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EVENT-BY-EVENT ELLIPTIC FLOW FLUCTUATIONS FROM PHOBOS*

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Recently PHOBOS has focused on the study of fluctuations and correlations in particle production in heavy-ion collisions at the highest energies delivered by the Relativistic Heavy Ion Collider (RHIC). In this report, we present results on event-by-event elliptic flow fluctuations in Au + Au collisions at $\sqrt{s_{\rm NN}}$ =200 GeV. A data-driven method was used to estimate the dominant contribution from non-flow correlations. Over the broad range of collision centralities, the observed large elliptic flow fluctuations are in agreement with the fluctuations in the initial source eccentricity.

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1. Introduction

The collective flow of produced particles, as measured by their azimuthal anisotropy, is a sensitive probe of the dynamics in heavy-ion collisions. When two nuclei collide with non-zero impact parameter, the initial spatial anisotropy of the overlapping region leads to a momentum anisotropy in the final state, provided that the system evolution from very early times proceeds via significant re-interactions between produced particles [1]. This final state momentum anisotropy can be quantified by the coefficients of the Fourier expansion of the azimuthal angle distributions measured with respect to the reaction plane. The coefficient of the second Fourier harmonic, v_2, the magnitude of elliptic flow, has been extensively studied in different collision systems and over a wide range of energy and collision centrality. At RHIC [2], large elliptic flow signals were found to be comparable in strength to the predictions of hydrodynamic models using Glauber initial conditions with negligible viscosity [3, 4]. RHIC results, combined with their consistency with the relativistic hydrodynamics lead to the discovery of a strongly coupled quark–gluon plasma with properties resembling those of a near-perfect fluid. A hydrodynamic description provides also a quantitative connection between initial spatial and final momentum anisotropy. Additional validation of this description can be obtained from the study of event-by-event fluctuations in v_2 and their relation to the event-by-event fluctuations in the initial spatial anisotropy.

In these proceedings we report on the PHOBOS measurements of elliptic flow fluctuations obtained from high-statistics data on Au + Au collisions at $\sqrt{s_{\rm NN}} = 200$ GeV [5,6]. The analysis methods used to determine elliptic flow fluctuations and to estimate the dominant part of the non-flow correlations rely crucially on the unique angular coverage of the PHOBOS detector [7], spanning more than ten units in pseudorapidity over the full azimuth.

2. Fluctuations in the collision geometry

The spatial anisotropy associated with the off-center collision of two nuclei can be characterized by the eccentricity of the overlap region in the plane (x, y), transverse to the beam axis. PHOBOS has introduced the notion of the participant eccentricity [8], $\epsilon_{\rm part}$, which takes into account the fluctuations in the positions of participant nucleons:

$$\epsilon_{\rm part} \equiv \frac{\sqrt{(\sigma_y^2 - \sigma_x^2)^2 + 4(\sigma_{xy})^2}}{\sigma_y^2 + \sigma_x^2}\,, \qquad (1)$$

where σ_x^2 and σ_y^2 are variances of the nucleon distributions in the transverse plane and $\sigma_{xy} = \langle xy \rangle - \langle x \rangle \langle y \rangle$. The covariance term σ_{xy} assures that even for the most central collisions the initial eccentricity is finite. Its importance is particularly essential for small collision systems for which the fluctuations in the nucleon positions are sizable. A Monte Carlo Glauber model (MCG) [9] was used to compute $\epsilon_{\rm part}$ on an event-by-event basis for Au + Au and Cu + Cu collisions. It has been shown [8] that the elliptic flow scaled by participant eccentricity, $v_2/\epsilon_{\rm part}$, is very similar for both collision systems (see Fig. 1).

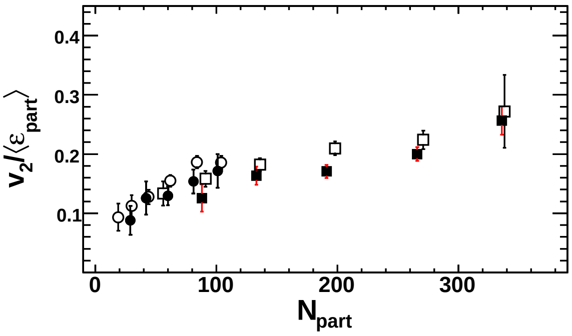

Fig. 1. $v_2/\epsilon_{\rm part}$ *versus* $N_{\rm part}$, for Cu + Cu (circles) and Au + Au (squares) collisions at $\sqrt{s_{\rm NN}} = 200$ (open symbols) and 62.4 GeV (filled symbols). v_2 is shown in $|\eta| < 1$. Bars represent 1σ statistical errors.

The MCG model was also used to calculate event-by-event fluctuations of $\epsilon_{\rm part}$. The magnitude of relative fluctuations, $\sigma_{\epsilon_{\rm part}}/\langle\epsilon_{\rm part}\rangle$, are found to be large, of the order of 30–50%. In the hydrodynamic scenario similarly large fluctuations in the elliptic flow should be observed, $\sigma_{\epsilon_{\rm part}}/\langle\epsilon_{\rm part}\rangle \approx \sigma_{v_2}/\langle v_2\rangle$.

3. Elliptic flow fluctuations

Previous PHOBOS elliptic flow measurements were obtained after averaging over large samples of events within a given centrality bin. For the measurement of elliptic flow fluctuations, v_2 is estimated on an event-by-event basis from a maximum likelihood fit to the hit distribution recorded in the PHOBOS multiplicity array covering pseudorapidity range $|\eta| < 5.4$ [7]. More specifically the likelihood function is defined for each event as:

$$L(v_2, \psi_2) \equiv \prod_{i=1}^{n} P(\phi_i, \eta_i | v_2, \psi_2)\,, \tag{2}$$

where the parameters are v_2, the elliptic flow at $\eta = 0$ and ψ_2, the event plane angle. $P(\phi_i, \eta_i | v_2, \psi_2)$ is the probability density function for a hit position (ϕ_i, η_i) recorded in a given event. This likelihood function is maximized by varying parameters v_2 and ψ_2, giving v_2^{obs} and ψ_2^{obs} for each event. Monte Carlo simulated events with fixed magnitude of flow are used to determine the response function containing both the statistical fluctuations and detector effects. The response function $K(v_2^{\mathrm{obs}}, v_2)$ gives the expected v_2^{obs} distribution for events with fixed true flow. The dependency of the response function on the event multiplicity was also taken into account. The measured (v_2^{obs}) and true v_2 distributions are related by:

$$g(v_2^{\mathrm{obs}}) = \int K(v_2^{\mathrm{obs}}, v_2) f(v_2) dv_2\,. \tag{3}$$

The true v_2 distribution, $f(v_2)$, is assumed to be Gaussian with two parameters, $\langle v_2 \rangle$ and σ_{v_2}. For a given set of these parameters, the expected v_2^{obs} distribution can be computed. The final values of $\langle v_2 \rangle$ and σ_{v_2} parameters are set by a maximum likelihood fit to the expected and measured v_2^{obs} distributions. These are shown in Fig. 2 as a function of N_{part} and compared to the previous PHOBOS measurements of $\langle v_2 \rangle$ obtained with the event-plane method. The consistency between the elliptic flow signals obtained with the two different methods validates out current approach. For more details see Ref. [5, 6].

The above described method gives elliptic flow fluctuations which include both dynamical fluctuations of v_2 and non-flow correlations due to resonance decays, HBT quantum mechanical effects and correlations associated with the jet or mini-jet production. To disentangle the two is not an easy task. PHOBOS has used a data-driven method to extract the dominant part of the non-flow component, characterized by the short-range rapidity correlations. The method uses the second Fourier coefficient of the two-particle correlations measured over a wide range in $\Delta\eta = \eta_1 - \eta_2$ [10]. This coefficient,

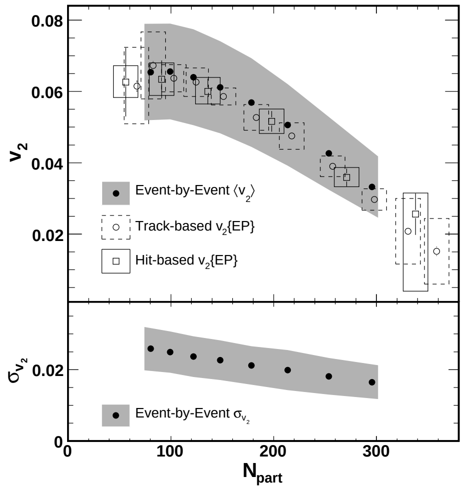

Fig. 2. (top) v_2 *versus* $N_{\rm part}$ for Au + Au collisions at $\sqrt{s_{\rm NN}} = 200$ from the event-by-event method (filled circles) compared to previous PHOBOS results obtained from the event-plane method (open symbols). (bottom) σ_{v_2} *versus* $N_{\rm part}$. Boxes and gray bands show 90% C.L. systematic errors.

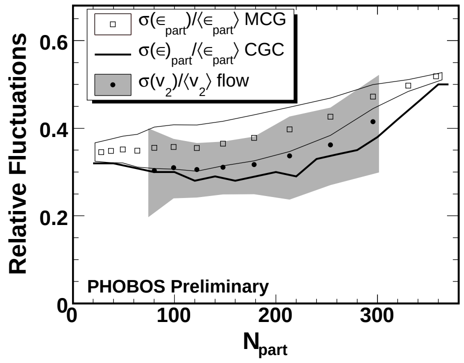

Fig. 3. Relative flow fluctuations, corrected for the non-flow effects, compared to the relative fluctuations of the initial eccentricity calculated from MCG and CGC models. The bands show 90% C.L. systematic errors.

$v_2^2(\eta_1, \eta_2)$, contains contributions from genuine flow correlations and a non-flow term, $\delta(\eta_1, \eta_2)$. It is possible, under the assumption that at large $\Delta\eta$, the non-flow component is negligible, to extract the genuine flow component from the two-particle correlations measured at $\Delta\eta > 2$, and then estimate the non-flow contribution, $\delta(\eta_1, \eta_2)$, by subtracting the genuine flow component from $v_2^2(\eta_1, \eta_2)$. The contribution from non-flow correlations to $\sigma(v_2)$ is $\sqrt{\langle\delta\rangle/2}$ [11]. The non-flow contribution extracted from the data is large, of the order of 25–30%. The relative flow fluctuations, after subtracting the non-flow contribution, are shown in Fig. 3 and compared to the relative fluctuations of the initial eccentricity calculated from MCG [9] and Color Glass Condensate (CGC) [12] models. It can be seen that the magnitude of the relative flow fluctuations agree, within the errors, with both MCG and CGC calculations of the fluctuations in initial source eccentricity, leaving essentially no room for other, later-stage contributions.

4. Summary

In this report we have presented results on event-by-event elliptic flow fluctuations, corrected for the dominant component of non-flow effects extracted from data, for $\mathrm{Au}+\mathrm{Au}$ collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV. This non-flow component was estimated under the assumption that it is negligible at large $\Delta\eta$. Although non-flow correlations contribute significantly to the measured flow fluctuations, the corrected relative flow fluctuations are large, with a magnitude in agreement with calculations of fluctuations in the participant eccentricity. These results indicate that system thermalizes very rapidly and the initial-state event-by-event source fluctuations are efficiently converted into final-state momentum fluctuations.

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