# Momentum Distribution of Nucleons in Isospin Asymmetric Nuclear Matter

Javier Rufino[1,2], Jeremy Holt[2]

1. Department of Physics and Astronomy, University of Texas at San Antonio, San Antonio, TX 78249
2. Cyclotron Institute, Texas A&M University, College Station, TX 77843

CYCLOTRON INSTITUTE TEXAS A&M UNIVERSITY

UTSA The University of Texas at San Antonio Department of Physics and Astronomy

## Motivation

Neutron stars are the densest observable objects in the universe and consist primarily of neutron rich nuclear matter in a background of ultra-relativistic electrons. They maintain stability from gravitational collapse with the support of the quantum mechanical degeneracy pressure and nuclear interactions. To better understand the effects of nuclear short-range correlations on neutron star structure and dynamics we compute the single-particle momentum distribution of protons and neutrons starting from high precision two- and three-body forces derived from chiral effective field theory.

## Methods

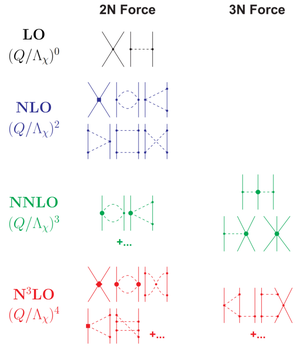


**Figure 1**: The diagrams in this figure are taken from Machleidt et al.[4] and represent the contributions to nuclear two-body and many-body forces. The solid lines represent nucleons and the dashed lines pions.

- From chiral effective field theory two- and three- body forces we computed the first- and second-order contributions to the nucleon self-energies.
- These self-energies are dependent on spin, isospin, momentum and density ($\Sigma^{(2a,2b)}_{p,n\,(q,\omega;k_f,\delta_{pn})}$), and once computed are summed up to produce single-particle potentials ($V_{(q,e(q))} = Re\,\Sigma_{(q,e(q))}$), of which are used to compute the momentum distribution.
- The nucleon self-energies were computed using the Texas A&M University supercomputer Terra. The following computations were done on C and Mathematica, and graphed on Mathematica.

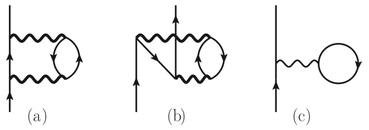


**Figure 2**: The first order and second order contributions of the nucleon self energies are represented diagrammatically provided by Holt et al1. The arrows pointing upwards and downwards represent nucleons, and hole states, respectively. The wavy line represents anti-symmetrized two nucleon interaction, and the thick wavy lines represent the sum of the free-space two-body force and the density dependent NN interaction.

## Single-Particle Momentum Distribution

Using the equations derived in the work of Sartor et al., we were able to compute the momentum distribution from our single-particle potentials. The following momentum distributions have been computed for values up to twice the nuclear saturation density, and arbitrary values of isospin asymmetries, $\delta_{np} = (N-Z)/A$ .

$$\frac{\bar{m}_{(q)_{(2a)}}}{m} = 1 - \left.\frac{\partial V_{(q,E)_{(2a)}}}{\partial E}\right|_{E=\frac{q^2}{2m}+Re\,\Sigma_{(q,e(q))}}$$

$$\frac{\bar{m}_{(q)_{(2b)}}}{m} = 1 - \left.\frac{\partial V_{(q,E)_{(2b)}}}{\partial E}\right|_{E=\frac{q^2}{m}+Re\,\Sigma_{(q,e(q))}}$$

$$\rho_{(q)} = \begin{cases} 2 - \dfrac{\bar{m}_{(q)_{(2a)}}}{m}, & for\ q < q_f \\ \dfrac{\bar{m}_{(q)_{(2b)}}}{m} - 1, & for\ q > q_f \end{cases}$$

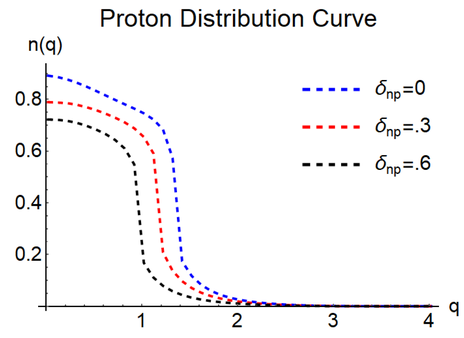


**Figure 3**: The momentum distribution of a proton under three arbitrary isospin asymmetries, and the nuclear saturation density $\rho = .16$

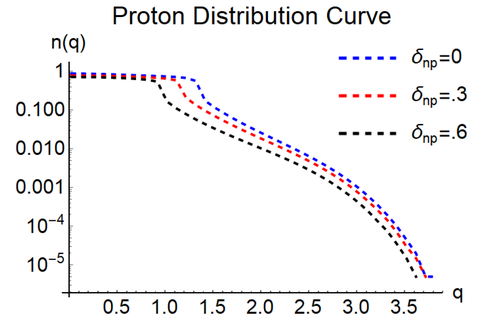


**Figure 4**: Logarithmic plot of figure 2, used to have a visual focus on the tail end of the plot.

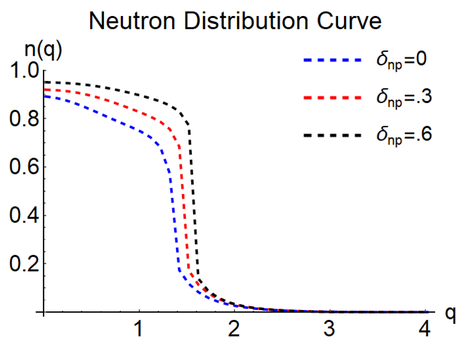


**Figure 5**: The momentum distribution of a proton under three arbitrary isospin asymmetries, and the nuclear saturation density $\rho = .16$

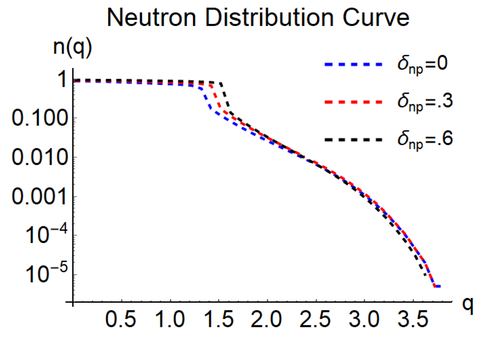


**Figure 6**: Logarithmic plot of figure 3, used to have a visual focus on the tail end of the plot.

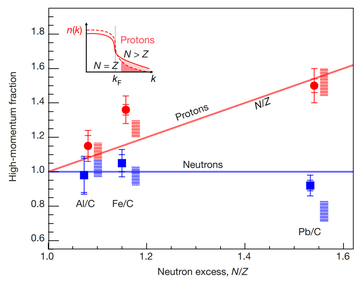


**Figure 7**: This figure is taken from a collaboration project of CLAS[2].

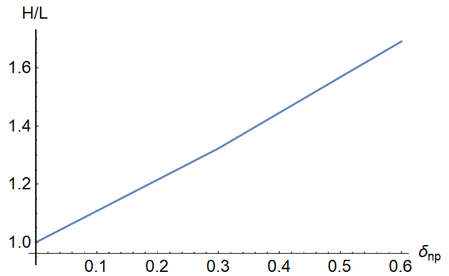


**Figure 8**: A plot showing the linear relationship between high momentum fractions vs neutron excess, similar to experimental data seen in **Figure 7**.

## Discussion

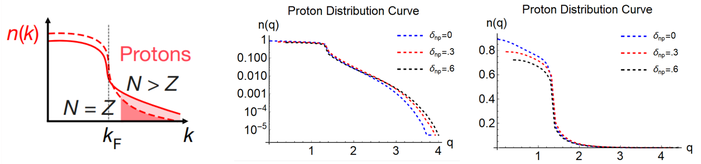


**Figure 9**: This figure taken from a collaboration project of CLAS[2], and is an inset from **Figure 7**.

**Figures 10 & 11**: These figures are the same graph as **Figures 3 & 4** with horizontal shifts in the curves with isospin asymmetries $\delta_{np} = 0.3$ and $0.6$.

The inset in the experimental data (**Figure 8**) provides a proton momentum distribution of neutron rich scattered nuclei. The experimental data states that as isospin asymmetry in a given nuclei increases, the ratio of high momentum protons to low-momentum protons also increases. We observe that our theoretical calculations also exhibit an increase in the proton high-momentum tail for isospin-asymmetric systems.

| | $\delta_{np}$=0.0 | $\delta_{np}$=0.3 | $\delta_{np}$=0.6 |
|---|---|---|---|
| High-Momentum States / Low-Momentum States | 0.342/0.342=1.0 | 0.453/0.342=1.3 | 0.578/0.342=1.7 |

## Conclusion and Future works

The present work demonstrates that theoretical calculations of nucleon momentum distributions in asymmetric nuclear matter from realistic two- and three-body chiral nuclear forces reproduce trends observed in experimental (e,e'p) and (e,e'n) reactions. In the future we will consider the role of nuclear short-range correlation on neutrino scattering rates in neutron stars

## References

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