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Systematic Studies of Jet-medium Interactions in STAR

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Abstract

In these proceedings, we report recent jet results from STAR in heavy-ion collisions. The first measurement of centrality dependence of di-jet momentum imbalance A_J at RHIC is presented. An apparent evolution of the A_J distributions from central to peripheral collisions is observed. A new di-hadron correlation measurement with a method to subtract all orders of flow background using data themselves is also presented to study how the lost energy of jets is redistributed to particles with low-to-modest transverse momentum.

Keywords: di-jet imbalance, di-hadron correlations

1. Introduction

Energetic partons originating from initial hard scatterings lose energy due to interactions in the hot dense medium created in relativistic heavy-ion collisions. Experimentally, different trigger objects can be measured to select hard scattering events to study the partonic energy loss mechanisms [1]. These triggers include high-p_T particles, jets, direct-photon and so on. High-p_T particle triggers at RHIC might bias towards hard scatterings produced in the surface of the collision zone. The away-side partner jet therefore has an enhanced likelihood to traverse a large path length in the medium. Di-jet trigger has different bias. The di-jet selection if required hard hadrons on the recoil jet will have a preference to almost tangential di-jets which traverse the medium with a shorter but finite in-medium path length. The direct-photon trigger does not suffer the surface bias, since the photon mean free path is much larger than the size of the medium.

2. Di-jet Momentum Imbalance

Jets are reconstructed from charged tracks measured in the Time Projection Chamber (TPC) [2] and neutral particle information recorded by the Barrel Electromagnetic Calorimeter (BEMC) [3], using the anti-k_T algorithm from the FastJet package [4, 5]. To avoid double-counting the energy deposition in the BEMC from charged tracks, the transverse momentum of any charged track that extrapolates to a BEMC tower is subtracted from the transverse energy (E_T) of that tower. A tower energy is set to zero if the extrapolated track has a larger momentum than the tower energy. Events were selected by an online high tower (HT) trigger, which required $E_T > 5.4$ GeV in at least one BEMC tower. Event centrality is determined by the raw charged particle multiplicity in the TPC within the pseudorapidity range of $|\eta| < 0.5$, corrected for

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luminosity and vertex position dependence. In the jet reconstruction, firstly, only tracks with $p_T > 2$ GeV/c are considered to minimize the background and combinatorial jets. We refer to this selection as (di-)jets with "hard cores". It is unnecessary to subtract the background energy since the median background energy density $\langle\rho\rangle$ is 0 at RHIC when only particles with $p_T > 2$ GeV/c are considered.

The di-jet momenta imbalance is defined as

$$A_J = (p_T^{\text{lead jet}} - p_T^{\text{sublead jet}})/(p_T^{\text{lead jet}} + p_T^{\text{sublead jet}})\,, \tag{1}$$

where $p_T^{\text{lead jet}}$ and $p_T^{\text{sublead jet}}$ are the transverse momenta of the leading and sub-leading jet, respectively.

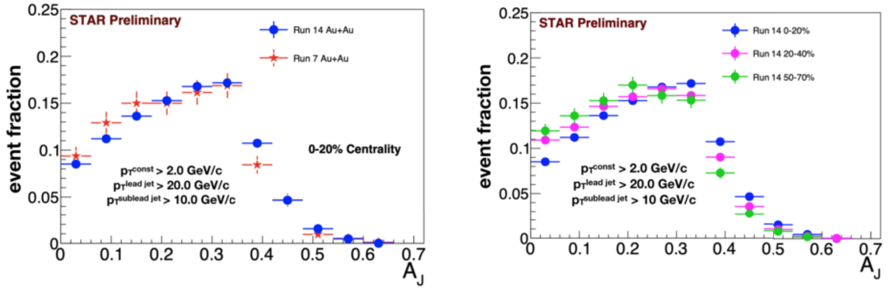

Fig. 1. (left) A_J distributions at detector level in 0 – 20% central Au+Au collisions from year 2007 [6] and 2014. (right) A_J distributions from year 2014 for three different centralities. Only statistical uncertainties are shown.

The di-jet momentum imbalance A_J is calculated for the leading and sub-leading jets with $p_T^{\text{lead jet}} > 20$ GeV/c, $p_T^{\text{sublead jet}} > 10$ GeV/c and $|\phi^{\text{lead jet}} - \phi^{\text{sublead jet}} - \pi| < 0.4$. Previous results [6] show that hard-core di-jets in central Au+Au collisions are significantly more imbalanced than the p+p di-jets. However, the momentum balance can be restored to the level of p+p baseline for resolution parameter R = 0.4 with soft particles included.

A large increase in the sample size obtained from year 2014 data allows us to study the centrality dependence of A_J. The left panel of Fig. 1 shows A_J distributions in 0 – 20% central Au+Au collisions from year 2007 (run 7) [6] and 2014 (run 14). In this analysis, jet energies are not corrected back to the original parton energies; all comparisons are done at detector level. The measured A_J distributions are relatively insensitive to the differences in the detector performance between year 2007 and 2014 and are comparable between the two years. The right panel of Fig. 1 shows A_J distributions from run 14 for three different centralities. An apparent evolution of the A_J distribution from central to peripheral collisions is observed where jets appear to be more balanced in peripheral Au+Au collisions.

3. Di-hadron Correlations

Measurements from both RHIC [6, 7, 8] and the LHC [9, 10] indicate that much of the lost energy of jets seems to re-emerge as low momentum particles. Redistribution of energy at low-to-modest p_T has been elusive to measure because of large flow background. We use a data-driven method for background evaluation and subtraction to measure the away-side jet-like correlation shape in heavy-ion collisions [11].

Because of the broad distribution of the underlying parton kinematics, the away-side jet direction is mostly uncorrelated in η relative to the trigger particle. It is therefore difficult to distinguish the jet signal from the underlying background. The away-side jet direction can be localized by requiring a second high-p_T particle back-to-back in azimuthal angle (ϕ) with respect to the trigger particle. However, by doing so, the back-to-back di-jets are biased towards being tangential to the collision zone, substantially weakening the purpose of studying jet-medium interactions. In this analysis, we impose a less biasing requirement of a large recoil transverse momentum (P_x) azimuthally opposite to the high-p_T trigger particle, within a given range of pseudorapidity. P_x is given by

$$P_x|_{\eta_1}^{\eta_2} = \sum_{\eta_1<\eta<\eta_2, |\phi-\phi_{\rm trig}|>\pi/2} p_T \cos(\phi - \phi_{\rm trig}) \cdot \frac{1}{\epsilon} , \quad (2)$$

where all charged particles ($0.15 < p_T < 10$ GeV/c) within the η range that are on the away side ($|\phi-\phi_{\rm trig}| > \pi/2$) of the trigger particle are included. Since the near-side jet is not included in the P_x calculation, the η distribution of the trigger particle is unbiased by the P_x cut. The inverse of the single-particle relative acceptance×efficiency (ϵ) is used to correct for the relative single-particle detection efficiency. The requirement of a large recoil P_x in a particular η region selects events with enhanced population of jets close to the η region. In this analysis, the trigger particle p_T range is $3 < p_T^{\rm trig} < 10$ GeV/c. We choose the windows $-1 < \eta < -0.5$ ($P_x|_{-1}^{-0.5}$) or $0.5 < \eta < 1$ ($P_x|_{0.5}^{1}$) for P_x calculation.

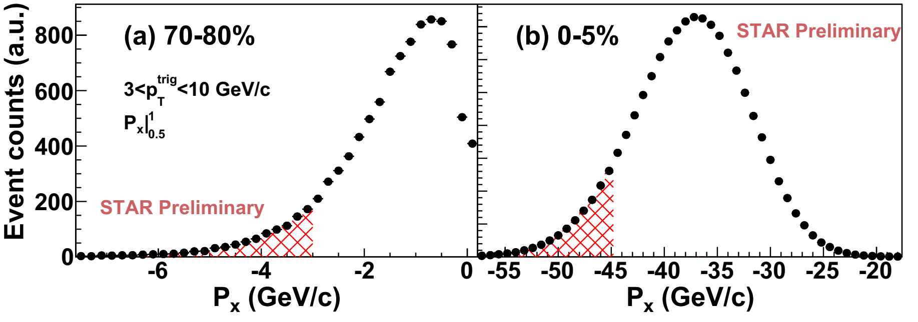

Fig. 2. Distributions of recoil momentum within $0.5 < \eta < 1$ ($P_x|_{0.5}^{1}$) from high-p_T trigger particles of $3 < p_T^{\rm trig} < 10$ GeV/c in 70-80% peripheral (a) and 0-5% central (b) Au+Au collisions at $\sqrt{s_{\rm NN}} = 200$ GeV. The shaded areas indicate a 10% selection of events with the highest $|P_x|$ to enhance the away-side jet-like population inside the acceptance. Statistical uncertainties only.

Figure 2 shows an example of $P_x|_{0.5}^{1}$ distributions for peripheral and central Au+Au collisions. Their difference comes mainly from event multiplicities. P_x has contributions from jets and anisotropic flow backgrounds. The flow background contribution is larger in central collisions which makes the P_x distribution more symmetric. For each centrality, we select the 10% of the events with the highest $|P_x|$ to enhance the away-side jet-like population. In the selected events, we analyze dihadron correlations of associated particles, with respect to trigger particles, in two η regions symmetric about mid-rapidity, one close to and the other far from the η window for P_x. For $P_x|_{-1}^{-0.5}$, the close-region is $-0.5 < \eta < 0$ and the far-region is $0 < \eta < 0.5$; for $P_x|_{0.5}^{1}$, they are swapped. The results from these two sets are combined. The away-side jet contributes more to the close region than to the far region due to the larger η gap of the latter. The anisotropic flow contributions, on the other hand, are on average equal in these two regions [12]. By focusing on the difference between close- and far-region correlations, we can therefore isolate jet-like correlations on the away-side.

The left panel of Fig. 3 shows the away-side correlation width (obtained as the Gaussian σ) as a function of centrality for four $p_T^{\rm assoc}$ bins. The width for the lowest $p_T^{\rm assoc}$ of 0.15-0.5 GeV/c is consistent with a constant over centrality; at such low $p_T^{\rm assoc}$, the correlations are fairly wide for all centralities and possible broadening with centrality may not be easily observable. For the three higher $p_T^{\rm assoc}$ bins, the width increases from peripheral to central collisions.

The right panel of Fig. 3 shows σ as a function of $p_T^{\rm assoc}$ in peripheral and central collisions. In peripheral collisions, the width decreases rapidly with $p_T^{\rm assoc}$. In central collisions the decrease is not as large. The right panel of Fig. 3 indicates stronger centrality dependence of broadening at higher p_T. In our measured $p_T^{\rm assoc}$ range, the away-side jet-like correlation broadening seems to display a different behavior than what was seen

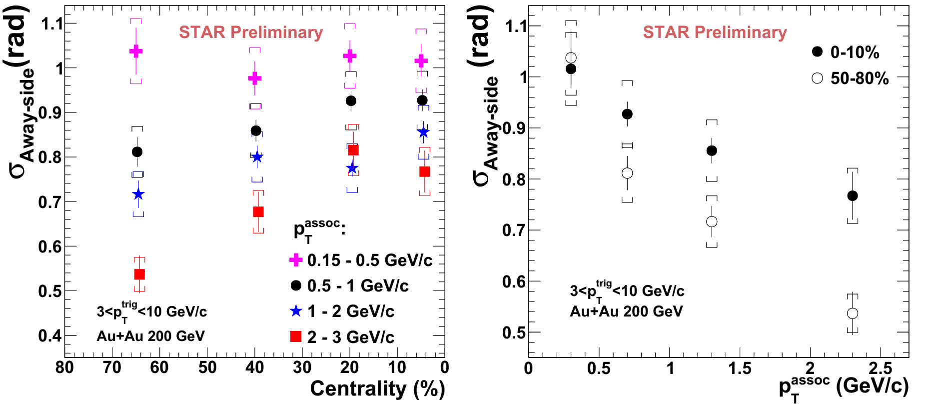

Fig. 3. (left) Away-side jet-like correlation width (Gaussian σ) as a function of centrality for $3 < p_T^{trig} < 10$ GeV/c and various p_T^{assoc} bins in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. The caps indicate the systematic errors. (right) Away-side jet-like correlation width as a function of p_T^{assoc} in peripheral and central collisions.

in jet-hadron correlations [7], which may be due to differences in kinematics and the selected trigger object. At higher p_T^{assoc} not covered by the current measurement, jet-hadron correlations, with much higher trigger (jet) p_T, indicate little broadening from proton-proton to central heavy-ion collisions. Relevant analysis of semi-inclusive hadron-jet correlations showed no evidence of significant intrajet broadening on the away-side within an angle of 0.5 relative to the jet axis [13].

4. Summary

In these proceedings, we presented the first measurement of centrality dependence of the di-jet momentum imbalance A_J at RHIC, with a clear evolution toward more balance in peripheral Au+Au collisions. A new measurement of away-side jet-like correlations is also reported with robust flow background subtraction. The correlation width broadens with increasing centrality except at low p_T. Stronger centrality dependence of away-side jet-like correlation broadening is observed at higher p_T.

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