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# Charge fluctuations in Pb–Pb collisions at $\sqrt{s_{NN}}$ =2.76 TeV measured by ALICE experiment

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Charge fluctuations provide a possible signature for the existence of the de-confined Quark Gluon Plasma phase (QGP). Being sensitive to the square of the charges, fluctuations in QGP, with fractionally charged partons, are significantly different from those of a hadron gas with unit charged particles. Studies of charge fluctuations have been carried out using the variable, $\nu_{(+-,dyn)}$ which, by its construction, is free from collisional bias (impact parameter fluctuations and fluctuations from the finite number of charged particles within the detector acceptance). The dependence of charge fluctuations on the pseudo–rapidity windows for various centrality bins is analyzed for Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV in the ALICE experiment at CERN-LHC. A scaling behavior is observed as a function of increasing pseudo-rapidity window for the charge fluctuations, expressed in terms of $N_{ch} \times \nu_{(+-,dyn)}$, where $N_{ch}$ is the number of charged particles. The results are compared to experimental measurements at lower energies and to model predictions.

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## 1. Introduction

Heavy-ion collisions at ultra-relativistic energies can produce a new state of matter characterized by high temperature and energy density, where the degrees of freedom are given not by hadrons but by their constituents, the quarks and gluons [1]. The ALICE experiment [2], located at the CERN LHC, is a multi-purpose experiment with highly sensitive detectors around the interaction point. The central detectors cover the pseudo-rapidity region $|\eta| < 0.9$, with good momentum measurement as well as good impact parameter resolution. This gives us an excellent opportunity to study the fluctuations and correlations of physical observable on an event–by–event basis. Details of the ALICE experiment and its detectors may be found in [2].

The fluctuations of net–charge depend on the squares of the charge states present in the system. The QGP phase, having quarks as the charge carriers, should result in a significantly different magnitude of fluctuation compared to a hadron gas (HG). As discussed in [3, 4], The net–charge fluctuation is measured in terms of D defined as

$$D = 4\frac{\langle \delta Q^2 \rangle}{\langle N_{\rm ch} \rangle} \tag{1.1}$$

where $Q = N_+ - N_-$ is the net–charge and $N_{\rm ch} = N_+ + N_-$, here $N_+$ and $N_-$ are the numbers of positive and negative particles. The net–charge fluctuation expressed in term of $D$ is predicted to be 4 for non–interacting pion-gas, $\simeq$3 for hadron resonance gas and $\simeq$1-1.5 for QGP [5].

However, on an event–by–event basis the fluctuations are best studied experimentally through “non-statistical” or “dynamical” fluctuations. The dynamic charge observable, $\nu_{(+-,dyn)}$is defined as

$$\nu_{(+-,dyn)} = \nu_{+-} - \nu_{stat} = \frac{\langle N_+(N_+-1)\rangle}{\langle N_+\rangle^2} + \frac{\langle N_-(N_--1)\rangle}{\langle N_-\rangle^2} - 2\frac{\langle N_-N_+\rangle}{\langle N_-\rangle\langle N_+\rangle}, \tag{1.2}$$

where

$$\nu_{+-} = \left\langle \left( \frac{N_+}{\langle N_+\rangle} - \frac{N_-}{\langle N_-\rangle} \right)^2 \right\rangle \tag{1.3}$$

and

$$\nu_{stat} = \frac{1}{\langle N_+\rangle} + \frac{1}{\langle N_-\rangle} \tag{1.4}$$

and $\langle .... \rangle$ denotes the average over all events. And the $\nu_{(+-,dyn)}$ is a measure of the relative correlation [6] strength of $++$, $--$, and $+-$ particles pairs. Note that by construction, these correlations are identically zero for Poissonian, or independent particle production. Furthermore $D$ can be expressed in terms of $\nu_{(+-,dyn)}$ as

$$D \approx \nu_{(+-,dyn)} \times \langle N_{\rm ch} \rangle + 4 \tag{1.5}$$

In this article we report the first measurement of the net–charge fluctuations in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV measured with the ALICE detector.The data were recorded in November 2010 during the first run with heavy ions at the LHC. In this analysis, the Time Projection Chamber (TPC) [7] is used for selecting tracks, the Inner Tracking System (ITS) is used for vertexing and triggering and the VZERO scintillator detector is used for estimating centrality [8] as well as



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triggering. The collision centrality is determined by cuts on the VZERO multiplicity as described in [9]. A study based on Glauber model fits [10] to the multiplicity distribution in the region corresponding to thw 90% of most central collisions, where the vertex reconstruction is fully efficient, facilitates the determination of the cross section percentile and the number of participants. The resolution in centrality is found to be $< 0.5\%$ RMS for the most central collisions (0-5%), increasing towards 2% RMS for peripheral collisions (70-80%). The present analysis is performed by taking vertexes within $\pm 10$ cm from the nominal interaction point along the beam axis (z) to ensure a uniform acceptance in the central pseudo-rapidity $|\eta| < 0.8$ and the charged particle transverse momentum, $p_{\mathrm{T}}$, from 0.15 GeV/$c$ to 5 GeV/$c$. The trigger consisted of a hit on the two VZERO scintillator detectors, positioned on both sides of the interaction point, in coincidence with a signal from the Silicon Pixel Detector (SPD). We have removed background events using the VZERO timing information and the requirement of at least two tracks in the central detectors.

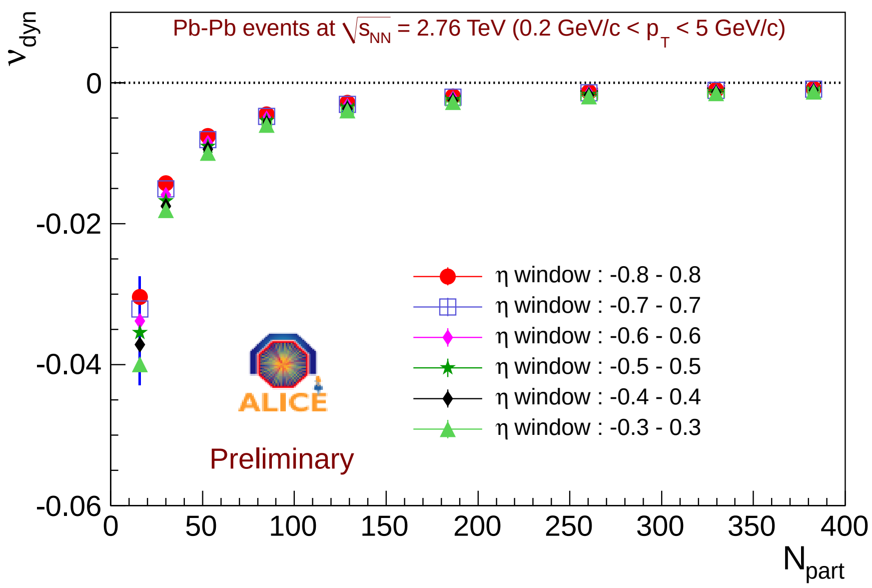


**Figure 1:** Dynamical net–charge fluctuations, $\nu_{(+-,dyn)}$, of charge particles within different pseudo-rapidity windows, as a function of number of participants.

The contribution to the systematic uncertainty originating from the following were considered: (a) uncertainty in the determination of interaction vertex, (b) the effect of magnetic field, (c) contamination from secondary tracks (DCA cuts), (d) centrality definition using different detectors, and (e) quality cuts of the tracks. The systematic and statistical uncertainties in the plots are represented by the shaded areas and the error bars, respectively.

The dynamic fluctuations, $\nu_{(+-,dyn)}$, were calculated on an event–by–event basis from the measurements of positive and negatively charged particles produced within $\Delta\eta$ windows defined around mid-rapidity. Fig. 1 shows, the $\nu_{(+-,dyn)}$ as a function of $N_{part}$, where moving from left to right along the x-axis implies moving from the most central to the most peripheral collisions. The value of $\nu_{(+-,dyn)}$ decreases monotonically, going from central to peripheral collisions for various $\Delta\eta$ windows.

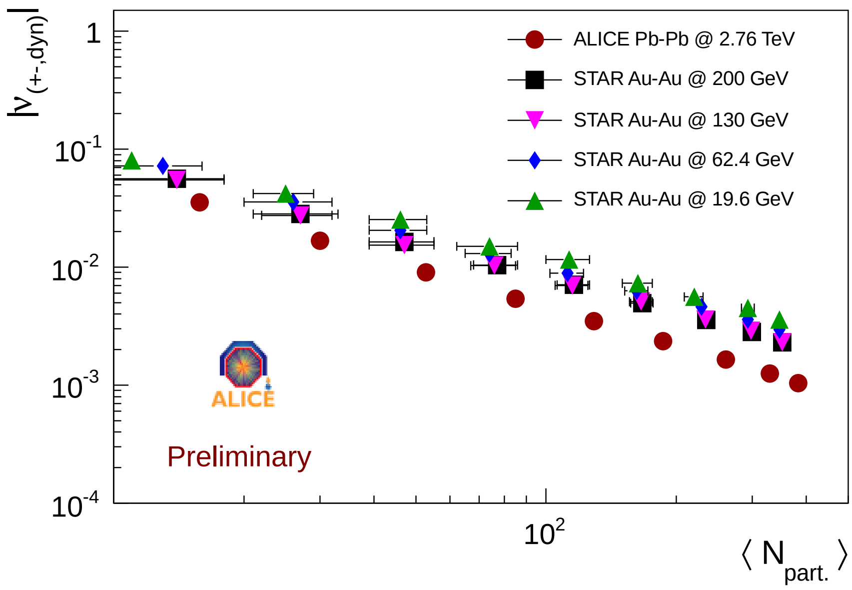


**Figure 2:** The absolute value of $\nu_{(+-,dyn)}$, as a function of the collision centrality compared with measurements for lower energies.

We have studied the beam energy dependence of the net–charge fluctuations by combining the ALICE points with those of RHIC data [11]. In Fig. 2, we present the absolute value $\nu_{(+-,dyn)}$ as a function of number of participants for $\Delta\eta = 1$, in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV at LHC and Au–Au collisions at STAR. In all cases dynamical net–charge fluctuations exhibit a monotonic dependence on the number of participating nucleons. The ALICE data are below the STAR points for Au–Au collisions at all centralities, indicating an additional reduction of the magnitude of fluctuations at LHC energies.

We examine the nature of the variation of $N_{ch} \times \nu_{(+-,dyn)}$ with $\Delta\eta$ by plotting its ratio with respect to the value at $\Delta\eta = 1$, as shown in Fig. 3. We observe that the relative value of $N_{ch} \times \nu_{(+-,dyn)}$ grows smoothly with increasing $\Delta\eta$ window. This behavior has been predicted in [12, 13] and was attributed to the spread of the signal arising from the diffusion during the evolution from the early QGP stage to the hadron resonance gas (HG). Charge conservation and longitudinal expansion affect the growth, which may limit the increase to an asymptotic value. We fit the data points of Fig. 3 with a function of the form erf($\Delta\eta\ /\sqrt{8}\sigma_f$) [14, 15], representing the diffusion in rapidity space, where $\sigma_f$ is the diffusion parameter. The diffusion coefficient, $\sigma_f$, obtained from the fitting is equal to $0.467 \pm 0.02$ at 0-5% centrality. An extrapolation of the fitted value indicates the onset of saturation at $\Delta\eta = 3$. It has been conjectured that, taking only dissipation into account, the asymptotic value of fluctuations may give back the original value of fluctuations at the early QGP stage.

In Fig. 4, the net–charge fluctuations, expressed in terms of $N_{ch} \times \nu_{(+-,dyn)}$ and $D$ (left– and right–axis, respectively) as a function of the $N_{part}$ are shown for three different $\Delta\eta$ windows, i.e. $\Delta\eta = 1$, $\Delta\eta = 1.6$ and the extrapolated asymptotic values at $\Delta\eta = 3$, along with the lines indicating the predicted values of fluctuations for three cases: pion gas, HG and QGP. The values at asymp-

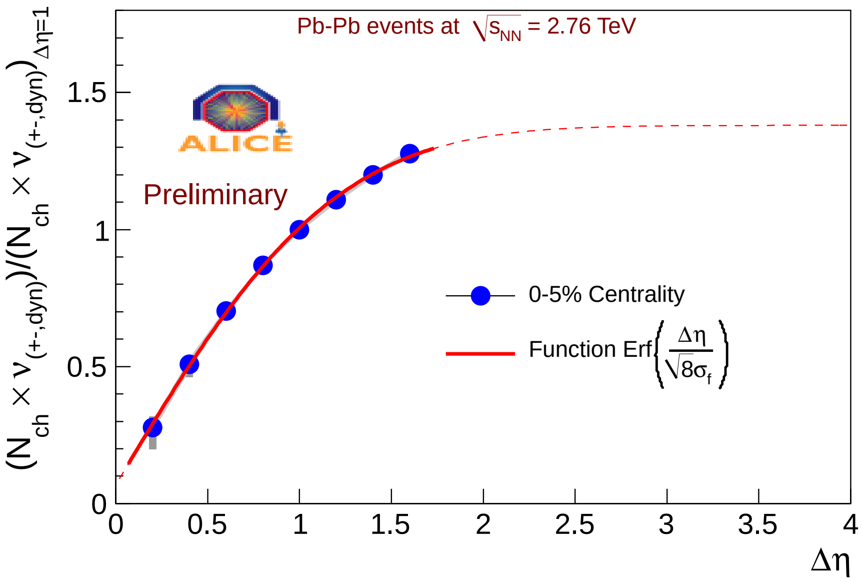


**Figure 3:** $N_{ch} \times \nu_{(+-,dyn)}$, normalized to the values for $\Delta\eta = 1$, are plotted as a function of $\Delta\eta$. The data points are fitted with the functional form erf($\Delta\eta / \sqrt{8}\sigma_f$) normally used for diffusion equations. The dashed line is an extrapolation of the fitted line.

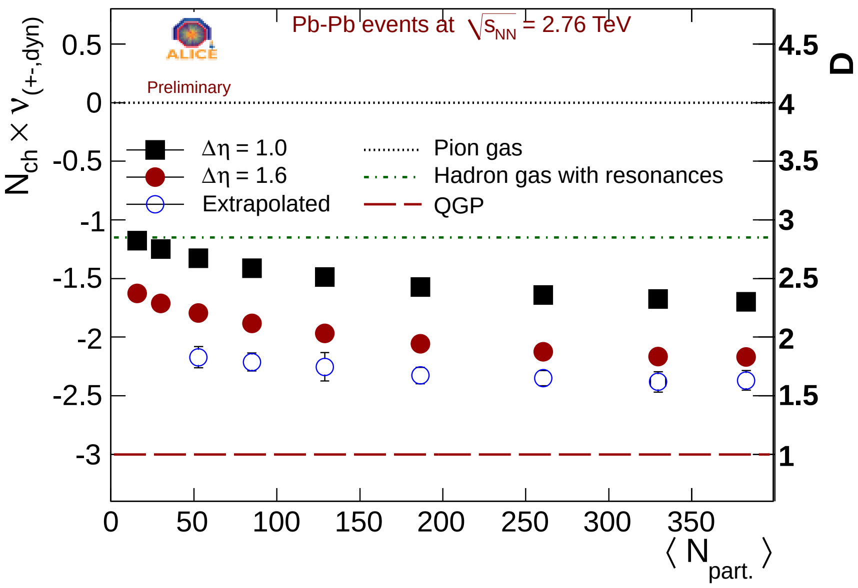


**Figure 4:** $N_{ch} \times \nu_{(+-,dyn)}$ (left-axis) and D (right-axis) are plotted for $\Delta\eta = 1$ and 1.6 as a function of the number of participants. The values after extrapolating to higher $\Delta\eta$ are shown by open circles.

totic limits are obtained for each centrality bin, separately. A decreasing trend of fluctuations is observed, measured in terms of D, when going from peripheral to central collisions. By confronting the measured value with the theoretically predicted fluctuations [4, 12], it is observed that the results are within the limits of the QGP and the HG scenarios. In reality the fluctuation might have been less than the observed value, because of further damping due to the final state interactions, expansion, collision dynamics, string fusion, or other effects discussed in [14, 15, 16, 17, 18, 19].

In summary, we have presented the first measurements of dynamic net–charge fluctuations at the LHC in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV using the observable $\nu_{(+-,dyn)}$. The net–charge fluctuations are observed to be dominated by the correlations of oppositely charged particles. The energy dependence of the dynamical fluctuations shows a decrease in fluctuation going from RHIC to LHC energies. A fit to the fluctuation in rapidity space is using the diffusion equation, which yields the asymptotic value of fluctuation, which is closer to the theoretically predicted value of Quark Gluon Plasma.

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