Title : Study of the hottest droplet of fluid through correlations and fluctuations of collective variables

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Abstract

Collisions of two heavy nuclei at relativistic speeds at the Relativistic Heavy Ion collider (RHIC) at BNL and the Large Hadron Collider (LHC) at CERN, create a state of matter which has a temperature 10^5 times that of Sun's core, a size of the order of nuclear radius (femtometer) and which behaves like a perfect fluid with minimal viscosity. This matter under extreme condition, is a medium where the quarks and gluons, normally existing as bound states in hadrons, travel freely with color degrees of freedom, with their interactions governed by Quantum Chromodynamics (QCD). This hot, dense, fluid-like droplet of de-confined state of quarks and gluons is known as the Quark Gluon Plasma (QGP). The QGP medium, surviving for a very short time (10^{-22} s) with its evolution dynamics described by the relativistic viscous hydrodynamics, creates thousands of particles hitting the detectors at the end. One of the most remarkable features is the collective flow of these particles, serving as a key phenomenon for probing the QGP medium in high energy nuclear collisions. The most peculiar and intriguing characteristics of the collective anisotropic flow, quantified in terms of flow harmonics, is the importance of event-by-event fluctuations, stemming mostly from event-by-event fluctuations in the initial state. In this thesis, we focus on fluctuations and correlations between the collective observables such as mean transverse momentum per particle ($[p_T]$) and harmonic flow coefficients (v_n) etc. Specifically, we show that the fluctuations of harmonic flow can be probed by the factorization-breaking coefficients between flow vectors in different p_T-bins. Experimental difficulty can be reduced by taking one of the flow vectors momentum averaged. Fluctuations cause a decorrelation between the flow vectors, which can be attributed to equal contributions from the flow magnitude and flow angle decorrelation. We study fluctuations of mean transverse momentum per particle ($[p_T]$) in ultra-central collisions and show that our model can explain the steep fall of its variance observed by the ATLAS collaboration. We also present robust predictions for the skewness and kurtosis, and highlight the role of impact parameter fluctuations in ultracentral collisions. We study the Pearson correlation coefficients between $[p_T]$ and v_n^2, which can map the initial state correlations between the shape and size of the fireball. We show that higher order normalized and symmteric cumulants between these observables can be constructed, which put useful additional constraints on the initial state properties. Furthermore, we study the momentum dependent Pearson correlation between $[p_T]$ and the transverse momentum dependent flow. It shows sensitivity to the Gaussian width of the nucleon at the initial state. Finally, we show that such correlations and fluctuations of collective observables can be used to study nuclear deformation and put robust constraints on their deformation parameters through high energy nuclear collisions. The research presented in this thesis has significantly contributed to the advancement of the field leaving ample opportunities for further developments in future, which remain beyond its current scope.

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