Event anisotropy $v_2$ at STAR

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Abstract

Collective flow reflects the dynamical evolution in high-energy heavy ion collisions. In particular, the elliptic flow reflects early collision dynamics [1]. We present a systematic analysis of elliptic flow ($v_2$) for identified particles measured in Au + Au and Cu + Cu collisions at $\sqrt{s_{NN}} = 200$ GeV. Number of quark scaling is tested in the intermediate $p_T$ region and in the smaller system (Cu + Cu). The Cu + Cu collisions results are compared with those from ideal hydrodynamic model calculations.

1. Introduction

When two nuclei collide in non-central heavy-ion collisions, their overlap area in the transverse plane has a short axis, which is parallel to the impact parameter, and a long axis, which is perpendicular to it. This initial spatial anisotropy of the overlap region of the colliding nuclei is transformed into an anisotropy in momentum space through interactions between the particles. The magnitude of this effect is characterized by elliptic flow, defined as

$$ v_2 = \langle \cos 2(\phi - \Psi_R) \rangle $$ (1)

where $\phi$ is azimuthal angle of an outgoing particle, $\Psi_R$ is the azimuthal angle of the impact parameter, and angular brackets denote an average over many particles and events.

The characterization of the elliptic flow of produced particles by their azimuthal anisotropy has proven to be one of the more fruitful probes of the dynamics in Au + Au collisions at the Relativistic Heavy Ion Collider (RHIC) [2, 3, 4], see recent review in [5, 6, 7]. It can provide much information about the degree of thermalization of the hot and dense medium. A systematic study of the $p_T$ dependence of $v_2$ for different particle species enables investigation of underlying phenomena and the properties of the produced matter.

2. Methods and Analysis

In this proceeding, we report $v_2$ measurements by the STAR experiment from $\sqrt{s_{NN}} = 200$ GeV Au + Au and Cu + Cu collisions. Data were taken from Run 5 (2005) and Run 7 (2007). STAR’s Time Projection Chamber (TPC) [8] is used as the main detector for particle identification and event plane determination. The centrality was determined by the number of tracks from the pseudorapidity region $|\eta| \leq 0.5$. Two Forward Time Projection Chambers (FTPCs) were also used for event plane determinations. The FTPCs cover $2.5 \leq |\eta| \leq 4$. The pseudorapidity gap

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between FTPC and TPC allows us to reduce some of the non-flow effects. In Au + Au collisions, the difference between $v_2$(TPC) (event plane determined by TPC tracks) and $v_2$(FTPC) (event plane determined by FTPC tracks) has been used to estimate the systematic errors, where in Cu + Cu collisions, we used $v_2$(FTPC) for the measurement, $v_{AA-pp}^{2+}$ (FTPC) \[9\] (subtracting the residual non-flow effects based on the azimuthal correlations in $p + p$ collisions) for the systematic study.

The PID is achieved via $dE/dx$ in TPC and topologically reconstructed hadrons: $K^0_S \to \pi^+ + \pi^-$, $\phi \to K^+ + K^-$, $\Lambda \to p + \pi^+$ ($\bar{\Lambda} \to \bar{p} + \pi^-$), $\Xi^- \to \Lambda + \pi^-$ ($\Xi^- \to \bar{\Lambda} + \pi^+$) and $\Omega^- \to \Lambda + K^-$ ($\Omega^- \to \bar{\Lambda} + K^+$). The detailed description of the procedure can be found in Refs. \[10, 11, 12\].

3. Results and Discussions

![Figure 1: The $v_2$ as a function of $p_T$ for $K^0_S$, $\Lambda$ and $\Xi$ in 0 - 60 % (top), 0 - 20 % and 20 - 60 % (bottom) Cu + Cu collisions at $\sqrt{s_{NN}} = 200$ GeV. Dashed lines represent ideal hydrodynamical calculation \[13\].](image)

Results using ideal hydrodynamical calculations \[13\] have been able to reproduce mass ordering of $v_2$ in the low $p_T$ region in Au+Au collisions. Figure 1 shows the $v_2$ for $K^0_S$, $\Lambda$ and $\Xi$ as a function of $p_T$ in different centrality selections for Cu + Cu collisions along with results of hydrodynamical calculations \[14\]. We observe that $v_2$ for $\Lambda$ is smaller than $v_2$ for $K^0_S$ for $p_T < 2$ GeV/c. For $p_T > 2$ GeV/c, $v_2$ for $\Lambda$ becomes larger than that of $K^0_S$. We have also found $\Xi$ has sizable $v_2$ in minimum bias 0 - 60 % centrality. The ideal hydrodynamical model does not describe the centrality dependence of our data. For 0 - 20 %, the model under-predicts the data and for 20 - 60 %, it over-predicts the $v_2$. Effects not included in the model which may be relevant are geometrical fluctuations in the initial conditions (particularly important in central collisions), finite viscosity effects and incomplete thermalization. It remains to be seen if these effects can account for the difference between the models and data.
Quark coalescence [15] or recombination [16] mechanisms in particle production predict that at intermediate $p_T$ (2 GeV/c < $p_T$ < 5 GeV/c) number of quark (NQ) scaled $v_2$ will follow a universal curve. Thus, the NQ scaling is considered evidence for partonic degrees of freedom in Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV [12]. With the large statistics from Run 7, we can test the scaling in the large $p_T$ region. Figure 2 shows the number of quark scaled $v_2$ for identified particles as a function of $(m_T - \text{mass})/n_q$ in Au + Au and Cu + Cu collisions at $\sqrt{s_{NN}} = 200$ GeV. Proton and $\Lambda$ begin to deviate from the NQ scaling when $(m_T - \text{mass})/n_q > 1$ GeV/c$^2$ in the Au + Au case. Scaling behavior can be seen in the smaller system (Cu + Cu) at the same energy.

Figure 2: Number of quark scaling of $v_2$ as a function of $m_T - \text{mass}$ in 0 - 80 % Au + Au (left) and 0 - 50 % Cu + Cu (right) collisions at $\sqrt{s_{NN}} = 200$ GeV. Green and gray bands show non-flow systematic errors for strange hadrons ($(m_T - \text{mass})/n_q > 0.5$ GeV/c$^2$) and $\pi$, $p$ ($(m_T - \text{mass})/n_q > 0.75$ GeV/c$^2$) respectively. PHENIX results were taken from [19].

Figure 3: $v_2$ as function of $p_T$ for $\pi$, $p$ (left) and $\phi$, $\Omega$ (right) in Au + Au minimum-bias collisions at $\sqrt{s_{NN}} = 200$ GeV. Open symbols represent results from PHENIX [17]. Lines represent NQ-inspired fit [18].

Figure 3 shows the $v_2$ for $\phi$ and $\Omega$ together with $v_2$ for $\pi$ and $p$ as a function of $p_T$ in minimum...
bias Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The $p_T$ dependence of $v_2$ for $\pi$ and $p$ is observed to be similar as the corresponding results for $\Omega$ baryons and $\phi$ mesons. This indicates that the heavier s quarks flow as strongly as the lighter u and d quarks, providing evidence for partonic collectivity.

4. Summary

In summary, we present the results from a systematic analysis of the identified particles elliptic flow ($v_2$) measurement from Au + Au and Cu + Cu collisions at $\sqrt{s_{NN}} = 200$ GeV. Ideal hydrodynamic model calculations fail to reproduce the data in Cu + Cu collisions. Proton and $\Lambda$ begin to deviate from the NQ scaling when $(m_T - \text{mass})/n_q > 1$ GeV/$c^2$ in Au + Au collisions; scaling behavior can be seen in the smaller system (Cu + Cu). The fact that the $\phi$ and $\Omega$ $v_2$ ($p_T$) follows a similar trend as that of $\pi$ and $p$ indicates that the heavier s quarks flow as strongly as the lighter u and d quarks suggesting partonic collectivity has been established at RHIC.

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