PROCEEDINGS OF SCIENCE

Measurement of the inclusive $W^{\pm}$ and Z/γ^{*} cross sections in the e and μ decay channels in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector

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Measurements by the ATLAS Collaboration are presented of the inclusive Drell-Yan $W^{\pm} \to \ell\nu$ and $Z/\gamma^{*} \to \ell\ell$ ($\ell = e, \mu$) production cross sections in proton-proton collisions at $\sqrt{s} = 7$ TeV. The cross sections are measured integrated over a fiducial kinematic range, extrapolated to the full range and also evaluated differentially as a function of the W decay lepton pseudorapidity and the Z boson rapidity, respectively. Based on an integrated luminosity of about 35 pb^{-1}, collected in 2010, the precision of these measurements reaches a few per cent. The integrated and the differential $W^{\pm}$ and Z/γ^{*} cross sections in the e and μ channels are combined, and compared with perturbative QCD calculations, based on a number of different parton distribution sets available at NNLO.

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1. Introduction

The inclusive Drell-Yan [1] production cross sections of W and Z bosons have been an important testing ground for Quantum Chromodynamics (QCD). The present measurement determines the cross sections times leptonic branching ratios, $\sigma_{W^{\pm}} \cdot \mathrm{BR}(W \to \ell\nu)$ and $\sigma_{Z/\gamma^{*}} \cdot \mathrm{BR}(Z/\gamma^{*} \to \ell\ell)$, of inclusive W and Z production for electron and muon final states, where $\ell = e,\ \mu$ [2]. The cross section values are integrated over the fiducial region of the analysis and also extrapolated to the full kinematic range. The data are also reported differentially, as functions of the lepton pseudorapidity η_l, for the $W^{\pm}$ cross sections, and of the boson rapidity, y_Z, for the Z/γ^{*} cross section.

The integrated and differential W and Z production cross sections are measured in the fiducial volume [2] and extrapolated to the total phase space using the equations

$$\sigma_{\mathrm{fid}} = \frac{N-B}{C_{W/Z} \cdot L_{\mathrm{int}}}, \qquad \sigma_{\mathrm{tot}} = \sigma_{W/Z} \times BR(W/Z \to \ell\nu/\ell\ell) = \frac{\sigma_{\mathrm{fid}}}{A_{W/Z}}, \tag{1.1}$$

where N is the number of candidate events observed in data, B the number of background events, determined using data and simulation, and L_{int} the integrated luminosity corresponding to the run selections and trigger employed. The combined efficiency factor $C_{W/Z}$ is calculated from simulation and corrected for differences in reconstruction, identification and trigger efficiencies between data and simulation. Where possible, efficiencies in data and MC are derived from $Z \to \ell\ell$ and, in the case of the electron channel, $W \to e\nu$ events [3, 4]. The Monte Carlo simulation is also corrected with respect to the data in the lepton energy (momentum) scale and resolution, and reweighted so that the resulting transverse momentum distributions of the W and Z bosons match the data [5, 6]. The effect of multiple pp interactions per bunch crossing is also properly taken into account. The acceptance $A_{W/Z}$ is used to extrapolate the cross section measured in the fiducial volume, σ_{fid}, to the full kinematic region. The acceptance is derived from MC, and the uncertainties on the simulation modeling and on parton distribution functions constitute an additional uncertainty on the total cross section measurement. They are found to be in the range $1.5-1.7\%$ in the W channels and they amount to 2.0% for the Z analysis. The total and fiducial cross sections are corrected for QED radiation effects in the final state.

2. Event selections and backgrounds

The analysis uses data taken in 2010 with proton beam energies of 3.5 TeV and corresponding to an integrated luminosity of about $35\,\mathrm{pb}^{-1}$. Single lepton triggers are used with thresholds of 15 and 13 GeV in the electron and muon channels, respectively.

Events are required to have at least one primary vertex formed by at least three tracks. To select W boson events in the electron channel, exactly one reconstructed "medium" [3] electron is required with $E_T > 20$ GeV and $|\eta| < 2.47$ and outside the barrel-endcap transition region $1.37 < |\eta| < 1.52$. The electron must in addition have a hit in the innermost layer of the tracking system, the "pixel b-layer" and small calorimeter energy deposited in a cone of size $\Delta R \leq 0.3$ around the electron cluster. The missing transverse energy [7], $E_{\mathrm{T}}^{\mathrm{miss}}$, is required to be larger than 25 GeV. Further, the transverse mass, m_T, has to be larger than 40 GeV. In the selection of $Z \to ee$ events two electrons are required to be reconstructed and pass only the "medium" criteria, to have opposite charge, and their invariant mass has to be within the interval 66 to 116 GeV. For the selection of Z events over an extended range of rapidity, a central electron passing "tight" [3] criteria as well as the calorimeter isolation requirement described above is required. A second electron candidate with $E_T > 20$ GeV has to be reconstructed in the forward region, $2.5 \leq |\eta| \leq 4.9$, and to pass "forward loose" identification requirements [3]. The invariant mass of the selected pair is required to be between 66 and 116 GeV.

In the muon channels, collision events are selected with the same vertex requirement as for the electron channels. In addition, the position of the primary vertex along the beam axis is required to be within 20 cm of the nominal position. W and Z events are selected requiring at least one or two combined track muons with $p_T > 20$ GeV and $|\eta| < 2.4$, respectively. The z position of the muon track extrapolated to the beam line has to match the z coordinate of the primary vertex within $\pm$ 1 cm. A track-based isolation criterion is defined requiring the sum of transverse momenta, $\sum p_T^{ID}$, of ID tracks with $p_T > 1$ GeV within a cone $\Delta R < 0.2$ around the muon direction, divided by the total muon transverse momentum p_T, to be less than 0.1. $W \rightarrow \mu\nu$ events are further selected requiring the missing transverse energy and the transverse mass above the same thresholds as in the electron analysis. $Z \rightarrow \mu\mu$ candidates are further selected, similarly as for $Z \rightarrow ee$ ones, requiring opposite charge muon pairs with invariant masses in the 66 to 116 GeV interval.

The sum of electroweak and $t\bar{t}$ backgrounds are found to be 3.2% (3.7%) in the W^+ (W^-) electron channel of the respective numbers of events. The QCD background is derived from the data using a template fit of the $E_{\mathrm{T}}^{\mathrm{miss}}$ distribution and it is determined to be 3.4% (4.8%) for the W^+ (W^-) channel. The relative uncertainty is estimated to be 8% (12%) for W^+ (W^-). The relative background contributions in the central $Z \rightarrow ee$ analysis due to electroweak processes are estimated to be 0.5% in total. The QCD background in the central $Z \rightarrow ee$ analysis is estimated from data to be 1.6%, by fitting the invariant mass distribution. The relative systematic uncertainty is evaluated to be 40%. In the forward $Z \rightarrow ee$ analysis the main electroweak background comes from $W \rightarrow e\nu$ events and it is estimated to be 1.9%. The QCD background is calculated by fitting the m_{ee} distribution and it is estimated to be 9.4% with relative statistical and systematic uncertainties of 8% and 17%, respectively.

In the muon analysis, the sum of electroweak and $t\bar{t}$ backgrounds are found to be 6.1% (7.6%) in the W^+ (W^-) channel. The QCD background is determined extrapolating from control regions defined by reversing the isolation and missing transverse energy requirements. This analysis yields a fraction of background events of 1.7% (2.8%) in the W^+ (W^-) channel. The systematic uncertainty is estimated to be about 23% relative to the number of background events. The relative background contributions in the $Z \rightarrow \mu\mu$ channel due to electroweak and $t\bar{t}$ events is estimated to be 0.4%. The QCD background is measured in control samples, selected using inverted isolation and $m_{\mu\mu}$ requirements. The measured fraction of background events is 0.4%. The relative systematic uncertainty amounts to 56% while the relative statistical uncertainty is 40%.

3. Results

Apart from the luminosity contribution of 3.4 %, the $W \rightarrow e\nu$ cross sections are measured with an experimental uncertainty of 1.8% to 2.1%, dominated by the electron reconstruction and identification as well as missing transverse energy performance related to the hadronic recoil [7].

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The $Z \to ee$ cross section is measured with an experimental precision of 2.7%, dominated by the uncertainty on the electron reconstruction and identification efficiency. The $W \to \mu\nu$ cross section is measured with an experimental uncertainty of 1.6%, with largest contributions from the muon efficiencies (1.1%). The $Z \to \mu\mu$ cross section is measured with an experimental precision of 0.9%. This is dominated by the uncertainty in the muon reconstruction efficiency (0.6%). The theoretical uncertainties on $C_{W/Z}$ for all channels are evaluated as described for the acceptances and they are found to be 0.6-0.8% for C_W and 0.3% for C_Z.

The electron and muon $W^\pm$ and Z cross sections are combined to form a single joint measurement taking into account the systematic error correlations between the various data sets. This combination provides the most accurate integrated inclusive W and Z/γ^* cross sections so far obtained by the ATLAS Collaboration and the first measurements of rapidity dependent cross sections.

Figure 1 shows the measured integrated W^+ and W^- cross sections (left) and the $(W^+ + W^-)$ and Z/γ^* cross section (right), evaluated in the fiducial region of the measurement and compared with the QCD NNLO theoretical predictions calculated with FEWZ [8, 9] and DYNNLO [10, 11] using the JR09 [12], ABKM09 [13, 14], HERAPDF1.5 [15, 16] and MSTW08 [17] NNLO PDF sets. The precision of the measured cross sections is $\sim 1.2\,\%$ with an additional uncertainty of $3.4\,\%$ resulting from the luminosity error. The uncertainties on the total integrated cross sections are about twice as large because of the extrapolation uncertainties in the determination of the acceptance correction.

Ratios of the $W^\pm$ and Z cross sections are calculated accounting for the correlations between uncertainties. The precision of these measurements is very high, with a total uncertainty of $0.9\,\%$ for the W^+/W^- ratio and of $1.3\,\%$ for the $W^\pm/Z$ ratio. The fiducial cross section ratios are compared in Fig. 2 with the theoretical predictions accounting for the correlations inherent in the PDF determinations.

Since the production of the W and Z bosons is independent of the flavour of the decay lepton, the corresponding cross section ratios represent new measurements of the ratios R_W and R_Z of the e and μ branching fractions: $R_W = 1.006 \pm 0.024$ and $R_Z = 1.018 \pm 0.031$ to be compared with the current world averages [18] of $R_W^{w.a.} = 1.017 \pm 0.019$ and $R_Z^{w.a.} = 0.9991 \pm 0.0024$. These results confirm e-μ universality in W and Z decays.

The combined differential Z and $W^\pm$ cross sections are compared in Fig. 3 with the theoretical predictions. The differential cross sections are determined in the fiducial region with a typical precision of $2\,\%$, apart from the most forward part of y_Z. One observes that the measured y_Z and η_ℓ dependencies are broadly described by the predictions of the PDF sets considered. Some deviations, however, are visible, for example the lower Z cross section at central rapidities in the case of the JR09 PDF set, or the tendency of the ABKM09 prediction to overshoot the Z and the W cross sections at larger y_Z and η_ℓ, respectively.

4. Summary

New measurements are presented of the inclusive cross sections of Drell-Yan $W^\pm$ and Z/γ^* production in the electron and muon decay channels. They are based on the full data sample collected by the ATLAS experiment at the LHC in 2010 at a centre-of-mass energy of 7 TeV, corresponding to an integrated luminosity of about 35 pb^{-1}.

The $W^{\pm}$ cross sections are measured differentially as a function of the lepton pseudorapidity, extending to $|\eta_{\ell}| \leq 2.5$. The Z/γ^{*} cross section is measured as a function of the boson rapidity $|y_Z|$ up to a value of 2.4.

The results are compared with QCD predictions calculated to NNLO in the fiducial regions of the measurements which allows for maximum sensitivity to details of the parton distributions used in these calculations. The broad agreement of the NNLO QCD theoretical predictions at the few per cent level with the data supports the validity of the QCD evolution equations, as the results rely on lower scale parton distribution functions evolved to the W and Z kinematic region, at the average value of Bjorken x of about 0.01. Interesting differences between sets of parton distributions are observed, both in the integrated and the differential fiducial cross sections. The results presented in this paper therefore provide a further basis for sensitive tests of perturbative QCD and determinations of the partonic content of the proton.

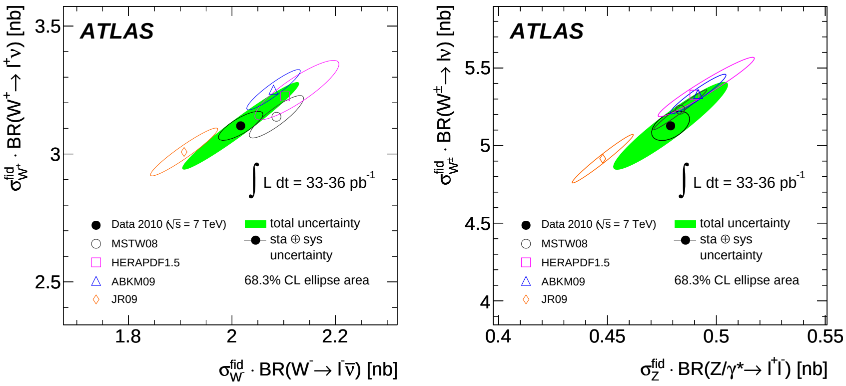

Figure 1: *Measured and predicted fiducial cross sections times leptonic branching ratios, σ_{W^+} vs. σ_{W^-} (left) and $(\sigma_{W^+}+\sigma_{W^-})$ vs. σ_{Z/γ^*} (right). The ellipses illustrate the 68 % CL coverage for total uncertainties (full green) and excluding the luminosity uncertainty (open black). The uncertainties of the theoretical predictions correspond to the PDF uncertainties only.*

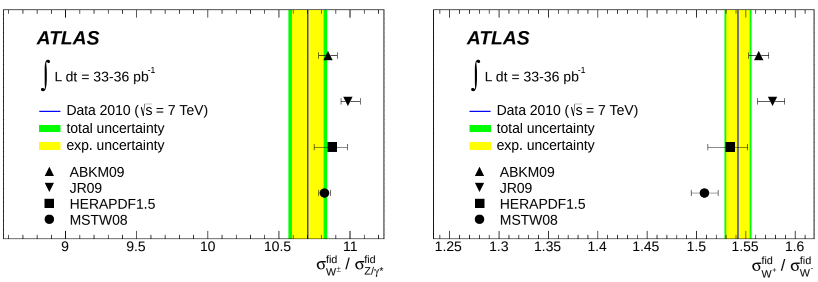

Figure 2: *Measured and predicted fiducial cross section ratios, $(\sigma_{W^+}+\sigma_{W^-})/\sigma_{Z/\gamma^*}$ (left) and $\sigma_{W^+}/\sigma_{W^-}$ (right). The experimental uncertainty (inner yellow band) includes the experimental systematic errors. The total uncertainty (outer green band) includes the statistical uncertainty and the small contribution from the acceptance correction.*

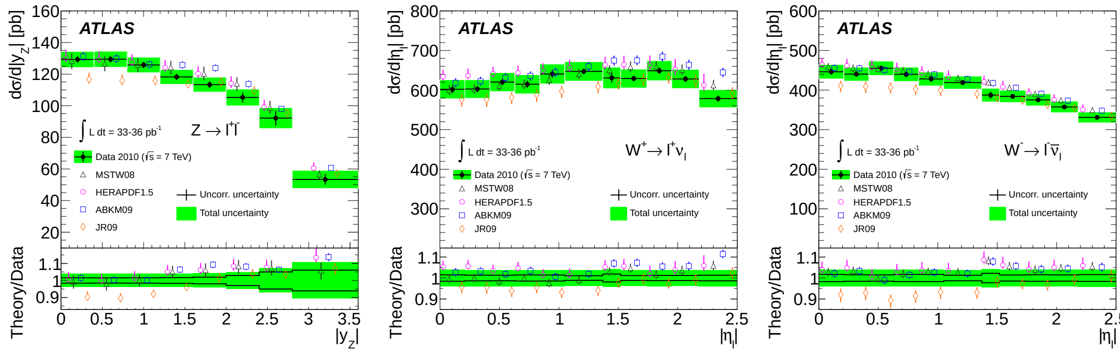

Figure 3: *Differential* $\mathrm{d}\sigma/\mathrm{d}|y_Z|$ *cross section measurement for* $Z \to \ell\ell$ *(left), differential* $\mathrm{d}\sigma/\mathrm{d}|\eta_{\ell^+}|$ *(center) and* $\mathrm{d}\sigma/\mathrm{d}|\eta_{\ell^-}|$ *(right) cross section measurements for* $W \to \ell\nu$ *compared to the NNLO theory predictions using various PDF sets. The ratio of theoretical predictions to data is also shown. Theoretical points are displaced for clarity within each bin.*

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