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Elucidating the event-by-event flow fluctuations in heavy ion collisions via the event-shape selection and twisting techniques

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Recent discovery of significant higher-order flow harmonics and theoretical study of the non-linear hydrodynamics have led to the realization of a large set of new event-by-event (EbyE) flow observables that can be measured in heavy-ion collisions. These observables can be expressed generally as a joint probability distribution of flow coefficients v_n and their phases Φ_n, $p(v_n, v_m, ..., \Phi_n, \Phi_m....)$. Initial measurements of a small subset of these flow observables, namely $p(v_n)$ and event-plane correlations $p(\Phi_n, \Phi_m....)$ at LHC, have already provided new insights on the geometry fluctuations in the initial state and the non-linear hydrodynamics in the final state. In a recent work, we propose an experimental method to further probe other flow observables based on the recently proposed event-shape selection technique a new event-shape twisting technique. In the first method (arXiv:1311.7091), events in fixed centrality are further divided in bins of v_n values in the forward pseudorapidity (η_F). This allows us to measure how the v_m and event-plane correlation respond to the change in v_n, which provide access to two classes of observables not studied before: $p(v_n, v_m)$ and $p(v_n, \Phi_n, \Phi_m....)$. Furthermore our method also allows a quantitative study of the correlation of v_n in different rapidity: $p(v_n(\eta_F), v_n(\eta))$. The robustness of this method is demonstrated using the AMPT model, which is known to describe reasonably the centrality dependence of v_n and event-plane correlations. Strong positive correlations are observed among all even harmonics v2, v4, and v6, between v2 and v5 and between v3 and v5, consistent with the effects of non-linear hydrodynamic response, while a significant anti-correlation is observed between v2 and v3. The $v_n(\eta)$ for events selected on $v_n(\eta_F)$ shows a significant forward/backward asymmetry, which indicates the de-correlation of event planes over pseudorapidity. In the second method (paper to be submitted), a twist angle between the event planes in the forward and backward rapidity is enforced by cutting on $\Delta\Phi = \Phi_n(\eta_F) - \Phi_n(\eta_B)$. This twisting procedure leads to a non-zero η-dependence $< \sin(n(\phi - \Psi_n)) >$ component in between, which can be used to calculate the event plane angle as a function of η. This allows us to distinguish between two competing mechanisms for the rapidity de-correlation: a systematic rotation versus a random fluctuation of event plane angles along the η direction. Indeed, a significant fraction of the observed rapidity de-correlation in the AMPT model is found to arise from a systematic rotation of event plane angles along the η direction. Our studies show that the event-shape selection and event-shape twisting techniques promise to provide unprecedented details on the EbyE flow fluctuations. The prospects of applying these techniques to Au+Au/Pb+Pb collisions at RHIC and LHC are discussed.

Author: Mr HUO, Peng (Stony Brook University)

Co-authors: Prof. JIA, Jiangyong (Stony Brook University); Dr MOHAPATRA, Soumya (State University of New York (US))

Presenter: Mr HUO, Peng (Stony Brook University)

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