Light hadron production studies in pp collisions at 0.9 and 7 TeV with the LHCb detector

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The LHCb experiment, designed for CP violation and rare decay studies in the heavy quark sector, also provides an important contribution to the study of the light hadron production at LHC energies. Due to its unique pseudorapidity coverage and to the possibility of extending the measurements to low transverse momenta, the LHCb data analyzed so far are already bringing an important insight to baryon transport studies and strangeness production mechanisms in a kinematical range where QCD models diverge. Measurements of the K_s^0 production cross section at 0.9 TeV centre-of-mass energy will be presented along with preliminary measurements of $\bar{\Lambda}/\Lambda$, $\bar{\Lambda}/K_s^0$ and $\bar{p}/p$ production ratios at 0.9 and 7 TeV.

1 Introduction

The LHCb experiment at the CERN LHC [1] is dedicated to heavy flavour physics, its primary goal being to look for New Physics through precise measurements of CP violation and rare decays in the b and c-hadrons. To make use of the large and correlated b$\bar{\text{b}}$ quark production in the forward region, the LHCb detector is designed as a forward single arm spectrometer with a coverage in the range of 15-300(250) mrad in the bending (non-bending) plane. For the 2010 data taking, LHCb was fully installed and all the subsystems were operating with high efficiency. Adding to the first 6.8 μb^{-1} at 0.9 TeV in the pilot run of 2009, a total of 0.3 nb^{-1} and 40 pb^{-1} of pp collision data at centre of mass energies of 0.9 TeV and 7 TeV, respectively, have been recorded in 2010.

The first LHCb results are related to light hadron production measurements, taking advantage of the fact that LHCb is the only LHC experiment fully instrumented in the forward region. This unique setup allows production measurements in a region of phase space where hadronisation models have been extrapolated not only in energy but also in rapidity. Measurements of the K_S^0 cross-section [2], the first LHCb publication, were followed by the ratios of V^0 particles [3] and $\bar{p}$ to p production [4] and are presented here. The J/ψ [5] and open charm cross-section results [6] opened the way towards the LHCb benchmark measurements. The first b-physics result, the b cross-section measurement, has also been published recently [7].

In what follows the LHCb results for the light hadron production are compared to two different Monte Carlo generated samples: the LHCb Monte Carlo [8] where the pp interaction is modeled using PYTHIA 6 [9], while the decay of the emerging particles is described by EvtGen [10] and the Perugia 0 [11] tuning of PYTHIA 6.

2 K_S^0 production

The K_S^0 production represented an ideal first measurement for LHCb as a high-purity sample could be obtained without using particle identification information[1]. The 6.8 μb^{-1} of data recorded in the pilot run in 2009 provided the very first K_S^0 cross-section measurement at the 0.9 TeV center of mass interaction energy. As one can see from Figure 1 the rapidity, y, and the transverse momentum, p_T, range were also extended towards low p_T and high y compared to the previous measurements. In general the agreement is reasonable, given the range of centre-of-mass energies and that the results are averaged over different ranges in rapidity or pseudorapidity.

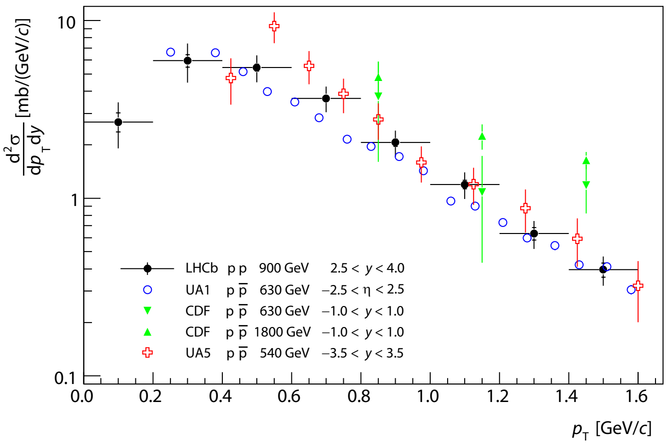

Figure 1: Absolute measurements of the prompt K_s^0 production cross-section as a function of transverse momentum p_{T}, performed by the UA1 [12], UA5 [13], CDF [14] and LHCb experiments, at different high-energy hadron colliders and in different rapidity (y) or pseudo-rapidity (η) ranges; for LHCb the tick marks on the error bars represent statistical uncertainties and the black horizontal line represents the width of the p_t bin.

The LHCb results presented in bins of y and p_T, Figure 2, represent an important input for the hadronization models and consequently for the tuning of the Monte Carlo generators. The different Monte Carlo predictions agree reasonably well with the data, although they tend to underestimate (overestimate) the measured production in the highest (lowest) p_T bins. In this analysis the main systematic contributions were given by the luminosity measurement, 12%, and by the tracking efficiency, 10% in the most challenging bins [2].

3 Baryon suppresion and baryon transport

To provide input for testing and building hadronisation models, ratios of the light particle production were measured: $\bar{\Lambda}/K_S^0$ to investigate the baryon suppression in the strange particle

[1] Samples of K_S^0 and Λ were used for the particle identification calibration.

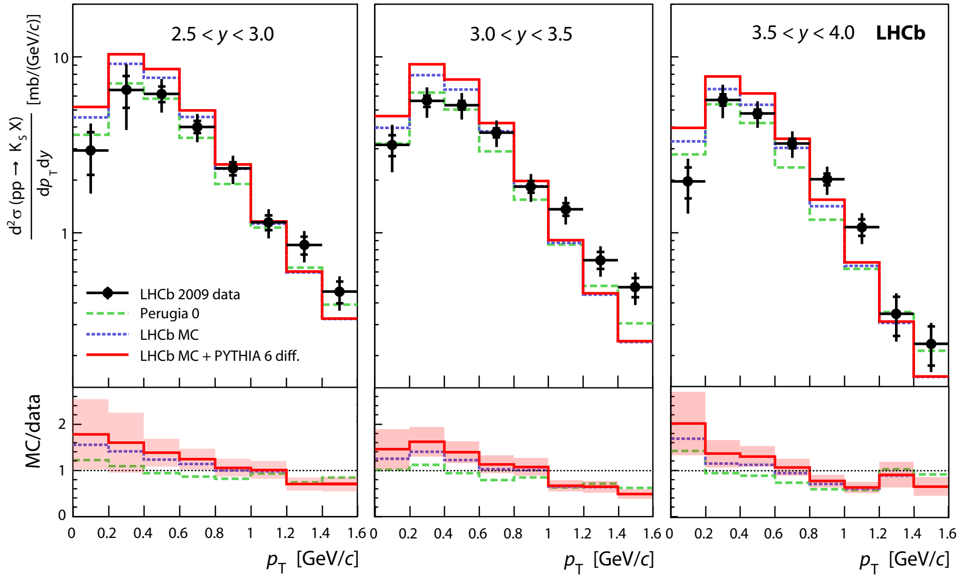

Figure 2: Double-differential prompt K_s^0 production cross-section in pp collisions at $\sqrt{s} = 0.9$ TeV as a function of transverse momentum $p_{\rm T}$ and rapidity y. The points represent LHCb data, with total uncertainties shown as vertical error bars and statistical uncertainties as tick marks on the bars. The histograms are predictions from LHCb Monte Carlo and Perugia 0 tuning of PYTHIA 6. The lower plots show the Monte Carlo/data ratios, with the shaded band representing the uncertainty for one of these ratios, dominated by the uncertainty on the measurements (the relative uncertainties for the other ratios are similar).

production; and $\bar{p}/p$, $\bar{\Lambda}/\Lambda$ for the study of the baryon transport in the pp interaction.

High-purity, prompt K_s^0, Λ and $\bar{\Lambda}$ samples were selected based on a Fisher discriminant constructed using the impact parameters of the V^0 particles and of their daughters [3]. The selection requirement of a primary vertex ensured that only the V^0 coming from non-diffractive events are kept[2]. The results presented here are from data corresponding to 0.31 nb^{-1} at $\sqrt{s} = 0.9$ TeV and 0.2 nb^{-1} at $\sqrt{s} = 7$ TeV.

From Figure 3 and Figure 4 one can see that $\bar{\Lambda}/K_S^0$ ratio is higher than expectation at both energies, while $\bar{\Lambda}/\Lambda$ measurements lie significantly under Monte Carlo predictions at 0.9 TeV. Reasonable agreement for $\bar{\Lambda}/\Lambda$ is observed at 7 TeV where the theoretical prediction for the ratio is very close to one. The same value of rapidity is effectively further away from the beam at 7 TeV than at 0.9 TeV, see Figure 6.

15 million events at $\sqrt{s} = 0.9$ TeV and 13 million events at $\sqrt{s}$ =7 TeV were used to measure the $\bar{p}/p$ ratios. The hadron particle identification was calibrated using samples of pions and protons obtained from $K_S^0 \to \pi^+\pi^-$ and $\Lambda \to p\pi^-$ selected with kinematic cuts only and samples of charged kaons from the $\phi \to K^+K^-$ decay with one track identified by RICH and

[2]Model based definition taking in to account the diffractive events as simulated in the framework of PYTHIA 6 [9] and PYTHIA 8 [15].

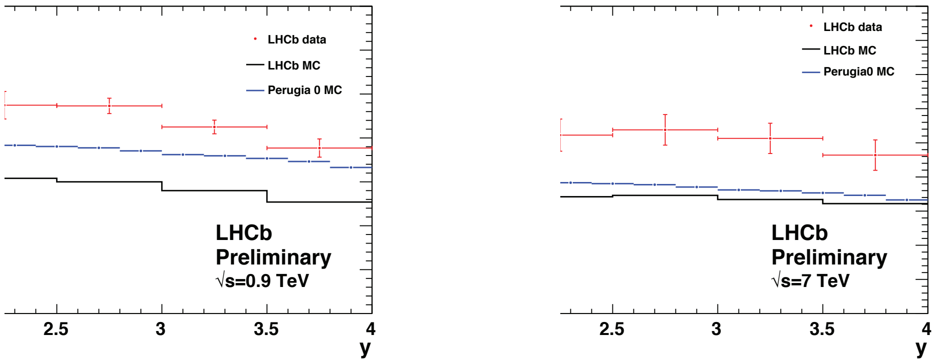

Figure 3: The $\bar{\Lambda}/K_s^0$ ratio as a function of rapidity is shown (left) at $\sqrt{s}$ = 0.9 TeV and (right) at $\sqrt{s}$ =7 TeV. For the data points the error bars are the quadratic sum of statistical and systematic uncertainties. Data are compared to LHCb Monte Carlo and PYTHIA 6 Monte Carlo generator with Perugia 0 tuning.

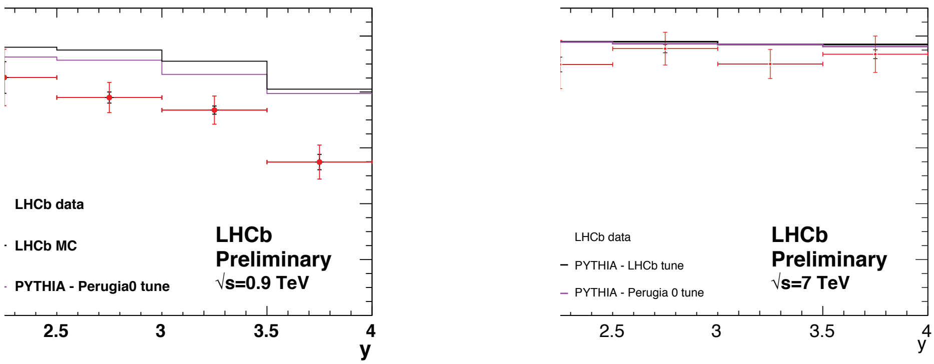

Figure 4: The $\bar{\Lambda}/\Lambda$ ratio as a function of rapidity is shown (left) at $\sqrt{s}$ = 0.9 TeV and (right) at $\sqrt{s}$ =7 TeV. For the data points the error bars are the quadratic sum of statistical and systematic uncertainties. Data are compared to LHCb Monte Carlo and PYTHIA-6 Monte Carlo generator with Perugia 0 tuning.

the other one left unbiased for particle identification measurements. High purity (anti)proton samples (90-95%) were obtained over the full LHCb acceptance. Similar to the baryon transport pattern for $\bar{\Lambda}/\Lambda$ the $\bar{p}/p$ shows a big deviation in ratio from unity at low energy (except of the highest p_t bin), Figure 5. At 7 TeV, there is reasonable agreement observed with both tunings of the PYTHIA Monte Carlo event generator.

Ratios benefit from reduced systematic uncertainties since an absolute luminosity measurement is not required. Most of the systematics cancel in the ratios and remaining systematics relate mainly to Monte Carlo data comparisons for the V^0 ratios and the finite statistics of RICH calibration sample for the $\bar{p}/p$. The measurements are systematically limited with a 2%

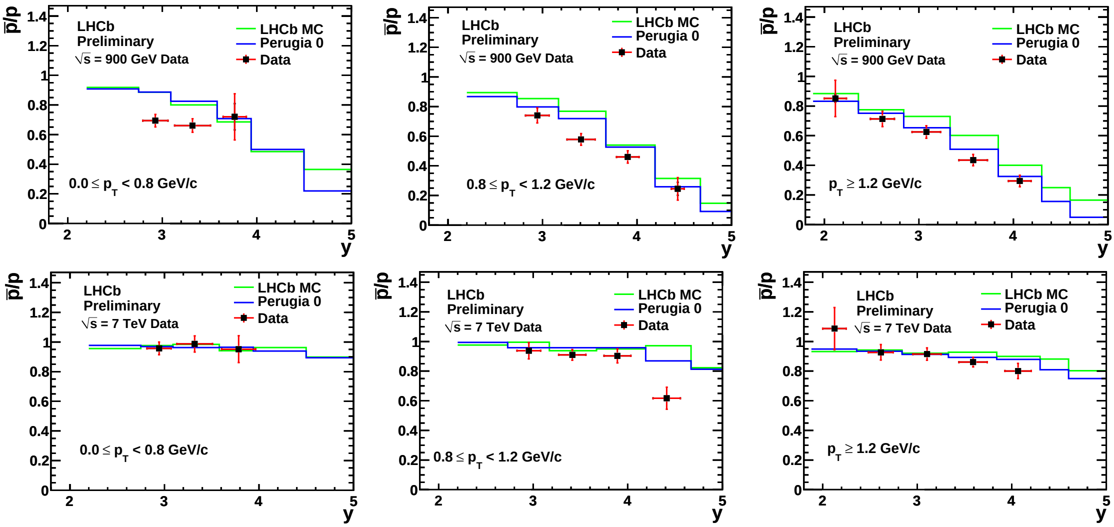

Figure 5: Distribution of the ratio $\bar{p}/p$ against y after corrections for reconstruction biases: up at $\sqrt{s} = 0.9$ TeV, down at $\sqrt{s} = 7$ TeV

error for $\bar{\Lambda}/\Lambda$, 2-12% for $\bar{\Lambda}/K^0_S$ and 3-14% for $\bar{p}/p$.

To compare the results obtained by LHCb at 0.9 TeV and 7 TeV and to probe scaling violations by comparing these results with previous experiment findings we studied also the baryon transport distributions as a function of the distance in units of rapidity to the beam (rapidity loss):

$$\Delta y = y_b - y \tag{1}$$

were y is the rapidity of the (anti)baryon and y_b the rapidity of the beam. Figure 6 shows the ratio of $\bar{\Lambda}/\Lambda$ and $\bar{p}/p$ as a function of Δy. The LHCb measurements of $\bar{\Lambda}/\Lambda$ at the two energies are consistent and are compatible with the measurements from STAR. For the $\bar{p}/p$, a good agreement with the previous results is observed if the same p_t range is covered (high p_t).

4 Summary

LHCb has analysed minimum bias data exploiting the unique rapidity and transverse momentum acceptance of the experiment. A first K_s cross-section measurement at 0.9 TeV was produced, the rapidity covered being extended at low transverse momentum and high rapidity compared to any of the previous experimental results. Preliminary measurements for ratios of V^0 and protons suggest lower baryon suppression and higher baryon transport in data than in the Monte Carlo models investigated. The LHCb data are consistent with data from lower energy experiments.

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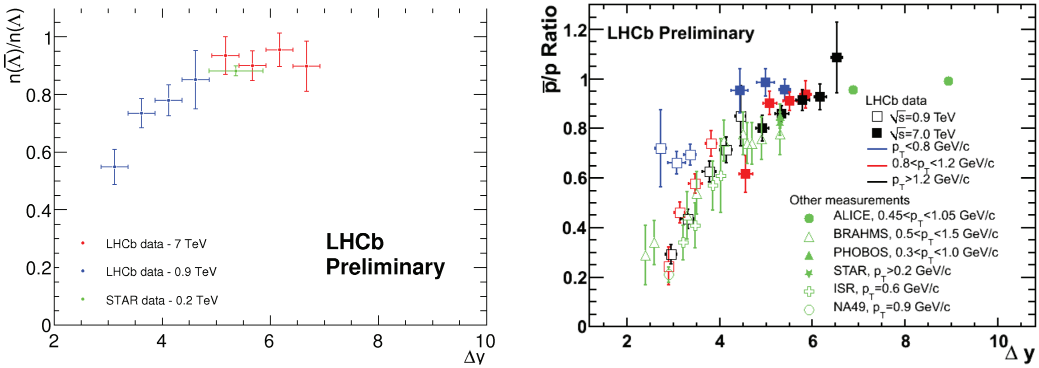

Figure 6: Left: The LHCb $\bar{\Lambda}/\Lambda$ ratio versus Δy is compared to a single data point from the STAR Collaboration [16]; Right: Measurements of the $\bar{p}/p$ ratio performed by LHCb and other experiments [17, 18, 19, 20, 21, 22, 23], plotted versus Δy. The error bar in all cases represents the total uncertainty, apart from the points marked ISR, where it signifies the statistical uncertainty alone. The region in Δy between 2 and 4.5 corresponds to the LHCb measurements at 0.9 TeV, while the region between 5 and 7.0 corresponds to the LHCb measurements at 7 TeV.

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