IL NUOVO CIMENTO **40 C** (2017) 7
DOI 10.1393/ncc/i2017-17007-8

Colloquia: IFAE 2016

Light flavor hadron production as a function of the charged-particle multiplicity at the LHC

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received 17 October 2016

Summary. — Recent measurements of identified particle production in high-multiplicity proton-proton (pp) and proton-lead (p–Pb) collisions have shown features that are similar to what is observed in lead-lead (Pb–Pb) collisions. Therefore, it is of interest to investigate these similarities by studying their evolution as a function of the charged-particle multiplicity. Most of the particles produced in a collision are composed by light flavor quarks (u, d and s). The study of identified hadron production may provide further insight into the systems from which they originated. We report on the measurements of π, K, p, K^0_s, K^*, ϕ, Λ, Ξ and Ω production at mid-rapidity in pp collisions at $\sqrt{s} = 7\,\text{TeV}$ as a function of the charged-particle multiplicity with the ALICE experiment.

1. – Introduction

Ultra relativistic heavy-ion collisions can be used to study the properties of the deconfined and strongly interacting state of matter called Quark-Gluon Plasma (QGP). The formation of the QGP in heavy-ion collisions is accompanied by some signatures, including the onset of collective flow and the enhancement of strangeness production with respect to the pp and p-Pb case. The transverse momentum (p_{T}) distributions can be used to study the properties of the system created in the collision. In heavy-ion collisions, identified particle spectra can be described in terms of hydrodynamic evolution. High-multiplicity pp and p-Pb collisions have shown some features which are reminescent of the Pb-Pb phenomenology, among these the onset of long-range and near-side angular correlations [1-4]. These observations warrant a comprehensive study of identified particle production so as to shed light into the origin of these features.

The ALICE experiment [5, 6] is particularly well equipped to study the production of identified particles over a wide range of transverse momentum, thanks to its excellent particle identification (PID) capabilities. In particular, in the region at mid-rapidity, the specific energy loss is measured with the Inner Tracking System (ITS) and with the Time

Projection Chamber (TPC). The particle velocity is measured via the Time Of Flight (TOF) detector, while the High Momentum Particle IDentification (HMPID) detector measures the angle of emission of Cherenkov light.

2. – Analysis and results

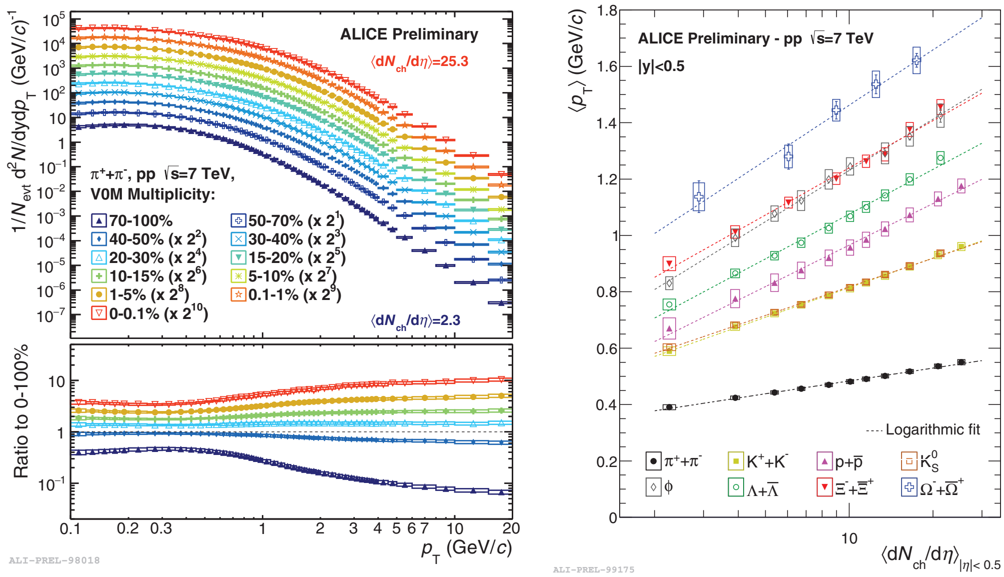
We report on the transverse momentum spectra of π, K, p, K^0_s, K^*, ϕ, Λ, Ξ and Ω measured as a function of charged-particle multiplicity in pp collisions at $\sqrt{s} = 7\,\text{TeV}$. The multiplicity has been estimated with the V0 detectors, which are two scintillator hodoscopes located at $2.8 < \eta < 5.1$ and $-3.7 < \eta < -1.7$ and covering the full azimuth. The data sample consists of $\sim 100\,\text{M}$ events, collected with a minimum-bias trigger, which requires at least one hit in either the V0 or one of the two inner layers of the ITS detector. Events have been divided into multiplicity classes based on the total charge deposited in the V0 detectors. For each multiplicity interval the corresponding mean multiplicity density at mid-rapidity $\langle \mathrm{d}N_{ch}/\mathrm{d}\eta \rangle$ is measured, as reported in [7]. In order to avoid contamination from pileup, events with more than one reconstructed vertex are discarded for the analysis(1).

The efficiency and acceptance have been estimated with a Monte Carlo simulation using events generated with PYTHIA 6 in its Perugia-0 tune and propagating particles through the full ALICE geometry using the GEANT3 [10] transport code. The results reported in these proceedings refer to primary particles, defined as all particles produced in the collision, including all decay products except those coming from the weak decays of strange particles. The contributions from the weak decays and the one from particle knock-out in the material have been removed with a data driven approach, as described in [8, 9]. Systematic uncertainties have been evaluated by varying the cuts used to select the track sample and to perform the particle identification.

The transverse-momentum spectra for $\pi^{\pm}$ are shown in fig. 1(a) for different event multiplicity classes. Analogous results for $K^{\pm}$, p, K^0_s, K^*, ϕ, Λ, Ξ and Ω are not shown for the sake of brevity. The evolution of the p_{T} distributions with respect to the inclusive spectra, shown in the bottom panel of fig. 1(a), reveals that particle production is shifted towards (smaller) larger transverse momenta at (lower) higher charged-particle multiplicities. This "hardening" of particle spectra with multiplicity is similar for all particle species. This effect is summarized in the multiplicity dependence of the average transverse momentum ($\langle p_{\mathrm{T}} \rangle$) of the various particle species under study, as shown in fig. 1(b). The distribution shows a clear rising trend with multiplicity, depending on the particle mass. The ratios between yields of different particle species have also been computed. In particular the ratios of K (p) spectra to π are shown for three multiplicity classes and the multiplicity integrated case in fig. 2(a) (fig. 2(b)). When comparing the ratios in each class to the multiplicity integrated one (bottom boxes) a different behaviour is found for the two particle species. While the p_{T}-differential K/π ratio is multiplicity-independent, the p/π ratio exhibits a depletion at a $p_{\mathrm{T}} < 1.5\,\text{GeV}/c$ and an enhancement for $p_{\mathrm{T}} > 1.5\,\text{GeV}/c$. This effect is qualitatively similar to the observations in p-Pb and Pb-Pb collisions [15], where the measurements are interpreted in terms of collective flow.

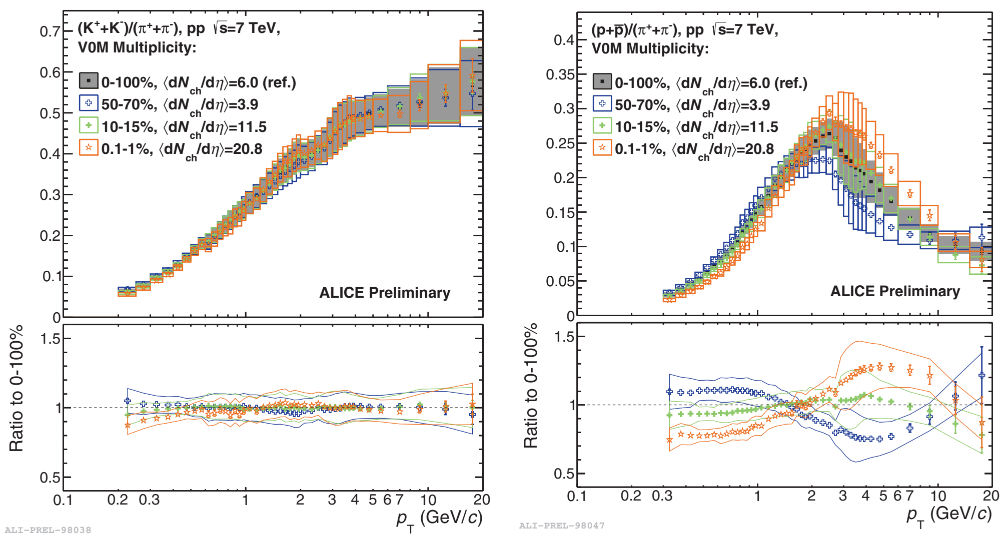
The spectra have been fitted with a Lévy-Tsallis function [11, 12] in order to extrapolate them down to zero transverse momentum and thus compute the p_{T}-integrated yields. In fig. 3 the integrated yield ratios K/π and p/π are plotted as a function of multiplicity

(1) The average number of interactions per bunch crossing is $\mu = 0.05$.



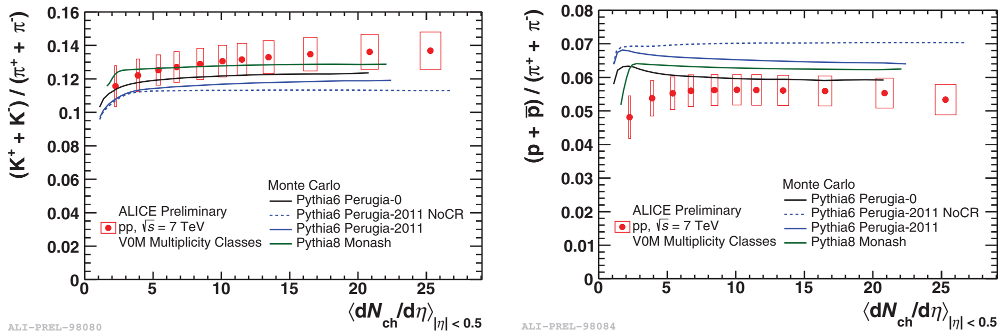
(a) (b)

Fig. 1. – a) Spectra of charged π as a function of the event multiplicity: warm (cold) colours represents the high (low) multiplicity. The ratio to the multiplicity integrated spectra is also shown in the bottom panel. The systematic uncertainties are represented with boxes. b) Mean transverse momentum as a function of the event multiplicity at mid-rapidity for several particle species. The lines represent the result of a logarithmic fit drawn to guide the eye.



(a) (b)

Fig. 2. – Ratio as a function of the transverse momentum of a) K/π and b) p/π spectra, computed for each multiplicity class. The ratio to the multiplicity integrated case is also reported in the bottom plots.



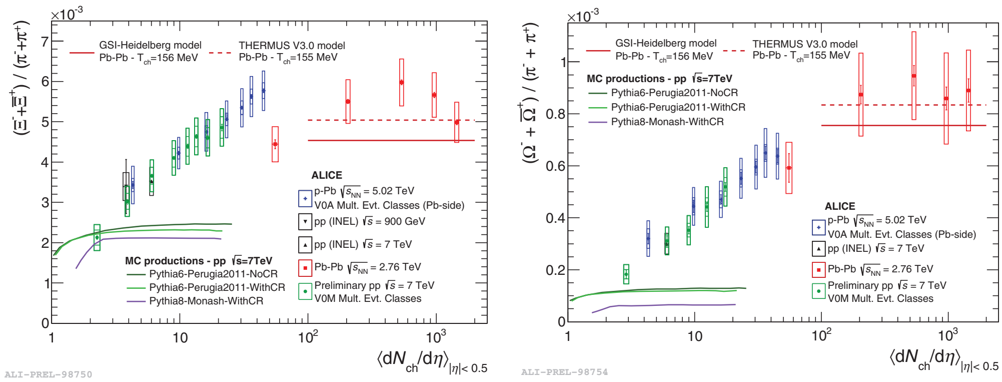
(a) (b)

Fig. 3. – a) K/π and b) p/π integrated ratios as a function of event multiplicity. Comparisons to different tunes of the PYTHIA event generator are also shown.

and compared to the Monte Carlo predictions from four tunes of the PYTHIA event generator. It is worth noting that the four tunes reproduce the measured ratios within $\pm 5\%$, except for the p/π ratio at low multiplicity.

The particle yields relative to pions are shown for Ξ in fig. 4(a) and Ω in fig. 4(b) as a function of the event multiplicity. The results obtained in p-Pb and Pb-Pb collisions are also included for comparison. In pp both Ξ/π and Ω/π ratios are found to increase with multiplicity, similarly to what was observed in p-Pb collisions.

Particle ratios have also been predicted in the context of statistical hadronization models such as THERMUS v3.0 [13] and the GSI-Heidelberg model [14]. The grand-canonical limits for the Ξ/π ratio obtained in these models are reached in highest-multiplicity pp collisions, but this is not the case for the Ω/π ratio. The predictions from three different versions of the PYTHIA event generator do not reproduce the trend of the observed data.



(a) (b)

Fig. 4. – Ratio as a function of the event multiplicity of a) Ξ/π and b) Ω/π. Comparisons to different tunes of the PYTHIA event generator are also shown.

3. – Conclusions

The ALICE Collaboration has presented the results on the production of identified light flavor hadrons as a function of the charged particle multiplicity in pp collisions at $\sqrt{s} = 7\,\text{TeV}$. The evolution of the p_{T}-differential p/π ratio shows, going from low to high multiplicities, a depletion in the low-p_{T} region and an enhancement at larger p_{T}. The multiplicity evolution is similar to what is observed in p-Pb and Pb-Pb collisions and may suggest common features among the three systems. It is worth noting that in the heavy-ion case these effects are usually explained in terms of hydrodynamic evolution (*e.g.*, *radial flow*), while in pp collisions a qualitatively good description of the data can also be obtained in models which include final state effects such as the colour reconnection mechanism [16]. Monte Carlo models show some tension when trying to describe the relative particle yields, especially for the case of strange baryons. The comparison between the production yields of Ξ and Ω, relative to the one of π, in pp, p-Pb and Pb-Pb shows an almost continuous evolution as the multiplicity rises. An increase in the production of strange particles has been observed, that reaches the values of Pb-Pb at the highest multiplicity for the Ξ/π ratio but not for Ω/π. The increase seems to be independent of the system under study, suggesting the presence of a common underlying mechanism for strangeness production.

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