Exploring cold nuclear matter effects in d+Au with high-p_T reconstructed jets at PHENIX

Dennis V. Perepelitsa (for the PHENIX Collaboration)[1]

Columbia University in the City of New York, New York, NY 10027, USA
Nevis Laboratories, Irvington, NY 10533, USA

Abstract

Proton-nucleus (p+A) collisions can be used to investigate cold nuclear matter effects on hard-scattered partons and serve as an important baseline for heavy-ion collisions. In particular, p+A collisions at different centrality selections can probe the impact parameter dependence of nuclear parton distribution functions, initial state energy loss and final state parton interactions in the cold nucleus. Jet reconstruction can better determine the initial parton kinematics and recent improvements in analysis techniques allow the exploration of these effects over a wide p_T range. We present the latest jet reconstruction measurements performed with the PHENIX detector at RHIC in deuteron-gold (d+Au) collisions at 200 GeV using the Gaussian filter algorithm and discuss the possible implications on descriptions of cold nuclear matter.

1. Introduction

Jet reconstruction in proton-nucleus (p+A) and deuteron-nucleus (d+A) collisions at the LHC and at RHIC can probe cold nuclear matter effects (CNM), such as initial state energy loss and modification of nuclear parton distribution functions (nPDFs), on high-p_T hard-scattered partons. These experiments are a crucial baseline for measuring the effects of the hot nuclear medium on jet production. Additionally, they test our understanding of perturbative QCD and effects such as Cronin enhancement.

At RHIC, reconstructed jets in d+Au collisions can explore CNM effects and serve as a control experiment for the jet suppression observed in Cu+Cu collisions [2]. The nuclear modification factors, R_{dA} and R_{CP}, quantify the deviation of jet production in d+Au collisions from the expectation of geometric scaling. The R_{dA} (R_{CP}) is defined as the ratio of jet yields in d+Au collisions at a given centrality relative to a scaled p+p reference (relative to peripheral collisions),

$$R_{\mathrm{dA}}^{cent} = (1/N_{\mathrm{evt}}^{cent})(dN^{\mathrm{cent}}/dp_{\mathrm{T}})/\left\langle T_{\mathrm{AB}}^{cent}\right\rangle(d\sigma^{\mathrm{p+p}}/dp_{\mathrm{T}}) \quad (1)$$

$$R_{\mathrm{CP}}^{cent} = (1/N_{\mathrm{coll}}^{cent})(1/N_{\mathrm{evt}}^{cent})(dN^{\mathrm{cent}}/dp_{\mathrm{T}})/(1/N_{\mathrm{coll}}^{peri})(1/N_{\mathrm{evt}}^{peri})(dN^{\mathrm{peri}}/dp_{\mathrm{T}}), \quad (2)$$

where T_{AB}^{cent} is the nuclear overlap function and N_{coll} is the mean number of nucleon-nucleon collisions derived from a Glauber simulation of d+Au collisions for each centrality bin. In the absence of any CNM effects, $R_{\mathrm{CP}} = R_{\mathrm{dA}} = 1$ is expected.

[1] A list of members of the PHENIX Collaboration and acknowledgements can be found at the end of this issue.

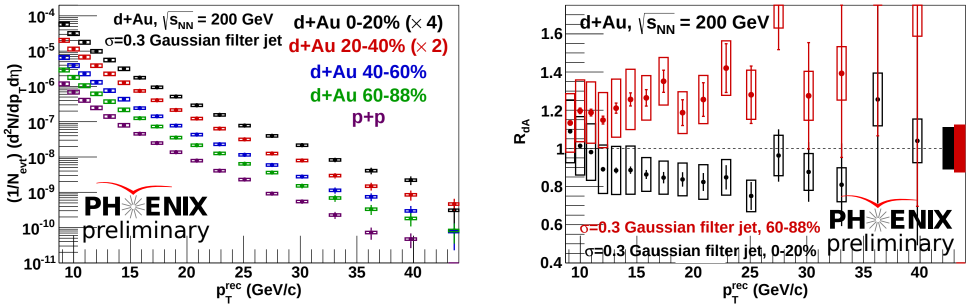

Figure 1: **Left:** $\sigma = 0.3$ Gaussian filter jet yields in p+p and d+Au collisions as a function of detector-scale reconstructed p_{T}. **Right:** Reconstructed jet R_{dA} for 0 – 20% and 60 – 88% collisions. Systematic uncertainty from the normalization is plotted as a vertical bar at the right edge of the axis.

2. Experimental setup

This analysis uses the PHENIX East arm spectrometer, which covers a pseudorapidity range of $-0.35 < \eta < +0.35$ and has an azimuthal acceptance of $\Delta\phi = \pi/2$. Charged tracks from charged hadrons and electrons are reconstructed using the drift chamber (DC), pad chamber (PC) and ring-imaging Čerenkov detector (RICH). Electromagnetic clusters from photons, π^0s and other neutral hadrons are measured by the electromagnetic calorimeter (EMCal). Clusters are required to have a time of flight within a $\pm 5\sigma_{tof}$ window of a light-speed particle, where σ_{tof} is the timing resolution of the calorimeter towers. Tracks and clusters are required to have $p_{\mathrm{T}} > 400$ MeV/c. When a charged track is associated with a neutral cluster, only the track (which better captures the momentum of the charged hadron) is ultimately used.

The data presented here were taken by the PHENIX detector in p+p and d+Au collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV in 2008. Minimum bias collisions are used to evaluate and extrapolate the performance of the high-p_{T} Electromagnetic/RICH Trigger (ERT), which requires $> 2.1(1.6)$ GeV within a 4×4 calorimeter tower window ($\Delta\eta\times\Delta\phi = 0.04\times0.04$) in the PbSc (PbGl) sectors of the EMCal. Efficiency-corrected, trigger-selected data is used to construct the final jet yields.

3. Methodology

Jets are reconstructed with the Gaussian filter algorithm (parameter $\sigma = 0.3$), a seedless, cone-like, infrared- and collinear-safe algorithm with a Gaussian weighting of energy deposits around the jet axis [3]. The continuous angular weighting stabilizes the jet axis in the presence of background and optimizes the signal to background ratio (S/B) by focusing on the energetic core of the jet. Reconstructed jets are required to have three or more constituents within a 30° solid angle of the jet axis and must also pass a fiducial cut requiring that they lie $\Delta\eta, \Delta\phi > 0.05$ units away from any edge of the PHENIX East arm acceptance.

Reconstructed jets are required to have $p_{\mathrm{T}} > 9$ GeV/c, where the fake rate in d+Au collisions is determined from data to be $< 5\%$. Furthermore, the reconstructed p_{T} can be smeared by the presence of the soft underlying event. To quantify the extent of this effect, Monte Carlo (MC) jets are embedded into d+Au minimum bias data and the jet energy before and after embedding

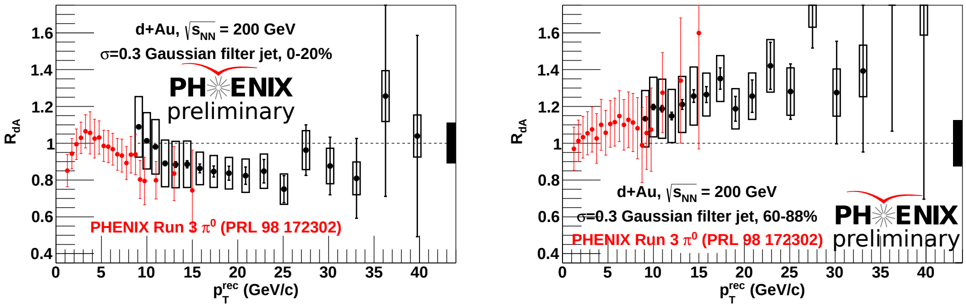

Figure 2: σ = 0.3 Gaussian filter jet R_{dA} for 0 – 20% (**left**) and 60 – 88% (**right**) collisions as a function of the detector-scale reconstructed p_T (black points), compared to previous π^0 R_{dA} from the RHIC 2003 run (red points, [4]). Systematic uncertainty from the normalization is plotted as a vertical bar at the right edge of the axis.

is compared. The reconstructed jet yields are statistically corrected in each centrality class to the p+p-equivalent yield with a bin-by-bin unfolding.

Minimum Bias events in p+p and d+Au collisions are required to have coincident hits in the beam-beam counters (BBC), good timing, and a reconstructed vertex within 20 cm of the nominal interaction point. It is estimated that the BBC fires on 24.5 ± 2.5% mb of the p+p inelastic cross-section. Examining jet events triggered by the ERT reveals that the BBC fires on 83 ± 2% of the jet production cross-section. The centrality of d+Au collisions is determined by the charge sum in the Au-going BBC, located at $3.1 < \eta < 4.0$. A standard Glauber MC simulation along with a negative binomial distribution description of the BBC signal is used to describe the data. This procedure determines that the minimum bias trigger is sensitive to 88% of the d+Au cross-section. The most central and peripheral centrality bins, along with their mean N_{coll} values, are 0-20% ($\langle N_{coll}\rangle = 15.1 \pm 1.0$) and 60-88% ($\langle N_{coll}\rangle = 3.2 \pm 0.2$). An additional correction to the jet yields is applied to account for autocorrelations between an increase in the BBC signal and jet production at midrapidity. This correction is −6% (+3%) in 0 – 20% (60 – 88%) events.

Several potentially important sources of systematic uncertainty are included in the results shown here, including the extraction of the trigger efficiency for jets and unfolding the d+Au yields to the p+p-equivalent detector scale. Although a strong effort has been made to ensure a constant acceptance and detector response, a p_T-independent systematic uncertainty is added to the R_{dA} to account for any residual differences in the geometric acceptance and energy scale between the d+Au and p+p parts of the RHIC run. Additionally, an upper limit on the residual fake rate from 9 – 12 GeV/c is used as a systematic error. Finally, the uncertainties on the $\langle N_{coll}\rangle$ values and the trigger efficiency in p+p collisions are added to the total systematic uncertainty.

4. Results

The reconstructed Gaussian filter jet yields in d+Au and p+p collisions and the R_{dA} from p_T = 9 to 40 GeV/c are shown in Figure 1 at the p+p-equivalent detector energy scale. At 9 GeV/c, both R_{dA} values are consistent with 1, indicating no CNM effects within sensitivity. The R_{dA} evolves with increasing p_T. For the most central 0 – 20% events, the $R_{dA} \approx 0.85 \pm 0.10$ at high-p_T. For the most peripheral 60 – 88% events, the R_{dA} rises to $\approx 1.3 \pm 0.1$ and remains constant within the statistical uncertainties up to 40 GeV/c.

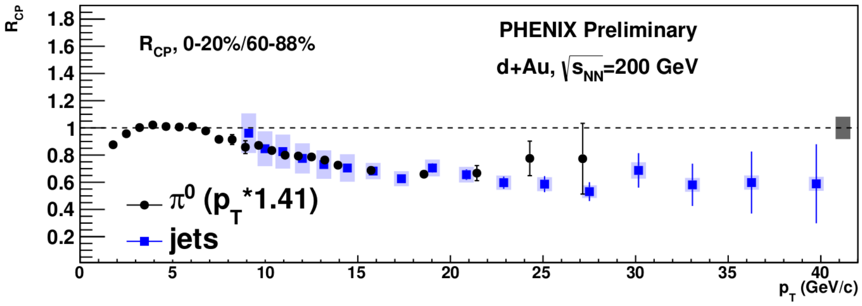

Figure 3: $\sigma = 0.3$ Gaussian filter jet R_{CP} (blue) compared with new π^0 results from PHENIX [5] (black). The π^0 p_T has been scaled by an empirical factor $1/\langle z\rangle$, where $\langle z\rangle = 0.7$ is a typical leading hadron momentum fraction. Systematic uncertainty from the $\langle N_{coll}\rangle$ is plotted as a vertical bar at the right edge of the axis.

Figure 2 compares the R_{dA} of reconstructed jets to that of π^0's measured in PHENIX during the RHIC 2003 d+Au run. The π^0 central (peripheral) R_{dA} hint at a mild suppression (moderate enhancement) at high-p_T. The reconstructed jet results confirms this behavior out to 40 GeV/c.

The reconstructed jet R_{CP} is shown in Figure 3 and has significantly reduced systematic uncertainties since it does not require a p+p baseline. The R_{CP} decreases smoothly as a function of p_T and reaches the asymptotic value of 0.6 ± 0.1 for $p_T > 20$ GeV/c, indicating a moderate modification of jet production from the geometric scaling expectation. Figure 3 compares this result to the R_{CP} for an updated PHENIX π^0 measurement which confirm the excess jet production in peripheral collisions relative to central ones. Additionally, both measurements an $R_{CP} \approx 1$ at low p_T (< 10 GeV/c), indicating no centrality-dependent relative modification of jet production.

5. Summary

PHENIX has measured reconstructed Gaussian filters jets in d+Au and p+p collisions from the RHIC 2008 run. The increased ($\approx 30\times$) d+Au statistics and use of jet reconstruction have greatly extended the kinematic reach of earlier d+Au measurements performed with single hadrons, allowing measurements of modified high-p_T jet production.

At moderate p_T ($\approx$ 10 GeV/c), jet production is consistent with the geometric scaling expectation. However, high-p_T jets are mildly suppressed ($R_{dA} \approx 0.85 \pm 0.10$) in central collisions and moderately enhanced ($R_{dA} \approx 1.3 \pm 0.1$) in peripheral collisions relative to the geometric scaling expectation. The strong centrality dependence in these data motivate the consideration of new effects in addition to initial state energy loss or the centrality-dependent modifcation of nPDFs. In particular, although the rising peripheral R_{dA} is also observed in new PHENIX π^0 and η^0 measurements [5], further work is needed to determine whether it is due to physics effects or a potential bias in the centrality classification of events with high-p_T particles.

References

[1] J. W. Cronin et al. Phys. Rev. D 11 (1975) 3105
[2] Y.S. Lai (PHENIX Collaboration), Nucl. Phys. A, 855 (2010), p. 295
[3] Y.S. Lai, B.A. Cole, nucl-ex/0806.1499
[4] S. S. Adler et al. (PHENIX Collaboration), Phys. Rev. Lett. 98, (2007) 172302
[5] B. Sahlmueller, these proceedings