PROCEEDINGS OF SCIENCE

# Identified-particle production and spectra with the ALICE detector in pp and Pb–Pb collisions at the LHC

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Unique capabilities of the ALICE experiment allow for measuring the production of identified particles over a wide momentum range both in pp and Pb–Pb collisions at the LHC. The current results on hadron transverse momentum spectra measured in pp collisions at $\sqrt{s} = 0.9$ and 7 TeV, and in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV are discussed. The proton-proton measurements on particle production yields, spectral shapes and particle ratios are presented as a function of the collision energy and compared to previous experiments and commonly used Monte Carlo models. The particle spectra, yields and ratios in Pb–Pb are measured as a function of the collision centrality and the results are compared with published RHIC data in Au–Au collisions at $\sqrt{s_{\mathrm{NN}}} =$ 200 GeV and predictions for the LHC.

*Sixth International Conference on Quarks and Nuclear Physics,*
*April 16-20, 2012*
*Ecole Polytechnique, Palaiseau, Paris*

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PoS(QNP2012)167

## 1. Introduction

Collisions of relativistic heavy nuclei can be used for creating a deconfined high temperature state of nuclear matter in a particle laboratory. Measuring the transverse momentum spectra and ratios of identified hadrons provides the means for studying the properties and probing the partonic degrees of freedom of this state of matter. In nucleus-nucleus collisions, the analysis of the spectra shapes as a function of centrality and for different particle species allows for extracting quantities characterising the system, such as its temperature at the moment of kinetic freeze-out and the mean transverse velocity of the collective expansion [1]. The latter, combined with measurements of the elliptic flow, puts up arguments in favour of the partonic origin of the collective flow. The thermal fits [2] to the particle ratios indicate that hadrons decouple from the "pre-hadronic fireball" at temperatures higher than the temperature of the kinetic freeze-out, and from a state quite close to thermodymanical equilibrium, which calls for the partonic nature of this state. Finally, because of the availability of additional production channels, the formation of baryons (especially multi-strange) out of a collective partonic phase might become enhanced relative to meson production or/and relative to the situation when the deconfinement is not expected to occur.

The studies outlined above cannot be effectively performed without having a reliable hadronic reference. Practically all heavy-ion measurements need to be compared with the corresponding, properly scaled, proton-proton results. It is also important to check if the models that successfully described the particle production in elementary collisions at lower energies still do so when extrapolated to the LHC energy domain. In addition, at these LHC energies, one might expect something completely new (like collective effects at the partonic level) to happen also in pp collisions. That is why the ALICE experiment at CERN [3, 4], primarily designed to study the physics of heavy-ion collisions, records and analyses the proton-proton data as well.

In the following, we briefly present a few selected measurements of identified hadron spectra and ratios resulted from a combined analysis using the ALICE silicon Inner Tracking System (ITS), Time Projection Chamber (TPC) and Time-Of-Flight (TOF) detector.

## 2. Identified particle production in pp collisions at $\sqrt{s} = 0.9$ and 7 TeV

ALICE has measured the transverse momentum spectra of primary charged pions, kaons and protons at mid-rapidity ($|y| < 0.5$) [5] as well as $\mathrm{K^0_S}$, $\Lambda(\overline{\Lambda}), \phi$ and $\Xi^+(\Xi^-)$ [6] in inelastic pp collisions at $\sqrt{s} = 0.9$ and also 7 TeV. Primary particles are defined as prompt particles produced in the collisions and all decay products, except those coming from weak decays of strange particles. The feed-down contribution from weakly decaying particles to pions and protons and from protons produced in interactions with the detector material are subtracted by fitting the experimental distributions of Distances of Closest Approach (DCA) between particle tracks and the primary vertex using the template DCA extracted from detailed Monte Carlo simulations.

The results have been compared with the predictions by QCD-inspired Monte Carlo models Pythia [7] and Phojet [8]. In general, different Pythia tunes describe the data reasonably well (see, for example, Fig. 1 left panel), with the exception of strange and multi-strange baryons. As shown in Fig. 2 (right panel), the models tend to underestimate the production of these particles by big factors ($\sim 2$ for $\Xi$ and $\sim 4$ for $\Omega$).

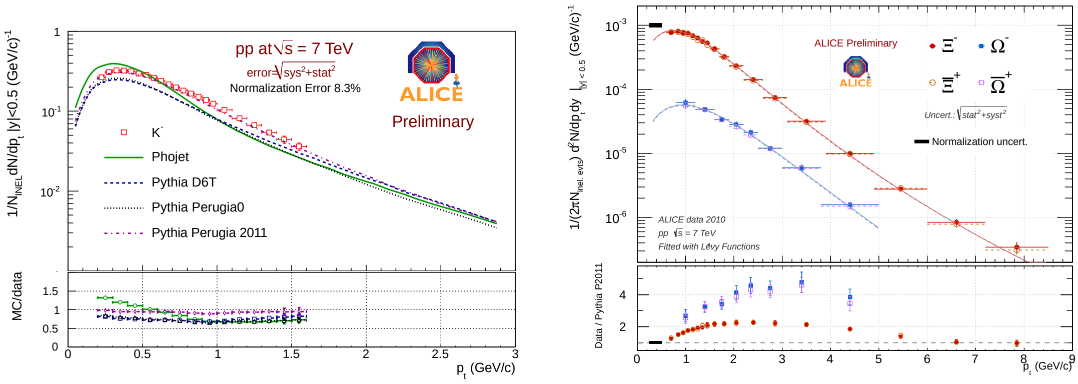


**Figure 1:** Examples of identified particle spectra measured in pp collisions at $\sqrt{s} = 7$ TeV. Left: Transverse momentum spectrum of negative kaons, compared with different Pythia tunes and Phojet (below). Right: Transverse momentum spectra of $\Xi$ and $\Omega$ baryons, fitted with the Levy-Tsallis function [9] (the lines), and compared with Pythia tune Perugia 2011 (below).

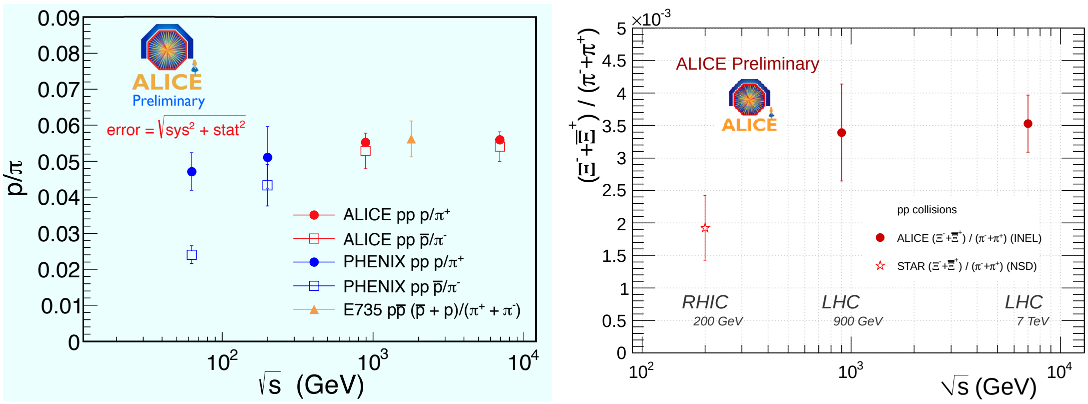


**Figure 2:** Examples of ratios of integrated identified particle yields measured in pp collisions at $\sqrt{s} = 0.9$ and 7 TeV. Left: p/$\pi$ ratios compared with the results by other experiments at different collision energies. Right: $(\Xi^- + \Xi^+)/(\pi^- + \pi^+)$ ratios compared with the STAR measurement at $\sqrt{s} = 200$ GeV.

Fits of the spectra with the Levy-Tsallis function [9] (like shown in Fig. 1 right) can be used for extrapolation down to $p_T = 0$ to extract the integrated particle yields. Despite the large increase in the centre of mass energy from RHIC to the LHC (from $\sqrt{s} = 0.2$ to 7 TeV), the K/$\pi$ ratio changes very little. The ratios of p/$\pi$ and $(\Xi^- + \Xi^+)/(\pi^- + \pi^+)$ ratios, presented in Fig. 2, rise with the collision energy and saturate at $\sqrt{s}$ somewhere between 0.9 and 7 TeV. The anti-baryon/baryon (and, in general, the anti-particle/particle) symmetry is fully restored at the LHC energies.

## 3. Identified particle production in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

A comparison between the identified particle spectra measured at RHIC and at the LHC reveals a dramatic change in their shapes (see Fig. 3, left panel). The LHC spectra are much flatter at low $p_T$ and harder, indicating a stronger radial flow. In order to quantify it, we performed a combined fit of our spectra using the blast wave parameterisation introduced in Ref. [1]. The kinetic freeze-out

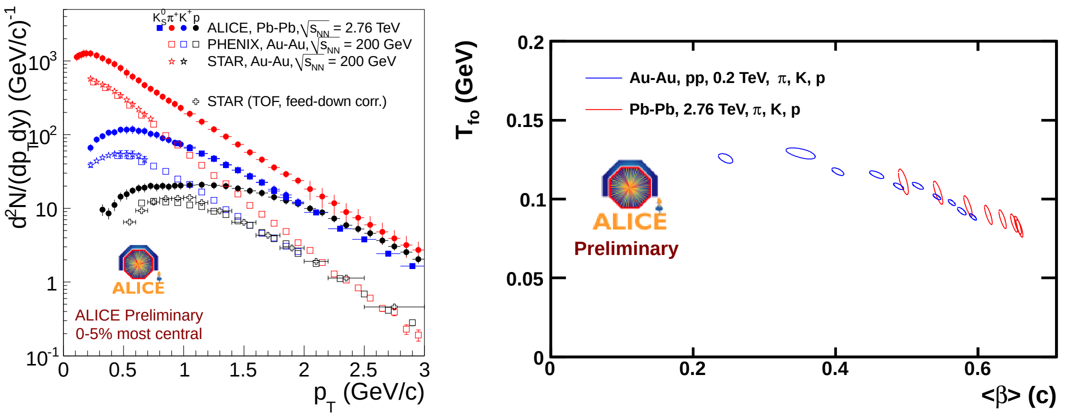


**Figure 3:** Left: Transverse momentum spectra of positive pions, kaons and protons measured in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV at the LHC and compared with the results obtained at RHIC. Right: Contours of the kinetic freeze-out temperature and mean transverse flow velocity extracted from blast wave fits to the identified particle spectra for different collision centralities, compared between ALICE and STAR.

temperature parameter $T_{fo}$ extracted from such a fit was found to be sensitive to the fit range used for the pions, likely because of the feed-down from resonances. This effect will need more detailed studies in the future. The results for the different centrality bins are compared in Fig. 3 (right panel) with those obtained by the STAR collaboration [10]. The mean transverse velocity of the radial flow that we observe in 0–5% centrality events is $<\beta>\sim 0.66$, which is about 10% higher than was observed at RHIC. The shapes of the ALICE spectra measured in Pb–Pb collisions are grossly reproduced by the hydrodynamical calculations from Ref. [11]. However, these calculations overestimate the proton and anti-proton spectra by a factor of $\sim 2$, which could be due to final state interactions (re-scattering and annihilation) in the hadronic phase [12, 13].

The integrated yields of different hadrons measured by ALICE in Pb–Pb collisions and normalised to the pion yield can be compared to thermal model [2] predictions. The fit to the data results in a temperature of chemical freeze-out of T$=$ 160 MeV, comparable with the temperature obtained in Au–Au collisions at RHIC [14]. However, the actual proton yields happen to be significantly lower than the values suggested by the model. The same model can reproduce proton yields with an ad-hoc temperature T$=$ 149 MeV, but then it fails to describe the production of multi-strange baryons.

The ALICE measurement of the $p_T$-dependent $\Lambda/K^0_S$ ratio is presented in Fig. 4 for different centrality bins. As it was observed at RHIC [15], this ratio strongly depends on collision centrality and is enhanced with respect to pp collisions. This enhancement at the LHC is slightly larger, and its maximum is shifted to larger $p_T$, than at RHIC. The enhancement is also observed to decrease less rapidly with the transverse momentum, being still a factor $\sim 2$ higher than at RHIC for $p_T \sim$ 6 GeV/$c$. The large shift in the position in $p_T$ of the enhancement maximum, of the order of 1–2 GeV/$c$, predicted by some models [16] for LHC energies is not seen.

The integrated yields of multi-strange baryons, normalised to the yields obtained in pp events at the same energy and scaled with the number of nucleons participating in the collision, are used for quantifying the potential enhancement of strangeness production out of a deconfined state. For

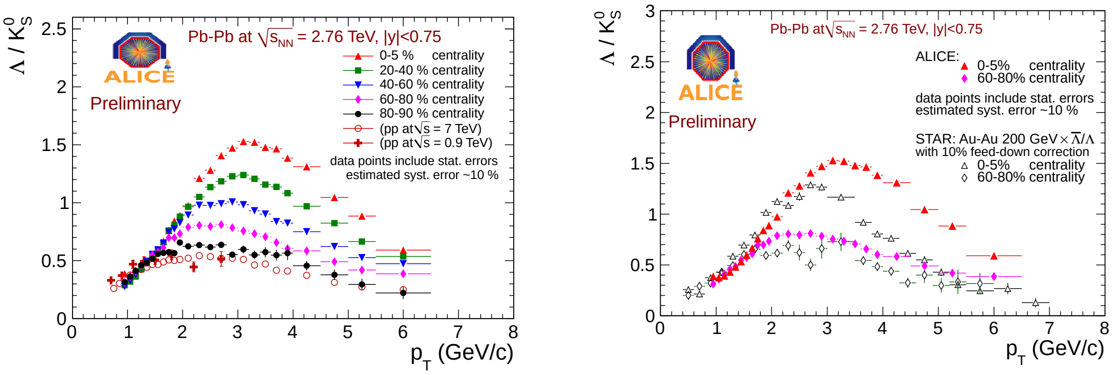


**Figure 4:** Left: $p_T$-dependent ratios of $\Lambda/K^0_S$ measured in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV for different centrality selections, compared with the same ratio in pp collisions at $\sqrt{s} = 0.9$ and 7 TeV. Right: $p_T$-dependent ratios of $\Lambda/K^0_S$ measured in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV for selected centrality selections, compared with the same ratios obtained in Au–Au collisions collisions at $\sqrt{s_{NN}} = 200$ GeV.

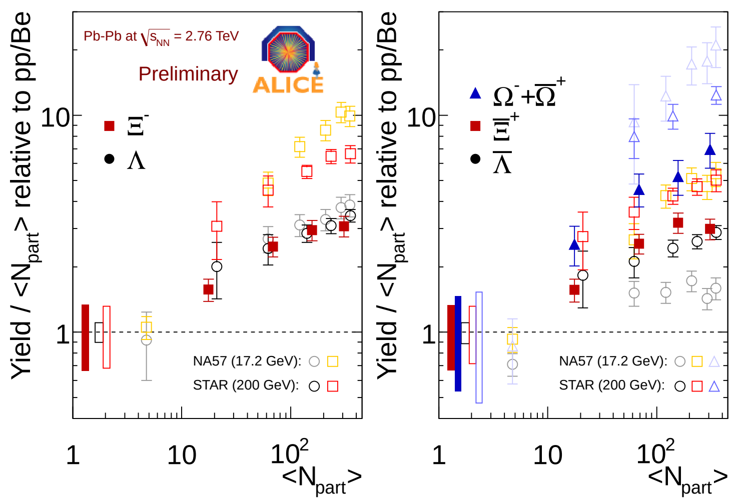


**Figure 5:** Integrated yields of strange baryons in $|y| < 0.5$ normalised to the mean number of participants $< N_{part} >$ as a function of $< N_{part} >$ measured by ALICE and compared with the SPS and RHIC data.

the analysis presented here, the pp reference values were calculated interpolating ALICE data at two energies ($\sqrt{s} = 0.9$ and 7 TeV) for the $\Xi$, and STAR data at $\sqrt{s} = 200$ GeV and ALICE data at 7 TeV for the $\Omega$. The ALICE results as a function of the mean number of participants are shown in Fig. 5. As was observed at lower energies, the enhancement increases with collision centrality and with the strangeness content of the particles. When comparing the ALICE measurements with those from SPS and RHIC, we find that the effect decreases with the centre-of-mass energy.

## 4. Summary

We have presented a few selected results on the identified hadron spectra and ratios obtained in pp events at $\sqrt{s} = 0.9$ and 7 TeV as well as in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV by the ALICE experiment at the LHC.

The measurements in pp collisions serve as an important reference for the analysis on the Pb–Pb data. At the same time, these results provide important constraints for the theory. They can be directly compared with, for example, the predictions of the QCD-inspired models like Pythia and Phojet. Overall, Pythia-Perugia2011 describes the particle production in pp quite well, with the exception of the multi-strange baryons at intermediate $p_{\mathrm{T}}$, where this model underestimates the yields of these particles by large factors.

Measuring the spectra of identified particles and particle yields in collisions of ultra-relativistic Pb nuclei is one of the means for studying the properties of hot QCD medium created in these collisions (such as the temperatures at different moments of the system's evolution and radial flow). With these measurements, we can also test the degree of thermal equilibrium reached at the moment of hadron decoupling from the "pre-hadronic phase" and evaluate the importance of additional possible mechanisms of particle production at the partonic level.

Compared with RHIC, the analysis of the ALICE Pb–Pb data shows $\sim$10 % higher radial flow. The baryon/meson ratio at intermediate $p_{\mathrm{T}}$ is higher as well, and the position of the maximum of this ratio is shifted towards higher transverse momenta. The anti-particle/particle symmetry is fully restored at the LHC, including the baryons. The thermal model can fit the ALICE particle ratios in Pb–Pb, except for the proton yields that are significantly lower than the model suggests. The ALICE results also indicate further decrease of the "strangeness enhancement" with the collision energy, following the same trend from SPS to RHIC, and finally to the LHC.

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