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Probing the hottest droplet of fluid through correlations and fluctuations of collective observables

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The matter produced in an ultra-relativistic heavy-ion collision, dubbed as the QGP, posses a temperature 10^5 times that of Sun's core and survives for a very short time (10^{-22} s), producing thousands of particles which exhibit collective motion described by some global observables, e.g. charged particle multiplicity(N_{ch}), mean transverse momentum per particle ($[p_T]$), harmonic flow (V_n) etc. Fluctuations and correlations between these observables contain crucial information of the QGP medium as well as of the nuclear properties. We study in hydrodynamic model Pearson correlation coefficient between $[p_T]$ and v_n^2, which serves as an excellent tool to map the correlations present in the initial state. We generalize such correlations to higher order in terms of the normalized symmetric cumulants which put additional useful constraints on the initial state models. To probe p_T-dependent event-by-event fluctuation of V_n, we study factorization breaking coefficient, which shows decorrelation at higher p_T-bins. We study these observables for different centralities and compare our model results with the experimental data. We further our study for the fluctuation of $[p_T]$ in ultra-central Pb+Pb collision and explain the sudden fall in the ATLAS data over a narrow range of multiplicity. We show in our model that this sharp fall is a consequence of the underlying thermalization assumption of the system. We also make further robust predictions for mean, skewness and kurtosis in the ultra-central domain. We also study recently introduced $v_0(p_T)$ which is similar to anisotropic flow in terms of its collective nature and, it correlates the spectra with the event-by-event mean transverse momentum per particle. Furthermore, we study multiplicity in ultra-central p+Pb collision as a function of pseudorapidity, and centrality defined from the energy deposited in a calorimeter, and show that fluctuations of the multiplicity and the centrality estimator are predominantly due to quantum fluctuations, with impact parameter fluctuations playing negligible role. We argue that by repeating the same analysis with a different centrality estimator, direct information can be obtained about the rapidity decorrelation in particle production. Through these above-mentioned studies, we present an overall picture how correlations and fluctuations of the collective observables can be used to study the dynamics and properties of the QGP medium. (arXiv: 2103.15338, 2109.07781, 2303.15323, 2405.14671, 2407.17313)

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