Glauber-based evaluations of the odd moments of the initial eccentricity relative to the even order participant planes

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Monte Carlo simulations are used to compute the centrality dependence of the odd moments of the initial eccentricity ε_{n+1}, relative to the even order (n) participant planes Ψ^*_n in Au+Au collisions. The results obtained for two models of the eccentricity – the Glauber and the factorized Kharzeev-Levin-Nardi (fKLN) models – indicate magnitudes which are essentially zero. They suggest that a possible correlation between the orientations of the the odd and even participant planes (Ψ^*_{n+1} and Ψ^*_n respectively), do not have a significant influence on the calculated eccentricities. An experimental verification test for correlations between the orientations of the the odd and even participant planes is also proposed.

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The magnitude and fluctuations of the initial eccentricity of the collision zone, has proven to be an essential ingredient in ongoing efforts to extract the transport properties of the quark gluon plasma (QGP) [1–29]. Experimental measurements of this eccentricity have not been possible to date. The necessary theoretical estimates can be obtained from Glauber-based models [30, 31] via the two-dimensional profile S of the density of sources in the transverse plane $\rho_s(\mathbf{r}_\perp)$ of the overlap collision geometry specified by the impact parameter b, or the number of participants $N_{\rm part}$ [18, 30, 32–40]:

$$S_{nx} \equiv S_n \cos(n\Psi^*_n) = \int d\mathbf{r}_\perp \rho_s(\mathbf{r}_\perp)\omega(\mathbf{r}_\perp)\cos(n\phi), \quad (1)$$

$$S_{ny} \equiv S_n \sin(n\Psi^*_n) = \int d\mathbf{r}_\perp \rho_s(\mathbf{r}_\perp)\omega(\mathbf{r}_\perp)\sin(n\phi), \quad (2)$$

$$\Psi^*_n = \frac{1}{n}\tan^{-1}\left(\frac{S_{ny}}{S_{nx}}\right), \quad (3)$$

where ϕ is the azimuthal angle of each source, the weight $\omega(\mathbf{r}_\perp) = \mathbf{r}_\perp{}^2$, Ψ^*_n is the azimuth of the rotation angle for the minor axis of the n-th harmonic of the shape profile, and

$$\varepsilon^*_n = \langle \cos n(\phi - \Psi^*_n)\rangle\,,$$
$$\varepsilon_n = \langle \cos n(\phi - \Psi^*_m)\rangle\,,\ n \neq m \quad (4)$$

are the n-th order moments of the eccentricity obtained relative to Ψ^*_n and Ψ^*_m respectively [34, 37, 41]; the brackets denote averaging over sources, as well as events belonging to a particular centrality or impact parameter range.

For such estimates, the geometric fluctuations associated with the positions of the nucleons are a primary source of the initial eccentricity fluctuations. That is, for a given centrality, the fluctuating positions of the participant nucleons lead to event-by-event fluctuations of the so-called participant planes (Ψ^*_n) about the reaction plane, defined by the beam direction and the impact parameter. An obvious consequence of these fluctuations is that the participant eccentricities ε^*_n are larger than the so-called standard eccentricities, evaluated relative to the reaction plane. The difference between the standard and participant eccentricities is of course centrality dependent and can be relatively sizable for central and peripheral collisions.

Trivial auto-generated correlations are also inherent in Glauber-based models. Such correlations stem from the fact that a single nucleon from nucleus A "wounds" several nucleons from nucleus B, when the two collide. Thus, a certain degree of clustering or correlations between the locations of "wounded" nucleons is expected to be generated in collisions. These correlations are tantamount to a decrease in the effective number of sources in the collision zone, so they are expected to lead to a small [centrality dependent] increase in the magnitudes for ε^*_n. The scaled fluctuations $\Delta\varepsilon^*_n/\varepsilon^*_n$ show a more complicated centrality dependence but are insensitive to the correlations in the most central events [34]. Another potential influence of the auto-generated correlations is that they could induce a correlation between the participant planes for the even (Ψ^*_n) and odd (Ψ^*_{n+1}) eccentricity moments (especially in peripheral events) and hence, influence their relative magnitudes. Thus, an important question is the degree to which such correlations influence the extracted values for ε^*_n (for odd and even n) [42]?

A simple approach to evaluate this influence, is to compute the odd eccentricity moments $\varepsilon_{3,5,...}$ with respect to the even order participant planes $\Psi^*_{2,4,...}$. Here, the essen-

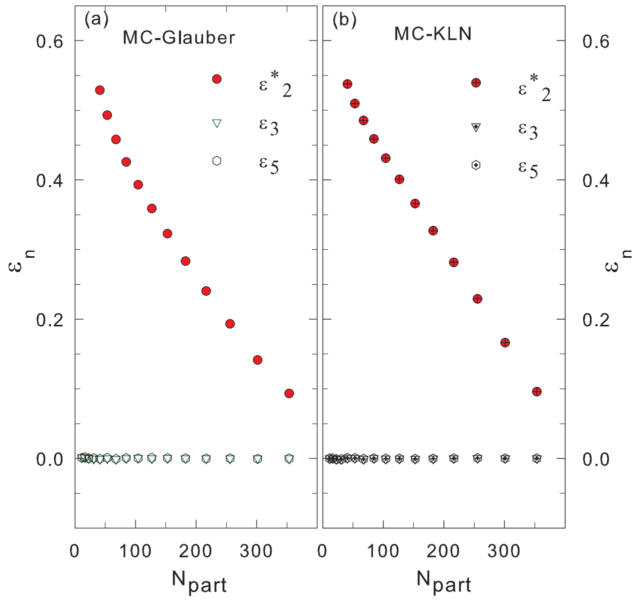

FIG. 1. Comparison of ε_2^* and $\varepsilon_{3,5}$ vs. $N_{\rm part}$, for Au+Au collisions. The odd eccentricity moments are evaluated with respect to the Ψ_2^* participant plane. The open and filled symbols show the results from MC-Glauber and MC-KLN as indicated.

tial point is that, a significant correlation between Ψ_2^* and $\Psi_{3,5,}^*$ [for example] should lead to sizable values for $\varepsilon_{3,5}$. On the other hand, if the computed values for $\varepsilon_{3,5,...} \approx 0$ then, for all intent and purposes, Ψ_n^* and Ψ_{n+1}^* can be considered to be uncorrelated, as has been claimed in several recent papers (see for example Refs. [39–41, 43]).

Monte Carlo calculations were performed following the implementation scheme outlined in Refs. [37, 41] for the Glauber (MC-Glauber) [30, 32] and the factorized Kharzeev-Levin-Nardi (MC-KLN) models [31, 44]. A subset of the results from these calculations is shown in Fig. 1; it shows calculated values for ε_2^* vs. $N_{\rm part}$ and $\varepsilon_{3,5}$ vs. $N_{\rm part}$ for Au+Au collisions. The reader is reminded here that both ε_2^* and $\varepsilon_{3,5}$ are computed relative to the Ψ_2^* participant plane.

The open symbols in Fig. 1 indicate that the values for the odd moments, obtained for both MC-KLN and MC-Glauber, remain flat as a function of collision centrality and are essentially equal to zero. Here, it is noteworthy that the event-by-event fluctuations of $\Psi_{3,5}^*$ about Ψ_2^* lead to a broad distribution of $\varepsilon_{3,5}$ values which range from negative to positive values. Thus, when averaged over events, they give magnitudes ≈ 0. Note as well that these magnitudes are minuscule when compared to the participant eccentricities $\varepsilon_{3,5}^*$ (calculated with respect to Ψ_3^* and Ψ_5^* respectively) reported in Ref. [41]. A similarly small magnitude was obtained for $\varepsilon_{3,5}$ when evaluated with respect to the even higher-order participant planes Ψ_n^* (eg. Ψ_4^*). These results show that our eccentricity evaluations suffer little, if any, influence from possible correlations between the odd and even participant planes.

The magnitudes and trends for ε_n^* are expected to influence the magnitude and trends for anisotropic flow [13, 37–41, 43, 45, 46], characterized by the Fourier coefficients v_n^*. Consequently, our approach can be used to perform actual experimental tests for correlations between the odd and even participant planes. That is, an experimental estimate can be obtained by measuring the Fourier coefficients v_{n+1} (v_n) with respect to the Ψ_n^* (Ψ_{n+1}^*) participant planes.

In summary, we have presented results for the odd initial eccentricity moments ε_{n+1}, determined relative to the even order Ψ_n^* planes for Au+Au collisions, for two primary models. The calculated values of ε_{n+1} are found to be essentially zero, indicating the absence of any significant influence from a possible correlation between the odd and even order participant planes, inherent in Glauber-based models. This finding reaffirms earlier conclusions that, for eccentricity evaluations, the odd and even order participant planes (Ψ_n^* and Ψ_{n+1}^*) can be taken to be uncorrelated. It remains to be seen whether these findings are supported by actual experimental measurements.

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