Forward-rapidity azimuthal and radial flow of identified particles for $\sqrt{s_{NN}}$ = 200 GeV Au+Au collisions

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Abstract

A strong azimuthal flow signature at RHIC suggests rapid system equilibration leading to an almost perfect fluid state. The longitudinal extent of the flow behavior depends on how this state is formed and can be studied by measuring the pseudorapidity and transverse momentum dependence of the second Fourier component ($v_2(p_T)$) of the azimuthal angular distribution. We report on a measurement of identified-particle v_2 as a function of p_t (0.5-2.0 GeV/c), centrality (0-25%, 25-50%), and pseudorapidity ($0 \leq \eta < 3.2$) for $\sqrt{s_{NN}}$ = 200 GeV Au+Au collisions. The BRAHMS spectrometers are used for particle identification (π, K, p) and momentum determination and the BRAHMS global detectors are used to determine the corresponding reaction-plane angles. The results are discussed in terms of the rapidity dependence of constituent quark scaling and in terms of models that develop the complete (azimuthal and radial) hydrodynamic aspects of the forward dynamics at RHIC.

In a non-central collision of two relativistic heavy-ions, strong pressure gradients are set up in the almond-shaped interaction region. Early results from RHIC have shown that this overlap region behaves as an almost perfect fluid, with the greater pressure that exists at the waist of the almond leading to greater particle production near the reaction plane. This azimuthal asymmetry in particle production is characterized by the strength of the second Fourier component (v_2) of an harmonic expansion of the angular distribution. The outward pressure can also lead to an outward radial flow of the streaming particles, giving a velocity boost to these particles. To fully understand the hydrodynamic properties of RHIC collisions, it is necessary to determine the integral and differential v_2 behavior, as well as establish the particle spectra and relative particle yields [1]. By exploring the interplay of elliptic and radial flow at both mid- and forward rapidity, the BRAHMS results better constrain models of the initial conditions and longitudinal extent of the interaction region.

The measurement explores the correlation of charged hadrons and identified particles detected in the two BRAHMS spectrometers with respect to reaction planes deduced using four azimuthally symmetric rings of detectors arranged around the beam line as part of the experiment's multiplicity array [2]. The $v_2(p_T)$ dependence of particles detected in the spectrometers was determined by the standard reaction-plane method [3]. The reaction-plane resolution correction was based on a full GEANT simulation of the BRAHMS experimental response. A pseudoevent generator was used to obtain a particle throw consistent with previously established particle spectra measured using the BRAHMS spectrometers, with the azimuthal asymmetry of the particle throw set to reproduce the PHOBOS integral v_2 results [4]. The correction factor was taken as the ratio of the $v_2(p_T)$ values obtained from the reconstructed events with that input to

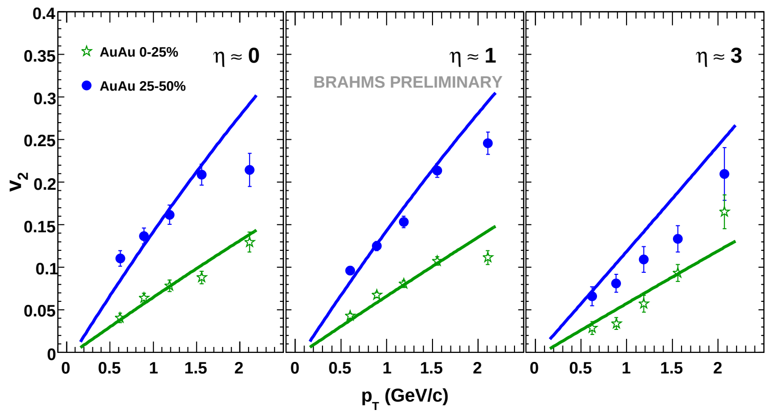

Figure 1: Charge-hadron $v_2(p_T)$ for central and mid-central events for $\eta \approx 0$, 1 and 3. The curves show 3D Hydro+Cascade calculations [5].

the event generator.

Figure 1 shows the resulting charged-hadron $v_2(p_T)$ values for 0-25% and 25-50% central events. The increasing v_2 behavior up to $p_T \approx 1.5$GeV/c is characteristic of hydrodynamic flow [6]. Near mid-rapidity the results show very little rapidity dependence. In going to forward pseudorapidity with $\eta \approx 3$, the slope is found to decrease for both centrality selections, with a greater decrease for the mid-central events. The curves show the results of 3D Hydro+Cascade calculations employing Glauber motivated initial conditions [5]. Good agreement is found with experiment for all but the mid-central, forward-rapidity results. Turning off the hadronic cascade part of the calculation leads to near rapidity independence of the $v_2(p_T)$ results, in strong disagreement with the observed slopes at $\eta \approx 3$. Folding the Fig. 1 results with the corresponding charged hadron spectra measured at $\eta \approx 0$ and 3 yield integral v_2 values of 0.036 ± 0.005 and 0.027 ± 0.004, respectively, at the two pseudorapidities, in good agreement with the PHOBOS integral v_2 results [4].

The identified particle $v_2(p_T)$ results are shown in Fig. 2. Again, the 3D Hydro+Cascade calculations, as shown by the smooth curves, are in good agreement with experiment except for the forward-rapidity, mid-central events. In addition to reproducing the experimental slopes, the calculations also do a good job reproducing the observed mass ordering.

One of the remarkable features of the RHIC elliptic flow behavior is how closely it follows that expected for a perfect fluid. This is particularly evident when the elliptic flow $v_2(p_T)$ values are scaled by the eccentricity ϵ of the overlap region and the number of consituent quarks of the detected particle n_q and then plotted against the mean transverse energy per constituent quark, $\langle E_T \rangle / n_q$, as shown in Fig. 3 for the BRAHMS results at $\eta \approx 0$, 1, and 3. With this scaling, the elliptic flow observed for $\sqrt{s_{NN}} = 200$ GeV Au+Au collisions for a large number of different outgoing particle types are found to follow a common trend [7], as shown by the curve in the figure. Such behavior is consistent with the creation of a near-perfect fluid, with the constituent quark scaling suggesting this fluid involves quark degrees-of-freedom, as expected in coalescence models. Our central results are consistent with the established systematics at all three

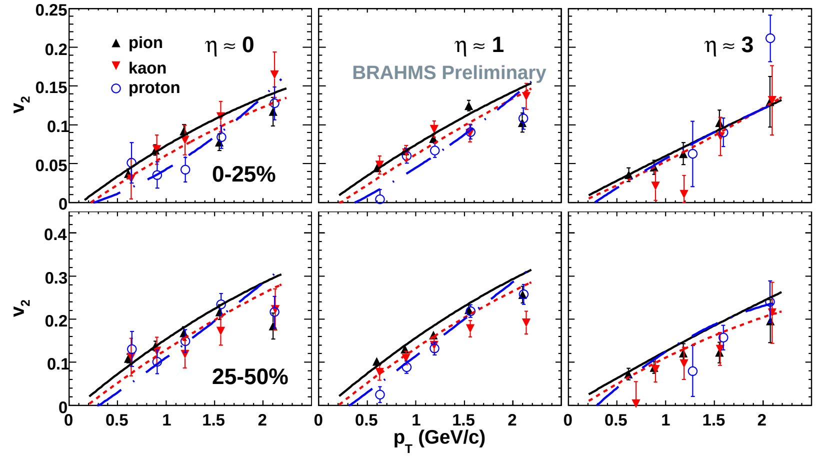

Figure 2: Identified particle $v_2(p_T)$ for central and mid-central events for $\eta \approx 0$, 1 and 3. The curves show 3D Hydro+Cascade calculations [5] for pions(solid), kaons(short dash), and protons (long dash).

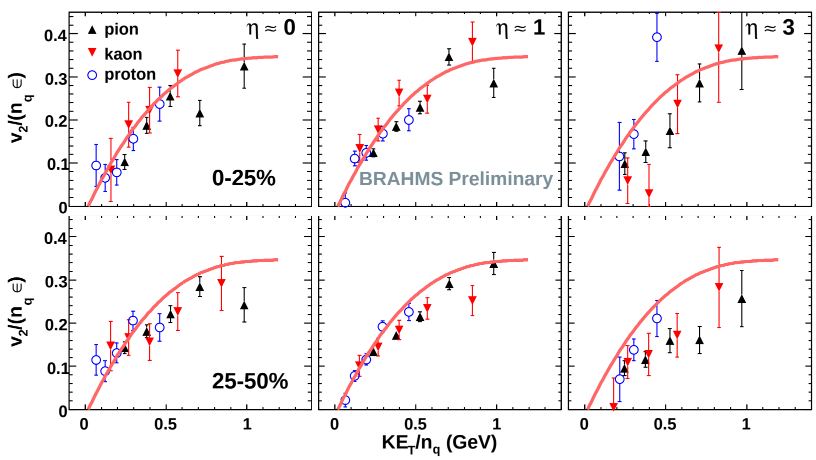

Figure 3: v_2 scaled by the number of valence quarks n_q and the participant eccentricity ϵ as a function of the transverse kinetic energy KE_T scaled by n_q. The curve, common to all panels, is based on the systematics observed for a large number particle types at RHIC [7].

pseudorapidities. For mid-central collisions, the data continue to track well with the systematics for $\eta \approx 0$ and 1, but show significantly reduced elliptic flow at forward rapidity. As also found in comparison of 3D Hydro+Cascade results to our data, the mid-central events at forward rapidity suggest a process other than ideal hydrodynamics is playing a role.

The elliptic flow behavior is believed to be established at an early stage of the reaction, with the integral elliptic flow largely fixed at the point of chemical freeze out. The differential elliptic flow also depends on the subsequent hadronization stage, where radial flow can significantly affect the final particle spectra. Since radial flow results in a velocity boost of the outwardly

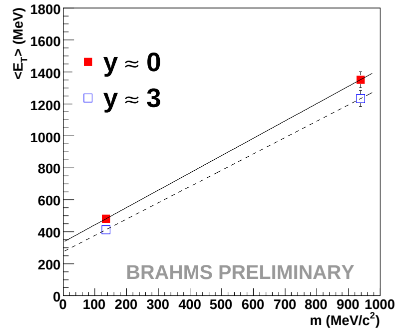

Figure 4: Transverse kinetic energy $\langle E_T \rangle$ as a function of the mass for pions and protons at rapidity y≈0 and 3. The curves are linear fits to guide the eye.

streaming particles, a simple scaling is expected of the mean transverse energy $\langle E_T \rangle$ of the particles as a function of mass. Figure 4 shows the observed $\langle E_T \rangle$ values for pions and protons at rapidities y=0 and y≈3. Protons are found to have a significantly larger transverse energy, as expected from radial flow. It is also observed that the transverse energy decreases in going to forward rapidity, suggesting a possible reduction in the radial flow. This change in the radial flow can strongly influence the differential elliptic flow behavior, but is expected to have less of an effect on the integral flow.

In conclusion, BRAHMS has measured identified particle $v_2(p_T)$ at $\eta \approx$0, 1, and 3 for the Au+Au system at $\sqrt{s_{NN}}$ = 200 GeV. The differential elliptic flow decreases at forward rapidity, with the decrease for central events consistent with the expectations of 3D Hydro+Cascade calculations. For mid-central collisions at forward rapidity the elliptic flow is found to be significantly less than expected by hydrodynamic calculations. This reduction in the elliptic flow is also evident when the current results are compared to previous mid-rapidity results using constituent quark scaling. A decrease is observed in the mean transverse energy of particles going to forward rapidity, suggestion a reduction in the radial flow component. This change in radial flow has a significant influence on the differential $v_2(p_T)$ values. In general, the forward rapidity elliptic and radial flow results place significant constraints on rapidity dependent model calculations of the dynamics of RHIC collisions.

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