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# Light flavour identified hadron production in pp collisions with ALICE at the LHC

Barbara Guerzoni[1,a] for the ALICE Collaboration

[1] *INFN and University of Bologna and Museo Storico della Fisica Centro Studi e Ricerche Enrico Fermi (Rome), Italy*

**Abstract.** ALICE is a dedicated heavy ion experiment that also collects and analyzes p-Pb and pp collisions. These data are important to provide a reference to the Pb-Pb data, tune MC generators based on the QCD inspired models and complement the results from the other LHC experiments. In this contribution a summary of the most recent results on light flavour identified hadron production in pp collisions is presented.

## 1 Introduction

The main feature that makes ALICE [1] unique among the LHC experiments is its excellent Particle IDentification (PID) performance both in the central barrel ($|\eta| < 0.9$) and in the forward region ($-4.0 < \eta < -2.5$). The low material budget in the central barrel together with the low magnetic field allow for PID down to very low transverse momentum ($p_T \sim 0.1$ GeV/c), using several different specialized detectors and PID techniques in complementary $p_T$ ranges. These detectors are the ITS and the TPC that identify particles through their energy loss, the TRD that uses the transition radiation, the TOF that uses the time taken by the particles to fly from the primary vertex to the TOF layer and three limited acceptance detectors: the HMPID (based on Cherenkov radiation) and the electromagnetic calorimeters, EMCal and PHOS. The good PID performance is also related to the excellent tracking and primary and secondary vertex recontruction capabilities in ALICE.

To illustrate the ALICE PID capabilities, in Fig.1 the $p_T$ spectra of $\pi, K, p$ produced in pp collisions at $\sqrt{s}$ = 7 TeV and identified by ITS, TPC, TOF and HMPID are shown. We can see how, combining the PID performance of these detectors that are able to identify particles in complementary $p_T$ regions, we can extend the range of identification from $p_T = 0.1$ GeV/c to $p_T = 20$ GeV/c.

In the following, some of the most recent results in pp collisions at $\sqrt{s} = 0.9, 2.76, 7.0$ TeV on light flavour hadron production identified thanks to the ITS, TPC, TOF and HMPID detectors will be reported. In particular, we will focus on multi-strange baryon production, resonances and anti-baryon to baryon ratios. These pp results are of fundamental interest for ALICE not only since they provide a reference for the Pb-Pb data but also because they give the possibility to test and tune MC generators based on the QCD inspired models. For this reason a detailed comparison with the models will also be shown.

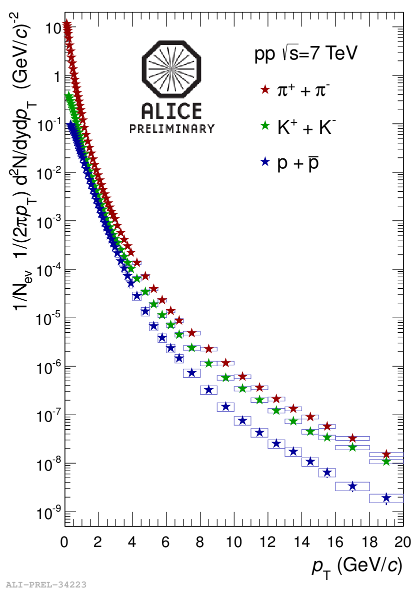


**Figure 1.** Transverse momentum spectra of $\pi$, $K$ and $p$ produced in primary pp collisions at $\sqrt{s}$ = 7 TeV.

## 2 Multi-strange baryon production

The multi-strange baryons $\Omega^-(sss)$ and $\Xi^-(dss)$ (and antiparticles), abundantly produced at the LHC energy and luminosity, are important for understanding particle production mechanisms. Their strange valence quarks can in fact be produced only in the course of the interaction since no strange valence quarks are present in the colliding system.

Multi-strange baryons are identified [2] via the reconstruction of the cascade-like topology of their weak decays

[a] e-mail: barbara.guerzoni@bo.infn.it

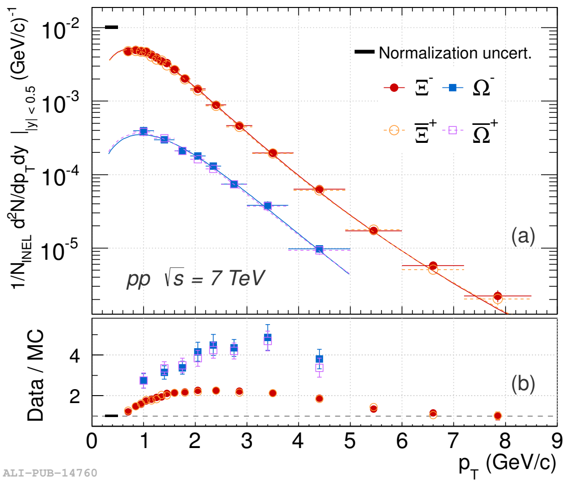


**Figure 2.** (Top) $\Xi$ and $\Omega$ transverse momentum spectra for pp collisions at $\sqrt{s}$ = 7 TeV. The Levy-Tsallis fits are also shown. (Bottom) Ratio between the data and the spectra predicted by PYTHIA Perugia 2011. [2]

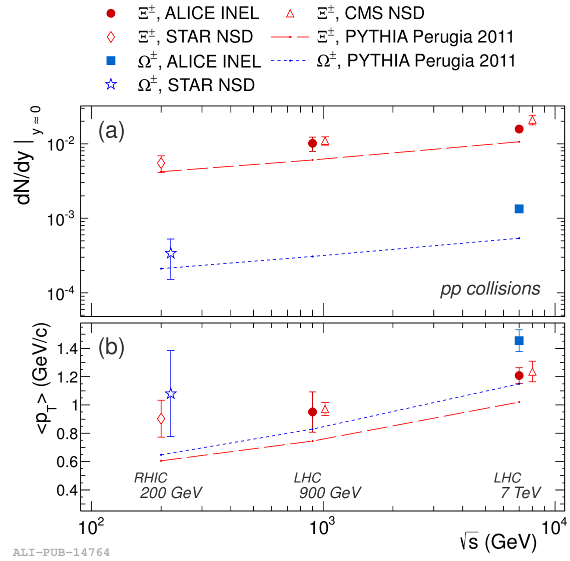


**Figure 3.** Integrated yield (top) and $\langle p_T \rangle$ (bottom) for $\Omega$ (blue) and $\Xi$ (red) at different collision energies. ALICE, CMS and STAR results are reported. The predictions of PYTHIA Perugia 2011 are also shown as dashed lines. [2]

into charged particles

$$\Xi^-(\overline{\Xi}^+) \rightarrow \Lambda(\overline{\Lambda}) + \pi^-(\pi^+)$$

$$\Omega^-(\overline{\Omega}^+) \rightarrow \Lambda(\overline{\Lambda}) + K^-(K^+)$$

that is the matching of the V-shaped decay of the daughter $\Lambda$ with the remaining secondary track. The final daughter pions, kaons and protons are identified using energy loss information from the TPC.

In Fig.2 (upper panel) the $\Xi$ and $\Omega$ transverse momentum spectra for inelastic pp collisions at $\sqrt{s}$ = 7 TeV for central rapidity range ($|y| < 0.5$) are reported. We can immediately see that the particle and anti-particle spectra are overlapping and their ratio was found to be compatible with one. The spectra are fitted with a Levy-Tsallis function that is used to exctract the integrated yield and the $\langle p_T \rangle$. In the bottom panel the ratios between the data and the spectra predicted by PYTHIA Perugia 2011 [3] are shown. Perugia 2011 is tuned on the first 2010 LHC results; in particular it can reproduce the multiplicity and the inclusive charged particles $p_T$ distributions and has an increased strange and multi-strange baryon yields production compared to the other PYTHIA tunes (i.e. larger $\Lambda/K$ ratio). Nevertheless it still underestimates the multi-strange production and can not reproduce their spectral shape with the exception of the $\Xi$ at high $p_T$.

In Fig.3 integrated yields and $\langle p_T \rangle$ obtained from the fits shown in Fig.2 are compared with the same quantities obtained in pp collisions by ALICE at $\sqrt{s}$ = 0.9 TeV [4], by STAR at $\sqrt{s}$ = 0.2 TeV [5] and by CMS at $\sqrt{s}$ = 0.9 and 7 TeV [6]. An increase of both integrated yield and $\langle p_T \rangle$ for increasing collision energy can be seen. With the current uncertainties of the measurements, a significant separation between $\langle p_T \rangle$ of $\Omega$ and $\Xi$ is observed at $\sqrt{s}$ = 7 TeV. The PYTHIA Perugia 2011 predictions are also shown, and underestimate both the integrated yield and $\langle p_T \rangle$.

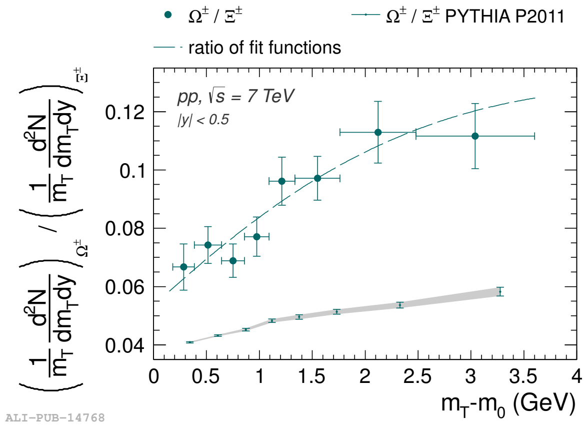


**Figure 4.** $(\Omega^+ + \Omega^-)/(\Xi^+ + \Xi^-)$ ratio as a function of $m_T - m_0$ for pp collisions at $\sqrt{s}$ = 7 TeV. The ratio of the Levy-Tsallis fit to the spectra is also reported (dashed curve). Data are compared to the PYTHIA Perugia 2011 simulation (solid curve)[2]

To investigate possible differences in the production mechanism of multi-strange baryons with and without non-strange quark the $(\Omega^+ + \Omega^-)/(\Xi^+ + \Xi^-)$ spectra ratio was studied. In Fig.4 it is reported as a function of $m_T - m_0$ to reduce the dependence on particle mass. It can be seen that the ratio clearly increases up to $m_T - m_0 \sim 1.5$ GeV while the uncertainties preclude us from any conclusions regarding a possible flattening, which could have indicated a saturation of the s-quark production with respect to the non-strange quarks. In the plot also the ratio predicted by PYTHIA Perugia 2011 is reported. It can not reproduce the shape nor the absolute value of the ratio.

## 3 Resonances

Studying resonances in pp collisions provides a method to investigate the hadron production mechanisms. For example, the $\phi$ (1020) which is composed only of $s$ quarks and the $K^*$ (892) which has a similar mass but different strangeness content, give the possibility to study the strangeness production and suppression compared to $u$ and $d$ quarks. The resonance data are also important to tune event generators.

Due to the resonances short lifetime (few fm/c), the decay products are not distinguishable from primary particles, and hence a topological reconstruction is not possible. Consequently, invariant mass analysis based on identified tracks (using TPC and TOF information) is performed. The resonances studied by ALICE in pp collisions are:

$$\Phi(1020) \rightarrow K^+ + K^-$$

$$K^*(892)^0 \rightarrow \pi^\pm + K^\pm$$

$$\Sigma(1385)^\pm \rightarrow \Lambda + \pi^\pm$$

$$\Xi(1530)^0 \rightarrow \Xi^- + \pi^+$$

$$\Lambda(1520) \rightarrow p + K^-$$

In Fig.5 the $K^*$ transverse momentum spectrum in pp collisions at $\sqrt{s}$ = 7 TeV is shown and compared to PYTHIA [3] and PHOJET [8] predictions. Different PYTHIA tunes, obtained by adjusting the model parameters to reproduce different sets of data, are considered: the D6T tune [9] obtained by fitting the CDF Run 2 data, the ATLAS-CSC tune [10] adjusted to minimum bias data from UA5, E735 and CDF, Perugia 2011[11] that takes into account the first 2010 LHC results and Perugia 0. The generator that better reproduce the spectrum is PYTHIA Perugia 2011 while PHOJET and ATLAS-CSC overestimate the low momentum region, PYTHIA D6T deviates from the data for $p_T > 2$ GeV/c and PYTHIA Perugia 0 underestimates the spectrum for $p_T > 0.5$ GeV/c. The same results can be found comparing the $\phi$ spectrum with the same MonteCarlo generators.

As we have already seen, studying the ratio between particles with different strangeness content provides information about the probability to produce $s$ quark pairs compared to $u$ and $d$ pairs. In Fig.6 and Fig.7 the $2\phi/(K^+ + K^-)$ and $2\phi/(\pi^+ + \pi^-)$ as a function of $p_T$ in pp collisions for different center of mass energies are reported respectively. It can be seen that while $\phi/K$ is independent of energy, $\phi/\pi$ seems to have a slight dependence. This can be better seen in Fig.8 where the relative production with respect to the yield at $\sqrt{s}$ = 2.76 TeV is reported in terms of the double ratio $(\phi/\pi^\pm)_{xTeV}/(\phi/\pi^\pm)_{2.76TeV}$. The shaded areas represent the PYTHIA predictions that reproduce the trend observed in the data and numerically agree within 10%. From Fig.7 it is also evident that $\phi/\pi$ increases with transverse momentum reaching a saturation for $p_T > 6$ GeV/c.

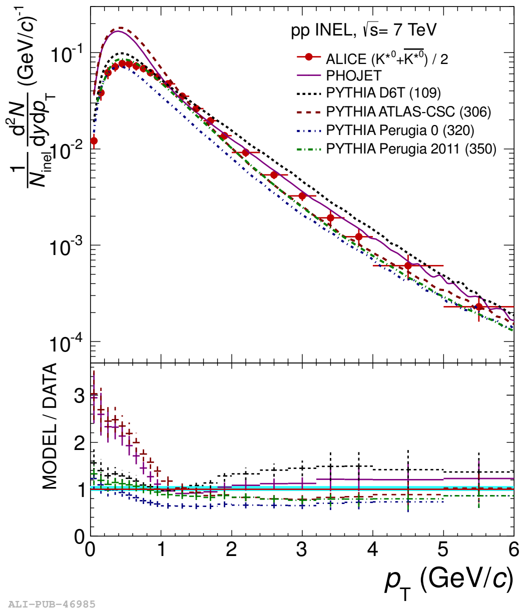


**Figure 5.** (Top) $K^*$ transverse momentum spectrum in pp collisions at $\sqrt{s}$ = 7 TeV compared with PHOJET and D6T, ATLAS-CSC, Perugia0, Perugia 2011 PYTHIA tunes. (Bottom) Ratio between the models and the data. [7]

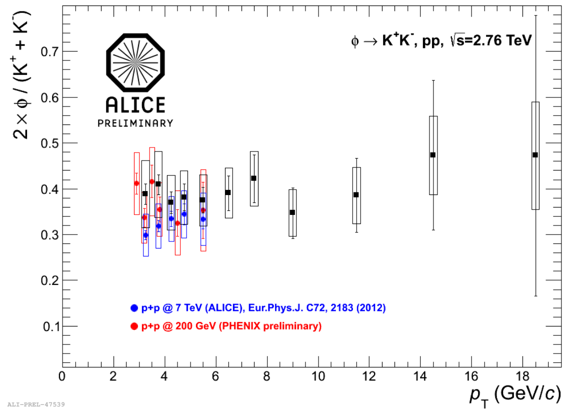


**Figure 6.** $2\phi/(K^+ + K^-)$ as a function of $p_T$ in pp collisions for different center of mass energies: black ALICE data at $\sqrt{s}$ = 2.76 TeV, blue ALICE data at $\sqrt{s}$ = 7 TeV, red PHENIX data at $\sqrt{s}$ = 0.2 TeV [7]

## 4 Anti-baryon to baryon ratio

A baryon can be represented as three valence quarks connected with three strings (the gluons) to a point, the string junction, that carries the baryon number. In baryon–baryon collisions, the anti-baryons can be produced only from vacuum in baryon/anti-baryon pairs namely by string junction and anti-string junction pairs plus sea quarks and anti-quarks. The baryons, instead, can have more production mechanisms since they can also contain one of the valence quarks, di-quarks or the string junction of the colliding baryons. Baryons and anti-baryons can hence have different spectrum at mid-rapidity if the constituents of the incoming baryons are diffused at

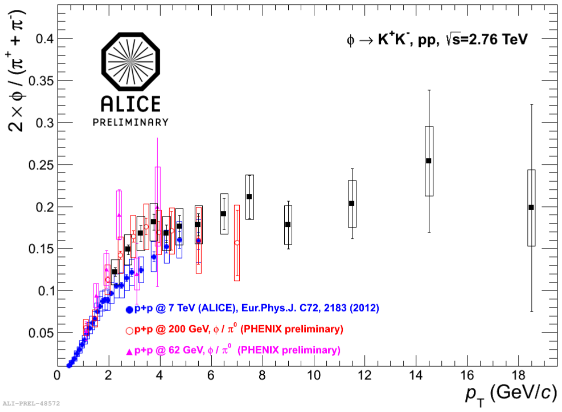


**Figure 7.** $2\phi/(\pi^+ + \pi^-)$ as a function of $p_T$ in pp collisions for different center of mass energies: black ALICE data at $\sqrt{s}$ = 2.76 TeV, blue ALICE data at $\sqrt{s}$ = 7 TeV, red PHENIX data at $\sqrt{s}$ = 0.2 TeV, magenta PHENIX data at $\sqrt{s}$ = 0.062 TeV [7]

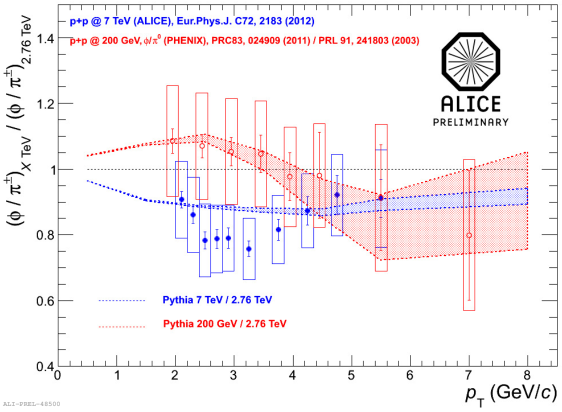


**Figure 8.** $(\phi/\pi^{\pm})_{xTeV}/(\phi/\pi^{\pm})_{2.76TeV}$ as a function of $p_T$. Shaded areas represent the PYTHIA 6.4 predictions. [7]

large rapidity intervals. If, on the opposite, the constituents of incoming protons do not contribute at large rapidity intervals we have the same yields of baryon and anti-baryon at mid-rapidity (see for example [12, 13]).

In Regge field theory [14], $exp[(\alpha_j - 1)\Delta y]$ is the probability of finding the string junction of a beam baryon at $\Delta y = y_{beam} - y$ where $y_{beam} = ln(\sqrt{s}/m_B)$ is the rapidity of the incoming baryon, $y$ is the rapidity of the string junction and $\alpha_j$ is the intercept of string-junction trajectory. The presence of a difference in the baryon/anti-baryon spectra at mid-rapidity depends on the $\alpha_j$ value. For example, if $\alpha_j$ = 0.5, the string-junction transport approaches zero for increasing $\Delta y$ hence the contribution at mid-rapidity decreases with increasing collision energy. Another difference between particle and anti-particle yields in the central region could be due to the presence of a Regge pole with negative signature and $\alpha_i \sim 1$ [14]. To get information on the various baryon production mechanisms, it is thus very interesting to study the baryon/anti-baryon ratio for baryons with different valence quark content as a function of collision energy, rapidity and particle multiplicity.

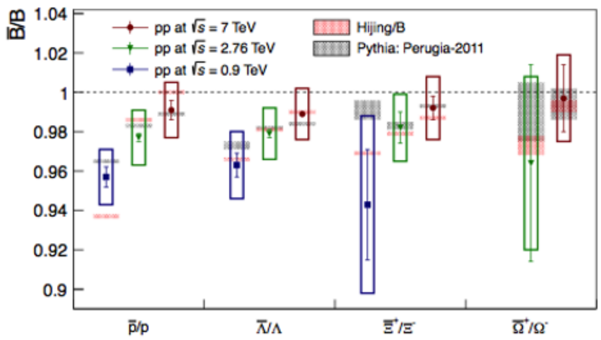


**Figure 9.** Mid-rapidity $\overline{p}/p$, $\overline{\Lambda}/\Lambda$, $\overline{\Xi}^+/\Xi^-$, $\overline{\Omega}^+/\Omega^-$ ratios at $\sqrt{s}$ = 0.9, 2.76 and 7 TeV integrated over the ALICE acceptance. The shaded areas are the Hijing/B (red) and PYTHIA Perugia 2011 (black) predictions. [15]

For this reason ALICE has studied $\overline{p}/p$, $\overline{\Lambda}/\Lambda$, $\overline{\Xi}^+/\Xi^-$, $\overline{\Omega}^+/\Omega^-$ ratios at $\sqrt{s}$ = 0.9, 2.76 and 7 TeV as a function of $p_T$, rapidity and multiplicity. $p$ are identified using the energy loss in the TPC while the hyperons are reconstructed via the topology of their weak decay into charged particles [15]. For all the particle species no dependence of the anti-baryon/baryon ratio on either the studied rapidity or $p_T$ ranges was observed.

In Fig.9 $\overline{p}/p$, $\overline{\Lambda}/\Lambda$, $\overline{\Xi}^+/\Xi^-$, $\overline{\Omega}^+/\Omega^-$ ratios for pp collisions at $\sqrt{s}$ = 0.9, 2.76 and 7 TeV integrated over the ALICE acceptance are shown and compared with the Hijing/B and Pythia Perugia 2011 predictions that are able to reproduce the data even if Hijing has a steeper increase with the energy of $\overline{p}/p$ ratio. One would expect that when increasing the strangeness of the particles, the contribution of the process related to the stopping of the constituents of beam particles would be reduced. With the current uncertainties no increase of the ratio with strangeness content for a given energy can be seen. We can anyway see for all species that the ratios increase with increasing beam energy, reaching values compatible with one at $\sqrt{s}$ = 7 TeV. This behavior is consistent with a Regge-trajectory intercept $\alpha_j \sim 0.5$ for baryon number transport while contributions from a Regge trajectory with $\alpha_j \sim 1$ are excluded like all the exchange that are not suppressed with increasing rapidity interval.

In Fig.10 (top) the $\overline{p}/p$ ratio as a function of the relative charged-particle pseudorapidity density $(dN_{ch}/d\eta)/\langle dN_{ch}/d\eta\rangle$ is shown. The data are compared with the PYTHIA Perugia 2011 predictions, while in the bottom panel the MonteCarlo/data ratios are shown. It can be noticed that while the data show no dependence on the particle multiplicity, PYTHIA has a steep rise of the ratio at low multiplicities followed by a saturation. This could be explained by a hypothesis that in the data the baryon number transfer increases with multiplicity as fast as the baryon/anti-baryon pair production while in PYTHIA Perugia 2011 the baryon number transfer increases with multiplicity slower than the baryon–anti-baryon pair production. The same conclusions just mentioned are valid also

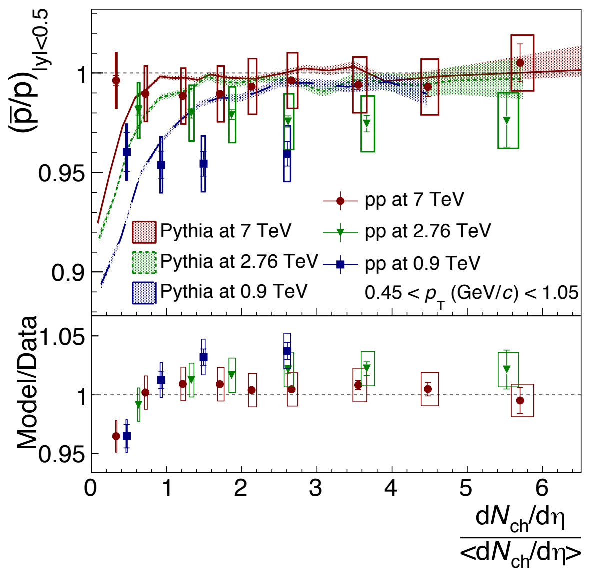


**Figure 10.** $\overline{p}/p$ ratio in pp collisions at $\sqrt{s}$ = 0.9, 2.76, 7 TeV as a function of the relative charged-particle pseudoraidity density. The shaded areas represent the PYTHIA Perugia 2011 predictions. [15]

for $\overline{\Lambda}/\Lambda$ and $\overline{\Xi}^{+}/\Xi^{-}$ not reported here ($\overline{\Omega}^{+}/\Omega^{-}$ was not studied due to insufficient statistics).

## 5 Summary and conclusions

Thanks to its unique PID capabilities, ALICE is able to identify particles over a wide $p_T$ range. In this contribution we have reported some of the most recent results on light flavour identified hadron production in pp collisions focusing on multi-strange baryon production, resonances and anti-baryon to baryon ratios. These results have been compared with different MC generators based on QCD inspired models. Of those studied here, PYTHIA Perugia 2011 was the most successful in reproducing the data, albeit with less success with increasing strangeness content of the studied particles. Anti-baryon/baryon ratios at mid rapidity were also studied, providing information on the baryon production mechanism. In particular the fact that the ratios at mid-rapidity get closer to one with increasing beam energy seems to be consistent with a Regge-trajectory intercept $\alpha_j \sim 0.5$ for baryon number transport. More data are necessary to better understand the particles production mechanisms and to better tune MonteCarlo generators.

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