Proc. 22nd Winter Workshop on Nuclear Dynamics (2006) 000–000

22nd Winter Workshop on Nuclear Dynamics
La Jolla, California, USA
March 11–18, 2006

High-p_T Particle Production with Respect to the Reaction Plane

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Abstract. The PHENIX Run4 dataset provides a powerful opportunity for exploring the angular anisotropy of identified particle yields at high p_T. Complementing traditional v_2 measurements, we present π^0 yields as a function of emission angle with respect to the reaction plane in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV/c. The centrality dependence of the angular anisotropy allows us to probe the density and path-length dependence of the energy loss of hard-scattered partons.

Keywords: heavy ion, pi0, high-pt, reaction plane
PACS: 25.75.-q, 25.75.Dw, 25.75.Ld, 25.75.Nq

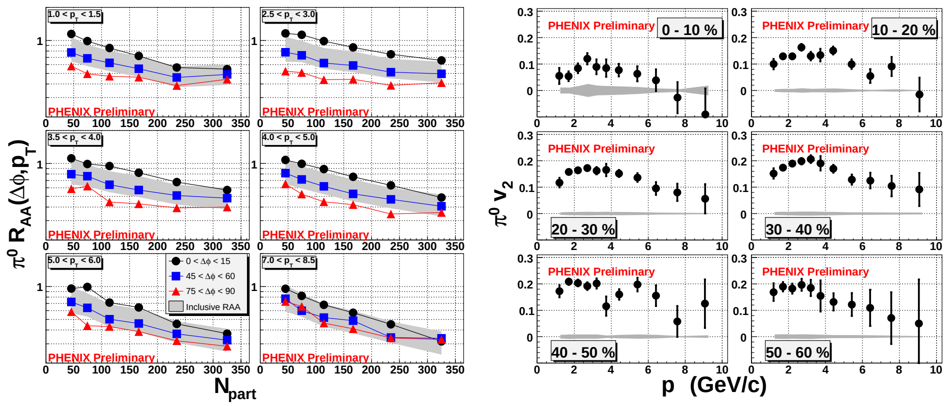
1. Introduction

One of the most intriguing puzzles in RHIC physics is the origin of the azimuthal anisotropy of particle yields at high p_T (> 5 GeV/c). Traditional flow and parton energy loss pictures have failed to describe the magnitude of this anisotropy. Measurement of the azimuthal asymmetry v_2 at high p_T will shed light on the contributions from flow, recombination, and energy loss, as well as the transition from soft to hard production mechanisms.

Two of the greatest mysteries that have arisen from the RHIC physics program is the source of the apparent flatness of the high p_T suppression of R_{AA} [1] and the source of non-trivial v_2 at high p_T [2]. The existence of high p_T v_2 was predicted early in the RHIC program [3], and has been the subject of many theoretical treatments (see [4, 5] for some additional examples).

2. Measuring π^0 yields and v_2 in PHENIX

During Run 4, PHENIX recorded 1.5 billion events; the data presented here is taken from 1 billion of those events. For measuring photons and π^0s, we use the Elec-



(a) π^0 R_{AA} vs. N_{part} (b) π^0 v_2 vs. p_T

Fig. 1. π^0 v_2 and R_{AA}: (a) shows $R_{AA}(p_T)$ as a function of $\langle N_{part} \rangle$ for each $\Delta\phi$ bin; the panels are for different p_T bins. (b) the π^0 $v_2(p_T)$, with each panel corresponding to a centrality bin. The grey bands indicate the systematic error due to the reaction plane resolution correction.

tomagnetic Calorimeter (EmCal) [6]. The angle of the reaction plane is measured event-by-event using the Beam-Beam Counters. Pairs of clusters that pass γ identification cuts are binned in angle with respect to the reaction plane ($\Delta\phi = \phi - \Psi_{RP}$). A similarly binned mixed event background is then subtracted. The counts in the remaining peak are integrated in a $\pm 2\sigma$ window, determined by a gaussian fit. Six bins in $\Delta\phi$ are used from $0 - \pi/2$.

To measure v_2, we fit the $\Delta\phi$ distribution as $1 + 2v_2^{raw} \cos(2\Delta\phi)$. The resulting v_2 parameter needs to be corrected for the reaction plane measurement resolution, hence the designation v_2^{raw}. The resolution σ is determined for each centrality bin, and leads to the corrected value $v_2^{corr} = v_2^{raw}/\sigma$. The yields as a function of $\Delta\phi$ can then be corrected with a factor

$$f = \frac{1 + 2v_2^{corr} \cos 2\Delta\phi}{1 + 2v_2^{raw} \cos 2\Delta\phi}. \quad (1)$$

3. Results and Discussion

To obtain $R_{AA}(\Delta\phi)$, we exploit the fact that the ratio of of the yield at a given $\Delta\phi$ to the inclusive yield is equivalent to the ratio of the angle-dependent R_{AA} to the inclusive R_{AA}. Thus mulitplying these relative yields by an inclusive measured R_{AA}, we have:

$$R_{AA}(\Delta\phi) = \texttt{Yield}(\Delta\phi)/\texttt{Yield} \times R_{AA} \quad (2)$$

The $R_{AA}(\Delta\phi, p_T)$ as a function of $\langle N_{part} \rangle$ is shown in Figure 1(a). It is clear

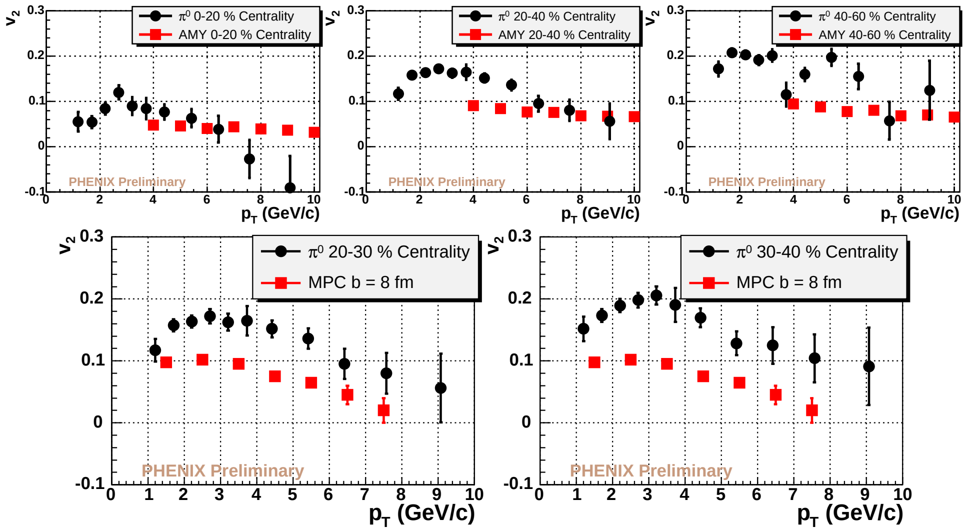


Fig. 2. Comparison of π^0 v_2 with models. The top three panels show the AMY calculation with data for three centralities. The bottom two panels compare two centralities with the $b = 8$ fm calculation of the MPC model.

that there is non-trivial substructure to the angular dependence of the R_{AA}, and that it varies with centralities. This feature is emphasized by plotting the data on a semi-log scale, showing that the R_{AA} behaves differently in different $\Delta\phi$ bins.

The resulting π^0 v_2 is shown in Figure 1(b). For the first time we observe v_2 up to 10 GeV/c, and we see a clear decrease at high p_T, then a leveling off to a large value.

To gain insight into the v_2 mechanisms at work at high p_T, we turn to models. We compare the π^0 v_2 to two models, an Arnold-Moore-Yaffe (AMY) calcuation [7] done by Turbide et al. and the Molnar Parton Cascade (MPC) model [8]. Figure 2 shows calculations from these models, plotted alongside data for similar centralities. The AMY calculation contains energy loss mechanisms only, and we see that the data appear to decrease to a value at high p_T that is consistent with this model; the comparison is most striking in the 20-30% bin.

The MPC model has a number of mechanisms in it, including corona effects, energy loss, and the ability to boost lower p_T partons to higher p_T (a unique feature). The calculation shown in Figure 2 does a better job of reproducing the overall shape of the v_2, though it is systematically low. It is important to note that this calculation is done for one set of parameters, so it should be very interesting to see if the MPC can better reproduce the data for a different set of parameters.

The prevailing thought is that the high p_T behavior of the v_2 is due to energy

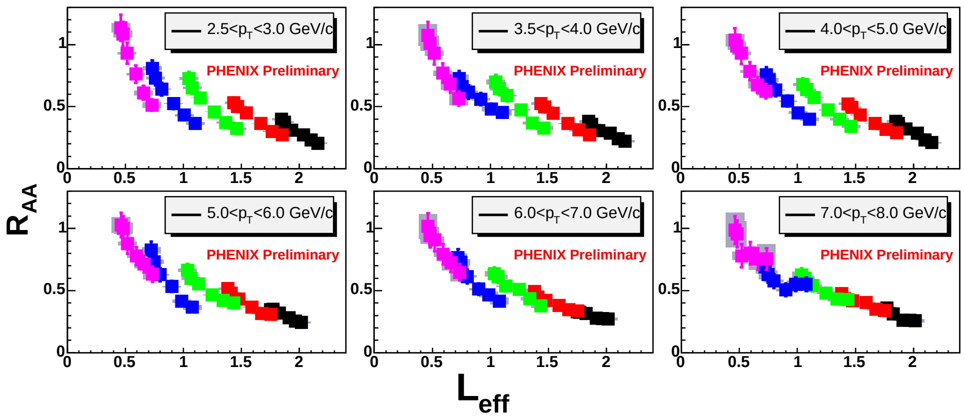


Fig. 3. $R_{AA}(\Delta\phi, p_T)$ vs. L_{eff}. The panels correspond to different p_T ranges. The colors represent the centrality bins: magenta is most peripheral while black is most central.

loss mechanisms. If this is true, the R_{AA} should be sensitive only to the geometry of the collision. To test this behavior, we seek to reparamaterize the two handles we have on geometry (centrality, or collision overlap, and angle of emission) into a single parameter, an effective path length which we will refer to as L_{eff}. Details of the calculation are described in [9]. In essence, it is propotional to the parton-density weighted average of the length from origin to edge of an ellipse. We also perform a Glauber Monte Carlo sampling of starting points to account for fluctuations in the location of the hard-scattering origin of the particles' paths.

The result of plotting R_{AA} for all centralities and angles vs. L_{eff} is shown in Figure 3. If the observed R_{AA} arose from only geometric effects, we would expect the data to exhibit a universal dependence on L_{eff}. For low p_T, this is clearly not the case; something more than just energy loss is taking place there. However, when the p_T reaches 7 GeV/c and above, the R_{AA} data do indeed appear to have a dependence on a single L_{eff} curve.

4. Conclusions

We have presented the first measurement of high p_T v_2 for π^0 and charged hadrons. It is now clear that the v_2 at high p_T decreases to a small but non-trivial value. Comparison with models suggest that the dominant mechanism at work at high p_T is energy loss. In addition, we have also presented the first measurement of π^0 R_{AA} as a function of angle with respect to the reaction plane. The $R_{AA}(\Delta\phi, p_T)$ exhibits interesting angular substructure. Furthormore, when the R_{AA} data are plotted as a function of an effective path length through the medium, they exhibit a universal behavior at high p_T.

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