Electroweak and QCD measurements at LHCb

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Abstract. The LHCb experiment at the LHC is fully instrumented over a unique pseudo-rapidity range in the forward region. Although it has been designed for $b$-physics, LHCb is able to provide valuable informations on particle production in this region of phase space. We summarize in this paper the electroweak bosons production measurement performed at $\sqrt{s} = 7$ TeV during the first half of 2010 data taking and the $\bar{\Lambda}/\Lambda$, $\bar{\Lambda}/K^0_s$ and $\bar{p}/p$ production ratios measurements performed at $\sqrt{s} = 900$ GeV and $\sqrt{s} = 7$ TeV.

1. Introduction
The LHCb experiment is dedicated to CP violation measurements and rare decays involving $b$ and $c$-hadrons at the LHC [1]. Since most of the correlated $b\bar{b}$ pairs are produced at low angle with respect to the beam line, the LHCb detector has been designed as a single arm spectrometer instrumented over the $2 < \eta < 5$ pseudo-rapidity range. This unique coverage of the forward region, together with excellent tracking and particle identification performances allows the probing of particle production at the LHC in an uncharted region of phase space.

Theoretical predictions on $W$ and $Z$ production have uncertainties of between 3% and 10%, depending on rapidity, where the dominant uncertainty is due to knowledge of the parton distribution functions (PDFs). A precise measurement of their production at the LHCb would provide input to constrain the PDFs, both in the unique forward region ($\eta > 2.5$), and in a rapidity region which is in common to ATLAS and CMS ($2 \leq \eta \leq 2.5$). $W$ and $Z$ production cross sections, as well as cross section ratios and $W$ charge asymmetry, have been measured in LHCb using approximately 16.5 pb$^{-1}$ recorded in 2010 at $\sqrt{s} = 7$ TeV [2] and are summarised in this paper.

Hadron production measurements in this region also give important inputs to tune the hadronisation models in the LHCb acceptance, since these models have been extrapolated from measurements performed in a different energy and rapidity regime. Production cross-section of several particles have been measured at the LHCb. $K^0_s$ cross section measurement at $\sqrt{s} = 900$ GeV [3] and $\phi$ cross section measurement at $\sqrt{s} = 7$ TeV [4] probe strangeness production. $J/\psi$ [5], $\psi(2S)$ [6], prompt charm [7] and $b$ [8] cross section measurements at $\sqrt{s} = 7$ TeV probe heavy flavour production. We present here the measurements of light particle production ratios: $\bar{\Lambda}/\Lambda$, $\bar{\Lambda}/K^0_s$ [9] and $\bar{p}/p$ [10] both at $\sqrt{s} = 900$ GeV and $\sqrt{s} = 7$ TeV.

1 On behalf of the LHCb Collaboration
2. Electroweak measurements

2.1. Production cross sections

Muons are selected in the pseudo-rapidity range \(2 < \eta < 4.5\). They are required to have \(p_T > 20 \text{ GeV/c}\) and good track quality and momentum measurement. \(Z \to \mu\mu\) candidates are made out of two such muons with the di-muon mass in the range \(81 \leq M_{\mu\mu} \leq 101 \text{ GeV/c}^2\), while \(W \to \mu\nu\) candidates require the muon to be prompt and isolated to reduce heavy flavour background [2]. All efficiencies are determined on data with tag and probe methods.

Considered backgrounds for \(Z \to \mu\mu\) candidates are \(Z \to \tau\tau\), b and c events with two semi-leptonic decays, and generic QCD events with misidentified muons. For \(W \to \mu\nu\), the considered backgrounds are \(Z \to \mu\mu\) with one muon outside acceptance, \(Z \to \tau\tau\), \(W \to \tau\nu\), b and c events with a semi-leptonic decay and generic QCD events. The fits of the candidates’ distributions shown in Figures 1 and 2, allow to extract the number of signal candidates and backgrounds which are reported on Table 1. \(Z \to \mu\mu\) backgrounds are found to be negligible after the selection.

![Figure 1. Invariant mass of the selected Z candidates.](image1)

![Figure 2. Transverse momentum of the muon of selected W candidates. Left for negative muons and right for positive muons.](image2)

| \(Z \to \mu\mu\) | \(W^+ \to \mu^+\nu\) | \(W^- \to \mu^-\bar{\nu}\) |
|-----------------|----------------|-----------------|
| Number of signal candidates | 883 | 7624 | 5732 |
| Number of background candidates | 1.2 ± 1.2 | 2194 ± 150 | 1654 ± 150 |

We find:

\[
\sigma_{Z}(2. < \eta_\mu < 4.5, p_T^\mu > 20, 81 < m_Z < 101) = 73 \pm 4 \pm 7 \text{ pb}, \\
\sigma_{W^+}(2. < \eta_\mu < 4.5, p_T^\mu > 20) = 1007 \pm 48 \pm 101 \text{ pb}, \\
\sigma_{W^-}(2. < \eta_\mu < 4.5, p_T^\mu > 20) = 680 \pm 40 \pm 68 \text{ pb}.
\]

where the first uncertainty is statistical and systematic (except luminosity) combined and the second is systematic due to absolute luminosity measurement.
It is interesting to note that all systematic uncertainties related to efficiencies are limited by the amount of statistics available to the tag and probe method. The uncertainty from background estimation is related to the knowledge of the background shapes, while the dominant 10% uncertainty comes from the absolute luminosity measurement [11]. All systematic uncertainties are expected to improve significantly in the update of the analysis.

2.2. Cross section ratios
Several cross-section ratios have been computed, as shown in Figure 3. In this case the systematics are reduced since the contribution of the absolute luminosity measurement cancels. The W charge asymmetry has also been evaluated:

\[ A_W = \frac{\sigma_W^+ - \sigma_W^-}{\sigma_W^+ + \sigma_W^-} \]

It is shown in five bins of rapidity in Figure 4. The main theory uncertainties on the predictions arise from the knowledge of u and d quark PDFs. It has been shown that this measurement already reduces the uncertainty at high x on the PDFs for NNPDF2.1 [12]. Improved constraints are expected from the update of the analysis.

3. Soft QCD measurements
3.1. \( \bar{\Lambda}/\Lambda \) and \( \bar{\Lambda}/K^0_s \) ratios
The ratio of the production cross-sections of baryon/anti-baryon, such as \( \bar{\Lambda}/\Lambda \), allow to study the baryon-number transport from the beam particles to the final state. \( \bar{\Lambda}/K^0_s \) ratio on the other hand is a measure of the baryon to meson suppression, which is a good test for different fragmentation models.
High purity sample of prompt $K_0^0$ decaying into $\pi^+\pi^-$ and $\Lambda$, $\bar{\Lambda}$ decaying into $p\pi$ are selected based on a Fisher discriminant combining the impact parameter of the $V^0$ particles and their daughters. Only events with one primary vertex are selected to avoid diffractive event contribution [9]. No particle identification is used here.

Systematics are reduced since the major uncertainty, coming from absolute luminosity measurement, cancels through the ratio. Remaining source of systematics comes from kinematic correction of the Monte Carlo simulation used to evaluate selection efficiency, uncertainty in the interaction with material and diffractive events pollution. Depending on the bins in $\eta$ and $p_T$, they add up to 0.02-0.06 for $\bar{\Lambda}/\Lambda$ and 0.02-0.03 for $\bar{\Lambda}/K_0^0$.

The measurement is performed with 0.3 nb$^{-1}$ at $\sqrt{s} = 900$ GeV and 1.38 nb$^{-1}$ at $\sqrt{s} = 7$ TeV. $\bar{\Lambda}/\Lambda$ is in rather good agreement with Perugia 0 tune for Pythia at low rapidity while at high rapidity, extreme models of baryon transport seams to be favoured [13], see Figure 5. This behaviour is observable both at $\sqrt{s} = 900$ GeV and $\sqrt{s} = 7$ TeV.

$\bar{\Lambda}/K_0^0$ shows an excess over the whole range of rapidity and at both center of mass energy, see Figure 6.

Figure 5. The production cross-section ratio $\bar{\Lambda}/\Lambda$ at $\sqrt{s} = 900$ GeV and $\sqrt{s} = 7$ TeV as a function of rapidity compared with the predictions of the LHCb MC tune [14], Perugia 0 and Perugia NOCR [13]. Vertical lines show the combined statistical and systematic uncertainties and the short horizontal bars (where visible) show the statistical component.

Figure 6. The production cross-section ratio $\bar{\Lambda}/K_0^0$ at $\sqrt{s} = 900$ GeV and $\sqrt{s} = 7$ TeV as a function of rapidity compared with the predictions of the LHCb MC tune [14], Perugia 0 and Perugia NOCR [13]. Vertical lines show the combined statistical and systematic uncertainties and the short horizontal bars (where visible) show the statistical component.
3.2. $\bar{p}/p$ ratio

Further tests of the baryon number transport have been performed by measuring the $\bar{p}/p$ production ratio. The measurement is done with $0.3\text{ nb}^{-1}$ at $\sqrt{s} = 900\text{ GeV}$ and $0.2\text{ nb}^{-1}$ at $\sqrt{s} = 7\text{ TeV}$, [10].

Prompt protons with $p > 5\text{ GeV}/c$ are selected, exploiting the powerful hadronic separation capabilities of the LHCb RICH system, in order to prevent $K$ and $\pi$ contamination. The performance of the particle identification is calibrated on kinematically isolated samples of $\phi \rightarrow K^+K^-$, $K_s \rightarrow \pi^+\pi^-$ and $\Lambda \rightarrow p\pi$.

The main systematic comes from cross contamination between $p$, $K$ and $\pi$ to the level of 2% to 10% at high rapidity. Results are consistent with Monte Carlo models at $\sqrt{s} = 7\text{ TeV}$ but differ significantly at $\sqrt{s} = 900\text{ GeV}$, especially at low $p_T$, as shown in Figure 7. They show a similar behaviour when compared to fragmentation models as the $\bar{\Lambda}/\Lambda$ results.

![Figure 7](https://example.com/figure7.png)

**Figure 7.** Distribution of the ratio $\bar{p}/p$ against rapidity, for different $p_T$ ranges. Up for $\sqrt{s} = 900\text{ GeV}$, down for $\sqrt{s} = 7\text{ TeV}$. Data are compared with the predictions of the LHCb MC tune [14] and Perugia 0 [13].

3.3. Comparison with other experiments

Another way to present the results of baryon transport number is to show the ratio of antibaryon to baryon as a function of the rapidity loss, $\Delta y = y_{beam} - y$ with $y_{beam}$ the rapidity of the incoming beam. It allows the comparison of the LHCb results with those of the previous experiments. Figure 8 shows that the LHCb measurement is in good agreement with the previous measurements.
4. Conclusions

The cross-sections and ratios of W and Z bosons have been measured using 16.5 pb$^{-1}$ of data. The luminosity uncertainty of 10% dominates the precision of the cross-section measurements. This luminosity uncertainty cancels in the cross-section ratios, which provide a more precise test of Standard Model predictions and probe of parton density functions. All results are consistent with NLO predictions. Preliminary measurements for ratios several neutral hadrons 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.

The first studies with data from the 2009 and 2010 runs showed that the LHCb experiment is ready for its core physics program. Early data were used to measure particle production in an unexplored region of phase space, producing valuable inputs for the tuning of Monte-Carlo models and for constraining PDFs.

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