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Addressing the Ultra-Central Puzzle with Initial-State Nuclear Structures

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Hydrodynamic models fail to describe the near-equal v_3/v_2 ratio observed in ultra-central heavy-ion collisions, despite their success in other centrality classes. This failure can not be resolved by adjusting the shear viscous coefficient, as shear viscosity suppresses higher-order anisotropic flows more strongly, leading to an underestimation of v_3 when v_2 matches experimental data. To address this issue, we explore two initial-state modifications to resolve this puzzle: (1) impose a minimum distance between nucleons to simulate the homogenization effect arising from short-range nucleon-nucleon repulsion; and (2) introduce sub-nucleonic structures, specifically 'hot spots' within protons, to provide a more refined description of initial-state fluctuations. Using TRENTo initial conditions and 3+1D viscous hydrodynamic model CLVisc, both approaches significantly lower geometric eccentricity, reduce required viscosity, and narrow the v_2–v_3 gap in ultra-central collisions. Our results implicate initial-state nuclear and sub-nucleon structures as critical factors in addressing this puzzle. Resolving it would advance nuclear structure studies and improve precision in extracting QGP transport coefficients (e.g., shear viscosity), bridging microscopic nuclear features to macroscopic quark-gluon plasma properties.

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