Understanding Initial-State Fluctuations

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1 Introduction

Good understanding of the initial conditions for hydrodynamic evolution of the matter produced in relativistic heavy-ion collisions is essential for a reliable extraction of the properties of the medium, such as its shear viscosity. In event-by-event hydrodynamics, the initial distribution of participants in the azimuthal plane fluctuates from event to event. Although this can be studied in the Monte-Carlo approach, it is important to develop a deeper understanding of the fluctuating initial geometry of the participant zone. To that end, we present here analytic results of the fluctuating eccentricities and their correlations.

Recently, we presented a number of independent flow observables that can be measured using multiparticle azimuthal correlations in heavy-ion collisions [1]. By taking ratios of these observables, we constructed quantities which are insensitive to the hydrodynamic response of the medium, and thus directly probe the initial conditions for the hydrodynamic evolution. In this Poster, we present analytic expressions for these quantities, and compare analytic results with numerical results based on the colour-glass-condensate inspired Monte-Carlo KLN model [2].

2 Analytic Results

We define the dipole asymmetry ε_1, eccentricity ε_2 and triangularity ε_3 as [3],

$$\varepsilon_1 e^{i\Psi_1} \equiv -\frac{\{r^3 e^{i\varphi}\}}{\{r^3\}}, \qquad \varepsilon_2 e^{2i\Psi_2} \equiv -\frac{\{r^2 e^{2i\varphi}\}}{\{r^2\}}, \qquad \varepsilon_3 e^{3i\Psi_3} \equiv -\frac{\{r^3 e^{3i\varphi}\}}{\{r^3\}}.$$

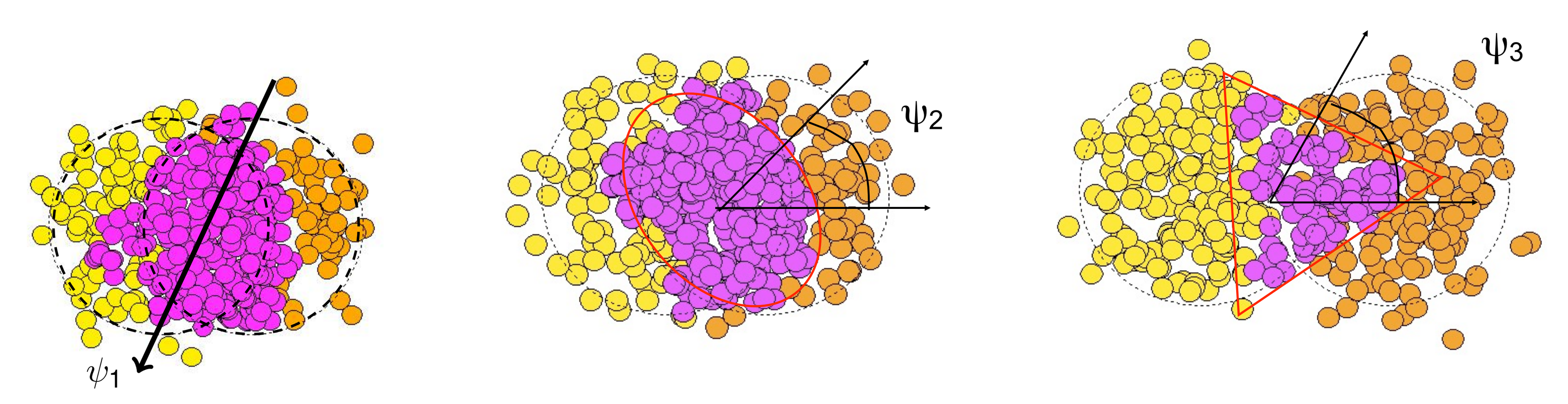

Figure 1: Dipole asymmetry, eccentricity and triangularity (courtesy B. Alver).

Here curly brackets denote an average over the transverse plane in a single event, weighted by the density at midrapidity, and the distribution is centered in each event, $\{re^{i\varphi}\} = 0$. These Fourier harmonics of the initial-state geometry have been shown to largely determine the flow coefficients v_1, v_2 and v_3, respectively, in hydrodynamic calculations, and so are of significant theoretical interest. In analogy with the experimentally measured elliptic flows $v_2\{2\}$ and $v_2\{4\}$, one defines

$$\varepsilon_n\{2\}^2 = \langle \varepsilon_n^2 \rangle \quad \text{and} \quad \varepsilon_n\{4\}^4 = 2\langle \varepsilon_n^2 \rangle^2 - \langle \varepsilon_n^4 \rangle,$$

as the corresponding measures of the initial eccentricity [4]. Angular brackets denote an average over events in a centrality class. The correlations among the orientation angles are defined as

$$\begin{aligned}
\varepsilon_{12} &= \langle \varepsilon_1^2\, \varepsilon_2\, \cos 2(\Psi_1 - \Psi_2) \rangle, \\
\varepsilon_{23} &= \langle \varepsilon_2^3\, \varepsilon_3^2\, \cos 6(\Psi_2 - \Psi_3) \rangle, \\
\varepsilon_{13} &= \langle \varepsilon_1^3\, \varepsilon_3\, \cos 3(\Psi_1 - \Psi_3) \rangle, \\
\varepsilon_{123} &= \langle \varepsilon_1\, \varepsilon_2\, \varepsilon_3\, \cos(\Psi_1 + 2\Psi_2 - 3\Psi_3) \rangle.
\end{aligned}$$

We consider fluctuations in the centre-of-mass of the participant distribution to order six. In an independent-source model, expressions for $\varepsilon_2\{2\}$, $\varepsilon_2\{4\}$ were derived in [4] and [5], respectively. In the present work, we have derived expressions for $\varepsilon_1\{2\}$, $\varepsilon_3\{2\}$, $\varepsilon_3\{4\}$, and various correlations among the orientation angles Ψ_1, Ψ_2 and Ψ_3. For brevity we present the leading-order expressions for the case of central collisions. (Figures, however, are based on more complete expressions.)

$$\begin{aligned}
\varepsilon_1\{2\}^2 &= \frac{1}{N\langle r^3\rangle^2}\left[\langle r^6\rangle - 4\langle r^2\rangle\langle r^4\rangle + 4\langle r^2\rangle^3\right], \\
\varepsilon_3\{2\}^2 &= \frac{\langle r^6\rangle}{N\langle r^3\rangle^2}, \\
\varepsilon_3\{4\}^4 &= \frac{1}{N^3}\left[\frac{2\langle r^6\rangle^2 - \langle r^{12}\rangle}{\langle r^3\rangle^4} + \frac{8\langle r^6\rangle\langle r^9\rangle}{\langle r^3\rangle^5} - \frac{8\langle r^6\rangle^3}{\langle r^3\rangle^6}\right], \\
\varepsilon_{12} &= \frac{1}{N^2}\left[\frac{4\langle r^4\rangle^2 - \langle r^8\rangle}{\langle r^2\rangle\langle r^3\rangle^2} + \frac{8\langle r^2\rangle^3 + 4\langle r^6\rangle - 16\langle r^2\rangle\langle r^4\rangle}{\langle r^3\rangle^2}\right], \\
\varepsilon_{23} &= \mathcal{O}(1/N^4) \quad \text{or smaller}, \\
\varepsilon_{123} &= \frac{1}{N^2}\left[\frac{2\langle r^6\rangle - 6\langle r^2\rangle\langle r^4\rangle}{\langle r^3\rangle^2} + \frac{3\langle r^4\rangle^2 - \langle r^8\rangle}{\langle r^2\rangle\langle r^3\rangle^2}\right].
\end{aligned}$$

3 Numerical Results

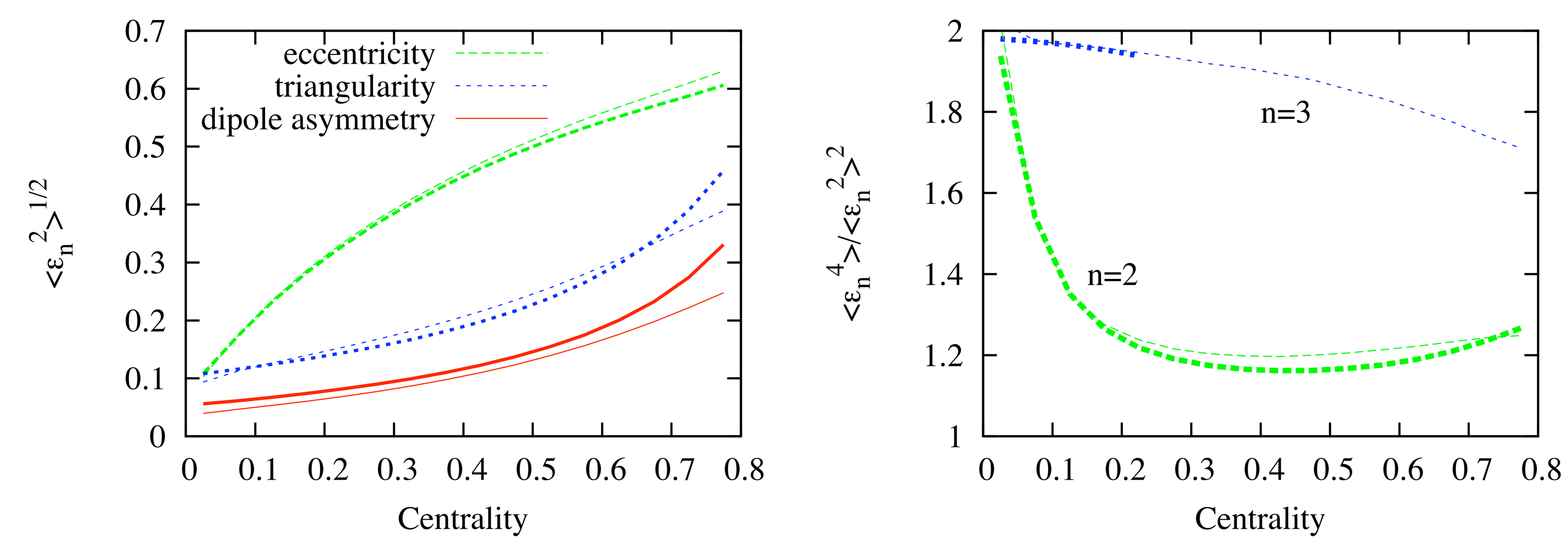

Figure 2: Pb-Pb collisions at 2.76 TeV per nucleon pair. Thin lines: Monte-Carlo KLN [2]. Thick lines: Analytic results to $\mathcal{O}(1/N)$.

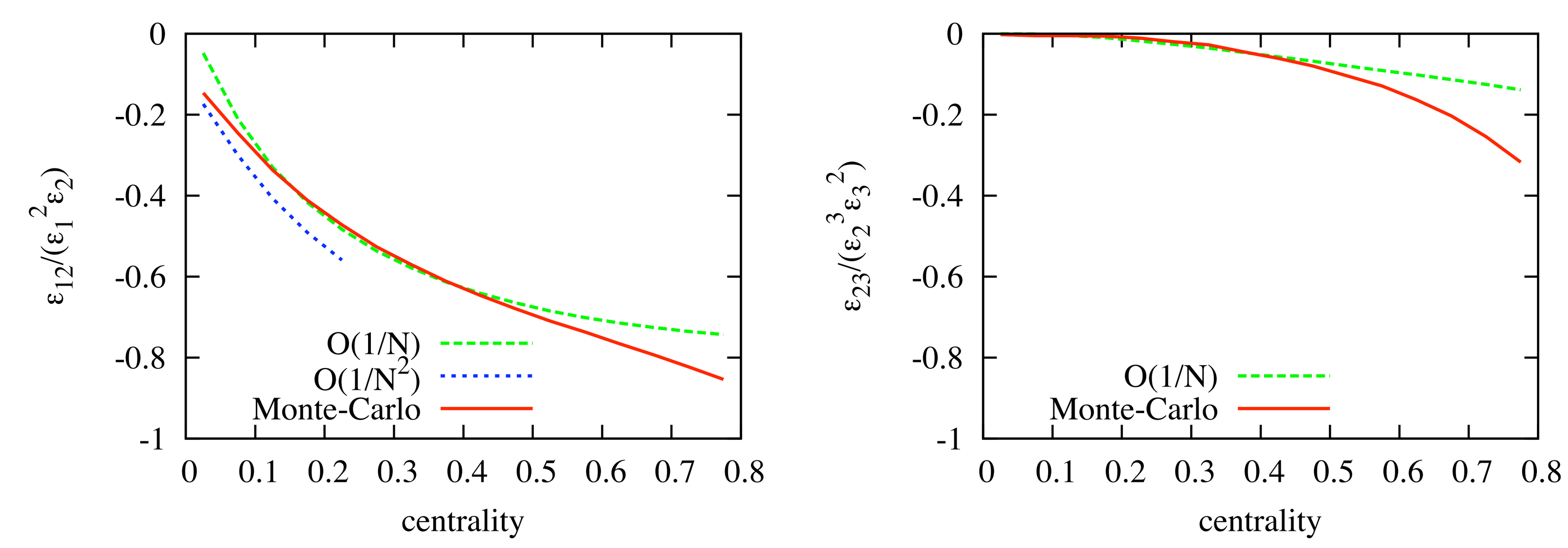

Figure 3: Pb-Pb collisions at 2.76 TeV per nucleon pair. Red: Monte-Carlo KLN [2]. Green and blue: Analytic results. ε_n in the denominator stands for $\varepsilon_n\{2\}$.

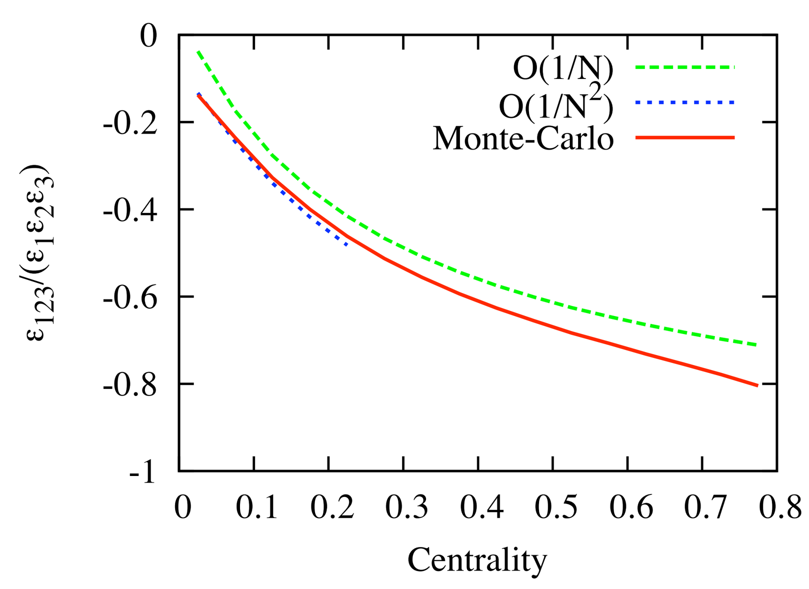

Figure 4: Same as Fig. 3.

We thus find that the independent-source model (with $N \simeq N_{part}/2$) explains many of the features seen in the Monte-Carlo KLN model, and thus provides insight into the fluctuations seen in heavy-ion collisions. More details will be presented in [6].

References

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