Monte-Carlo study of long-range correlations of average transverse momentum and multiplicity for strange particles in pp-collisions at the LHC energies

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Abstract. This study is motivated by the puzzling enhanced production of multi-strange hadrons observed for the first time by the ALICE Collaboration in high-multiplicity pp-collisions at $\sqrt{s} = 7$ TeV at the LHC. We investigate this effect of strangeness enhancement in pp-collisions in the framework of the MC event generator PYTHIA 8 where the collectivity processes are taken into account by the formation of a so-called flavour rope. The latter is hadronized with a larger effective string tension providing the increase of strangeness yield. This concept of the flavour rope, as a source of multi-strange hadrons, extended in rapidity, is being tested by the study of so called long-range correlations (LRC) between the average transverse momentum $\langle p_T \rangle$ and multiplicity $n$ for charged particles containing strange quarks produced in high energy pp-collisions. The dependencies of correlation coefficients $b_{n-n}$, $b_{p_T-n}$ and $b_{p_T-p_T}$ on the gap between forward and backward pseudorapidity windows, and on the width of the forward pseudorapidity windows, are studied and the results are discussed.

1. Introduction

Recently, new results on the enhanced production of multi-strange hadrons in high-multiplicity pp-collisions at $\sqrt{s} = 7$ TeV were obtained by the ALICE Collaboration at the LHC [1]. It was found that strangeness production may reach values similar to those observed in Pb-Pb collisions, where a QGP is formed. The enhanced strangeness yield was originally proposed as a signature of QGP formation in nuclear collisions [2]. Therefore, the remarkable similarity of high-multiplicity pp-case to the relativistic Pb-Pb high energy collisions, where the QGP is formed, is very interesting. In particular, the question of the main contributing processes, related either to the initial or to the final states, is still open. In this work we study the initial [3] state effects in pp-collisions assuming the formation of the interacting color strings as a system, preceding the quark-gluon plasma (QGP) formation.

The concept of the color strings (tubes of the color fields) stretched between partons of the interacting nuclei is one of the main model approaches to describe the multiparticle production in high-energy hadron collisions. In the framework of this model, the observed particles are produced due to the decays (i.e. hadronization) of these strings. In case of high density, the color strings can overlap and interact with each other [4, 5]. As a result of this interaction in the form of fusion, the increase of $\langle p_T \rangle$ and $n$ of particles produced in a single collision is expected along with the enhancement of strange particles yield.
2. Observables and details of analysis

Space-time diagram showing the causal relation of the particles produced in hadronic interaction is presented in the figure 1. In order to investigate the effects of the initial states [3] we use the approach of the long-range correlations (LRC) [4, 5] between such observables as \( p_T \) and \( n \) in two sufficiently separated pseudorapidity intervals (so-called ”forward” and ”backward” pseudorapidity windows). We study the following types of correlations: between multiplicity of particles in forward pseudorapidity window \( n_F \) and event mean multiplicity of particles in backward pseudorapidity window \( n_B \) (\( n-n \) correlations); between \( n_F \) and event average transverse momentum of particles in backward pseudorapidity window \( \langle p_T \rangle_B \) (\( p_T-n \) correlations); between event average transverse momentum of particles in forward pseudorapidity window \( \langle p_T \rangle_F \) and \( \langle p_T \rangle_B \) (\( p_T-p_T \) correlations). The strength of the LRC coefficient \( b_{corr} \) between observables in forward and backward pseudorapidity windows is determined by the following expression:

\[
b_{corr} = \frac{\langle FB \rangle - \langle F \rangle \langle B \rangle}{\langle F^2 \rangle - \langle F \rangle^2},
\]

where

\[
F = \begin{cases} n_F & \text{for } n-n \text{ and } p_T-n \text{ correlations}, \\ \langle p_T \rangle_F & \text{for } p_T-p_T \text{ correlations}, \end{cases} \quad B = \begin{cases} n_B & \text{for } n-n \text{ correlations}, \\ \langle p_T \rangle_B & \text{for } p_T-n \text{ and } p_T-p_T \text{ correlations}. \end{cases}
\]

In this study the LRC are obtained for pp-collisions at \( \sqrt{s} = 7 \) TeV for the events simulated with PYTHIA 8 event generator with the account of the mechanism of a so-called flavour ropes formation as the plug-in [7, 10]. Actually, the flavour ropes are the same objects as fused strings in the model of color string fusion. In the figure 2 it is demonstrated that PYTHIA 8 with flavour ropes is able to describe yield ratios to charged pions and transverse momenta of strange particles produced in high-energy pp-collisions (one has to note that PYTHIA 8 without the flavour ropes [1] is not able to reproduce this effect).

In the present study, we consider particles with \( p_T < 2 \) GeV/c produced in processes of inelastic scattering only. The number of simulated events – \( 4 \times 10^6 \). The following set of parameters of the flavour ropes model is used: the ratio of the string transverse area to a proton transverse area \( \frac{R_{string}}{R_{proton}} = 0.3 \) (determines the amount of overlaps in the collisions); rapidity span – 0.9 (determines how far in rapidity from a string break overlaps are counted). The considered groups of particles are: charged particles, \((K^+ + K^-)\)-mesons, \(K_S^0\)-mesons and \((\Lambda + \bar{\Lambda})\)-hyperons.

3. Results

The implementation of PYTHIA 8 event generator with the account of the mechanism of flavour ropes formation allows to describe the recently obtained phenomena of enhancement of strange
Figure 2. $p_T$-integrated yield ratios to pions ($\pi^+ + \pi^-$) as a function of $(dN_{ch}/d\eta)$ measured in $|y| < 0.5$ (a) and $p_T$-differential yields of $K^0_S$, $\Lambda + \bar{\Lambda}$, $\Xi^- + \Xi^+$ and $\Omega^- + \bar{\Omega}^+$ measured in $|y| < 0.5$ (b). Experimental data [1] are compared to the data simulated by PYTHIA 8 with flavour ropes formation mechanism.

particles yield – the signal of a possible formation of quark-gluon plasma [1]. In the figure 2 it is demonstrated that PYTHIA 8 with flavour ropes is able to describe both the ratio of particle yields and transverse momenta of strange particles produced in high-energy pp-collisions.

The dependencies of the LRC coefficients $b_{n-n}$, $b_{p_T-n}$ and $b_{p_T-p_T}$ on the distance between the forward and the backward pseudorapidity windows $\eta_{gap}$ are obtained and presented in the Figure 3. It is seen that for all considered types of particles the positive LRC coefficients are observed. The LRC coefficients of strange particles are substantially smaller than LRC coefficients of charged particles, which is probably due to the fact that strange particles are emitted mainly by the new type of sources – the flavour ropes (e.g. the fused strings). Also, unlike charged particles, the LRC coefficients of strange particles depend on $\eta_{gap}$ negligibly. The only one exception is for $b_{p_T-p_T}$ of charged kaons, where the behavior is significantly different (this phenomenon requires additional study).

Also the dependencies of the LRC coefficients $b_{n-n}$, $b_{p_T-n}$ and $b_{p_T-p_T}$ on the width of forward pseudorapidity window $\delta\eta_F$ with the constant backward pseudorapidity window and $\eta_{gap}$ are obtained (see Figure 4). The behaviour of the LRC coefficients of strange and charged particles is found to be noticeably different. While the LRC coefficients of charged particles depend on $\delta\eta_F$ strongly, in case of strange particles this dependence is much weaker (see Figures 3, 4).

4. Conclusions

It is demonstrated, that the implementation of flavour ropes formation mechanism into the event generator PYTHIA 8 makes it possible to describe the enhancement of strange particles yields which is observed in the experiment. Using PYTHIA 8 with the flavour ropes formation mechanism, the positive LRC coefficients are observed for all considered types of particles. The influence of changing of $\eta_{gap}$ and $\delta\eta_F$ on the values of the LRC coefficients is found in general to be much weaker than for charged particles. The only one exception is the case of $\eta_{gap}$ dependence of $b_{p_T-p_T}$ of charged kaons. This unexpected behaviour is to be investigated further.
Figure 3. The dependencies of the LRC coefficients $b_{n-n}$ (a), $b_{pT-n}$ (b) and $b_{pT-pT}$ (c) on the distance between forward and backward pseudorapidity windows $\eta_{gap}$.

Figure 4. The dependencies of LRC coefficients $b_{n-n}$ (a), $b_{pT-n}$ (b) and $b_{pT-pT}$ (c) on the width of forward pseudorapidity window $\delta\eta_F$ with constant backward pseudorapidity window and $\eta_{gap}$.

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