potential. The high momentum components present in the exact t-matrix have been projected out.

Cross sections

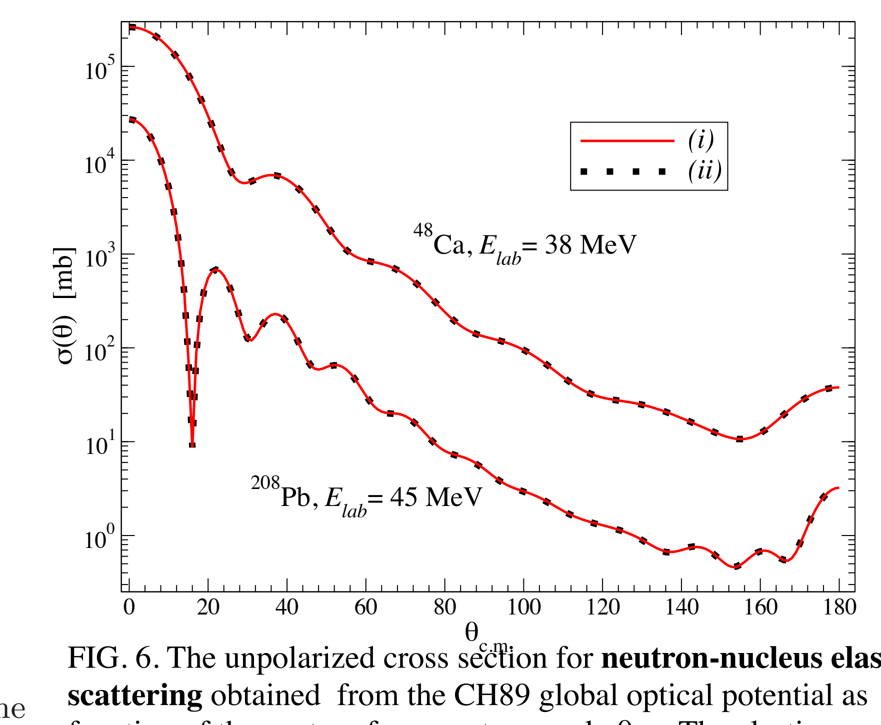


FIG. 6. The unpolarized cross section for **neutron-nucleus elastic scattering** obtained from the CH89 global optical potential as function of the center of momentum angle $\theta_{c.m.}$. The elastic cross section is calculated at a laboratory kinetic energy of 38 MeV (scaled up by a factor of 40) for n+^{48}Ca and 45 MeV for n+^{208}Pb. The red solid line (i) gives the elastic neutron-nucleus cross section calculated from the momentum space separable representation of the CH89 global optical potential, while the black dotted line (ii) depicts the corresponding coordinate space calculation.

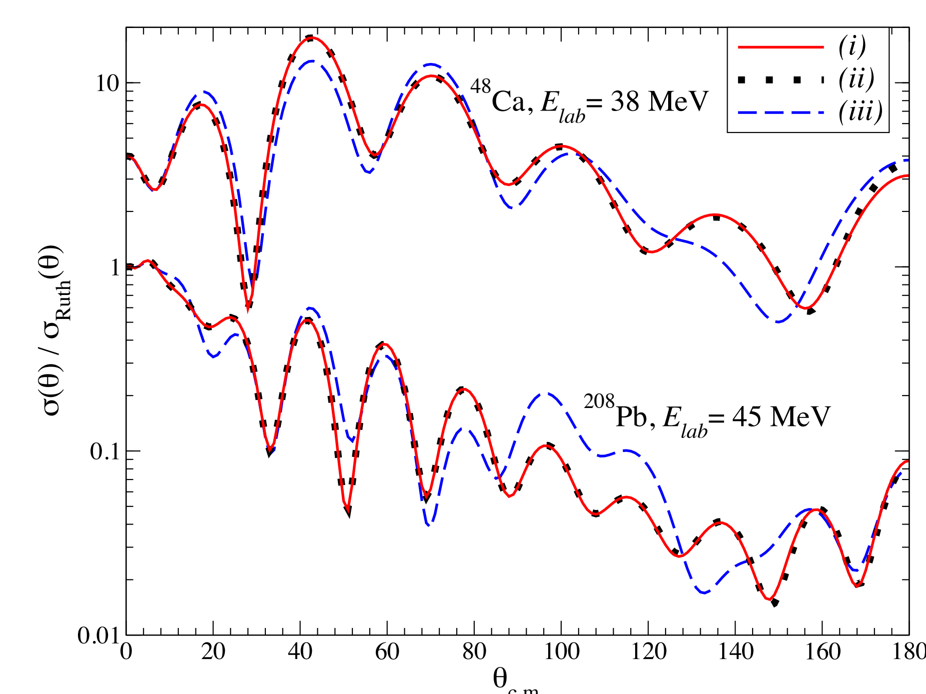
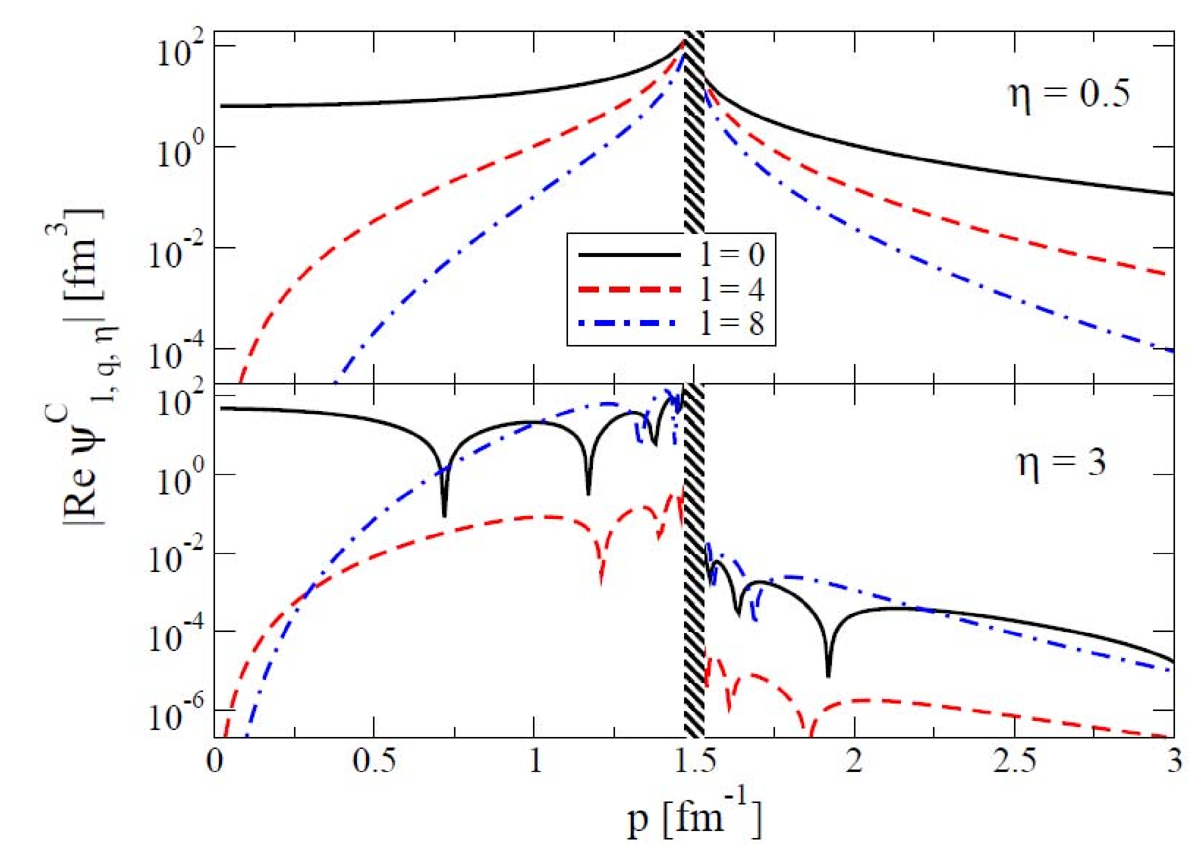


FIG. 7. The unpolarized cross section for **proton-nucleus elastic scattering** obtained from the CH89 global optical potential as function of the center of momentum angle $\theta_{c.m.}$. The elastic cross section is calculated at a laboratory kinetic energy of 38 MeV (scaled up by a factor of 4) for p+^{48}Ca and 45 MeV for p+^{208}Pb. The red solid line (i) gives the elastic proton-nucleus cross section calculated from the momentum space separable representation of the CH89 global optical potential, while the black dotted line (ii) depicts the corresponding coordinate space calculation. The blue dash-dotted line shows the calculation in which the short-range Coulomb potential is omitted.

METHODS

- The starting point for developing separable interactions is the EST scheme
  - requires that at fixed energies E_i the scattering wavefunctions from the original potential and separable representation are identical
  - complex potentials: generalize EST scheme to use 'in' and 'out' scattering states to preserve reciprocity
  - charged particles: EST scheme is generalized to use Coulomb scattering states instead of plane waves
- Coulomb distorted form factors in momentum space

Momentum space Coulomb wavefunction



- Gel'fand-Shilov regularization of oscillatory singularity in folding integrals of form factors with Coulomb wavefunctions

Research for this project was supported in part by the US Department of Energy, Office of Science of Nuclear Physics under the TORUS collaboration and contact DE-FG02-93ER40756.