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Transverse momentum dependence of balance functions in small collision systems with PYTHIA8 and EPOS4

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Balance functions are an important observable in understanding particle production and correlations in high-energy collisions of hadrons and nuclei. Measurements of balance functions for inclusive and identified particles are reported for two transverse momentum intervals, $0.2 < p_{\mathrm{T}} < 1.0$ GeV/c and $1.0 < p_{\mathrm{T}} < 2.0$ GeV/c, in proton–proton (pp) collisions at $\sqrt{s} = 13.6$ TeV simulated with the PYTHIA8 and EPOS4 event generators. The results exhibit amplitudes and shapes that depend on the particle considered and p_{T} range, highlighting the influence of particle production mechanisms. Additionally, the balance functions show different responses in PYTHIA8 and EPOS4 owing largely to the different charge production mechanisms implemented into the two generators. These results compared with experimental data will allow us to separate between the various particle production mechanisms considered in PYTHIA8 and EPOS4, thus enhancing the understanding of particle dynamics in small collision systems.

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1. Introduction

In recent years, the study of collective effects in small collision systems has gained significant attention within the high-energy physics community. Signals similar to the ones observed in heavy-ion collisions were revealed by measurements of two particle correlation functions in pp and p–Pb collisions [1, 2]. Although balance functions (BFs) do not directly probe the emergence of the collective effects, they can be used to investigate the particle production mechanisms and the dynamics of particle interactions in high-energy physics [3]. Thus, measurements of BFs provide important insights into the dynamics of the small collision systems.

The p_{T}-dependence of pion, kaon, and proton BFs is investigated in pp collisions at $\sqrt{s}$ = 13.6 TeV using two Monte Carlo event generators, EPOS4 [4] and PYTHIA8 [5], by performing measurements in $0.2 < p_{\mathrm{T}} < 1.0$ GeV/c and $1.0 < p_{\mathrm{T}} < 2.0$ GeV/c within the rapidity range $|y| < 1.0$. The EPOS4 model introduces parallel scatterings and implements a “core-corona" picture coupled to a hadronic afterburner where soft processes are evolved hydrodynamically in the “core" region and hard processes are controlled by strings in the “corona" part. The “core" decays micro-canonically, ensuring the conservation of charges as well as the conservation of the 4-momentum of the system. PYTHIA8 uses string fragmentation [6] to handle the hadronization which explicitly conserved quantum numbers. The Monash tune [7] with color reconnection is employed in PYTHIA8 simulations. Weak decays have been suppressed for both event generators.

Generalized balance functions [3] describe the conservation of different quantum numbers by looking at the balancing of each particle species produced in collisions, denoted as α and β. The antiparticles of each species α and β are represented by $\bar{\alpha}$ and $\bar{\beta}$, respectively. Balance functions are computed according to

$$B^{\alpha\bar{\beta}}(\Delta y, \Delta\varphi) = \bar{\rho}_1^{\bar{\beta}} \left[R_2^{\alpha\bar{\beta}}(\Delta y, \Delta\varphi) - R_2^{\bar{\alpha}\bar{\beta}}(\Delta y, \Delta\varphi) \right], \tag{1}$$

where the two-particle normalized correlation function R_2 is given by

$$R_2^{\alpha\beta}(\Delta y, \Delta\varphi) = \frac{\rho_2^{\alpha\beta}(\Delta y, \Delta\varphi)}{\rho_1^{\alpha} \otimes \rho_1^{\beta}(\Delta y, \Delta\varphi)} - 1. \tag{2}$$

The $\rho_2(\Delta y, \Delta\varphi)$ represents the pair density at relative rapidity $\Delta y = y_1 - y_2$ and relative azimuthal angle $\Delta\varphi = \varphi_1 - \varphi_2$ and $\rho_1 \otimes \rho_1$ is the cross product of single particle densities of each species α and β. The method is robust against acceptance effects because the BF measurements are done in a small rapidity range $|y| < 1.0$.

2. Results

Figure 1 presents the charged hadron inclusive BFs measured in $0.2 < p_{\mathrm{T}} < 1.0$ GeV/c (left) and $1.0 < p_{\mathrm{T}} < 2.0$ GeV/c (right) within $|\eta| < 1.0$ from EPOS4 (top) and PYTHIA8 (bottom) simulations of pp collisions at $\sqrt{s}$ = 13.6 TeV. Qualitatively similar features are exhibited in the two momentum intervals by both generators. However, large differences are found between the two p_{T} intervals. While the low p_{T} interval shows a near-side broad peak centered at $\Delta\eta = \Delta\varphi = 0$ and a long range $\Delta\eta$ component that decays slowly, the high p_{T} interval features a narrow near-side

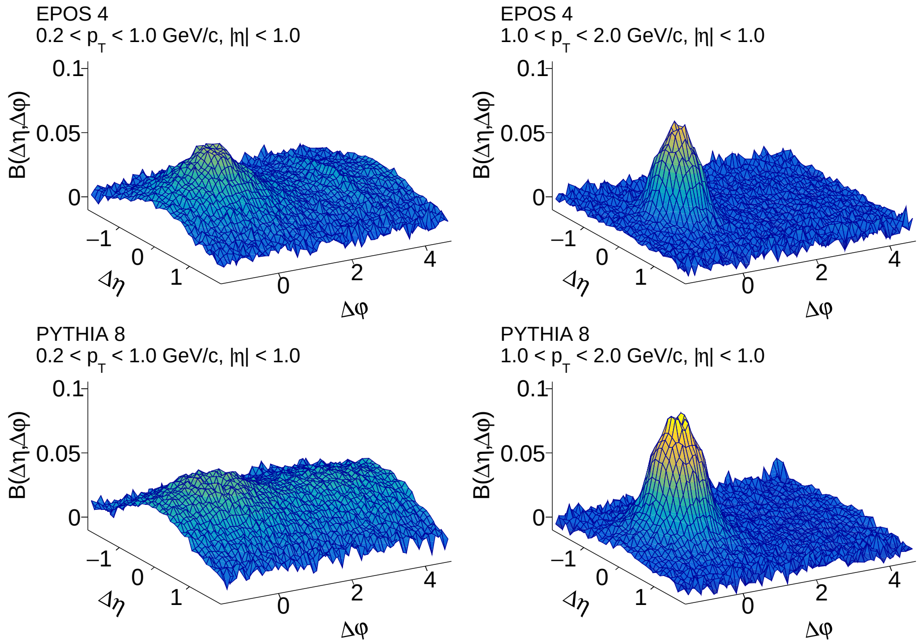

Figure 1: Charge balance functions measured in $0.2 < p_T < 1.0$ GeV/c (left) and $1.0 < p_T < 2.0$ (right) within $|\eta| < 1.0$ from EPOS4 (top) and PYTHIA8 (bottom) simulations of pp collisions at $\sqrt{s} = 13.6$ TeV.

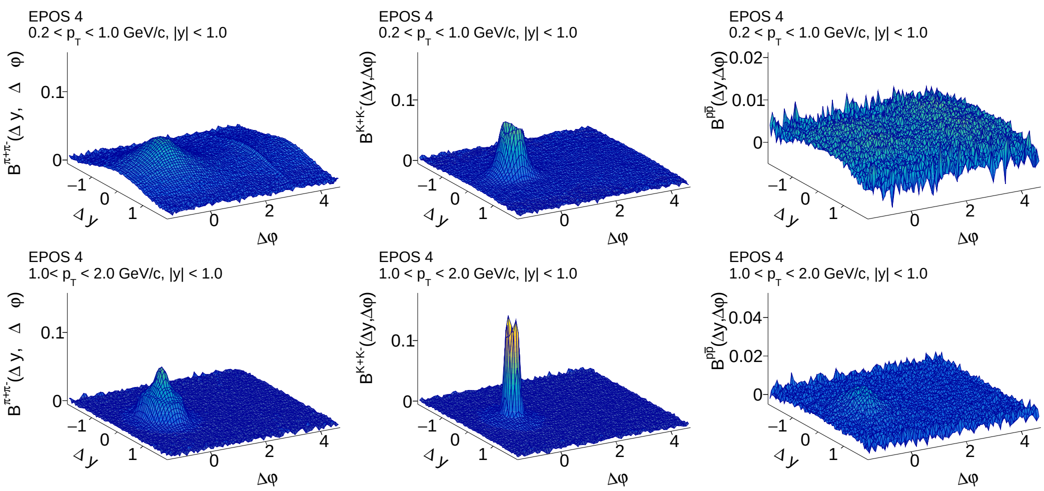

Figure 2: Pion (left), kaon (middle), and proton (right) balance functions measured in in $0.2 < p_T < 1.0$ GeV/c (top) and $1.0 < p_T < 2.0$ (bottom) within $|y| < 1.0$ from EPOS4 simulations of pp collisions at $\sqrt{s} = 13.6$ TeV.

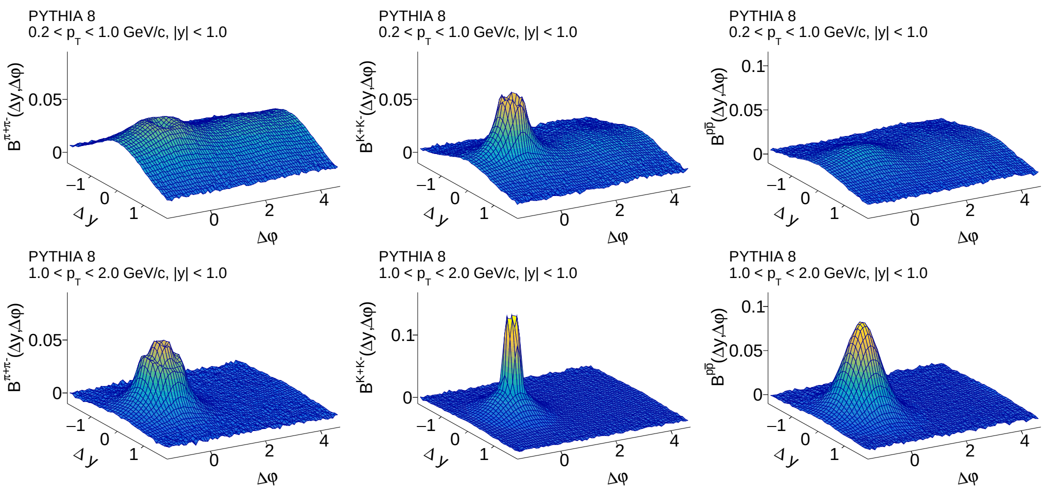

Figure 3: Pion (left), kaon (middle), and proton (right) balance functions measured in in $0.2 < p_T < 1.0$ GeV/c (top) and $1.0 < p_T < 2.0$ (bottom) within $|y| < 1.0$ from EPOS4 simulations of pp collisions at $\sqrt{s} = 13.6$ TeV.

peak and no visible structures on the away-side. The near-side peak of the BF from PYTHIA is somewhat wider than that from EPOS and its amplitude is larger in PYTHIA than in EPOS for both p_T intervals.

The pion, kaon, and proton BFs measured in $0.2 < p_T < 1.0$ GeV/c (top) and $1.0 < p_T < 2.0$ GeV/c (bottom) within $|y| < 1.0$ are presented from EPOS4 and PYTHIA8 simulations in Figs. 2 and 3, respectively. The BFs obtained from EPOS and PYTHIA exhibit differences relative to one another and among the two p_T intervals. The pion BFs from PYTHIA reveal a strong away-side component in the low p_T interval, while it is not present for the high p_T. The near-side peak also narrows and the amplitude increases from low to high p_T. The ring-like structure in the near-side peak indicates the impact of the ρ^0-meson decay. The pion BFs from EPOS feature a more prominent near-side peak with no evidence for the ρ^0-meson decay. In addition, a ridge-like structure centered at $\Delta\varphi = \pi$ over the full $\Delta\eta$ range is only present on the away-side in the low p_T interval. The kaon BFs are significantly influenced by the decay of heavy resonances, particularly the ϕ-meson. The PYTHIA results feature a tapered near-side peak and a modest away-side component, while a narrow near-side peak and a flat away-side are obtained with EPOS. The baryon balancing represented by $B^{p\bar{p}}$ exhibit a wide near-side peak and a modest away-side in PYTHIA, while a very weak near-side peak and no away-side are produced by EPOS.

3. Summary

Common qualitative features are found for both inclusive and identified particle BFs obtained with PYTHIA8 and EPOS4. However, the strength and shape of the correlation functions differs significantly between the two models. The results from both models show a strong dependence on transverse momentum, thus reflecting the contribution from different particle production mechanisms.

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