Longitudinal Scaling Property of the Charge Balance Function in Au + Au collisions at √s[subscriptNN] = 200GeV

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ABSTRACT

We present measurements of the charge balance function, from the charged particles, for diverse pseudorapidity and transverse momentum ranges in Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV using the STAR detector at RHIC. We observe that the balance function is boost-invariant within the pseudorapidity coverage $[-1.3, 1.3]$. The balance function properly scaled by the width of the observed pseudorapidity window does not depend on the position or size of the pseudorapidity window. This scaling property also holds for particles in different transverse momentum ranges. In addition, we find that the width of the balance function decreases monotonically with increasing transverse momentum for all centrality classes.

Particle production in elementary collisions at high energy is constrained by conservation laws. Electric charge conservation, in particular, constrains the balance of charged particles produced in a collision. The electric charge balance function (BF) is an observable specifically designed to measure the balance, and thereby provide insight into the particle production processes in elementary collisions at high energy [1]. It has been used in hadron–hadron, lepton–hadron, and e^+e^- collisions to study hadronization schemes [1–3]. The BF has recently gained particular interest in clocking hadronization in relativistic heavy-ion collisions, where a new state of matter – the quark–gluon plasma (QGP) – would be formed. The formation of QGP will allow a partonic charge diffusion in longitudinal phase space, and would lead to a widening of the charge balance function [4].

The BF is defined in terms of a combination of four different conditional densities of charged hadrons [1]. It measures how the net charge at any point of the phase space is rearranged if the charge at a selected point changes. Projected on to the pseudorapidity difference $\delta\eta = \eta_1 - \eta_2$ of two charged particles in a given pseudorapidity window $\eta_{\rm w}$, the BF becomes [4,5]

$$B(\delta\eta|\eta_{\rm w}) = \frac{1}{2}\left[\frac{\langle n_{+-}(\delta\eta,\eta_{\rm w})\rangle - \langle n_{++}(\delta\eta,\eta_{\rm w})\rangle}{\langle n_{+}(\eta_{\rm w})\rangle} + \frac{\langle n_{-+}(\delta\eta,\eta_{\rm w})\rangle - \langle n_{--}(\delta\eta,\eta_{\rm w})\rangle}{\langle n_{-}(\eta_{\rm w})\rangle}\right] \quad (1)$$

where $\langle n_+(\eta_{\rm w})\rangle$ and $\langle n_-(\eta_{\rm w})\rangle$ are respectively the event averaged number of measured positively and negatively charged particles. $\langle n_{+-}(\delta\eta,\eta_{\rm w})\rangle = \langle n_{-+}(\delta\eta,\eta_{\rm w})\rangle$ is the event averaged number of pairs of particles with opposite charges separated by pseudorapidity $\delta\eta$. $\langle n_{++}(\delta\eta,\eta_{\rm w})\rangle$ and $\langle n_{-+}(\delta\eta,\eta_{\rm w})\rangle$ are defined correspondingly for pairs of positively and negatively charged particles, respectively. The charge balance function is a differential combination of all possible charge correlations. Its integral over rapidity space is related to measures of charge fluctuation [6].

Measurements of the BF in relativistic heavy-ion collisions have been reported by several experiments [5,7,8]. However, these experiments feature significant difference of acceptance in pseudorapidity and transverse momentum. Comparison of results from these experiments is thus only qualitative. A quantitative comparative analysis of these results requires a better understanding of the BF dependence on pseudorapidity and momentum acceptance [5,7,9,10].

This BF dependence has been studied in π^+p and K$^+$p collisions at 250 GeV/c incident beam momentum by a fixed target experiment with large acceptance [9]. In those collisions, the BF is found to be invariant under longitudinal boost over the whole rapidity range of produced particles ($-5 < y < 5$), i.e., the ratio of $B(\delta y|y_{\rm w})$ to $(1-\delta y/|y_{\rm w}|)$ is independent of the observed window, $|y_{\rm w}|$, and corresponds to the BF of the whole rapidity range [6].

The aim of the analysis presented in this Letter is to verify whether the boost invariance observed in elementary collisions is also present in Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV. To this end, we first study the BF using equal size pseudorapidity windows spanning various pseudorapidity ranges within a relatively wide pseudorapidity coverage of the STAR Time Projection Chamber (TPC). Given that the shape of the BF depends by definition on the width of the pseudorapidity acceptance, we next scale the measured BF by an acceptance factor determined by the width of the observed pseudorapidity window. The scaled balance function, $B_s(\delta\eta)$, is defined as

$$B_s(\delta\eta) = \frac{B(\delta\eta|\eta_{\rm w})}{1 - \frac{\delta\eta}{|\eta_{\rm w}|}} \quad (2)$$

where $\delta\eta$ is the particle separation in pseudorapidity, and $|\eta_{\rm w}|$ represents the size of pseudorapidity window. This scaled BF shows how the balance function extends with the widening of the pseudorapidity window.

We further explore the scaling property of the BF in different ranges of transverse momentum $p_{\rm T}$. The $p_{\rm T}$ of final state particles is suggested to characterize their emission proper-time τ [11–13]. Particles with different $p_{\rm T}$ may be produced at different stages of the evolution after the collision. This relation between $p_{\rm T}$ and τ has been assumed in hydrodynamic models [14], which qualitatively describe the data of $p_{\rm T}$ dependence of anisotropic collective flow [15]. Examining the $p_{\rm T}$ dependence of the scaling of the BF will provide an additional experimental test of this assumption.

In thermal models, particle velocities are determined by the local temperature, collective flow velocity and the particle masses. For relativistic particles, the thermal velocity along the beam axis is a function of the particle's transverse mass, and therefore is affected by transverse expansion. Lower freeze-out temperature

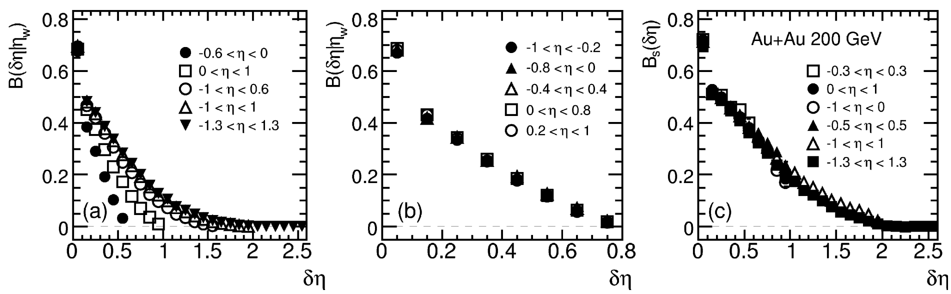

Fig. 1. (a) Balance functions in five pseudorapidity windows of different width; (b) Balance functions observed at five different positions of pseudorapidity windows with $|\eta_{\mathrm{w}}| = 0.8$; (c) Scaled balance function, $B_s(\delta\eta)$, obtained for various pseudorapidity window widths and positions. The data are from 0–80% Au + Au collisions at 200 GeV and the particle p_{T} range is $0.15 < p_{\mathrm{T}} < 2$ GeV/c. Statistical errors are smaller than the symbol sizes. Systematic errors are of the order of 5%.

and/or larger transverse mass of higher p_{T} particles are expected to result in smaller thermal velocity in the longitudinal direction and narrower BF [4,6].

In this Letter, we first give brief descriptions of the analysis parameters and techniques. We then present measurements of the BF, and its dependence on the width of the pseudorapidity window. We test the boost-invariance of the BF, i.e. verify whether it is independent of the position of same-width pseudorapidity windows. We next examine the universality of the scaled BF. Finally, the scaling property of the BF for particles within different transverse momentum ranges is studied.

Our BF analysis is restricted to charged particles measured within the STAR TPC detector [16]. This detector is well suited for precise studies of correlation structures given its relatively wide pseudorapidity range $-1.3 < \eta < 1.3$ and full azimuthal acceptance. Recorded events were selected on the basis of a minimum-bias trigger defined by the coincidence of two zero-degree calorimeters (ZDCs) [17] located at ±18 m from the center of the TPC. Events are further required to have a primary vertex position within 25 cm, longitudinally, of the TPC center and within 1 cm, radially, of the beam line. This analysis is restricted to charged particle tracks in the p_{T} range $0.15 < p_{\mathrm{T}} < 2.0$ GeV/c. After all these cuts, 5.7 million minimum-bias events were selected for the analysis. Tracks are required to pass within 2 cm of the primary vertex in order to reduce weak-decay contributions. Tracks are further required to consist of a minimum of 15 measured points and have a ratio of the numbers of measured to possible points larger than 0.52 to avoid track splitting effects. These two cuts minimize detector and track reconstruction effects, such as ghost tracks, track splitting, and enable optimal momentum resolution.

Fig. 1(a) displays balance function obtained with five different pseudorapidity windows, located at various positions, and with sizes ranging from $|\eta_{\mathrm{w}}| = 0.6$ to 2.6. It shows that the BF is strongly dependent on the width of the pseudorapidity window. Vertical bars shown in this and following figures indicate statistical errors only. Statistical errors are smaller than the symbol sizes in Fig. 1. Systematic errors are of the order of 5% and due to uncertainties in the track reconstruction efficiency associated with the track cuts, and event-by-event variations of the vertex position.

In order to test directly whether the BF is boost-invariant under longitudinal translation within the STAR TPC, we examine, in Fig. 1(b), five BFs measured in equal size ($|\eta_{\mathrm{w}}| = 0.8$) pseudorapidity windows located at different positions. One observes that the five BFs overlap with one another thereby indicating that the BF is independent of the position of the pseudorapidity window, i.e., $B(\delta\eta|\eta_{\mathrm{w}})$ is invariant under a longitudinal translation within the range $-1 < \eta < 1$. Note that the large BF values measured at $\delta\eta = 0.01$ arise in part from HBT and Coulomb effects [5,6]. We also considered five equal size and non-overlapping windows, not shown in Fig. 1, and found similar agreements.

In Fig. 1(c), we present scaled balance functions, B_s, calculated with Eq. (2), obtained from BFs measured with four distinct pseudorapidity window widths ($|\eta_{\mathrm{w}}| = 0.6, 1, 2, 2.6$) and six window positions. We find that the scaled balance functions have equal shape and magnitude, and are identical within experimental errors. Therefore B_s is independent of the size and position of the window η_{w} in the pseudorapidity range $-1 < \eta < 1$. A similar invariance of B_s was observed in hadron–hadron interactions over the whole rapidity range of produced particles [9]. These data indicate that the charge compensation is essentially the same in any longitudinally-Lorentz-transformed frame [6,9]. This is important because the longitudinal Lorentz invariance is assumed in most particle production models, such as PYTHIA and AMPT [18].

Lastly, we investigate whether the scaling property of the BF holds for particles in different p_{T} ranges and study how the width of the BF changes with p_{T}. Fig. 2 displays scaled balance function obtained for four p_{T} ranges: $(0.15, 0.4)$, $(0.4, 0.7)$, $(0.7, 1)$ and $(1, 2)$ GeV/c, and the same pseudorapidity windows as used in Fig. 1(c). We find that the distributions measured in specific p_{T} intervals are independent of the size and position of the pseudorapidity window used to carry out the measurement. We thus conclude that the invariance of B_s observed for $0.15 < p_{\mathrm{T}} < 2.0$ GeV/c also holds for small transverse momentum ranges.

This property of balance function provides an additional constraint in particle production mechanisms. For example, the invariance of BF in different p_{T} bins are observed in PYTHIA and default AMPT models, but violated in the AMPT with string melting [18]. The violation stems from the fact that the partons evolving into melted strings have their own freeze-out time, which occurs long after the impact of the colliding nuclei [19]. The particles in the same transverse-momentum range do not freeze-out simultaneously with well-balanced charges, and the longitudinal boost-invariance of the BF in small p_{T} ranges is therefore violated.

Comparing the distributions shown in Fig. 2(a) to 2(d), we observe that the scaled balance function, $B_s(\delta\eta)$, changes significantly in shape and amplitude with the transverse-momentum of final state particles. The widths of $B_s(\delta\eta)$ defined as [5]

$$\langle\delta\eta\rangle = \frac{\sum_i B_s(\delta\eta_i)\delta\eta_i}{\sum_i B_s(\delta\eta_i)} \tag{3}$$

are presented in Table 1. The first data point in Fig. 2(a) is affected by HBT correlations, which result in a strong correlation at small relative p_{T}. On the other hand, track merging effects deplete the balance function at small $\delta\eta$. To assess the systematic uncertainties on the extracted width, we use extrapolated values for the data points at the two lowest $\delta\eta$ instead of their measured ones in calculating the width. For the lower bound of systematic uncertainty estimate, the extrapolations from the larger $\delta\eta$ data are

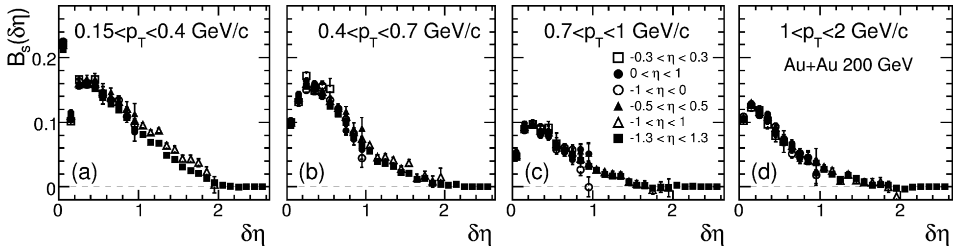

Fig. 2. $B_s(\delta\eta)$ based on $B(\delta\eta|\eta_w)$ values measured in different pseudorapidity windows for particles in four p_T bins. The data are from 0–80% Au + Au collisions at 200 GeV. Error bars are statistical only. Systematic errors are of the order of 5%.

Table 1
The widths $\langle\delta\eta\rangle$ of the $B_s(\delta\eta)$ for four p_T bins. The first and second errors are statistical and systematic, respectively. The data are from 0–80% Au + Au collisions at 200 GeV.

p_T (GeV/c)	(0.15, 0.4)	(0.4, 0.7)	(0.7, 1)	(1, 2)
$\langle\delta\eta\rangle$	$0.652 \pm 0.006^{+0.081}_{-0.029}$	$0.609 \pm 0.008^{+0.049}_{-0.037}$	$0.536 \pm 0.016^{+0.047}_{-0.041}$	$0.487 \pm 0.014^{+0.079}_{-0.021}$

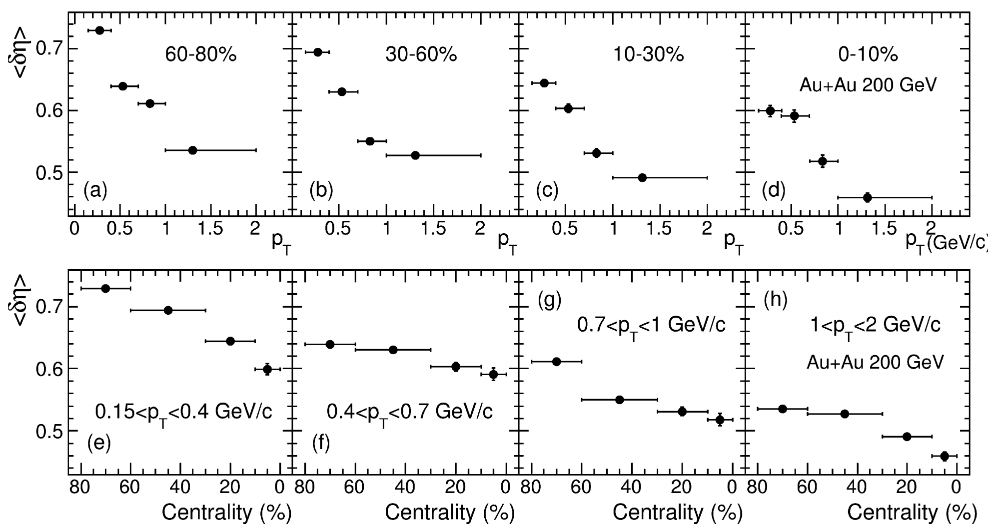

Fig. 3. Upper panel: the p_T dependence of the width of the BF in different centrality bins; Lower panel: the centrality dependence of the width of the BF in different p_T intervals. Data are from Au + Au collisions at 200 GeV.

done by two functional forms in order to well fit the data. One is exponential for the p_T in (0.15, 0.4) GeV/c and Gaussian for the other three p_T bins. For the upper bound of systematic uncertainty estimate, the extrapolated function is multinomial for all four p_T bins. Table 1 shows that the width of the scaled BF becomes narrower for increasing p_T. This observation is qualitatively consistent with expectations from thermal models [6].

As shown in [5], the width of the BF decreases with collision centrality. The decreases in the BF width with increasing p_T and increasing centrality could be associated with transverse radial flow [20]. In order to disentangle these effects, we further study the p_T dependence of $\langle\delta\eta\rangle$ in different centrality bins. This is shown in the upper panel of Fig. 3. It shows clearly that the width of the BF decreases with increasing transverse momentum of final state particles in each centrality bin. We also study the centrality dependence of $\langle\delta\eta\rangle$ in different p_T intervals. This is presented in the lower panel of Fig. 3. It shows that the narrowing of the BF with increasing centrality is present in all p_T bins. Our results demonstrate that the BF becomes narrower with increasing p_T in each given centrality bin, and in more central collisions in each given p_T bin. The width of BF depends on both centrality and p_T. The origin of these narrowings and their possible connections should provide more insight into the particle production dynamics in relativistic heavy-ion collisions.

In summary, we present a first measurement of the longitudinal scaling property of the charge balance function in Au + Au collisions at 200 GeV with the STAR detector at RHIC. The results demonstrate that within the pseudorapidity range $-1.3 < \eta < 1.3$, the balance function in equal size windows is independent of the position of the window, and the balance function, when properly scaled by the width of the pseudorapidity window, is found to be independent of the position and size of the window. This scaling property of the balance function is also observed for particles in different p_T ranges. It is further shown that the width of the scaled BF decreases with increases of both the particle transverse momentum and the collision centrality.

We conclude that the scaling property of the BF, observed in hadron–hadron collisions [9], is also present in nucleus–nucleus collisions at mid-rapidity at RHIC. This indicates that charge compensation in strong interactions is essentially boost-invariant. It provides a good test for the hadronization mechanism in currently available models [18]. The narrowing of the BF with increasing p_T and centrality warrants further investigation.

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References

[1] D. Drijard, et al., Nucl. Phys. B 166 (1980) 233;
D. Drijard, et al., Nucl. Phys. B 155 (1979) 269.
[2] P.D. Acton, et al., Phys. Lett. B 305 (1993) 415;
M. Arneodo, et al., Z. Phys. C 36 (1987) 527.
[3] R. Brandelik, et al., Phys. Lett. B 100 (1981) 357;
M. Althoff, et al., Z. Phys. C 17 (1983) 5;
H. Aihara, et al., Phys. Rev. Lett. 53 (1984) 2199;
H. Aihara, et al., Phys. Rev. Lett. 57 (1986) 3140.
[4] S.A. Bass, P. Danielewicz, S. Pratt, Phys. Rev. Lett. 85 (2000) 2689.
[5] J. Adams, et al., STAR Collaboration, Phys. Rev. Lett. 90 (2003) 172301;
G.D. Westfall (for STAR Collaboration), J. Phys. G 30 (2004) S345.
[6] S. Jeon, S. Pratt, Phys. Rev. C 65 (2002) 044902.
[7] C. Alt, et al., NA49 Collaboration, Phys. Rev. C 71 (2005) 034903.
[8] K. Adcox, et al., PHENIX Collaboration, Phys. Rev. Lett. 89 (2002) 082301.
[9] M.R. Atayan, et al., NA22 Collaboration, Phys. Lett. B 637 (2006) 39.
[10] T.A. Trainor, hep-ph/0301122.
[11] R.C. Hwa, Y. Wu, Phys. Rev. C 60 (1999) 054904.
[12] M. Asakawa, S.A. Bass, B. Müller, C. Nonaka, Phys. Rev. Lett. 101 (2008) 122302.
[13] F. Grassi, Y. Hama, T. Kodama, Phys. Lett. B 355 (1995) 9;
Y.M. Sinyukov, S.V. Akkelin, Y. Hama, Phys. Rev. Lett. 89 (2002) 052301.
[14] P. Huovinen, P.F. Kolb, U. Heinz, P.V. Ruuskanen, S.A. Voloshin, Phys. Lett. B 503 (2001) 58.
[15] J. Adams, et al., STAR Collaboration, Nucl. Phys. A 757 (2005) 102.
[16] M. Anderson, et al., Nucl. Instrum. Meth. A 499 (2003) 659.
[17] C. Adler, et al., Nucl. Instrum. Meth. A 461 (2001) 337.
[18] N. Li, Z. Li, Y. Wu, Phys. Rev. C 80 (2009) 064910.
[19] M. Yu, J. Du, L. Liu, Phys. Rev. C 74 (2006) 044906.
[20] S. Pratt, S. Cheng, Phys. Rev. C 68 (2003) 014907;
S.A. Voloshin, Phys. Lett. B 632 (2006) 490.