Two Particle Azimuthal Correlation Measurements in PHENIX

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Two particle azimuthal correlation functions are presented for charged hadrons produced in Au + Au collisions at RHIC ($\sqrt{s_{NN}}$ = 200 GeV). The correlation functions indicate sizeable asymmetries and anisotropies. The trend of the asymmetries is compatible with the presence of emission patterns associated with mini-jets. The magnitude and the trend of the differential anisotropies $v_2(p_T)$ and $v_2(N_{Part})$, provide important model constraints.

1. Introduction

Differential measurement of azimuthal ($\Delta\phi$) correlation functions for charged hadrons is arguably one of the most important experimental probes for high energy-density nuclear matter created at the Brookhaven Relativistic Heavy Ion Collider (RHIC). The anisotropy as well as the asymmetry of such correlation functions are predicted to; (i) serve as a "barometer" for collective transverse flow and hence a probe for the equation of state (EOS) [1,2], (ii) provide important constraints for the density and effective energy loss of partons [3–5], and (iii) provide invaluable information on nuclear saturation scales [6]. Full exploitation of these correlation functions require a good understanding of the mechanistic origin of two-particle azimuthal correlations at RHIC energies. Detailed systematic measurements of such correlations constitute important steps in this endeavor.

2. Analysis and Results

The colliding Au beams ($\sqrt{s_{NN}}$ = 200 GeV) used in these measurements have been provided by the RHIC. Charged particles from mimum-bias triggered events were detected in the fully instrumented east and west central arms of PHENIX [7]. Each of these arms subtends 90^o in azimuth ϕ, and ± 0.35 units of pseudo-rapidity η. The axial magnetic field of PHENIX (0.5 T) allowed for the tracking of particles with p > 0.2 GeV/c (δp/p $\simeq$ 1%) in the fiducial volume of both arms. Good track quality was ensured via matching and veto cuts to outer detectors in each arm. The Zero Degree Calorimeters (ZDC), were used in conjunction with the Beam-Beam Counters (BBC), to provide off-line selections of a wide range of centralities expressed as a fraction of the total interaction cross section.

Two-particle azimuthal correlation functions were constructed via the ratio of two distributions [8]; $C(\Delta\phi) = N_{cor}(\Delta\phi)/N_{mix}(\Delta\phi)$, where $N_{cor}(\Delta\phi)$ is the observed $\Delta\phi$ distribution for charged particle pairs selected from the same event, and $N_{mix}(\Delta\phi)$ is the $\Delta\phi$

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distribution for particle pairs selected from mixed events. Mixed events were obtained by randomly selecting each member of a particle pair from different events having similar centrality and vertex position. Two correlation functions were obtained for each p_T-range of interest. In the first, charged hadron pairs were formed by selecting both particles from a reference range $p_{T_{Ref}}$, which excludes the p_T range of interest (i.e. a reference correlation [8]). In the second, hadron pairs were formed by selecting one member from the p_T range of interest, and the other from the reference range $p_{T_{Ref}}$ (i.e. an assorted-p_T correlation [8]).

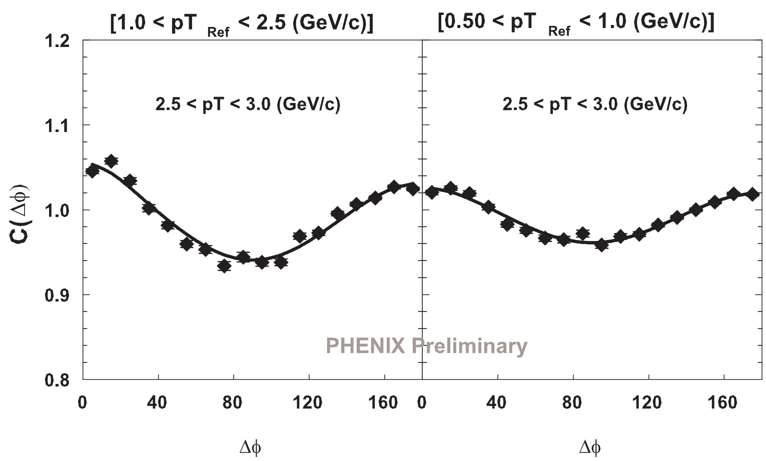

Figure 1. Assorted-p_T correlation functions for charged hadrons of $2.5 < p_T < 3.0$ GeV/c. Correlation functions are shown for $1.0 < p_{T_{Ref}} < 2.5$ GeV/c (left panel) and for $0.5 < p_{T_{Ref}} < 1.0$ GeV/c (right panel). The solid line represents a fit to the correlation function, see text.

Figure 1 shows representative differential assorted-p_T correlation functions for an event centrality cut of 20-40%. The hadron pairs were formed by selecting one member from the range $2.5 < p_T < 3.0$ GeV/c and the other from a non-overlapping reference range $p_{T_{Ref}}$. An additional requirement that particle pairs detected in the same PHENIX arm have the same charge (++ or - -) was also imposed to reduce [but not exclude] non-flow correlations. The right panel of Fig. 1 indicates an essentially symmetric correlation function for $0.5 < p_{T_{Ref}} < 1.0$ GeV/c. By contrast the correlation function for $1.0 < p_{T_{Ref}} < 2.5$ GeV/c (left panel) shows an asymmetry at small $\Delta\phi$. This asymmetry grows if narrow pseudo-rapidity cuts ($\Delta\eta < 0.35$) are imposed or if particle pairs are required to have dissimilar charge (+-). These trends are compatible with the effects of jet fragmentation [9].

The anisotropy and asymmetry of the generated correlation functions have been characterized via fits. A good representation of the data for the reference-p_T and the assorted-p_T correlation functions is obtained with the fit functions

$$C(\Delta\phi) = \lambda \cdot exp(-0.5(\Delta\phi/\sigma)^2) + a_1(1 + 2v_{2_f}^2 cos(2\Delta\phi))$$

$$C(\Delta\phi) = \lambda \cdot exp(-0.5(\Delta\phi/\sigma)^2) + a_1(1 + 2v_{2_a} cos(2\Delta\phi))$$

respectively. Here the Gaussian term and the $cos(2\Delta\phi)$ term is used to characterize the asymmetry [at small $\Delta\phi$] and the anisotropy respectively. The anisotropy parameter for the p_T range of interest v_2', is given by $v_2' = v_{2_a}/v_{2_f}$ where v_{2_a} and v_{2_f} are the anisotropies extracted from the assorted and the reference correlations respectively. The value of v_2' can be compared to the second Fourier coefficient v_2, commonly used to quantify the anisotropy with respect to the reaction plane [10]. Differential values of v_2' (hereafter referred to as v_2) are summarized in Figs. 2 and 3.

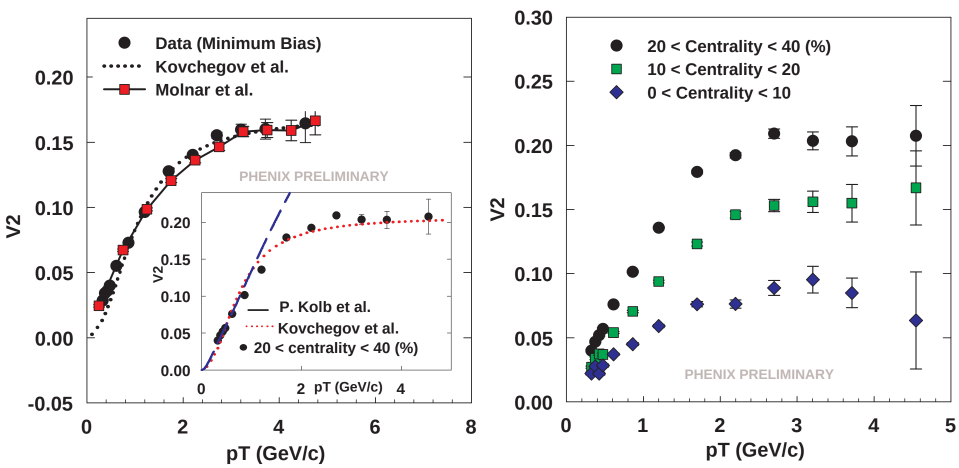

Figure 2. v_2 vs. p_T for minimum bias events (left panel) and for several different centralities as indicated (right panel). Model comparisons [4,6], are indicated for the minimum bias data. The inset shows model comparisons [2,6] to data for the centrality cut of 20-40%.

Figure 2 shows differential anisotropies $v_2(p_T)$, which increase with p_T followed by an apparent saturation for $p_T \gtrsim 2.5$ GeV/c. This trend is similar for all centralities shown and is without doubt related to the collision dynamics. Hydrodynamic models [1,2] provide a good description of the data for p_T up to ~ 1.5 GeV/c. However, these models do not predict the observed saturation of $v_2(p_T)$ (see inset). The lack of saturation indicates that the model assumption that local equilibrium can be maintained until a sudden freeze-out hypersurface is reached, is invalid outside some finite domain of phase space. Results obtained from the jet dominated model HIJING, also show poor agreement with the data at high p_T. Models incorporating only strong jet quenching [5] or jet quenching acting in concert with hydrodynamic expansion [3] do not provide a good description of the high-p_T data as well. By contrast, results from a recent implementation of a covariant transport theory [4] gives a good representation of the data if either extremely high initial gluon density or very large parton-parton scattering cross sections are employed in the calculations (see left panel of Fig. 2). Results from a saturation model [6] can also account for the observed anisotropies (see left panel and inset of Fig. 2).

The mechanistic origin of two-particle correlations in the transport and saturation models are very different. Consequently, additional constraints are required to facilitate a distinction between them. One such constraint is the centrality dependence of v_2. The saturation model predicts that v_2 should scale as $1/\sqrt{N_{Part}}$ [6], where N_{Part} represents the number of participants in the collision. For large opacities (high initial gluon density or very large parton-parton scattering cross sections) one expects the transport model to exhibit essentially N_{Part} scaling. Fig. 3 show initial tests for $1/\sqrt{N_{Part}}$ scaling (right panel), and N_{Part} scaling (left panel) for charged hadrons of $2.5 < p_T < 4.0$ GeV/c.

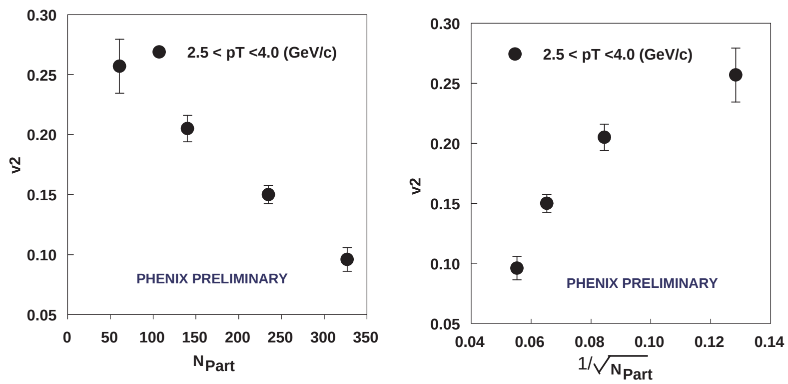

Figure 3. v_2 vs. N_{Part} (left panel), and $\sqrt{N_{Part}}$, (right panel) for charged hadrons of $2.5 < p_T < 4.0$. Error bars indicate statistical errors only.

The data indicates better overall agreement with N_{Part} scaling for the centrality range presented but does not exclude $1/\sqrt{N_{Part}}$ for relatively central collisions.

3. Summary

In summary, two-particle correlation measurements indicate sizeable anisotropies and asymmetries. The trend of the asymmetries are compatible with the asymmetric emission pattern of mini-jets. The anisotropy (v_2) increases with decreasing centrality and increases with p_T up to $p_T \sim 2.5$ GeV/c. For higher p_T's the anisotropy saturates for each centrality cut. This important feature is not reproduced by hydrodynamic models but is well reproduced by the covariant transport theory of Molnar *et al.* [4], and the saturation model of Kovchegov *et al.* [6]. More detailed measurements of the centrality dependence of v_2 may allow one to distinguish between the two very different mechanisms for two-particle correlations, implied by the latter models.

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