A comprehensive measurement of the multiplicity dependence of identified particle production in proton-proton (pp) collisions is important for the understanding of small and large colliding systems. The transverse momentum ($p_T$) dependence of particle ratios and the integrated yield ratio of various particles such as $\pi$, $K$, $K^0_S$, $K^{*0}$, $p$, $\Lambda$, $\Xi$, $\Omega$ in pp collisions at 7 TeV are reported. The measurements are also compared with the results obtained in proton-lead (p–Pb) and lead-lead (Pb–Pb) collisions at $\sqrt{s_{NN}} = 5.02$ TeV and 2.76 TeV, respectively.

The production of strange and multi-strange hadrons in pp collisions exhibits a significant increase with the average charged particle multiplicity similar to the increase observed in p–Pb collisions. None of the common QCD-inspired models (DIPSY, EPOS, PYTHIA8) are able to simultaneously describe the observed multiplicity dependent particle ratios.

1 Introduction

Recent measurements have drawn the attention on features of p–Pb collisions $^{1,2,3,4}$ that are similar to those observed in heavy-ion reactions, where they are associated with the presence of collectivity arising from the formation of a strongly interacting medium. For instance, the $p_T$-differential baryon-to-meson particle ratios (such as $p/\pi$) in p–Pb show an evolution with centrality qualitatively similar to that in Pb–Pb collisions $^5$. Identified particle observables are well suited to investigate the presence of collective phenomena. Strangeness enhancement in heavy-ion collisions with respect to minimum bias pp collisions is a well known effect, which historically has been proposed as a signature of Quark-Gluon Plasma (QGP) formation in nuclear collisions $^6$. The observation of an enhancement in the strange to non-strange production rate with increasing centrality in p–Pb collisions $^7$ has opened the way for further studies in small systems. A comprehensive study of identified particle production in pp collisions has been performed by the ALICE experiment.
2 ALICE Detector and Analysis Details

ALICE is one of the main LHC experiments and it is optimised for heavy-ion physics, with the aim to study the formation and properties of the QGP. The excellent particle identification capability of ALICE allows the measurement of identified hadron production in a wide momentum range down to very low $p_T$ ($\sim$100 MeV) in pp, p–Pb, and Pb–Pb collisions. ALICE can provide an important contribution to the LHC pp physics program in the soft (non-perturbative) and hard (perturbative) regimes of QCD. It can also probe QCD in a wide range of particle densities.

The particle identification is performed via specific energy loss measurement in the Inner Tracking System (ITS) and in the Time Projection Chamber (TPC). The particle velocity is measured by Time Of Flight (TOF) detector. The High Momentum Particle IDentification (HMPID) detector identifies particles by measuring the angle of Cherenkov light emission. The multiplicity selection is performed via the sum of the signal amplitudes of V0 plastic scintillator arrays at forward and backward rapidity (V0M). In this analysis, the production of non-strange, strange and multi-strange hadrons ($\pi$, K, $K_S$, $K^*$, p, $\Lambda$, $\Xi$, $\Omega$) at mid-rapidity ($|y|<0.5$) is studied. The pions, kaons and protons are identified by using the information of the specific energy loss $dE/dx$ from ITS and the TPC, as well as the TOF measurement. The weak decay topology is used for the detection of short lived particles like $K^0_S$, $\Lambda$, $\Xi$, $\Omega$. The $K^*$ resonance is reconstructed via the invariant mass $(\pi K)$ method.

The $\sqrt{s}=7$ TeV pp collisions events have been collected in 2010 having low pile-up with minimum bias trigger and requiring at least one charged particle in $|\eta|<1$ (INEL>0). The data sample collected is divided in ten V0M event multiplicity classes from highest (I) to lowest (X) multiplicity.

3 Results

![Figure 1 – $p_T$ dependent $p/\pi$ ratio for different V0 multiplicity event classes in pp (left), p–Pb (middle), Pb–Pb (right) collisions at $\sqrt{s_{NN}}=7$ TeV, 5.02 TeV and 2.76 TeV, respectively.](ALI-PREL-110279)

The $p_T$-spectra of different identified particles ($\pi$, K, $K_S$, $\Lambda$, $\Xi$, $\Omega$) for various event multiplicity classes at mid-rapidity in pp collisions at $\sqrt{s} = 7$ TeV have been measured. The $p_T$-differential $p/\pi$ ratios for different multiplicity classes in pp, p–Pb and Pb–Pb collisions are shown in Fig. 1. In all three colliding systems a qualitatively similar multiplicity dependence and an enhancement at intermediate-$p_T$ ($\sim$2-3 GeV/c) are observed. The magnitude of enhancement in the $p/\pi$ ratio from low to high event multiplicity is larger in Pb–Pb followed by p–Pb and
pp collisions. In Pb–Pb collisions, the increase in p/π at the intermediate-\(p_T\) is attributed to radial flow or recombination\(^9\). A similar observation is found for the \(p_T\)-dependent \(\Lambda/K^0_S\) ratio with a depletion at low and enhancement at intermediate-\(p_T\) for pp, p–Pb and Pb–Pb colliding systems\(^5\).

Figure 2 shows the \(p_T\)-integrated yield ratio of hadrons having one or more strange valence quark to π for pp, p–Pb and Pb–Pb collisions. A multiplicity-dependent increase in the relative yield of particles having a net strangeness content is observed with a smooth evolution across different colliding systems. Furthermore the relative increase seems to depend on the number of constituent s quarks, as the increment is higher for multi-strange hadrons. These particle ratios in pp collisions are similar to those found in p–Pb collisions at the same multiplicity densities. The Monte-Carlo (MC) event generators DIPSY and EPOS LHC describe the relative increase qualitatively, but fail to predict quantitatively its magnitude. In contrast to this, PYTHIA8 does not show any strangeness enhancement.

In pp collisions, the increase of yield ratio to pion might be due to (i) mass (ii) baryon/meson nature of the particle or (iii) strangeness content. In order to factorise these potential contributions, Fig. 3 (left panel) shows the \(p_T\)-integrated baryon-to-meson ratio having equal number of strange quark (\(\Lambda/K^0_S\)) or not having any strange quark (\(p/\pi\)) as a function of average charged particle multiplicity in pp and p-Pb collisions. Both the ratios are almost independent of event multiplicity, which indicates that the increase in strange particle production is not related to baryon/meson nature or the mass difference of the particles. None of the MC models (DIPSY, EPOS LHC, PYTHIA8) satisfactorily describes both the particle ratios simultaneously.

Furthermore, the integrated baryon (p, \(\Lambda\), \(\Xi\), \(\Omega\)) to pion yield ratios, normalised to their corresponding yield ratio in 0-100% multiplicity class, are shown in Fig. 3 (right panel) for pp, p-Pb and Pb-Pb collisions as a function of charged particle density. This ratio is almost independent of event multiplicity for protons (no strange quark). However, the multi-strange hadrons experience a steeper increase towards high-multiplicity events, indicating the observed increase is driven by strange (s) quark content of the particles.
Figure 3 – On the left panel, $\Lambda/K^0_s$ and $p/\pi$ ratio as a function of average charged particle multiplicity in pp and p–Pb collisions. On the right panel, ratios of baryons ($p, \Lambda, \Xi, \Omega$) to pions, normalised to the corresponding ratio in the 0-100% multiplicity class as a function of average charged particle multiplicity in pp and p–Pb collisions.

4 Conclusion

The ALICE Collaboration has presented the results of identified light flavour hadrons production as a function of the charged particle multiplicity in pp collisions at $\sqrt{s} = 7$ TeV. The baryon-to-meson ratio ($p/\pi$) shows qualitatively similar evolution in different multiplicity classes as a function of $p_T$ and the baryon enhancement at intermediate $p_T$ is also observed in pp collisions analogous to p-Pb and Pb-Pb collisions. The integrated yield ratios to pions show a relative increase in the production of strange and multi-strange particles as function of event multiplicity in pp collisions. This behaviour is not reproduced by any of the commonly known MC models which suggests that further tuning is needed to understand the strangeness production in high-multiplicity pp collisions. There is no significant increase observed when comparing the production of particles with the same number of constituent strange quark. This indicates that is due to the strangeness content rather than the particle mass or its baryon number.

All together the results presented in this proceeding show that the similarity between pp, p–Pb, and Pb–Pb collisions extends to the production of strange particles.

References