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EVENT-BY-EVENT PHYSICS IN ALICE*

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Fluctuations of thermodynamic quantities are fundamental for the study of the QGP phase transition. The ALICE experiment is well suited for precise event-by-event measurements of various quantities. In this article, we review the capabilities of ALICE to study the fluctuations of several key observables such as the net charge, the temperature, and the particle ratios. Among the observables related to correlations, we review the balance functions and the long range correlations.

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1. Introduction

Lattice QCD calculations predict that in an environment characterized by high temperature and energy density a new state of matter can emerge, where the degrees of freedom are given no more by the hadrons but by their constituents, the quarks and the gluons (quark–gluon plasma — QGP) [1]. Experimentally, important information about the nature and the time evolution of this predicted phase transition can be extracted by studying the final system which emerges after a relativistic heavy ion collision. Among other observables, the study of correlations and fluctuations on an event-by-event basis is expected to provide additional information on the order of this transition [2].

2. Event-by-event studies in ALICE

ALICE [3], located at the CERN LHC, is a multi-purpose experiment with highly sensitive detectors around the interaction point. The central detectors that cover the region $|\eta| < 0.9$, provide good reconstruction and

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particle identification capabilities as well as momentum measurements for each particle species in every event. The forward detectors extend the coverage of charged particles and photons. A combination of the information given by these detectors provides excellent opportunity to study the fluctuations and correlations of physics observables on an event-by-event basis at the LHC [3].

In the next paragraphs, we will review the ongoing studies about some of the key event-by-event topics, such as the net charge, and the temperature fluctuations, the balance functions, the fluctuations of particle ratios and the long range correlations.

2.1. Fluctuations of the net charge

Fluctuations of conserved quantities such as the electric charge provide information about the initial stage of the formation of the system after a collision, when possibly a phase with different degrees of freedom existed. Both experiments at SPS [4] and at RHIC [5] have reported that the initial fluctuations can be masked by the presence of final state effects (*e.g.* resonances).

ALICE plans to study different parameters that are proposed as measures of the net charge fluctuations, such as the D parameter [6] the multiplicity dependence of which for simulated Pb + Pb HIJING collisions is shown in Fig. 1. In addition, we plan to study the higher moments of the net charge (Fig. 1), such as the skewness and kurtosis in order to explore possible discontinuities in their dependence on different parameters [3].

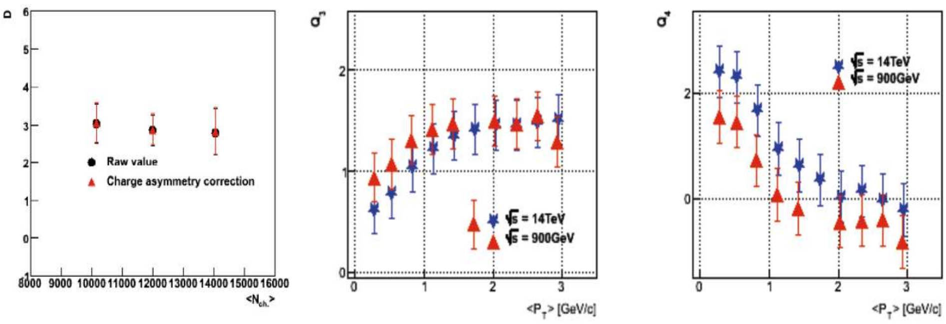

Fig. 1. The multiplicity dependence of the variable D (left plot) calculated for HIJING Pb + Pb collisions at $\sqrt{s_{\rm NN}} = 5.5$ TeV. The $P_{\rm T}$ dependence of the higher moments of the net charge distribution (Q_3 middle and Q_4 right plot) (PYTHIA $p+p$ collisions at different energies).

2.2. Temperature fluctuations

The temperature fluctuations provide information about whether there is a unique freeze-out temperature of the system or if this parameter fluctuates from event to event. The study can be performed either by extracting the information from the shape of the P_{T} distributions or by relating the temperature with the events transverse mass and extracting the variance as proposed in [7].

Figure 2 shows the distributions of the inverse slope parameter extracted from an exponential fit to the single event P_{T} distribution on an event-by-event basis for pions and protons. The results are obtained after the analysis of central HIJING Pb + Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.5$ TeV based on ALICE simulations.

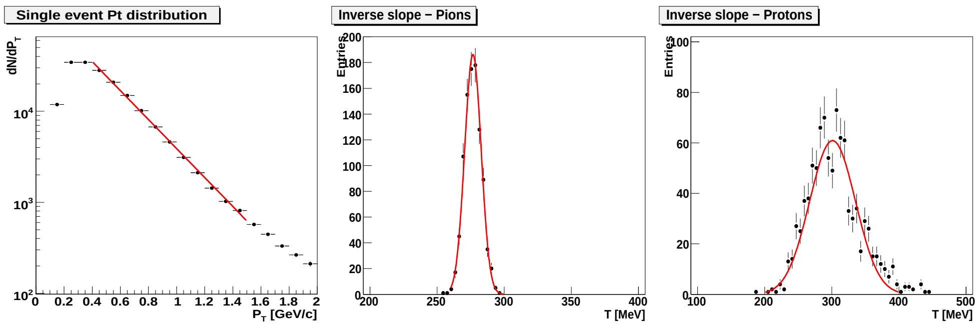

Fig. 2. The distributions of the inverse slope parameter extracted from the single P_{T} distribution on an event-by-event basis (left plot) for identified pions (middle plot) and protons (right plot) (ALICE simulations).

2.3. Balance functions

The balance function is mainly used to study the event-by-event correlations of opposite charged particles but it can also be extended to strangeness or baryon number correlations. The width of the balance function can be related to the correlation length between the oppositely charged particles as they are created at the same location in space-time [8], thus having an indirect connection between the width and the time of the hadronization. The balance function has been studied by both the NA49 [9] and the STAR [10] experiments, where both reported a decrease of the width with centrality.

For ALICE the balance function will be studied for non-identified charged particles but also for different particle species. The balance function will also be studied as a function of the $Q_{\mathrm{inv.}}$ (Fig. 3 (left plot)) and its components as proposed in [11], providing a clearer physics interpretation since these parameters tend to be less sensitive to mechanisms that have been proposed as being responsible for the narrowing of the width of the balance function (*e.g.* transverse flow). The balance function study can also be extended to a two-dimensional differential analysis, in $\eta - P_{\mathrm{T}}$ (Fig. 3 (middle and right plot)) or $\eta - \phi$ space to probe the effect of the radial flow [12].

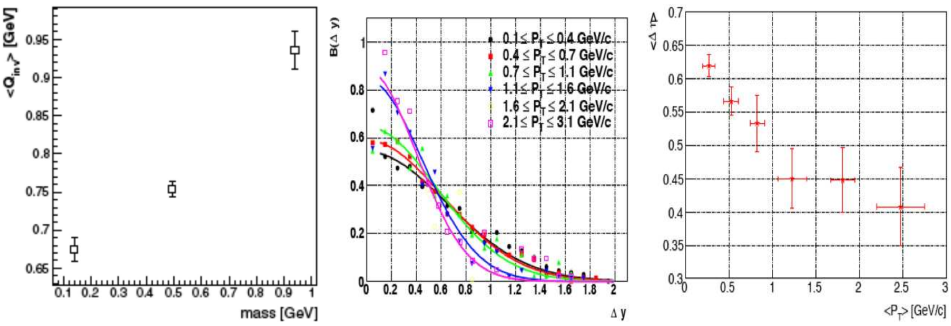

Fig. 3. The dependence of the $\langle Q_{\mathrm{inv.}} \rangle$ on the mass of the particle that form the pairs (left plot). The balance function distributions as a function of Δy for different P_{T} intervals (middle plot) and the dependence of the width on the $\langle P_{\mathrm{T}} \rangle$ (ALICE simulations).

2.4. Particle ratios

The particle ratios, especially those that contain information about strangeness, are sensitive to the QCD phase transitions. The measure of the fluctuations is the $\sigma_{\mathrm{dyn.}}$ and is related to the variance of the distribution of a given particle ratio for real data and mixed events. The ratio of the K/π has been studied by different experiments and has been reported to decrease with energy throughout the SPS energy range [13] and then stay constant at RHIC energies [14].

Figure 4 shows the K/π and p/π ratios calculated event-by-event for central HIJING Pb + Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.5$ TeV based on ALICE simulations. In ALICE we can take advantage of the particle identification

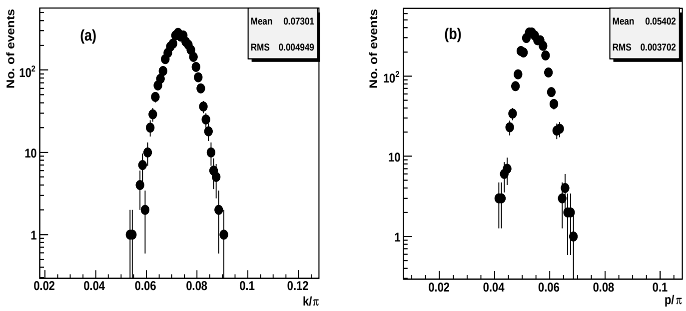

Fig. 4. The K/π and p/π ratios calculated event-by-event for central HIJING Pb + Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.5$ TeV based on ALICE simulations.

capabilities of the central barrel detectors and extract these ratios by using different detector combinations, starting from a stand-alone TPC approach and adding detectors reaching the level where the combined PID approach, which gives the best results, can be applied.

2.5. Long range correlations

The study of correlations among particles produced in different rapidity regions can give insight about the particle production mechanism. The production of particles in the central region is dominated by short range correlations (SRC) at all energies whereas the long range correlation (LRC) may be enhanced in hadron–nucleus and nucleus–nucleus collision compared to hadron–hadron collision [15].

ALICE plans to use the central barrel detectors (ITS and TPC) but also the forward ones (mainly FMD) for these studies. Figure 5 shows the dependence of the parameter b, which is defined as the ratio of the dispersion of the backward–forward and forward–forward components, on the pseudo-rapidity keeping the η gap fixed (left plot) and on the η gap keeping the pseudo-rapidity interval between the forward and backward regions fixed (middle plot). The right plot shows the dependence of the parameter b on the energy of the collision for real data coming from different experiments. These values were fitted with a linear function and extrapolated to the LHC energies. The squares (red) correspond to the result obtained from the analysis of PYTHIA pp events at $\sqrt{(s)} = 10$ TeV.

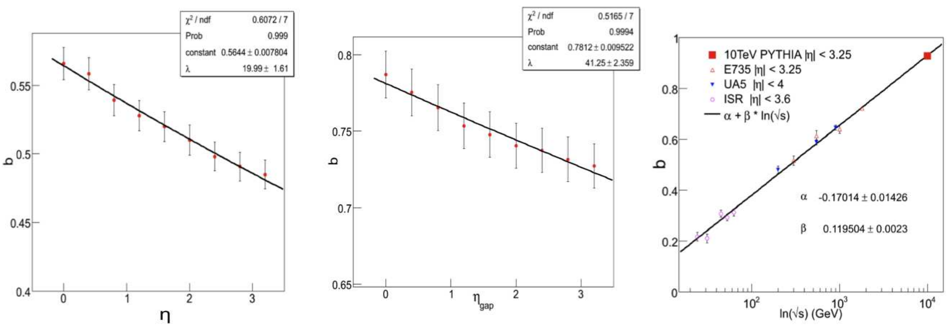

Fig. 5. The dependence of the parameter b on the pseudo-rapidity keeping the η gap fixed (left plot) and on the η gap keeping the pseudo-rapidity interval between the forward and backward regions fixed (middle plot). The right plot shows the dependence of the parameter b on the energy of the collision (PYTHIA pp events at $\sqrt{(s)} = 10$ TeV).

3. Conclusions

The capabilities and prospectives of performing event-by-event measurements with the ALICE detectors have been presented motivated also by recent lattice QCD calculations predicting that at the very low baryochemical potential that corresponds to the LHC energies, interesting fluctuation patterns will prevail for heavy ion collisions. ALICE will be very well suited to measure the net charge, transverse momentum and temperature fluctuations, to study the balance function, to extract the event-by-event particle ratios as well as to perform long range correlation studies. In addition, the multiplicity the transverse momentum and the azimuthal anisotropy fluctuations, the disoriented chiral condensates and the fluctuations in the intermediate and high P_{T} sectors will also be studied extensively, though not covered in this article.

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