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Event Plane Dependence of Di-hadron Correlations with Event Shape Engineering at the STAR Experiment

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Abstract

In high-energy-nuclear collisions, di-hadron correlations are used as a probe to study energy-loss mechanisms of jets in the Quark-Gluon Plasma (QGP). In order to understand the interplay between jet-medium interaction and medium expansion, we measured di-hadron correlations where events were classified by the trigger-hadron's angle with respect to the event plane. We further constrained the collision geometry using event-shape engineering based on the magnitude of the reduced flow vector q_2. This measurement provides new and unique constraints for the dependence of energy loss of jets on in-medium path length and the role of flow.

1. Introduction

In heavy-ion collisions, two-body scatterings can occur with large momentum transfer. The scattered partons are created back-to-back and fragment into di-jet pairs. Jets lose their energy by interacting with the Quark-Gluon Plasma (QGP). Thus, jets are a good probe to study energy-loss mechanisms of jets in the QGP. Di-hadron correlations with high-p_T trigger particles as proxies for the jets are established-robust method to investigate energy loss of jets. The correlation function is calculated as:

$$C(\Delta\phi) = \frac{\int(\Delta\phi)N^{mix}(\Delta\phi)}{\int(\Delta\phi)N^{real}(\Delta\phi)} \cdot \frac{N^{real}(\Delta\phi)}{N^{mix}(\Delta\phi)}, \tag{1}$$

where $\Delta\phi = \phi^{asso} - \phi^{trig}$ is the relative angle of associated particles with respect to the trigger particle and N^{real} and N^{mix} are the number of pairs from real events and from mixed events, respectively. Rapidity-independent background is subtracted via:

$$J(\Delta\phi) = \frac{N^{pair}}{N^{trig}} \cdot (C(\Delta\phi) - b_0 F(\Delta\phi)), \tag{2}$$

where N^{pair} and N^{trig} are the number of pairs and the number of particles, respectively, b_0 is a normalization factor determined by assuming zero correlated yield at minimum, and $F(\Delta\phi)$ is a background term including

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v_2, v_3 and v_4 contributions [2]. While the magnitude of the rapidity-odd v_1 at mid-rapidity is small and its contribution to the measured correlation function may be neglected [3], the rapidity-even v_1 has a non-zero value and its contribution is not negligible [4]. However, the measured rapidity-even v_1 includes momentum conservation due to di-jet production which forms part of the signal we are trying to observe. Therefore the v_1 contribution is not included in the background term.

The data were collected by the STAR detectors [5] in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV in 2011. Charged hadrons are reconstructed with the Time Projection Chamber (TPC) [6]. In this analysis, di-hadron correlations are measured in one half of the TPC, while the event plane is determined in the other half with a gap of 0.5 units in pseudorapidity η; e.g. $C(\Delta\phi)$ is calculated in $-1 < \eta < 0$ for an event where the event plane was determined in $0.5 < \eta < 1$. Azimuthal anisotropy v_n for background components are determined by the TPC [1], with a pseudorapidity gap of 1.0 units in order to reduce the non-flow contribution e.g. v_n is measured in $-1 < \eta < -0.5$ with respect to the event plane determined in $0.5 < \eta < 1$.

2. Di-hadron Correlations with Respect to the Second Order Event Plane

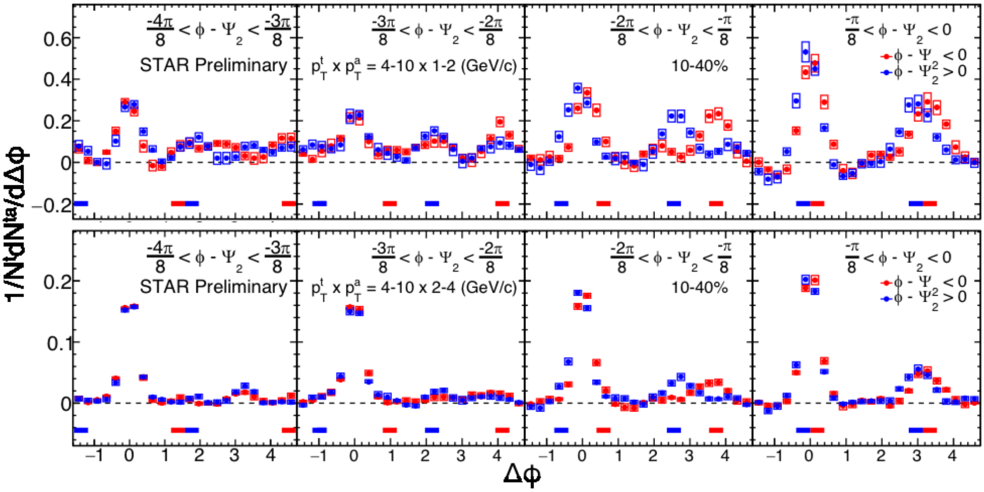

Fig. 1. (Color online) Di-hadron correlations in bins of trigger angle with respect to the second order event plane at $\sqrt{s_{NN}}$ = 200 GeV in 10-40% centrality, ranging from out-of-plane (left) to in-plane (right). Trigger particles are selected with $4 < p_T^{trig} < 10$ GeV/c and associate particles are selected with $1 < p_T^{asso} < 2$ GeV/c (upper panels) and $2 < p_T^{asso} < 4$ GeV/c (bottom panels). The trigger angle is measured to the left ($\phi - \Psi_2 < 0$, red marker) and right ($\phi - \Psi_2 > 0$, blue marker) of Ψ_2. Statistical errors may be smaller than the symbol size, systematic uncertainties are indicated as colored boxes. The bars at $y \sim 0.2$ indicate the event-plane directions.

The correlations with left ($\phi - \Psi_2 < 0$) / right ($\phi - \Psi_2 > 0$) separated trigger-angle selections can provide more information about away-side modification than previous measurements at STAR [2]. Figure 1 shows di-hadron correlations with left and right separated trigger-angle selections with respect to the second order event plane in 10-40% centrality. An asymmetric shape is observed because of different path lengths while traversing the medium. Moreover, mirror-symmetric correlation shape between left and right triggers is observed because mirror-symmetric path lengths are expected with mirror-symmetric selection for trigger angle. When the trigger particle's direction changes from the in-plane to out-of-plane direction, the heights of both the near-side (same side as trigger particle's direction) and away-side (back-to-back direction to trigger particle's direction) peaks decrease, and the away-side peak for low-p_T associate particles broadens toward the in-plane direction. The change in the peak height indicates that jets can penetrate more in the

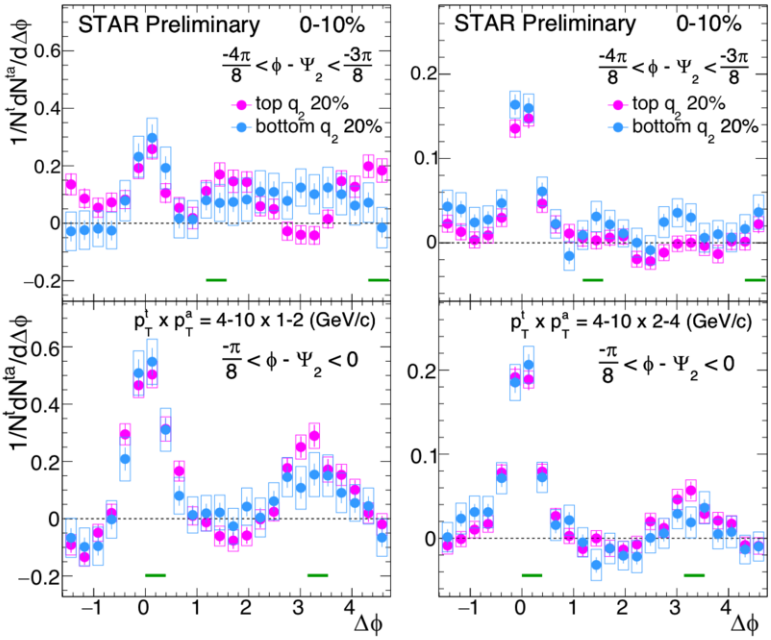

Fig. 2. (Color online) Di-hadron correlations in bins of trigger angle to the second-order event plane at $\sqrt{s_{NN}}$ = 200 GeV in 0-10% Au+Au, with top-q_2 20% (magenta markers) and bottom-q_2 20% (azure markers), with out-of-plane (top panels) and in-plane trigger (bottom panels). Trigger particles are selected with $4 < p_T^{trig} < 10$ GeV/c and associate particles are selected with $1 < p_T^{asso} < 2$ GeV/c (left panels) and $2 < p_T^{asso} < 4$ GeV/c (right panels). Statistical errors may be smaller than the symbol size, systematic uncertainties are indicated as colored boxes. The bars at $y \sim 0.2$ indicate the event-plane directions.

in-plane direction, while the change in the position of away-side peak suggests that the lost energy of the jets is redistributed to low-p_T particles in the in-plane direction. This observation could be a possible sign of conical emission or stronger flow with longer path length.

3. Further Constraints from Event Shape Engineering

The evolution of the system is sensitive to fluctuations of the initial geometry of the participant region. Recently, event-shape engineering (ESE) was proposed as a useful tool to select the initial geometry of the system by utilizing the fluctuations of the magnitude of the reduced flow vector q_2 [7]. The combination of centrality selection and ESE allows us to control the initial geometry while keeping the average energy density fixed. Measurements of di-hadron correlations with event-shape engineering open up the potential to disentangle the respective roles of event geometry and activity and allow new differential insight into energy-loss mechanism of jets as a function of initial energy density and shape.

Figure 2 shows di-hadron correlations with trigger-angle selection with respect to the second-order event plane with top-q_2 20% and bottom-q_2 20% selections in 0-10% centrality. Azimuthal anisotropy for the background component is measured independently in each event class. We expect shorter path lengths for in-plane triggers in namely, large-q_2 events than out-of-plane triggers in small-q_2 events because large-q_2 events are expected to have a more elliptic shape. Out-of-plane triggers show a behavior consistent with these expectations, namely, large-q_2 events show more suppressed peaks around $\Delta\phi \sim \pi$ for both p_T ranges while the low-p_T yield is enhanced in the shorter direction around $\Delta\phi \sim \pi/2$ and $\Delta\phi \sim 3\pi/2$. On the other hand, in-plane triggers show only a small difference between large-q_2 and small-q_2 events within current systematic uncertainties. The peak height around $\Delta\phi \sim \pi$ is higher with lower associate p_T in large-q_2 events but the results with lower associated-particle p_T are consistent with those with high associated-particle p_T within systematic uncertainties.

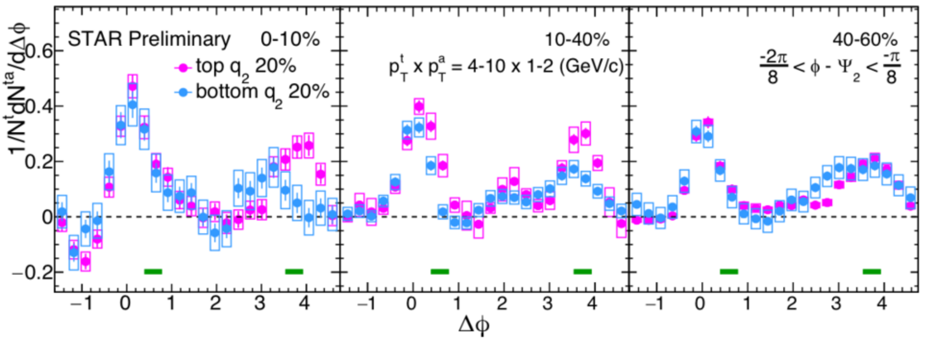

Fig. 3. (Color online) Di-hadron correlations with trigger angle selected to mid-plane ($-2\pi/8 < \phi - \Psi_2 < -\pi/8$) with respect to the second order event plane with top-q_2 20% (magenta markers) and bottom-q_2 20% (azure markers) selections in 0-10, 10-40 and 40-60% centrality. Trigger particle's p_T range is $4 < p_T^{trig} < 10$ GeV/c and associate particle's p_T range is $1 < p_T^{asso} < 2$ GeV/c. Statistical errors may be smaller than the symbol size, systematic uncertainties are indicated as colored boxes. The bars at $y \sim 0.2$ indicate the event-plane directions.

In Figure 3, we focus on the centrality dependence of mid-plane region ($-2\pi/8 < \phi - \Psi_2 < -\pi/8$) with large-$q_2$ and small-q_2 selections in 0-10, 10-40 and 40-60% centrality. Larger shift of a peak position in the away side is observed in large-q_2 events in 0-10 and 10-40% centrality and the difference is larger in central events, but no q_2 dependence is observed in 40-60% within systematic uncertainties. The difference of correlation shapes between large-q_2 and small-q_2 events might be due to the difference in the strength of elliptic flow, and the difference is larger in lower-p_T associate particles. This might be a hint of quenched jets coupling with the expanding medium.

4. Summary

The latest STAR results of di-hadron correlations with trigger-angle selections and event-shape engineering in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV are presented. Di-hadron correlations with left- and right-separated trigger angle selections have clear asymmetric yield and display significant dependence on the trigger angle with respect to the event plane. Di-hadron correlations with different trigger angle and q_2 selections have different correlation shapes. This observations might be explained by coupling of quenched jets and the expanding medium. Additionally, constraining the event shape using the q_2 variable leads to strong amplification of the observed effects. These results will provide more information about jet-medium interaction in the expanding system.

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