

First results on the event-by-event fluctuations and correlations in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

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Fluctuations of thermodynamic quantities are fundamental for the study of the QGP phase transition. Among several observables calculated on an event-by-event basis, the different measures of the charge and mean transverse momentum fluctuations are of particular interest since they are considered to be indicators of the existence and of the order of this transition as well as of the thermalization in heavy-ion collisions. In this article, we review the first results from the event-by-event physics program of the ALICE experiment at the LHC in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. The experimental results will be compared to previously published data and available model predictions.

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1. Introduction

Relativistic heavy-ion collisions have been used extensively throughout the last decades as a tool to create and eventually study the properties of the deconfined matter, the Quark–Gluon–Plasma or QGP. In view of the latest findings, both at RHIC [1] and at the LHC [2], we have strong evidence that the phase transition from the cold nuclear matter to the hot and dense deconfined state of quarks and gluons is observed. This opens up new horizons in the field of heavy-ion physics, the main focus of which now turns towards the study and characterization of the properties of this newly created state of matter. Among all available observables, the study of charge and mean transverse momentum fluctuations on an event-by-event basis provides direct information about the nature of the phase transition and gives insight on the properties of the QGP [3]. In this article, we present the first results of these studies, performed using the ALICE detector [4] in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. The data were recorded in November–December 2010 during the first run with heavy ions at the LHC.

2. Analysis and results

For both studies, we used the Time Projection Chamber (TPC) and the Inner Tracking System (ITS) to reconstruct the charged particle tracks. For details about the experimental setup of ALICE, see [4]. The trigger consisted of a hit on both sides of the VZERO scintillator counters, positioned on both sides of the interaction point, in coincidence with a signal from the innermost ITS layer, the Silicon Pixel Detectors (SPD). We removed the background events offline using the VZERO timing information and the requirement of two tracks in the central detectors. We only consider events with a reconstructed primary vertex. The phase space analyzed was restricted to $|\eta| \leq 0.8$ and $0.2 \leq p_t \leq 2.0$ GeV/c.

Net-charge fluctuations: The fluctuations of net-charge depend on the squares of the charge states present in the system. The QGP phase, having the quarks as the charge carriers, should result into fluctuations with significantly different magnitude compared to a hadron gas (HG) [5].

The measure of charge fluctuations used in these studies is the variable $v_{(+-,dyn.)}$, defined in Eq. 2.1, first introduced in [6]. It was found to be less dependent on detector and acceptance effects [6, 7] which is essential in this category of studies where applying corrections on an event-by-event level is highly non-trivial. Figure 1–left shows the dynamical fluctuations as a function of the mean number of participating nucleons $\langle N_{part.} \rangle$, which is a measure of the collision’s centrality. The plot shows the results for different pseudo-rapidity (η) windows around mid-rapidity. The magnitude of the dynamical fluctuations is negative, indicating the dominance of the correlation between oppositely charged particles with respect to the same charge pairs. In addition, the absolute value of $v_{(+-,dyn.)}$ decreases monotonically, when going from peripheral to central collisions.

$$v_{(+-,dyn.)} = \frac{\langle N_+(N_+ - 1) \rangle}{\langle N_+ \rangle^2} + \frac{\langle N_-(N_- - 1) \rangle}{\langle N_- \rangle^2} - 2 \frac{\langle N_- N_+ \rangle}{\langle N_- \rangle \langle N_+ \rangle}, \quad (2.1)$$

Figure 1–right presents the centrality dependence of the absolute value of $v_{(+-,dyn.)}$ in a log–log scale. Our measurements, represented by the red full circles, are compared to the relevant measurements of the STAR collaboration obtained from the analysis of Au–Au collisions at different RHIC energies [8]. The ALICE data points indicate an additional reduction of the magnitude of fluctuations at the LHC energies. It is important also to note that if one fits the centrality dependence of $|v_{(+-,dyn.)}|$ with a power-law of the form $AN_{part.}^b$, then there seems to be a modest

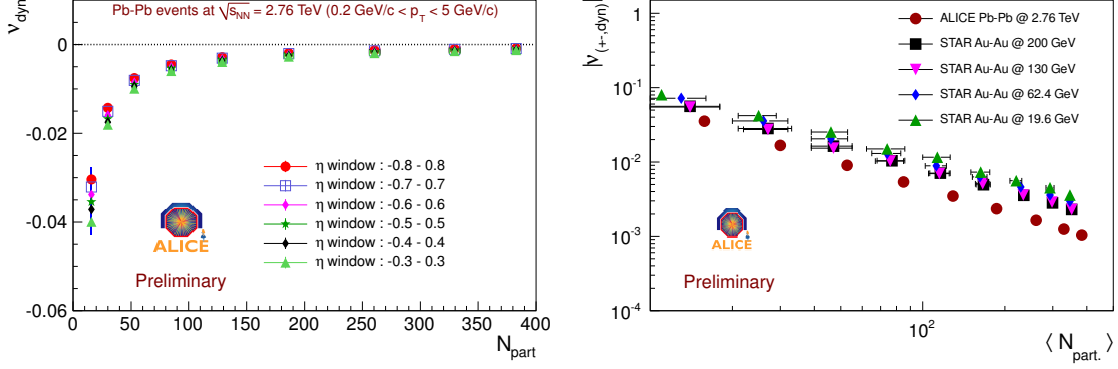


Figure 1: (Left panel) Dynamical net-charge fluctuations, $v_{(+,-,dyn)}$, of charged particles produced in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV as a function of centrality, expressed by the number of participating nucleons for different $\Delta\eta$ windows. (Right panel) The values of $v_{(+,-,dyn)}$ for $\Delta\eta = 1$ of charged particles in Pb-Pb collisions at the LHC and Au-Au collisions at RHIC energies from the STAR experiment [8], plotted as a function of centrality (i.e. number of participating nucleons).

change between the slopes that are extracted at the LHC with respect to the ones extracted from the analysis of RHIC data.

Mean transverse momentum fluctuations: The mean transverse momentum of emitted particles in an event is correlated to the temperature associated to the p_t distribution but also to the transverse collective expansion of the colliding system. The latter starts to develop at the first stages of the collision, when the parton re-interaction leads to a pressure build-up. Thus, the study of the fluctuations of the mean transverse momentum can probe the dynamics and the underlying correlations of the created system. It is argued, that they can serve as indicators of the phase transition [9] but also of the degree of thermalization and collectivity of the system [10].

In this analysis [11], the two-particle correlator $C_m = \langle \Delta p_{t,i} \Delta p_{t,j} \rangle_m$ that comprises the dynamical component of the relevant fluctuations [12], is used. Figure 2-left shows the relative fluctuations, expressed by $\sqrt{C_m} / \langle p_t \rangle_m$, as a function of the number of accepted tracks for pp collisions at $\sqrt{s} = 7$ TeV. The experimentally measured values, represented by the red circles, are compared to the expectations from two different model (PYTHIA and PHOJET). Both models give a poor description of the measured fluctuations in the low multiplicity region, while PYTHIA seems to agree with the measured values for $N_{acc} \geq 7$.

Figure 2-right shows the relevant picture for Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. The black points, representing the experimentally measured values of the relative fluctuations, indicate a significant non-statistical value of the magnitude of the fluctuations. The dependence on the number of accepted tracks is not reproduced by HIJING [13]. What is striking though is the fact that if we fit the pp points (also shown in this plot) with a power-law of the form AN_{acc}^b , then we can describe at the same time the heavy-ion points up to $N_{acc} \approx 600$. However, the central Pb-Pb collisions deviate from this trend, indicating a significant additional reduction of fluctuations. Finally, the relevant HIJING points can be described by a single (power-law) function over the entire spectrum of N_{acc} , the slope being significantly different with respect to the one obtained from the collision data.

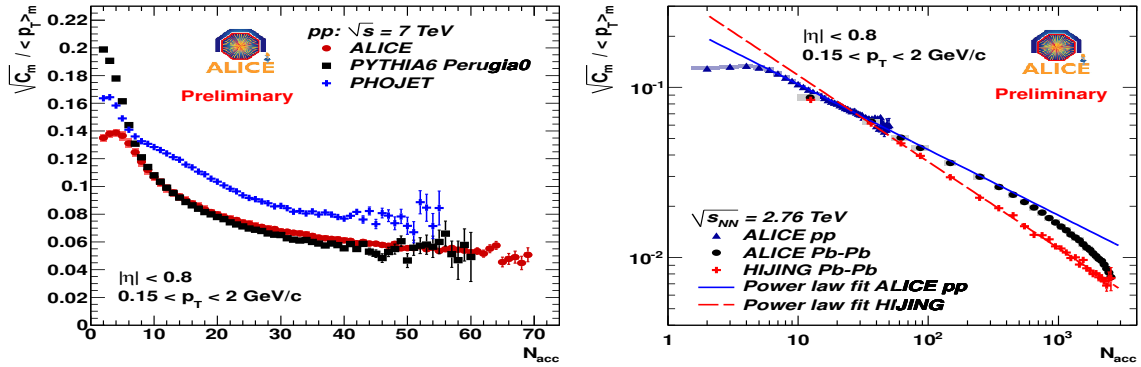


Figure 2: The dependence of the relative fluctuations on the number of accepted tracks in pp (left) and Pb–Pb (right) events at $\sqrt{s} = 7$ TeV and $\sqrt{s_{NN}} = 2.76$ TeV, respectively. The experimental values are compared to different model predictions in both plots.

3. Outlook

The first results from the analysis of both the net-charge and the mean transverse momentum fluctuations reveal interesting behavior in both pp and Pb–Pb collisions. In a future set of publications we will attempt to address in a quantitative way the effect of the diffusion of fluctuations during the hydro-dynamical expansion of the system but also at the hadronization phase, as well as how the onset of thermalization is reflected in these measurements. We hope that these measurements will also stimulate additional theoretical studies that will contribute to our better understanding of the properties of the system that we create in heavy-ion collisions.

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