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Nuclear Clustering and Non-Equilibrium Dynamics in Small-System Collisions

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Understanding the impact of nuclear structure in high-energy nuclear collisions is critical to advancing our knowledge of quark-gluon plasma (QGP) formation. In this study, we investigate the role of nuclear clustering, in particular the alpha-cluster structure in ^{16}O, using anisotropic flow observations from $^{16}\mathrm{O} +^{16} \mathrm{O}$ collisions at RHIC energy. Through systematic simulations with an improved AMPT model, we show that a longer effective hadron formation time is essential to match recent STAR experimental data. Importantly, the anisotropic flow coefficients serve as sensitive probes for distinguishing alpha-clustering configurations in ^{16}O nuclei [1].

Additionally, we extend this investigation to $^{20}\mathrm{Ne} +^{20} \mathrm{Ne}$ and $^{16}\mathrm{O} +^{16} \mathrm{O}$ collisions at LHC energies, where we compare the results from the AMPT transport model with those from hydrodynamic models. The AMPT model, which accurately simulates non-equilibrium dynamics, shows significant deviations from hydrodynamic predictions, especially in key observables such as elliptic flow v_2 , Pearson correlation coefficient $\rho(v_2^2\{2\}, \langle p_T \rangle)$, and , symmetric cumulants $\mathrm{SC}(3,2)$, and four-particle cumulant $c_2\{4\}$. These discrepancies underscore the limitations of hydrodynamics, which assumes local thermal equilibrium, in small systems.

The advantage of the transport model lies in its ability to capture the microscopic dynamics of particle collisions, making it more suitable for the study of small and intermediate collision systems such as $^{20}\mathrm{Ne} +^{20} \mathrm{Ne}$ and $^{16}\mathrm{O} +^{16} \mathrm{O}$, where non-equilibrium effects are significant. Unlike hydrodynamic models that assume local thermal equilibrium, the AMPT model effectively describes partonic interactions in systems with fewer particles, providing a more accurate description of initial state fluctuations and parton escape dynamics.

These results underscore the importance of transport models in the study of the complex dynamics of small and medium-sized nuclear systems, providing critical insights into the influence of nuclear clustering and improving the understanding of QGP formation at RHIC and the LHC.

[1] X.L. Zhao, G.L. Ma, Y. Zhou, Z.W. Lin, and C. Zhang, arXiv:2404.09780.
[2] X.L. Zhao, P. Li, G.L. Ma, Y. Zhou, Z.W. Lin, and C. Zhang, preparing.

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