STAR’s measurement of Long-range forward-backward multiplicity correlations as the signature of “dense partonic matter” in the Heavy Ion collisions at $\sqrt{s_{NN}} = 200$ GeV.

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Abstract.

Forward-backward multiplicity correlations have been measured with the STAR detector for Au+Au, Cu+Cu and $p+p$ collisions at $\sqrt{s_{NN}} = 200$ GeV. A strong, long-range correlation is observed for central heavy ion collisions that vanishes in semi-peripheral events and $pp$ collisions. There is no apparent scaling of correlation strength with the number of participants involved in the collision. Both the Dual Parton Model and the Color Glass condensate indicate that the long range correlations are due to multiple parton interactions. This suggests that the dense partonic matter might have been created in mid-central and central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

The investigation of high energy nucleus-nucleus collisions provides a unique tool to study the properties of hot and dense matter. The motivation is drawn from lattice QCD calculations, which predicts a phase transition from hadronic matter to a system of deconfined quarks and gluons (QGP) at high temperature [1]. The study of event-by-event correlations and fluctuations provides a probe to explore such transition in the search for the QGP. In particular the measurement of particle correlations has been suggested as a method to search for the existence of a phase transition in ultra-relativistic heavy ion collisions [2].

It has been suggested that long-range rapidity correlations (LRC) might be enhanced in hadron-nucleus and nucleus-nucleus interactions, compared to hadron-hadron scattering at the same energy [3, 4]. The presence of long range correlations implies the existence of multiple inelastic collisions and provides a test of the multiple scattering models [4]. The Color Glass Condensate also predicts the large scale rapidity correlations in heavy ion collisions [5].

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 $N_f$, $\langle N_b \rangle = a + bN_f$, where $a$ is a constant and $b$ measures the strength of the correlation [3, 4]:

$$b = \frac{\langle N_f N_b \rangle - \langle N_f \rangle \langle N_b \rangle}{\langle N_f^2 \rangle - \langle N_f \rangle^2} = \frac{D_{2f}^2}{D_{ff}^2}$$

(1)
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\[ D_{bf}^2 \] and \[ D_{ff}^2 \] are the backward-forward and forward-forward dispersions respectively. The correlation strength given by Eq.(1) has the contributions from both short and long range sources. The long range part can be obtained by giving a large gap in rapidity between the forward and backward hemispheres.

\[ \text{FIGURE 1. FB Correlation strength as a function of } \Delta \eta \text{ (a) for Au+Au at three centrality bins and (b) for } p+p \text{ and 30-40 and 40-50% Au+Au. All errors are systematic.} \]

The STAR detector is most suited for forward-backward (FB) multiplicity correlations as it is symmetric about mid rapidity. This is the first measurement of the FB correlation strength in nucleus-nucleus collisions at the highest RHIC energy. The data utilized for this analysis is for Au+Au, Cu+Cu and \( p+p \) collisions at \( \sqrt{s_{NN}} = 200 \) GeV at the Relativistic Heavy Ion Collider (RHIC), as measured by the STAR (Solenoidal Tracker at RHIC) experiment. The main tracking detector at STAR is the Time Projection Chamber (TPC) \[0]. \] All charged particles in the TPC pseudorapidity range -1.0 < \( \eta \) < 1.0 and \( p_T > 0.15 \) GeV/c were considered. The collision events were part of the minimum bias dataset. The minimum bias collision centrality was determined by an off-line cut on the TPC charged particle multiplicity within the range -0.5 < \( \eta \) < 0.5. The forward-backward intervals were located symmetrically about midrapidity with the distance between bin centers (\( \Delta \eta \)) ranging from 0.2 to 1.8 with an interval of 0.2.

Tracking efficiency and acceptance corrections were applied to each event. These were then used to calculate the backward-forward and forward-forward dispersions, \( D_{bf}^2 \) and \( D_{ff}^2 \), binned according to the STAR centrality definitions and normalized by the total number of events in each bin.

The plot of FB correlation strength (\( b \)) as a function of the pseudorapidity gap is shown in Fig. (a) for the 0-10, 10-20 and 20-30% central Au+Au events. 0-10% being most central events. It is observed that the value of \( b \) does not change with the pseudorapidity gap. Fig. (b) shows \( b \) as a function of \( \Delta \eta \) for 30-40 and 40-50% Au+Au collisions.
STAR’s measurement of Long-range forward-backward multiplicity correlations as the signature of “dense partonic collisions along with the $p+p$ events. In this case $b$ decreases with the increasing $\Delta \eta$, which is expected if there were only short range correlations. The centrality of the collision plays an important role in the growth of long range component of the total correlation strength. The magnitude of the LRC is quite large for the most central collisions when $\Delta \eta > 1.0$. Figure 1(b) shows that FB correlation strength in 40-50% Au+Au falls faster with $\Delta \eta$ as compared to $p+p$ collisions. There is some hint of decreasing FB correlation strength with $\Delta \eta$ in 30-40% Au+Au events as well.

The plot of $D_{bf}^2$ and $D_{ff}^2$ as a function of the pseudorapidity gap is shown in Fig. 2(a) for the 0-10% most central Au+Au events. It is observed that the value of $D_{bf}^2$ and $D_{ff}^2$ does not change with the pseudorapidity gap. Figure 2(b) shows $D_{bf}^2$, and $D_{ff}^2$, as a function of $\Delta \eta$ for the $p+p$ collisions. Figures 2(a) and (b) show that change in $D_{bf}^2$ with $\Delta \eta$ is quite different in 0-10% Au+Au as compared to $p+p$. $D_{bf}^2$ falls with $\Delta \eta$ for $p+p$ and can be approximated by Gaussian or exponential function. This shows that FB correlation strength is controlled mainly by $D_{bf}^2$.

The FB correlation strength from the analysis of Cu+Cu at $\sqrt{s_{NN}} = 200$ GeV is shown in Fig. 3(a) along with the Au+Au for 0-10% centrality. It is observed that the FB correlation strength is decreased by 15% in going from Au+Au to Cu+Cu system. This suggests that system size does not have large effect on FB correlation strength.

The 0-10% results are also compared with phenomenological models HIJING [7] and the Dual Parton Model (DPM) [4]. Monte Carlo codes HIJING and the Parton String Model (PSM) [4, 8, 9] were used to generate minimum bias events for Au+Au collisions at 200 GeV. The PSM is based on DPM [4]. The variation of FB correlation strength with $\Delta \eta$ is shown in Fig. 3(b) along with the experimental value for 0-10% central Au+Au collisions. HIJING predicts SRC with a large value of $b$ near midrapidity.

Figure 2. Backward-forward dispersion ($D_{bf}^2$) and forward-forward dispersion ($D_{ff}^2$) as a function of pseudorapidity gap $\Delta \eta$ (a) For Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and (b) for $p+p$ collisions. All errors are systematic.
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Figure 3. (a) FB corelation strength for 0-10% Cu+Cu and Au+Au events. (b) Model comparison with data. The correlation strength is shown for HIJING and the Parton String Model for the 0-10% centrality in Au+Au collisions.

in agreement with the data. A sharp decrease is seen in FB correlation 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, long range correlations are due to fluctuations in the number of elementary inelastic collisions and is given by the backward-forward dispersion [4]:

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

(2)

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 CGC also argues for the existence of a LRC in rapidity, similar to those predicted in DPM [10].

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