Correlations between multiplicities and transverse momenta in nucleus-nucleus collisions from model with cluster of fused color strings

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Abstract. The long-range rapidity correlations between the multiplicities \( (n-n) \) and the transverse momentum and the multiplicity \( (p_T-n) \) of charged particles are analyzed in the framework of the simple string inspired model with two types of sources. The sources of the first type correspond to the initial strings formed in a hadronic collision. The sources of the second type imitate the appearance of the emitters of a new kind resulting from interaction (fusion) of the initial strings. The model enabled to describe effectively the influence of the string fusion effects on the strength both the \( n-n \) and the \( p_T-n \) correlations. Modification of the model to the analogue of the “core-corona” mechanism allows to take into account event selection criteria based on centrality and perform a comparison with existing experimental data on correlation measurements in nucleus-nucleus collisions at LHC energies. It is shown that string fusion effects in the model with the core-corona mechanism lead to the change of a sign of the \( p_T-n \) correlation coefficient with a decrease of a centrality interval width.

1. Introduction
The long-range rapidity correlations (or forward-backward correlations) analysis is considered as a sensitive tool to probe initial conditions and collective effects in high energy ion collisions [1]. In this work we apply a two-stage scenario of particle production [2,3] where at the beginning of a collision several extended in rapidity quark-gluon strings are stretched between colliding ions, which then decay into observed charged particles. Fluctuations in a number of these strings and formation of strings clusters [4] are considered as the main sources of correlations in the proposed model. In this paper we study two types of correlations: the correlation between multiplicities of charged particles in two rapidity windows separated by some gap and the correlation between event-mean value of transverse momentum and multiplicity in these windows. The strength of the correlations is characterized by the correlation parameters:

\[
\begin{align*}
    b_{n-n}^{abs} &= \frac{\langle n_F n_B \rangle - \langle n_F \rangle \langle n_B \rangle}{\langle n_F^2 \rangle - \langle n_F \rangle^2}, \\
    b_{p_T-n}^{abs} &= \frac{\langle n_F p_T B \rangle - \langle n_F \rangle \langle p_T B \rangle}{\langle n_F^2 \rangle - \langle n_F \rangle^2}.
\end{align*}
\]
(1)

The averaging \( \langle \ldots \rangle \) in (1) is over all events. In order to decrease dependence on the window width the normalized versions of the correlation parameters are considered:

\[
\begin{align*}
    b_{n-n}^{rel} &= \frac{b_{n-n}^{abs}}{n_B}; \\
    b_{p_T-n}^{rel} &= \frac{b_{p_T-n}^{abs}}{p_T B}.
\end{align*}
\]
(2)
For symmetric reaction and symmetric observation windows we clearly have $b_{n-n}^{rel} = b_{n-n}^{abs}$.

The suggested observables have already been extensively studied both experimentally [5–8] and theoretically [9–15]. The main feature of this paper is an implementation of an analogue of the core-corona mechanism [16] in terms of string fusion to be discussed below.

2. Monte-Carlo model

2.1. Initial conditions

The analysis was performed for Pb+Pb collisions at 2.76 TeV. The setting of the initial conditions in the toy model was adopted from [17]. It includes generation of nucleons positions in transverse plane, generation of partons within nucleons and the string formation process. In order to find high-density string clusters the transverse plane was split into cells of 1 fm width. Cells with the number of strings larger than $N_{crit} = 5$ were attributed to the so-called “core”, representing a cluster of fused strings, while cells with the number of strings lower than 5 were attributed to the so-called “corona”, a set of the non-interacting independent strings.

According to the string fusion model [4] interaction of strings changes fragmentation properties. We set mean multiplicity in both observation windows from one string to be 0.5 and from core with $w$ interacting strings to be $0.5 \cdot \sqrt{w}$, mean transverse momentum of particles in observation window from one string to be 0.3 GeV/c and from cell with $w$ interacting strings to be $0.3 \cdot \sqrt{w}$ GeV/c. It is these modifications that lead to non-zero $p_T$-$n$ correlations within this model.

2.2. Event selection by centrality

Experimentally correlations are studied in classes of events characterized by different centralities. As an impact parameter is not measured, pure geometrical picture is inapplicable and estimators based on multiplicity or energy in some experimental acceptance are considered.

In the ALICE experiment these estimators are [18]:

- V0 signal (multiplicity type estimator)
- ZDC signal (energy of nucleons spectators type estimator)

In order to mimic these selection criteria we generate a number of particles that are produced within V0 acceptance region and count number of nucleons-spectators that should hit ZDC detectors event-by-event. It should be noted that two alternative versions of particle production in the V0 acceptance were considered. In the first version string interaction was not taken into account and it was assumed that strings decay independently in the V0 acceptance. In the second approach string interactions were considered to happen along the full string “length”. The second version was giving the results that were more resembling of available data on multiplicity correlations than the first one. Therefore, results to be shown below are corresponding to the second version.

3. Results

Figure 1 presents results on the $n$-$n$ correlation coefficient that was calculated for different centrality classes that are determined through the number of nucleons-spectators. Lines with different colors represent different widths of centrality classes. Figure 2 is the same correlation coefficients but measured for V0 centrality classes.

In both cases a decrease in the centrality class width leads to a decrease of the correlation coefficient what is consistent with the experimental data [19]. The qualitative description of experimental results [19] is better for V0 centrality classes while for ZDC selection there are some discrepancies for narrow centrality classes. In order to improve description one can simulate the ZDC detector response and take into account its non-perfect energy resolution.
Figure 1. $n-n$ correlation coefficient calculated in centrality classes defined by the number of nucleons-spectators (ZDC-like estimator). Different lines represent different widths of centrality classes: magenta - 20%, red - 10%, blue - 5%, black - 2.5%, green - 1%.

Figures 3 and 4 shows the same dependencies obtained for the $p_T$-$n$ correlation coefficient. In this case the difference between to ways of the centrality estimation is more pronounced. Selection of narrow centrality classes by ZDC allows for restrict fluctuations in a number of primary strings, i.e. strings that are not yet transformed into core-corona. Therefore, the only source of correlations in this case are fluctuations in core-corona configurations with a fixed number of original strings. Such fluctuations lead to significant negative $p_T$-$n$ correlations that are observed in figure 3. Selection by V0 restricts fluctuations in core-corona configurations leading to almost negligible correlations for narrow centrality classes as seen in figure 4. Similar effects have already been observed in [9] where the local string fusion scenario was considered.

Figure 2. $n-n$ correlation coefficient calculated in centrality classes defined by the number of particles in the V0 acceptance. Different lines represent different widths of centrality classes: magenta - 20%, red - 10%, blue - 5%, black - 2.5%, green - 1%.

Figure 3. $p_T$-$n$ correlation coefficient calculated in centrality classes defined by the number of nucleons-spectators (ZDC-like estimator). Different lines represent different widths of centrality classes: magenta - 20%, red - 10%, blue - 5%, black - 2.5%, green - 1%.

Figure 4. $p_T$-$n$ correlation coefficient calculated in centrality classes defined by the number of particles in the V0 acceptance. Different lines represent different widths of centrality classes: magenta - 20%, red - 10%, blue - 5%, black - 2.5%, green - 1%.
4. Conclusions
We presented results on Monte-Carlo simulations of the $n$-$n$ and $p_T$-$n$ backward-forward correlation coefficients. It was shown that different centrality estimators that are used in modern experiments select different subsets of events leading to different values of correlation coefficients. Moreover, it was shown that selections by different estimators can be sensitive to initial conditions and collective effects such as string fusion. String fusion effects in the model with the core-corona mechanism lead to change of a sign of the $p_T$-$n$ correlation coefficient with decrease of a centrality interval width.

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