PROCEEDINGS OF SCIENCE

W, Z and top production measurements at LHCb

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Due to its unique pseudorapidity coverage between 2 and 5 and excellent performance, the LHCb detector allows for complementary probe of electroweak and QCD processes to those at ATLAS and CMS experiments. Studies of electroweak boson and top production provide important probes of the Standard Model at LHC energies and constrain parton distribution functions. The recent results on the W, Z and top production are briefly summarized in the present proceedings.

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1. Introduction

The LHCb detector [1] is a single-arm forward spectrometer covering the pseudorapidity range of $2 < \eta < 5$, initially designed for the study of particles containing b or c quarks. This allows LHCb to extend its physics programme and perform electroweak measurements in a kinematic region that is complementary to the general purpose detectors. Because of LHCb's forward acceptance, the collisions occur typically between a parton at high momentum fraction, Bjorken-x, and another one at low-x. The parton distribution functions (PDFs) that describe the partons at high-x are partially constrained by previous measurements, and LHCb can directly access the low Bjorken-x region of the phase space. Precision measurements of W and Z bosons as well as top production in the forward region may probe the Standard Model (SM), i.e. the perturbative QCD and electroweak theory.

2. Measurement of the forward Z production in Run I and II

The measurement of the inclusive $Z \to \mu^+\mu^-$ and $Z \to e^+e^-$ production cross-sections has been performed by LHCb using data from pp collisions at a centre-of-mass energy of 7, 8 and 13 TeV, corresponding to 1.0 fb^{-1}, 2.0 fb^{-1} and 294 pb^{-1} of integrated luminosity [2, 3, 4, 5]. Z candidates are identified in the same fiducial acceptance for muons and electrons, i.e. by requiring two reconstructed charged leptons produced by the boson decay with $2.0 < \eta < 4.5$ and $p_T >$ 20 GeV/c, and the combined two muons invariant mass in the region $60 < M < 120$ GeV/c^2 in the case of $Z \to \mu^+\mu^-$, while for $Z \to e^+e^-$ the combined two electrons invariant mass must be greater than 40 GeV/c^2. Events are selected with a purity of 99.7% for $Z \to \mu^+\mu^-$ and 95.5% for the $Z \to e^+e^-$ decay, respectively. For $Z \to \mu^+\mu^-$ decay data-driven techniques are applied to estimate backgrounds related to semileptonic decays of heavy flavour hadrons and QCD events where kaons or pions either decay in flight or punch through the detector to be misidentified as muons, while the simulation is used to determine the contribution from $Z \to \tau^+\tau^-$, top and di-boson production. In the case of $Z \to e^+e^-$ the background related to particle misidentification is determined based on a data sample of same-sign electron pairs and the residual contribution from heavy flavour hadrons and $Z \to \tau^+\tau^-$ is found to be insignificant. A comparison with Next-to-Next-to-Leading-Order theoretical predictions of the measured differential cross-sections as a function of the boson rapidity at 8 TeV for $Z \to \mu^+\mu^-$ and $Z \to e^+e^-$ is shown in Fig.1.

3. Measurement of the forward W production in Run I

The measurements of the inclusive $W \to \mu\nu$ at a centre-of-mass energy of 7 TeV [3], corresponding to 1.0 fb^{-1}, as well as $W \to \mu\nu$ and $W \to e\nu$ at 8 TeV [2, 5], corresponding to 2.0 fb^{-1} have been performed by LHCb using data from pp collisions. W candidates are identified by requiring a single isolated lepton produced by the boson decay with $p_T > 20$ GeV/c and with $2.0 < \eta_\mu < 4.5$ and $2.0 < \eta_e < 4.25$. The signal purity is estimated by fitting the lepton p_T spectrum to the shapes expected for signal and each background category in bins of the lepton η. It is estimated to ∼78% for $W \to \mu\nu$ and ∼60% for $W \to e\nu$. The signal yield is determined by a simultaneous fit to the p_T spectra of positively and negatively charged muons in data in bins of lepton

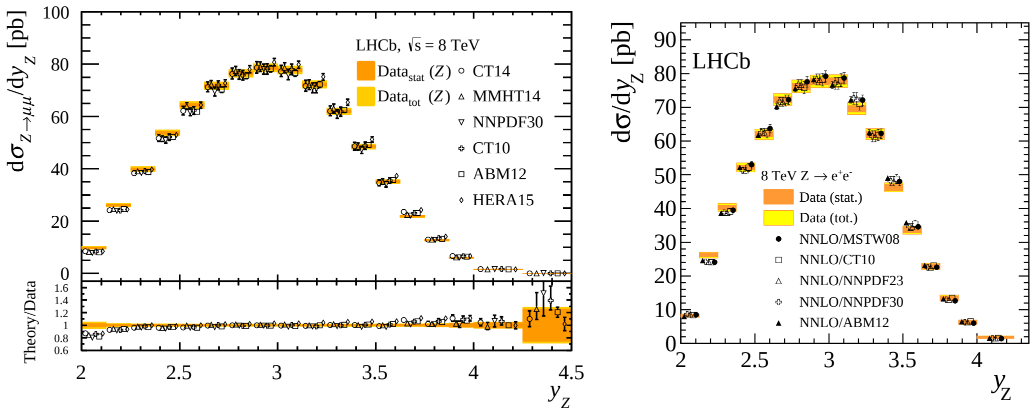

Figure 1: Differential Z boson production cross-section in bins of boson rapidity at 8 TeV: (left) $Z \to \mu^+\mu^-$ [2] and (right) $Z \to e^+e^-$ [5].

pseudorapidity. Data-driven methods have been employed to estimate the background from heavy flavor and electroweak processes. In Fig. 2 differential cross sections for $W \to \mu\nu$ and $W \to e\nu$ at 8 TeV in bins of lepton pseudorapidity are compared with Next-to-Next-to-Leading-Order predictions using different PDFs, showing a good agreement, where the systematic uncertainty is dominated by the luminosity measurement.

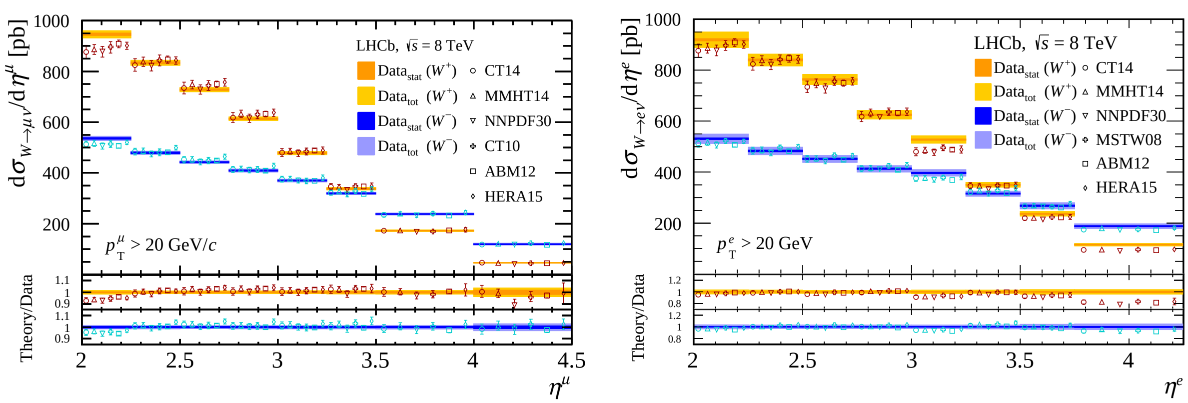

Figure 2: Differential W boson production cross-section in bins of lepton pseudorapidity at 8 TeV: (left) $W \to \mu\nu$ [2] and (right) $W \to e\nu$ [6].

4. W+jet and Z+jet forward production in Run I

The cross sections of vector bosons produced in association with a forward jet have been measured in pp collisions at a centre-of-mass energy of 7 and 8 TeV, corresponding to 1 fb^{-1} and 2 fb^{-1} of integrated luminosity [7, 8]. The jets are reconstructed using a particle flow approach, clustering particles with the anti-k_T algorithm [9] with a distance parameter $R = 0.5$. The analysis is based on isolated muons from a vector boson and reconstructed jets with $p_T > 20$ GeV. Where appropriate, the heavy flavour jet tagging is performed by searching for secondary vertices reconstructed inside jets [10]. The requirement on secondary vertices consistent with the decay of a beauty or charm hadron to be inside a jet reduces significantly the background from light partons. The jet composition is obtained with a fit to the distributions of two multivariate discriminators to separate heavy from light and b from c components, respectively. The W^+, W^- and Z + jet production cross-sections have been measured, together with the ratio of the W^++jet and W^-+jet production cross sections as well as the ratio of W+jet production cross-section to the Z+jet production cross-section in both 7 and 8 TeV pp collisions. As it may be observed in Fig. 3 the measured ratios of the W^++jet and W^-+jet production cross-sections agree well with the Next-to-Leading-Order theory predictions.

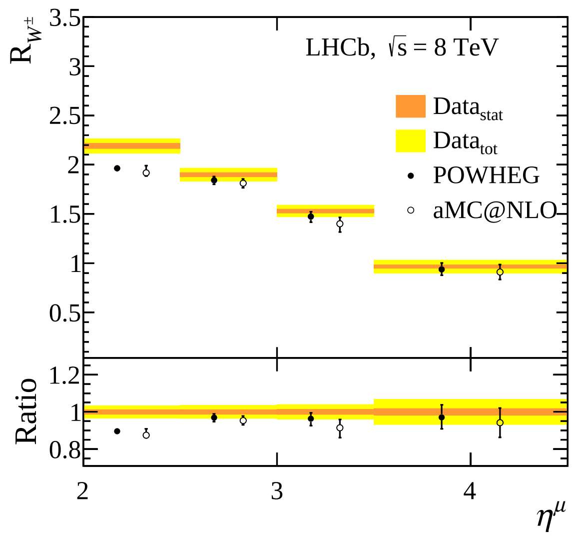

Figure 3: The measured ratio of the W^++jet and W^-+jet production cross sections comapred to the Next-to-Leading-Order theory predictions [7].

5. Inclusive top production cross section

The first observation of the top production in the forward region, in the $W+b$ final state, has been performed in LHCb using pp collision data collected at the center-of-mass energy of 7 and at 8 TeV [11]. This kind of study may be used to constraint gluon PDFs at large momentum fraction. The W boson is identified through an isolated muon with transverse momentum greater than 25 GeV, and the b-tagged jet must have $p_T > 50$ GeV. This reduces the uncertainties associated with QCD backgrounds, and improves and improves the significance and purity at large transverse component of the sum of the reconstructed μ and b momenta, $p_T(\mu+b)$. In particular, this observable can be used to discriminate between top and direct $W+b$ production, which is the main background for this kind of study. In order to measure top production cross sections, the number of candidates measured as a function of $p_T(\mu+b)$ are fitted with SM templates, as shown in Fig 4. The experimental points are consistent with the presence of the top (blue bars) with a statistical significance of 5.4σ, and the measured cross sections are: σ_{top}(7 TeV) = 239 $\pm$ 53 (stat.) $\pm$ 33 (syst.) $\pm$ 24 (th.) fb and σ_{top}(8 TeV) = 289 $\pm$ 43 (stat.) $\pm$ 40 (syst.) $\pm$ 29 (th.) fb, being compatible with the theoretical predictions within the experimental uncertainties.

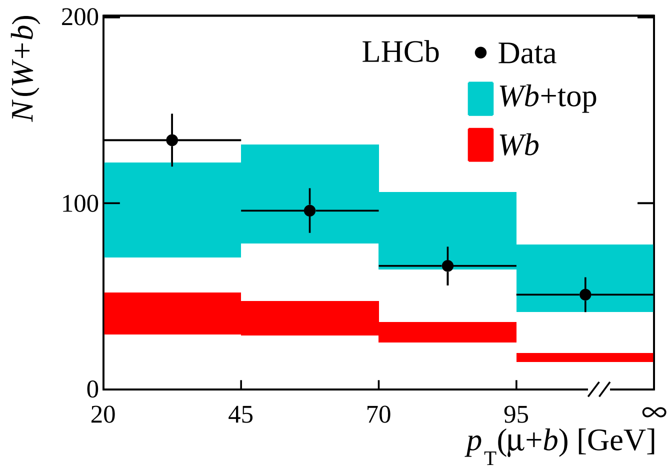

Figure 4: Number of candidates measured in LHCb at $\sqrt{s}$ = 8 TeV data as a function of $p_T(\mu+b)$ [11] comapred to the expected SM contribution from $W+b$ and top production.

6. $W+b\bar{b}$, $W+c\bar{c}$ and $t\bar{t}$ production cross sections

$W+b\bar{b}$, $W+c\bar{c}$ and $t\bar{t}$ production cross sections have been measured in LHCb using a sample of pp collision events taken at $\sqrt{s}$ = 8 TeV containing one isolated lepton (muon or electron) with high-p_T and two heavy flavour tagged jets (b or c) [12]. The jets and leptons are reconstructed and selected as described in the previous sections of the present document. The main background in this kind of search includes $Z+b\bar{b}$, $Z+c\bar{c}$, single top and QCD multi-jets. The strategy was to perform a simultaneous four-dimensional fit for μ^+, μ^-, e^+ and e^- samples to the following variables: dijet mass, and multivariate discriminator to separate $t\bar{t}$ from $W+b\bar{b}$ and $W+c\bar{c}$ events (referred to as uGB [13]), and multivariate discriminator to separate b- and c-jets, used for both jets. In this fit only the background from QCD multi-jets is extrapolated with a control sample in data, while other background contributions are fixed to the SM theory expectations. Only the signal components are unconstrained in the fit. The projections of the fit result on four input variables for the μ^+ sample are illustrated in Fig. 5. The cross sections measured in the LHCb fiducial acceptance agree well with the Next-to-Leading-Order theory predictions. The statistical significances of measured $W^+ + b\bar{b}$, $W^+ + c\bar{c}$, $W^- + b\bar{b}$, $W^- + c\bar{c}$ and $t\bar{t}$ production cross sections are 7.1σ, 4.7σ, 5.6σ, 2.5σ and 4.9σ, respectively.

7. Conclusions

Even though initially designed to measure flavour physics, LHCb provides electroweak boson and top measurements in a unique forward direction, complementary to the results from general purpose LHC detectors. The measured W and Z production cross sections together with the vector boson production in association with jets place important constraints on PDF parameterisations. Furthermore, different top production cross sections in the forward region have been measured. The present results play an important role in understanding QCD and electroweak physics, and will be supplemented by future measurements.

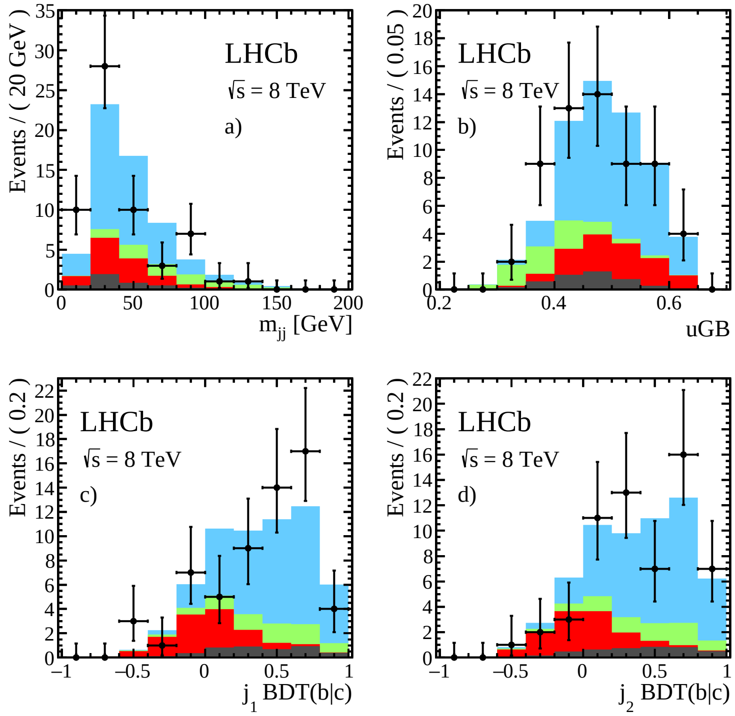

Figure 5: Projections of the simultaneous four-dimensional fit for the μ^+ sample [12] to: (a) dijet mass, (b) discriminator to separate $t\bar{t}$ from $W+b\bar{b}$ and $W+c\bar{c}$, (c) discriminator to separate b and c leading jets (d) sub-leading jets.

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