

# Multiplicity and transverse momentum evolution of charge-dependent correlations in pp, p-Pb, and Pb-Pb collisions at the LHC

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**Abstract.** We report measurements of two-particle charge-dependent correlations in pp, p-Pb, and Pb-Pb collisions at  $\sqrt{s_{NN}} = 7, 5.02, \text{ and } 2.76 \text{ TeV}$ , respectively, as a function of pseudorapidity and azimuthal angle differences. These measurements, carried out using the balance function, probe the charge creation time and the development of collectivity in the produced systems. The balance function is studied as a function of the event multiplicity as well as the transverse momentum ( $p_T$ ) of charged particles detected in the range  $|\eta| < 0.8$ . In the low transverse momentum region,  $0.2 < p_T < 2.0 \text{ GeV}/c$ , the balance function becomes narrower in both  $\Delta\eta$  and  $\Delta\varphi$  directions in all three systems for events with higher multiplicity. For higher values of transverse momenta, the balance function becomes even narrower but exhibits no significant multiplicity dependence, indicating that the observed narrowing with increasing multiplicity at low  $p_T$  is a feature of bulk particle production.

## 1. Introduction

The charge-dependent part of two-particle correlations is studied with the balance function (BF) [1], defined by Formula (1), where  $\langle N_{++} \rangle$ ,  $\langle N_{+-} \rangle$ ,  $\langle N_{-+} \rangle$  and  $\langle N_{--} \rangle$  denote the average number of different charged particle pairs, while  $\langle N_+ \rangle$  and  $\langle N_- \rangle$  for the average number of single charged particles. For each pair, the first (trigger) particle has a transverse momentum  $p_{T,\text{trig}}$ , while the second (associated) charged particle has a transverse momentum  $p_{T,\text{assoc}}$ . Particle production is often governed by conservation laws. Local charge conservation, in particular, ensures that each produced charged particle is balanced by an oppositely-charged partner, created at the same location in space and time, but transported in momentum space according to the collision dynamics and system evolution. By design, the BF reflects the distribution of balancing charges in momentum space. Theoretical studies have shown that the BF is a sensitive probe of both the pair creation time [1,2] and the collective nature of the system's evolution [3,4]. In particular, a reduced BF width is expected for heavy systems in which particle production dominantly occurs at low temperature following an isentropic expansion of Quark Gluon Plasma [1-4].

$$B(\Delta\eta, \Delta\varphi) = \frac{1}{2} \left\{ \frac{\langle N_{+-} \rangle(\Delta\eta, \Delta\varphi) - \langle N_{++} \rangle(\Delta\eta, \Delta\varphi)}{\langle N_+ \rangle} + \frac{\langle N_{-+} \rangle(\Delta\eta, \Delta\varphi) - \langle N_{--} \rangle(\Delta\eta, \Delta\varphi)}{\langle N_- \rangle} \right\} \quad (1)$$

In these proceedings, we present recent BF measurements in pp, p-Pb, and Pb-Pb collisions at  $\sqrt{s_{NN}} = 7, 5.02, \text{ and } 2.76 \text{ TeV}$ , respectively by the ALICE collaboration[5,6]. Results are

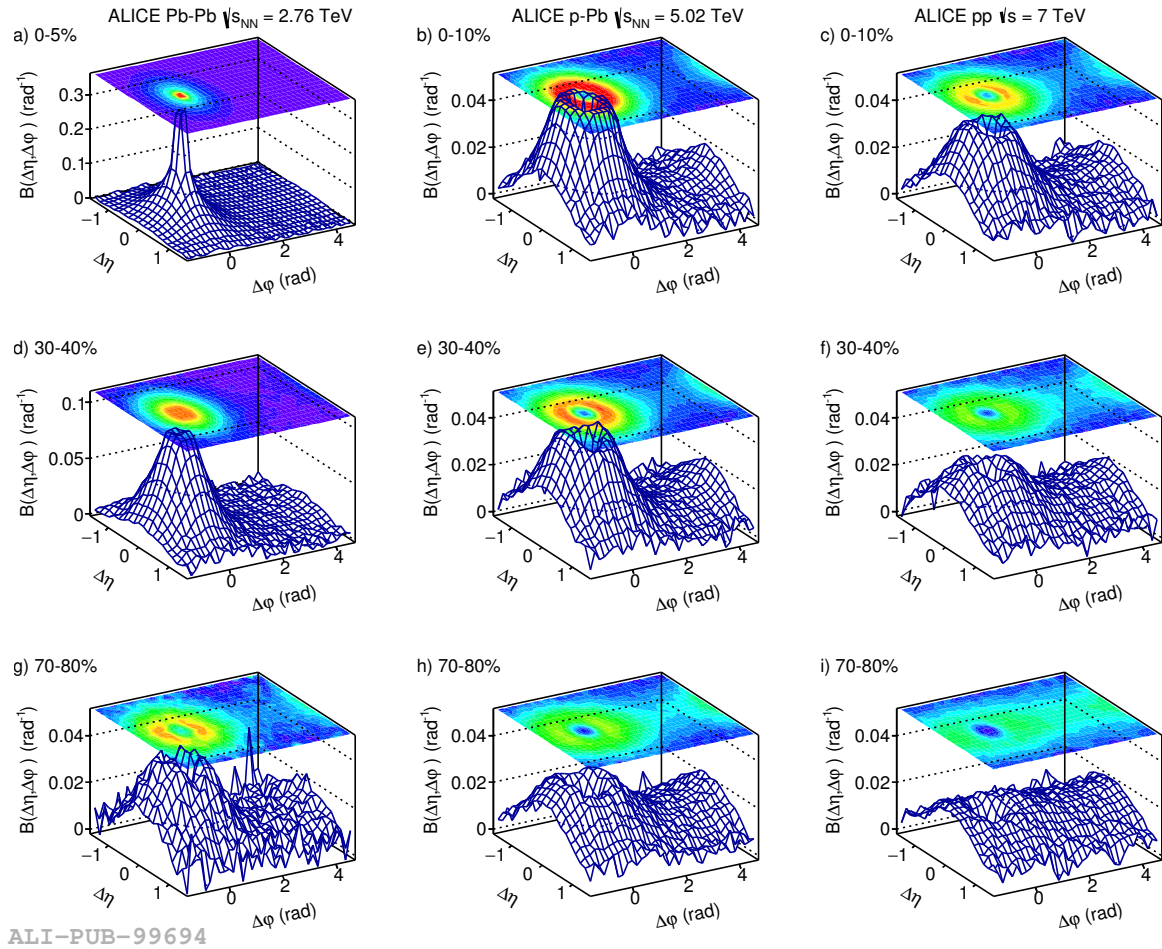


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presented as a function of produced particle multiplicity and transverse momentum ( $p_T$ ) to investigate potential scaling properties, similarities, and differences between the three systems.

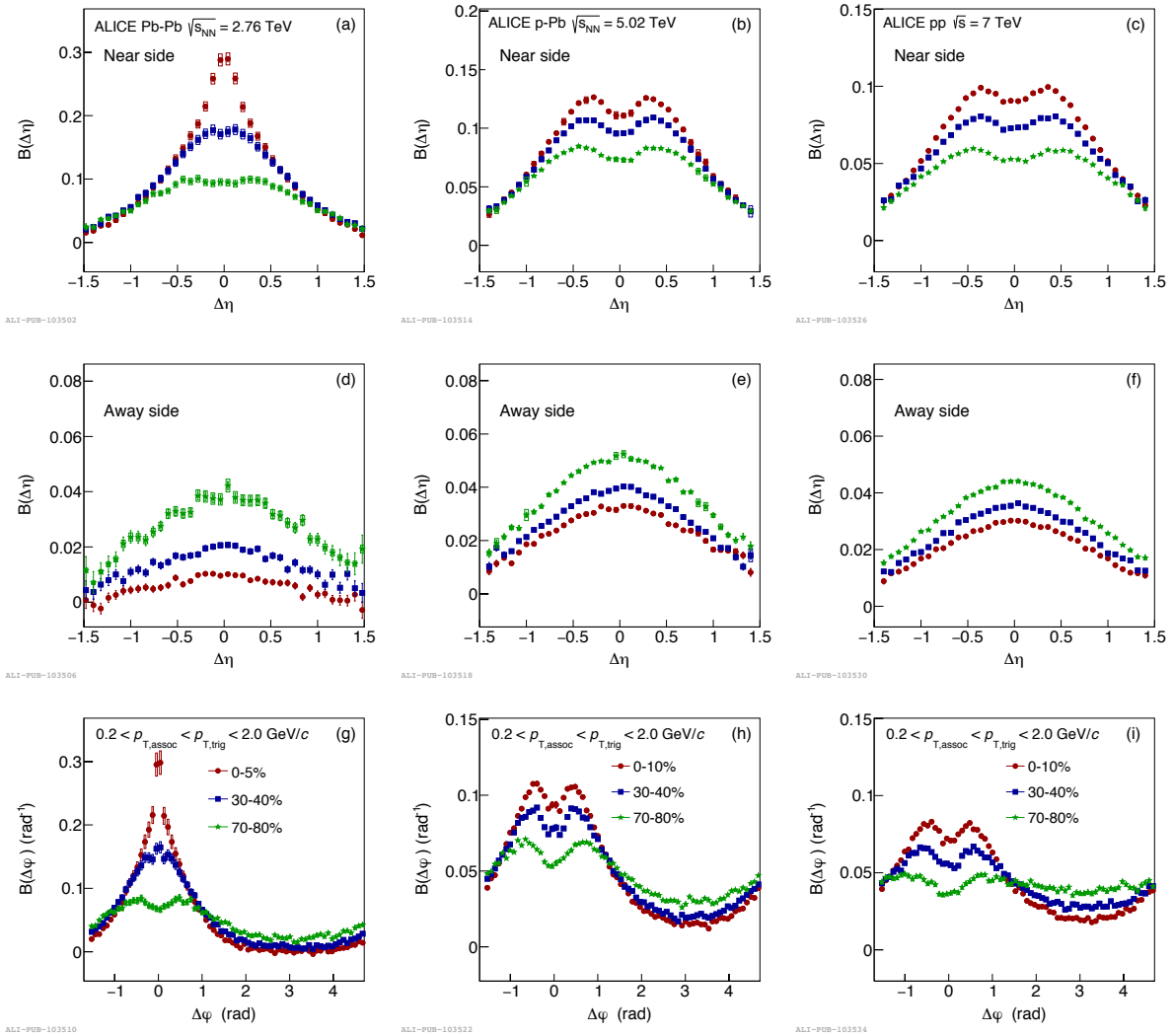
## 2. Balance Function Results

Figure 1 presents inclusive charge BF's as a function of  $\Delta\eta$  and  $\Delta\varphi$  for three multiplicity classes of Pb-Pb, p-Pb, and pp collisions. The BF's feature a prominent near-side peak at  $|\Delta\varphi| < \pi/2$ , which is observed to narrow with increasing multiplicity for all three collision systems. The peak amplitude also changes with multiplicity, with higher values corresponding to collisions with higher multiplicity. On the away-side,  $\pi/2 < \Delta\varphi < 3\pi/2$ , the BF has a larger magnitude for lower multiplicity events. In addition, a depletion in the correlation pattern around  $(\Delta\eta, \Delta\varphi) = (0, 0)$  starts to emerge in mid-central (e.g. 30-40% multiplicity class) events in Pb-Pb collisions and becomes more pronounced in p-Pb and pp collisions with decreasing multiplicity. This depletion is in large part associated with the HBT effect which produces a relatively narrow peak in like-sign correlation whose width is expected to decrease with increasing source size.



**Figure 1.** Balance function,  $B(\Delta\eta, \Delta\varphi)$ , for charged particles with  $0.2 < p_{T, \text{assoc}} < p_{T, \text{trig}} < 2.0$  GeV/c, in Pb-Pb, p-Pb, and pp collisions at  $\sqrt{s_{NN}} = 2.76, 5.02$ , and 7 TeV, respectively, for selected multiplicity classes.

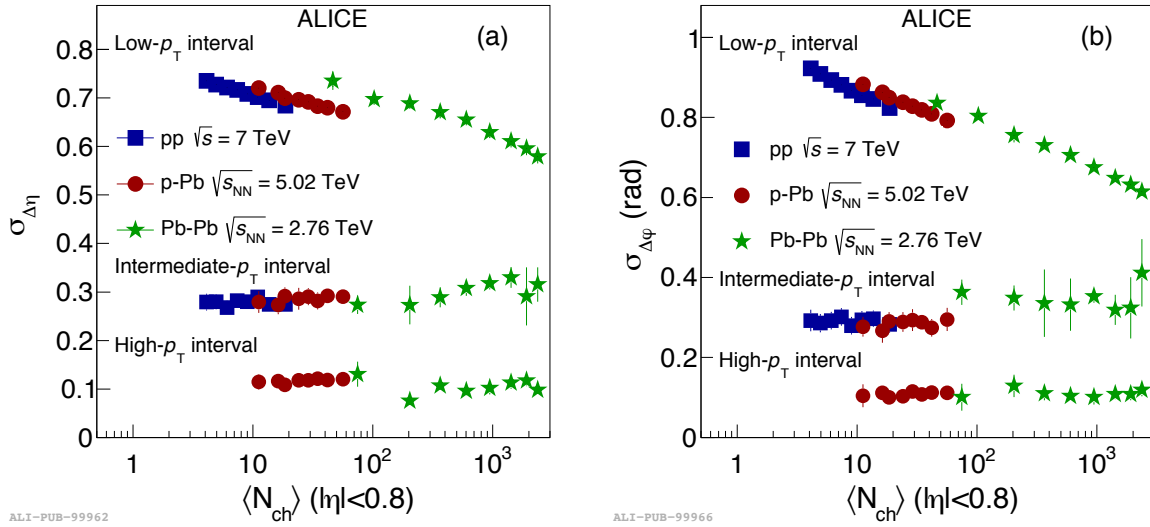
Figure 2 presents projections of the BF's onto  $\Delta\eta$  on the near-side in panels (a-c), away-side in panels (d-f), and onto  $\Delta\varphi$  in panels (g-i). Statistical uncertainties are represented by



**Figure 2.** BF for charged particles with  $0.2 < p_{T,assoc} < p_{T,trig} < 2.0$  GeV/c as a function of  $\Delta\eta$  on the near-side (upper row) and away-side (middle row) and  $\Delta\phi$  (lower row) in different multiplicity classes of Pb-Pb in panels a, d and g, p-Pb in panels b, e and h, and pp collisions in panels c, f and i at  $\sqrt{s_{NN}} = 2.76, 5.02$ , and 7 TeV, respectively.

vertical error bars while systematic uncertainties, calculated as the quadratic sum of correlated and uncorrelated contributions, are shown as shaded boxes. One finds that the BF near-side peak shape and width exhibit a significant multiplicity dependence for all collision systems. In particular, the distribution narrows and the peak amplitude increases for higher multiplicity events. However, the magnitude of the BF on the away-side exhibits a different trend, with larger values measured for lower multiplicity events.

Figure 3 presents the charged-particle multiplicity and  $p_T$  dependence of the width of BF in  $\Delta\eta$  (a) and  $\Delta\phi$  (b) for all three systems. The multiplicity is determined from the number of charged particles reconstructed in  $|\eta| < 0.8$  and  $p_T > 0.2$  GeV/c. One observes that between the pp and the p-Pb systems, and for overlapping multiplicities in the low  $p_T$  region, the widths in  $\Delta\eta$  and  $\Delta\phi$  have similar values. This could indicate that the charge-



**Figure 3.** BF widths in  $\Delta\eta$  (a) and in  $\Delta\varphi$  (b) measured in pp, p-Pb, and Pb-Pb collision as a function of the charged-particle multiplicity, measured in  $|\eta| < 0.8$  and  $p_T > 0.2$  GeV/c. The low-, intermediate-, and high- $p_T$  intervals correspond to  $0.2 < p_{T,assoc} < p_{T,trig} < 2.0$  GeV/c,  $2.0 < p_{T,assoc} < 3.0 < p_{T,trig} < 4.0$  GeV/c, and  $3.0 < p_{T,assoc} < 8.0 < p_{T,trig} < 15.0$  GeV/c, respectively.

dependent correlations have similar origin in these two systems. On the other hand, widths observed in p-Pb and Pb-Pb at similar multiplicities show significant differences, which may be attributed to the strong radial flow profile in Pb-Pb collisions. These differences may also signal that a different mechanism drives the charge-dependent correlations in smaller systems. With increasing transverse momentum, the BF widths become narrower and exhibit no significant multiplicity dependence for all systems. The agreement of  $\sigma_{\Delta\eta}$  and  $\sigma_{\Delta\varphi}$  for all multiplicities over all three systems clearly indicates that the dynamics responsible for the high- $p_T$  charge-dependent correlations do not change significantly between pp, p-Pb, and Pb-Pb collisions.

### 3. Summary

These proceedings presented measurements, with the ALICE detector, of balance functions (BF) for charged particles in pp, p-Pb, and Pb-Pb collisions at the LHC. BF widths were studied in ranges  $0.2 < p_{T,assoc} < p_{T,trig} < 2.0$  GeV/c,  $2.0 < p_{T,assoc} < 3.0 < p_{T,trig} < 4.0$  GeV/c, and  $3.0 < p_{T,assoc} < 8.0 < p_{T,trig} < 15.0$  GeV/c. The  $\Delta\eta$  and  $\Delta\varphi$  widths of balance functions were found to decrease with increasing multiplicity in three systems only in the low  $p_T$  region (for  $p_T < 2.0$  GeV/c). For higher  $p_T$  ranges, the BF widths dependence on produced particle multiplicities is drastically suppressed relative to that observed at low  $p_T$ .

### 4. References

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