PROCEEDINGS OF SCIENCE

W, Z and top production measurements at LHCb

Lorenzo Sestini, on behalf of the LHCb collaboration.[*]
Universitá di Padova e INFN
E-mail: `lorenzo.sestini@cern.ch`

The LHCb experiment offers a complementary phase space region to ATLAS and CMS to study electroweak and QCD processes, thanks to the forward acceptance, with a pseudo-rapidity coverage between 2 and 5, and the large bandwidth trigger at low energy threshold. For this reason at LHCb electroweak and top measurements can provide unique constraints to the Parton Distribution Functions. In these proceedings the latest measurements on W, Z and top production performed during the LHC Run I and Run II data taking are presented.

XXIV International Workshop on Deep-Inelastic Scattering and Related Subjects
11-15 April, 2016
DESY Hamburg, Germany

[*]Speaker.

PoS(DIS2016)050

1. Introduction

Precision measurement involving W and Z bosons are important tests of perturbative QCD and electroweak theory, within the Standard Model (SM). Moreover, they can be used to probe Parton Distribution Functions (PDFs).

LHCb is a forward spectrometer, initially designed for b and c quarks Physics [1]. Within the LHC experiments, LHCb alone provides precision coverage in the forward region of pp collisions corresponding to the $2 \leq \eta \leq 5$ pseudo-rapidity range. At LHCb two different region are available in the $x - Q^2$ phase space, where x is the momentum fraction of the parton and Q^2 is the transferred momentum: the region at low x and high Q^2 is unexplored by other experiments. The LHCb kinematical acceptance in comparison with other experiments is shown in fig. 1.

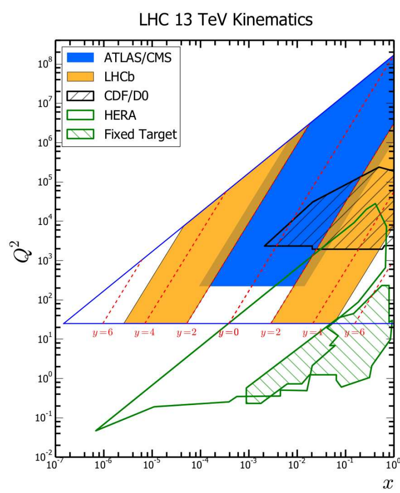

Figure 1: *LHCb acceptance in $x - Q^2$ phase space, in comparison with other experiments.*

2. Measurement of forward W production at $\sqrt{s}$ = 7 and 8 TeV

The measurement of the inclusive $W \to \mu\nu$ production cross-section has been performed by LHCb using data from pp collisions at a centre-of-mass energy of 7 and 8 TeV, corresponding to 1.0 fb^{-1} and 2.0 fb^{-1} of integrated luminosity [2].

The signature of $W \to \mu\nu$ consists of a high transverse momentum (p_T) muon: the fiducial region is defined by a muon with a p_T greater than 20 GeV$/c$ and a pseudo-rapidity in the range $2.0 < \eta < 4.5$. To reduce the background, additional requirements are applied. The muon isolation, defined as the scalar sum of the p_T of charged particles in a cone of radius $R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} =$ 0.5 around the selected muon, has to be less than 2 GeV$/c$. To reduce the background from muons from τ decays or from heavy flavour semileptonic decays, the impact parameter with respect to the pp interaction vertex is required to be less than 40 μm.

The signal yield is determined by simultaneously fitting the p_T spectra of positively and negatively charged muons in data [2]. The electroweak and heavy flavor fractions have been constrained to data-driven estimates and joined between the two fits. The measured W^+ and W^- cross sections as function of the muon pseudo-rapidity at 8 TeV are presented in fig. 2. The results are compared to predictions at NNLO in QCD with different PDF parametrizations. Generally there is a good agreement within the uncertainties, which are dominated by the luminosity uncertainty.

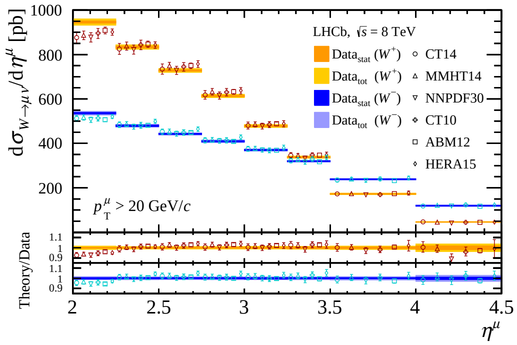

Figure 2: *Measured W^+ and W^- differential cross sections as function of the muon pseudo-rapidity at 8* TeV*, compared with different predictions, obtained using different PDF parametrizations[2].*

3. Measurement of forward Z production at $\sqrt{s}$ = 7, 8 and 13 TeV

The cross sections of $Z \to \mu^+\mu^-$ in the forward region at 7, 8 and 13 TeV in the centre-of-mass energy are based on data samples of respectively 1.0 fb^{-1}, 2.0 fb^{-1} and 294 pb^{-1} of integrated luminosity [3] [2] [4].

The muons must have a pseudo-rapidity in the range $2 < \eta < 4.5$ and $p_T > 20$ GeV$/c$. The selected samples have high purity, greater than 99 %. The low background contamination is evaluated using simulation and data-driven techniques. The measured cross-sections are presented in fig. 3, compared with theoretical predictions: these are in good agreement with data.

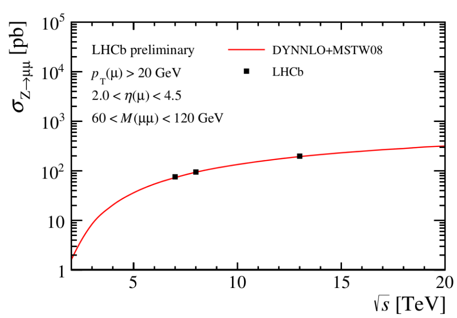

Figure 3: *Comparison of the measured Z cross section at 8, 7 and 13* TeV *with a theoretical prediction.*

4. Measurement of the $W+b$ / c / light-jet cross-section at $\sqrt{s}$ = 7 and 8 TeV

The cross-section measurement of the W boson in association with a jet has been performed

	7 TeV	8 TeV	7 TeV (exp.)	8 TeV (exp.)
$\frac{\sigma(Wb)}{\sigma(Wj)} \times 10^2$	$0.66 \pm 0.13 \pm 0.13$	$0.78 \pm 0.08 \pm 0.16$	$0.74^{+0.17}_{-0.13}$	$0.77^{+0.18}_{-0.13}$
$\frac{\sigma(Wc)}{\sigma(Wj)} \times 10^2$	$5.80 \pm 0.44 \pm 0.75$	$5.62 \pm 0.28 \pm 0.73$	$5.02^{+0.80}_{-0.69}$	$5.31^{+0.87}_{-0.52}$
$\mathscr{A}(Wb)$	$0.51 \pm 0.20 \pm 0.09$	$0.27 \pm 0.13 \pm 0.09$	$0.27^{+0.03}_{-0.03}$	$0.28^{+0.03}_{-0.03}$
$\mathscr{A}(Wc)$	$-0.09 \pm 0.08 \pm 0.04$	$-0.01 \pm 0.05 \pm 0.04$	$-0.15^{+0.02}_{-0.04}$	$-0.14^{+0.02}_{-0.03}$

Table 1: *Measured $W+b$ and $W+c$ cross sections normalized to the W+jet cross section and W charge asymmetry, compared to the Standard Model expectation. The measurements are reported in the first two columns, where the first uncertainty is statistical and the second is systematic. The Standard Model expectations with the theoretical uncertainty are reported in the last two columns.*

by LHCb using 1 fb^{-1} and 2 fb^{-1} of integrated luminosity of pp collisions respectively at a centre-of-mass energy of 7 TeV and 8 TeV [5]. The W bosons are reconstructed in the $W \to \mu^+\nu^-$ decay, where the muons have a p_T greater than 20 GeV$/c$ and a pseudo-rapidity in the range $2.0 < \eta < 4.5$. The jet must have a p_T greater than 10 GeV$/c$ and must be in the range $2.2 < \eta < 4.2$.

In the jets reconstruction, charged and neutral particles are clustered using the anti-k_T algorithm with a distance parameter $R = 0.5$. Jets have to be isolated from W muons, requiring $\Delta R(jet, \mu) > 0.5$. The algorithm described in [6] is used for the identification of secondary vertices (SVs) consistent with the decay of a beauty or charm hadron, using tracks that belong to the jets. By requiring SVs inside the jet, the background originating from light partons is reduced. The number of b/c and light jets is extracted by fitting the distributions of two multivariate discriminators, which exploit properties of the jet and the SVs to separate heavy from light and b from c respectively. The measured $W+b$ and $W+c$ cross sections normalized to the W+jet cross section are presented in table 1, as well as the W charge asymmetry. These results are in agreement with theoretical predictions within the uncertainties.

5. Observation of the quark top in the forward region

LHCb performed the observation of the top in the forward region of pp collisions, studying the $W+b$ final state [10]. This is the first step for measuring the $t\bar{t}$ asymmetry in the forward region, where it is expected to be enhanced and it is more sensitive to some models of new physics contributions with respect to the central region [11]. Forward $t\bar{t}$ events can also be used to constrain PDFs at large Björken x and Q^2. The datasets used for this measurement correspond to pp collisions at 7 TeV and at 8 TeV of center-of-mass energy. The W is identified through an isolated muon with transverse momentum greater than 25 GeV while the jet, identified as originated from a b quark, must have a transverse momentum greater than 50 GeV. In order to measure top production, the number of collected $W+b$ events and the muon charge asymmetry as functions of the $\mu+b$ transverse momentum are fitted with SM templates, as showed in fig 4. The experimental points are consistent with the presence of the top (red bars), with an estimated significance, obtained using the Wilk's theorem, greater than 5-σ, that makes this the first top observation in the forward region. The measured top cross sections at 7 TeV and 8 TeV are compatible with the theoretical predictions within the experimental uncertainties (fig. 5).

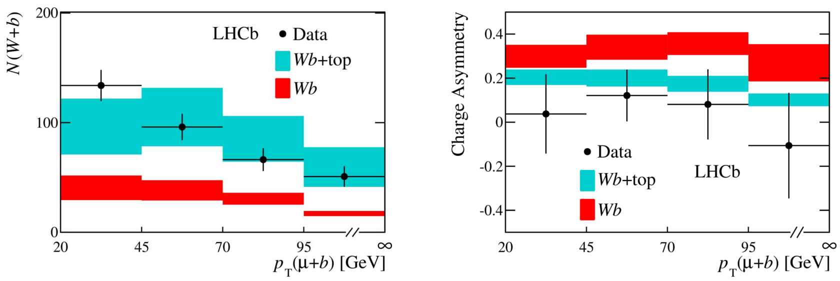

Figure 4: *Number of collected $W+b$ events and the muon charge asymmetry as functions of the $\mu+b$ transverse momentum.*

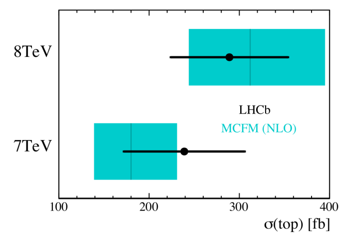

Figure 5: *Comparison of the measured top cross sections at 7 and 8* TeV *with theoretical predictions .*

6. Determination of the effective electroweak mixing angle

The electroweak mixing angle θ_W is a fundamental parameter of the Standard Model electroweak lagrangian: it quantifies the relative strength between the electromagnetic and the weak forces. The determination of the effective electroweak mixing angle by LHCb has been performed by measuring the forward-backward asymmetry (A_{FB}) in the decay $Z/\gamma^* \to \mu^+\mu^-$. The asymmetry is measured in the Collins-Soper frame [7]: an unfolding bayesian technique is applied to obtain the true asymmetry from the raw asymmetry [8]. The measured asymmetry, obtained in bins of dimuon invariant mass, is presented in fig. 6 for the 7 TeV and 8 TeV data sample. A χ^2 comparison is made between simulation samples generated with different values of $\sin^2\theta_W^{\text{eff}}$, and the measured A_{FB} as a function of the dimuon mass. The χ^2 minimum sets the favoured value of $\sin^2\theta_W^{\text{eff}}$ to be

$$sin^2\theta_W^{eff} = 0.23142 \pm 0.00073(stat.) \pm 0.00052(syst.) \pm 0.00056(th.) \tag{6.1}$$

The experimental uncertainty is dominated by momentum biases originated from remaining detector misalignment; the theoretical error is dominated by the PDFs uncertainties. This is the most precise determination of $\sin^2\theta_W^{\text{eff}}$ at the LHC: the forward-backward asymmetry is enhanced in the forward region due to better knowledge of the direction of the colliding quark and anti-quark, consequently giving LHCb greater sensitivity to $\sin^2\theta_W^{\text{eff}}$ than ATLAS and CMS.

7. Conclusions

The latest measurements performed by LHCb including W and Z bosons have been presented:

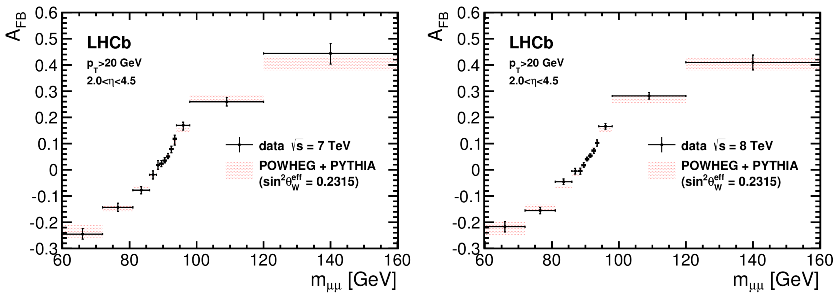

Figure 6: *Measured asymmetry and theoretical prediction in bins of dimuon invariant mass, for the 7* TeV *and the 8* TeV *dataset.*

they are competitive and complementary with the corresponding measurements of the other LHC experiments. The measured W and Z cross sections can provide constraints to PDFs in a unique kinematical region. Thanks to its forward acceptance, LHCb performed the most precise measurement at LHC of the effective electroweak mixing angle. Moreover the first observation of the top quark in the forward region was made.

References

[1] A. A. Alves Jr. *et al.*, *The LHCb detector at LHC*, JINST 3 (2008) S08005.

[2] R. Aaij *et al.*, *Measurement of forward W and Z bosons production in pp collisions at 8* TeV, JHEP 01 (2016) 155.

[3] R. Aaij *et al.*, *Measurement of the forward Z boson production cross section in pp collisions at $\sqrt{s}$ = 7* TeV, JHEP 08 (2015) 039.

[4] R. Aaij *et al.*, *Measurement of the $Z \to \mu^+\mu^-$ production cross section at forward rapidities in pp collisions at $\sqrt{s}$ = 13* TeV, LHCb-CONF-2016-002.

[5] R. Aaij *et al.*, *Study of W boson production in association with beauty and charm*, Phys. Rev. D92 (2015) 052001.

[6] R. Aaij *et al.*, *Identification of beauty and charm quark jets at LHCb*, JINST 10 (2015) P06013.

[7] J. Collins and D. Soper, *Angular distribution of dileptons in high-energy hadron collisions*, Phys. Rev. D 16 (1977) 2219.

[8] G. D'Agostini, *A multidimensional unfolding method based on Bayes theorem*, Nucl. Instrum. Meth. A362 (1995) 487.

[9] LHCb collaboration, R. Aaji *et al.*, *Measurement of the forward-backward asymmetry in $Z/\gamma^* \to \mu^+\mu^-$ decays and determination of the effective weak mixing angle*, JHEP 11 (2015) 190.

[10] R. Aaij *et al.*, *First observation of top quark production in the forward region*, Phys. Rev. Lett. 115, 112001 (2015).

[11] A. L. Kagan *et al.*, *Probing new top physics at the LHCb experiment*, Phys. Rev. Lett. 107, 082003 (2011).