Observation of $\Delta\phi\Delta\eta$ Scaled Correlation Signals which increase with Centrality of Au Au collisions at $\sqrt{s_{NN}} = 200$ GeV

R.S. Longacre$^a$ for the STAR Collaboration

$^a$Brookhaven National Laboratory, Upton, NY 11973, USA

Abstract

We show the preliminary charged-particle pair correlation analyses presented in a poster session at the 2006 International Quark Matter Conference in Shanghai China. The correlation analysis space of $\Delta\phi$ (azimuth) and $\Delta\eta$ (pseudo-rapidity) are considered as a function of centrality for minimum bias Au + Au collisions in the mid-transverse momentum range in the STAR detector. The analyses involve unlike-sign charge pairs and like-sign charge pairs, which are transformed into charge-dependent (CD) signals and charge-independent (CI) signals. We use a multiplicity scale to compare the different centralities. We find the signals increase with increasing centrality. A model featuring dense gluonic hot spots as first proposed by van Hove predicts that the observables under investigation would have sensitivity to such a substructure should it occur. A blast wave model including multiple hot spots motivates the selection of transverse momenta in the range $0.8 \text{ GeV/c} < p_t < 4.0 \text{ GeV/c}$.

1 Introduction

The search for a Quark-Gluon Plasma (QGP) has a high priority at the Relativistic Heavy Ion Collider (RHIC). Van Hove[1] and others[2] have proposed that bubbles localized in phase space (dense gluon-dominated hot spots) could be the sources of final state hadrons from a QGP. Such structures would have smaller spatial dimensions than the region of the fireball. Correlations resulting from these smaller structures might persist in the final state of the collision. The Hanbury-Brown and Twiss (HBT) results demonstrate that for $\sqrt{s_{NN}} = 200$ GeV mid rapidity central Au + Au, when $p_t > 0.8 \text{ GeV/c}$ the average final state space geometry for pairs close in momentum is approximately described by dimensions of around 2 fm[3]. This should lead to observable modification of the $\Delta\eta\Delta\phi$ correlation.

2 $\Delta\phi$ Correlation for Minimum Bias Data

The $\Delta\phi$ correlation function[4] is defined as:

$$C(\Delta\phi) = \frac{S(\Delta\phi)}{M(\Delta\phi)}.$$  (1)

$^1$This research was supported by the U.S. Department of Energy under Contract No. DE-AC02-98CH10886
Where $S(\Delta \phi)$ is the number of pairs at the corresponding values of $\Delta \phi$ coming from the same event, after we have summed over all the events. $M(\Delta \phi)$ is the number of pairs at the corresponding values of $\Delta \phi$ coming from the mixed events, after we have summed over all our created mixed events. A mixed event pair has each of the two particles chosen from a different event.

**Table I.** The minimum bias data is split up into standard STAR binning.

| Au + Au Collisions | Centrality     |
|--------------------|----------------|
| 70% to 80%         | peripheral     |
| 60% to 70%         |                |
| 50% to 60%         |                |
| 40% to 50%         |                |
| 30% to 40%         |                |
| 20% to 30%         |                |
| 10% to 20%         |                |
| 5% to 10%          |                |
| 0% to 5%           | most central   |

The mixed events were selected based on centrality and the Z (beam axis) position of the primary vertex. The events selections was achieved by sorting events into the centrality bins above and ten 5cm wide bins covering -25cm to +25cm in Z vertex. Thus only tracks were mixed for events which had the same multiplicity and acceptance.

**3 The CD and The CI Correlations**

Using equation 1, we can form $\Delta \phi$ correlations for unlike-sign charge pairs (US) and like-sign charge pairs (LS). We can also form a $\Delta \phi$ correlation using all the particle pair combinations which would be charge independent. This CI (Charge Independent) correlation is equal to the average of the US and LS correlations.

$$CI = (US + LS)/2.$$  \hspace{1cm} (2)

We also can form a Charge Dependent (CD) correlation by taking the difference between the US and the LS correlations.

$$CD = US - LS.$$  \hspace{1cm} (3)

The CI correlation is a quantitative measure of the average structure of the correlated emitting sources. The CD correlation is a qualitative measure of the emission correlation of unlike-sign charge pairs emitted from the same space and time region. Similar CI and CD are used by other STAR analyses[5].
4  How does one compare different Centralities?

The signal present in the correlation comes from pairs that are correlated. The number of signal pairs increase linearly with the number of particles. The total number of pairs is proportional to the square of the number of particles. Thus the ratio of signal pairs to all pairs decrease as $1/\text{particles}$. We can cancel out this effect by multiplying the CD and CI correlations by the multiplicity of particles used in forming the correlations.

5  Comparing the CD Correlations

We compare the CD yield in Figure 1 and the overall shape of the CD in Figure 2. Multiplicity scaling is used in Figure 1 while we normalize each centrality in Figure 2. In Figure 2 the $\Delta \phi = 10^\circ$ for $0.0 < \Delta \eta < 0.3$ is normalized to 1. All other $\Delta \eta$ bins are determined by this normalization.

6  Comparing the CI Correlations

We need to compare the CI yield for the different centralities. The CI correlation as a function of $\Delta \phi$ averages to 1 over the $\Delta \phi$ range. In order to compare the signal strength we must multiply by the multiplicity for each centrality. The scale correlation will then have a much different range and be hard to compare. The average multiplicity ranges from 6 to 216. We choose to shift up each scaled correlation until it is in the 216 range.

6.1 Elliptic Flow

Elliptic flow is a background that we need to worry about. The elliptic flow is given by $2v_2^2 \cos(2\Delta \phi)$ and is symmetric about $\Delta \phi = 90^\circ$. For a constant value of elliptic flow ($v_2$), the scaled correlation will get a bigger dip at $\Delta \phi = 90^\circ$ with increasing multiplicity. The dip is proportional to the multiplicity.

Elliptic flow ($v_2$) decreases linearly with centrality and the correlation has a quadratic dependence on $v_2$. Thus for the scaled correlation the elliptic flow effect increases because the multiplicity is increasing and then decreases because of the quadratic response of $v_2$, becoming very small at the most central (0% to 5%).

6.2 Determining the Shift Value

To first order we want to remove the $v_2$ effect from the comparison. If the away side of the scaled correlation ($\Delta \phi = 180^\circ$) is mainly $v_2$ then a signal on the near side ($\Delta \phi = 0^\circ$) would
Figure 1: The multiplicity (MULT) times the CD correlation vs. $\Delta \phi$ for $0.0 < \Delta \eta < 0.3$. Nine centralities are shown from 70% to 80% increasing to 0% to 5%. The CD increases with centrality.
STAR Preliminary

Figure 2: The multiplicity (MULT) times the CD correlation vs. $\Delta\phi$ for all $\Delta\eta$ bins 0.3. Nine centralities are shown from 70% to 80% increasing to 0% to 5%. Each of the nine centralities were scaled so that the $10^\circ \Delta\phi$ bin for $0.0 < \Delta\eta < 0.3$ is normalized to 1. We see that the shape of the CD correlation is virtually independent of centrality.
rise above the value of the away side. Thus if we would shift all scaled correlations such that
the away side is equal, then we could compare the signals on the near side.

6.3 Comparing the CI(Δφ) vs. Δη

The scaled CI correlation is split up into 5 Δη bins (Figure 3 to Figure 7). Each centrality
for a given Δη bin is plotted with the away side (Δφ = 180°) scaled correlation shifted to
the same value. The horizontal line for each centrality shows the shifted average multiplicity
line which was 1 in the original CI correlation and became equal the average multiplicity
after becoming the scaled correlation.

We have assumed in our comparison that the elliptic flow accounted for the away side
peak. A bubble model[2] predicts that there should be an away side correlation between
bubbles. Thus our normalization would lead to a reduced signal on the near side. The
bubble model[2] showed that there is an away side signal when the width of the away side
becomes much wider then the near side as it does for the most central (0% to 5%).

7 Conclusions

The scaled CD correlations increase with centrality see Figure 1. The scaled CI correlations
increase until 20% centrality and remains the same for the rest of the centralities. If we
assume the wider away side peak is also a signal, we have a consistent picture between the
scaled CD and CI correlations, both increasing with centrality. Ref.[2] is in good agreement
with our central CD and CI correlations. The bubble model[2] assumes localized gluonic hot
spots on the surface of the fireball created by the central Au + Au collision.

References

[1] L. Van Hove, Hadronization Quark-Gluon Plasma in Ultra-Relativistic Collisions
CERN-TH (1984) 3924, Hadronization Model for Quark-Gluon Plasma in Ultra-
Relativistic Collisions, Z. Phys. C27 (1985) 135.

[2] S.J. Lindenbaum and R.S. Longacre, Parton Bubble Model, Eur. Phys. J. C.(accepted-in
press) Published online: 15 Nov. 2006, DOI: 10.1140/epjc/s10052-006-0131-4.

[3] J. Adams et al., Phys. Rev. C. 71 (2005) 044906, S.S. Adler et al., Phys Rev. Lett. 93
(2004) 152302.

[4] R.S. Longacre, RHIC Physics and Beyond (Kay Kay Gee Day), AIP Conference Pro-
cedings 482, Upton, New York, October 1998, Editors B. Muller and R.D. Pisarski,
pp. 85-103.
[5] J. Adams et al., Phys. Rev. C. 73 (2005) 064907, Phys. Lett. B (2006) 347, nucl-ex/0607003, submitted to Phys Rev. C. (2006).
STAR Preliminary

Figure 3: The multiplicity (MULT) times the CI correlation vs. $\Delta \phi$ for $0.0 < \Delta \eta < 0.3$. Nine centralities are shown from 70% to 80% increasing to 0% to 5%. 216 is the multiplicity for 0% to 5% and all other centralities are shifted up so that the 180° value is equal. Each multiplicity for each centrality is shown shifted.
Figure 4: The multiplicity (MULT) times the CI correlation vs. $\Delta \phi$ for $0.3 < \Delta \eta < 0.6$. Nine centralities are shown from 70% to 80% increasing to 0% to 5%. 216 is the multiplicity for 0% to 5% and all other centralities are shifted up so that the 180° value is equal. Each multiplicity for each centrality is shown shifted.
Figure 5: The multiplicity (MULT) times the CI correlation vs. $\Delta \phi$ for $0.6 < \Delta \eta < 0.9$. Nine centralities are shown from 70% to 80% increasing to 0% to 5%. 216 is the multiplicity for 0% to 5% and all other centralities are shifted up so that the 180° value is equal. Each multiplicity for each centrality is shown shifted.
Figure 6: The multiplicity (MULT) times the CI correlation vs. $\Delta \phi$ for $0.9 < \Delta \eta < 1.2$. Nine centralities are shown from 70% to 80% increasing to 0% to 5%. 216 is the multiplicity for 0% to 5% and all other centralities are shifted up so that the 180° value is equal. Each multiplicity for each centrality is shown shifted.
Figure 7: The multiplicity (MULT) times the CI correlation vs. $\Delta \phi$ for $1.2 < \Delta \eta < 1.5$. Nine centralities are shown from 70% to 80% increasing to 0% to 5%. 216 is the multiplicity for 0% to 5% and all other centralities are shifted up so that the $180^\circ$ value is equal. Each multiplicity for each centrality is shown shifted.