PROCEEDINGS OF SCIENCE

Electroweak boson production 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 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. Moreover these measurements can be used to validate reconstruction techniques. 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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*Speaker.

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1. Introduction

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).

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, qualifying it as a general purpose forward detector.

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 coverage of the phase space in $\sqrt{s}$ = 13 TeV collisions by the different LHC experiments is shown in Fig. 1.

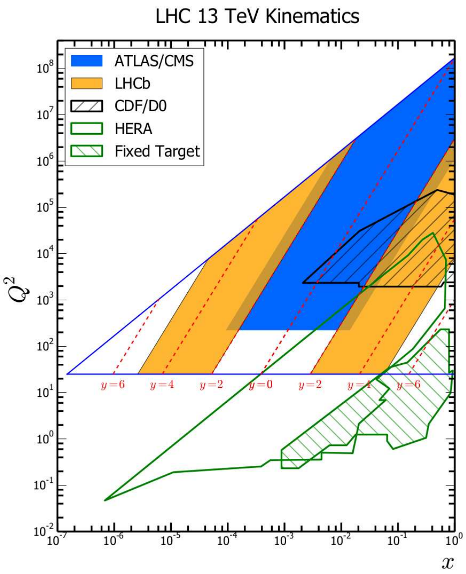

Figure 1: *LHCb acceptance in $x - Q^2$ phase space, in comparison with other experiments.*

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 $p_{\mathrm{T}} > 20$ GeV$/c$. The electrons must have $2 < \eta < 4.25$ and $p_{\mathrm{T}} > 20$ GeV$/c$. In addition, the di-lepton invariant mass must be in the $60 < m_{jj} < 120$ GeV$/c^2$ range. The low background contamination has been evaluated using simulation and data-driven techniques, 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. As example the measured $Z \to \mu^+\mu^-$ cross-section as a function of the Z boson p_{T} and the Z boson cross-section as a function of the Z boson rapidity are shown in Fig. 2, compared with theoretical predictions. The theoretical cross-section as a function of the p_{T} has been obtained with a leading-order (LO) and next-to-leading-order (NLO) plus parton shower (PS) calculation, the theoretical cross-section as a function of the rapidity has been calculated with next-to-next-to-leading-order (NNLO) perturbative QCD. The measurements are compatible with the predictions within their uncertainties, which are dominated by the uncertainty on the luminosity calibration (3.8 %). Future improvements in the luminosity calibration will reduce this uncertainty.

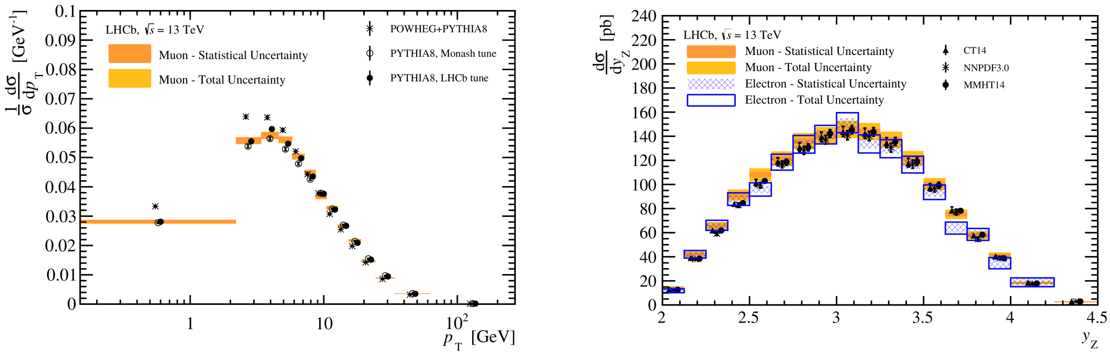

Figure 2: *$Z \to \mu^+\mu^-$ cross-section as a function of the Z boson p_{T} (left) and the Z boson cross-section as a function of the Z boson rapidity, for the electron and muon final states (right). The cross-sections are compared with the theoretical predictions.*

3. 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 [3]. 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, it must have a p_{T} greater than 20 GeV$/c$ and must be in the range $2.2 < \eta < 4.2$.

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 muon. This observable gives a good separation between signal and background. The measured purity is 46.7(36.5)% for the $W^+(W^-)$+jet process. The purity of the Z+jet sample has been evaluated by using background-enhanced data samples and simulation samples, and it is 97.8%.

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. 3. 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.

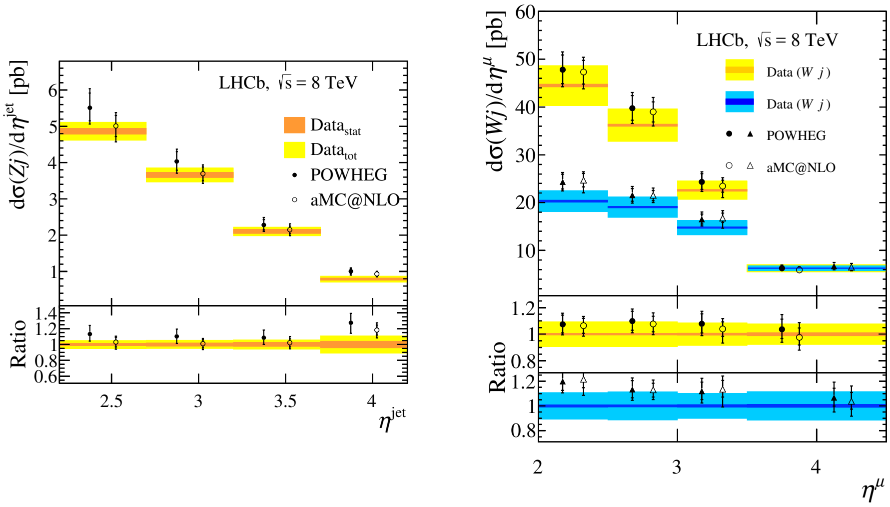

Figure 3: *Z+jet cross-section as a function of the jet p_{T} (left) and the W+jet cross-section as a function of the jet η (right), the theoretical predictions are also shown.*

4. 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 [4]. 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 $p_{\mathrm{T}} > 20$ GeV$/c$ and $2.0 < \eta < 4.5(4.25)$, jets are reconstructed as in the W+jet measurement, but with $p_{\mathrm{T}} > 12.5$ GeV$/c$.

The algorithm described in [5] 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 last classifier has been obtained with a technique that makes the discriminator output uncorrelated from the di-jet invariant mass, the uniform Gradient Boost algorithm [6]. The measurements together with the theoretical predictions are shown in Fig. 4.

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. This sample has also been used to set a limit on the $H \to b\bar{b}$ production, as explained in [7].

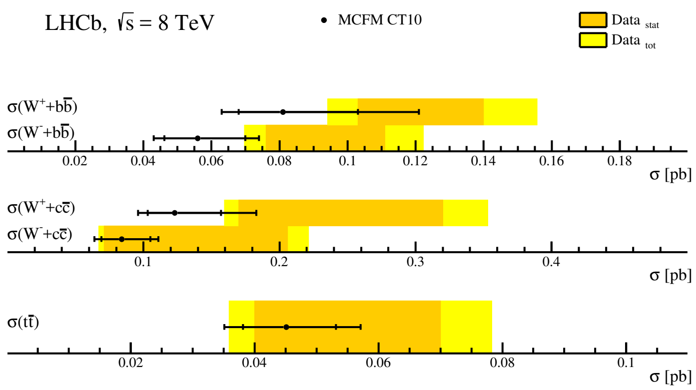

Figure 4: *Measured $W+b\bar{b}$, $W+c\bar{c}$ and $t\bar{t}$ cross-sections together with the theoretical predictions.*

5. 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 [8]. 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 recostructed and identified as in the $W+b\bar{b}$ cross-section measurement.

An additional jet recoiling to 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. Again the uniform Gradient Boost algorithm is used to achieve uncorrelation with the di-jet invariant mass. 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 are shown in Fig. 5.

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 NLO plus PS, which is 272^{+10}_{-13} pb.

6. 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

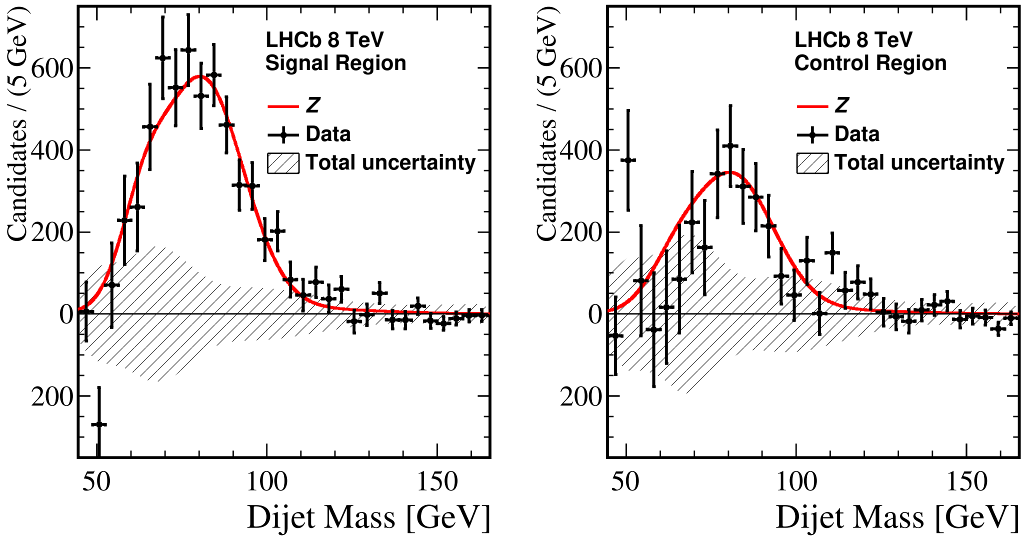

Figure 5: *Background subtracted di-jet invariant mass distributions in the signal region (left) and in the control region (right). The uncertainty band in the background only hypothesis is also shown.*

experiments. The measured W and Z cross-sections, with or without associated jets, can provide constraints to PDFs in a unique kinematical region. Moreover the first observation of the $Z \to b\bar{b}$ process in the forward region is presented: this measurement can act as standard candle in the search of other $b\bar{b}$ resonances in the forward region.

References

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