π⁰-h correlation in Cu+Cu at √s_{NN}=200 GeV

Jiangyong Jia, for the PHENIX Collaboration
Chemistry Department, State University of New York at Stony Brook, Stony Brook, NY 11794-3400, USA
Physics Department, Brookhaven National Laboratory, Upton, NY 11796, USA
jjia@bnl.gov

We present the results of the two-particle ∆φ correlation between high p_T π⁰ and charged hadrons in Cu+Cu collisions at √s_{NN} = 200 GeV. Clear away-side jet signals are seen in central Cu+Cu collisions at all associated hadron p_T, albeit suppressed by factor of 2 above 2 GeV/c. This level is similar to the suppression seen for inclusive hadrons at high p_T (> 7 GeV/c). However, this agreement is argued to be the result of a cancellation between a flatter away-side parton spectra due to the requirement of high p_T triggers and a bigger energy loss due to a longer path length traversed by the away-side jet.

1. Introduction

PHENIX have done a detailed mapping of the two-particle correlations in centrality, p_T and particle types. Non-trivial modifications relative to p-p of the correlation patterns are observed in the trigger p_T (p_T^A) and partner p_T (p_T^B) below 4 GeV/c. There are strong evidences suggesting that the p_T dependence of the jet shape at the near- and away-side is a consequence of the detailed interplay between jet-quenching and response of the medium to the energy lost by energetic jets. Additional complication (only for jet yield) can be traced back to the soft contribution to the triggers, which are used to normalize jet pair rate into per-trigger yield (Y_{jet}). For example, imagine we try to correlate hadrons in 2-3 GeV/c (p_T^1) with those 5-10 GeV/c (p_T^2). Since R_{AA}(p_T^1) > R_{AA}(p_T^2), arguably due to recombination contribution, one expects I_{AA} (ratio of Y_{jet} in A+A to that in p+p) for using p_T^1 as trigger and p_T^2 as partner is lower than the other way around.

In this analysis, we present results using high p_T π⁰ as triggers. These triggers comes dominantly from jet fragmentation, thus provide a cleaner physical inter-

*For the full list of PHENIX authors and acknowledgements, see Appendix 'Collaborations' of this volume.

[i.e. R_{AA}(p_T^1)I_{AA}(p_T^1, p_T^2) = R_{AA}(p_T^2)I_{AA}(p_T^2, p_T^1)]. Note I_{AA} is function of trigger and partner p_T: I_{AA}(p_T, \text{trigger}, p_T, \text{partner}).
interpretation of the per-trigger yield. In terms of \( N_{\text{part}} \), Cu+Cu collisions cover from peripheral to 30-40% central Au+Au collisions. \( N_{\text{part}} \) can be determined with better precision that in Au+Au, thus allows a more detailed mapping of the centrality dependence of the onset of the jet quenching. Additionally, systematic error from on the jet yield due to elliptic flow is much more reduced in Cu+Cu due to a smaller combinatoric background level.

2. Analysis and results

The measurement was carried with 5-10 GeV/c \( \pi^0 \) as triggers and charged hadrons in several ranges in 0.4-10 GeV/c as partners. The per-trigger jet yield is obtained via

\[
Y_{\text{jet}} = \frac{\int d\Delta \phi N_{\text{mix}}^{\text{mix}}}{2\pi N_1 \varepsilon_B} \left( \frac{N_{\text{same}}^{\text{same}}(\Delta \phi)}{N_{\text{mix}}^{\text{mix}}(\Delta \phi)} - \xi \left( 1 + 2v_2^2 \cos 2\Delta \phi \right) \right)
\]

where \( N_A \) is the number of triggers, \( \varepsilon_B \) is the single particle efficiency for partners in the full azimuth and \(|\eta| < 0.35\); \( N_{\text{same}}^{\text{same}}(\Delta \phi) \) and \( N_{\text{mix}}^{\text{mix}}(\Delta \phi) \) are pair distributions from the same- and mixed-events, respectively. Mixed-event pairs are obtained by selecting partners from different events with similar centrality and vertex. The \( \varepsilon_B \) values include detector acceptance and reconstruction efficiency, with an uncertainty of \( \sim 10\% \), evaluated similar to \( \varepsilon_B \).

\( \xi \) is a normalization factor which is the ratio of the combinatorics pairs in the same event to those in the mixed event. \( \xi \) is typically bigger but very close to 1.

Fig.2 shows the correlation function, \( CF = N_{\text{same}}^{\text{same}}(\Delta \phi)/N_{\text{mix}}^{\text{mix}}(\Delta \phi) \), in 0-20% Cu+Cu compared with that in p+p. A clear away-side excess can be seen in all partner \( p_T \) ranges. No concave shape is expected even after the \( v_2 \) background subtraction. At partner \( p_T > 2 \) GeV/c, the away-side can be well described by a gaussian function. Fig.2 shows the near-side and away-side jet width as function of partner \( p_T \) for p+p, 0-20% and 20-40% Cu+Cu collisions. No significant differences can be seen between Cu+Cu and p+p within systematic errors, suggesting partners come mostly from jet fragmentation in the \( p_T \) range under consideration (0.4 < \( p_T^B < 10 \) GeV/c at the near side and \( p_T^W > 2 \) GeV/c at the away side).

Comparing the top and the bottom panels of Fig.2 one notices that there is a larger asymmetry between the near- and away-side in Cu+Cu than that in p+p. To quantify the medium modifications, we extract the \( Y_{\text{jet}} \) for Cu+Cu and p+p and construct the \( I_{\text{AA}} \) as function of \( x_E \) (\( x_E = p_{T, A}/p_{T, T} \cos(\Delta \phi) \)). The results for 0-20% central Cu+Cu collisions are shown in left panel of Fig.3 \( I_{\text{AA}} \) at the near side is consistent with 1 in the full \( x_E \) range of 0.1-1.4; the away-side \( I_{\text{AA}} \) starts at slightly above 1 at small \( x_E \), and gradually decreases towards larger \( x_E \), at \( x_E > 0.4 \) the suppression value approaches a constant of 0.5 up to \( x_E \sim 1 \). This constant behavior is also seen by STAR in Au+Au collisions, where the level of suppression was found to be similar to single particle \( R_{\text{AA}} \).

The right panel of Fig.3 shows the integrated \( I_{\text{AA}} \) in 0.4 < \( x_E < 1 \) as function \( N_{\text{part}} \), comparing with the integrated \( R_{\text{AA}} \) for the single particle. Assuming \( \langle z \rangle \sim \)
\( \pi^0 - \Lambda \) correlation in Cu+Cu

Fig. 1. The correlation function in Cu+Cu (upper panels) and p+p (bottom panels) for 5-10 GeV/c \( \pi^0 \) and various partner \( p_T \) ranges within 0.4-10 GeV/c.

Fig. 2. The near-side and away-side jet gauss width vs. \( p_T \) for p+p, 0-20% and 20-40% Cu+Cu collisions.

0.7 for leading \( \pi^0 \)s, the \( p_T \) of the original jets should be around 5/0.7=7 GeV/c. Thus the \( I_{AA} \) of the away-side should be directly comparable to the single particle at \( p_T > 7 \) GeV/c. In reality, since the \( \pi^0 \) \( R_{AA} \) is flat at \( p_T > 4 \) GeV/c, the exact values of the energy of the jets for high \( p_T \) \( \pi^0 \)s are not important.

Fig. 2 indicates that the near-side \( I_{AA} \) is around one in all centralities, consistent with surface emission picture. In contrast, away-side \( I_{AA} \) shows a suppression that has a similar centrality dependence in \( N_{\text{part}} \) relative to single particle suppression. This is rather surprising given that the away-side jet travels more medium than the single particles in the naive jet absorption picture. Suggesting that the simple geometrical bias argument is too naive. In jet quenching picture, the suppression is due to the energy degradation of the high \( p_T \) jets. The suppression
Fig. 3. a) The $I_{AA}$ as function of $x_E$ in p+p and Au+Au for near and away-side; b) The $I_{AA}$ for yield integrated in 0.4-1 as function of $N_{part}$, compared with suppression factor for high $p_T$ $\pi^0$.

factor $R_{AA}$ depends on both the energy loss as well as on the input parton spectra shape. For the single particle, the expected $N_{binary}$ scaled p+p spectra have a typical power-law shape with a power of 8. In the di-hadron correlation, the away-side spectra associated with the leading particles have much flatter distribution with a much smaller power. Thus for the same amount of energy loss for single jet and away-side jet, the suppression level observed for $I_{AA}$ could be smaller than the that for $R_{AA}$.

To illustrate this idea, we follow the prescription in Ref. 13. The fractional energy loss $S_{loss}$ is related to $R_{AA}$ as:

$$S_{loss} = 1 - R_{AA}(p_T)^{1/(n-1)} \quad \text{or} \quad R_{AA} = (1 - S_{loss})^{n-1} \quad (1)$$

The power “n” is 7.1 for single particle spectra in $dN/dp_T$. The power for the away-side associated spectra can be determined from RUN5 p+p data in Fig.4 (see also RUN3 p+p data results) via a modified power-law fit: $dN/dp_T \sim A/(p_T+p_0)^n$. The power n is found to be about 4.8.

If we assume the away-side jet have same fraction energy loss as single particles, we have:

$$S_{loss} = 1 - R_{AA}(p_T)^{1/(nR-1)} = 1 - I_{AA}(p_T)^{1/(nI-1)} \quad (2)$$

$R_{AA} = 0.2$ in central Au+Au collisions would lead to $I_{AA} = R_{AA}^{(nI-1)/(nR-1)} = 0.37$, indicating a much smaller suppression than that for $R_{AA}$. On the other hand, if we require $I_{AA} = R_{AA}$, then the away hadron energy loss fraction would be $S_{loss} = 1 - I_{AA}(p_T)^{1/(nI-1)} = 0.345$, much bigger than the single hadron energy loss fraction $S_{loss}^R = 0.23$, as expected (about 50% more energy loss). If we apply
\( \pi^0 - h \) correlation in Cu+Cu

![Graph showing \( \pi^0 - h \) correlation in Cu+Cu collisions.](image)

**Fig. 4.** The RUN5 p+p away-side jet yield associated with 5-10 GeV/c trigger \( \pi^0 \) and the corresponding modified power-law fit.

this trick to central Cu+Cu collisions, and assumes \( I_{AA} = R_{AA} = 0.5 \), the fractional energy loss for away-side jet would be \( S_{R\text{loss}} = 0.167 \). This value is significantly larger than the value for inclusive hadrons of \( S_{I\text{loss}} = 0.167 \).

In summary, high \( p_T \) \( \pi^0 - h \) correlations are studied in Cu+Cu and p+p collisions. Clear, relatively unmodified jet peaks are seen in rather low partner \( p_T \) in central Cu+Cu collisions, albeit suppressed by factor of 2 that is similar to that for inclusive hadrons. These observations suggest that the high \( p_T \) correlation is dominated by fragmentation of the jet that survives the medium. The similar suppression level observed for \( I_{AA} \) relative to \( R_{AA} \) is the combined results of a larger energy loss and a flatter parton spectra.

**References**

1. S. S. Adler *et al.* Phys. Rev. Lett. **97**, 052301 (2006)
2. A. Adare *et al.* [nucl-ex/0611019](http://arxiv.org/abs/nucl-ex/0611019).
3. J. Jia [PHENIX Collaboration], AIP Conf. Proc. **828**, 219 (2006)
4. N. Grau [PHENIX Collaboration], Nucl. Phys. A **774**, 565 (2006)
5. N. N. Ajitanand [PHENIX Collaboration], Nucl. Phys. A **783**, 519 (2007); C. Zhang, QM2006 proceedings.
6. A. Adare [PHENIX Collaboration], [arXiv:nucl-ex/0611016](http://arxiv.org/abs/nucl-ex/0611016).
7. J. Jia, [arXiv:nucl-ex/0702048](http://arxiv.org/abs/nucl-ex/0702048).
8. J. Jia, AIP Conf. Proc. **842**, 116 (2006) [arXiv:nucl-ex/0601023](http://arxiv.org/abs/nucl-ex/0601023).
9. J. Jia, J. Phys. G **31**, S521 (2005) [arXiv:nucl-ex/0409024](http://arxiv.org/abs/nucl-ex/0409024).
10. S. S. Adler *et al.* Phys. Rev. C **73**, 054903 (2006)
11. S. S. Adler *et al.* Phys. Rev. C **69**, 034910 (2004)
12. J. Adams *et al.* [STAR Collaboration], [arXiv:nucl-ex/0604018](http://arxiv.org/abs/nucl-ex/0604018).
13. S. S. Adler [PHENIX Collaboration], arXiv:nucl-ex/0611007
14. A. Drees, H. Feng and J. Jia, Phys. Rev. C 71, 034909 (2005)