PHENIX Measurement of High-$p_T$ Hadron-hadron and Photon-hadron Azimuthal Correlations

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Abstract.
High-$p_T$ hadron-hadron correlations have been measured with the PHENIX experiment in Cu + Cu and p + p collisions at $\sqrt{s_{NN}} = 200$ GeV. A comparison of the jet widths and yields between the two colliding systems allows us to study the medium effect on jets. We also present a first measurement of direct photon-hadron correlations in Au + Au and p + p collisions. We find that the near-side yields are consistent with zero in both systems. By comparing the jet yields on the away side, we observe a suggestion of the expected suppression of hadrons associated with photons in Au + Au collisions.

1. Introduction

The method of high-$p_T$ two-particle azimuthal correlations is a unique probe of the hot, dense medium created in heavy-ion collisions at RHIC. Early RHIC results on hadron-hadron correlations indicate a strong modification of the away-side jet shape and yield by the medium [1]. These modifications provide valuable constraints on the properties of the hot, dense medium. However, the physics interpretations of the away-side modification are complicated as the trigger hadrons mostly come from the surface of the medium. Direct photons, due to their weak coupling with the medium, provide a cleaner calibration of the energy and direction of the away-side jets. Thus, direct photon-hadron correlations can provide less biased and quantitative measurements of the away-side modifications.

At RHIC energies, identification of direct photons is difficult due to the large number of background photons from hadronic decays, mostly from $\pi^0$ decays. Therefore the extraction of the direct photon-hadron per-trigger yields relies on a statistical subtraction of the decay photon-hadron per-trigger yields from the inclusive photon-hadron per-trigger yields.

† For the full list of PHENIX authors and acknowledgements, see Appendix 'Collaborations' of this volume
A two-particle correlation function \( C(\Delta \phi) \) as measured in the PHENIX central spectrometer arms is constructed as

\[
CF(\Delta \phi) \sim \frac{dN_{\text{real}}/d\Delta \phi}{dN_{\text{mix}}/d\Delta \phi} = J_{\text{et}}(\Delta \phi) + B_{\text{kg}}(\Delta \phi) \tag{1}
\]

where \( dN_{\text{real}}/d\Delta \phi \) is the same-event pair distribution and \( dN_{\text{mix}}/d\Delta \phi \) is the mixed-event pair distribution. The mixed-event distribution is used to correct for the non-uniform PHENIX pair acceptance. The correlation function (CF) can be decomposed into a jet function \( J(\Delta \phi) \) and a underlying flow modulated background term. After subtracting the background, we correct the remaining \( J(\Delta \phi) \) by the single particle efficiency and the PHENIX acceptance, then normalize it by the number of triggers, thus obtaining the per-trigger yield [3].

2. High-\( p_T \) hadron-hadron correlations

The per-trigger yield distributions are fitted with a double Gaussian function to extract the Gaussian width for both peaks (\( \Delta \phi = 0/\pi \) for near-side/away-side). The jet yield is integrated over a \( \Delta \pi \) region of \( \pi \) around each peak. Two other useful jet variables are defined as

\[
p_{\text{out}} = p_{T,\text{asso}} \cdot \sin(\Delta \phi), \quad x_E = \frac{p_{T,\text{asso}}}{p_{T,\text{trig}}} \cdot \cos(\Delta \phi) \tag{2}
\]

\( p_{\text{out}} \) is the transverse momentum component of the associated particle perpendicular to the trigger, \( x_E \) measures the relative associated particle \( p_T \) to trigger \( p_T \) along the trigger direction.

![Figure 1](image)

**Figure 1.** (a) Near-side \( p_{\text{out}} \) distribution, \( p+p \) (black) and \( Cu+Cu \) (red) and (b) Away side Gaussian width as a function of associated \( p_T \), \( p+p \) (black), \( Cu+Cu \) 0–20\% (red) and \( Cu+Cu \) 20–40\% (blue)

Fig. 1(a) shows the near-side \( p_{\text{out}} \) distribution. Near-side Gaussian widths are also extracted and no significant difference is seen between \( Cu+Cu \) and \( p+p \). However, the \( p_{\text{out}} \) distribution is a more sensitive quantity to study medium-induced jet modification, especially at the large \( p_{\text{out}} \) region. On Fig. 1(a), we see an enhancement in \( Cu+Cu \) compared with \( p+p \) in the tail region. It indicates that the near-side jets are modified...
by the medium through additional radiation with components transverse to the jet direction. Fig. 1(b) shows the away-side Gaussian widths, we do not see a width broadening from p + p to Cu + Cu. We are working on the away-side $p_{out}$ distribution to better study the away-side shape modification.

Figure 2. (a) $I_{AA}$ as a function of associated $p_T$, near side (red) and away side (blue). and (b) Integrated $I_{AA}$ and $R_{AA}$ as a function of $N_{part}$, near side (red), away side (blue) and $R_{AA}$ (black).

PHENIX measures jet yield modification via $I_{AA}$, which is the yield ratio of Cu + Cu to p + p. $I_{AA} = 1$ indicates no suppression in Cu + Cu with respect to p + p whereas the lower the $I_{AA}$, the stronger the suppression. Fig. 2(a) shows $I_{AA}$ of most central (0-20%) Cu + Cu collisions. The near-side $I_{AA}$ is close to unity and the away-side $I_{AA}$ shows substantial suppression in the central Cu + Cu collisions. Fig. 2(b) shows the $I_{AA}$ integrated over $x_E = 0.4 - 1$ as a function of $N_{part}$. The near-side $I_{AA}$ is consistent with unity within error bars, whereas the away-side $I_{AA}$ shows a decreasing trend from peripheral to central collisions. On the same plot is a comparison to the nuclear modification factor $R_{AA}$ of high-$p_T$ $\pi^0$s, the observed $I_{AA}$ is similar to the nuclear modification factor.

3. High-$p_T$ direct photon-hadron correlations

While dijet measurements suffer from trigger bias and possible trigger surface bias, an ideal probe for studying the jet modification in medium is the use of direct photon-hadron correlations [4]. This measurement is aided by the fact that PHENIX has observed a factor of $\sim2$ excess of photons above the hadronic decay background at $p_T > 5 GeV/c$ in the most central Au + Au collisions, which is consistent with direct photon production as calculated by pQCD [5]. We employ a statistical subtraction method to extract direct photon-hadron correlations and per-trigger yields. First, the inclusive photon-hadron per-trigger yields ($Y_{incl-h}$) are constructed by subtracting the background term (using the measured inclusive photon $v_2$) from the inclusive photon-hadron CF. Then, starting from $\pi^0$-hadron pairs, we construct the decay photon-hadron CF. This is done by performing a pair by pair weighted sum to convolute the
contributions from feeddown from $\pi^0$ decays. The weights applied are derived from the $\pi^0$ decay kinematics. From the decay photon-hadron CF, we subtract the background term using the decay photon-hadron $v_2$ derived from the measured $\pi^0$ $v_2$ in order to finally get the decay photon-hadron per-trigger yields. The inclusive photon and $\pi^0$ $v_2$'s that we used were measured with the standard PHENIX single particle method [2]. Once both per-trigger yields are obtained, the direct photon-hadron per-trigger yield ($Y_{dir-h}$) is found by:

$$Y_{dir-h} = \frac{1}{R - 1} (R \cdot Y_{incl-h} - Y_{decay-h})$$

in which $R$ measures the number of inclusive photons divided by the number of decay photons from all decay channels. $R$ is independently measured by PHENIX [3].

![Figure 3](image.png)

**Figure 3.** (a) The direct photon-hadron per-trigger yield in p + p (red) and Au + Au (black) and (b) The integrated away side yields as a function of trigger photon $p_T$ in p + p (blue) and Au + Au (black).

The direct photon-hadron yield in p + p is an important baseline measurement. Fig. 3(a) shows direct photon-hadron per-trigger yield in p + p, a near-side yield consistent with zero is seen, which is consistent with what one would expect from direct photon and small fragmentation photon contribution. A comparison between the p + p per-trigger yield and the PYTHIA simulation results shows a qualitative agreement. In Au + Au collisions, the direct photon-hadron per-trigger yield is shown in Fig. 3(a). The near-side yield is consistent with zero and the away-side yield is small.

Comparing p + p to Au + Au in Fig. 3(a), we see some indication of away-side suppression. Although error bars are large, there is a systematic trend that the p + p yield is higher than Au + Au. To make a quantitative statement, the away-side yield is integrated over the $[\pi/2, 3\pi/2]$ region. Fig. 3(b) shows the integrated away-side yields as a function of trigger photon $p_T$. We observe an increasing trend of yields in p + p, whereas yields in Au + Au are suppressed, especially when $p_T > 7 GeV/c$. 

4. Conclusions

PHENIX has made precision measurements of high-$p_T$ dijets. We observe near-side jet modification at large $p_{out}$. Away-side yield is suppressed, whereas the width is unchanged. Also, the away-side $I_{AA}$ is quantitatively consistent with $R_{AA}$. Moreover, PHENIX has made the first measurement of high-$p_T$ direct photon-hadron yields. The near-side yield is consistent with zero and the away-side yield is suppressed compared to yields in $p + p$. Therefore these data indicate the modification of the away-side jets from photon triggers in $Au + Au$.

References

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