Contribution ID: **86** Type: **Oral**

Dynamical modeling the conserved baryon density with causality near the QCD critical point

Monday, 27 October 2025 08:40 (20 minutes)

Exploring the QCD phase transition is one of the most important goals in relativistic heavy-ion collisions. The Beam Energy Scan Program at RHIC has revealed a preliminary non-monotonic behavior of net-proton multiplicity fluctuations with increasing collision energy [1], which is consistent with theoretical predictions [2].

However, the quark-gluon plasma created in relativistic heavy-ion collisions is a highly complex system, and several factors can modify the signal of the QCD phase transition. Dynamical modeling near the QCD phase transition in a realistic experimental context is essential for the ultimate discovery of the QCD phase transition in heavy-ion collisions. Several dynamical models of conserved baryon density have been developed based on the assumption that only diffusive modes are relevant to the slow dynamics near the QCD critical point [3-5]. However, as pointed out by Hydro+ [6], critical slowing-down effects induce a quasi-diffusive mode, described by a relaxation timescale τ, which affects the evolution of dynamical fluctuations and ensures the causality of the diffusion process. By employing the deterministic equations of the non-Gaussian fluctuations dynamics of baryon density [7], we study the effects of the causality of diffusion near the QCD critical point [8]. We find that the relaxation effects induced by causality strongly enhance the fluctuations of the baryon density, as well as large oscillatory behavior, especially for fast modes. These effects are particularly significant for higher-order fluctuations of baryon density. Consequently, further studies of the quasi-diffusion process in experimental measurements are essential for QCD critical point research.

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Session Classification: Parallel I

Track Classification: QCD 相变与状态方程 (QCD phase transition and equation of state)