W and Z Production measured using the ATLAS Detector and impact on Parton Densities of the proton

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Abstract. Inclusive and differential cross sections for $W^\pm \rightarrow l\nu$ and $Z/\gamma^* \rightarrow ll$ ($l = e, \mu$) production are presented, as well as the lepton charge asymmetry as a function of lepton pseudorapidity. Data from pp collisions at $\sqrt{s} = 7$ TeV, collected in 2010 using the ATLAS detector at the Large Hadron Collider at CERN, are compared to the predictions of perturbative QCD calculations based on a number of different parton distribution sets available at next-to-next-to leading order. The impact of these measurements on the knowledge of the structure of the proton is discussed.

Finally, a first measurement of the ratio of the W + one to Z + one jet cross sections, is presented.

Keywords: ATLAS, Vector Bosons, QCD, PDF

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MOTIVATION AND SIMULATION

The inclusive production cross sections of W and Z bosons not only are necessary to calibrate and align the ATLAS detector [1] but they have also been an important testing ground for Quantum Chromodynamics (QCD). Theoretical calculations of these processes extend to next-to-leading order (NLO) and next-to-next-to leading order (NNLO) perturbation theory. A crucial ingredient of the resulting QCD cross section calculations are parameterisations of the momentum distribution functions of partons in the proton (PDF). These have been determined recently in a variety of phenomenological analyses to NLO by the CTEQ group and to NNLO by the MSTW, ABKM, HERAPDF, JR and NNPDF groups. Moreover these physics processes are considered as background to many beyond Standard Model physics searches; therefore their thorough study is crucial.

This analysis [2] uses simulated events to calculate acceptances and to model the properties of both signal and background processes. Events are generated using the MC@NLO, POWHEG, PYTHIA and HERWIG Monte Carlo (MC) programs. All generators are interfaced to PHOTOS to simulate the effect of final state QED radiation. Passage of particles through the ATLAS detector is modelled using GEANT4. The CTEQ 6.6 PDF set is used for the MC@NLO and POWHEG samples. For the PYTHIA and HERWIG samples the MRST LO* parton distribution functions are used. The W and Z Monte Carlo samples are normalised to the NNLO cross sections by the FEWZ program.

EVENT SELECTION AND ANALYSIS PROCEDURE

All events are required to pass the appropriate trigger requirements and have at least one primary vertex formed by at least three tracks. To select W boson events in the electron channel, one isolated electron with tight identification is required with $E_T > 20$ GeV and pseudorapidity $|\eta| < 2.47$ excluding the transition region between barrel and endcap calorimeter, $1.37 < |\eta| < 1.52$. For the W boson events selection in the muon channel, one isolated muon with $p_T > 20$ GeV and $|\eta| < 2.4$ is required. The missing transverse energy is required to be larger than 25 GeV while the transverse mass has to be larger than 40 GeV. The same selections are also used for the Z events selection, but instead of one, two oppositely charged same flavour leptons are required with an invariant mass between 66 and 116 GeV.

The production cross sections for the W and Z bosons times the branching ratios for decays into leptons can be expressed as:

$$\sigma_{tot}^{W(Z)} \cdot BR(W(Z) \rightarrow l\nu(ll)) = \frac{N - B}{A_{W/Z} \cdot C_{W/Z} \cdot L_{int}} \quad (1)$$

- N is the number of candidate events measured in data.

- B is the number of background events determined using data-driven methods and simulation.
- $C_{W/Z}$ denotes the efficiency correction factor calculated from simulation and data that corrects for detector effects and includes the efficiencies for triggering, reconstructing and identifying the W and Z boson decays falling within the acceptance. Its theoretical uncertainties are due to MC@NLO and POWHEG comparisons and different PDFs.
- $A_{W/Z}$ denotes the acceptance factor calculated at generator level. It is used to extrapolate the fiducial cross section measurement to the full kinematic region of the total cross section. Its theoretical uncertainties are due to different PDFs in MC@NLO, differences between MC@NLO and POWHEG and different parton shower and hadronization modelling.
- L_{int} denotes the integrated luminosity corresponding to the run selections and trigger employed.

RESULTS AND COMPARISON WITH THEORY

The measured fiducial cross sections for the electron and muon channels are combined into one joint measurement taking the systematic error correlations between the various data sets into account and then are compared to different sets of PDFs available in NNLO perturbative QCD calculations. Figure 1(a) shows the $(W^+ + W^-)$ vs. the Z/γ^* cross section. These precise NNLO calculations have been performed for the first time in the fiducial region. The fiducial measurements are extrapolated to the full kinematic range and comparisons with theory are also performed revealing an overall remarkable agreement with NNLO PDF predictions (Fig. 1(b)). There is a small additional extrapolation uncertainty in the total cross section results due to the inclusion of the acceptance factor $A_{W/Z}$. The total uncertainty, excluding the luminosity uncertainty of 3.4%, of the fiducial measurement is about 1%, while for the total cross section measurement is about 2%.

FIGURE 1. Measured and predicted cross sections times leptonic branching ratios ($(\sigma_{W^+} + \sigma_{W^-})$ vs. σ_{Z/γ^*}): (a) fiducial and (b) total cross sections. The ellipses illustrate the 68% CL coverage for total uncertainties (shaded ellipse) and excluding the luminosity uncertainty (open black ellipse). The uncertainties of the theory are the PDF uncertainties only.

The combined differential cross sections with respect to the Z boson rapidity, $d\sigma/d|y_Z|$, and to the $W^\pm$ lepton pseudorapidity, $d\sigma/d|\eta_{l^\pm}|$, (Fig. 2(a)), are also measured and compared to NNLO predictions. It is observed that the measured y_Z and η_l dependencies are broadly described by the theory with some deviations. Therefore it can be expected that the differential cross sections presented here will influence the central values and uncertainties of PDF determinations.

The charge asymmetry of leptons from W bosons, A_l , as a function of lepton pseudorapidity, η_l , defined as,

$$A_l(|\eta_l|) = \frac{\sigma_{W^+}(\eta_l) - \sigma_{W^-}(\eta_l)}{\sigma_{W^+}(\eta_l) + \sigma_{W^-}(\eta_l)}, \quad (2)$$

provides important information about the proton structure described by the PDFs. It is sensitive to the valence quark distributions. The W differential charge asymmetry for electrons and muons in bins of absolute pseudorapidity is shown in Fig. 2(b) compared to three different NNLO PDFs. All distributions rise with η and there is best agreement with the ABKM09 PDF.

FIGURE 2. (a) Differential cross section measurement for $W^+ \rightarrow l^+ \nu$ compared to the NNLO theory predictions using various PDF sets, (b) measured W charge asymmetry as a function of lepton pseudorapidity $|\eta_l|$ compared to different NNLO PDFs.

R_{jets} MEASUREMENT

An important and precise ATLAS measurement, which is very sensitive to new physics rather than the choice of PDFs, is the ratio of the W + one to Z + one jet cross sections (R_{jets}) as a function of the jet transverse momentum threshold. Figure 3 shows the combined electron and muon results for R_{jets} in a common fiducial region compared to NLO predictions from MCFM (corrected to particle-level using PYTHIA) using 2010 data. The extrapolation of the measurement to the full kinematic range has been also performed and is also in agreement with the theory [3].

FIGURE 3. Combined electron and muon results for R_{jets} in a common fiducial region compared to theoretical predictions from MCFM (corrected to particle-level). The shaded band shows statistical and systematic uncertainties added in quadrature. The theory uncertainty (dashed line) includes contributions from PDFs and renormalisation and factorisation scales.

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