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# IDENTIFIED PRIMARY HADRON SPECTRA IN *pp* AND Pb–Pb COLLISIONS WITH THE ALICE DETECTOR AT THE LHC*

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The ALICE experiment at the LHC collected *pp* collisions at $\sqrt{s} = 0.9$, 2.76 and 7.0 TeV and Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. ALICE has several detectors dedicated to Particle IDentification (PID), covering complementary transverse momentum ($p_{\mathrm{T}}$) ranges; this enables ALICE to reconstruct identified charged hadron spectra over a wide $p_{\mathrm{T}}$ range at mid-rapidity. After a brief review of the different ALICE identification techniques and performance, the $\pi/K/p$ spectra obtained in *pp* ($\sqrt{s} = 0.9$ TeV and 7.0 TeV) and Pb–Pb ($\sqrt{s_{NN}} = 2.76$ TeV) collisions will be presented. In addition, studies on the energy dependence of the spectral shape and transverse radial flow will be shown.

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## 1. Introduction

The ALICE experiment [1] has been designed to measure ultrarelativistic Pb–Pb collisions in order to study the properties of a new state of matter, the quark-gluon plasma (QGP), predicted by lattice QCD to be formed at high temperature ($T \sim 170$ MeV) or density. To access the thermal parameters of the system created in heavy-ion collisions at the kinetic and chemical freezeout, the measurement of identified particle $p_{\mathrm{T}}$ spectra is mandatory. ALICE has several detectors able to identify particles with different methods over complementary $p_{\mathrm{T}}$ ranges. ALICE provides identified particle spectra not only in Pb–Pb collisions but also in *pp* interactions which provide a useful reference for the understanding of heavy-ion data and is crucial to tune Monte Carlo models.

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In this paper, we give details on the PID performance of the detectors used in this analysis (Sec. 2) then the spectra in $pp$ collisions at $\sqrt{s} = 7$ TeV (Sec. 3) and, finally, in Pb–Pb at $\sqrt{s_{NN}} = 2.76$ TeV are presented.

## 2. Particle identification

The ALICE detector has several barrel detectors dedicated to particle identification using different PID techniques and covering complementary $p_{\mathrm{T}}$ ranges. The main ones are the Inner Tracking System (ITS), the Time Projection Chamber (TPC), the Transition Radiation Detector (TRD), the Time of Flight (TOF) and the High Momentum Particle IDentification (HMPID) but only ITS, TPC and TOF are actually used for this analysis. They all have full azimuthal coverage and are able to identify particles in the central pseudorapidity region ($|\eta| \leq 0.9$).

The ITS [2] consists of six cylindrical layers of silicon detectors. The four outer layers provide analogue readout identifying particles via $dE/dx$ measurements in the non-relativistic ($1/\beta^2$) region. Also the TPC [3] provides $dE/dx$ information with up to 159 samples, and even extends the identification with the relativistic rise. The reach in $p_{\mathrm{T}}$ is also increased, again, thanks to the TOF detector [4] which identifies particles through the measurement of the time taken to travel from the primary vertex to the TOF sensitive layer. The reach in $p_{\mathrm{T}}$ depends on the total time resolution $\sigma_{\mathrm{tot}}$ that is the square sum of the intrinsic TOF time resolution and of the start time resolution which is a function of the event multiplicity (in Pb–Pb collisions $\sigma_{\mathrm{tot}} = 85$ ps while in $pp$ collision $\sigma_{\mathrm{tot}} = 120$ ps).

In order to extend the particle identification on a wider $p_{\mathrm{T}}$ range, different PID detectors, techniques and tracking were used. Four independent analyses have been performed. The global tracking (combining TPC and ITS information) was used in two independent studies with either the TPC or the ITS PID information, in order to cross-check the PID performance. The TOF information was used, with global tracks, to extend the reach at high $p_{\mathrm{T}}$. Finally, the ITS was also used as a standalone tracker to extend the coverage at low $p_{\mathrm{T}}$. For more details see [5]. The spectra provided by these four analyses have been compared and, since they are compatible, have been combined using systematic errors as weights. Primary tracks are prompt particles produced in the collision including electromagnetic and strong decays but excluding weak decays of strange particles.

## 3. Identified primary hadron spectra in *pp* collisions at $\sqrt{s} = 7$ TeV

In Fig. 1 the Minimum-Bias (MB) combined transverse momentum spectra for negative $\pi$, $K$ and $p$ in $pp$ collisions at $\sqrt{s} = 7$ TeV are shown (similar spectra for positive particles). To obtain the integrated yields and the mean $p_{\mathrm{T}}$ they are fitted with a Lévy–Tsallis function (see [5]) that describes the shape of the $p_{\mathrm{T}}$ spectra within few percent.

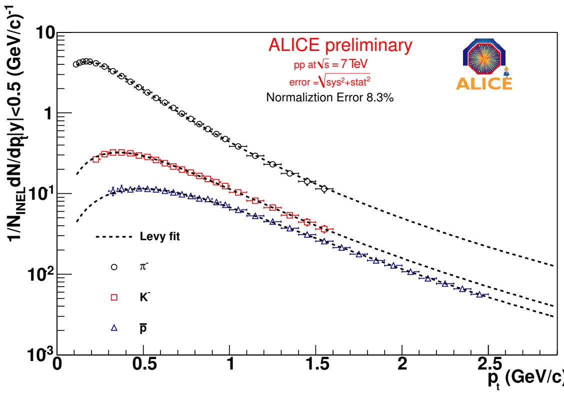


Fig. 1. Transverse momentum spectra of negative $\pi$, $K$, $p$ in $pp$ collisions at $\sqrt{s} = 7\,\mathrm{TeV}$. The lines are the Lévy–Tsallis fits.

In Fig. 2 the ratio of integrated yields $K/\pi$ is shown for different collision energies. This ratio does not vary from $0.9\,\mathrm{TeV}$ (already published in [5]) to $7\,\mathrm{TeV}$ ALICE data while it has a slight increase at the lower energies.

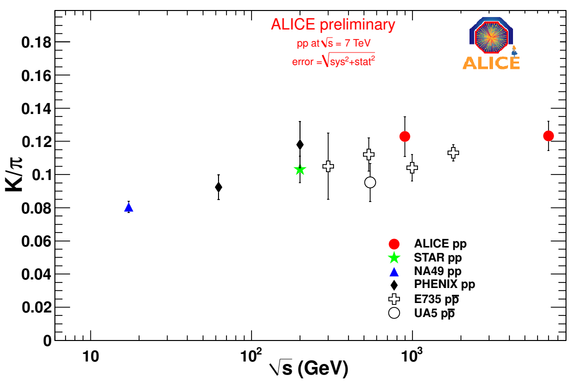


Fig. 2. $K/\pi$ integrated yield ratios in $pp$ collisions as a function of collision energy.

In Fig. 3 the $p/\pi$ ratio is shown for separate charges to point out how the baryon/antibaryon asymmetry vanishes at the LHC energy (as already reported in [6]).

In Fig. 4 the mean $p_{\mathrm{T}}$ for $\pi$, $K$ and $p$ at different collision energies is reported. An increase of the mean $p_{\mathrm{T}}$ with both the mass of the particles and the collision energy (harder spectra) is evident.

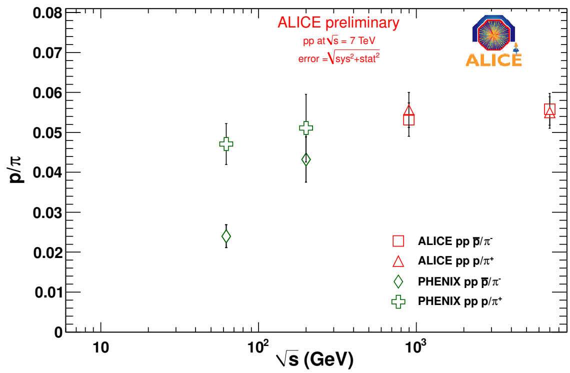


Fig. 3. $p/\pi$ integrated yield ratios in $pp$ collisions as a function of collision energy.

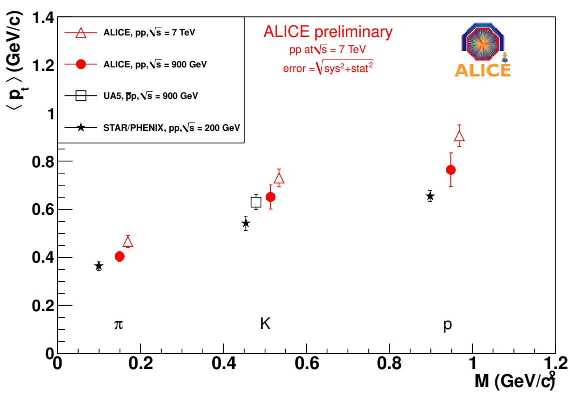


Fig. 4. Mean $p_{\rm T}$ for $\pi$, $K$ and $p$ at different collision energy in $pp$ collisions.

## 4. Identified primary hadron spectra in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

The same analysis has been performed for Pb–Pb interactions selecting different centrality regions. In Fig. 5 Pb–Pb spectra for the most central bin are compared with STAR [7] and PHENIX [8] results at $\sqrt{s_{NN}} = 200$ GeV. It can be seen that ALICE spectra are harder than RHIC ones and protons are flatter probably due to stronger radial flow.

To determine integrated yields and average $p_{\rm T}$, fits on individual particles with a blast-wave function [10] have been performed.

From Fig. 6, which shows the mean $p_{\rm T}$ for $\pi$, $K$ and $p$ as a function of $dN_{\rm ch}/d\eta$, an increase of mean $p_{\rm T}$ with the particle mass and the collision centrality is present, and at ALICE the mean $p_{\rm T}$ is higher than at STAR for the same value of $dN_{\rm ch}/d\eta$.

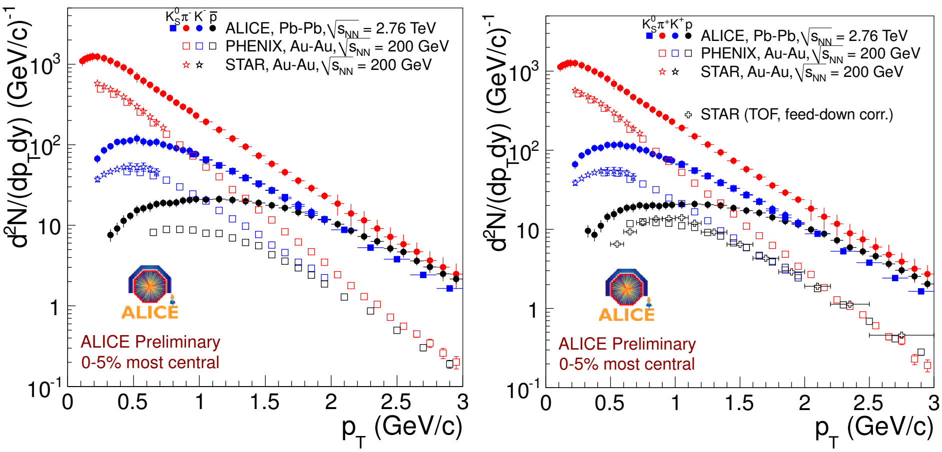


Fig. 5. Transverse momentum spectra for $\pi$, $K$ and $p$ negative (left) and positive (right) in the most central bin. A comparison between results obtained by ALICE, STAR and PHENIX collaborations is shown.

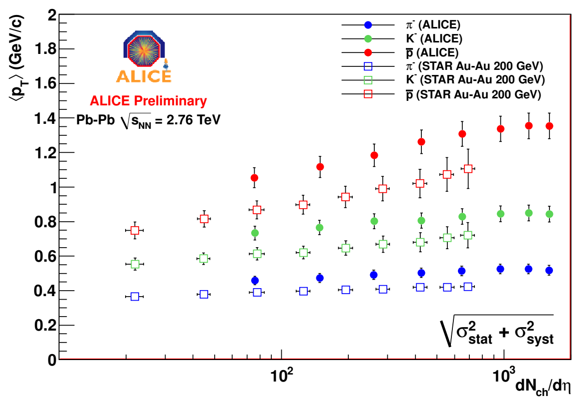


Fig. 6. Mean $p_{\mathrm{T}}$ for $\pi$, $K$ and $p$ at different event multiplicity for ALICE and STAR.

In order to obtain information on the thermal properties of the medium at the kinetic freezeout, a global fit of the spectra with a blast-wave function in which the kinetic freezeout temperature ($T_{\mathrm{fo}}$) and the radial flow ($\langle\beta\rangle$) are free parameters, is used. In Fig. 7, the fit parameters for ALICE and STAR in different centrality bins are shown. It can be noticed how the radial flow is $\sim 10\%$ higher at $\sqrt{s_{NN}} = 2.76$ TeV than at $\sqrt{s_{NN}} = 0.2$ TeV.

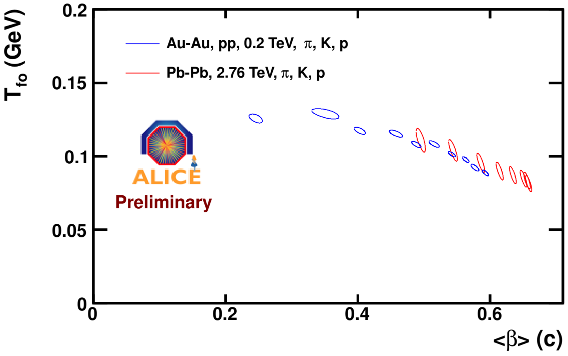


Fig. 7. Kinetic freezeout temperature and radial flow parameter as obtained from a global fit of the spectra with a blast-wave function for increasing centrality.

## 5. Conclusions

Thanks to its excellent PID performance, ALICE is able to identify particles over a wide $p_{\mathrm{T}}$ range both in *pp* and in Pb–Pb collisions. About primary hadron spectra in *pp* collisions, we have shown that particle ratios are similar in 0.9 and 7 TeV collisions, the baryon/antibaryon asymmetry vanishes at the LHC energy (as expected) and the spectra become harder with the collision energy. We have also shown that ALICE $p_{\mathrm{T}}$ spectra in Pb–Pb collisions are harder than RHIC ones and the mean $p_{\mathrm{T}}$ increases with the multiplicity. Finally, for extracting information on the thermal property of the medium at the kinetic freezeout a global blast-wave fit of the spectra has been performed showing that the transverse radial flow at ALICE is $\sim 10\%$ higher than at RHIC.

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