Multiplicity dependence of light flavour hadrons in small systems with the ALICE experiment

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Abstract. The large statistics of data collected at the high energies reached at the Large Hadron Collider have provided unprecedented opportunities to probe in more detail the mechanisms of particle production in small collision systems such as proton–proton (pp) and proton–lead (p–Pb) collisions. It is particularly interesting to perform such studies in high-multiplicity events, where, in the last years, features where found that are reminiscent of phenomena interpreted as signs of collective behaviour in lead–lead (Pb–Pb) collisions. These observations justify a comprehensive study of the production of identified particles to further investigate the dynamics in small collision systems. The ALICE detector, thanks to its excellent particle identification capabilities, allows the measurement of identified particles over a wide range of transverse momentum ($p_T$). In these proceedings we report on the $p_T$ distributions of $\pi$, $K$, $p$, $K^0_S$, $K^*$, $\Lambda$, $\Xi$ and $\Omega$ measured as function of the charged-particle multiplicity density in pp collisions at $\sqrt{s} = 7$ TeV. We further report on the study of particle ratios in comparison to Monte Carlo models and in different collision systems. In particular, the production of hadrons containing strange quarks is also discussed as a function of the event multiplicity.

1. Introduction

High energy heavy-ion collisions, such as Pb–Pb collisions at the Large Hadron Collider, provide a unique way to study the deconfined state of matter known as Quark-Gluon Plasma (QGP). The onset of this strongly interacting phase is accompanied by some peculiar signatures in the final state. These include the collective flow of particles created in the collision and an increase in the relative production rates of strange and multi-strange hadrons with respect to minimum-bias pp and p–Pb collisions.

The transverse momentum ($p_T$) distributions of identified particles are fundamental observables that can be used to study in detail the properties of the system created in the collision. Particle production measured in heavy-ion collisions is well described by models which include a hydrodynamic evolution [1]. A similar phenomenology to the Pb–Pb case has also been observed for high energy pp and p–Pb collisions when selecting events with a higher number of charged particles produced (the event multiplicity) with respect to the minimum-bias values. In particular some clear analogies have been found for the three systems when comparing long-range and near-side angular correlations [2, 3, 4, 5]. These observations motivate a comprehensive study of the identified particle production in order to investigate in more detail the origin of these features.
The ALICE experiment [6, 7] is particularly well suited for the study of identified particles thanks to the high detector granularity coupled with the excellent particle identification (PID) capabilities ensured over a wide range of transverse momentum by its different detectors. In particular, PID is performed in the region at mid-rapidity via the measurements of specific energy loss in the Inner Tracking System (ITS) and in the Time Projection Chamber (TPC). In addition the particle velocity is measured via the Time Of Flight (TOF) detector, while the high Momentum Particle IDentification (HMPID) detector identifies particles by measuring the angle of emission of Cherenkov light.

2. Particle spectra

We report on the transverse momentum spectra of $\pi$, $K$, $p$, $K^0_S$, $K^*$, $\Lambda$, $\Xi$ and $\Omega$ measured as a function of multiplicity in pp collisions at $\sqrt{s} = 7$ TeV [8]. These measurements refer to primary particles, i.e. particles produced either directly in the collision or formed by non-weak particle decays. Weak decays and contributions from particle knock-out in the material were removed with the data driven approach described in [9, 10]. The systematic uncertainties were estimated by varying the PID techniques and the selection criteria used to select the track sample. The data sample, consisting of $\sim$ 100 M events collected in 2010 with a minimum-bias...
Figure 3. Ratios of $K^0_S$, $\Lambda$, $\Xi$ and $\Omega$ yields to the one of $\pi$ for pp, p–Pb and Pb–Pb collisions as a function of the charged multiplicity density compared to Monte Carlo models.

Figure 4. $\Lambda/K^0_S$ and $p/\pi$ ratios for pp and p–Pb as a function of multiplicity compared to Monte Carlo models.

trigger, was divided into ten classes (I-X), where class I (X) corresponds to the highest (lowest) multiplicity. The different classes were defined by measuring the total charge deposited in the V0 detectors (V0M amplitude), which consist of a set of two scintillator hodoscopes located in the pseudorapidity region $2.8 < \eta < 5.1$ (V0A) and $-3.7 < \eta < -1.7$ (V0C) and covering the full azimuth. The corresponding mean multiplicity density at mid-rapidity ($\langle dN_{ch}/d\eta \rangle$) was also measured for each multiplicity class as reported in [11]. In order to minimise spurious measurements originating from pile-up, events with more than one reconstructed vertex were rejected.

An estimate of the efficiency and acceptance corrections was performed by means of a full Monte Carlo simulation using events generated with PYTHIA6 Tune Perugia0 and propagating particles through a detailed description of the ALICE detector with the GEANT3 transport code.

The spectra of $\pi$, $K$, $p$, $K^0_S$, $K^*$, $\Lambda$, $\Xi$ and $\Omega$, obtained by combining the two highest multiplicity classes (I+II), are shown in Fig. 1. A mass-dependent shift of the spectral shapes towards higher momenta is observed when comparing different particle species, with the effect being more pronounced for particles with higher mass. This feature is similar to what is observed in Pb–Pb collisions, where the phenomenon is understood in terms of radial flow. The spectra for $\pi$, $K$ and $p$ are fitted simultaneously with the Blast-Wave model [12], while for the other species a prediction from the same model is computed by using the parameters obtained from the fit to $\pi$, $K$ and $p$. From the ratio between the spectra and the Blast-Wave model, shown in the lower panels of Fig. 1, one can see that it offers a fairly good description of the data. Moreover,
when comparing the Blast-Wave fit parameters in pp and p–Pb as a function of multiplicity in Fig. 2, an almost continuous evolution is found.

From the ratios between the $p_T$-integrated yields of strange and multi-strange hadrons and the one of $\pi$, shown in Fig. 3 for the pp, p–Pb and Pb–Pb systems, a multiplicity-dependent increase in the relative yield for particles having non-zero net strangeness content is observed. Furthermore, the observed increase seems to be dependent on the number of constituent strange quarks, as the increase is larger for multi-strange hadrons. The comparison of the ratios with the predictions from Monte Carlo models shows that the increase is reproduced by the DIPSY event generator, while it is unable to reproduce the $p/\pi$ ratio shown in Fig. 4. The EPOS model manages to describe only the magnitude of the effect and overestimates the rise while PYTHIA misses both trend and magnitude with increasing differences as the strangeness content increases.

The ratios between the $p_T$-integrated yields of particles with equal amount or no $s$ quark, such as $\Lambda/K_0^S$ and $p/\pi$ respectively, are reported in Fig. 4 as a function of the charged particle multiplicity for pp and p–Pb events. The trends for both ratios are independent of the event multiplicity, thus suggesting that the increase in the production of strange particles is related to the strangeness content rather than due to a difference in the particle masses. Comparisons to Monte Carlo models show poor agreement, especially when trying to reproduce all observations simultaneously.

3. Conclusions

The ALICE Collaboration has presented the results on the production of identified light flavour hadrons as a function of the charged particle multiplicity in pp collisions at $\sqrt{s} = 7$ TeV. A mass-dependent hardening of the spectral shapes was observed for high multiplicity collisions. The Blast-Wave model describes the measured spectra of $\pi$, $K$ and $p$ well. This holds true also for other particle species whose spectra show a qualitative good agreement with the spectral shapes predicted by the Blast-Wave model. The fit parameters exhibit a continuous evolution with multiplicity in pp and p–Pb. An increase in the production, relative to $\pi$, of strange particles was found as a function of the multiplicity. This increase is more pronounced for particles with higher strangeness content. No significant increase is found when comparing the production of particles with the same number of constituent $s$ quarks, indicating that this effect is related to the strangeness content rather than the particle masses. This observation is qualitatively reproduced by models such as DIPSY, while the same model is not in quantitative agreement with the analogous measurement for $p/\pi$.

In conclusion, the results presented in these proceedings show some clear similarities between the pp, p–Pb and Pb–Pb systems, possibly suggesting that the same particle production mechanisms are at play at high energies and particle densities, regardless of the colliding system.

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