

Two and Three Particle Flavor Dependent Correlations

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The PHENIX collaboration has developed novel methodologies for reliable extraction of jet functions from two and three particle azimuthal correlation functions measured at mid-rapidity in Au+Au collisions at $\sqrt{s} = 200$ GeV. The extracted jet shape and the yield of jet-associated partner hadrons (per trigger hadron) are found to vary with particle type and collision centrality, indicating a significant effect of the nuclear collision medium on the (di)jet fragmentation process.

1. Introduction

It is well known that the high energy density achieved in semi-central Au + Au collisions at RHIC, far exceeds the lattice QCD estimate for creating a de-confined phase of quarks and gluons (QGP)[1]. It's rapid thermalization gives rise to large pressure gradients evidenced by the sizable azimuthal anisotropy (v_2) observed for particle emissions from the collision zone [2]. The magnitude of this anisotropy is compatible with the predictions of the hydrodynamic model which in turn implies the creation of a strongly interacting medium and essentially full local thermal equilibrium. In addition to the soft processes giving rise to the formation of the medium, there are relatively rare hard parton-parton collisions. The scattered partons may propagate through the medium radiating gluons and interacting with the medium till they finally fragment into jet-like clusters. Since such interactions can modify jet fragmentation, jets provide a powerful probe of the medium, provided one can reliably extract the jet signal from the relatively large background which exist in RHIC collisions. Possible medium associated modifications of the jet properties are a shock wave induced conical flow or “sonic boom” [3] and “bending” induced by interactions between the propagating partons and the flowing medium [4].

2. Methodology and results:

Correlation Functions: To study jet properties we use two- and three-particle azimuthal correlation functions. These azimuthal correlation functions were built by pairing a leading hadron in a specified transverse momentum range $p_T(\text{trig})$, with an associated hadron also in a specified range $p_T(\text{assoc})$. For two-particle correlations, the correlation function $C(\Delta\phi)$ is given by:

$$C(\Delta\phi) = \frac{N_{real}(\Delta\phi)}{N_{mix}(\Delta\phi)},$$

where $\Delta\phi$ is the difference of the azimuthal angles of the pair. The real distribution ($N_{real}(\Delta\phi)$) is built from pair members belonging to the same event and the mixed distribution ($N_{mix}(\Delta\phi)$) is made of pair members belonging to different events. Thus the correlation function is free of geometric acceptance effects and carries only the combined correlations from flow and jets. Decomposition of these correlations into their jet and flow contributions, constitute an important prerequisite for obtaining the jet function and hence, information about jet fragmentation.

Decomposition of the correlation function: Following a two source model ansatz, $C(\Delta\phi)$ can be written as;

$$C(\Delta\phi) = a_0 [H(\Delta\phi) + J(\Delta\phi)],$$

where $H(\Delta\phi)$ is a second harmonic function having an amplitude $p_2 = v_2(\text{assoc}) \times v_2(\text{trig})$ and $J(\Delta\phi)$ is the jet function [5]. Here, $v_2(\text{assoc})$ and $v_2(\text{trig})$ are the amplitudes of the harmonic distributions of trigger and associated hadrons (respectively) relative to the azimuth of the reaction plane Ψ_{RP} , ie. $v_2(\text{assoc, trig}) = \langle \cos(2(\phi_{\text{assoc, trig}} - \Psi_{RP})) \rangle$. For these measurements, Ψ_{RP} was obtained from Beam-Beam counters having $\eta \pm 3.5$. To obtain $J(\Delta\phi)$ one simply uses the value a_0 , obtained by assuming that the magnitude of the Jet function $J(\Delta\phi)$ is zero at its minimum (ZYAM assumption) [5], and subtracts the measured values of $H(\Delta\phi)$.

Extinction Method: One can also obtain $J(\Delta\phi)$ via extinction of the the harmonic function $H(\Delta\phi)$ [5]. This is done by aligning the trigger hadron within an appropriately chosen angular range $\Delta\phi_c$, perpendicular to the reaction plane. The harmonic amplitude for the trigger particle in this configuration $v_2^{out}(\text{trig})$, is given as [6]

$$v_2^{out}(\text{trig}) = \left(\frac{2v_2(\Delta\phi_c) - \sin(2\Delta\phi_c) \langle \cos(2\Delta\Psi_R) \rangle + \frac{v_2^2}{2} \sin(4\Delta\phi_c) \langle \cos(4\Delta\Psi_R) \rangle}{2(\Delta\phi_c) - 2v_2 \sin(2\Delta\phi_c) \langle \cos(2\Delta\Psi_R) \rangle} \right).$$

Thus, it is clear that $v_2^{out}(\text{trig})$ can be made to vanish ($v_2^{out}(\text{trig}) \sim 0$) by appropriate choice of $\Delta\phi_c$ for a particular reaction plane resolution $\Delta\Psi_R$.

Results: Figures 1 and 2 show the application of these decomposition methods to meson-meson and baryon-meson correlation functions. They show that the jet-pair distributions, obtained after subtraction or extinction of the harmonic contributions, are significantly broadened on the away-side, independent of whether or not the trigger hadron is a baryon or meson. We attribute such broadening to the strong interactions between scattered partons and the high energy density medium.

It is straightforward to evaluate the conditional or per trigger yields (CY) for the near- and away-side jets via the integrated pair fractions indicated by the hatched area in Figs. 1 and 2 [5] or by building per trigger yield distributions. Fig. 3 compares proton and anti-proton jet yields obtained for near-side jets via the latter technique. The near-side yield is non-zero only for baryon-anti-baryon pairs, suggesting that baryon number conservation may play an important role in jet fragmentation.

One can also compare the baryonic and mesonic content of the near- and away-side jets by comparing the ratio $CY(\text{baryon})/CY(\text{meson})$ for the near- and away-side jets. Fig. 4 shows the double ratio

$$DBR = (CY(\text{baryon})/CY(\text{meson}))_{\text{away-jet}} / (CY(\text{baryon})/CY(\text{meson}))_{\text{near-jet}}$$

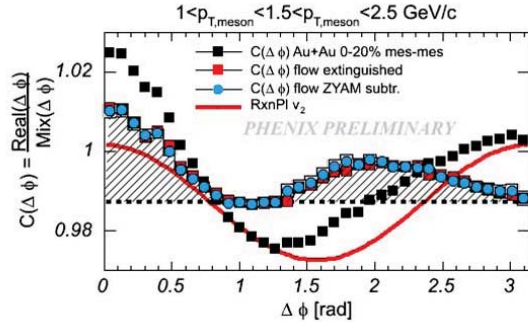


Figure 1. Correlation function for meson-meson pairs with $1. < p_T(\text{assoc.meson}) < 1.5 < p_T(\text{trig.meson}) < 2.5$ GeV/c (black squares). The red curve shows the harmonic contribution. The blue circles and red squares show the jet correlations which result from subtraction and harmonic extinction respectively (see text).

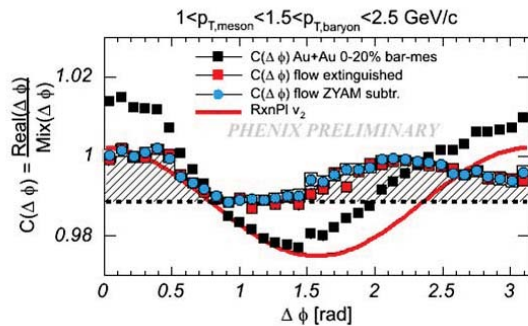


Figure 2. Same as Fig. 1, but for baryon-meson pairs.

for central - mid-central collisions. The observed ratio of ~ 2.5 suggests that the away side jet is more baryon rich than the near side jet, possibly because of a modification to the fragmentation function of the away-side jet.

Three particle correlations: Three-particle correlation functions consisting of a trigger hadron from the range $2.5 < p_T < 4.0$ GeV/c (hadron #1) and two associated hadrons from the range $1.0 < p_T < 2.5$ GeV/c (hadron #2 and #3) were also studied. Correlation surfaces were constructed by way of $\Delta\phi_{1,2}$ and $\Delta\phi_{1,3}$ distributions. For these correlation functions, the harmonic extinction method was used and the mixed background was created by combining the high p_T particle from the real events with associated particles from two different events.

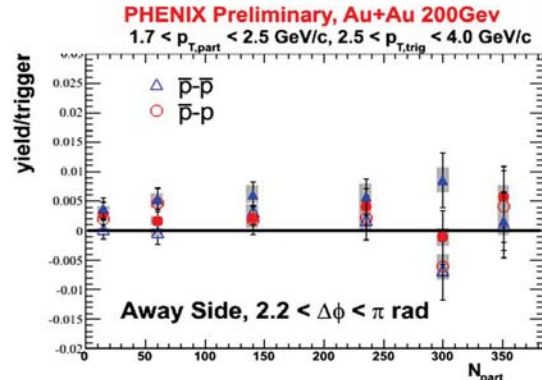


Figure 3. Per trigger yields vs. centrality for near-side jets obtained from p-p and p- \bar{p} pairs.

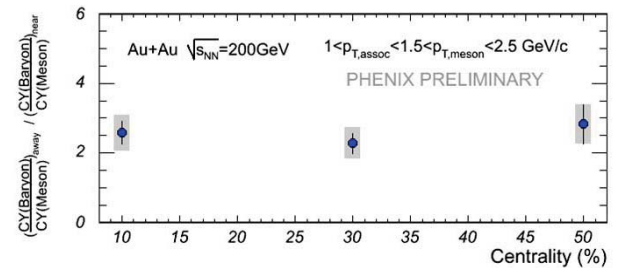


Figure 4. Centrality dependence of the double ratio DBR

The correlation functions therefore contain both triples and doubles contributions. Simulated three-particle correlation surfaces ($\Delta\phi_{1,2}$ vs. $\Delta\phi_{1,3}$) are shown in Figs. 5 - 7 for three distinct away-side jet scenarios; (i) a “normal jet” in which the away-side jet axis is aligned with the leading jet axis with a spread, (ii) a “bent jet” in which the away-side jet axis is misaligned by 60° , and (iii) a “Cherenkov or conical jet” in which the leading and away-side jet axes are aligned but fragmentation is confined to a very thin hollow cone with a half angle of 60° . The simulated results show relatively clear distinguishing features for the three scenarios considered.

The correlation surfaces obtained from data for the centrality selection 10-20 % are shown in Figs. 8 - 10. They show a strong dependence on the flavor (PID) of the associated particle and clearly do not follow the expected patterns for a “normal jet”. We conclude that these three-particle correlation surfaces provide additional compelling evidence for strong modification of the away-side jet.

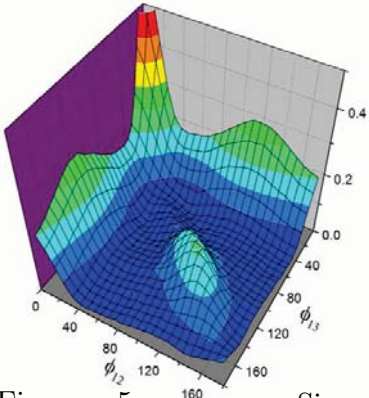


Figure 5. Simulated 3-particle correlations for “bent” jets.

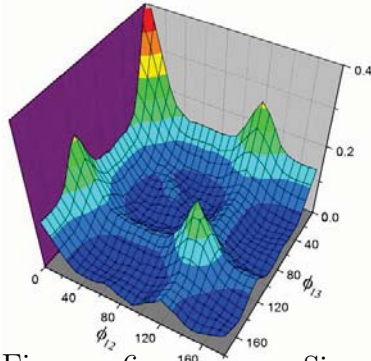


Figure 6. Simulated 3-particle correlations for Cherenkov jets or conical flow.

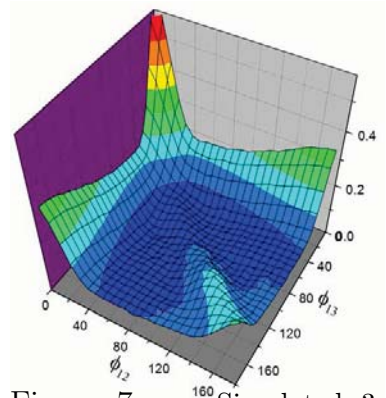


Figure 7. Simulated 3-particle correlations for “normal” jets.

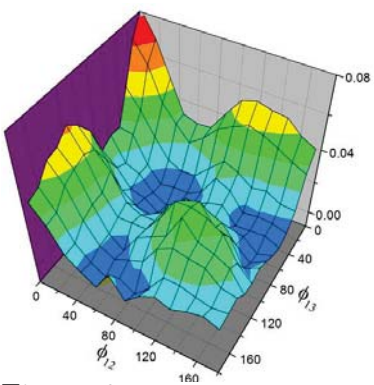


Figure 8. Hadron-hadron-hadron correlation function.

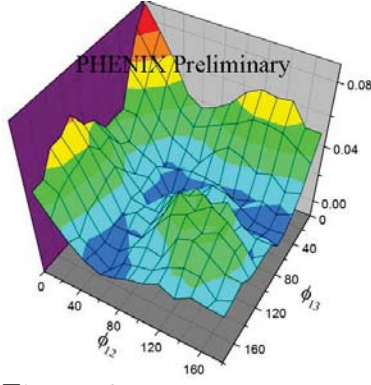


Figure 9. Hadron-meson-meson correlation function.

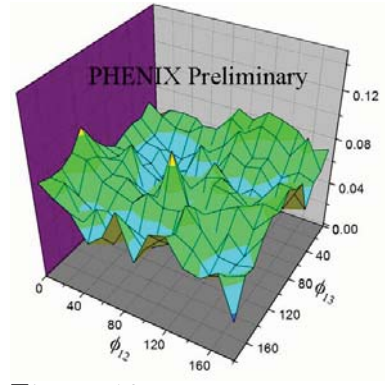


Figure 10. Hadron-baryon-baryon correlation function.

Further detailed quantitative investigations are however required to firm up the signatures in the data which distinguish between a “bent jet” and a “conical jet”.

Summary: Novel methodologies have been developed to remove harmonic contributions and extract jet functions from azimuthal correlation functions. Jet function and yields show strong dependence on particle flavor. The near-side jet yield is non-zero only for baryon-anti-baryon pairs. The jet landscape for three particle correlations have been obtained as a function of particle flavor. They provide further compelling evidence for strong modification of the away-side jet.

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