PROCEEDINGS OF SCIENCE

Recents results on electroweak boson production at LHCb

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The LHCb experiment offers a complementary phase space to ATLAS and CMS to study electroweak processes, thanks to the forward acceptance and the large bandwidth of the trigger allowing low energy thresholds. For this reason electroweak measurements at LHCb can provide unique constraints to the Parton Distribution Functions. In these proceedings the latest measurements on W and Z bosons production performed during the LHC Run I and Run II data taking are presented.

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1. Introduction

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.

In both LHC Run I and Run II LHCb demonstrated its capability in electroweak physics and jet physics as a general purpose forward detector. Precision measurements 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).

At LHCb two different region are available in the $x - Q^2$ phase space, where x is the momentum fraction of proton momentum taken by the parton and Q^2 is the transferred momentum between the partons that participate to the hard interaction: the region at low x and high Q^2 is unexplored by other experiments. The coverage of the phase space in $\sqrt{s}$ = 13 TeV collisions by the different LHC experiments is shown in Fig. 1.

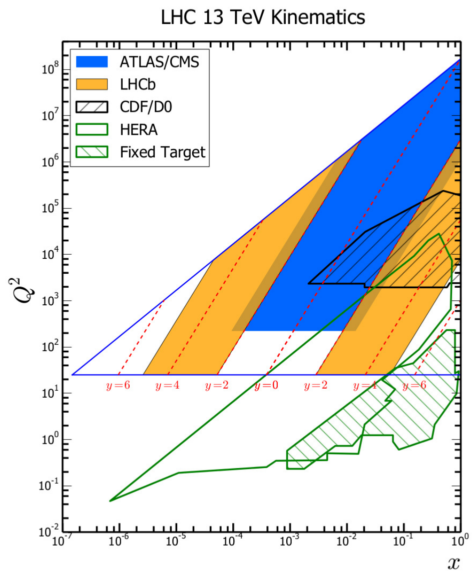

Figure 1: *LHCb acceptance in $x - Q^2$ phase space, in comparison with other experiments.*

2. Measurement of forward Z production at $\sqrt{s}$ = 13 TeV

LHCb performed the measurement of the Z boson production cross-section at the LHC, reconstructing the $Z \to \mu^+\mu^-$ and $Z \to e^+e^-$ decays in pp collisions at $\sqrt{s}$ = 13 TeV [2]. This measurement used a data sample of 294 pb^{-1} of integrated luminosity.

The muons of the final state are selected with pseudo-rapidity in the range $2 < \eta < 4.5$ and transverse momentum $p_{\text{T}} > 20$ GeV$/c$. The electrons must have $2 < \eta < 4.25$ and $p_{\text{T}} > 20$ GeV$/c$. In addition, the di-lepton invariant mass must be in the $60 < m_{ll} < 120$ GeV$/c^2$ range. The low background contamination has been evaluated using simulation and data-driven techniques,

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obtaining purities of 99.2 % and 92.2 % for the muon and electron final states, respectively. Thanks to the high statistics of the collected data samples it has been possible to measure the differential cross-sections as a function of the Z boson kinematic observables.

The integrated $Z \to \mu^+\mu^-$ and $Z \to e^+e^-$ cross sections are shown in Fig. 2, compared with theoretical predictions obtained with next-to-next-to-leading-order (NNLO) perturbative QCD and with different sets of PDFs. The measurements are compatible with the prediction and the measured $Z \to \mu^+\mu^-$ and $Z \to e^+e^-$ cross sections are compatible within themselves: this can also be considered as a test of Lepton Flavour Universality.

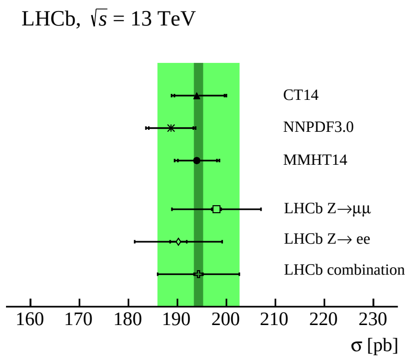

Figure 2: *Integrated $Z \to \mu^+\mu^-$ and $Z \to e^+e^-$ cross sections compared with theoretical predictions.*

3. Measurement of the $W \to e\nu$ production at $\sqrt{s}$ = 8 TeV

LHCb performed the measurement of the $W \to e\nu$ boson production cross-section at the LHC in pp collisions at $\sqrt{s}$ = 8 TeV [3]. This measurement used a data sample of 2 pb^{-1} of integrated luminosity. Electrons candidates must have $2 < \eta < 4.25$ and $p_T > 20$ GeV$/c$ and a certain degree of isolation with respect to other particles is also required. The purity of the $W^{\pm}$ samples has been obtained with fits to the electron p_T distribution. The cross section has been measured as a function of the electron pseudorapidity, the results are shown in Fig. 3. They are compatible with theoretical predictions calculated with different PDFs sets.

4. Measurement of the W and Z bosons production in association with a jet at $\sqrt{s}$ = 8 TeV

The cross-section measurement of the W and Z boson production in association with a jet has been performed by LHCb using 2 fb^{-1} of integrated luminosity of pp collisions at a centre-of-mass energy of 8 TeV [4]. The W and Z bosons are reconstructed in the $W \to \mu^+\nu^-$ and $Z \to \mu^+\mu^-$ decays, 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 associated jet is reconstructed using the anti-k_t algorithm with a distance parameter of 0.5 and is required to have p_T greater than 20 GeV$/c$ and must be in the range $2.2 < \eta < 4.2$.

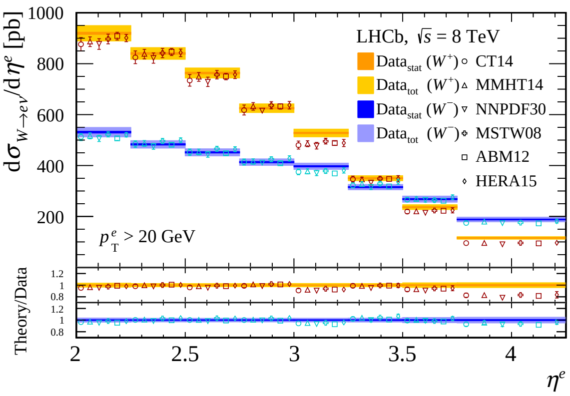

Figure 3: *Measured $W \to e\nu$ cross-section as a function of the electron pseudorapidity compared with theoretical predictions.*

The purity of the W^++jet and W^-+jet samples has been evaluated by fitting the distribution of the muon isolation, defined as the p_T of the muon, divided for the p_T of the jet that contains the signal muon after performing a jet reconstruction with relaxed jet selection requirements. This observable gives a good separation between signal and background. The purity of the Z+jet sample has been evaluated by using background-enhanced data samples and simulation samples.

The cross-sections have been measured as a function of the jet and muons kinematic: as examples the Z+jet cross-section as a function of the jet p_T and the $W^+(W^-)$+jet cross-section as a function of the jet η are both shown in Fig. 4. The systematic uncertainties are dominated by the purity determination and by the uncertainty on the jet energy scale. As shown in the figure data are compatible with the theoretical predictions.

5. Measurements of the $W+b\bar{b}$ and $W+c\bar{c}$ production in the forward region

LHCb performed the observation of the $W+b\bar{b}$ production and the first measurement of the $W+c\bar{c}$ process in pp collisions, with a significance very close to 5σ, using a sample of 2 fb^{-1} of integrated luminosity collected at $\sqrt{s}$ = 8 TeV [5]. Using the same sample, the $t\bar{t}$ cross-section in the forward region has been also measured. The W boson is recostructed in the muon(electron) final state, with $p_T > 20$ GeV$/c$ and $2.0 < \eta < 4.5(4.25)$, jets are reconstructed as in the W+jet measurement, but with $p_T > 12.5$ GeV$/c$.

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 jets, the background originating from light partons is reduced.

The number of $W^+ + b\bar{b}$, $W^- + b\bar{b}$, $W^+ + c\bar{c}$, $W^- + c\bar{c}$ and $t\bar{t}$ events is extracted by simultaneously fitting the distribution of the di-jet invariant mass, the distribution of two multivariate discriminators, one for each selected jet, which exploit properties of the jets and the SVs to separate b from c, and the distribution of one multivariate discriminator that separates the $W+b\bar{b}$ process from the $t\bar{t}$ process. The measurements together with the theoretical predictions are shown

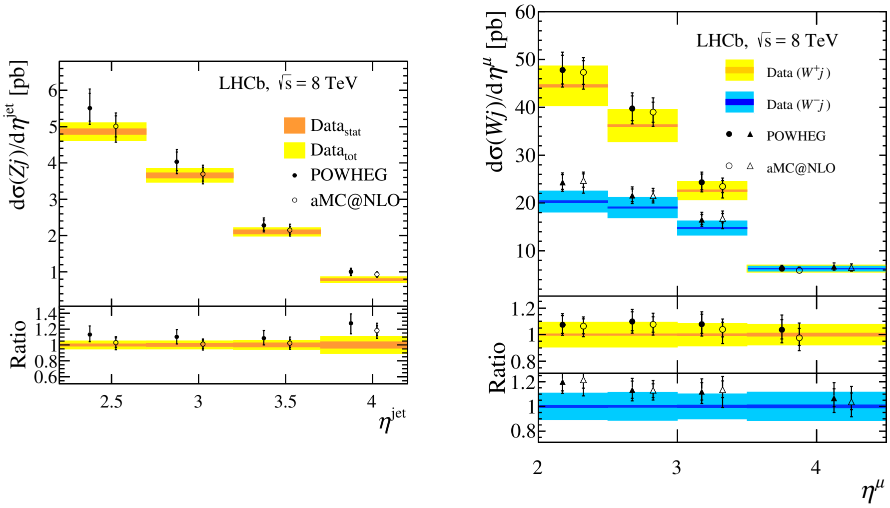

Figure 4: *Z+jet cross-section as a function of the jet p_{T} (left) and the W+jet cross-section as a function of the jet η (right). Theoretical predictions are also shown.*

in Fig. 5. The uncertainties are dominated by the knowledge of the b identification efficiency. The measured cross-sections are in agreement with the theory within the uncertainties.

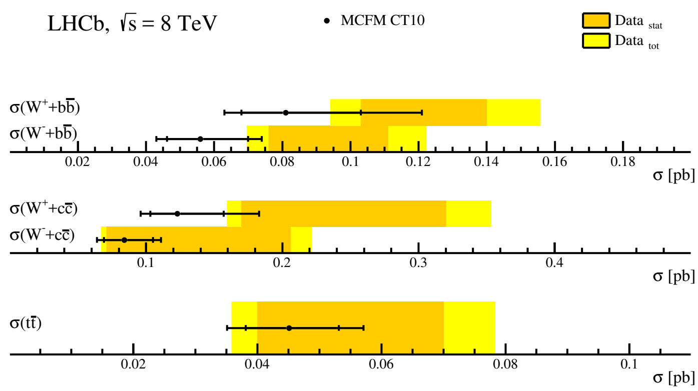

Figure 5: *Measured $W+b\bar{b}$, $W+c\bar{c}$ and $t\bar{t}$ cross-sections together with the theoretical predictions.*

6. Measurement of the $Z \to b\bar{b}$ production in the forward region

The decay $Z \to b\bar{b}$ has been reconstructed by LHCb in pp collision data at a centre-of-mass energy of $\sqrt{s} = 8$, corresponding to 2 fb^{-1} of integrated luminosity, and the corresponding production cross-section has been measured [7]. The fiducial region of the measurement is defined by b-jets with $2.2 < \eta < 4.2$, $p_{\mathrm{T}} > 20$ GeV$/c$ and with a di-jet invariant mass in the range

$45 < m_{jj} < 165$ GeV$/c^2$. The b-jets are reconstructed and identified as in the $W + b\bar{b}$ cross-section measurement.

An additional jet recoiling against the Z boson candidate is also selected, to achieve extra discrimination between the signal and the QCD multi-jet events, which constitute the main source of background. A multivariate discriminator is trained to obtain such separation, employing observables related to the Z+jet kinematics. The classifier output is used to define a signal region, with enhanced $Z \to b\bar{b}$ contribution, and a control region, enriched with QCD events. The di-jet invariant mass distributions in the signal and control regions are simultaneously fitted to determine the $Z \to b\bar{b}$ and QCD yields. The background subtracted di-jet invariant mass distributions in signal and control regions are shown in Fig. 6.

A production cross-section times branching fraction of $332 \pm 46 \pm 59$ pb is obtained, where the first uncertainty is statistical and the second systematic. The systematic uncertainty is dominated by the knowledge of the b identification efficiency and the measurement is in agreement with the theoretical prediction calculated at next-to-leading order plus parton shower, which is 272^{+10}_{-13} pb.

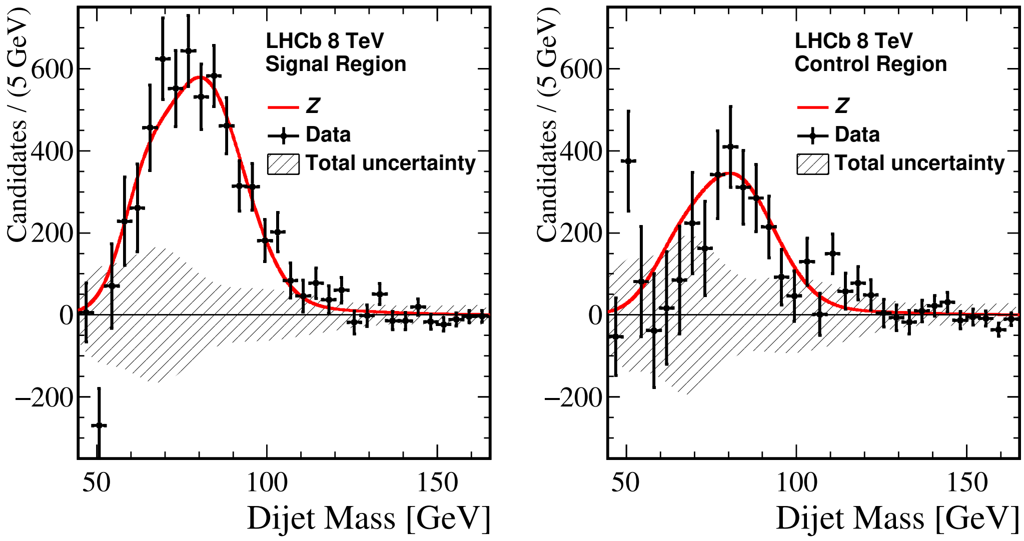

Figure 6: *Background subtracted di-jet invariant mass distributions in the signal region (left) and in the control region (right). The uncertainty band in the background only hypothesis is also shown.*

7. Conclusions

The latest measurements performed by LHCb including W and Z bosons have been presented: they are competitive and complementary with the corresponding measurements of the other LHC experiments. The measured W and Z cross-sections, with or without associated jets, are important tests of the Standard Model and they can provide constraints to PDFs in a unique kinematic region.

References

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