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Abstract. The shapes of correlation functions are known to give information about the spatial and temporal extent of an emitting source. Since these two properties can be sensitive to the density-dependence of the asymmetry energy, these functions have been constructed using transport models in the past. In this work, correlation functions extracted using Constrained Molecular Dynamics (CoMD) are used to investigate the possibility of experimentally probing the density-dependence of the asymmetry energy using these correlation functions and detectors with high angular resolution.

1. Motivation

Interactions between nucleons (proton-proton (p-p), neutron-neutron (n-n), proton-neutron (p-n)) continue to be an area of study [1, 2, 3]. Correlation functions, which can help characterize these interactions, are sensitive to the size of the source and the timescale of the particle emission from the source[1, 2, 3]. Chen *et al.* have shown that the emission timescale of protons, and, therefore, the shape of the correlation function, is sensitive to the nuclear asymmetry energy using results from the isospin-dependent Boltzmann-Uehling-Uhlenbeck (iBUU) transport model [1].

Correlation functions can show the effects from Pauli blocking, Coulomb, and other final-state interactions between nucleons. Correlation functions are used to extract spatial and temporal information about excited emitting sources from nucleon-nucleon interactions [2, 3, 4, 5]. Theoretical predictions have suggested that the contribution of the asymmetry potential to the behavior of nucleon-nucleon interactions may be large enough that n-n, p-p, and p-n correlation functions could be used to constrain the density-dependence of the asymmetry energy [1]. For this proceedings and the subsequent experiment, protons will be used as the nucleons for the construction of correlation functions for this purpose.

2. Correlation Function Theory

Correlation functions are defined and plotted as a function of the relative momentum ($\vec{q}_{Rel}$) of any two protons ($\vec{p}_1,\vec{p}_2$) from the emitting source, where

$$|\vec{q}_{Rel}| = \frac{1}{2}|\vec{p}_1 - \vec{p}_2|. \tag{1}$$

These functions, $C(p_1, p_2)$, from the Koonin-Pratt formalism, can be written as [3, 4, 5]

$$C(\vec{q}_{Rel}) = N\frac{A(\vec{q}_{Rel})}{B(\vec{q}_{Rel})}, \tag{2}$$

and plotted as a function of q_{Rel} in the center of mass of the two protons. The individual momenta of proton 1 and proton 2 are denoted p_1 and p_2. N is a normalization coefficient defined to make $C(p_1, p_2) = 1$ at large values of q_{Rel} (the protons are assumed to have very little correlation when they have a large spacial separation). The numerator $A(\vec{q}_{Rel})$ is the yield of pairs of protons at each q_{Rel} from the same event, some of which are correlated. The denominator, $B(\vec{q}_{Rel})$, is the yield of pairs of uncorrelated protons, obtained by selecting proton pairs from different events is known as "event mixing" [3, 6].

The shapes of the correlation functions are due to the attractive strong force, pauli blocking, and coulomb repulsion; the magnitude of these effects on the shape of the correlation function depends on the size of the source and the timescale of its decay. A ratio ($C(\vec{q}_{Rel})$) of greater than one means that correlations dominate at that point, while a ratio less than one indicates an anticorrelation for that region in $\vec{q}_{Rel}$ (e.g. the "Coulomb hole").

3. Correlation Functions from Constrained Molecular Dynamics

In the past, correlation functions have been examined in transport models such as the iBUU model [1]. In this work, Constrained Molecular Dynamics (CoMD) [7] was used to simulate nucleus-nucleus reactions, and p-p correlation functions were constructed for 31 MeV/nucleon ^{40}Ca+^{40}Ca and 30 MeV/nucleon ^{48}Ca+^{64}Ni reactions. Figure 1 shows the asymmetry energy input to CoMD for the "super-stiff" and "soft" cases. The super-stiff case (dashed gray) increases dramatically with larger densities, while the "soft" decreases its slope at larger density. These differences, which come from different nucleon-nucleon interactions, should be visible in correlation functions extracted using these formulations of the asymmetry energy.

Figure 2 shows the p-p correlation function, as a function of q_{Rel}, from central 31 MeV ^{40}Ca+^{40}Ca CoMD events. There is no correlation above a relative momentum of about 40 MeV/c. There is a slight anticorrelation below 40, which increases as the q_{Rel} decreases. These lower C(q) values demonstrate the correlation function's sensitivity to the coulomb repulsion of the protons at a small relative momentum.

Figure 3 shows correlation functions calculated from "super-stiff" and "soft" density-dependences of the asymmetry energy. Both have a ratio of correlated-to-uncorrelated of one at q_{Rel} above 60 MeV/c, but the "soft" asymmetry energy, which has higher values of the asymmetry energy (more repulsion) below normal density, exhibits larger correlations at lower relative momenta. This effect will need to be disentangled from the density in the future, perhaps by more stringent source cuts. The bump in the correlation function at a relative momentum of about 20 MeV/c is caused by final-state p-p interactions [2, 3].

4. Experimental: FAUST Upgrade

The correlation functions shown above for ^{48}Ca+^{64}Ni, as well as a corresponding neutron-poor system, will be experimentally obtained at Texas A & M. The Forward Array Using Silicon
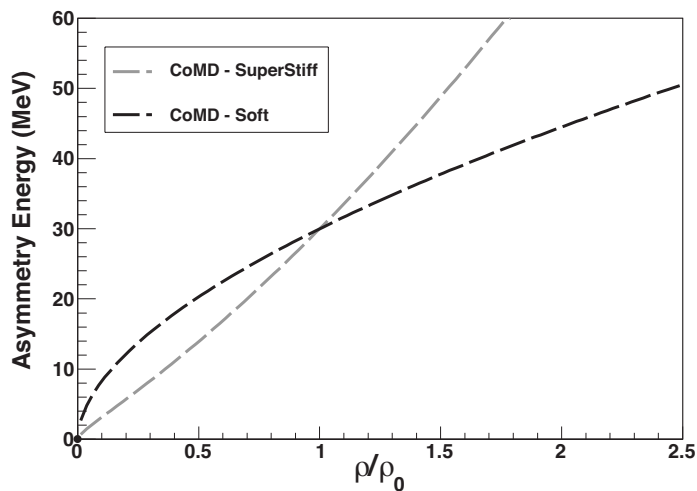
Figure 1. The semi-classical mean-field approximation gives values of the asymmetry energy and slope of the density-dependence, which are used as inputs for the "super-stiff" and "soft" cases in CoMD [8]. They are plotted here.
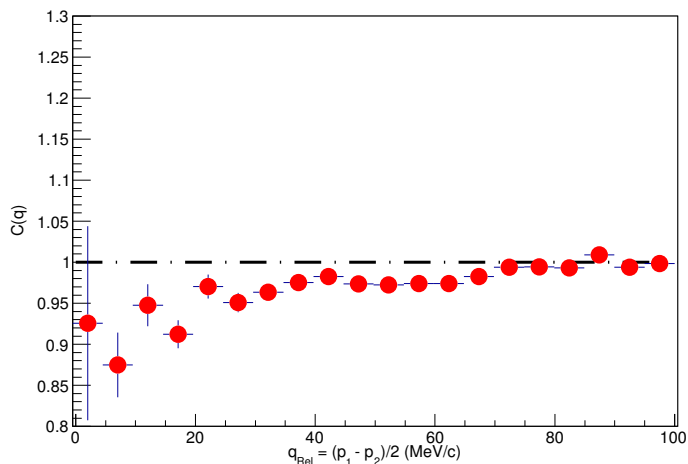

Figure 2. Correlation function for protons, central impact parameter events of 31 MeV/u ^{40}Ca+^{40}Ca events. The dip at low relative momentum indicates that the protons behave as fermions.

Technology (FAUST), schematically depicted in Figure 4, will be used to detect the free protons for this project. The array has 90 percent geometric acceptance from $1.6°$ to $33.6°$. In order to increase the angular resolution of charged-particle detection in the upcoming experiment, an upgrade of the array is planned using Dual-Axis Dual-Lateral (DADL) Si detectors. The DADLs have uniform resistance across the front and back of the detectors and use charge-splitting to determine the position of a detected particle to within 200 μm [9]. Isotope identification will be achieved with standard E-ΔE techniques from Si-CsI telescopes.
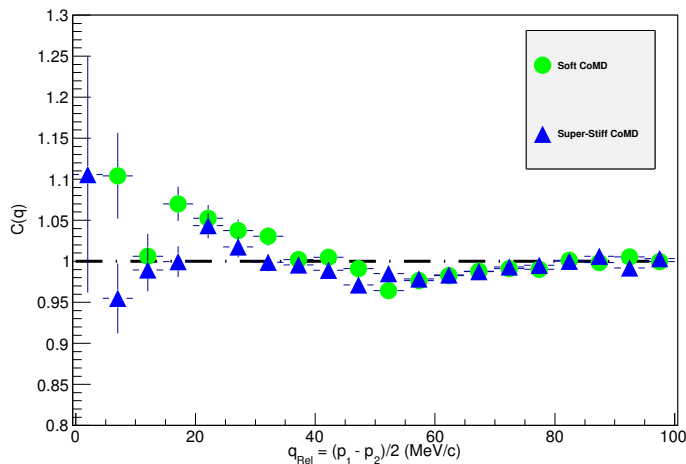
Figure 3. Correlation function for protons for all impact parameter events of 30 MeV/u ^{48}Ca+^{64}Ni events. The (green) circles denote the "soft" implementation of the asymmetry energy, while the (blue) triangles denote the "super-stiff". The bump at 20 MeV/c relative momentum is characteristic of p-p interactions [2, 3].
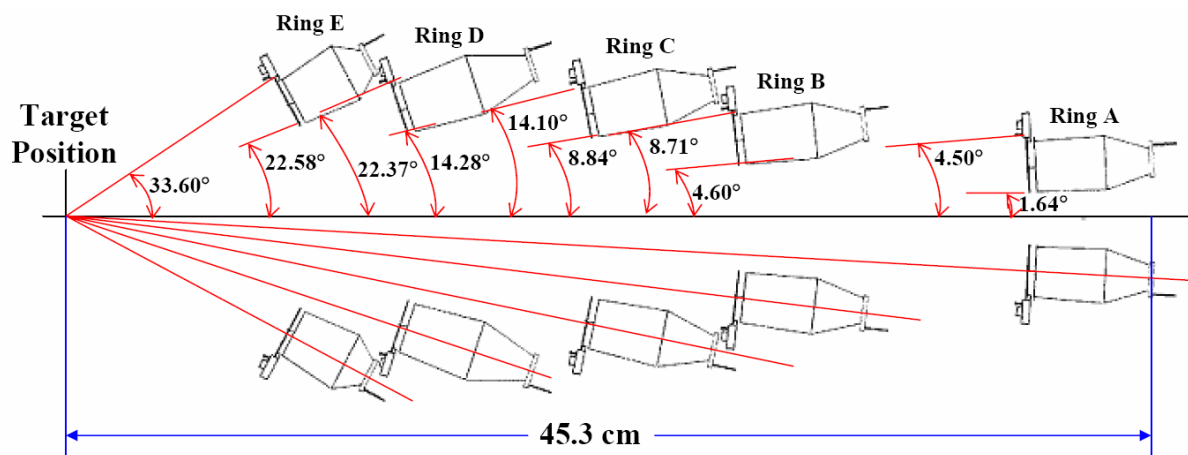

Figure 4. Geometric schematic of the Si-CsI telescopes of the FAUST detector array[10].

5. Conclusions

Characteristic features of known correlation functions (the bump from p-p interactions and the dip from pauli blocking) can be reproduced by CoMD. Some difference exists in the shape of the correlation functions between those obtained from different formulations of the density-dependences of the asymmetry energy in CoMD, which indicates that the correlation functions extracted from the CoMD model are sensitive to the different interactions which simulate different equations of state in the model. Further investigation into the correlation function extracted from the ^{48}Ca+^{68}Ni reaction in different density-dependences of the asymmetry energy in CoMD, along with a transport model, is planned. Experimental correlation functions from this reaction, along with a neutron-poor system of the same projectile and target Z, is planned with the upcoming FAUST upgrade.

Acknowledgments

6. References

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