Vol. 42 (2011) *ACTA PHYSICA POLONICA B* No 7

W AND Z PRODUCTION IN THE FORWARD REGION AT LHCb*

Katharina Müller

for the LHCb Collaboration

Physikinstitut der Universität Zürich
Winterthurerstrasse 190, 8057 Zürich, Switzerland

(Received April 29, 2011)

Results are presented on the production of $Z \to \mu\mu$ and $W \to \mu\nu$ in the forward region at LHCb. The analysis is based on an integrated luminosity of 16.5 ± 1.7 pb^{-1}. The production cross-section for Z with muons in the pseudorapidity range $2 < \eta_\mu < 4.5$ and $81 < m_Z < 101$ GeV is $74 \pm 2 \pm 3 \pm 7$ pb and is also measured differentially in rapidity of the Z. The total cross-section for W production is $\sigma_{W^+}(2 < \eta < 4.5) = 1007 \pm 48 \pm 101$ pb and $\sigma_{W^-}(2 < \eta < 4.5) = 680 \pm 40 \pm 68$ pb in the lepton pseudorapidity range $2 < \eta < 4.5$. The charge asymmetry is measured as a function of the lepton pseudorapidity. All results are in agreement with next to leading order perturbative QCD predictions.

DOI:10.5506/APhysPolB.42.1531
PACS numbers: 12.15.–y, 14.70.–e, 14.70.Fm, 14.70.Hp

1. Introduction

The LHCb [1] experiment is one of the four experiments at the Large Hadron Collider (LHC) and is designed for CP violation and rare decay studies in the heavy quark sector. It also provides an important contribution to the study of electroweak processes at the LHC energies such as W, Z and Drell–Yan production. At LHC both B hadrons from $b\bar{b}$ production are predominantly produced in forward and backward direction, therefore LHCb has been constructed as a forward single-arm spectrometer. The experiment has successfully taken data in proton–proton collisions at a centre of mass energy of 7 TeV since March 2010. Due to its unique pseudorapidity[1] cov-

* Presented at the Cracow Epiphany Conference on the First Year of the LHC, Cracow, Poland, January 10–12, 2011.

[1] The pseudorapidity η is defined to be $\eta = -\ln\tan(\theta/2)$, where the polar angle θ is measured with respect to the beam axis.

erage of $1.9 < \eta < 4.9$ and to the possibility of extending the measurements to low transverse momenta, results are complementary to the measurements at ATLAS and CMS.

Measurements of W and Z cross-sections provide an important test of the standard model at LHC energies. Next-to-next-to-leading order (NNLO) predictions have an uncertainty between 3% and 10% depending on the rapidity, where the dominant theoretical error is due to the knowledge of the parton distribution functions (PDFs). Precise measurements of the cross-sections by LHCb can test the Standard Model and constrain the PDFs, both in regions common to ATLAS and CMS and in the region of $\eta > 2.5$ which is unique to LHCb. The results presented in this contribution are based on an integrated luminosity of 16.5 ± 1.7 pb^{-1}. In this analysis, the W decays to a muon and a neutrino and Z decays to two opposite sign muons have been considered. The data are compared to next-to-leading order (NLO) perturbative QCD predictions. The signal efficiency and background contribution are mostly derived from data.

2. Electroweak boson production at LHCb

Figure 1 shows the kinematic regions probed by events at LHCb with electroweak boson production as a function of the longitudinal momentum fraction x carried by the interacting parton and Q^2, the square of the four momentum exchanged in the scattering process. For particle production processes at LHCb, the momenta of the two interacting partons will be

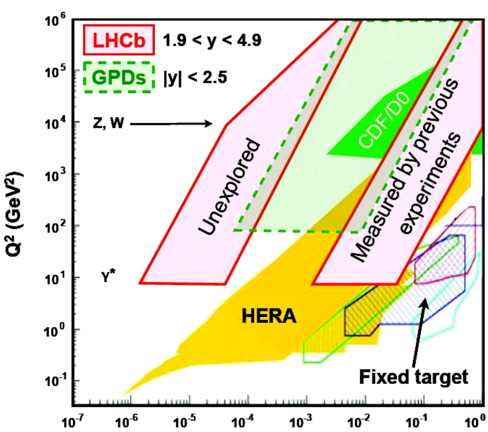

Fig. 1. The kinematic region $x - Q^2$ probed by the LHCb experiment with electroweak boson production together with the region probed by Tevatron, HERA and fixed target experiments.

highly asymmetric, meaning that events at LHCb will simultaneously probe a region at high-x and a currently unexplored region at very low-x which can be probed by Z and W production. The main theoretical uncertainties on the cross-section predictions for electroweak boson production at the LHC is due to the uncertainty on the PDFs. At high x they have been determined from fixed target and HERA data and confirmed at higher Q^2 by W and Z production at the Tevatron. For smaller x values, the PDFs have been measured by HERA alone but at much lower Q^2 from where they must be evolved to the energies probed by LHCb using the DGLAP [2] equations.

3. Selection

Events containing Z or W bosons are selected through a three level hardware and software based trigger that selects events with a muon with a threshold on the transverse momentum $p_{\mathrm{T}} > 10$ GeV.

$Z \to \mu\mu$ candidates are then selected off-line by requiring two identified muons with $p_{\mathrm{T}} > 20$ GeV and $2.0 < \eta < 4.5$, which combine to a mass $81 < m_Z < 101$ GeV. To ensure a good track quality, cuts on the fractional momentum uncertainty and the χ^2 probability of the track are applied. No impact parameter or isolation cut is imposed. In total 833 Z candidates are selected, their mass distribution is shown in Fig. 2.

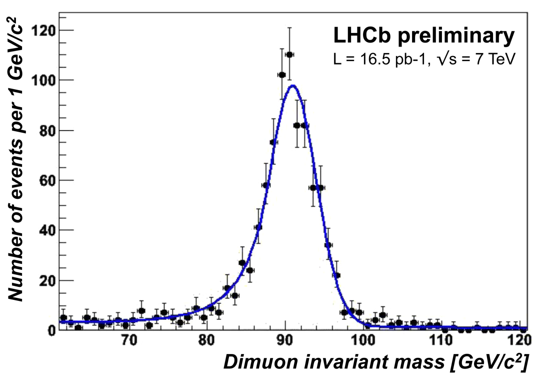

Fig. 2. Invariant mass of the dimuon system. The data points are fitted to a Gaussian on a polynomial background.

$W \to \mu\nu$ candidates are selected by requiring one identified muon with $p_{\mathrm{T}} > 20$ GeV, $2.0 < \eta < 4.5$ and an impact parameter significance $\mathrm{ip}_{\mathrm{sig}}$ less than two. To reduce background from semileptonic b and c decays and from other QCD processes with kaons or pions misidentified as muons due to punch through or decay in flight further cuts are applied on the activity in the rest of the event. The invariant mass of the rest of the event (m_{rest})

is required to be less than 20 GeV, the transverse momentum of the vector sum of all other particles ($p_{\perp\mathrm{rest}}$) to be less than 10 GeV and the transverse vector sum of all tracks inside a cone of 0.5 in $\eta-\phi$ around the muon ($p_{\perp\mathrm{cone}}$) to be less than 2 GeV. These cuts effectively reduce the QCD background. 7624 (5732) W^+ (W^-) candidates are selected with a selection efficiency of $55 \pm 1\%$.

Z events with one muon removed from the event (pseudo-W events) are used to determine the efficiency and purity of the cuts against background in the W sample. Since the cuts on the impact parameter and the activity in the rest of the event are independent of the muon they should have the same characteristic shape for W and Z bosons. Figure 3 shows the m_{rest} and $\mathrm{ip}_{\mathrm{sig}}$ distribution for pseudo-W events in comparison with Monte Carlo distributions for W and pseudo-W events as well as the QCD background distribution. The templates for the QCD background are obtained from data, m_{rest} by a cut on $\mathrm{ip}_{\mathrm{sig}} > 5$ and $\mathrm{ip}_{\mathrm{sig}}$ by requiring $p_{\perp\mathrm{cone}} > 5$ GeV. The agreement between the simulations and the data is qualitatively good and shows that the pseudo-W events from the data can be used to determine the efficiency of the selection cuts.

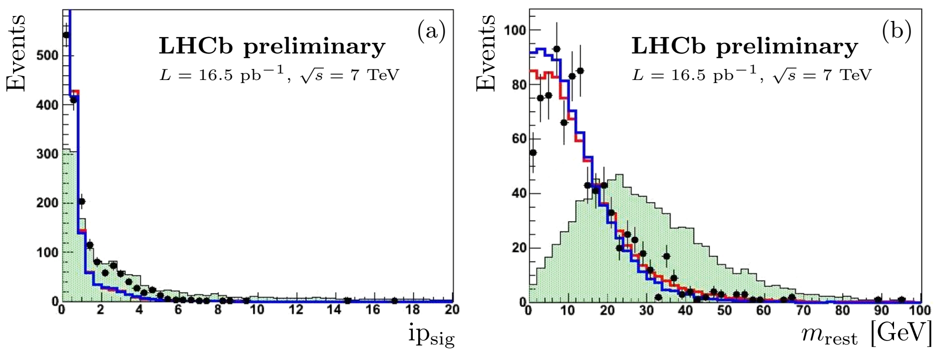

Fig. 3. Distribution of two variables used to select W: (a) the impact parameter significance $\mathrm{ip}_{\mathrm{sig}}$ and (b) the invariant mass of the rest of the event m_{rest}. The points are pseudo-W events from data, the solid (red/blue) histogram is the simulation for the pseudo-W (W) events and the shaded histogram shows the QCD background.

The efficiencies for triggering, muon identification and track finding have all been estimated from data. Since the Z events are required to be triggered by one of the muons, this sample is used to measure the efficiency for the other muon to trigger the event. The efficiency for Z (W) events is $86 \pm 1\%$ ($73 \pm 1\%$), it is found to be flat in η, ϕ and p_{T} and there is no evidence for a charge bias. Track finding and muon identification efficiencies are found by a tag and probe method in the Z sample. The track finding efficiency for Z

events is $83 \pm 3\%$ and slightly lower for the W events due to the harder cuts on the track quality. The muon identification efficiency was measured to be $98 \pm 1\%$.

4. Background

The background for the Z analysis is very low and is estimated to be 1.2 ± 1.2 events in the mass region considered for the measurement. The dominant contribution comes from b and c events with two semileptonic decays. It has been estimated from data by using events with two muons with an impact parameter significance greater than 5.

For the W analysis the background is considerably higher since there is only one high momentum muon required. There are several sources considered: $Z \to \mu\mu$, where one of the muons is outside the LHCb acceptance, $Z \to \tau\tau$ with one of the taus decaying leptonically, $W \to \tau\nu$ where the τ decays to a muon, b and c events with a semileptonic decay to a muon and QCD events with pions or kaons decaying in flight or punch through to the muon stations. The last two contributions, called QCD background, are the dominant background sources. Their contribution is determined by a fit to the transverse momentum distribution of the lepton as shown in Fig. 4. The shapes for the distribution from W and Z production are taken from simulation and the shape for the QCD background is taken from data by selecting a sample with a very small signal contribution by anti-cutting on the selection variables ($\mathrm{ip_{sig}} > 5$, $p_{\perp\mathrm{cone}} > 5$ GeV, $p_{\perp\mathrm{rest}} > 15$ GeV, $m_{\mathrm{rest}} > 40$ GeV).

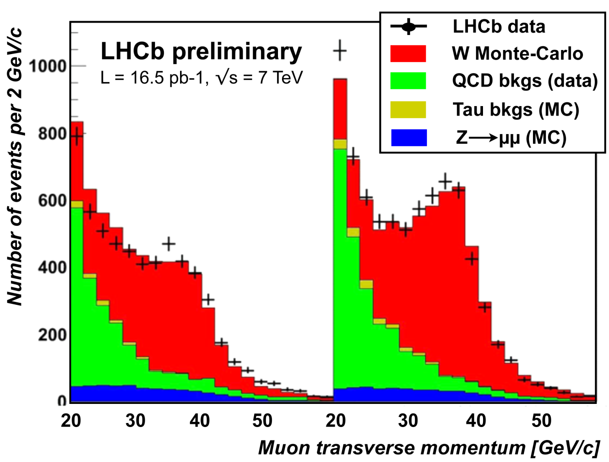

Fig. 4. Distribution of the muon p_{T} for negative (left) and positive (right) charged leptons. The data points are shown in black, the W contribution in grey (red), the Z background in dark grey (blue), the tau background in pale grey (yellow) and the QCD background in light grey (green).

5. Results

The cross-section is defined as

$$\sigma_{Z,W} = \frac{N_{\rm tot}^{Z,W} - N_{\rm bkg}^{Z,W}}{\epsilon^{Z,W} L} \,.$$

Here, $N_{\rm tot}$ is the number of selected candidates, $N_{\rm bkg}$ the number of background events and L the integrated luminosity. The luminosity was determined using a Van der Meer scan [3]. ϵ is the overall efficiency for selecting the events.

The total cross-section for Z with $2 < \eta_\mu < 4.5$ and $81 < m_Z < 101$ GeV is $74 \pm 2 \pm 3 \pm 7$ pb, where the first error is statistical, the second systematic and the third comes from the luminosity determination.

The total cross-section for W production with a muon with $2 < \eta < 4.5$ and $p_{\rm T} > 20$ GeV is $\sigma_{W^+} = 1007 \pm 48 \pm 101$ pb and $\sigma_{W^-} = 680 \pm 40 \pm 68$ pb, here the first error is the statistical error including the systematic uncertainty from the efficiency and purity estimation and the second comes from the luminosity determination.

Figure 5 (a) shows the cross-section for Z production as a function of the rapidity of the Z boson. It is compared to NLO calculations from FEWZ [4] with the MSTW08NLO [5] PDFs which describe the measurement within the errors. The large uncertainty from the luminosity measurement cancels by taking the ratio of W^+/W^- or W/Z. Figure 5 (b) shows the asymmetry $A_\mu = (\sigma(W^+) - \sigma(W^-)/(\sigma(W^+) + \sigma(W^-))$ as a function of the pseudorapidity of the lepton. The NLO prediction from MCFM [6] describes well the asymmetry distribution. The uncertainty of the measurement is comparable

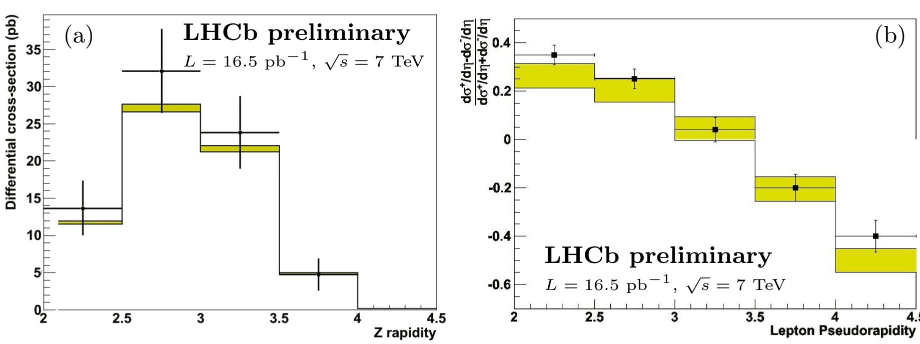

Fig. 5. (a) Z rapidity distribution, the points are data and the histogram the NLO prediction from FEWZ [4]. (b) Lepton asymmetry as a function of the pseudorapidity of the lepton. The data is compared to the NLO prediction from MCFM [6]. The shaded area is the PDF uncertainty.

to the PDF uncertainty of the prediction. The main uncertainty comes from the knowledge of the difference of the up and down valence quark distributions, so with higher statistics this measurement will allow constraints to be placed on the PDFs.

Figure 6 summarises the LHCb measurements of Z and W cross-sections and their ratios by a comparison to the NLO predictions from MCFM. All measurements are consistent with the NLO predictions. With increased statistics these results will provide a very sensitive test of the standard model.

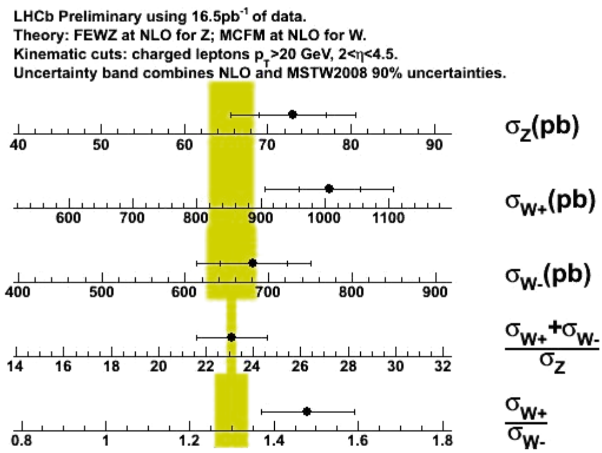

Fig. 6. Z and W cross-sections and rations compared to MCFM [6] NLO predictions using the MSTW08NLO PDFs [5]. The inner error bars combine the statistical and systematic uncertainty. The outer error bar includes the luminosity uncertainty. The yellow error bar is the theoretical uncertainty.

6. Conclusions

Since the LHCb detector is fully instrumented in the forward region, electroweak boson production will explore a unique region in x and Q^2. Using the first data from LHCb, $Z \to \mu\mu$ and $W \to \mu\nu$ cross-sections are measured for muons with a transverse momentum larger than 20 GeV and $2 < \eta_\mu < 4.5$. The results are based on an integrated luminosity of 16.5 ± 1.7 pb^{-1}. All the results are well described by NLO perturbative QCD calculations. With larger statistics these measurements will provide important tests of QCD and will constrain the proton PDFs.

REFERENCES

[1] [LHCb Collaboration], *JINST* **3**, S08005 (2008).

[2] V.N. Gribov, L.N. Lipatov, *Sov. J. Nucl. Phys.* **15**, 43 (1972); G. Altarelli, G. Parisi, *Nucl. Phys.* **B126**, 298 (1977); Yu.L. Dokshitzer, *Sov. Phys. JETP* **46**, 641 (1977).

[3] S. van der Meer, ISR-PO/68-31, KEK68-64.

[4] R. Gavin, Y. Li, F. Petriello, S. Quackenbush, `arXiv:1011.3540v1 [hep-ph]`.

[5] A.D. Martin, W.J. Stirling, R.S. Thorne, G. Watt, *Eur. Phys. J.* **C63**, 189 (2009) [`arXiv:hep-ex/0901.0002v2`].

[6] J.M. Campbell, R.K. Ellis, *Phys. Rev.* **D60**, 113006 (1999) [`arXiv:hep-ph/9905386`]; `http://mcfm.fnal.gov`