Forward-backward multiplicity correlations in separated azimuth and pseudorapidity in pp collisions at LHC energies

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Introduction

Colliding heavy-ions at ultra-relativistic speeds is the only possible way to produce and study the properties of Quark-Gluon Plasma (QGP) in a laboratory setting. The space-time evolution of the created matter in the final state typically fluctuates from event to event due to the event-by-event density fluctuations in the initial state of the collision [1]. These final state fluctuations are believed to be a potential source of correlations observed in pp, pA, and AA collisions. Examining these correlations at ultra-relativistic beam energies across different collision configurations can shed light on the underlying dynamics of multi-particle production. The correlations observed among final state particles may arise from two primary sources: Short Range Correlations (SRCs) and Long Range Correlations (LRCs). SRCs are supposed to arise from various short-range final state effects such as decays of clusters, Bose-Einstein's correlations, mini-jets, etc. The correlation strength dominated by SRCs vanishes rapidly as pseudorapidity gap ($\eta_{\rm gap}$) between forward and backward window increases. LRCs, on the other hand, originate from initial state phenomena, for example, fluctuations in pomerons, strings, mini-jets etc. [5, 6]. To better understand the origins of SRCs and LRCs, as well as to distinguish between the two, one can examine observable like the forward-backward (FB) multiplicity correlation [5]. The FB correlation strength, $b_{\rm corr}(mult.)$ can be defined in terms of the Pearson correlation coefficient, which is extracted from a linear relation between mean multiplicity measured in the backward η-window, $\langle N_b \rangle_{N_f}$, as a function of the event multiplicity in the forward η-window, N_f.

$$b_{\rm corr}(mult.) = \frac{\langle N_f N_b \rangle - \langle N_f \rangle \langle N_b \rangle}{\langle N_f^2 \rangle - \langle N_f \rangle^2} \qquad (1)$$

The ALICE collaboration [3] measured $b_{\rm corr}(mult.)$ for pp collisions at $\sqrt{s} = 0.9$, 2.76 and 7 TeV and compared the experimental data with theoretical models like `PHOJET` [7] and `PYTHIA6` (Perugia Tune 0 and 2011) [8]. Although these models could explain the data qualitatively, there was a disagreement between the experimental results and the model calculations. Another study performed using `QGSM` model [4] reported 20% underestimation of $b_{\rm corr}(mult.)$ at lower $\eta_{\rm sep}$ (< 0.8). This discrepancy can be attributed to the lower production cross-section of resonance particles in the `QGSM` model. As these models fail to explain experimental data, henceforth, in the present investigation, we have attempted to study these correlations separated in azimuth and pseudorapidity at LHC energies using the `PYTHIA8` [2] model by altering the multi-parton interaction (MPI)-based color reconnection (CR) ranges. CR is a non-perturbative effect that occurs during the final stages of hadronization and parton showering, where the rearrangement of color strings takes place, leading to changes in the final-state particle distributions. For the present work, MPI-based CR is utilized with three distinct values of CR ranges i.e., 1.8, 3.6, and 5.4. Three million inelastic (INEL) non-diffractive pp interactions at $\sqrt{s} = 0.9$, and 7 TeV have been simulated using `PYTHIA8` version 8.311.

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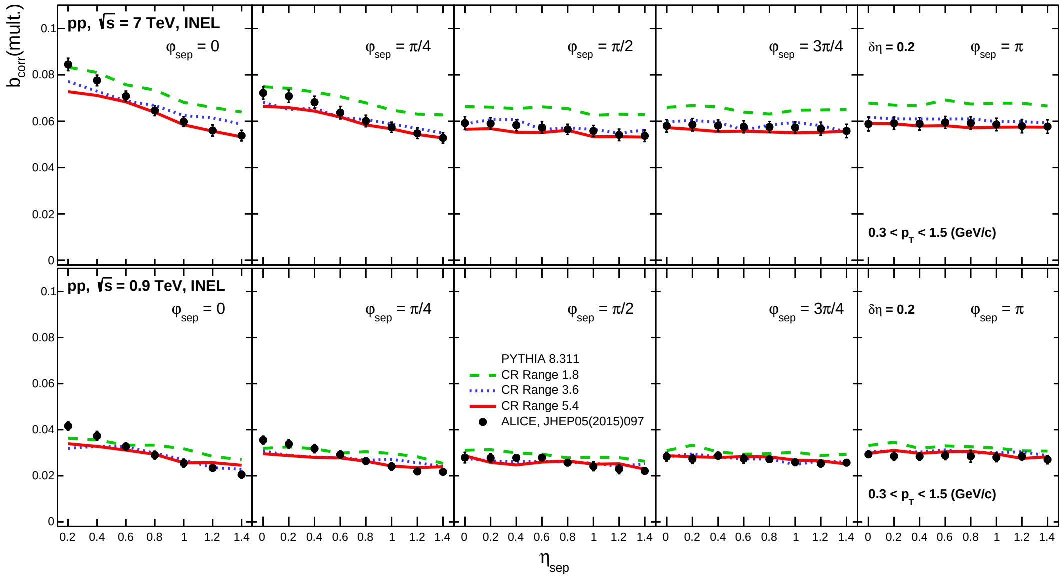

FIG. 1: Correlation strength, $b_{\mathrm{corr}}(mult.)$ in separated η-φ planes plotted as a function of η_{sep} for `PYTHIA8` (version 8.311) simulated pp interactions at $\sqrt{s} = 0.9$ and 7 TeV along with ALICE results [3].

Results and discussion

$b_{\mathrm{corr}}(mult.)$ as described by Eqn.(1) is plotted in Fig.1 as a function of η_{sep} for `PYTHIA8` simulated pp interactions at $\sqrt{s} = 0.9$ and 7 TeV and compared with available ALICE results [3]. This study has been carried out for five different φ_{sep} separations (0, $\pi/4$, $\pi/2$, $3\pi/4$ and π). For both the studied energies a decrease of the $b_{\mathrm{corr}}(mult.)$ as a function of η_{sep} is observed for $\varphi_{\mathrm{sep}} = 0$ and $\pi/4$. However, the decrease is more pronounced for $\sqrt{s} = 7$ TeV. This observation can be attributed to the dominance of SRCs among particles concentrated in the narrow phase space separated by $\varphi_{\mathrm{sep}} \leq \pi/4$. At $\varphi_{\mathrm{sep}} = \pi/2$ and beyond, $b_{\mathrm{corr}}(mult.)$ tends to saturate for both $\sqrt{s} = 7$ and 0.9 TeV, attaining a value of around 0.06 and 0.03 respectively. This study concludes that azimuthal sectors with $\varphi_{\mathrm{sep}} > \pi/4$ are solely influenced by contributions from LRCs. The CR range 1.8 fails to explain ALICE results quantitatively across all azimuthal sectors. Overall, the `PYTHIA8` model with CR range 5.4 offers a reasonably good description of the data at $\sqrt{s} = 7$ TeV, while both CR ranges 3.6 and 5.4 are consistent with the ALICE data at $\sqrt{s} = 0.9$ TeV.

References

[1] M. Aaboud et al. (ATLAS Collaboration), Phys. Rev. C, **95**, 064914 (2017).

[2] C. Bierlich et al., SciPost Phys. Codebases, 8 (2022).

[3] J. Adam et al. (ALICE Collaboration), J. High Energy Phys., **2015**, 097 (2015).

[4] L.V Bravina, J. Bleibel and E.E Zabrodin, Phys. Lett. B, **787**, 146-152 (2018).

[5] A. Capella et al., Phys. Rept., **236**, 225-329 (1994)

[6] A. Capella and A. Krzywicki, Phys. Rev. D, **18**, 4120 (1978).

[7] R. Engel and J. Ranft, Phys. Rev. D, **54**, 4244 (1996).

[8] P. Z Skands, Phys. Rev. D, **82**, 074018 (2010).