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HEAVY ION PHYSICS

Return of the Volcano: PHENIX Azimuthal Correlations 62.4 GeV $Au + Au$

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Abstract. As in previous analyses at $\sqrt{s_{NN}}$ 200 GeV, correlations in azimuthal angles between inclusive charge particles at intermediate transverse momentum (p_T = 1.0-4.0) GeV are studied at $\sqrt{s_{NN}}$ 62.4 GeV. The di-jet correlations reveal similar modification as in 200 GeV. Specifically large modification, including the "volcano" or "cone" structure, persists in the awayside correlation.

Keywords: jet, cone, volcano
PACS: see: http://www.aip.org/pacs/

1. Introduction

Much effort has been made toward understanding the medium effects in $\sqrt{s_{NN}}$ = 200 GeV Au+Au collisions at RHIC via jet properties extracted from correlations in di-hadron azimuthal opening angle. Initially these results included the observation of quenching, [3],[4] and later broadening in the very low momentum (< 1 GeV) (presumed) jet particles compared to such correlations from normal jet fragmentation. [5]. In [1], PHENIX showed that under 2-source (flow+jet) assumptions, the awayside correlations have a distinctive "volcano-like" or "conical" structure, with a peak displaced from 180 degrees from the nearside trigger particle, in stark contrast to the normal "back to back" jet fragmentation correlation which peaks at 180. This interesting feature is also evident in STAR data obtained with similar methods [6], albeit with less significance due to a larger systematic error assignment for the v_2 subtraction. Nonetheless the observations have generated much speculation as to possible physical "conical flow" origins of the displaced peak [7],[8], [9]. We extend these works by applying a similar analysis to $\sqrt{s_{NN}}$ = 62.4 GeV Au+Au collisions in order to observe whether such effects continue to exist at this

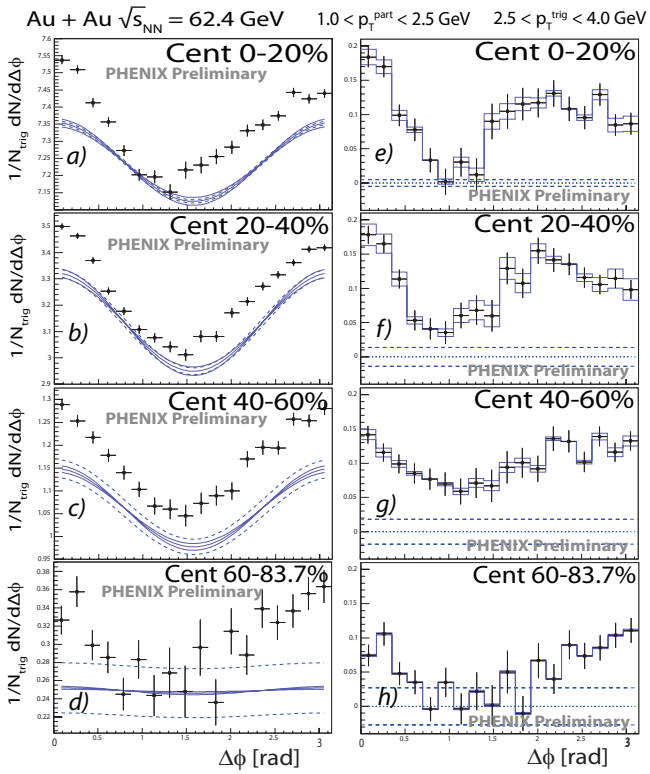

Fig. 1. *a)-d)*: Per-trigger $dN/\Delta\phi$ yields without combinatorial background subtraction, proportional to the two particle $\Delta\phi$ correlation function (see text). The calculated background contribution is shown in the solid curves [dashed curve 1-σ uncertainty]. *e)-h)*: Background subtracted $dN_{dj}/\Delta\phi$ per-trigger conditional yields. The awayside "volcano" is evident in the more central bins.

lower energy.

2. Analysis

This analysis is based on a sample of 41.4 M minimum bias events taken during the RHIC Run4 in 2004 at $\sqrt{s_{NN}} = 62.4$ GeV. We follow the basic methods outlined in [1],[2]. Two categories of unidentified charged hadron tracks are considered based on track p_T: *trigger* (t) particles [2.5 GeV/c $< p_T <$ 4.0 GeV/c] and *partner* (p) particles [1.0 GeV/c $< p_T <$ 2.5 GeV/c]. We define the number of di-jet correlated particle pairs per event as a function of the $\Delta\phi$ between the two particles, $dN_{dj}/d\Delta\phi$, according to the formula

$$\frac{1}{N_{evts}}\frac{dN_{dj}}{d\Delta\phi} = \frac{1}{N_{evts}Acc(\Delta\phi)}\left(\frac{dN_{pairs}}{d\Delta\phi} - \frac{dN_{bkg}}{d\Delta\phi}\right) \tag{1}$$

where $dN_{pairs}/d\Delta\phi$ represents all t-p pairs made in real events and $Acc(\Delta\phi)$ represents the pair acceptance and efficiency correction function. The $\Delta\phi$ shape of $Acc(\Delta\phi)$ is derived from a mixed event procedure, making pair combinations taking t and p particles from different events, and its overall normalization is set by the single particle acceptance and efficiency in the t/p category p_T ranges. $dN_{bkg}/d\Delta\phi$ is generated by the exact same event mixing procedure, therefore dividing it by $Acc(\Delta\phi)$ results in a constant function of $\Delta\phi$. Under the assumptions of the 2-source model [1], this constant background is modulated by the independently determined per-event averaged flow measurements, $\langle v_2^t\rangle$ and $\langle v_2^p\rangle$ according to:

$$\frac{1}{N_{evts}Acc(\Delta\phi)}\frac{dN_{bkg}}{d\Delta\phi} = B\left(1 + 2\langle v_2^t\rangle\langle v_2^p\rangle\cos(2\Delta\phi)\right) \tag{2}$$

where B defines the normalization of the non-interesting background. To obtain B in this analysis we employ an "absolute" method also used in [2], as well as the "Zero Yield At Minimum" (ZYAM) method described in [1] for comparison. In the absolute method, it is assumed the background level B is simply the product of the per-event averaged single's multiplicities for both the trigger and partner particle categories, along with an additional factor ξ which accounts for residual multiplicity correlations: that is, $B = \xi\langle n_t\rangle\langle n_p\rangle$. Neglecting ξ, this assumption has a first-order error equal to $\langle j_t\rangle\langle j_p\rangle$, where j_x represents the number of true jet particles in category x. In p+p events it was checked that compared to the signal size $\langle n_t n_p\rangle \approx \langle j_t j_p\rangle$, $\langle j_t\rangle\langle j_p\rangle$ is negligible, and it is assumed that in $Au + Au$, where the background and combinatoric contributions dominate, the approximation continues to hold. The need for ξ, a correction for the finite sized centrality binning/resolution effects in the mixing discussed in [2], is due to residual multiplicity correlation between numbers of jet and non-jet particles due to event geometry/global event multiplicity, which affects the overall normalization but not the $\Delta\phi$ shape of the total correlation. We scale our final results per trigger particle.

3. Results, Discussions, and Conclusions

In figure 1 the shape of the correlations are shown for 4 centrality bins. Since $Acc(\Delta\phi)$ as calculated is proportional to the product of the independent t/p probabilities $P(t)$ and $P(p)$, the quantity in the left column *a)-d)*, $1/Acc(\Delta\phi)(dN_{pairs}/d\Delta\phi)$, is proportional to the raw correlation strength $P(t,p)/P(t)P(p)$. Figure 1 *e)-h)* are the $dN_{dj}/d\Delta\phi$ yields, eq. (1), after subtraction of the harmonic background. Both a gaussian shaped peak on the nearside (and awayside in the two peripheral selections), typical of jet correlations in this kinematic regime [1], as well as the displaced "volcano" peak in the awayside region previously observed at 200 GeV are evident.

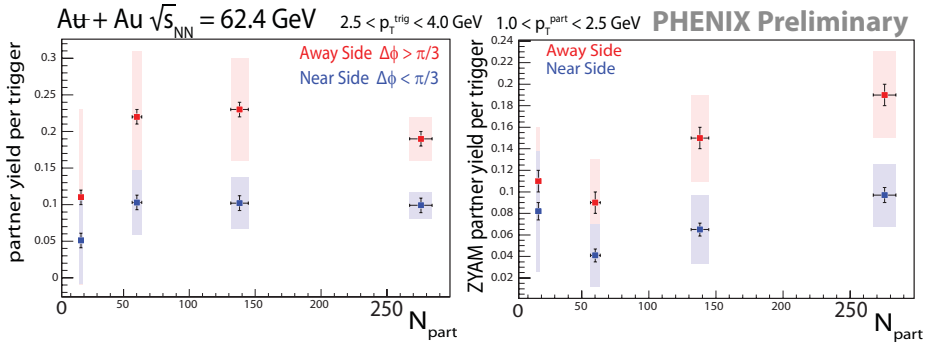

Fig. 2. Nearside and awayside integrated per-trigger conditional yields *a*) using the "absolute" background normalization method and *b*) using the ZYAM method, both *vs*. number of participants.

In figure 2, the yields are integrated and plotted vs. the collision centrality (parameterized as N_{part}). Within large uncertainties, no clear centrality dependence as seen in [1] can be confirmed or denied, though the comparison between these integrated yield results and the 200 GeV [1] (not shown) shows that the 62.4 GeV near-side yields are lower, with significance, for all centrality bins. This behavior is expected for jet fragmentation, due to a larger (high-z) trigger bias at lower energy due to the more steeply falling hard-scattering cross sections.

In summary, the same abnormal awayside features of the apparent di-jet correlations seen at 200 GeV are present in the 62.4 GeV PHENIX data. Combining information of the full energy dependence of the modification along with possibly the dependence on system size as in such studies of Cu+Cu collisions should constrain the possible theoretical explanations of their origins.

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