Measurement of W/Z production with the ATLAS detector

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The production of W and Z bosons at the LHC has been measured with the ATLAS detector. These measurements include inclusive and differential cross sections, W polarisation, and the polarisation of τ leptons from W decays. They show sensitivity to the proton structure and are also used to test predictions from perturbative QCD and phenomenological models.

Introduction

A large number of W and Z bosons have been produced at the LHC and recorded by the ATLAS detector [1] during the years 2010 and 2011. These datasets allowed for the precise measurement of inclusive and differential production rates as well as other important physical quantities such as the W polarisation. These measurements are key ingredients that can be used to constrain parton distribution functions (PDFs) and test various predictions from perturbative QCD (pQCD) and Monte Carlo generators. A short overview of these measurements is given in the present proceedings. All of them are based on the dataset recorded in 2010, corresponding to an integrated luminosity of about 35 pb^{-1}, with the exception of the inclusive $Z \to \tau\tau$ cross section measurement that makes use of up to 1.55 fb^{-1} of 2011 data.

1 Inclusive cross section measurements

The production cross sections of the inclusive Drell-Yan processes $W^{\pm} \to \ell\nu$ and $Z/\gamma^{*} \to \ell\ell$ ($\ell = e, \mu$) have been measured and compared with pQCD calculations based on a number of different PDF sets available at NNLO [2]. They have been measured within a restricted phase space defined by cuts on the charged leptons and the neutrino transverse momenta (i.e., fiducial cross-section measurements), and have also been extrapolated to the full kinematic range to obtain the total W and Z/γ^{*} cross sections.

The measurements in the electron and in the muon decay channels have been found to be consistent with each other. They have been combined using a method which accounts for the correlations among the different sources of systematic uncertainty [3, 4]. The precision of the integrated cross sections in the fiducial region is about 1.2 %, with an additional uncertainty of 3.4 % resulting from the luminosity measurement. The uncertainties on the total cross sections are about twice as large because they include the uncertainties arising from the determination of the acceptance correction. A broad agreement of the theory predictions with the data is observed (see Figure 1).

Ratios of cross sections have been computed accounting for the correlations between uncertainties [2]. 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 due to the cancellation of the luminosity uncertainty. The $W^\pm/Z$ ratio measures a rather PDF-insensitive quantity, provided that the parton sea is flavour-symmetric, and the agreement with the measurement supports the assumption of a flavour-independent light-quark sea at the W and Z scale. On the other hand, charge-dependent ratios are more sensitive to up-down quark distribution differences and exhibit more significant deviations. Again, a broad agreement between the predictions and the data is observed.

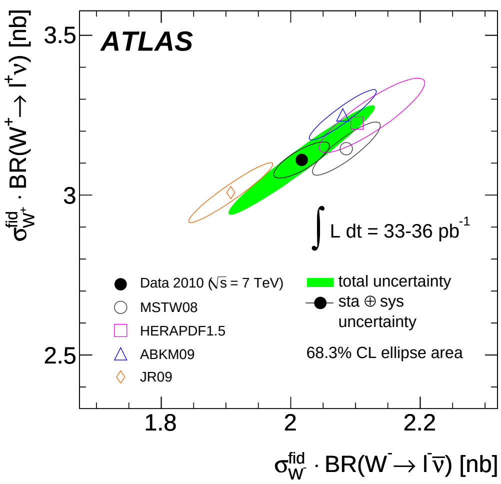

Figure 1: Measured and predicted fiducial cross sections times leptonic branching ratios: σ_{W^+} vs σ_{W^-} [2]. The ellipses illustrate the 68 % CL coverage for total uncertainties (full green) and excluding the luminosity uncertainty (open black). The uncertainties of the theoretical predictions correspond to the PDF uncertainties only.

Inclusive W and Z cross sections have also been measured in the τ-lepton decay channel [5, 6]. Since these processes constitute a major background for many searches, it is important to characterise them as precisely as possible. The latest $Z \to \tau\tau$ measurement uses about 1.5 fb^{-1} of 2011 data and combines three different pairs of τ decay channels. The systematic uncertainty estimated for this measurement is at the 10 % level. Both the $W \to \tau\nu$ and the $Z \to \tau\tau$ measurements are consistent with the ones that use electrons or muons, providing a validation of the τ reconstruction and identification algorithms.

2 Differential cross section measurements

In addition to the integrated cross sections, the $W^\pm$ cross sections have been measured differentially as a function of the lepton (electron or muon) pseudorapidity in the region $|\eta_\ell| \leq 2.5$ [2]. The Z/γ^* cross section has been measured as a function of the boson rapidity $|y_Z|$ up to 2.4 and an extension to $|y_Z| \leq 3.6$ has been obtained in the electron channel, with the inclusion of the forward detector region [2]. These measurements allow one to probe a large range of parton momentum fraction due to its dependence on the rapidity of the vector bosons.

The measured y_Z (see Figure 2–left) and η_ℓ dependencies are broadly described by the predictions of the PDF sets considered. However, some deviations are visible; for example, the JR09 PDF set predicts a lower Z cross section, at central rapidities, than the measurement, and almost all predictions tend to overestimate the Z and W cross sections at large y_Z and η_ℓ. These measurements can therefore provide additional constraints on PDFs, especially on the strange-quark density [7], for which very little is known.

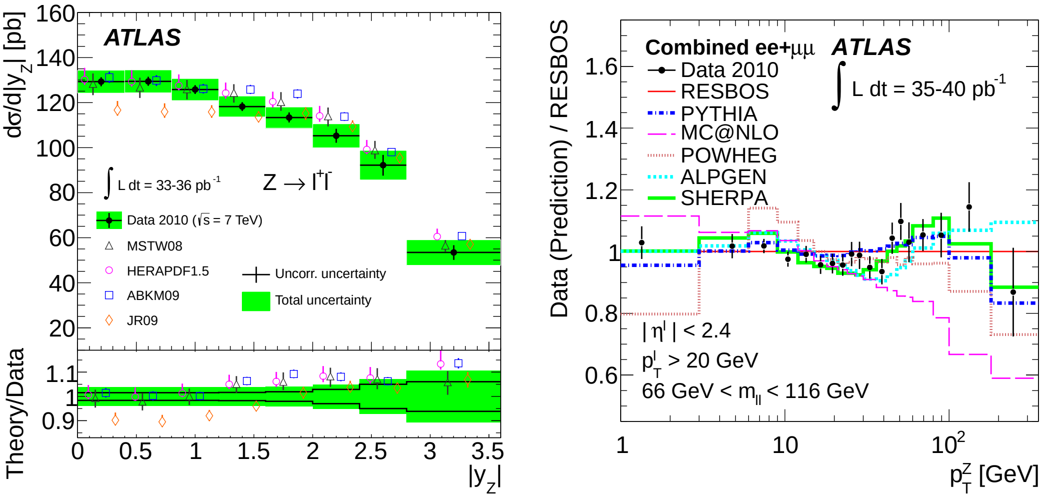

Figure 2: (Left) Differential $d\sigma/d|y_Z|$ cross section measurement for $Z \to \ell\ell$ compared to NNLO theory predictions using various PDF sets [2]. (Right) Ratios of the combined data and various predictions to the RESBOS prediction for the normalised differential cross section as a function of p_{T}^{Z} [8].

The W and Z production cross sections have also been measured as a function of the vector boson p_{T} in the electron and muon channels, and the two channels have been combined [8, 9] (see Figure 2–right). These measurements are used to test pQCD predictions and the phenomenological models used in Monte Carlo generators. Two regimes are particularly interesting: the low-p_{T} regime, which is dominated by soft and collinear parton emission, and the high-p_{T} regime, which corresponds to events containing at least one hard parton. The low-p_{T} region can be modeled by logarithmic resummations or parton shower algorithms. On the other hand, pQCD calculations and generators using NLO matrix elements or tree-level $2 \to n$ matrix elements can be tested at high p_{T}.

The RESBOS prediction, which combines resummed and fixed-order pQCD calculations, shows good agreement with the measurement over the entire p_{T} range, indicating the importance of resummation (the RESBOS prediction is used as a reference in Figure 2). The ALPGEN+HERWIG, SHERPA, and PYTHIA predictions also give a good description of the data. On the other hand, NLO generators such as MC@NLO or POWHEG+PYTHIA underestimate the data at high transverse momentum. Fixed-order pQCD calculations predict too few events at high p_{T} at $\mathcal{O}(\alpha_S)$ but the agreement with the measured distributions is significantly improved by the $\mathcal{O}(\alpha_S^2)$ calculations [8, 9].

3 Polarisation measurements

Using the decay-lepton transverse momentum and the missing transverse momentum, the W decay angular distribution projected onto the transverse plane has been measured and analysed in terms of the helicity fractions f_0, f_L and f_R [10]. These helicity fractions have been obtained in two different kinematic ranges (35 GeV $< p_{\mathrm{T}}^{W} <$ 50 GeV and $p_{\mathrm{T}}^{W} >$ 50 GeV) by fitting distributions of the cosine of the "transverse helicity" angle $\cos\theta_{2D}$ with templates representing longitudinal, left- and right-handed W bosons. The measurements of $f_L - f_R$ and f_0 have been compared to the values obtained from the MC@NLO and POWHEG generators (see Figure 3). No stringent constraints nor clear inconsistencies can be deduced, due to large uncertainties on the measurements, especially on f_0.

The polarisation of τ leptons has been measured for the first time at a hadron collider, using $W \to \tau\nu$ decays [11]. Hadronic 1-prong τ decays have been used, and the τ polarisation has been obtained from the energy sharing between charged and neutral pions. The measured value $P_\tau = -1.06 \pm 0.04\,(\text{stat})^{+0.05}_{-0.07}\,(\text{syst})$ is in agreement with the Standard Model prediction.

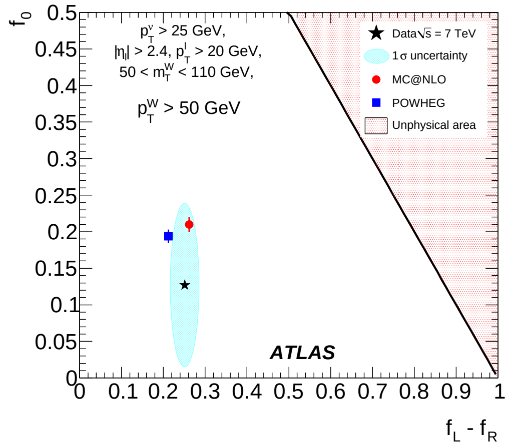

Figure 3: Measured values of f_0 and $f_L - f_R$ for $p_T^W > 50$ GeV compared with the predictions of MC@NLO and POWHEG [10]. The ellipse around the data point corresponds to one standard deviation.

Conclusion

The high production rate of W and Z bosons at the LHC enables detailed studies such as precise total and differential cross-section measurements or polarisation measurements. These measurements can be used to further refine our knowledge of the proton structure, and test predictions from perturbative QCD and various phenomenological models. $W \to \tau\nu$ and $Z \to \tau\tau$ decays have also been measured, proving the ability of ATLAS to measure τ observables (e.g. polarisation), which are key ingredients for searches and the characterisation of new phenomena.

Most of the measurements presented in these proceedings have been performed using the dataset recorded in the year 2010. Efforts are ongoing to publish results using the larger 2011 dataset.

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