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

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This study explores how α-clustering in light nuclei (e.g., 16O) and non-equilibrium dynamics shape quark-gluon plasma (QGP) signals in small collision systems (16O+16O, 20Ne+20Ne). Using the AMPT model, we simulate collisions at RHIC and LHC energies and show that α-clustering induces initial-state inhomogeneities that imprint distinct collective flow. Extended parton interaction times are critical to match the experimental data, challenging hydrodynamic models that assume rapid thermalization.

Key discrepancies between AMPT and hydrodynamics highlight the dominance of pre-equilibrium dynamics in small systems, where limited rescattering preserves initial-state memory. Nuclear clustering reshapes the fireball energy density, requiring structure-aware models, while non-equilibrium phases blur traditional QGP formation criteria. Collective signals may be due to pre-thermal parton interactions rather than thermalized matter.

These results bridge nuclear structure and QGP physics, urging unified frameworks to address QCD phase diagram puzzles. Future experiments probing clustered nuclei will refine our understanding of strongly interacting matter under extreme conditions.

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