PHENIX Measurement of Particle Yields at High p_T with Respect to Reaction Plane in Au+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV

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The PHENIX Run 4 Au+Au 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 angle with reaction plane, up to p_T 10 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. We will discuss various mechanisms for particle production in this high p_T region.

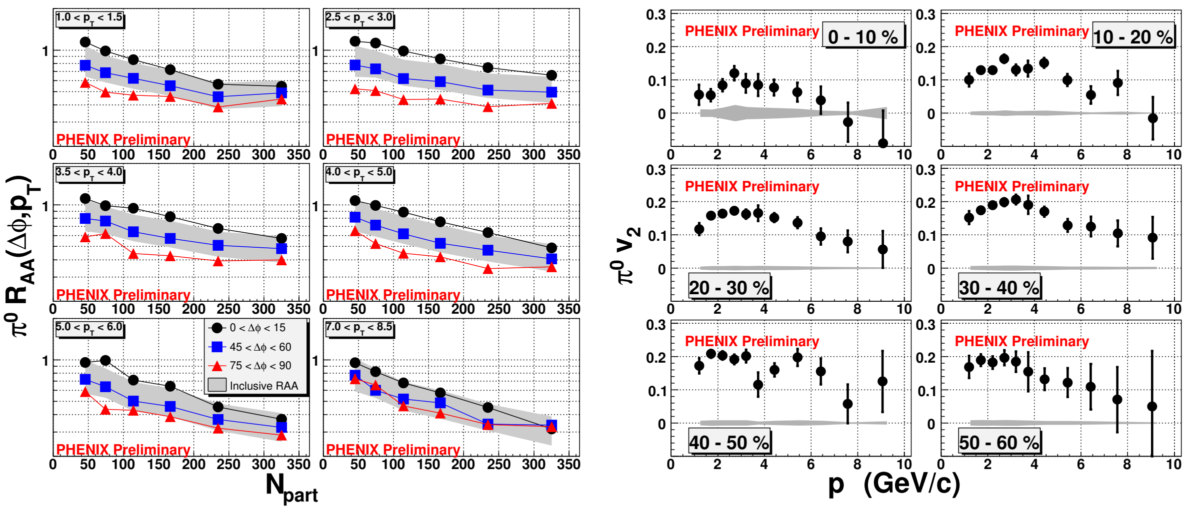
1. Introduction

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) [1,2]. Parton energy loss, which can reproduce the flat, suppressed R_{AA} in single particle spectra [3], fails to reproduce the required v_2 at intermediate p_T [4,5]. The complicated interplay between soft and hard physics (for example, recombination, flow, and energy loss) at intermediate p_T makes it critical to measure v_2 at high p_T, where we expect the only contribution to be from energy loss. We report here on the measurement of the π^0 azimuthal asymmetry, and discuss what it tells us about the source(s) of high p_T v_2. First we describe the method by which we measure R_{AA} as a function of angle with respect the reaction plane and v_2 for π^0s in PHENIX. We then discuss two model calculations that help to shed light on the mechanisms giving rise to the high p_T v_2.

2. Measuring π^0 yields and v_2 in PHENIX

During Run 4, PHENIX recorded 1.5 billion minimum bias Au+Au events at $\sqrt{s} =$ 200 GeV/c; the data presented here is taken from 1 billion of those events. For measuring photons and π^0s, we use the Electomagnetic 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 $0 - \pi/2$.

*For the full list of PHENIX authors and acknowledgements, see Appendix 'Collaborations' of this volume



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

Figure 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.

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 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

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

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:

$$R_{AA}(\Delta\phi) = \mathtt{Yield}(\Delta\phi)/\mathtt{Yield} \times R_{AA} \tag{2}$$

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

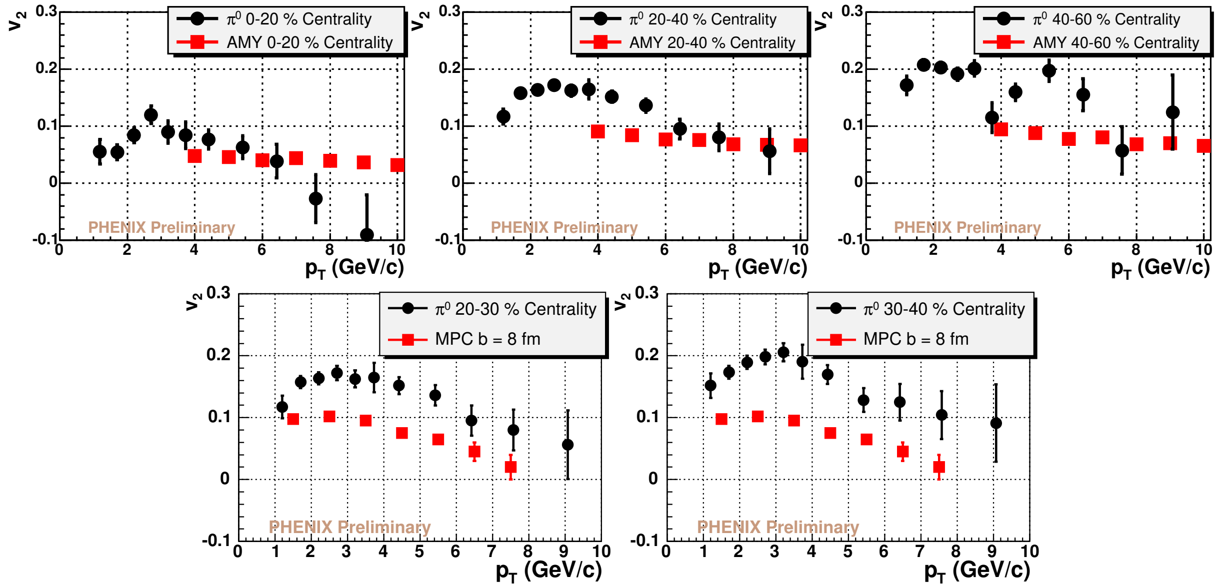


Figure 2. Comparison of π^0 v_2 with models. The top three panels show the AMY calculation with data for three centralities. The bottom two panels compare two centralities with the $b = 8$ fm calculation of the MPC model.

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 agreement 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 mechanism for high p_T v_2 is parton energy loss in the dense medium. 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.

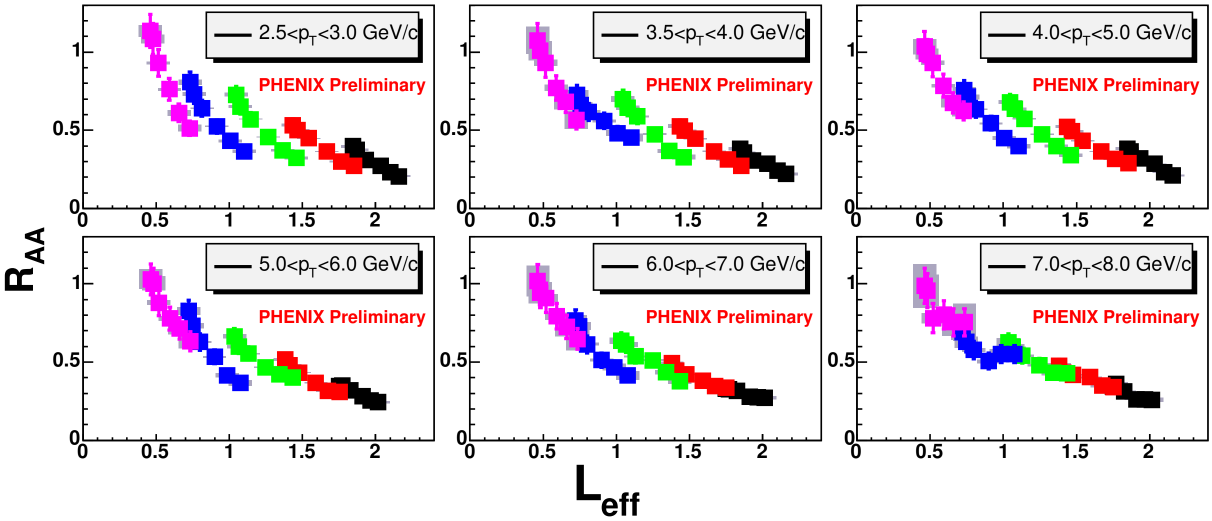


Figure 3. $R_{AA}(\Delta\phi, p_T)$ vs. L_{eff}. The panels correspond to different p_T ranges. The colors represent the centrality bins: magenta is most peripheral while black is most central.

4. Summary

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 $p_T > 7$ GeV/c 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. Furthermore, when the R_{AA} data are plotted as a function of an effective path length through the medium, they exhibit a universal behavior at $p_T >$ 7 GeV/c.

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