Nuclear $k_T$ in d+Au Collisions from Multiparticle Jet Reconstruction at STAR

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Abstract. This paper presents the most recent nuclear $k_T$ measurements from STAR derived from multiparticle jet reconstruction of d+Au and p+p collisions at $\sqrt{s} = 200$ GeV. Since jets reconstructed from multiple particles are relatively free of fragmentation biases, nuclear $k_T$ can be measured with greater certainty in this way than with traditional di-hadron correlations. Multi-particle jet reconstruction can also be used for a direct measurement of the fragmentation function.

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1. Introduction

Many analyses of Au+Au collisions at RHIC probe the dense medium using jets by studying medium modifications of the jet yields and jet shapes [1]. The results from d+Au and p+p collisions provide the baseline for medium modification studies in Au+Au collisions. For these simpler systems, jets can be examined in great detail via full jet reconstruction.

This study presents the most recent d+Au nuclear $k_T$ measurements from full jet reconstruction at RHIC based upon year 2003 STAR data. The transverse and longitudinal jet shapes characterized by the $j_T$, and $z$ distributions from p+p collisions are also presented. $k_T$ measures the transverse momentum of a parton within a nucleon or nucleus, and its growth from p+p to nuclear collisions is believed to contribute to the Cronin effect [2].
2. Experiment

The STAR detector is well suited for investigating jet production at RHIC, due to the complete $\phi$ coverage and large $\eta$ coverage of the TPC and EMC. The STAR Barrel EMC data used in this study provide neutral energy measurements including $\pi^0$ decay photons. During the 2003 RHIC run, only half of the full barrel EMC was installed. This first half of the detector consists of 2400 towers of $0.05 \otimes 0.05$ in $\eta \otimes \phi$ each, leading to full azimuthal coverage in $0 < \eta < 1$. The barrel EMC was read out in minimum bias events. It was also used to trigger on “high tower” events, where one of the towers was above a nominal energy threshold of $E_T > 2.5$ GeV. This “high tower” triggered event sample contains a much larger fraction of jets than the minimum bias event sample.

![Figure 1. Average difference between the simulated parton $E_T$ and the total reconstructed jet $E_T$. The gray region outlines the 1-standard deviation spread of this average difference.](image)

This analysis uses two different algorithms that reconstruct a jet by capturing the spray of fragmenting particles in a geometric cone. One centers the cone on the most energetic hadrons in the event, while the other optimizes the cone direction to maximize the included energy. Only the hadron centered cone algorithm is robust enough at high multiplicity to be used for reconstructing jets in d+Au collisions.

Measurement of jet energy requires corrections for charged particle energy deposition in the EMC, for the finite efficiencies of the TPC and EMC, and for the unmeasured energy carried by long-lived neutral particles ($n$, $K_L$, ...). It is also possible for the jet reconstruction algorithm to miss soft particles.

A sample of PYTHIA\(^1\) events processed by the STAR detector simulator was analyzed in the same fashion as the data. Since the originating parameters for each parton were recorded in the monte-carlo PYTHIA sample, the energy scale response of the STAR detector could be quantified. Figure 1 shows the total energy scale correction for jet radii of 0.7 and 0.5 as a function of $E_{T(\text{Uncorrected})}$. From here on, $E_T$ will exclusively refer to reconstructed transverse jet energy, corrected for detector energy response using the curves in Figure 1.

\(^1\)PYTHIA version 6.203 and 6.205.
3. Inclusive Jet Studies

Fig. 2. The left panel shows jet $j_T$, the transverse component of the hadron momentum ($p_h$) relative to the jet axis, for charged hadrons. The upper (lower) data and grey PYTHIA monte-carlo histograms refer to hadron $p_h > 0.6$ GeV/c ($p_h > 2.0$ GeV/c). For $p_h > 2.0$ GeV/c, RMS $j_T = 486 \pm 36$ MeV. The right panel shows $p_h/E_T$ for charged hadrons. The black data points and monte-carlo histogram are for $6.0 < E_T < 7.0$ GeV. The grey data points are for $7.0 < E_T < 9.0$ GeV. The upper range PYTHIA monte-carlo curve is statistically consistent with the lower, and is not shown.

Jets in this study are required to pass the following cuts: number charged hadrons > 1, Cone Radius=0.5, $E_{neutral}/E_{charged} < .65$, and jet thrust axis > 40(70) cm from the inside(outside) of the BEMC (roughly $2 < \eta < .65$ depending on z-Vertex). When analyzing jet shape, the perpendicular component of the hadron momentum ($j_T$), and the fragmentation fraction $z$, are generally used. Figure 2 shows jet $j_T$ and $p_h/E_T$ distributions using these cuts. Jets with high hadron count are biased toward higher detector energy response. The $p_h/E_T$ distribution, since it is a per hadron distribution, is biased toward jets with high hadron count. This means $p_h/E_T$ is not directly comparable to the theoretical fragmentation function $D_h(z)$, due to the bias introduced by the high hadron count jets. However, the substantial agreement between PYTHIA and the data demonstrates that the phenomenological parameterizations embodied by PYTHIA continue to be valid at these jet energies.

The di-jet opening angle is another basic observable obtained from jet events. For di-jets, $\Delta \phi = \pi$ in leading order QCD. Gluon radiation broadens $\Delta \phi$, which is measured by the per-parton intrinsic $k_T \equiv E_T \sin \Delta \phi$. When reconstructing di-jets, one “trigger” jet with observed $E_T > 7$ GeV is reconstructed from both neutral and charged hadrons using the high tower which triggered the event. The other “away” jet direction is reconstructed using charged particles only, allowing the “away” jet to range $-0.5 < \eta < 0.5$. The “away” jet is not used to estimate jet energy scale.

Figure 3 shows the di-jet $k_T$ distribution comparison for p+p and d+Au collisions. The p+p collisions have been supplemented with d+Au minbias background such that the multiplicity distributions of the supplemented p+p events matches that of the d+Au “high tower” sample. Taking $\sigma^2_{kT(obs)} = \sigma^2_{kT(pp)} + \sigma^2_{kT(nucl)}$, the
\sqrt{\sigma_{kT(nucl)}^2} = 1.21 \pm 0.35 \pm 0.65 \text{ GeV/c} \text{ in } d+Au \text{ collisions. The major systematic uncertainties are the jet energy scale in } p+p \text{ and } d+Au, \text{ the detector resolution, fit uncertainties, and } d+Au \text{ background multiplicity. The fit uncertainties are largest. The systematic error on the } d+Au \sigma_{kT(nucl)} \text{ due to the detector } kT \text{ resolution is small. In contrast, it is potentially large for the absolute measurement of } \sigma_{kT(pp)}, \text{ and this effect is currently under study.}

**Fig. 3.** $k_T$ distributions at $\sqrt{s} = 200 \text{ GeV}$. $d+Au \ k_T$ is shown in black, and $p+p$ supplemented with $d+Au$ background is shown in grey. Here $k_T$ has been corrected for energy but not thrust axis resolution.

4. Conclusion

Jets have been reconstructed in both $p+p$ and $d+Au$ collisions. The $p+p$ jets have been used to measure $j_T$, $z$ and $k_T$. The inclusive jet $j_T$ and $z$ results compare well with the PYTHIA monte-carlo simulation studies. The $d+Au \ k_{T(nucl)}$ value, though having large uncertainty, appears to be smaller than previous experiments [4] at much lower energy. The $\langle j_T \rangle$ and \( \langle k_T^2 \rangle \) results from full jet reconstruction agree well with similar measurements using di-hadron correlations [3].

References

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