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FORWARD–BACKWARD CORRELATIONS AND MULTIPLICITY FLUCTUATIONS IN PB–PB COLLISIONS AT $\sqrt{s_{NN}} = 2.76$ TeV FROM ALICE AT THE LHC[*]

Iwona Sputowska

for the ALICE Collaboration

Institute of Nuclear Physics Polish Academy of Sciences
Radzikowskiego 152, 31-342 Kraków, Poland

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This paper presents a comparative study of forward–backward correlations and multiplicity fluctuations in the HIJING Monte Carlo simulations of Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. The analysis focuses on two observables which are: the forward–backward correlation coefficient b_{corr}^{n-n} and the strongly intensive quantity Σ. Results are discussed in the context of the influence of event-by-event fluctuations of the geometry of the Pb–Pb collisions on the measured quantities.

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1. Introduction

Studies of multiplicity correlations have a long history in particle physics. A very popular technique is the analysis of forward–backward (FB) correlations which describe the (linear) correlation between the number of particles produced in two pseudorapidity (η) intervals, one located in the forward (n_{F}) and the other in the backward (n_{B}) hemisphere of the heavy-ion collision. A typical measure of the forward–backward correlation strength is the FB correlation coefficient b_{corr}^{n-n}.

In this paper, the coefficient b_{corr}^{n-n} is defined in terms of the Pearson correlation coefficient as the covariance of two multiplicity distributions in forward and backward pseudorapidity bins, divided by the product of their standard deviations (Eq. (1))

$$b_{\mathrm{corr}}^{n-n} = \frac{\mathrm{Cov}(n_{\mathrm{B}}, n_{\mathrm{F}})}{\sqrt{\mathrm{Var}(n_{\mathrm{B}})\mathrm{Var}(n_{\mathrm{F}})}}\,. \tag{1}$$

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As has been shown in Refs. [1, 2], in addition to carrying important information on the early dynamics of heavy-ion collisions, the FB correlation coefficient appears to be dominated by more trivial effects such as geometrical fluctuations, *i.e.* the fluctuation of the number of interacting nucleons. In order to gain a better understanding of the processes occurring during the ultra-relativistic nuclear collision, it is important to define observables that are sensitive to the initial dynamics of the heavy-ion collisions but also independent of event-by-event geometrical fluctuations. Such properties are expected from so-called *strongly intensive quantities* of two families which were defined in Ref. [3].

The Σ observable belongs to one of these families. In the context of FB multiplicity fluctuations studies, the Σ quantity is defined by a combination of forward and backward first moments $\langle n_{\mathrm{F(B)}}\rangle$, forward and backward scaled variances $\omega_{\mathrm{B(F)}}$ and the covariance of forward and backward multiplicity distributions (Eq. (2))

$$\Sigma = \frac{(\omega_{\mathrm{B}}\langle n_{\mathrm{F}}\rangle + \omega_{\mathrm{F}}\langle n_{\mathrm{B}}\rangle - 2\mathrm{Cov}(n_{\mathrm{B}}, n_{\mathrm{F}}))}{\langle n_{\mathrm{B}}\rangle + \langle n_{\mathrm{F}}\rangle}\,. \tag{2}$$

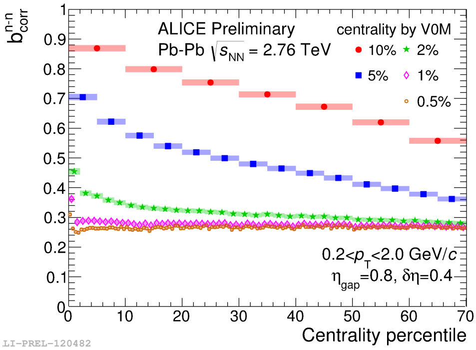
As has been shown in Ref. [3] in terms of independent source models[1] of multi-particle production, the observable Σ does not depend on the number of sources or their event-by event fluctuations. In fact, it carries information on characteristics of the single source distribution.

Recently, new experimental results from the ALICE experiment on forward–backward correlations in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV were presented in Ref. [5] (Fig. 1).

The results obtained in the ALICE experiment on the value of the FB correlation coefficient exhibit a strong dependence on the centrality selection method (Fig. 1 (left) *versus* Fig. 1 (right)) as well as on the width of the centrality class interval. Therefore, caution should be exercised when interpreting the results of Fig. 1 in the context of the information that they would provide on the early stages of the collision.

In order to better understand the contribution coming from event-by-event volume fluctuations, a more detailed Monte Carlo (MC) study was performed using the HIJING event generator. This paper presents the result of this study for forward–backward correlations and multiplicity fluctuations in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV in ALICE. The analysis focuses on two observables: the FB correlation coefficient b^{n-n}_{corr} and the strongly intensive quantity Σ.

[1] That is, simple superposition models of statistically identical sources producing particles independently. An example of an independent source model is the Wounded Nucleon Model [4].



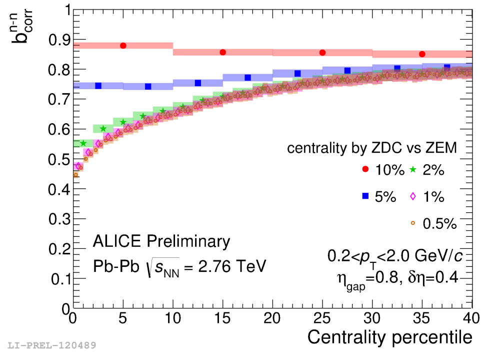


Fig. 1. Strength of the FB multiplicity correlations as a function of centrality in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV [5]. Centrality classes of different width are determined by the V0 (left) and by the ZDCvsZEM (right). Systematic uncertainties are shown as rectangles (widths correspond to the sizes of centrality classes), statistical uncertainties are smaller than marker sizes.

2. Results and discussion

The analysis of the coefficient b_{corr}^{n-n} and the Σ observable presented in this paper was carried out for primary charged particles produced in two pseudorapidity intervals: $\eta_{\mathrm{B}} \in (-0.8, -0.6)$ and $\eta_{\mathrm{F}} \in (0.6, 0.8)$, each of width $\delta\eta = 0.2$. The observables b_{corr}^{n-n} and Σ were studied as a function of centrality bin width for a fixed value of the distance between the forward and backward pseudorapidity bins: $\Delta\eta = 1.2$. In this analysis, the width of the centrality class was varied from 10%, where the largest contribution from geometrical fluctuations was expected, down to a 1% centrality bin width.

Results for the forward–backward correlations b_{corr}^{n-n} and the strongly intensive quantity Σ were determined for different centrality classes of Pb–Pb collisions, from central to peripheral. The observables were obtained for two different centrality selection methods.

The first method was a direct selection on the impact parameter of the collision. The second method was based on the selection of the charged particle multiplicity in the V0 acceptance ($-3.7 < \eta < -1.7$ and $2.8 < \eta < 5.1$); this directly corresponds to the V0M centrality estimator in the ALICE experiment [5]. We note that the present version of the ALICE simulation framework does not provide calorimetric centrality selection, which would coincide with the ALICE ZDC centrality estimator.

2.1. Results on the forward–backward correlation coefficient: dependence on centrality bin width

The results presented in Fig. 2 reveal similar trends as observed in the experimental data (Fig. 1) for the behavior of the values of $b^{n-n}_{\rm corr}$ in relation to centrality bin size. First, in both panels, a monotonic increase of the correlation strength with increasing size of the centrality class interval (from 1% to 10%) can be seen, regardless of the chosen centrality selection method. Second, the dependence of the coefficient $b^{n-n}_{\rm corr}$ on the centrality bin size for a given centrality class depends strongly on the centrality selection method.

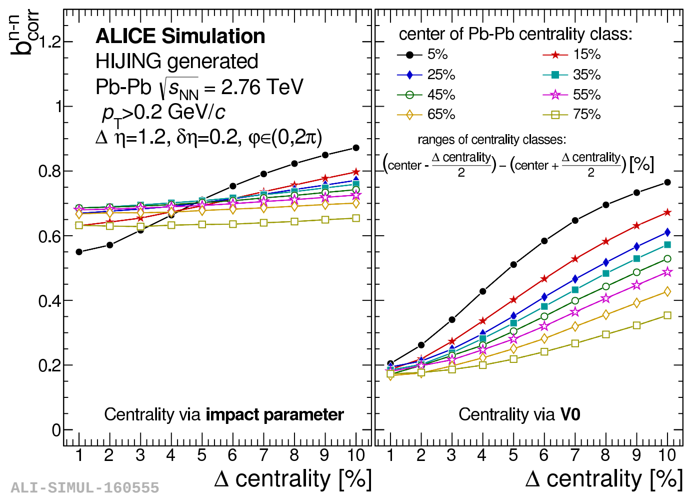


Fig. 2. (Color online) The forward–backward correlation coefficient $b^{n-n}_{\rm corr}$ obtained for HIJING generated Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, drawn as a function of centrality class size (*Δ centrality*), for a fixed value of pseudorapidity gap $\Delta\eta = 1.2$. The results are obtained for two different centrality selection methods: via V0 and via impact parameter selection, shown in right and left panel, respectively. The width of the centrality class changes from 1% to 10%. The different colors of the data points correspond to different centralities of the Pb–Pb collision.

A comprehensive theoretical explanation of the observed qualitative behavior of the correlation coefficient as a function of centrality bin width can be found in [2]. The paper provides Eq. (3) for the forward–backward correlation coefficient in the Wounded Nucleon Model [4] supplemented with a binomial multiplicity distribution (described with parameters $\hat{n}$, k) for charged particles emitted from each wounded nucleon

$$b^{n-n}_{\rm corr} = 1 - \left[1 + \frac{\hat{n}}{4}\left(\frac{2}{k} + \frac{\langle w^2\rangle - \langle w\rangle^2}{\langle w\rangle}\right)\right]^{-1} . \tag{3}$$

Equation (3) shows a clear dependence of the coefficient $b_{\rm corr}^{n-n}$ on the scaled variance of the number of wounded nucleons (participants) $\frac{\langle w^2\rangle-\langle w\rangle^2}{\langle w\rangle}$.

From the above formula, it is evident that the value of the correlation coefficient should decrease with the reduction in the fluctuation of the number of participants, induced in the presented analysis by a reduction of the centrality bin from 10% down to 1%. The largest effect is expected for the most central collisions, which is indeed the case shown in Fig. 2.

It is important to remark that a different selection of centrality (V0 or impact parameter) leads to a different selection on the number of participants and, therefore, to a different reduction of its fluctuations. This is very well visible in Fig. 2 where the centrality selection both via impact parameter and via V0 leads to different results for the value of correlation coefficient. The latter can be regarded as a direct reflection of Eq. (3).

2.2. *Strongly intensive quantity Σ: dependence on centrality bin width*

The results for Σ obtained from the HIJING simulations of Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV are shown in Fig. 3: this observable appears to be insensitive to the centrality bin size. The values of the Σ observable

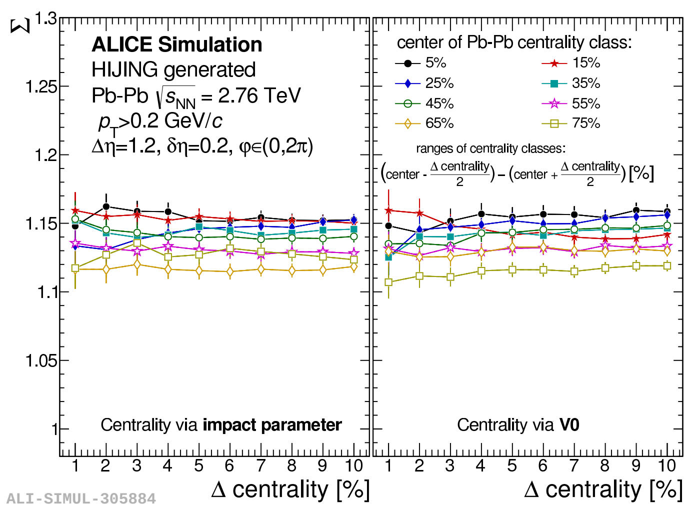


Fig. 3. (Color online) The quantity Σ obtained for the HIJING generated simulations of Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV and drawn as a function of size of centrality class (Δ *centrality*) bin, for a fixed value of pseudorapidity gap $\Delta\eta = 1.2$ for two different centrality selection methods: via V0 and via impact parameter, shown in right and left panel, respectively. The width of the centrality class changes from 1% to 10%. The various colors of the data point correspond to different centralities of the Pb–Pb collision.

do not change while reducing the width of centrality class from the wide 10% centrality bin, the most affected by the contribution from geometrical fluctuations, down to 1%. This behavior is valid for all centralities of Pb–Pb collisions, from central to peripheral.

From the comparison between values obtained for the centrality selection using impact parameter (left panel in Fig. 3) and V0 (right panel in Fig. 3), one can see that there is no significant qualitative nor quantitative difference between results determined with different centrality class selections. Thus, the obtained values appear basically independent of the adopted centrality estimator.

3. Summary and outlook

Recently, new data on forward–backward multiplicity correlations in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV have been obtained in the ALICE experiment. In this paper, a detailed complementary analysis of the FB correlation coefficient $b_{\rm corr}^{n-n}$, as well as a new analysis of the Σ observable in Pb–Pb collision at $\sqrt{s_{NN}} = 2.76$ TeV simulated using the HIJING model in the ALICE framework was carried out. In the case of the forward–backward correlation coefficient, information on the early dynamics of the collision is mixed with event-by-event geometrical fluctuations. Results for the coefficient $b_{\rm corr}^{n-n}$ show a large dependence on centrality bin width and centrality selection method for both experimental data and Monte Carlo simulations. In this paper, we also report on a first study of the Σ observable at ALICE energies. In MC HIJING simulations, Σ exhibits the properties of a strongly intensive quantity. As has been verified in this analysis, the values of Σ do not depend on the centrality estimator and are basically insensitive to geometrical fluctuations. As a next step of the analysis presented here, experimental analysis of the strongly intensive quantity Σ will be presented in Ref. [6]. Bearing in mind that in terms of independent source models Σ should carry information dependent only on characteristics of single sources, this new analysis is expected to provide important information on the early dynamics of heavy-ion collisions, unaffected by trivial geometrical fluctuations.

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