Direct photon-hadron correlation measurement and a way towards photon-triggered jets at RHIC

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Abstract. We report the results of $\gamma_{\text{dir}}$- and $\pi^0$–hadron azimuthal correlations as a measure of the away-side jet-like correlated yields in central Au+Au and p+p collisions at $\sqrt{s_{NN}} = 200$ GeV in the STAR experiment. The charged-hadron per-trigger yields at mid-rapidity with respect to high-$p_T$ $\gamma_{\text{dir}}$ and $\pi^0$ in central Au+Au collisions are compared with p+p collisions. Within uncertainties, the same $z_T(p_{\text{assoc}}^T/p_{\text{trig}}^T)$ dependence of the suppression is observed for $\gamma_{\text{dir}}$- and $\pi^0$- triggers. The results are compared with energy-loss model predictions. The $\gamma$–jet measurements can provide further understanding on the redistribution of in-medium energy loss. Ongoing $\gamma$–jet studies in the STAR experiment are also discussed.

1. Introduction
The azimuthal correlation of charged hadrons with respect to a direct-photon ($\gamma_{\text{dir}}$) trigger was proposed as a promising probe to study the mechanisms of parton energy loss [1]. Since a $\gamma_{\text{dir}}$-trigger escapes without interacting with the medium, it approximates the initial energy of the recoil parton, which is subject to medium modifications. The recoil parton of a $\gamma_{\text{dir}}$ trigger is a quark in leading-order QCD processes, whereas that of a high-$p_T$ $\pi^0$ trigger can be a quark or a gluon. In addition, a coincidence measurement of $\pi^0$ is biased to have been produced near the surface of the medium, while that of a $\gamma_{\text{dir}}$ does not suffer from the same bias [2, 3]. Hence the comparison between the suppression of per-trigger away-side associated yields of $\gamma_{\text{dir}}$ to those of $\pi^0$ triggers should exhibit differences due to both the color-factor dependence and the path-length dependence of energy loss.

2. STAR detectors and experimental techniques
The data were taken by the Solenoidal Tracker at RHIC (STAR) experiment in 2011 and 2009 for Au+Au and p+p collisions at $\sqrt{s_{NN}} = 200$ GeV, respectively. The Time Projection Chamber (TPC) is the main charged-particle tracking detector providing track information for the charged hadrons with $|\eta| < 1.0$ [4]. Events having a cluster with transverse energy $E_T > 8$ GeV, with $|\eta| \leq 0.9$, are selected for this analysis in the Barrel Electromagnetic Calorimeter (BEMC) [5]. The associated charged particles are selected in range $1.2$ GeV/$c < p_{\text{assoc}}^T < 20$ GeV/$c$. In order to distinguish a $\pi^0$, which at high $p_T$ predominately decays to two photons with a small opening angle, from a single-photon cluster, a transverse shower-shape analysis is performed. A detailed discussion about the transverse shower profile (TSP) method and experimental techniques used in this analysis can be found in Ref. [6, 7].
Figure 1. (Color online.) Left panel: The $z_T$ dependence of $\pi^0$-hadron yield for Au+Au at 0-12% centrality (filled symbols) and $p+p$ (open symbols) collisions at $\sqrt{s_{NN}} = 200$ GeV. Right panel: The $z_T$ dependence of $\gamma_{\text{dir}}$-hadron yield for Au+Au at 0-12% centrality (filled diamonds) and $p+p$ (open diamonds) collisions [6]. Vertical lines represent statistical errors, and the vertical extent of the boxes represents systematic uncertainties.

3. Results: $\gamma_{\text{dir}}$ and $\pi^0$-hadron azimuthal correlation
The integrated away-side and near-side charged-hadron yields per $\pi^0$ trigger, $D(z_T)$, are plotted as a function of $z_T$, both for Au+Au (0-12% centrality) and $p+p$ collisions, in the left panel of Fig. 1. The away-side $D(z_T)$ for $\gamma_{\text{dir}}$ triggers as a function of $z_T$ for central Au+Au and minimum-bias $p+p$ collisions is shown in the right panel of Fig 1. Yields of the away-side associated charged hadrons are suppressed, in Au+Au relative to $p+p$, at all $z_T$ except in the low $z_T$ region both for $\gamma_{\text{dir}}$ and $\pi^0$ trigger. On the other hand, no suppression is observed on the near-side in Au+Au, relative to $p+p$ collisions, due to the surface bias imposed by triggering on a high-$p_T$ $\pi^0$. In order to quantify the medium modification for $\gamma_{\text{dir}}$ and $\pi^0$-triggered recoil jet production as a function of $z_T$, the ratio defined as $I_{AA}^{\gamma_{\text{dir}}} = \frac{D(z_T)^{\gamma_{\text{dir}},\text{Au+Au}}}{D(z_T)^{\gamma_{\text{dir}},p+p}}$, of the per-trigger conditional yields in Au+Au to those in $p+p$ collisions is calculated.

Figure 2. (Color online.) The $I_{AA}^{\gamma_{\text{dir}}}$ for $\gamma_{\text{dir}}$ (red squares) and $I_{AA}^{\pi^0}$ for $\pi^0$ (blue circles) triggers are plotted as a function of $z_T$. The points for $I_{AA}^{\gamma_{\text{dir}}}$ are shifted by +0.03 in $z_T$ for visibility. The vertical line and shaded boxes represent statistical and systematic errors, respectively [6]. The curves represent theoretical model predictions [3, 8, 9, 10].
Figure 3. (Color online.) The values of $I_{AA}^{\gamma_{\text{dir}}}$ are plotted as a function of $p_T^{\text{trig}}$ (left panel) and $p_T^{\text{assoc}}$ (right panel) [6]. The vertical line and shaded boxes represent statistical and systematic errors, respectively. The curves represent theoretical model predictions [3, 8, 9].

Figure 2 shows the away-side medium modification factor for $\pi^0$ triggers ($I_{AA}^{\pi^0}$) and $\gamma_{\text{dir}}$ triggers ($I_{AA}^{\gamma_{\text{dir}}}$), as a function of $z_T$. $I_{AA}^{\pi^0}$ and $I_{AA}^{\gamma_{\text{dir}}}$ show similar suppression within uncertainties. At low $z_T$ ($0.1 < z_T < 0.2$), both $I_{AA}^{\pi^0}$ and $I_{AA}^{\gamma_{\text{dir}}}$ show an indication of less suppression than at higher $z_T$. This observation is not significant in the $z_T$-dependence of $I_{AA}$ because the uncertainties in the lowest $z_T$ bin are large. However, when $I_{AA}$ is plotted vs. $p_T^{\text{assoc}}$ (in Figure 3), the conclusion is supported with somewhat more significance. At high $z_T$, both $I_{AA}^{\pi^0}$ and $I_{AA}^{\gamma_{\text{dir}}}$ show a factor $\sim 3 - 5$ suppression. The ZOWW calculation also predicts $I_{AA}^{\gamma_{\text{dir}}}$ as a function of $p_T^{\text{trig}}$ to be approximately flat in this range [3]. The YaJEM model predicts that at low $z_T = 0.2$, $I_{AA}^{\gamma_{\text{dir}}} = 1$ and rises above unity even at lower $z_T$, although at lower triggered $p_T$ range 9-12 GeV/c.

The values of $I_{AA}^{\gamma_{\text{dir}}}$ are plotted as function of $p_T^{\text{assoc}}$ in Fig. 3. It shows that the low-$p_T^{\text{assoc}}$ hadrons on the away-side are not as suppressed as those at high $p_T^{\text{assoc}}$. Both model predictions shown [3, 8], which do not include the redistribution of lost energy, are in agreement with the data. $I_{AA}^{\gamma_{\text{dir}}}$ shows no sensitivity as a function of $p_T^{\text{trig}}$, for
0.3 < z_T < 0.4, indicating that away-side parton energy loss is not sensitive to the initial energy of the parton in the range of 8-20 GeV/c.

4. Simulation study on γ + jet

We have performed a feasibility study for γ + jet measurement in the kinematic acceptance for the STAR detector system using PYTHIA simulations. The γ-triggered events are generated within 15 < p_T^{trig} < 20 GeV/c and all tracks are selected within 0.2 < p_T^{track} < 20 GeV/c. Recoil full (including all charged and neutral particles) jets are reconstructed using the anti-k_T algorithm [11, 12] for a jet resolution parameter of R = 0.8. Recoil jets are selected within |Δφ − π| < π/4, where |Δφ| is the difference between triggered γ_{dir} and reconstructed jet azimuth. The uncorrelated reconstructed full jets (UE) are selected within 0.2 < p_T^{track} < 20 GeV/c.

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5. Summary and outlook

Within experimental uncertainty, both I^{0}_{AA} and I^{γ_{dir}}_{AA} show similar levels of suppression with the expected differences due to the color-factor effect and the path-length dependence of in-medium energy loss not manifesting themselves. At high z_T(p_{assoc}^{T}), I^{γ_{dir}}_{AA} shows high suppression than at low z_T(p_{assoc}^{T}). There is no trigger-energy dependence observed in the suppression of γ_{dir}-triggered yields, suggesting little dependence for energy loss on the initial parton energy, in the range of p_T^{trig} = 8-20 GeV/c. A semi-inclusive study of jets correlated with high-p_T γ is underway in the STAR experiment to explore more on the jet energy loss in the medium created at RHIC.

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