System size, energy and pseudorapidity dependence of directed and elliptic flow at RHIC

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PHOBOS measurements of elliptic flow are presented as a function of pseudorapidity, centrality, transverse momentum, energy and nuclear species. The elliptic flow in Cu-Cu is surprisingly large, particularly for the most central events. After scaling out the geometry through the use of an alternative form of eccentricity, called the participant eccentricity, which accounts for nucleon position fluctuations in the colliding nuclei, the relative magnitude of the elliptic flow in the Cu-Cu system is qualitatively similar to that measured in the Au-Au system.

1. Introduction

The characterization of the collective flow of produced particles by their azimuthal anisotropy has proven to be one of the more fruitful probes of the dynamics of heavy ion collisions at RHIC. In particular, differential flow measurements provide information crucial in constraining three-dimensional hydrodynamic models of relativistic heavy ion collisions.

This work presents new results on data taken by the PHOBOS experiment at RHIC showing a detailed comparison of differential measurements of flow across species. The data were taken with the PHOBOS experiment at RHIC during Au-Au and Cu-Cu collisions ranging over an order of magnitude in collision energy. The PHOBOS detector employs silicon pad detectors to perform tracking, vertex detection and multiplicity measurements. Details of the setup and the layout of the silicon sensors can be found elsewhere [1]. The Au-Au data shown here are from previous work [2][3]. The presented Cu-Cu data are analyzed in a similar fashion.

2. Results

PHOBOS has recently completed measurements of the directed flow signal, v_1, as a function of pseudorapidity (η) in Au-Au collisions at $\sqrt{s_{_{NN}}}$ =200, 130, 62.4 and 19.6 GeV. These measurements were performed with the standard subevent technique described in reference [4] and confirmed with a mixed harmonic method [5]. The directed flow signal exhibits extended longitudinal scaling in a fashion analogous to that seen in the elliptic

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[*]For the full list of PHOBOS collaborators and acknowledgments, see the appendix ‘Collaborations’ of this volume.

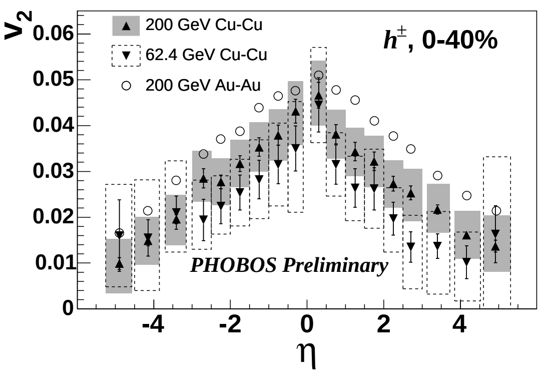

Figure 1. v_2 vs. η for Cu-Cu collisions at $\sqrt{s_{NN}}$ =200 and 62.4 GeV. The boxes show the 90% C.L. systematic errors and the bars represent the 1-σ statistical errors. Previously published Au-Au data (without error bars) is shown for comparison.

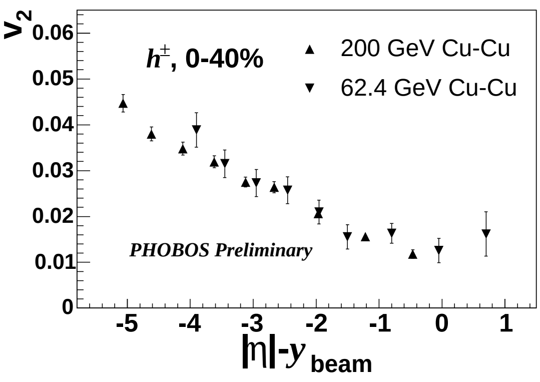

Figure 2. v_2 vs. $|\eta|-y_{beam}$ for Cu-Cu collisions at $\sqrt{s_{NN}}$ =200 and 62.4 GeV. Only statistical errors are shown.

flow [2]. These results are presented in reference [6].

Figure 1 shows the elliptic flow signal, v_2, as a function of η in Cu-Cu collisions at $\sqrt{s_{NN}}$ =200 and 62.4 GeV for the 40% most central collisions. The resemblance to published Au-Au results (also shown in Figure 1) is striking [2]. The Cu-Cu system also exhibits extended longitudinal scaling, as shown in Figure 2, and as already seen in Au-Au collisions [2]. The centrality dependence of v_2 is presented in Figure 3. Substantial flow is present in the Cu-Cu signal for even the most central events.

In order to compare flow signals across nuclear species it is important to scale out the difference in the initial geometric asymmetry of the collision, i.e., the eccentricity of the collision. This is crucial since for a selected centrality range, the average eccentricity depends on the size of the colliding species. Typically, the eccentricity is defined by relating the impact parameter of the collision in a Glauber model simulation to the eccentricity calculated assuming the minor axis of the overlap ellipse to be along the impact parameter vector. Thus, if the x-axis is defined to be along the impact parameter vector and the y-axis perpendicular to that in the transverse plane, the eccentricity is determined by $\varepsilon = \frac{\sigma_y^2-\sigma_x^2}{\sigma_y^2+\sigma_x^2}$, where σ_x and σ_y are the RMS widths of the participant nucleon distributions projected on the x and y axes, respectively. Let us call the eccentricity determined in this fashion $\varepsilon_{\text{standard}}$.

For small systems or small transverse overlap regions, fluctuations in the nucleon positions frequently create a situation where the minor axis of the ellipse in the transverse plane formed by the participating nucleons is not along the impact parameter vector. One way to address this issue is to make a principal axis transformation, rotating the x and y axes used in the eccentricity definition in the transverse plane in such a way that σ_x is minimized. Let us call the eccentricity determined in this fashion $\varepsilon_{\text{part}}$. In terms of the

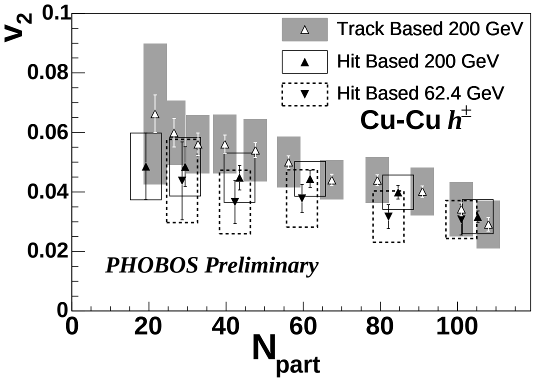

Figure 3. v_2 vs. N_{part} for Cu-Cu collisions at $\sqrt{s_{NN}}$ =200 and 62.4 GeV. The boxes show the 90% C.L. systematic errors and the lines represent the 1-σ statistical errors. The results from two analysis methods are shown, similar to those presented in [2] and [3].

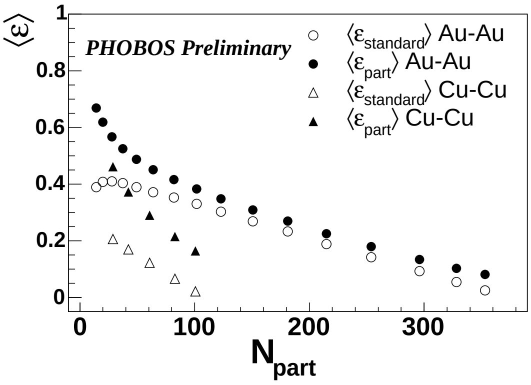

Figure 4. The average eccentricity defined in two ways ($\langle\varepsilon_{\mathrm{standard}}\rangle$ and $\langle\varepsilon_{\mathrm{part}}\rangle$), as described in the text, vs. N_{part} for simulated Au-Au and Cu-Cu collisions at $\sqrt{s_{NN}}$ =200 GeV. Only statistical errors are shown.

original x and y axes (in fact, any pair of perpendicular transverse axes),

$$\varepsilon_{\mathrm{part}} = \frac{\sqrt{(\sigma_y^2 - \sigma_x^2)^2 + 4(\sigma_{xy})^2}}{\sigma_y^2 + \sigma_x^2}. \qquad (1)$$

In this formula, $\sigma_{xy} = \langle xy\rangle - \langle x\rangle\langle y\rangle$. The average values of $\varepsilon_{\mathrm{standard}}$ and $\varepsilon_{\mathrm{part}}$ are quite similar for all but the most peripheral interactions for large species, as is shown in Figure 4 for Au-Au. For smaller species such as Cu, however, fluctuations in the nucleon positions become quite important for all centralities and the average eccentricity can vary significantly depending on how it is calculated. This is also illustrated in Figure 4. It is worth noting that the Glauber model used in these calculations does not include an excluded volume for the nucleons.

3. Summary

The crucial importance of the definition of eccentricity in comparing Au-Au and Cu-Cu results can be seen in Figures 5-6, where various comparisons are made between Au-Au and Cu-Cu data using the eccentricity-scaled elliptic flow. Given the qualitative and quantitative similarities between the results in the Au-Au and Cu-Cu systems when scaled by $\langle\varepsilon_{\mathrm{part}}\rangle$, it seems likely that $\varepsilon_{\mathrm{part}}$ or a rather similar quantity is the relevant eccentricity for the azimuthal expansion. Perhaps more interesting is the fact that these data show that qualitative features attributed to collective effects in Au-Au persist down to the relatively small numbers of participants seen in the Cu-Cu collision and are of comparable magnitude.

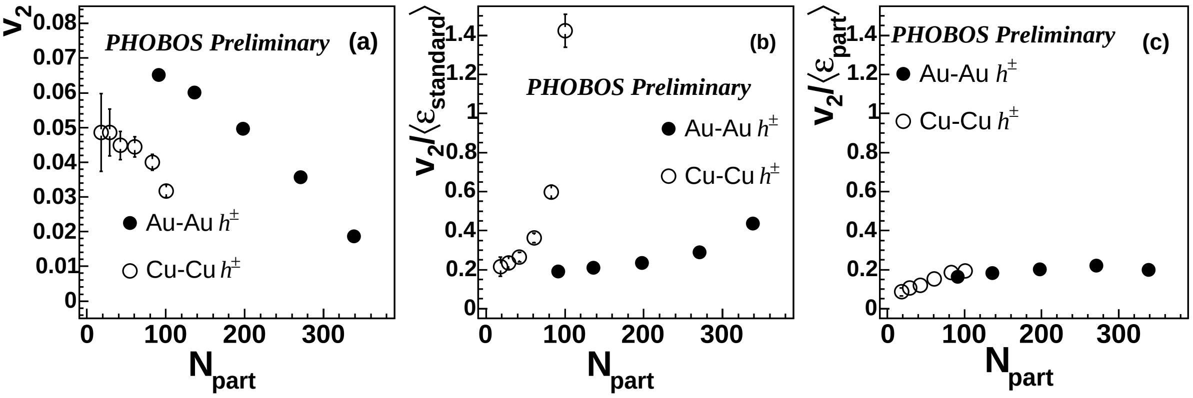

Figure 5. (a) v_2 (unscaled) vs. N_{part}, (b) $v_2/\langle\varepsilon_{standard}\rangle$ vs. N_{part} and (c) $v_2/\langle\varepsilon_{part}\rangle$ vs. N_{part}, for Cu-Cu and Au-Au collisions at $\sqrt{s_{NN}}$ =200 GeV. Only statistical errors are shown.

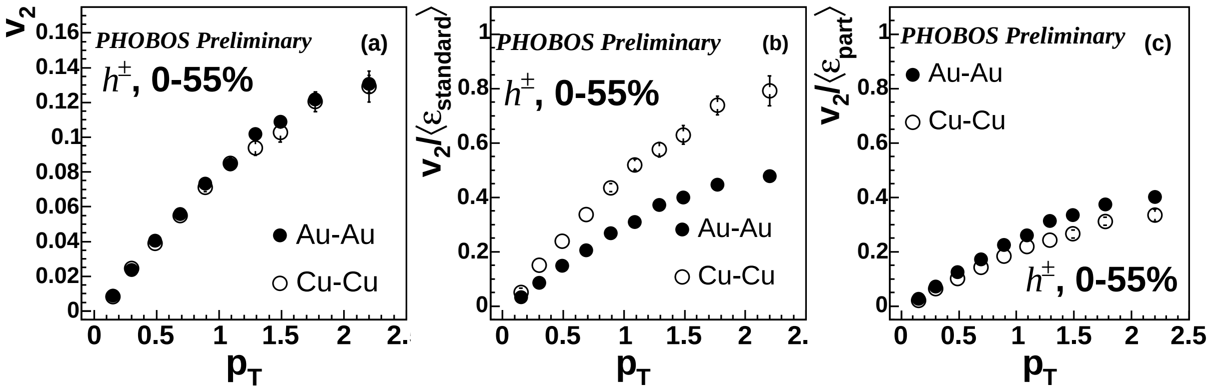

Figure 6. (a) v_2 (unscaled) vs. p_T, (b) $v_2/\langle\varepsilon_{standard}\rangle$ vs. p_T and (c) $v_2/\langle\varepsilon_{part}\rangle$ vs. p_T, for the 55% most central Cu-Cu and Au-Au collisions at $\sqrt{s_{NN}}$ =200 GeV. Only statistical errors are shown.

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