Medium Effects on Jet Correlations in Au+Au and Cu+Cu Collisions at PHENIX-RHIC

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Abstract. Strong di-jet correlations have been observed in p+p and d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV at RHIC. It is important to study how this jet-correlation is affected by the hot, dense medium produced in heavy-ion collisions. In this contribution we will study how the di-jet shape evolves in Au+Au and Cu+Cu collisions compared to p+p, as well as examining the medium response to the jets. We will show the results and their dependence on the collision energy, geometry, trigger and associated particle p_T, and particle types.

1. Introduction

A jet is defined as a localized collection of hadrons which come from a fragmenting parton. In p+p collisions this jet is produced by the fragmentation of a hard-scattered parton, while during heavy-ion collisions, these partons interact with the hot, dense medium, losing energy. Thus the jet shapes provide us a good tool to study the medium's properties. Rather than reconstruct the whole jet, we use two-particle correlations to provide information on how the jet shape changes due to its interaction with medium, and also information on how the medium responds. These correlations produce a range of observables, including di-jet shapes, yields, mean p_T or E_T, all of which we will describe in this paper.

2. Data

RHIC has been successfully running nucleus-nucleus collisions for multiple systems and energies. During these runs PHENIX has gathered large statistics of data from Au+Au, Cu+Cu and p+p collisions. Table 1 lists the different data sets that are used in this paper.

Table 1. Data types, including collision systems and energies, used in this article

RHIC Run	Species	Energy $\sqrt{s_{NN}}$ in GeV
3	d+Au	200
	p+p	200
4	Au+Au	200, 62.4
	p+p	200
5	Cu+Cu	200, 62.4
	p+p	200
6	p+p	200

3. Analysis

3.1. Two-Particle Correlations

We form two-particle correlations to characterize the jet shape. These correlations include contributions from near-side jets, away-side jets, and a background from the underlying event. In A+A collisions the background is also modulated by elliptic collective flow (v_2). To obtain just the jet contributions we subtract the background using a method called Zero-Yield-At-Minimum (ZYAM) [1]. Operationally we adjust the normalization of the v_2-corrected background until it reaches the mixing-event-acceptance corrected foreground data, and subtract this background.

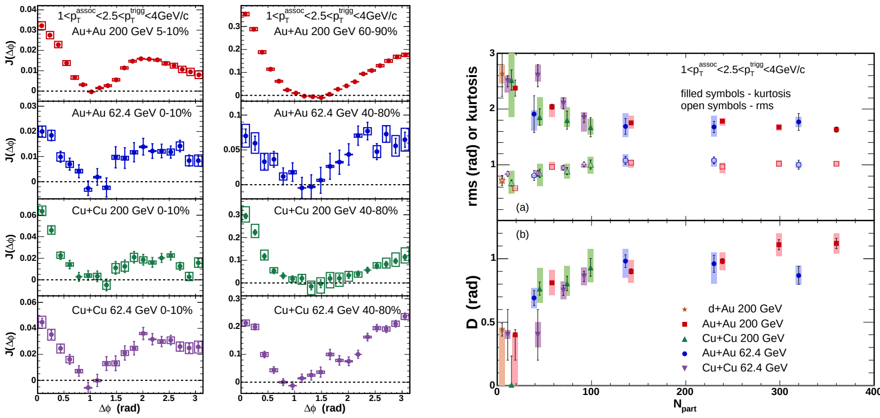
3.2. Medium Response

Fig.1(a) shows the number of associated particles per trigger particle as a function of the azimuthal angle between the particles. This is the jet function, $J(\Delta\phi)$. Each panel corresponds to different collision energies and colliding systems[4]. At the near-side, $\Delta\phi \sim 0$, particles come from the same jet, whereas at the away-side, $\Delta\phi \sim \pi$, the particles come from back-to-back jets. On this away-side the jet-structure changes with centrality and develops a shoulder region at angles away from $\Delta\phi = \pi$. There is also a dip in the correlation strength at $\Delta\phi = \pi$. It is possible that particles in the shoulder region come from the response of the medium to the passage of the jet. This hypothesis can be explored by fitting the away-side peak with a double Gaussian, each Guassian centered at $\Delta\phi = \pi \pm D$. The fitted parameter **D** is shown in Fig.1(b) along with the kurtosis parameter for the away-side. The observation that **D** scales with the number of participants implies that the shoulder depends on the volume of the medium and supports the hypothesis that the shoulder comes from the medium's response to the energy deposited by the traversing jets.

Future work will extend this analysis by controlling the path-length that the parton travels through the medium, e.g. via a reaction plane dependence, and by searching for any indication of a medium response on the near-side jet.

3.3. Interplay between Jet and Medium

By increasing the p_T of the particles in the far-side region we can study the relative contributions of particles that fragment from the quenched jet and those that come from response of the medium. This p_T dependence of $J(\Delta\phi)$ is shown in Fig.2 (a)-(h), with the p+p result as a reference. We observe that the far-side shape evolves



(a) (b)

Fig. 1. (a) The number of associated particles per trigger particle as a function of the azimuthal angle between the particles for different collision energies and systems, and (b) the parameterized away-side jet shapes as a function of N_{part}.

from being broad and flat at the lowest p_T, to concave, then to a reduced amplitude but conventional jet-shape at the highest p_T.

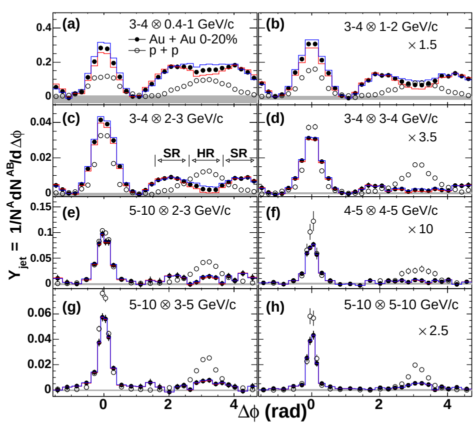
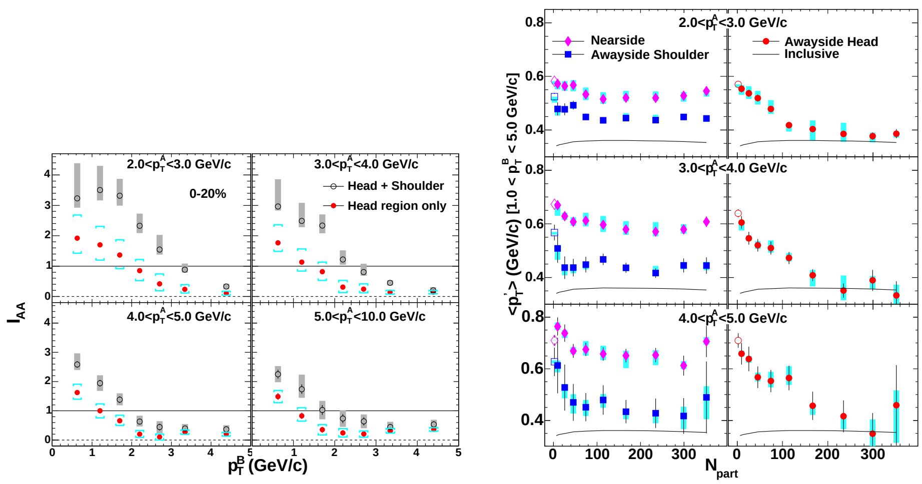


Fig. 2. Jet functions from Au+Au and p+p collisions for different trigger and associated p_T ranges. Note that Panel (c) defines the head and shoulder regions in the far-side shape.

This evolution of the away-side jet shape with p_T suggests that there is a separate contribution from the medium that is centered near $\Delta\phi \sim \pi \pm 1.1$ and a fragmentation component centered at $\Delta\phi \sim \pi$. To quantify this jet-shape evolution we divide the away-side into two regions, the "head region, **HR**" at $|\Delta\phi - \pi| < \pi/6$, and the "shoulder region, **SR**" at $\pi/6 < |\Delta\phi - \pi| < \pi/2$, as indicated in Fig.2c. To describe the modification of jet yields between Au+Au and p+p, we define their ratio as I_{AA}^{W} in Equation.1.

$$I_{AA}^{W} = \int_{\Delta\phi \in W} d\Delta\phi Y_{jet}^{Au+Au} / \int_{\Delta\phi \in W} d\Delta\phi Y_{jet}^{p+p} \qquad (1)$$

I_{AA} is taken for both the shoulder plus head region, and the head region by itself. These ratios are plotted in Fig.3(a) as a function of p_T. Note the I_{AA} for the **HR** are upper limit estimates for the jet fragmentation component, because the **HR** yield includes possibly the tails of the **SR** yield, as well as from bremsstrahlung gluon radiations.



(a) (b)

Fig. 3. (a) The ratio of away-side jet yields between Au+Au and p+p, I_{AA}. The ratio is calculated in the head region only and head+shoulder region. and (b) Near and away-side truncated mean$-p_T^B$ vs. N_{part} and trigger p_T^A, compared to the inclusive spectrum.

To further explore the interplay between the **HR** and **SR**, we calculate the mean p_T of the associated hadrons in the away-side within the p_T range between 1 and 5 GeV/c. The di-jet shape is divided into the **HR**, **SR**, and **NR** ($|\Delta\phi| < \pi/3$) during mean p_T calculation. These mean p_Ts are shown in Fig.3(b).

For the near-side (**NR**) the mean p_T^B is larger than the inclusive spectrum, and increases with trigger p_T^A. These two observations are consistent with the dominance of jet fragmentation on the near-side, i.e., a harder spectrum for partner hadrons for higher p_T trigger hadrons.

For the far-side, the different patterns observed in Fig.3 suggest their different origins. The suppression of the **HR** of A+A relative to p+p is consistent with jet quenching, as is comprised of contributions from "punch-through" jets, potentially with a smaller componenent of radiated gluons and feed-in from the **SR**. In contrast, the enhancement of the **SR** suggests that this region contains the response of the medium to jets, since there is no comparable response in p+p collisions. But the **SR** characteristics (peak location and mean p_T) have a weak dependence on trigger p_T and centrality. This is inconsistent with either a simple, deflected jet [6] [7] model, or the Cherenkov gluon radiation models [8]. Both models claim the deflection/radiation angles and the slope of the jet spectra depend on the p_T of the trigger or associated particles. However, the observations are consistent with expectations from "Mach Shock" from a near-ideal hydrodynamical medium [9] [10]. Thus our measurement provides strong constraints on competing mechanisms for the transport of energy through the medium.

3.4. Near-side modification

The above results show that the shape of the near-side jet is only weakly modified by the medium. This can be examined more sensitively by measuring the distribution of associated particle as a function of $p_{Tout} = p_T^{assoc} * sin(\Delta\phi)$, for both Cu+Cu and p+p. We observe (Fig.4) that the near-side is broader for Cu+Cu than in p+p, implying that the medium contributes to, or changes the effective fragmentation. STAR has also reported that there is an "ridge" in $\Delta\eta$ on the near-side. However, the "ridge" spectrum STAR measured is softer in p_T than particles from the jet, indicating that the ridge particles are possibly from the medium's response. In contrast, our broadening extends to high-p_{Tout}^{Near}, suggesting that these particles are from a modified jet-fragmentation.

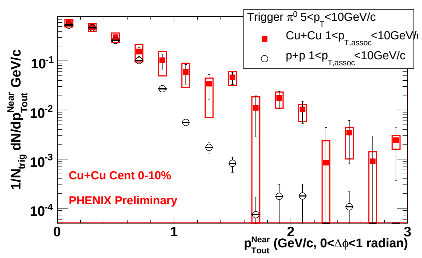


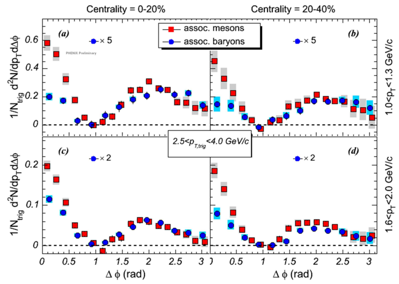
Fig. 4. The per-trigger yield of associated particles as a function of $p_{Tout}^{nearside}$. Results are for both central Cu+Cu(red) and p+p(black).

3.5. Identified Associates

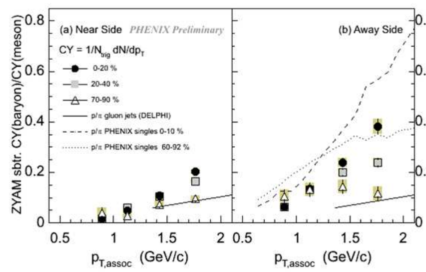
We can obtain more information on the interplay between the jet and the medium-response by examining the jet shapes for different particle types. In Fig.5(a) we plot the di-jet shapes separately for associated mesons and baryons. From these distributions we calculate the baryon/meson yield ratio for both the near- and far-sides and compare them with the ratio from inclusive spectra, as well as from other experiments. These comparisons are shown in Fig.5(b). A clear increase in the associated baryon/meson ratio is observed from peripheral to central collisions especially on the far-side, where this ratio reaches close to the level observed for singles spectra from central collisions. The singles spectra are well reproduced by coalescence models, hence the similarity between the jet-function ratios and the single-particle ratios suggests that the jet-yields are also influenced by coalescence from soft partons in the medium,

4. Summary

High$-p_T$ particle production gives access to hard-scattering processes, and we use azimuthal correlation functions as an important tool to study jet and medium interactions. PHENIX has steadily progressed beyond the "discovery" state and has begun addressing the next level of questions:
→ How are jets affected by passage through the medium created in RHIC collisions?
→ How does the medium respond to the impact of a high$-p_T$ probe parton?
→ Can we use these interactions to map out the properties of the plasma?
The results shown here represent some of our first answers to these questions, though



(a)



(b)

Fig. 5. (a) Per-trigger jet function. Associated particles are mesons(red) or baryons(blue). Notice jet functions of baryon associates are scaled to be comparable. and (b) Baryon/Meson ratio of the jet yields, compared to the ratio from inclusive spectra.

as we learn more and gather higher levels of statistics we will be able to reach greater precision and breadth in our investigations.

References

1. S. S. Adler *et al. Phys. Rev. Lett.* **97**, 052301 (2006)
2. **PHENIX Collaboration,** A. Adare *et al.* **nucl-ex/0608033**,
3. Thorsten Renk **Quark Matter 2006** Proceeding, *Mach cones and dijets - angular correlations as a probe of early medium evolution mentioned*
4. A. Adare *et al. Phys. Rev. Lett.* **98**, 232301 (2007)
5. A. Adare *et al.* **nucl-ex/arXiv:0705.3238.**
6. C. Chiu and R. Hwa, Phys. Rev. C **74**, 064909 (2006)
7. N. Armesto, C.A. Salgado and U.A. Wiedemann, Phys. Rev. Lett. **93**, 242301 (2004)
8. I. M. Dremin, JETP Lett. **30** (1979) 140; V.Koch, A. Majumder and X.N. Wang, Phys. Rev. Lett. **96**, 172302 (2006)
9. J. Casalderrey-Solana, E.V. Shuryak and D. Teaney, J.Phys.Conf.Ser.**27**, 22(2005); hep-ph/0602183
10. T. Renk and J. Ruppert, Phys.Rev.C **73**, 011901(2006)