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PHENIX results on nuclear modification of π^0-hadron correlations in small and large collision systems

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Two-particle correlations using high-p_T particles allow jet-like measurements at low Q^2 where jet reconstruction is challenging. Therefore, such correlations provide critical input to our understanding of how partons interact in a colored medium. PHENIX has measured π^0-hadron correlations in multiple collisions systems. The away-side widths in p+Au collisions are broader than those in p+p collisions. In Au+Au collisions both the shape and the yield of the away-side distributions are modified compared to those in p+Au and p+p collisions. The implications of these results to our understanding of energy loss in cold and hot nuclear matter are discussed.

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1. Introduction

High momentum two particle correlations have been a useful observable for studying jets in heavy ion collisions as well as in smaller collision systems. Early in the collision, hard scatterings produce high momentum partons that experience all stages of the collision process and eventually fragment into hadrons. In p+A and A+A collisions the produced parton may lose energy as it traverses the nucleus or medium. This energy loss may appear as a suppression of final state high momentum hadrons and an angular broadening of the associated hadrons. These effects can be studied by selecting a high momentum hadron called the trigger and measuring the angular correlation with all other hadrons referred to as associated hadrons in the event. The trigger particle selects events in which jets were produced. When plotted as a function of their azimuthal angular separation, $\Delta\phi$, particles from the same jet as the trigger particle will appear at $\Delta\phi = 0$ while particles from the opposing jet will appear around $\Delta\phi = \pi$.

The PHENIX electromagnetic calorimeter (EMCal) composed of lead glass and lead scintillators is used to measure the daughter photons resulting from π^0 decays. The invariant mass of the photon pairs is used to reconstruct π^0 candidates by selecting pairs with an invariant mass in the range of 120-160 MeV. The azimuthal angle difference, $\Delta\phi$, beween the π^0 and the associated hadrons is measured in a variety of p_T bins. Charged tracks are reconstructed using the PHENIX drift and pad chambers. Charged hadron tracks are selected by imposing a RICH veto cut to remove electron tracks. Mixed events are used to correct for the detector acceptance effects. Hadron efficiency corrections based on GEANT simulations are applied on the yield measurements. Results presented here include data for 200 GeV p+p, p+Al, and p+Au collisions collected by PHENIX during 2015 and Au+Au collisions collected in 2010 and 2011. These measurements are for pseudorapidity range $|\eta| < 0.35$.

In p+p and p+A collisions, contributions from the underlying event are small and do not need to be subtracted to extract the physics of interest. However, the large underlying event produced in heavy ion collisions must be carefully removed from the measured correlations. In particular correlations due to the flow of the underlying event must be considered.

2. π^0-h in Au+Au Collisions

Previous PHENIX measurements of π^0-hadron correlations in Au+Au collisions revealed a suppression of high p_T hadrons and a broadening of the angular distribution of low momentum hadrons on the away-side. However, these previous measurements of π^0-hadron correlations considered only the second order modulation, v_2, of the underlying Au+Au event in the background subtraction. To properly quantify the modifications due to the QGP in Au+Au, the current PHENIX analysis combines data from the 2010 and 2011 RHIC runs and accounts for n=2,3,4 harmonics in the background subtraction. This background term subtracted from the correlations can be written as

$$BG = b_0(1 + \sum_n n v_{nn} \cos(n\Delta\phi)), \tag{2.1}$$

where $v_{nn} = v_n^{trig} v_n^{assoc}$ and b_0 is the background level, which is determined according to the absolute normalization method [1]. Since v_3 and v_4 measurements in this p_T range are limited, we use measured v_2 values from PHENIX [2] and apply acoustic scaling [3]. According to the acoustic scaling method,

$$v_{nn} = v_n^{\pi^0} v_n^h = g_{n2}^2 (v_2^{\pi^0} v_2^h)^{n/2} \tag{2.2}$$

and the scale factor g_{n2}^2 is constant over all p_T. The away-side jet peak after subtraction are fit with a Gaussian. The width as a function of associated hadron p_T is plotted for each trigger p_T bin in Fig. 1. At lower associated p_T, the widths from the Au+Au collisions are larger than the widths measured in p+p. At high p_T the widths are consistent in the two collision systems.

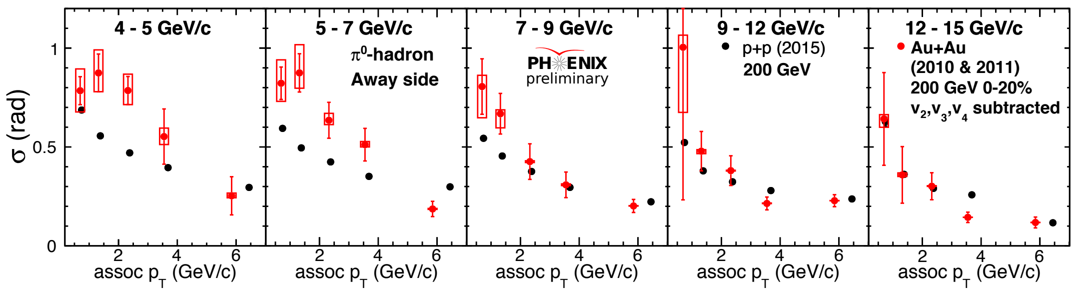

Figure 1: The Gaussian width of the away-side jet peak in Au+Au as a function of $h^{\pm}$ p_T for each trigger p_T bin compared to that in p+p collisions.

In Fig. 2 modifications to the away-side yield, Y^{Away} relative to the near-side yield Y^{Near} in Au+Au compared to p+p collisions are quantified with the ratio, R_I which is defined as

$$R_I = \frac{Y_{AA}^{Away}/Y_{Near}^{AA}}{Y_{pp}^{Away}/Y_{pp}^{Near}}. \tag{2.3}$$

Fig. 2 shows that the away-side yield is suppressed for hadrons above 2 GeV/c for all trigger p_T bins. The data is consistent with an enhancement of the yield for hadrons below 1 GeV/c for all trigger p_T bins but the enhancement is only significant for the lowest p_T triggers. This is consistent with the theory that the energy lost at p_T is redistributed to low p_T particle production. Because R_I is a double ratio, most of the systematic uncertainties cancel. The statistical precision of this measurement can be improved by analyzing additional Au+Au data collected in 2014 and 2016.

3. π^0-h in Small Systems

An alternative way of presenting the correlations is to measure the p_{out} distribution, where

$$p_{out} = p_T^{assoc} \sin\Delta\phi. \tag{3.1}$$

The p_{out} distributions were measured in 200 GeV p+p, p+Al and p+Au collisions for 5-9 GeV/c π^0 triggers and 0.5-10 GeV/c associated hadrons. The distributions, which exhibit a Gaussian like behavior for small p_{out} with power law tails at larger p_{out}, demonstrate the transition from non-perturbative to perturbative physics regimes. The width of the Gaussian fit to the small

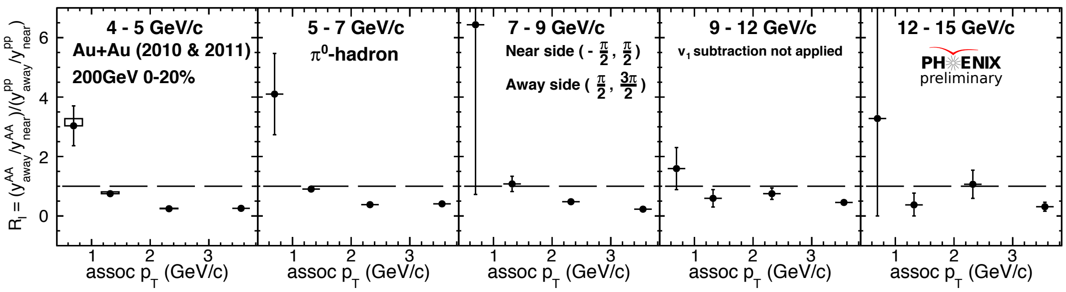

Figure 2: R_I as a function of $h^{\pm}$ p_T for each trigger p_T bin

p_{out} regions are extracted for the near and away-side jets in p+A and compared to those extracted from p+p collisions. While p_{out} is the transverse momentum component of the associated hadron with respect to the trigger axis, the variable x_E is the ratio of the longitudinal component of the associated hadron to the trigger momentum and is defined as

$$x_E = -\frac{p_T^{assoc}}{p_T^{trig}} \cos\Delta\phi. \tag{3.2}$$

The difference in the width of the p+A and p+p p_{out} distributions are plotted as a function of x_E in Fig. 3. The figure shows that the widths of the p_{out} distributions for the near-side jet peaks are consistent in p+p and p+A while a clear difference is observed for some x_E bins for the away-side jet peaks measured in p+Au. The difference is less significant for the away-side p+Al. However, plotting both the p+Al and p+Au measurements in Fig 4, a trend as a function of N_{coll} is measured for two x_E bins. This suggests that the broadening of the p_{out} distribution for the away-side jets increases with N_{coll} in small systems. A variety of processes including multiple scatterings, an additional k_T from the nucleus or energy loss could contribute to these observations. Additional studies and theory comparisons are needed to disentangle the significance these effects could contribute.

4. Conclusions

π^0-hadron correlations were measured in Au+Au collisions at 200 GeV with data collected by PHENIX in 2010 and 2011. To study modifications of the jet peaks, the underlying event subtraction accounts for the second, third, and fourth order flow harmonics. Comparisons of the widths and yields in Au+Au and p+p suggest that the suppression of number of observed high p_T hadrons is compensated by an increased production of low p_T hadrons at broader angles. This is consistent with expectations for partonic energy loss in the QGP. These improved measurements should be used to constrain energy loss models. Additional statistical precision can be achieved by analyzing the Au+Au data collected by PHENIX in 2014 and 2016.

Broadening of the p_{out} distribution for the away-side π^0-h jet peak was observed in p+A collisions. The broadening appears to increase with increasing N_{coll}. Additional studies and comparisons to theory are needed to determine which mechanism is responsible for these observations.

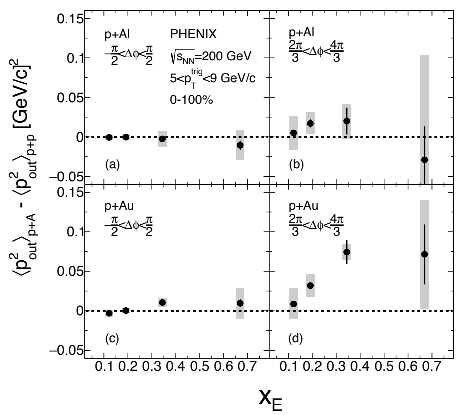

Figure 3: Difference between the width of the p_{out} distributions in p+A and p+p as a function of x_E for the near-side (left) and away-side (right) in p+Al (top) and p+Au (bottom) collisions. [4]

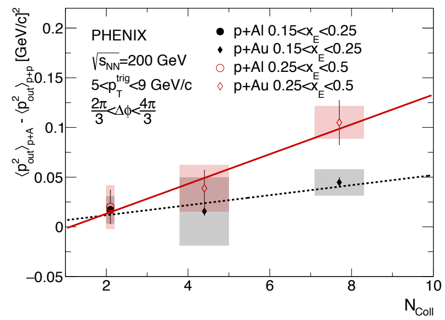

Figure 4: Difference between the width of the p_{out} distributions in p+A and p+p as a function of N_{coll} for two x_E bins [4].

These results demonstrate the ability to probe QCD effects with two particle correlations from p+p to p+A to A+A collisions. The presented observations should be used in conjunction with other jet observables to constrain theoretical models.

References

[1] Sickles et al., *Extraction of Correlated Jet Pair Signals in Relativistic Heavy Ion Collisions*, PRC 81, 014908 (2010)

[2] A. Adare et al., *Measurements of Higher Order Flow Harmonics in Au+Au Collisions at* $\sqrt{s_{NN}}$*=200 GeV* PRL 107, 252301

[3] R. Lacey et al., *Scaling of the higher-order flow harmonics: implications for initial-eccentricity models and the "viscous horizon"* arXiv:1105.3782

[4] C. Aidala et al., *Nonperturbative transverse momentum broadening in dihadron angular correlations in* $\sqrt{s_{NN}}$*=200 GeV proton-nucleus collisions*, arXiv:1809.09045