Forward-Backward Multiplicity Correlations for Identified Particles in Au+Au 200 GeV Collisions

Michael Skoby (for the STAR Collaboration)
Department of Physics, Purdue University, 525 Northwestern Avenue, West Lafayette, IN 47907
E-mail: skoby@purdue.edu

Abstract. Preliminary STAR measurements of the forward-backward multiplicity correlation as a function of rapidity separation for pions and (anti)protons in Au+Au 200 GeV collisions are presented for 0-10% and 10-20% centralities. A strong, uniform correlation is shown for pions, and is smaller for (anti)protons. The Color String Percolation Model predicts the long-range correlation, and suggests a possible measurement to study a transition from percolation to the quark-gluon plasma.

1. Introduction
Kinematic observables of hadronic matter from relativistic heavy-ion collisions are measured at STAR in search of the so-called 'quark-gluon plasma'. Long-Range (rapidity separation > 1) Forward-Backward multiplicity correlations (LRC) may be a signal for multiple partonic interactions in dense matter, whereas short-range (rapidity separation < 1) correlations are due to independent sources [1,2]. Previously, strong LRC have been measured at STAR in 200 GeV central Au+Au collisions, and were shown to decrease with decreasing centrality [3]. To further investigate the origin of the forward-backward correlation, it can be studied with respect to its particle species dependence (pions, kaons, protons), and measured as a function of rapidity separation (Δy). The Color Glass Condensate (CGC) model, which describes sources as longitudinal flux tubes, predicts that the correlation will grow with centrality [4,5]. Furthermore, fluctuations in the number of gluons at early times will produce a long range correlation significantly larger for pions than (anti)protons [5]. Pions and (anti)protons are identified at STAR by measuring their specific ionization energy loss in the Time Projection Chamber (TPC) [6]. Preliminary results of the measured correlation are presented for pions, kaons, and protons for 0-10% and 10-20% centralities. As seen previously in hadron-hadron experiments, the average multiplicity of particles in the backward region can be related to the multiplicity in the forward region.

\[ \langle N_B \rangle \langle N_F \rangle = a + b N_F \tag{1} \]

Applying a linear regression one can obtain the correlation strength b.

\[ b = \frac{\langle N_f N_b \rangle - \langle N_f \rangle \langle N_b \rangle}{\langle N_f^2 \rangle - \langle N_f \rangle^2} = \frac{D_{gb}}{D_{ff}} \tag{2} \]
2. Data analysis

The data used in this analysis are from 2004 Au+Au 200 GeV collisions acquired at STAR. The correlation was measured for 0-10% and 10-20% centralities. Tracks in the TPC with rapidity < 1 and distance of closest approach from the primary vertex < 3 cm were used for the measurement. Previous measurements of forward-backward correlations were made as a function of pseudorapidity. However, once particle species are identified the measurement of the correlation as a function rapidity is possible. Particle identification is done by making transverse momentum and average energy loss cuts. Particle species are separated into bands when the average energy loss is plotted as a function of transverse momentum, as in figure 1.

Figure 1. Average energy loss vs. \( p_T \) shows bands for various particle species.

The particle species bands overlap with each other in certain momentum ranges. The \( p_T \) cuts used in this analysis are 0.2-0.6 GeV/c for pions and kaons, and 0.4-1.0 GeV/c for (anti)protons. Background protons contaminate the proton sample by about 30% for \( p_T = 0.4 \) GeV/c and about 2% for \( p_T = 0.8 \) GeV/c. Also, the cuts in the number of standard deviations from the measured particle species’ \(<dE/dx>\) to those obtained from theoretical expectations [7] were \( n_{\sigma_{p}} < 2, n_{\sigma_{K}} > 2 \) for pions, \( n_{\sigma_{p}} > 3, n_{\sigma_{K}} < 1.5 \) for kaons, and \( n_{\sigma_{p}} > 2, n_{\sigma_{K}} > 2 \), \( n_{\sigma_{p}} < 2 \) for (anti)protons. After particles are identified the rapidity region is divided into bins of width \( y = 0.16 \), so the correlation is measured across \( \Delta y = 0.16, 0.32, 0.48, 0.64, 0.80, 0.96 \) for kaons and (anti)protons. In addition to the aforementioned rapidity separations, the measurement is also done for \( \Delta y = 1.12, 1.28, 1.44, 1.60 \) for pions. The pseudorapidity acceptance in the TPC accounts for the limited rapidity measurement for kaons and (anti)protons. Particles used to determine the centrality of an event were counted in a rapidity region separate from the particles used to measure the correlation in order to avoid autocorrelations.

Particles were counted in the forward and backward regions on an event-by-event basis, and binned by event centrality. In order to reduce the effect of centrality fluctuations, a fit is made to the average values of \( N_f, N_b, N_fN_b, N_{\mu}N_b \) as a function of the number of charged particles used to determine the centrality. After applying acceptance corrections and tracking efficiencies this fit gives the average values used to calculate the dispersions \( D_{yf}^2 \) and \( D_{yf}^2 \), normalized by the total number of events in each bin.
3. Results and discussion

Figure 2 shows the forward-backward correlation for (a) (anti)protons, (b) kaons, and (c) pions in 0-10% and 10-20% centrality Au+Au 200 GeV collisions as a function of rapidity separation $\Delta y$. Only the short-range correlation is measured for (anti)protons and kaons due to the pseudorapidity acceptance at STAR. The correlation is small (~0.25) and uniform for kaons and (anti)protons in 0-10% collisions, and decreases to ~0.10 for 10-20% collisions. The decrease in the (anti)proton correlation strength from 0-10% to 10-20% is not expected in the context of the CGC picture, which says the baryon correlation should not grow with increasing centrality [5]. Conversely, a strong (~0.50) uniform correlation is observed for pions in 0-10% collisions and decreases to ~0.40 in 10-20% collisions. The small short-range correlation for (anti)protons and kaons, compared to pions, suggests the LRC will also be small for these species. Figure 2 (d) shows a comparison of the correlation for all species in central collisions, where the LRC for pions is substantially larger than what is expected for (anti)protons. CGC predicts the LRC will be larger for pions, which presumably arise from gluons, than for (anti)protons due to fluctuations in the number of gluons in early times [5]. CGC also predicts measurements of the correlation for inclusive charged hadrons at high transverse momentum in central collisions may not be as large since contributions from baryons increase at high $p_T$. This will be studied in the future.

The observation of the LRC motivates a future investigation into other models that predict it. In the Color String Percolation Model (CSPM) color strings responsible for particle production overlap as the string density $(\Box)$ increases-forming clusters [8]. At a critical string density these clusters form a connected system that extends across the medium (see figure 3). STAR can investigate a transition from percolation to QGP in the context of the CSPM by extracting the string density from the measured pT spectra for increasing centralities.
Figure 3. 2-D representation of percolation. The green disks are strings, which overlap to form clusters as the string density increases, and finally percolation is reached when the clusters span the across the medium as a connected system.

The CSPM predicts LRCs due to multiplicity fluctuations within overlapping strings, where the overlap region acts as an independent emitter. Color fields added in the overlap area reduce the effective color field, invoking an overlapping factor.

\[ F(\eta) = \frac{1 - e^{-\eta}}{\eta} \] (3)

Measuring the string density in p+p and Au+Au collisions can be done by extracting \( F(\eta) \) from fits to the \( p_T \) distributions [9]. First, a fit to the p+p \( p_T \) distribution will yield fit parameters \( a, p_v, \) and \( m \).

\[ \frac{dN}{dp_t^2} = \frac{a}{(p_0 + p_t)^m} \] (4)

For Au+Au collisions, adjust \( p_v \) to account for the percolation of strings.

\[ p_0 \rightarrow p_0 \left( \frac{\langle nS_1 / S_n \rangle_{Au-Au}}{\langle nS_1 / S_n \rangle_{pp}} \right)^{1/4} \] (5)

Here, \( n \) is the number of strings in a cluster, \( S_1 \) is the area of one string, and \( S_n \) is the area of a cluster. \( F(\eta) \) can be determined using the relation

\[ \sqrt{\frac{F(\eta)_{pp}}{F(\eta)_{Au-Au}}} = \left( \frac{\langle nS_1 / S_n \rangle_{Au-Au}}{\langle nS_1 / S_n \rangle_{pp}} \right)^{1/4} \] (6)

Due to the low string overlap probability in p+p collisions \( F(\eta)_{pp} \sim 1 \).
4. Summary
Strong long-range correlations indicate the occurrence of multiple partonic interactions. Preliminary measurements show a strong, uniform LRC across ∆y for pions in central Au+Au collisions at 200 GeV, which decreases from central to peripheral collisions. The small short-range correlation for (anti)protons, compared to pions, suggests the LRC will also be small for this species. CGC claims that the LRC is larger for pions than (anti)protons due to the fluctuation in the number of gluons, and can only be created at early times. A possible transition from percolation to QGP can be investigated by measuring the percolation string density in the context of the CSPM picture.

References
[1] A. Capella and A. Krzywicki, Phys. Rev. D 18, 4120 (1978).
[2] A. Capella et al., Phys. Rep. 236, 225 (1994).
[3] B. I. Abelev et al. (STAR Collaboration), Phys. Rev. Lett. 103, 172301 (2009).
[4] Y. V. Kovchegov, E. Levin, and L. McLerran, Phys. Rev. C 63, 024903 (2001).
[5] N. Armesto, L. McLerran, and C. Pajares, Nucl. Phys. A 781, 201 (2007).
[6] K.H. Ackermann et al., Nucl. Instr. and Meth. A 499, 659 (2003).
[7] B. I. Abelev et al. (STAR Collaboration), Phys. Rev. C 79, 034909 (2009).
[8] M. A. Braun and C. Pajares, Eur. Phys. J. C 16, 349 (2000).
[9] M. A. Braun and C. Pajares, Phys. Rev. C 65, 024907 (2002).