Anomalous centrality variation of minijet angular correlations in Au-Au collisions at 62 and 200 GeV from STAR

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Abstract. We have measured 2D autocorrelations for all charged hadrons in STAR with $p_t > 0.15$ GeV/c and $|\eta| < 1$ from Au+Au collisions at 62 and 200 GeV. The correlation structure is dominated by a peak centered at zero relative opening angles on $\eta$ and $\phi$ which we hypothesize is caused by minimum-bias jets (minijets). We observe a large excess of minijet correlations in more-central Au-Au collisions relative to binary-collision scaling (more correlated pairs than expected from surface emission or even volume emission). We also observe a sudden increase of the minijet peak amplitude and $\eta$ width relative to binary-collision scaling of scattered partons which occurs at an energy-dependent centrality point. There is a possible scaling of the transition point with transverse particle density. The large minijet correlations bring into question the degree of thermalization in RHIC collisions.

1. Introduction

Low momentum jets are estimated to produce 50% of transverse energy in RHIC heavy ion collisions and 80% at the LHC [1]. Despite the large role these minijets play, they have received little attention from the general community since the start of the RHIC experimental program. As minijet abundance increases at higher energies, the dynamics of minijet interactions are becoming essential to understanding heavy ion collisions.

While low momentum jets are not individually resolvable, their combined effect generates an observable correlation. In a theoretical context minijets are typically defined within the range of applicability of pQCD by specifying a low hadron $p_t$ cutoff around 2 GeV/c, even though QCD interactions continue to lower $p_t$. We experimentally define minijets based on correlation structure rather than an a priori $p_t$ range. This requires a minimum-bias two-particle correlation analysis where every possible pair of particles is considered instead of selecting a few trigger/associated pairs. Minijets are distinguished from other sources by decomposing the unique correlations. Previous analyses have used this technique to reveal large minijet contributions in transverse [2] and axial ($\eta$, $\phi$) [3] spaces at 130 GeV at four centralities. Here we report the detailed energy and centrality dependence of minijet angular correlations at RHIC.
2. Analysis

Charged particle tracks detected in the STAR TPC with $p_t > 0.15$ GeV/c, $|\eta| < 1$, and full $2\pi$ azimuth were analyzed from 1.2M minbias triggered 200 GeV Au+Au and 6.7M 62 GeV Au+Au events. Pair densities $\rho(\vec{p}_1, \vec{p}_2)$ were measured as number of pairs per unit area on relative angles ($\eta_\Delta \equiv \eta_1 - \eta_2$, $\phi_\Delta \equiv \phi_1 - \phi_2$) for all possible unique particle pairs. Particles within the same event form sibling pair densities $\rho_{\text{sib}}$, while mixing particles from different events measures the uncorrelated reference $\rho_{\text{ref}}$. These are formed into a normalized covariance to produce a correlation measure. The difference $\Delta \rho \equiv \rho_{\text{sib}} - \rho_{\text{ref}}$ measures the covariance in number of pairs between histogram bins, and the normalization is provided by bin-wise division of $\sqrt{\rho_{\text{ref}}}$. Thus we use the notation $\frac{\Delta \rho}{\sqrt{\rho_{\text{ref}}}}$ for a per-particle correlation measure, shown in figure 1 for selected centralities.

![Figure 1](image-url). Minimum-bias correlations for several centralities from peripheral (left) to central (right) in 200 GeV Au+Au collisions.

3. Fit Results

Proton-proton collisions provide a reference for measuring the contributions to these structures. Analysis of minimum-bias correlations [4] and single particle $p_t$ spectra [5] show that p+p collisions are well described by a two-component soft and semi-hard scattering model, as commonly used in event generators such as Pythia. The soft component represents longitudinal fragmentation in unlike-sign pairs and produces a 1D gaussian correlation centered along $\eta_\Delta=0$. The semi-hard component contains a same-side peak, modeled as a 2D gaussian at the $\eta_\Delta = \phi_\Delta = 0$ origin, and an away-side ridge centered at $\phi_\Delta=\pi$. For an inclusive $p_t$ range the away-side is completely represented by function $-\cos(\phi_\Delta)$ that approximates a wide gaussian which narrows with increasing $p_t$ [4]. The final component necessary to describe p+p data is a 2D exponential at the origin containing contributions from HBT in like-sign pairs and conversion $e^\pm$ in unlike-sign pairs. To ensure the simplest possible fit function for Au+Au collisions, we use these components from p+p collisions with only one additional $\cos(2\phi_\Delta)$ quadrupole term to account for correlations conventionally attributed to elliptic flow [6]. The eleven parameter fit function used for the correlation structures in figure 1 is then:
\[ F = A_{\phi_{\Delta}} \cos(\phi_{\Delta}) + A_{2\phi_{\Delta}} \cos(2 \phi_{\Delta}) + G_s(\eta_{\Delta} : A_0, \sigma_0) + G_h(\eta_{\Delta}, \phi_{\Delta} : A_1, \sigma_{\eta_{\Delta}}, \sigma_{\phi_{\Delta}}) \\
+ E(\eta_{\Delta}, \phi_{\Delta} : A_2, w_{\eta_{\Delta}}, w_{\phi_{\Delta}}) + A_3 \]  

where \( G_s \) and \( G_h \) are the soft and hard Gaussian terms and \( E \) is an exponential function with parameters listed after the colon. An example of this fit is shown in figure 2.

Figure 2. An example of the fit function showing correlation data (first panel), model function (second panel), residual (third panel) defined as data minus model fit, and the same-side gaussian and exponential peaks (last panel).

Figure 3 shows the measured fit parameters for the same-side peak amplitude, \( \eta_{\Delta} \) width, and volume (= \( 2\pi A_1 \sigma_{\eta_{\Delta}} \sigma_{\phi_{\Delta}} \)). Fitting errors are shown and systematic error is estimated to be ±9% of the correlation amplitude and at most a few percent of the widths. The dashed lines show the binary scaling reference expected from independent nucleon-nucleon collisions. Using the Kharzeev and Nardi two-component model [7] and path length \( \nu \equiv 2\langle N_{\text{bin}} \rangle / \langle N_{\text{part}} \rangle \), the minijet amplitude in Au+Au collisions is expected to scale as \( A_1(\nu) = A_{1,pp} \nu / \left[ 1 + x(\nu - 1) \right] \) from the p+p value. Peripheral collisions follow the binary scaling reference closely, deviating only by small increases in \( \eta_{\Delta} \) and decreases in \( \phi_{\Delta} \) widths. The data show a sharp transition at approximately 55% centrality for 200 GeV and 40% for 62 GeV where the amplitude and \( \eta_{\Delta} \) widths increase dramatically while the \( \phi_{\Delta} \) widths continue to decrease slightly. Centrality in figure 3 is represented by transverse particle density calculated as \( \frac{3}{2} \frac{dN_{\text{ch}}}{d\eta} / \langle S \rangle \) with initial collision overlap area \( \langle S \rangle \) from Monte Carlo Glauber. Transverse density brings the transition points for the two energies to coincidence, whereas conventional centrality measures displace the transition points and tend to compress the peripheral data.

4. Discussion

The correlation structures are modified at the transition, but are still likely to be associated with minijets for several reasons. First, these results, particularly when taken with a similar analysis of \( p_t \) correlations [8], show that contributions from a new physical mechanism unrelated to minijets are unlikely. Any such hypothetical process must have \( \phi_{\Delta} \) widths and \( p_t \) correlations that match seamlessly with minijets, which would be a remarkable coincidence. Second, the amplitude and \( \eta_{\Delta} \) width increases are
consistent with further minijet interactions, which may be possible due to path-length considerations [9]. Finally, it is possible that the new correlation structures are due to changes in minijet fragmentation. The trends in the data also suggest a lower $p_t$ manifestation of the “ridge” [10], and these results may help to discriminate among the many competing models of ridge formation.

The same-side peak volume gives the total number of correlated pairs, though finding the particle yield requires estimating the average number of correlated structures per event. Assuming each structure originates with a semi-hard parton and that semi-hard scattering follows binary scaling, we estimate that 30% of all final-state hadrons in central 200 GeV Au+Au collisions are associated with this same-side correlation.

As a source of correlated low momentum particles, minijets provide an extremely sensitive probe of the collision system. The binary scaling reference represents one extreme limit of a transparent medium, while the other extreme is a completely thermalized system opaque to minijets [11]. These results call into question the existence of the latter system at RHIC energies.

References

[1] Wang X-N and Gyulassy M 1991 Phys. Rev. D 44 3501
[2] Adams J et al (STAR Collaboration) 2007 J. Phys. G: Nucl. Part. Phys. 34 799
[3] Adams J et al (STAR Collaboration) 2006 Phys. Rev. C 73 064907
[4] Porter R J and Trainor T A 2005 J. Phys.: Conf. Ser. 27 98
[5] Adams J et al (STAR Collaboration) 2006 Phys. Rev D 74 032006
[6] Trainor T A and Kettler D T 2007 Preprint arXiv:0704.1674 [hep-ph]
[7] Kharzeev D and Nardi M 2001 Phys. Lett. B 507 121
[8] Adams J et al (STAR Collaboration) 2006 J. Phys. G: Nucl. Part. Phys. 32 L37
[9] Kajantie K et al 1987 Phys. Rev. Lett. 59 2527
[10] Putschke J (STAR Collaboration) 2007 Preprint nucl-ex/0701074
[11] Nayak G C et al 2001 Nucl. Phys. A 687 457; Shin G R and Müller 2003 J. Phys. G: Nucl. Part. Phys. 29 2485