DIRECT JET RECONSTRUCTION IN d+Au COLLISIONS AT PHENIX

PHENIX

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1. ABSTRACT

Deuteron-gold (d+Au) collisions at RHIC can be used to investigate cold nuclear matter effects on hard parton scattering. d+Au collisions at different centrality (different $N_{\rm coll}$) can probe nuclear parton distributions, initial state energy loss and final state parton interactions in the cold nucleus. They also provide a valuable baseline for hard-scattering processes in heavy ion collisions. Measurements using jet reconstruction may provide a more sensitive probe of the parton level physics than inclusive single-particle measurements or two-particle correlations. We present the current results from direct jet reconstruction at PHENIX in d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. We discuss some of the challenges of direct jet reconstruction in a high-multiplicity heavy ion environment.

2. INTRODUCTION

Reconstructed jets are thought to be a better probe of parton-level physics because they approximate the full parton kinematics better than a leading fragmentation hadron and are therefore a direct probe of hard scattering. Additionally, measurements with reconstructed jets do not suffer the same trigger bias as measurements of single particles. Angular correlation analyses using reconstructed di-jets are less susceptible to combinatorial background than two-particle correlations. Furthermore, two-particle correlations are sensitive to angular distributions within a jet, while reconstructed jets are sensitive only to the angular distribution between jets.

In heavy ion experiments, direct jet reconstruction in hadron-nucleon collisions can probe centrality-dependent suppression of partons over a wide $p_{\rm T}$ range, modification of the fragmentation function and angular broadening in di-jets. This is the first jet reconstruction measurement in d+Au collisions at PHENIX.

Data from the 2008 d+Au run with $\sqrt{s_{NN}} = 200$ GeV at RHIC was taken with the PHENIX detector. The data set was collected using the Electromagnetic/RICH Trigger (ERT), which selects events depositing $\gtrsim 1.6$ GeV in the calorimeter. In this analysis we test the performance of the anti-$k_{\rm T}$ algorithm[1] in an experimental environment with low combinatorial background.

Previous jet measurements at PHENIX in p+p and Cu-Cu collisions used the Gaussian filter algorithm[2], which is not as susceptible to detector edge effects and has better fake jet rejection capability compared to other algorithms. In the future, we will repeat this analysis with the filter and perform a direct comparison.

3. JETS IN PHENIX

Charged tracks in the drift chamber and clusters in the electromagnetic calorimeter at mid-rapidity within the PHENIX central arms ($|\eta| < 0.35$, $\Delta\phi \sim \pi$) that passed a $p_{\rm T}$ cut of > 400 MeV/c are used as inputs to the anti-$k_{\rm T}$ jet algorithm. A time of flight cut in the calorimeter required electromagnetic clusters to lie within five σ of a light-speed particle, where σ is the calorimeter time of flight resolution. Reconstruction was performed with two values of the anti-$k_{\rm T}$ parameter R (0.3, 0.5) to understand and control for the effects of the underlying event.

We require three or more constituents in a jet, and apply a fiducial cut to require jets to be more than 0.05 units away from the edge of the PHENIX acceptance in η/ϕ-space.

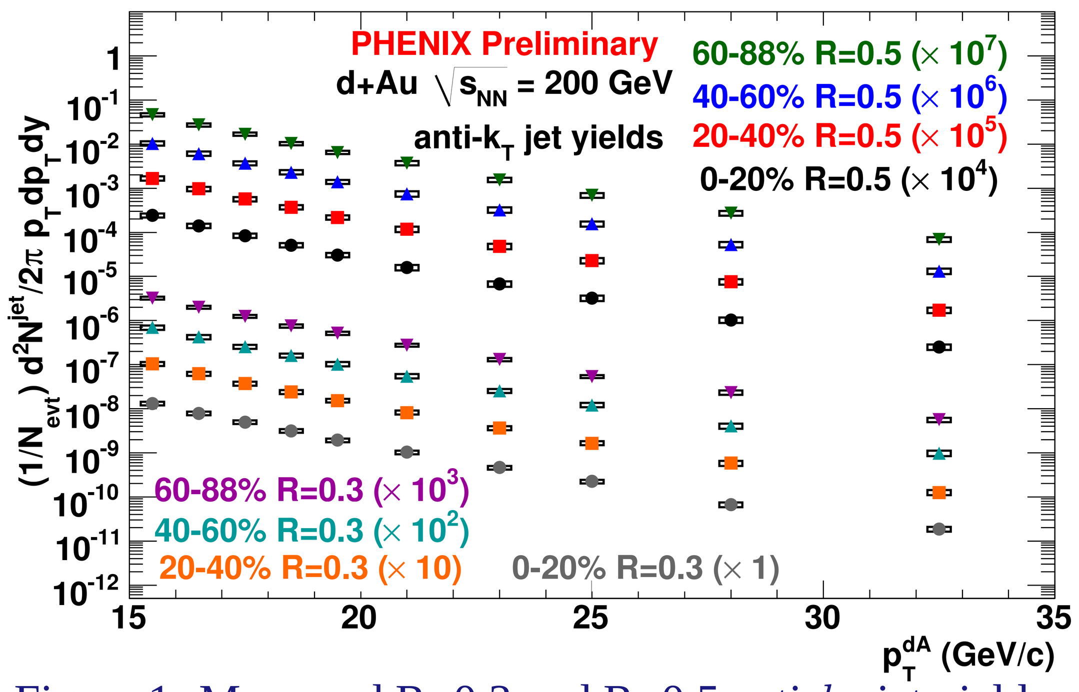

Figure 1: Measured R=0.3 and R=0.5 anti-$k_{\rm T}$ jet yields in PHENIX, 2008 d+Au data.

We include only $p_{\rm T}^{dAu} > 15$ GeV/c anti-$k_{\rm T}$ jets for single jet analyses. Below this value, the impact of the underlying event on jet measurements is still not completely understood. Measured jet yields for both R values from the efficiency-corrected, triggered data set are shown in Figure 1. From these, we can measure the $R_{\rm CP}$ for jets, as described in Section 4.

For di-jet analyses, we look at events with two or more $p_{\rm T}^{dAu} > 5$ GeV/c anti-$k_{\rm T}$ jets. Acceptance-corrected, per-dijet-normalized $\Delta\phi$ correlations as a function of anti-$k_{\rm T}$ trigger jet $p_{\rm T}^{dAu}$ are shown in Figure 4 for an example R value and centrality bin. From these, we can measure two observables that characterize angular broadening, as described in Section 5.

During this study, we have developed methods to deal with jet reconstruction in a high-background, heavy ion environment. To correct for the underlying event contribution to the reconstructed jet energy and unfold the measured energy $p_{\rm T}^{dAu}$ to the reconstructed scale $p_{\rm T}^{rec}$, we embedded jets from Monte Carlo hard scattering into minimum bias events to see how the underlying event affects reconstruction. To estimate the $p_{\rm T}$ extent of the fake jet contribution, we compared the di-jet to single-jet spectrum ratio between different centralities and a p+p baseline (where there is no underlying event).

4. ANTI-$k_{\rm T}$ JET $R_{\rm CP}$

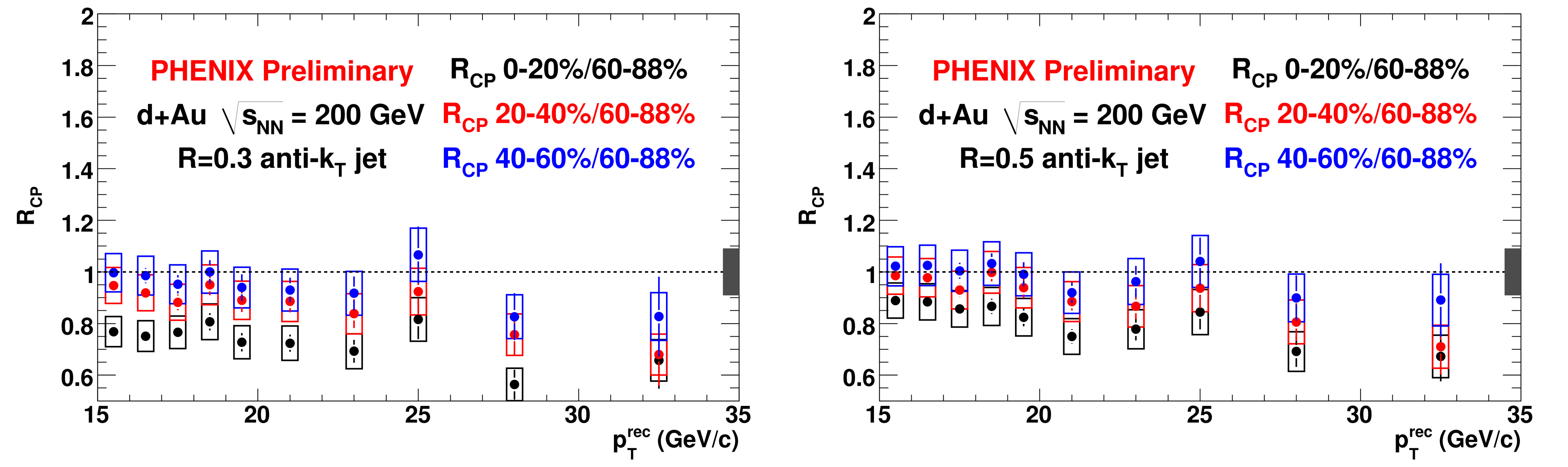

Figure 2: Anti-$k_{\rm T}$ jet R$_{CP}$ ratios with the peripheral 60-88% bin (R=0.3 and R=0.5 on the left and right, respectively).

The anti-$k_{\rm T}$ jet $R_{\rm CP}$ (defined as $R_{\rm CP}^{0-20/60-88} \equiv \left(1/\left\langle N_{\rm coll}^{0-20}\right\rangle N_{\rm evt}^{0-20})(dN_{\rm jet}^{0-20}/dp_{\rm T}\right) / \left(1/\left\langle N_{\rm coll}^{60-88}\right\rangle N_{\rm evt}^{60-88})(dN_{\rm jet}^{60-88}/dp_{\rm T}\right)$ for the first ratio) for 0-$20\%/60$-$88\%, 20$-$40\%/60$-88% and 40-$60\%/60$-88% is plotted in Figure 2 against the reconstructed jet energy $p_{\rm T}^{rec}$. We observe suppression of high $p_{\rm T}^{rec}$ jets in central collisions relative to peripheral ones. This suppression is present in both $R = 0.3$ and $R = 0.5$ reconstruction results, is flat over a wide $p_{\rm T}^{rec}$ range, and shows a monotonic decrease with increasing centrality.

This result provides information about the impact parameter dependence of the modification of nPDFs, as well as initial state energy loss and final state effects in hadron-nucleus collisions. Further analysis can reduce the magnitude of the systematic error and extend the range to lower-$p_{\rm T}^{rec}$ jets.

5. ANTI-$k_{\rm T}$ DI-JET $RMS_{\Delta\phi}$ AND $p_{\rm out}$

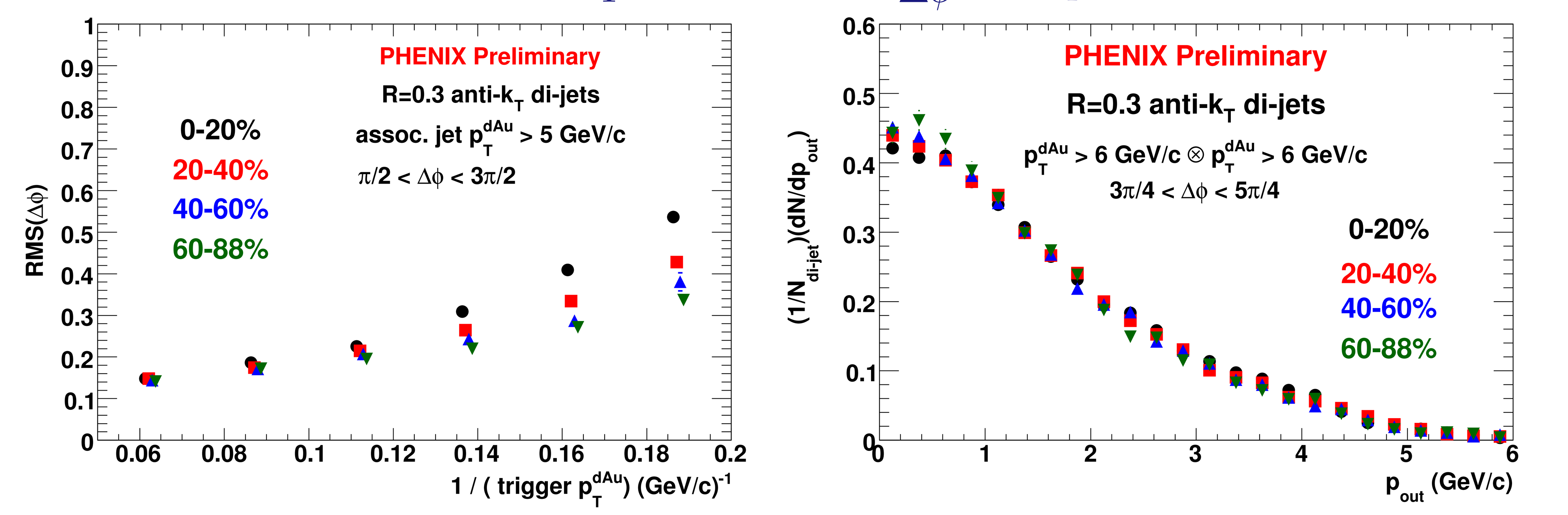

Figure 3: R=0.3 anti-$k_{\rm T}$ jet RMS of away-side $\Delta\phi$ peak vs. inverse trigger jet $p_{\rm T}$ (left) and away-side $p_{\rm out}$ (right).

The RMS of $\Delta\phi$ distributions around $\phi = \pi$ $\left(\text{defined as } \sqrt{\left\langle(\Delta\phi - \pi)^2\right\rangle},\ \pi/2 < \Delta\phi < 3\pi/2\right)$ for R=0.3 anti-$k_{\rm T}$ di-jets is plotted on the left-hand side of Figure 3. The magnitude of the broadening effect should go as $1/p_{\rm T}$ of is the higher-$p_{\rm T}^{dAu}$ jet, so we plot the differences in centrality against this variable. At low $p_{\rm T}^{dAu}$, we cannot separate physical broadening from broadening due to the underlying event. At high $p_{\rm T}^{dAu}$, as the effects of the underlying event become small and we see essentially no physical broadening as the RMS widths from different centralities become indistinguishable.

The $p_{\rm out}$ of R=0.3 di-jets (defined as $(p_{\rm T}^{dAu})_{\rm low} \cdot \sin(\Delta\phi)$ with an angular cut $3\pi/4 < \Delta\phi < 5\pi/4$ on the di-jet and $p_{\rm T}^{dAu} > 6$ GeV/c requirement on both jets to remove the combinatorial contribution) is plotted on the right-hand side of Figure 3, and can be used to further constrain centrality dependent angular broadening effects. The self-normalized $p_{\rm out}$ distributions show that there are only very small centrality-dependent differences. It is likely that any remaining difference in the $p_{\rm out}$ is due to a residual shoulder in the most central collisions from the flat $\Delta\phi$ combinatorial jet background.

6. CONCLUSION

These results measure the impact parameter dependence of nuclear parton distribution function modification in hadron-nucleus collisions, as well as other cold nuclear matter effects.

Our $R_{\rm CP}$ results (Fig. 2) can confirm predictions of suppression of single hadron production in coherent multiple scattering due to nuclear shadowing over a range of transverse momenta [3]. Our $\Delta\phi$ RMS and $p_{\rm out}$ measurements (Fig. 3) can constrain the centrality dependence of modified di-jet away-side width and transverse momentum in the plane perpendicular to the collision axis [4], respectively. Furthermore, these cold nuclear matter effects serve as an important baseline against which to measure hot nuclear matter effects such high-$p_{\rm T}$ parton energy loss in heavy ion collisions.

In addition to effects from dynamical nuclear attenuation, improved jet measurements in d+Au can probe possible angular broadening or low-$p_{\rm T}^{rec}$ Cronin enhancements due to elastic scattering corrections.

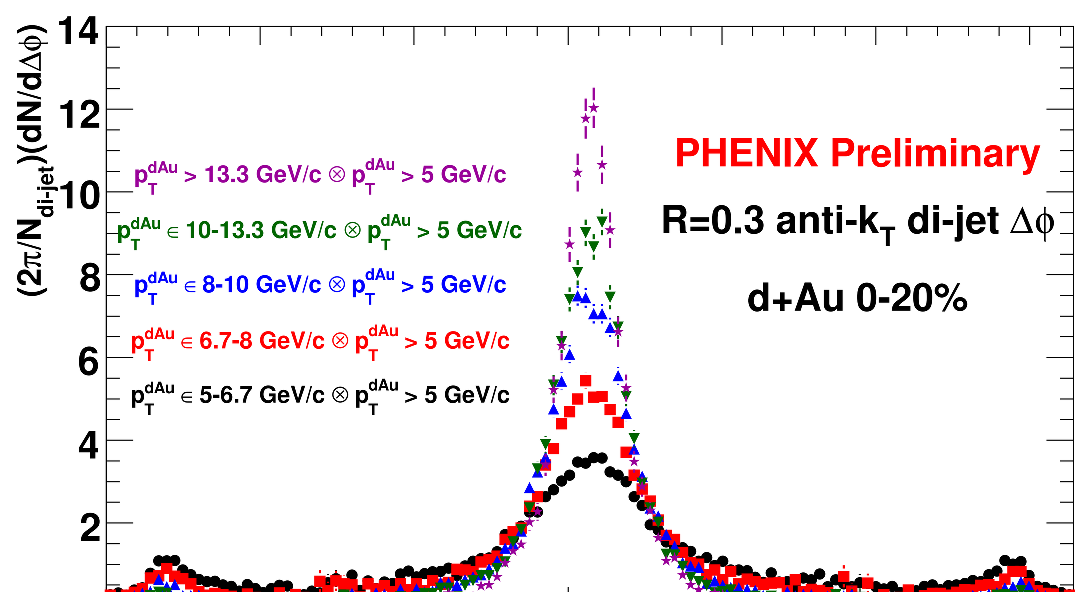

Figure 4: R=0.3 anti-$k_{\rm T}$ di-jet $\Delta\phi$ correlations, for an example centrality bin (0-20%)

7. FUTURE WORK

Future improvements in analysis techniques will lower systematics and allow more precise measurements over a wider $p_{\rm T}$ reach, including:

- Extend the $p_{\rm T}$ reach of $R_{\rm CP}$ measurements to lower $p_{\rm T}^{rec}$ using shape-based fake jet rejection and a comparison to Gaussian filter[5] reconstruction measurements, and investigate any possible low-$p_{\rm T}^{rec}$ enhancement or other behavior.
- Measure the R_{dA} for jets and investigate the absolute magnitude of cold nuclear matter effects by analyzing the 2008 p+p @ $\sqrt{s} = 200$ GeV data at PHENIX. Since this data is from the same experimental run as the d+Au data, many of the systematics are expected to cancel.
- Correct for detector effects by unfolding the measured anti-$k_{\rm T}$ $p_{\rm T}^{dAu}$ spectrum back to the ideal hadron $p_{\rm T}^{truth}$ level.
- Better constrain centrality-dependent physical broadening effects in di-jets by subtracting the combinatoric jet contribution in di-jet correlations.

This analysis is also in preparation for future jet reconstruction work in heavier systems (such as Au+Au collisions) using the PHENIX Silicon Vertex Tracker (VTX)[6], installed for the spring 2011 run. The VTX will reduce background in single electron and high-$p_{\rm T}$ hadron measurements, distinguish heavy flavor decays, and increase the η and ϕ acceptance nearly four-fold and two-fold, respectively.

8. REFERENCES

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