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Fluctuation in π, K and p production in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76\,\text{TeV}$

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Summary. — This paper describes the importance of the study of fluctuations of identified hadrons for the understanding of the properties of the Quark-Gluon Plasma (QGP) that is supposed to be formed in ultrarelativistic heavy ion collisions. The data were collected in 2010 with the ALICE detector at the LHC in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76\,\text{TeV}$. The technique specifically used for identifing hadrons is described in detail. The first results on K/π fluctuations are shown.

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PACS 25.75.Gz – Particle correlations and fluctuations.

1. – Introduction

Quantum Chromodynamics (QCD) is the theory of the Standard Model (SM) which describes strong interactions. At extreme values of temperature and energy density, as in ultrarelativistic heavy ion collisions, the transition from hadronic matter to a deconfined state of quarks and gluons (Quark-Gluon Plasma, QGP) should occur. It is possible to investigate a new energy domain to study the properties of the matter formed with the experiments at the CERN Large Hadron Collider (LHC).

Fluctuations of identified particles are studied using the data collected by the ALICE experiment, a multipurpose detector optimized for the study of heavy ion collisions at LHC [1]. The data were collected in 2010 in minimum bias Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76\,\text{TeV}$.

Section **2** describes fluctuations of identified hadrons, in sect. **3** the data sample is discussed, sect. **4** addresses particle identification and sect. **5** reports the results obtained on K/π ratio fluctuations. This study is based on my thesis work [2].

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2. – Identified hadron fluctuations

QGP formation influences the behaviour of different physical observables as the multiplicity or the momentum spectra of the emitted particles in nuclear collisions. The study of the fluctuations of conserved quantities on a event-by-event basis is a way to investigate the properties of the dense and hot matter that should form into heavy ion collisions [3]. Some features of the plasma should survive the hadronization phase and show up as fluctuations in the final state. The three quantities relative to this study are the baryon number, the electric charge and the strangeness. Information can be obtained on the structural change due to the formation of the plasma from the behaviour of these quantities [3].

Net charge fluctuations could be used to evaluate if the elementary degrees of freedom are quarks (fractionary charge) and gluons or hadrons (unit charge). Fluctuations depend on the square of the electric charge and therefore vary depending on the phase they originate from [3, 4]. To evaluate this difference it is useful to define D as

$$D = \langle N_{\mathrm{ch}} \rangle \langle \delta R^2 \rangle, \tag{1}$$

where N_{ch} is the average number of charged particles, R is the ratio of positive to negative particles and $\langle \delta R^2 \rangle$ is defined as $\langle R^2 \rangle - \langle R \rangle^2$. The prediction in the limit cases of QGP and hadron gas (HG) is

$$D_{\mathrm{HG}} = \langle N_{\mathrm{ch}} \rangle \langle \delta R^2 \rangle |_{\mathrm{HG}} \simeq 4, \tag{2}$$

$$D_{\mathrm{QGP}} = \langle N_{\mathrm{ch}} \rangle \langle \delta R^2 \rangle |_{\mathrm{QGP}} \simeq 0.75, \tag{3}$$

implying a significantly different behaviour in the two cases [4].

Fluctuations of the K/π and the p/π ratio could be used to study the QCD phase transition and may lead to the observation of the QCD critical point [5]. The phase transition could be of the first order, of the second order or an analytic crossover, depending on the masses of the quarks u, d and s and the position of the critical point in the phase diagram is related to the order of the transition [6].

Fluctuations of the K/p ratio are sensitive to the correlation that could exist between strangeness and baryon number. In the QGP phase a correlation between these two quantities is predicted because strangeness is carried by the quark s ($S = -1, B = \frac{1}{3}$) and therefore the strangeness S can only exist with non-vanishing baryon number B. In a hadron gas no correlation is expected because kaons ($S = -1, B = 0$) allow strangeness with vanishing baryon number [7].

It is convenient to use a variable that is robust and independent of the efficiency and the acceptance of the detector for the fluctuations measurement. In that way the comparison between the results obtained by different experiments is simplified. The variable used in this study is ν_{dyn}, which is defined, in the case of K/π fluctuations, as

$$\nu_{\mathrm{dyn},K\pi} = \nu_{K\pi} - \nu_{\mathrm{stat},K\pi}, \tag{4}$$

where

$$\nu_{K\pi} = \left\langle \left(\frac{N_K}{\langle N_K \rangle} - \frac{N_\pi}{\langle N_\pi \rangle} \right)^2 \right\rangle , \tag{5}$$

$$\nu_{\mathrm{stat},K\pi} = \frac{1}{\langle N_K \rangle} + \frac{1}{\langle N_\pi \rangle} . \tag{6}$$

The variable ν_{dyn} measures the difference from a Poissonian behaviour and is therefore non-vanishing when the correlation term is the dominant one [8].

3. – Trigger and event selection

The detectors used for the minimum bias trigger are the Silicon Pixel Detector (SPD), the innermost part of the Inner Tracking System (ITS), and the V0 counters. The SPD consists of two cylindrical layers of hybrid silicon pixel assemblies covering $|\eta| < 2.0$ and $|\eta| < 1.4$ for the inner and outer layers, respectively. The V0 counters are two arrays of 32 scintillator tiles covering the full azimuth within $2.8 < \eta < 5.1$ (V0-A) and $-3.7 < \eta < -1.7$ (V0-C). A detailed review of these detectors can be found in [1].

The trigger used to select minimum-bias events was configured for high efficiency for hadronic events, requiring at least two of the following conditions:

i) two pixel chips hit in the outer layer of the SPD;

ii) a signal in V0-A;

iii) a signal in V0-C.

The rate for this trigger configuration was about 50 Hz, with 45 Hz coming from electromagnetic processes, 4 Hz from nuclear interactions and 1 Hz coming from beam background [9]. An offline event selection is obtained by using the information of two-neutron Zero Degree Calorimeters (ZDCs) located at ±114 m from the interaction point [1]. Events coming from beam background are removed using V0 and ZDC timing information, while electromagnetic events are reduced with the request of a minimum energy deposition of 500 GeV in each of the ZDCs [9].

The study on fluctuations of identified particles is achieved by dividing the events in 9 centrality classes. The collision centrality is determined using V0 counters and details on centrality determination can be found in [9].

The event sample used for the analysis consists in 1.3 million minimum-bias events and a further selection is carried out to ensure the quality of tracking and to select candidate primary tracks.

4. – Particle identification

Particle Identification (PID) is needed in order to study fluctuations in π, K and p production. In this analysis PID is performed with the ALICE Time-Of-Flight (TOF) and Time Projection Chamber (TPC) detectors. The TOF system is composed of Multigap Resistive Plate Chamber (MRPC) strip detectors and it covers the full azimuthal angle within $|\eta| < 0.9$, with an inner radius of 370 cm. The TPC covers $|\eta| < 0.9$ and the full azimuthal angle, its inner radius is 85 cm while the external one is 250 cm.

TABLE I. – *Selection cuts used for identification.*

	PID cuts	
	TPC	TOF
N_σ	$(-2.0, 2.0)$	$(-2.0, 2.0)$
π	$p_T < 500\,\text{MeV}/c$	$p_T < 1.5\,\text{GeV}/c$
K	$p_T < 500\,\text{MeV}/c$	$p_T < 1.5\,\text{GeV}/c$
p	$p_T < 700\,\text{MeV}/c$	$p_T < 2.0\,\text{GeV}/c$

The variables used for PID are

$$N_\sigma^{\text{TOF}} = \frac{t - t_{\text{exp}}^{(i)}}{\sigma_{\text{PID}}^{\text{TOF}}}, \quad i = \pi, Kp, \tag{7}$$

where t is the time-of-flight measured by the detector, $t_{\text{exp}}^{(i)}$ is the expected time-of-flight for the i-type particle and $\sigma_{\text{PID}}^{\text{TOF}}$ is the global resolution of $\sim 85\,\text{ps}$ and

$$N_\sigma^{\text{TPC}} = \frac{\mathrm{d}E/\mathrm{d}x - (\mathrm{d}E/\mathrm{d}x)_{\text{exp}}^{(i)}}{\sigma_{\text{PID}}^{\text{TPC}}}, \qquad i = \pi, Kp, \tag{8}$$

where $\mathrm{d}E/\mathrm{d}x$ and $(\mathrm{d}E/\mathrm{d}x)_{\text{exp}}^{(i)}$ are, respectively, the energy loss measured by the detector and the expected one for the i-type particle, $\sigma_{\text{PID}}^{\text{TPC}}$ is the detector resolution, that is $\sim 7\%$ of the measured energy loss. Cuts in N_σ and transverse momentum are performed in order to identify hadrons. These cuts are chosen to obtain high PID performance in terms of purity and so to avoid contamination. The PID cuts are summarized in table I and consist in a 2σ cut on the N_σ variable both for TPC and TOF plus transverse momentum cuts. For TPC $p_T < 500\,\text{MeV}/c$ for pions and kaons, $p_T < 700\,\text{MeV}/c$ for protons are requested. For TOF $p_T < 1.5\,\text{GeV}/c$ for pions and kaons and $p_T < 2.0\,\text{GeV}/c$ for protons are requested.

Figure 1a shows the energy loss measured by TPC detector as a function of the momentum of the particle, in the centrality bin 0–10%. The bands relative to different

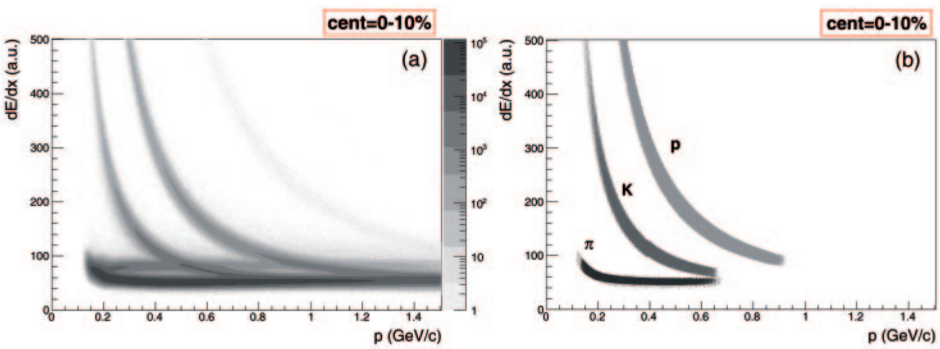

Fig. 1. – Energy loss measured by TPC for all candidate primary tracks (left) and for identified particles (right).

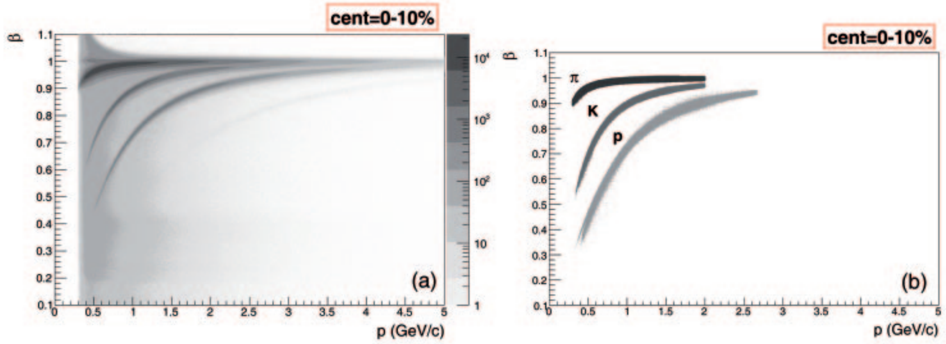

Fig. 2. – Particle velocity β measured by TOF for all candidate primary tracks (left) and for identified particles (right).

kind of hadrons are clearly visible. Figure 1b reports only the energy loss relative to the hadrons that have passed the selection cuts for $\pi/K/p$.

In fig. 2a the particle velocity $\beta = v/c$ measured by TOF is shown as a function of the momentum of the particle, in the centrality bin 0–10%. Also in this case the bands relative to different kinds of hadrons are clearly visible. Figure 2b reports the values of β only for the tracks that have passed the PID selection cuts.

Figure 3 shows the effects of the selection cuts on the N_σ variable for the TPC detector. Figure 3a reports N_σ^{TPC} for pions for $0.45 < p_T < 0.5\,\mathrm{GeV}/c$ (solid line) and the selected particles are highlighted by the fill area. Figures 3b and 3c show the same quantities for kaons and protons in a p_T interval respectively of $(0.45,\ 0.5)\,\mathrm{GeV}/c$ and $(0.65,\ 0.7)\,\mathrm{GeV}/c$. These p_T values are chosen because they are the higher values accepted with the selection cuts. Figures 3a, 3b and 3c show that contamination is low also at the maximum allowed transverse momenta.

Figure 4 shows the measured N_σ for the TOF signal for different identified hadrons. N_σ^{TOF} for pions in a momentum region $1.45 < p_T < 1.5\,\mathrm{GeV}/c$ is reported in fig. 4a (solid line) and the selected tracks are highlighted by the shaded area. Figures 4b and 4c report N_σ^{TOF} for kaons and protons in a momentum interval of $(1.45,\ 1.5)\,\mathrm{GeV}/c$ and $(1.95,\ 2.0)\,\mathrm{GeV}/c$, respectively, showing that also in this case the contamination is under control near the applied cut.

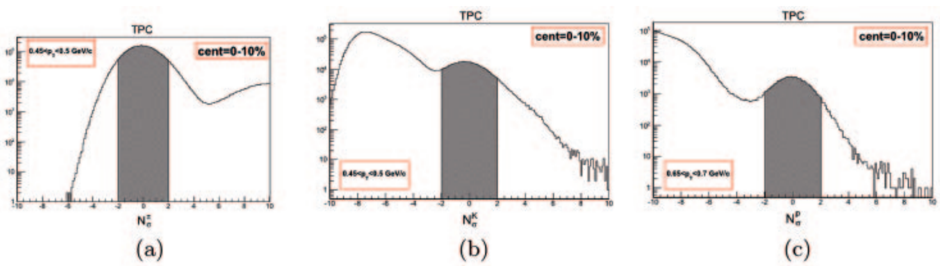

Fig. 3. – N_σ measured for the TPC signal for π, K and p. Shaded areas show particles selected with PID cuts.

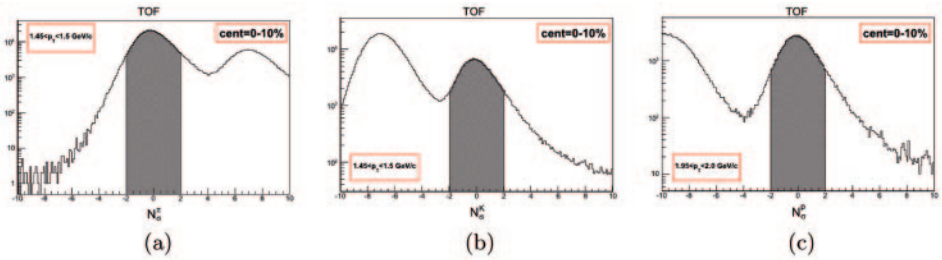

Fig. 4. – N_σ measured for the TOF signal for π, K and p. Shaded areas show particles selected with PID cuts.

5. – Fluctuations in K/π ratio

In this section the first results on the fluctuation of K/π ratio are presented. Figure 5 shows $\nu_{\mathrm{dyn},K\pi}$ as a function of the track density per pseudorapidity unit. The results of the STAR Collaboration in Au-Au collision at 200 and 64.2 GeV and the results of the NA49 Collaboration in Pb-Pb central collision at 6.3, 7.6, 8.8, 12.3, and 17.3 GeV, respectively, are reported [10]. The fluctuations measured in this analysis are positive with a trend similar to STAR. $\nu_{\mathrm{dyn},K\pi}$ depends on multiplicity for peripheral collisions (low $\mathrm{d}N/\mathrm{d}\eta$), while shows little centrality dependence for central collision (high $\mathrm{d}N/\mathrm{d}\eta$). The results of this analysis are closer to the statistical limit than STAR, also for similar track densities.

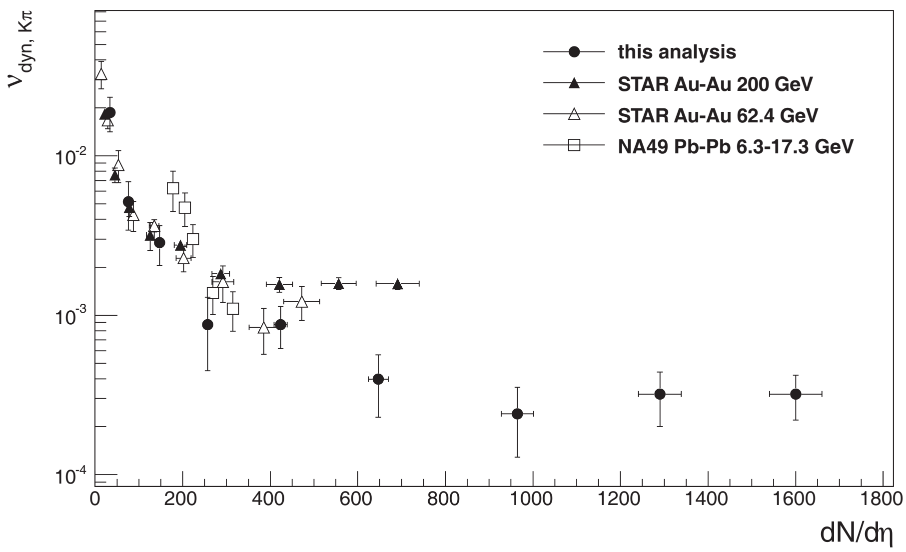

Fig. 5. – Fluctuations of the K/π ratio as a function of the track density. The results of the STAR and NA49 collaborations are reported [10].

6. – Conclusions

A preliminary study on fluctuations of identified hadrons in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76\,\text{TeV}$ is presented. Using data from the ALICE detector, the particle identification technique used is described in details, showing the PID capability of the detector. High PID performance in terms of purity is obtained and any unwanted contamination due to mis-identification is minimized. The aim of the study of identified hadrons is presented and the variable ν_{dyn} is described. This variable is chosen thanks to its robustness and due to its independence of the efficiency and the acceptance of the detector used for the measurement.

The first results on K/π fluctuations are presented and they show a similar trend to the one measured by previous experiments, but closer to the statistical limit. Further studies on fluctuations of identified hadrons are needed and the expectations from various Monte Carlo event generators have to be considered to give the correct interpretation of the measurements.

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