Jet-triggered dihadron correlations

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Abstract. Dihadron correlations in nuclear collisions continue to serve as an important tool for accessing energy loss and medium modification of jet shapes and yields, particularly in comparison to p+p reference data. However, there remain unsettled issues in the methodology and interpretation of dihadron correlations. In particular, the disentanglement and subtraction of event anisotropy from a correlated and (possibly highly quenched) jet signal in a large heavy-ion background is not a closed case. A new technique for reducing background in a triggered correlation analysis is to require trigger particles to reside within the cone radius of a reconstructed jet. A simulation study of the influence of background on dihadron correlations is presented together with improvements afforded by using jet reconstruction for purity enhancement of trigger particles. Additionally, progress using these techniques in Au+Au data from the STAR detector is reported along with discussion of their relation to existing results.

1. Introduction
Energy loss of fast partons escaping the hot matter produced in relativistic nuclear collisions is an important signature of the quark-gluon plasma. Angular distributions of correlated leading and associated charged hadrons (here denoted respectively as type “A” and “B”) have exhibited significant modification in both shape and yield in central Au+Au collisions compared to a p+p reference [1, 2, 3]. In particular, a doubly-peaked structure has been reported on the recoil side. Three-particle correlations suggest the feature to be conical [4], and its explanation has attracted theoretical interest. Notably, at high trigger momenta ($p_T^A \gtrsim 7$ GeV/c), the doubly-peaked structure is not observed at any $p_T^B$ [5]. If energy loss scales with parton energy such that a cone feature from medium response remains constant or rises relative to other correlation structures, such experimental results do not seem to support theoretical expectations. This talk explores how spurious “Mach cones” can arise from the presence of non-jet background and improper characterization of event shapes, and introduces $h_{jet}^\pm - h^\pm$ correlations as a tool to clarify understanding of energy loss and medium response.

2. The two source model and event geometry
Dihadron correlation analyses conventionally assume that anisotropic pairing in phase space arises from either jet fragmentation or event-wide mechanisms such as elliptic flow. Disentangling the two components is complicated by jet-medium interactions, initial and final-state radiation, and fluctuations at various scales. Despite such complications, the underlying event shape is
often parametrized with Fourier coefficients $v_n$ as

$$\frac{dN_{bkg}}{d\Delta \phi} = B_0 \left(1 + 2 \sum_n v_n^{AB} \cos n \Delta \phi \right).$$

(1)

To date, most analyses have neglected all terms but $n = 2$, describing the background as a pure ellipse modulating a pedestal $B_0$, generated presumably by initial anisotropy and hydrodynamic flow. However, fluctuations have recently been shown to strongly affect the shape of individual events. In particular, Glauber Monte Carlo simulations indicate that some events bear a strong triangular shape, and a mapping of triangular anisotropy to $v_3$ in simulations such as AMPT has led to calculated $v_3/v_2$ ratios of 20-100% [6].

3. Background in correlations: expected influences

In general, correlated signals $S$ are very sensitive to the shape and normalization of the background $B$ when $S/B$ is very small. Because the low $S/B$ region is precisely where 2-peak structures have been most prominent, it is important to understand how background influences correlations.

If all trigger particles are from jet-related sources, adding background to the population of associated particles results in a pedestal with magnitude $n_{bkg}^B/2\pi$ (where $n = N/N_{evt}$), since

$$\int d\Delta \phi \frac{1}{N^A_{jet}} \frac{dN_{jet-bkg}^{AB}}{d\Delta \phi} = \frac{n_{bkg}^B}{2\pi}.$$

(2)

Adding non-jet trigger particles does not change the total pair yield per trigger in each event, since the pair and trigger multiplicities rise at the same rate and thus cancel. However, the correlation is weakened. The jet peak yields are diluted by a factor $f \equiv N^A_{jet}/N^A$. But the total per-trigger yield is unchanged, again due to the cancellation. Thus the pedestal rises by $(1 - f)n_{jet}^B$. These expectations are tested in a simulation described in the following section.

4. Jet-triggered dihadron correlations: simulations and real data

The trigger purity can be enhanced by requiring the trigger particle to be inside a reconstructed jet. In this analysis, the FastJet anti-$k_T$ clustering algorithm is used due to its relatively low sensitivity to background fluctuations and its tendency to reconstruct conical jets. An angular distance is defined between each trigger particle and the nearest jet axis, $\Delta R \equiv \sqrt{(\phi_{jet} - \phi_A)^2 + (\eta_{jet} - \eta_A)^2}$. We distinguish $h^+_{jet} - h^\pm$ correlations from inclusive $h^\pm - h^\pm$ by requiring $\Delta R < R_c$, where $R_c = 0.4$.

In order to study how non-jet trigger particles influence correlations, a simple Monte Carlo study was conducted in which 20 GeV pythia jets were embedded in an isotropic thermal background, where $dN_{bkg}/dp_T = N_0 \exp(-p_T/T)$. Fits to STAR 0-5% central $h^\pm$ spectra at 1-2 GeV/c motivated a choice of $T = 260$ MeV. $N_0$ was chosen to match central Au+Au collisions at RHIC: in the STAR acceptance, $N_0 = dN_{ch}/d\eta \cdot \Delta \eta \cdot N_{all}/N_{ch} = 650 \cdot 2 \cdot 3/2 = 1950$.

Figure 1 (top) shows $h^+_{jet} - h^\pm$ pair yields per trigger particle for pythia particles in the presence of background, where $2 < p_T^A < 3$ and $1 < p_T^B < 2$ GeV/c. To check the expectation of equation 2, the background pedestal level shown as a red line is calculated explicitely as

$$\frac{n_{bkg}^B}{2\pi} = \frac{1}{2\pi} \frac{N_{bkg}(1 - 2 \text{ GeV})}{N_{bkg}(\text{all } p_T)} = \frac{1}{2\pi} \cdot 1950 \cdot 0.105 = 32.8.$$ 

(3)

When the background pedestal is subtracted, the original background-free yield is recovered
A critical conclusion is that non-jet trigger particles diminish jet correlation signals, causing enhanced sensitivity to misrepresentation of the background shape. Thus, distortions in the background-subtracted result due to incorrect $v_2$ values, neglect of $v_{n\neq 2}$ components, and normalization errors are exacerbated by the diminished signal strength.

A first result from $h_{jet}^+ - h^\pm$ correlations in real data was produced from a STAR Au+Au and p+p high tower (HT) triggered data sample rich in highly energetic jets. Moreover, only particles with $p_T > 2$ GeV/c are used in jet reconstruction, and jets are required to have a background-corrected $p_T > 10$ GeV/c.$^1$

A comparison of $h_{jet}^+ - h^\pm$ ($\Delta R < 0.4$) and $h^\pm - h^\pm$ is shown for Au+Au and p+p for two different $p_T^A$ bins in figures 3 and 4. Both measurements are from a common event selection; every event contains a jet with $p_{jet}^T > 10$ GeV/c. Thus, even the inclusive dihadron correlations (blue points) have enhanced correlations relative to those expected from minimum bias events. In the top panels, the background is included, and in the bottom panels, it has been subtracted. Apart from the event selection and $\Delta R$ cut, the analysis follows the procedure leading to the results in [1]. Thus, the background is shaped as in equation 1 with $v_n = 0$ for all $n \neq 2$. A

\[^1\] Background subtraction is performed as $p_T^{jet} = p_T^{meas} - \rho A$, where $\rho$ is the median $p_T$ per unit area.
Figure 3. $h_{jet}^+ - h^\pm$ and $h^\pm - h^\mp$ from STAR Au+Au and p+p at moderate $p_T^A$.

Figure 4. $h_{jet}^+ - h^\pm$ and $h^\pm - h^\mp$ from STAR Au+Au and p+p at high $p_T^A$.

$v_2$ value from STAR measurements is used for both cases as an initial estimate, and the ZYAM assumption determines $B_0$.

5. Discussion and summary

The most striking feature of the results is the signal enhancement at low $p_T^A$. Apart from the fact that these results may depend sensitively on the jet definition, an explanation for the enhanced signal is not as straightforward as in the simulation for several reasons.

First, background sources in real data are more complicated. The trigger particle population may be contaminated by thermal fluctuations, recombination, and soft particles boosted by hydrodynamics or radial expansion. Moreover, many particles from hard scatterings unrelated to the primary di-jet are removed in $h_{jet}^+ - h^\pm$. Thus, $h_{jet}^+ - h^\pm$ does not sample the minimum-bias jet cross section. Additionally, the kinematics are not the same. While the simulation used essentially mono-energetic jets, the STAR results may reflect a selection of higher-$Q^2$ events in the $h_{jet}^+ - h^\pm$ case than for inclusive. At a given $p_T^A$, $h_{jet}^+ - h^\pm$ correlations sample harder collisions and lower-z hadrons.

In summary, triggering on more jet-like particles in Au+Au collisions enhances the correlation strength and diminishes the recoil-side double-peak feature precisely where it might be expected if energy loss which triggers medium response scales with parton energy. Although requiring careful interpretation, $h_{jet}^+ - h^\pm$ correlations add useful information to investigations of medium response and energy loss.

References
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