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A new investigation of hydrodynamic response

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Abstract

In the present work, I would like to study the hydrodynamic response and to present the best estimator of the final transverse momentum distribution by initial distribution.

1 Intorduction

Anisotropic flow [1] is one of the most important probes of ultra-relativistic nucleus-nucleus collisions. Flow phenomena are best modeled with ideal or viscous hydrodynamics. Event-by-event hydrodynamics provides a natural way of studying flow fluctuations. The largest source of uncertainty in these hydrodynamic models is the initial conditions [2]—that is,the state of the system after which it has sufficiently thermalized or isotropized for the hydrodynamic description to be valid. Several models of initial geometry fluctuations have been proposed. The usual procedure is to choose one or two of these simple models for the initial conditions and calculate the resulting flow observables. Significant progress has been made recently by simultaneously comparing to several of the newly-measured flow observables. With this approach, hydrodynamic calculations can be used to rule out a particular model of initial conditions if results do not match experimental data [3]. But it does not tell us why a particular model fails. In order to constrain the initial state directly from data, we need to identify which properties of the initial state determine a given observable. These constraints can then provide valuable guidance in the construction of better, more sophisticated models of the early-time dynamics. The goal of this paper is to improve our understanding of the hydrodynamic response to initial fluctuations. I carry out event-by-event ideal hydrodynamic calculations with realistic initial conditions and then quantitatively compare the final values of v_n with estimates derived from the initial density profile. I are thus able to systematically determine the best estimators of flow observables v_n, $n = 2, 3$ from the initial transverse density profile.

2 Hydrodynamic evolution

In the present work, I use simulated events for ultrarelativistic heavy-ion collisions generated with an event by event (3+1)D viscous hydrodynamics [4]. Hydrodynamic calculations are performed starting from Glauber model initial conditions. I apply the wounded quark model for Pb-Pb collisions at 5.02 TeV center of mass energy[5]. The initial entropy deposition in the transverse plane is given as a sum of contributions from N_p participant nucleons $s(x,y) = \sum_{i=1}^{N_p} \exp\left(-\frac{(x-x_i)^2+(y-y_i)^2}{2\sigma^2}\right)$ in which each nucleon gives a Gaussian-smeared contribution. The azimuthal spatial anisotropies of the initial entropy density profile in the transverse plane are usually characterized by complex eccentricity coefficients [6],

$$\mathcal{E}_{m,n} \equiv \varepsilon_{m,n} e^{in\Phi_{m,n}} = -\frac{\{r^m e^{in\phi}\}}{\{r^m\}}, \tag{1}$$

where $\{\cdots\}$ denotes an average over the transverse plane in a single event. On the other hand, anisotropic flow, which is the hydrodynamic response to the anisotropic initial density profile, is one of the most important observables in relativistic heavy-ion collisions[7]. The azimuthal asymmetry of the final state single-particle distribution,

$$\frac{dN}{d\phi} \propto \sum_{n=-\infty}^{\infty} V_n e^{-in\phi}, \tag{2}$$

is quantified by the complex anisotropic flow coefficients $V_n \equiv v_n e^{in\Phi_n} = \{e^{in\phi}\}$. Solutions to hydrodynamics equations of motion are completely determined once an initial condition is specified. With respect to the fluctuating initial state characterized in terms of initial state eccentricities, the hydrodynamic predictions of harmonic flows are expected as a function of these eccentricities, $V_n = V_n(\mathcal{E}, \alpha)$, where $\mathcal{E}$ denotes a set of initial state eccentricities that are responsible to V_n, while α contains parameters related to the medium dynamical properties, such as the transport coefficient η/s and so on. Although the explicit form of this equation is not known a priori from first-principle calculations, there is mounting evidence from numerical hydrodynamic simulations suggesting that one may expand it for both elliptic flow V_2 and triangular flow V_3, lower order flow harmonics with ignoring nonlinear terms, as following

$$V_2 = K_2(\alpha)\mathcal{E}_2 + \delta_2, \quad V_3 = K_3(\alpha)\mathcal{E}_3 + \delta_3, \tag{3}$$

with respect to the fact that $|\mathcal{E}| < 1$. $K_n(\alpha)$ are the hydro response coefficient which quantifies how much the contribution of V_n comes from the mixing of $\mathcal{E}_n$ in the linear case. Actually, this means that we predict the flow harmonics so that the flow distribution can be estimated by the distribution of initial geometry. The quantity δ_n is the residual, defined as the difference between the flow and terms of eccentricities. Since no known estimator can perfectly predict harmonic flows in every event, people have always been looking for finding the best estimator. If one would like to find the best estimator in the linear case of the lower order flow harmonics can be truncated the expansion of the function $K_n(\alpha)$ at a finite order, so that harmonic flow can be well approximated. On the other hand, I investigate the correlation of flow harmonics with average transverse momentum or multiplicity. Since the transverse momentum and the multiplicity fluctuations from event to event are caused by fluctuations in the initial size of the fireball and are more directly related to a physical situation in the initial state or entropy density, respectively, I consider the effects of initial size $[r^2]$ and entropy density $[s]$ as following

$$K_n(\alpha) = \alpha_n^{(1)} + \alpha_n^{(2)}\varepsilon_m^2 + \alpha_n^{(3)}[r^2] + \alpha_n^{(4)}[s],$$

where all of coefficients $\alpha_n^{(m)}$ are constants. In Ref. [8] authors have used the simple ratio

$$\frac{\langle v_2^4\rangle}{\langle v_2^2\rangle^2} = \frac{\langle K_2(\alpha)^4 \varepsilon_2^4\rangle}{\langle K_2(\alpha)^2 \varepsilon_2^2\rangle^2} \tag{4}$$

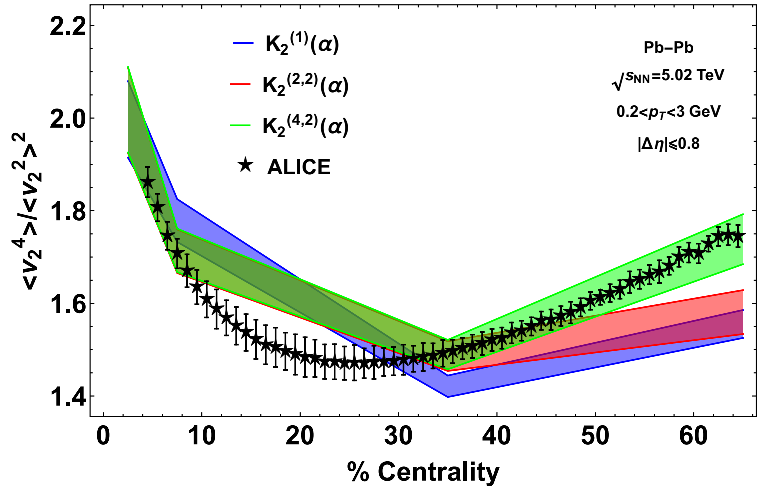

Figure 1: Comparing the different truncations with ALICE data

to compare the estimators of elliptic flow with experimental data as another way to determine the best estimator, where angular brackets denote an average over events in a centrality class. As illustrated in Fig. 1, the results of various truncations are same from central to semiperipheral collisions, but there is the difference between full truncation and others in peripheral collisions so that it can perfectly explain ALICE data [9] in this centrality class. But the agreement with the experimental data is qualitatively correct in other classes. Note that here we chose particles in $|\Delta\eta| < 0.8$, because in the experiment these track selection criteria ensure an optimum rejection of secondary particles and a p_T resolution better than 5% in the p_T range $[0.2, 3]$ GeV [10].

3 Conclusion

I have investigated hydrodynamic response in lower order harmonic flows by considering the effects of initial size and entropy density. The results of this new investigation have good consistency with experimental data.

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