UNDERSTANDING THE PARTICLE PRODUCTION MECHANISM
WITH CORRELATION STUDIES USING LONG AND SHORT
RANGE CORRELATIONS

B. K. SRIVASTAVA, R. P. SCHARENBERG AND T. J. TARNOWSKY
(for the STAR Collaboration)
Department of Physics, Purdue University,
West Lafayette, Indiana-47907, USA
brijesh@physics.purdue.edu

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Long range forward-backward multiplicity correlations have been measured with the
STAR detector for Au+Au collisions at \( \sqrt{s_{NN}} = 200 \, \text{GeV} \). Strong long range cor-
relations are observed in central Au+Au collisions. Based on the Dual Parton model and
Color Glass Condensate considerations the data suggests that these long range correla-
tions are due to multiple parton interactions. This suggests that dense partonic matter
is created in central Au+Au collisions at \( \sqrt{s_{NN}} = 200 \, \text{GeV} \).

1. Introduction

The study of correlations among particles produced in different rapidity regions may
provide understanding of the mechanisms of particle production. Strong short-range
correlations (SRC) are observed in hardon-hadron collisions, indicating clustering
over a region of \( \sim \pm 1 \) unit in rapidity \(^1\(^2\(^3\(^4\)).\) Correlations that extend over a longer
range are observed in hadron-hadron interactions only at higher energies \(^2\(^4\)).\)

Multiparticle production can be described in terms of color strings stretched
between the oncoming partons. These strings then decay into observed secondary
hadrons. In this scenario, the strings emit particles independently \(^5\(^6\(^7\). \) It has
been suggested that long-range correlations (LRC) might be enhanced in hadron-
nucleus and nucleus-nucleus interactions, compared to hadron-hadron scattering
at the same energy \(^5\(^6\)).\) One way to study the correlation is to measure forward-
backward multiplicity correlations which have been studied in several experiments
\(^1\(^2\(^3\(^4\)).\)

The correlation strength is defined by the dependence of the average charged
particle multiplicity in the backward hemisphere \( \langle N_b \rangle \), on the event multiplicity in
the forward hemisphere \( N_f \), \( \langle N_b \rangle = a + b N_f \), where \( a \) is a constant and \( b \) measures
the strength of the correlation\cite{30,10}

\[ b = \frac{\langle N_f N_b \rangle - \langle N_f \rangle \langle N_b \rangle}{\langle N_f^2 \rangle - \langle N_f \rangle^2} = \frac{D_{bf}^2}{D_{ff}^2} \]  

In “Eq.(1)” $D_{bf}^2$ and $D_{ff}^2$ are the backward-forward and forward-forward dispersions respectively.

2. Data Analysis

The data utilized for this analysis is for Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV at the Relativistic Heavy Ion Collider (RHIC), as measured by the STAR experiment\cite{8}. The collision events were part of the minimum bias data set. The centralities presented in this analysis account for 0-10%, 10-20%, 20-30%, 30-40% and 40-50% of the total hadronic cross section and were obtained by use of the multiplicity of all charged particles ($N_{ch}$) measured in the TPC with $|\eta| < 0.5$. All charged particles in the Time Projection Chamber (TPC) pseudorapidity range $|\eta| < 1.0$ and with $p_T > 0.15$ GeV/c were considered. This region was subdivided into bin widths $\eta = 0.2$. The forward-backward intervals were located symmetrically about midrapidity with the distance between bin centers ($\Delta \eta$): 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, and 1.8. An analysis of the data from $pp$ collisions at 200 GeV was also performed on minimum bias events using the same quality cuts as in the case of Au+Au. Corrections for detector geometric acceptance and tracking efficiency were carried out using a Monte Carlo event generator and propagating the simulated particles through a GEANT representation of the STAR detector geometry.

In order to eliminate (or at least reduce) the effect of impact parameter (centrality) fluctuations on this measurement, each relevant quantity ($N_f, N_b, N_f^2, N_f N_b$) was obtained on an event-by-event basis as a function of $N_{ch}$, and was fitted to obtain the average values of $\langle N_f \rangle, \langle N_b \rangle, \langle N_f \rangle^2$, and $\langle N_f N_b \rangle$\cite{9,10}. This method removes the dependence of the correlation strength $b$, on the size of the centrality bin $N_{ch}$. Tracking efficiency and acceptance corrections were applied to each event. Systematic effects dominate the error determination. The systematic errors are determined by varying cuts on the z-vertex $|v_z|$ (< 30, 20, and 10 cm), number of fit points on the individual tracks in the TPC.

3. Results and Discussions

The plot of correlation strength ($b$) as a function of the pseudorapidity gap is shown in Fig. 1 for the 0-10% most central Au+Au events. It is observed that the value of $b$ does not change with the pseudorapidity gap. Fig. 1 also shows $b$ as a function of $\Delta \eta$ for 40-50% mid-central Au+Au collisions. In this case $b$ decreases with the increasing $\Delta \eta$, which is expected if there were only short range correlations.

Short range correlations have been extensively studied. The shape of the SRC function has a maximum at, and is symmetric about, midrapidity (pseudorapidity,
Fig. 1. Correlation strength $b$ for 0-10% and 40-50% centrality as a function of pseudorapidity gap $\Delta \eta$ for Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

$\eta = 0$). It can be fitted with a Gaussian or an exponential function. The short range correlations are significantly reduced by a separation of 1.5 - 2.0 units of pseudorapidity. Fig. 1 shows that in case of 0-10% most central Au+Au the $b$ value is flat with $\Delta \eta$, while the mid central 40-50% has a sharp fall like SRC. Since the analysis is limited to $-1 < \eta < 1$, the short range component cannot be completely eliminated. The pp collisions is used to estimate the short range component from Au+Au collisions. Fig. 2 shows $b$ as a function of $\Delta \eta$ for the pp collisions. The $b$ value from pp decays exponentially with increasing $\Delta \eta$. Fig. 1 and Fig. 2 show that the correlation strength with $\Delta \eta$ is quite different in 0-10% Au+Au as compared to pp. An analysis of the mid-central and peripheral events in Au+Au shows that for the 40-50% centrality bin the shape of correlation strength $b$ with $\Delta \eta$ is similar to the pp case.

Traditionally, the LRC is measured with a large gap in the forward-backward window and is based on experimental observation of charged particle correlations in pp at $\sqrt{s_{NN}} = 200$, 500, and 900 GeV. The strength of the SRC is reduced considerably with a $\Delta \eta$ of 2.0 units. Thus the remaining portion of the correlation strength is mainly due to the LRC. As shown in Fig. 2 it appears that pp at 200 GeV only has a SRC. We assume that the fall of SRC as a function of $\Delta \eta$ does not change in going from pp to Au+Au. The 40-50% Au+Au supports this assumption. To extract the short range part in 0-10% Au+Au collisions, the pp value of $b$ at $\Delta \eta = 0$ (non-overlapping measurement windows), is scaled up to the $b$ value in
the Au+Au case, as the SRC has a maximum at $\eta = 0$. $b$ vs $\Delta \eta$ in Fig. 2 for pp was fitted with an exponential function. The scaled $b$ value for the other $\Delta \eta$ points were calculated using the fit function. The remaining part of the correlation strength (long range), is obtained by subtracting the short range component from the measured correlation strength. This is shown in Fig. 3 as the long range. There is a growth of the LRC with increasing $\Delta \eta$.

Two other analyses in STAR have focused on the correlations of charged particle pairs in $\Delta \eta$ (pseudorapidity) and $\Delta \phi$ (azimuth). It was observed that near-side peak is elongated in $\Delta \eta$ in central Au+Au as compared to peripheral collisions. The centrality of the collision plays an important role in the growth of long range component of the total correlation strength. Data from 10-20%, 20-30%, and 30-40% most central Au+Au collisions have been analyzed, following the same procedure as for 0-10% centrality, to determine the evolution of the LRC strength. The growth of LRC is shown in Fig. 3. The magnitude of the LRC is quite large for the most central collisions when $\Delta \eta > 1.0$. From Fig. 3 it is clear that the magnitude of the LRC increases from peripheral to central collisions. The 0-10% results are also compared with phenomenological models HIJING and the DPM Monte Carlo codes HIJING and the Parton String Model (PSM) were used to generate minimum bias events for Au+Au collisions at 200 GeV. The PSM is based on DPM. The analysis was carried out in the same manner as with real data. The PSM was used without the string fusion option. The variation of $b$ with $\Delta \eta$ is shown in Fig. 4 along with the experimental value for 0-10% central Au+Au.

Fig. 2. (a) Correlation strength $b$, and the line is the exponential fit to $b$ vs $\Delta \eta$. 

STAR Preliminary

$p+p 200\text{GeV}$

$b \sim e^{-\frac{(\Delta \eta)}{\lambda}}$
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Fig. 3. Growth of LRC for centrality bins 0-10%, 10-20%, 20-30% and 30-40%.

HIJING predicts SRC with a large value of $b$ near midrapidity in agreement with the data. A sharp decrease in $b$ is seen beyond the $\Delta \eta \sim 1.0$. PSM has both short and long range correlations and is in qualitative agreement with the data.

In the DPM the particle production occurs via string fragmentation. There are two strings per inelastic collision and the long range component is expressed as

$$ \langle N_f N_b \rangle - \langle N_f \rangle \langle N_b \rangle \propto \langle n^2 \rangle - \langle n \rangle^2 \langle N_{q-\bar{q}} \rangle_f \langle N_{q-\bar{q}} \rangle_b $$

where the average multiplicities of $q-\bar{q}$ in the forward and backward regions is given by $\langle N_{q-\bar{q}} \rangle_f$ and $\langle N_{q-\bar{q}} \rangle_b$ respectively in each elementary inelastic collision.

“Eq. (2)” shows that the LRC is due to fluctuations in the number of elementary inelastic collisions. It is believed that the experimental observation of the LRC originates from these multiple partonic interactions. The Color Glass Condensate (CGC) provides a theoretical QCD based description of multiple string interactions

16, 17. The CGC 18 argues for the existence of a LRC in rapidity, similar to those predicted in DPM. Recently, long range forward-backward multiplicity correlations have been discussed in the framework of the CGC and predict the growth of the LRC with the centrality of the collision 19.

4. Summary

In summary, this is the first work on the measurement of the long-range correlation strength ($b$), in ultra relativistic nucleus-nucleus collisions. The DPM and CGC ar-
Fig. 4. Model comparison with data. The correlation strength is shown for HIJING (open square) and the Parton String Model, PSM(open circle) for the 0-10% centrality in Au+Au collisions.

It is hypothesized that the long range correlations are due to multiple parton-parton interactions. This indicates that dense quark-gluon matter is formed in central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. An analysis of the correlation for baryons can further address the CGC picture.

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