Measurement of $\gamma$+jet and $\pi^0$+jet in central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV with the STAR experiment

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We present the semi-inclusive measurement of charged jets recoiling from direct-photon and $\pi^0$ triggers in central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV, using a dataset with integrated luminosity 13 nb$^{-1}$ recorded by the STAR experiment in 2014. The photon and $\pi^0$ triggers are selected within transverse energy ($E_{T}^{\text{trig}}$) between 9 GeV and 20 GeV. Charged jets are reconstructed with the anti-$k_T$ algorithm with resolution parameters $R = 0.2$ and 0.5. A Mixed-Event technique developed previously by STAR is used to correct the recoil jet yield for uncorrelated background, enabling recoil jet measurements over a broad $p_{T,\text{jet}}$ range. We report fully corrected charged-jet yields recoiling from direct-photon and $\pi^0$ triggers for the above two jet radii and also discuss the jet $R$ dependence of in-medium parton energy loss at the top RHIC energy.

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Jet quenching arises from partonic interactions in the Quark-Gluon Plasma (QGP) formed in heavy-ion collisions [1]. A valuable observable to probe the QGP is the coincidence of a reconstructed jet recoiling from a high transverse energy (high $E_T^{\text{trig}}$) direct photon ($\gamma_{\text{dir}}$) [2], since $\gamma_{\text{dir}}$ does not interact strongly with the medium. A comparison of $\gamma_{\text{dir}}$+jet and $\pi^0$+jet measurements may elucidate the color factor and path-length dependence of jet quenching [3]. In addition, a comparison of recoil jet distributions with different cone radii provides a probe of in-medium jet broadening.

In these proceedings, we present the analysis of fully-corrected semi-inclusive distributions of charged jets recoiling from high-$E_T^{\text{trig}}$ $\gamma_{\text{dir}}$ and $\pi^0$ triggers in central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The data were recorded during the 2014 RHIC run with a trigger requiring an energy deposition greater than 5.6 GeV in a tower of the STAR Barrel Electromagnetic Calorimeter (BEMC), corresponding to an integrated luminosity of 13 nb$^{-1}$. We compare the measured recoil jet yield in Au+Au collisions to a $pp$ reference via PYTHIA simulation and corresponding yield suppression is then further compared with theoretical calculations. We express the suppression in terms of jet energy loss and compare to other in-medium jet measurements at RHIC and the LHC.

The offline analysis selects events corresponding to the 0-15% most central Au+Au collisions, based on uncorrected charged-particle multiplicity within $|\eta| < 1$. The BEMC Shower Max Detector (BSMD) was used offline to select clusters in the range $9 < E_T^{\text{trig}} < 20$ GeV that have an enhanced population of direct photons ($\gamma_{\text{rich}}$) or $\pi^0$ ($\pi^0_{\text{rich}}$). A Transverse Shower Profile (TSP) method is used to discriminate between $\pi^0_{\text{rich}}$ and $\gamma_{\text{rich}}$ triggers [3]. The purity of direct photons in the $\gamma_{\text{rich}}$ sample is 65–85% in the range $9 < E_T^{\text{trig}} < 20$ GeV. The final corrections are applied on both $\gamma_{\text{rich}}$ and $\pi^0_{\text{rich}}$ to get the fully corrected recoil jet yields. Charged jets are reconstructed with the anti-$k_T$ algorithm [4, 5] for $R = 0.2$ and 0.5, using charged particle tracks measured in the Time Projection Chamber (TPC) with $0.2 < p_T < 30$ GeV/c and $|\eta| < 1$. The jet acceptance is $|\eta_{\text{jet}}| < 1-R$.

Recoil jets are selected with a $\Delta \phi \in [3\pi/4, 5\pi/4]$, where $\Delta \phi$ is the azimuthal angle between the trigger cluster and the jet axis. The semi-inclusive distribution is defined as the yield of recoil jets in a bin of transverse momentum ($p_{T,\text{jet}}^{\text{ch}}$) normalized by the number of triggers. The uncorrelated background jet yield in this distribution is corrected using the Mixed-Event (ME) technique developed in [6]. Corrections to the recoil jet distributions for instrumental

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**Figure 1:** Semi-inclusive distributions of charged jets recoiling from $\gamma_{\text{dir}}$ (upper) and $\pi^0$ (lower) triggers. Light and dark bands represent systematic and statistical uncertainties, respectively. Broken and dotted lines represent calculations based on PYTHIA-8 and PYTHIA-6 STAR tune.
effects and residual $p_{T,jet}^{ch}$ fluctuations due to background are carried out using unfolding methods. The main systematic uncertainties arise from unfolding, ME normalization, and $\gamma_{dir}$ purity.

Due to limited trigger statistics in the current analysis of STAR $pp$ data, the reference distribution from $pp$ collisions is calculated using the PYTHIA event generators. For $\gamma_{dir}$-triggered distributions, both PYTHIA-8 [7] and PYTHIA-6 STAR tune [8] events are used, whereas for $\pi^0$-triggered distributions only PYTHIA-8 is used.

Figure 2: $p_{T,jet}^{\gamma_{dir}}$ vs. $p_{T,jet}^{ch}$ for $\gamma_{dir}$ triggers (red) and $\pi^0$ triggers (blue) with $9 < E_{T,jet}^{\pi^0} < 11$ GeV (upper) and $11 < E_{T,jet}^{\pi^0} < 15$ GeV (lower) and for jets with $R = 0.2$ (left) and 0.5 (right). Light and dark bands represent systematic and statistical uncertainties.

Figure 3: $\gamma_{dir}$+jet: $p_{T,jet}^{\gamma_{dir}}$ (upper) and $p_{T,jet}^{\pi^0}$ (lower) vs. $p_{T,jet}^{ch}$ for $15 < E_{T,jet}^{\gamma_{dir}} < 20$ GeV and jets with $R = 0.2$ (left) and 0.5 (right). Light and dark bands represent systematic and statistical uncertainties. Theory calculations: Jet-fluid [9], LBT [10], and SCET [11].

Figure 1 shows fully corrected charged-jet $p_T$ spectra for $R = 0.2$ and 0.5 recoiling from $\gamma_{dir}$ in three $E_{T,jet}^{\gamma}$ bins, and $\pi^0$ in two $E_{T,jet}^{\pi^0}$ bins, measured in central Au+Au collisions and compared to those calculated by PYTHIA for $pp$ collisions. The two PYTHIA versions exhibit negligible difference for $R = 0.2$ and up to 40% difference for $R = 0.5$. The ratio of recoil jet yield measured in Au+Au collisions to PYTHIA calculations for $pp$ collisions are denoted as $p_{T,jet}^{\gamma_{dir}}$ and $p_{T,jet}^{\pi^0}$ for the two versions of PYTHIA used.

Figure 2 shows $p_{T,jet}^{\gamma_{dir}}$ for $\gamma_{dir}$ and $\pi^0$ triggers in $9 < E_{T,jet}^{\pi^0} < 15$ GeV for $R = 0.2$ and 0.5. The recoil jet yields show similar suppression for both triggers for $R = 0.2$, with no significant $E_{T,jet}^{\gamma}$ dependence. Smaller suppression is observed for $R = 0.5$ for both triggers compared to $R = 0.2$. 

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**Figure 4:** Left panel: Ratio of recoil jet yields for $R = 0.2$ and 0.5 as a function $p_{T,jet}^ch$. Upper: $h$+jet and $\pi^0$+jet. Lower: $\gamma$+jet. Right panel: The $p_{T,jet}^ch$ shift (-Δ $p_{T,jet}^ch$) for $\gamma$+jet, $\pi^0$+jet, inclusive jet, h+jet measurements at RHIC, and h+jet at the LHC. Note the different $p_{T,jet}^ch$ ranges.

Figure 3 compares $I_{AA}$ and $I_{AA}$ for $\gamma$+jet triggers with $15 < E_{T,trig} < 20$ GeV. Comparison is also made to theoretical model calculations [9–11], which predict different $p_T$ dependence to those observed in data.

Figure 4, left panel, shows the ratio of recoil jet yields for $R = 0.2$ and 0.5 measured in central Au+Au collisions with both $\gamma$+jet and $\pi^0$+jet triggers. This ratio is sensitive to the jet transverse profile [6, 12]. The $\gamma$+jet-triggered ratio is consistent with a calculation based on the PYTHIA-6 STAR tune, indicating no significant in-medium broadening of recoil jets whereas a notable quantitative difference is observed between Au+Au and PYTHIA-8. The ratios for $\pi^0$ and charged-hadron triggers measured in central Au+Au collisions are consistent within uncertainties.

Jet quenching is commonly measured by yield suppression at fixed $p_T$ ($R_{AA}$ and $I_{AA}$). However, these ratio observables convolute the effect of energy loss with the shape of the spectrum. To isolate the effect of energy loss alone we convert the suppression to a $p_T$-shift, -Δ $p_{T,jet}^ch$, enabling quantitative comparison of jet quenching measurements with different observables, and comparison of jet quenching at RHIC and the LHC. Figure 4, right panel, shows -Δ $p_{T,jet}^ch$ from this measurement, compared to those of inclusive jets and h+jet at RHIC, and h+jet at the LHC [6, 12–14]. The energy loss from the RHIC measurements is largely consistent for the different observables, with some indication of smaller energy loss for $R = 0.5$ than for $R = 0.2$ considering PYTHIA-8 for the vacuum expectation. In addition, the results from $R = 0.2$ measurements at RHIC are comparable to those from inclusive $\pi^0$ [15]. An indication of smaller in-medium energy loss is observed at RHIC than at the LHC.

In summary, we have presented the analysis of semi-inclusive charged-jet distributions recoiling from $\gamma$+jet and $\pi^0$+jet triggers in central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. Significant yield suppression is observed for recoil jets with $R = 0.2$, and a less suppression is seen for $R = 0.5$ using PYTHIA-8 as $pp$ reference. However, the difference between PYTHIA-8 and PYTHIA-6 precludes quantitative conclusions. On the other hand, a definitive conclusion on in-medium jet broadening from the ratio of recoil jet yields at different $R$ can be drawn when the vacuum reference will be resolved by the same measurements in $pp$ collisions at 200 GeV, currently in progress. Theoretical calculations of jet quenching predict a different $p_T$-dependence of the suppression than...
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that observed in data. Conversion of the measured suppression to a $p_T$-shift reveals similar energy loss due to the quenching of various jet measurements at RHIC and an indication of smaller energy loss at RHIC than at the LHC.

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References

[1] X. N. Wang, M. Gyulassy and M. Plumer, Phys. Rev. D 51, 3436-3446 (1995) doi:10.1103/PhysRevD.51.3436 [arXiv:hep-ph/9408344 [hep-ph]].

[2] X. N. Wang, Z. Huang and I. Sarcevic, Phys. Rev. Lett. 77, 231-234 (1996) doi:10.1103/PhysRevLett.77.231 [arXiv:hep-ph/9605213 [hep-ph]].

[3] L. Adamczyk et al. [STAR], Phys. Lett. B 760, 689-696 (2016) doi:10.1016/j.physletb.2016.07.046 [arXiv:1604.01117 [nucl-ex]].

[4] M. Cacciari, G. P. Salam and G. Soyez, JHEP 04, 063 (2008) doi:10.1088/1126-6708/2008/04/063 [arXiv:0802.1189 [hep-ph]].

[5] M. Cacciari, G. P. Salam and G. Soyez, Eur. Phys. J. C 72, 1896 (2012) doi:10.1140/epjc/s10052-012-1896-2 [arXiv:1111.6097 [hep-ph]].

[6] L. Adamczyk et al. [STAR], Phys. Rev. C 96, no.2, 024905 (2017) doi:10.1103/PhysRevC.96.024905 [arXiv:1702.01108 [nucl-ex]].

[7] T. Sjostrand, S. Mrenna and P. Z. Skands, Comput. Phys. Commun. 178, 852-867 (2008) doi:10.1016/j.cpc.2008.01.036 [arXiv:0710.3820 [hep-ph]].

[8] J. Adam et al. [STAR], Phys. Rev. D 100, no.5, 052005 (2019) doi:10.1103/PhysRevD.100.052005 [arXiv:1906.02740 [hep-ex]].

[9] N. B. Chang and G. Y. Qin, Phys. Rev. C 94, no.2, 024902 (2016) doi:10.1103/PhysRevC.94.024902 [arXiv:1603.01920 [hep-ph]].

[10] T. Luo, S. Cao, Y. He and X. N. Wang, Phys. Lett. B 782, 707-716 (2018) doi:10.1016/j.physletb.2018.06.025 [arXiv:1803.06785 [hep-ph]].

[11] M. D. Sievert, I. Vitev and B. Yoon, Phys. Lett. B 795, 502-510 (2019) doi:10.1016/j.physletb.2019.06.019 [arXiv:1903.06170 [hep-ph]].

[12] J. Adam et al. [ALICE], JHEP 09, 170 (2015) doi:10.1007/JHEP09(2015)170 [arXiv:1506.03984 [nucl-ex]].

[13] J. Adam et al. [STAR], [arXiv:2006.00582 [nucl-ex]].

[14] R. Licenik, Hard Probes-2020 proceedings.

[15] A. Adare et al. [PHENIX], Phys. Rev. C 87, no.3, 034911 (2013) doi:10.1103/PhysRevC.87.034911 [arXiv:1208.2254 [nucl-ex]].