**Energy and system size dependence of elliptic flow: using rapidity gaps to suppress non-flow contribution**

Sergei A. Voloshin and the STAR Collaboration

*Department of Physics and Astronomy, Wayne State University, Detroit, 48201*

**Abstract.** In this talk I present new STAR results on measurements of integrated elliptic flow at midrapidity in Au+Au and Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ and 62 GeV energies. These results have been obtained from azimuthal correlations between particles in the main STAR TPC and two forward TPCs, and are to a large extent free from so-called non-flow correlations. These results along with the previously reported values of “participant” eccentricity taking into account eccentricity fluctuations are used for testing the $v_2/\varepsilon$ scaling, which is found to hold relatively well.

**Keywords:** Elliptic flow, eccentricity, flow fluctuations

**PACS:** 25.75.Ld

**INTRODUCTION**

Anisotropic flow, and, in particular, elliptic flow plays a very important role in the understanding of heavy ion collisions at high energies. Since the discovery of the in-plane elliptic flow at AGS [1], and later at CERN SPS [2], the attention to this phenomena has been continuously increasing. The first RHIC measurements [3] by the STAR Collaboration made it one of the most important observable at RHIC [4]. The large elliptic flow, along with its mass dependence at low transverse momenta [5, 6] are often used as a strong argument for early thermalization of the system; the observed [7] constituent quark scaling [4, 8] of elliptic flow strongly suggests that the system spends significant time in the deconfined state.

In order to understand deeper the physics of the elliptic flow and the processes governing the evolution of the system, one has to measure and understand elliptic flow dependence on the system size and collision energy. Having in mind also the dependence on the centrality of the collision makes the problem indeed 'multi-dimensional'. In [9] the authors suggested that the elliptic flow follows a simple scaling in the initial system eccentricity and the particle density in the transverse plane, $v_2/\varepsilon \propto 1/S \, dN_{ch}/dy$ (where $S$ is the area of the overlap region of two nuclei). If true, all the data taken at different energies, colliding different nuclei, and at different centralities should collapse on the same universal curve. Indeed the available data are consistent with such a scaling [4, 10].

Unfortunately, the systematic uncertainties in the results are too large to conclude on how well the scaling holds. The main difficulties are the evaluation/elimination of the so-called non-flow correlations (azimuthal correlations not related to the reaction plane orientation), and effects of flow fluctuations, along with uncertainties in the calculation of the initial system eccentricity needed for such a plot.
The non-flow contribution is usually suppressed when one uses multi-particle correlations to measure anisotropic flow \([11, 12]\). Unfortunately, multi-particle correlations are sensitive to flow fluctuations in very different way, thus leaving the problem of disentangling of non-flow contribution and flow fluctuations unresolved. An alternative way to suppress non-flow contributions, pursued in this analysis, is the correlation of particles with large rapidity gaps, the main focus of this analysis. In particular we present the results for anisotropic flow at midrapidity measured in the STAR main TPC \((-0.9 < \eta < 0.9)\) from correlations with particles in the two Forward TPCs \((2.9 < |\eta| < 3.9)\). Detailed study of these correlations indicate that in this case the non-flow contribution is suppressed up to about factor of 4-5 compared to the case of particle correlation only in the main TPC region.

The results presented in this talk are based on the analysis (after all event quality cuts) of 5.9 M Au+Au 200 GeV, 7 M Au+Au 62 GeV, 3.5 M Cu+Cu 200 GeV, and 19 M Cu+Cu 62 GeV Minimum Bias events. Centrality of the collision was determined in accordance with the so-called Reference Multiplicity - the multiplicity of primary tracks in \(|\eta| < 0.5\) region. For Au+Au collisions the centrality determination was done directly from data taking into account known vertex reconstruction efficiency. For Cu+Cu collision, where vertex reconstruction efficiency is still under study, the centrality was defined based on Glauber Monte-Carlo calculations (with additional simulation of charged particle production per nucleon participant) matching the experimental distribution at high multiplicities, where the vertex reconstruction efficiency is close to 100%.

Fig. 1 and Fig. 2 presents the results for elliptic flow of charged particles in the pseudorapidity window \(|\eta| < 0.9\), for all four systems studied in this analysis. Charged particles are selected from \(0.15 < p_t < 2.0\) GeV region; the low transverse momentum cut is due to TPC acceptance. In black, noted as \(v_2\{2\}\), are shown the results obtained from two particle azimuthal correlations with both particle from the main TPC region. In blue, noted as \(v_2\{FTP\}\), are the results obtained from correlation with large rapidity gap (correlating particles in the main and Forward TPCs regions). The larger values of \(v_2\{2\}\) compared to \(v_2\{FTP\}\) are attributed to the non-flow contribution. The relative contribution of non-flow in Cu+Cu collisions is significantly larger compared to that in Au+Au collisions due to smaller values of flow itself. Cu+Cu results exhibit also weaker centrality dependence, which can be explained by weaker correlations of Reference Multiplicity and impact parameter.

Besides suppression of non-flow contribution, an adequate treatment of flow fluctuations is essential for understanding the flow dependence on centrality of the collision and the size of colliding nuclei. Usually it is assumed that elliptic flow closely follows initial eccentricity of the system, \(\varepsilon = \langle y^2 - x^2 \rangle / \langle y^2 + x^2 \rangle\). Under this assumption one can estimate flow fluctuations by calculation of eccentricity fluctuations \([12, 13]\), e.g. in Glauber Monte-Carlo model. It was argued \([14, 15]\) that the so-called “participant” eccentricity should be used in this calculations. The corresponding results for the four systems studied in this analysis have been presented in \([15]\), and are used in the current analysis.

The final plots of this presentation, Fig. 3, show how new results fit to the \(v_2/\varepsilon\) scaling. Two plots are made under different assumptions for how strongly flow fluctuations in the main TPC region, \(|\eta| < 0.5\), are correlated with flow fluctuations in the Forward TPC regions \(2.9 < |\eta| < 3.9\). If the fluctuations are totally independent one has to use \(\langle \varepsilon_{part} \rangle\) for
such a plot. This is shown on the left panel. If flow fluctuate coherently in the main TPC region and in Forward TPC regions, one should use $\varepsilon_{\text{part}} \{ 2 \} = \sqrt{\langle \varepsilon_{\text{part}}^2 \rangle}$ for the scaling plot, shown in the right panel. The scaling in latter case is somewhat better. More details on how flow results obtained in different ways should scale with eccentricity can be found in [15]. For the references to other data presented in Fig. 3 see in [10].

Note that for the $v_2/\varepsilon$ scaling plots the results from Figures 1 and 2 have been rescaled/extrapolated to a full transverse momentum coverage using blast wave fits to spectra; rapidity density has been obtained from pseudorapidity density using scaling factors based on HIJING and RQMD calculations. The presented (ideal) hydrodynamic predictions are based on calculations [16]. The curves shown are obtained from hydro results made for fixed impact parameter ($b = 7$ fm) and different particle densities (collision energies). Note that hydro results do not scale perfectly in this plot and in

**FIGURE 1.** Elliptic flow in Au+Au collisions as function of centrality at $\sqrt{s_{NN}} = 200$ and 62 GeV.

**FIGURE 2.** The same as Fig. 1 for Cu+Cu collisions.
FIGURE 3. $v_2/\varepsilon$ scaling plot using $v_2$ [FTP] results and rescaled with $\langle \varepsilon_{\text{part}} \rangle$ (left panel) and $\varepsilon_{\text{part}}$ (right panel).

In general exhibit somewhat flatter centrality dependence at each collision energy.

ACKNOWLEDGMENTS

I thank the organizers for a very interesting and stimulating conference and giving me the opportunity to present our results. Financial support provided by US Department of Energy Grant No. DE-FG02-92ER40713.

REFERENCES

1. J. Barrette et al. [E877 Collaboration], Phys. Rev. Lett. 73, 2532 (1994); J. Barrette et al. [E877 Collaboration], Phys. Rev. C 55, 1420 (1997).
2. H. Appelshauser et al. [NA49 Collaboration], Phys. Rev. Lett. 80, 4136 (1998).
3. K.H. Ackermann et al. [STAR Collaboration], Phys. Rev. Lett. 86, 402 (2001).
4. S. A. Voloshin, Nucl. Phys. A 715, 379 (2003) [arXiv:nucl-ex/0210014].
5. C. Adler et al. [STAR Collaboration], Phys. Rev. Lett. 87, 182301 (2001).
6. P. Huovinen, P. F. Kolb, U. W. Heinz, P. V. Ruuskanen and S. A. Voloshin, Phys. Lett. B 503, 58 (2001); S. A. Voloshin, Phys. Rev. C 55, 1630 (1997).
7. J. Adams et al. [STAR Collaboration], Phys. Rev. Lett. 92, 052302 (2004).
8. D. Molnar and S. A. Voloshin, Phys. Rev. Lett. 91, 092301 (2003).
9. S. A. Voloshin and A. M. Poskanzer, Phys. Rev. C 66, 034904 (2002).
10. M. Miller and R. Snellings, arXiv:nucl-ex/0312008.
11. S. Manly et al. [PHOBOS Collaboration], arXiv:nucl-ex/0510031.