PROCEEDINGS OF SCIENCE

Jets and high-p_T probes measured in the STAR experiment

Nihar Ranjan Sahoo (for the STAR collaboration)
Texas A&M University, Texas, USA
E-mail: nihar@rcf.rhic.bnl.gov

Hard probes created through large momentum transfers are used to study the properties of QCD matter created in heavy-ion collisions, by comparing the measurements to those in p+p collisions. Jets, and the "quenching" or suppression of jets in the medium created in heavy-ion collisions, are studied through various different observables. We present the most recent measurements from $\sqrt{s_{NN}}$ = 200 GeV Au+Au collisions, with p+p collisions as the reference, by the STAR Collaboration. The observables are semi-inclusive charged jets and di-jet transverse momentum imbalance. Additionally, correlation measurements of direct photon-hadron and neutral pion-hadron are presented and discussed.

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1. Introduction

Jets and high-p_T particles are produced on very short time scales (~ 0.1fm/c) in collisions with large momentum transfer ($p_T > \mathrm{Q}_0 \gg \Lambda_{\mathrm{QCD}}$). Hence they are considered good tomographic probes of the hot and dense QCD medium created in heavy-ion collisions. Over the last decade or so, many compelling measurements, such as the disappearance of away-side jets and high-p_T suppression [1], di-jet suppression [2] and high-p_T suppression balanced by low p_T enhancement in jet-hadron correlation [3] etc., contributed to our understanding of jet quenching in the medium created at RHIC. In these proceedings, I discuss three recent measurements in the STAR experiment: (i) Jet-like direct photon-hadron and π^0-hadron correlations, (ii) di-jet transverse momentum imbalance, and (iii) semi-inclusive recoil charged jets.

2. Jet-like direct photon-hadron and π^0-hadron correlation

The motivation for jet-like direct photon-hadron and π^0-hadron correlation studies is to understand the flavor and path length dependence of parton energy loss in the hot and dense medium [4]. In this analysis, the triggered γ_{dir} and π^0 are selected with 12< p_T^{trig}< 20 GeV/c and charged tracks with 1.2 GeV/c< p_T^{assoc} in order to attain low $z_T(=p_T^{\mathrm{assoc}}/p_T^{\mathrm{trig}})$ values down to 0.1. A detailed discussion and analysis techniques can be found in the Ref. [4]. The suppression of these jet-like yields in central Au+Au collisions is then quantified by comparing to the per-trigger yields measured in p+p collisions, denoting the ratio of integrated yields I_{AA}. The away-side medium modification for γ_{dir} ($I_{AA}^{\gamma_{dir}}$) and π^0 ($I_{AA}^{\pi^0}$) triggers are shown as a function of z_T in Fig. 1. The away side I_{AA} for both triggers has a systematic trend to lower values with increasing z_T though not significant within uncertainties. This observation is somewhat more significant when I_{AA} is plotted as a function of p_T^{assoc} in Fig. 2 (right panel). The expected difference between $I_{AA}^{\gamma_{dir}}$ and $I_{AA}^{\pi^0}$ triggers as in models [5, 6] at low z_T is difficult to observe because of large uncertainties in the data. $I_{AA}^{\gamma_{dir}}$ is plotted for three p_T^{trig} bins ranging from 8 to 20 GeV/c for $0.3 < z_T < 0.4$ in Fig 2 (left panel). It is found that $I_{AA}^{\gamma_{dir}}$ is insensitive to the γ_{dir}-trigger energy in this range at RHIC energy. Further understanding on the redistribution of lost energy in heavy-ion collisions can be explored by measuring the distribution of fully reconstructed recoil jets with respect to a γ_{dir}-trigger. Such a measurement of charged and full jets is underway in the STAR experiment.

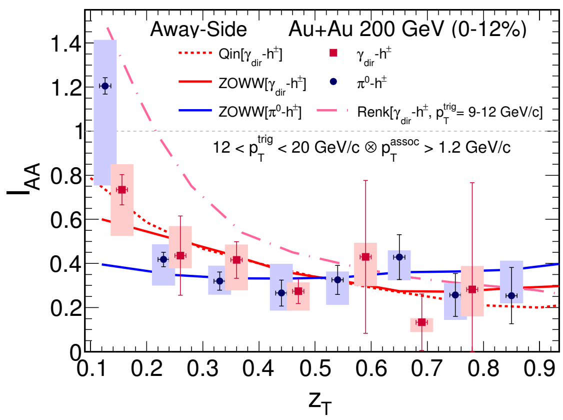

Figure 1: (Color online.) The I_{AA} for γ_{dir} (red squares) and π^0 (blue circles) triggers are plotted as a function of z_T. The points for I_{AA} for γ_{dir} are shifted by $+0.03$ in z_T for visibility. The vertical line and shaded boxes represent statistical and systematic errors, respectively [4]. The curves represent theoretical model predictions [5, 6, 7, 8].

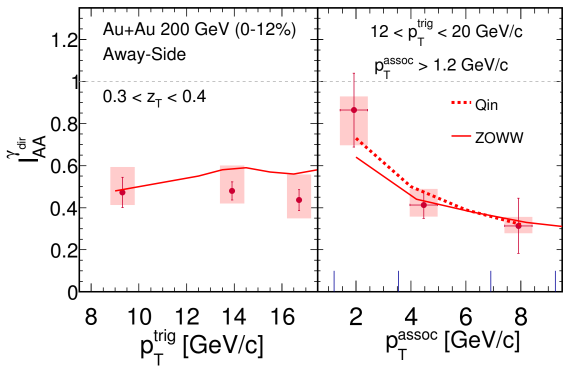

Figure 2: (Color online.) $I_{AA}^{\gamma_{dir}}$ are plotted as a function of $p_T^{\rm trig}$ (left panel) and $p_T^{\rm assoc}$ (right panel). The vertical line and shaded boxes represent statistical and systematic errors, respectively. The curves represent theoretical model predictions [5, 6, 7].

3. Semi-inclusive recoil charged jets

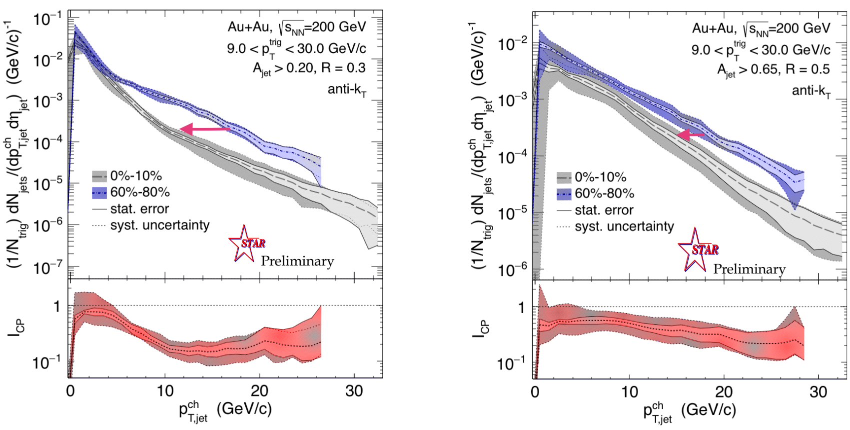

Figure 3: (Color online.) Upper panels: Corrected charged recoil jet $p_{T,jet}^{ch}$ distributions for peripheral and central Au+Au collisions for R=0.3 (left) and R=0.5 (right). Arrow represents level of horizontal shift in $p_{T,jet}^{ch}$ spectra (guide to eyes) [11]. Lower panels: I_{CP} for R=0.3 (left) and R=0.5 (right).

A new jet measurement performed in the STAR experiment is the semi-inclusive charged jet spectrum on the recoil side of a high-p_T charged-hadron trigger. The reconstructed charged recoil jets are termed as semi-inclusive, since the triggered hadron p_T is not inclusive (within $9 < p_T^{\rm trig} < 30$ GeV/c). This type of measurement is very challenging owing to the high-multiplicity environment and underlying background fluctuations in heavy-ion collisions. A novel mixed-event technique was used for correcting uncorrelated jet background from the reconstructed jets by a statistical subtraction method [10, 11]. One trigger hadron is selected randomly in the above p_T range and charged jets (consisting of charged tracks with p_T > 0.2 GeV/c) are reconstructed using the anti-k_T algorithm for a given resolution parameter (R = 0.3 and 0.5 for these results). The recoil jet acceptance is in $|\pi - \Delta\phi| < \pi/4$. The estimated background energy density (ρ) scaled by jet area (A) is subtracted from each reconstructed jet raw transverse momentum ($p^{raw}_{T,jet}$), $p^{reco}_{T,jet} = p^{raw}_{T,jet} - \rho A$. This reconstructed jet $p^{reco}_{T,jet}$ spectrum is then corrected by subtracting that of mixed-events. This raw correlated distribution is finally corrected by an unfolding procedure for instrumental effects and p_T-smearing due to the background. The upper panels of Fig. 3 show the semi-inclusive corrected and recoil charged jet transverse momentum ($p^{ch}_{T,jet}$) spectra for peripheral and central Au+Au collisions for R=0.3 and 0.5. Significant suppression in central vs. peripheral, via the medium modification, I_{CP}, is observed for $p^{ch}_{T,jet} > 10$ GeV/c in case of R=0.3 and R=0.5. The horizontal shift in $p^{ch}_{T,jet}$ spectra in central compared with peripheral for R=0.3 indicates that the jet energy is transported out of the cone due to the *jet-quenching effect*. This horizontal shift is -2.3 ± 0.2 GeV/c for R=0.5 and -5.0 ± 0.5 GeV/c for R=0.3 with $p^{ch}_{T,jet} > 10$.

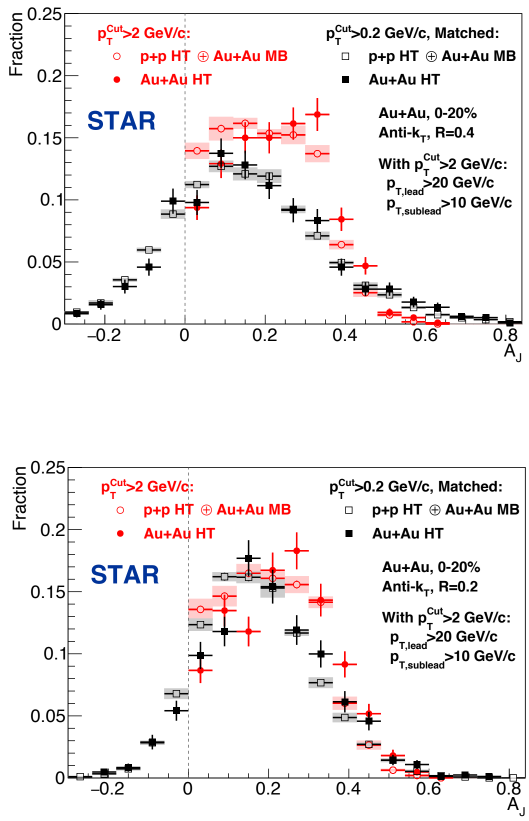

Figure 4: (Color online.) Normalized A_J distributions for Au+Au HT data (filled symbols) and p + p HT ⊕ Au+Au MB (open symbols). The red circles points are for jets found using only constituents with $p_T^{\rm Cut} >$ 2 GeV/c and the black squares for matched jets found using constituents with $p_T^{\rm Cut} > 0.2$ GeV/c [14, 15]. Upper panel: for R = 0.4. Lower panel: for R = 0.2.

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4. Di-jet transverse momentum imbalance

Di-jet measurement has been performed in the STAR experiment to understand the emission of soft particles with respect to the di-jet axis by measuring the di-jet transverse momentum (p_T) imbalance. The di-jet p_T imbalance observable is defined as $A_J = (p_{T,lead} - p_{T,sublead})/(p_{T,lead} + p_{T,sublead})$. Where $p_{T,lead}$ and $p_{T,sublead}$ are the p_T of the leading and sub-leading jets, respectively. Events were required to have a high tower trigger (HT) with an uncorrected transverse energy of $E_T > 5.4$ GeV in the barrel electromagnetic calorimeter (BEMC) towers. In these HT events, A_J is calculated using $p_{T,lead} > 20$ GeV/c and $p_{T,sublead} > 10$ GeV/c with $|\phi_{lead} - \phi_{sublead} - \pi| < 0.4$. Full jets are reconstructed using charged tracks measured in the TPC and neutral tracks information recored in the BEMC using the anti-k_T algorithm [12, 13]. Details of the technique used in this analysis can be found in Ref. [14, 15].

The upper panel of Fig. 4 shows the normalized distributions of A_J for R=0.4 in Au+Au HT events compared with p+p HT $\oplus$ Au+Au MB events (events of p+p HT embedded into Au+Au 0-20% central events of minimum bias data sample) for constituents $p_T > 2$ GeV/c. It is observed that di-jets in Au+Au HT are significantly imbalanced compared with p+p HT $\oplus$ Au+Au MB events. This behavior is further studied by including soft particles p_T >0.2 GeV/c in jet reconstruction and then performing a geometrical matching ($\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2} < R$) with the initial hardcore di-jets. The di-jet imbalance is restored by including soft particles for jet cone parameter R=0.4. A similar study is also performed using R=0.2, and the A_J distributions are shown in the lower panel of Fig. 4. It shows that the di-jet p_T imbalance can not be restored including soft particles for R=0.2. The above observations indicate that the studied selection of "hard core" di-jets clearly experiences medium modification, but in contrast to corresponding LHC measurements, the redistributed energy is still contained within the original $R = 0.4$ cone. With a smaller cone size, balance cannot be recovered, suggestive of broadening of the jet structure compared with p+p collisions.

5. Summary

The STAR experiment recently measured the following three jet observable to study the hot and dense matter created at RHIC.

- Jet-like direct photon-hadron and π^0-hadron correlations: Both $I_{AA}^{\gamma_{dir}}$ and $I_{AA}^{\pi^0}$ show similar levels of suppression. The expected differences due to the color factor and path length dependence are not observed within current experimental uncertainties. At top RHIC energy, no $\gamma_{\rm dir}$-trigger energy dependence is observed on the suppression of away-side yields in the range of 8< $p_T^{\rm trig}$< 20 GeV/c. The lost energy reappears predominantly at low p_T (p_T<2 GeV/c), regardless of the trigger p_T of $\gamma_{\rm dir}$.

- Semi-inclusive recoil charged jets: A novel mixed-event method was developed to correct the uncorrelated fake jets contribution in heavy-ion collisions in the STAR experiment. After this correction, the semi-inclusive recoil charged-jets spectra of a high-p_T hadron trigger show ~80% suppression in recoil jet p_T in central collisions with respect to peripheral collisions with R=0.3. A significant horizontal shift in the recoil jet p_T spectra in central collisions with respect to peripheral collisions at R=0.3 compared with that at R=0.5 indicates that a comparatively wider jet cone is the consequence of jet-quenching in heavy-ion collisions.

- Di-jet transverse momentum imbalance: A significant di-jet imbalance is observed in Au+Au collisions in comparison with the p+p reference for the jet resolution parameter R=0.4 including constituent particles with $p_T > 2$ GeV/c. When including softer particles (with $p_T > 0.2$ GeV/c), the balance is restored to the level of the embedded p+p reference, indicating that redistributed energy is still contained within the original R = 0.4 cone, though not within a smaller jet resolution parameter of R=0.2. It indicates that the energy loss in di-jet events can not be recovered within a narrow jet cone in heavy-ion collisions at $\sqrt{s_{NN}}$ = 200 GeV for this particular selection of di-jets.

Beside these measurements, new jet measurements like neutral triggered jets, soft drop grooming in jet etc., are ongoing in the STAR experiments to study the QCD medium.

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