Electroweak results with the ATLAS 2010 data

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Abstract. The ATLAS Experiment is one of the two multi-purpose detectors at the LHC. During the year 2010 it has collected 45 pb$^{-1}$ of $pp$ collisions at a center-of-mass energy of 7 TeV. In this paper the ATLAS electroweak results with 2010 data are described. Measurements of total inclusive $W$ and $Z$ production cross sections are presented, as well as differential cross sections and $W$ charge asymmetry. As the production of pairs of bosons is an important process for investigating the electroweak sector of the Standard Model, the measurements of the cross section of such processes are also presented.

1. Introduction
Electroweak measurements are among the first studies performed at the LHC with early 2010 $pp$ collision data at a center-of-mass energy of 7 TeV. $W$ and $Z$ final states are interesting because they are the “standard candle” used to get to know the detector, i.e. understand and calibrate it. They are used, for example, to validate the different object reconstructions and identifications, such as electron and muon reconstruction, to define the energy scale of missing energy and trigger efficiencies. Moreover, channels with $W$ and $Z$ bosons in the final state are important backgrounds to searches for new particles.

Diboson production plays an important role in electroweak physics. Their production rates and the kinematic distributions of the final states are sensitive to triple gauge boson couplings. In Figure 1 the Standard Model s-channel Feynman diagram for $W^+W^-$ production through the quark-antiquark annihilation is shown. This channel contains the $WWZ$ and $WW\gamma$ triple gauge boson coupling (TGC) vertices. Moreover, diboson channels are an important background to Higgs boson and new physics searches.

ATLAS (A Toroidal LHC ApparatuS) is one of the two multi-purpose experiments at the LHC. It consists of an inner tracking detector surrounded by a superconducting solenoid which provides a 2 T magnetic field, electromagnetic and hadronic calorimeters and a muon

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spectrometer with a toroidal magnetic field. The inner detector provides precision tracking of charged particles for $|\eta| < 2.5$. It consists of a silicon pixel detector, a silicon strip detector and a straw tube tracker that also provides transition radiation measurements for electron identification. The calorimeter system covers the pseudorapidity range $|\eta| < 4.9$. It is composed of sampling calorimeters with either liquid argon (LAr) or scintillating tiles as active media. In the region $|\eta| < 2.5$ the electromagnetic LAr calorimeter is finely segmented and plays an important role in electron identification. The muon spectrometer has separate trigger and high-precision tracking chambers which provide muon identification in $|\eta| < 2.7$ [1].

In the year 2010 the ATLAS Experiment has collected 45 pb$^{-1}$ of data from $pp$ collisions at a center-of-mass energy of 7 TeV. It corresponds to 93.6% of the luminosity delivered by the LHC. This high fraction of data collected was achieved thanks to the good performance of all sub-detectors. In Figure 2 the cumulative luminosity during the 2010 $pp$ run at 7 TeV as function of time is shown. Considering data quality requirements, the luminosity available then for analyses amounts to $\sim 35$ pb$^{-1}$. During the running of the first year, the luminosity profile changed considerably, due to an intense machine commissioning. Therefore the amount of multiple interactions per beam crossing increased throughout the data taking. This is shown in Figure 3, where the maximum mean number of interactions per beam crossing is plotted as a function of time.

In this paper, several cross section measurements are presented. In ATLAS, the total cross section (here for the $W \rightarrow \ell\nu\ell$ decay) is calculated as:

$$\sigma_{W}^{\text{tot}} \times BR(W \rightarrow \ell\nu\ell) = \frac{N_{\text{obs}} - N_{\text{bkg}}}{A_{W}C_{W}\mathcal{L}}$$

where $N_{\text{obs}}$ is the number of observed events in data, $N_{\text{bkg}}$ is the number of background events (extracted from data or from Monte Carlo, depending on the analysis), $\mathcal{L}$ is the integrated luminosity corresponding to the selected runs and trigger choice, $A_{W}$ denotes the kinematic and geometric acceptance (fiducial acceptance) for the signal process and is determined from generator level Monte Carlo, and $C_{W}$ is the ratio between the number of reconstructed signal events passing the selections of the analysis and the number of events within the fiducial acceptance.

![Figure 2. Online plot of the cumulative luminosity versus day delivered to (green), and recorded by ATLAS (yellow) during the 2010 pp data taking.](image1)

![Figure 3. The maximum mean number of events per beam crossing versus day during the 2010 pp data taking.](image2)
The cross section is also measured in the fiducial region as:

\[ \sigma_{\text{fid}}^{W} \times BR(W \rightarrow \ell \nu_{\ell}) = \frac{N_{\text{obs}} - N_{\text{bkg}}}{C_{W} L}. \] (2)

This cross section is not affected by significant theoretical uncertainties. Therefore, future improvements on the prediction of the acceptance can be used to extract improved total cross section measurements.

2. W and Z boson production

In the following, the W and Z/\gamma^{*} cross section measurements are presented in the electron and muon channels (Section 2.1). The cross section measurement for the production of W and Z bosons in association with jets is described in Section 2.2. Finally, in Section 2.3 the measurement of the W charge asymmetry in the muon channel is presented.

2.1. W and Z/\gamma^{*} cross section measurements

The W and Z/\gamma^{*} cross sections have been measured by ATLAS [2] in their leptonic decay channels. In particular, the electron and muon channels have been studied.

For the \( W \rightarrow e\nu_{e}/\mu\nu_{\mu} \) channels, the signature is one lepton and missing energy from the neutrino. Therefore the event selection requires the presence of one well reconstructed lepton with \( p_{T} > 20 \) GeV, sizable missing energy, \( E_{\text{T}}^{\text{miss}} > 25 \) GeV, and transverse mass \( m_{T} > 40 \) GeV. In Figures 4 and 5 the distributions of the transverse mass of the selected \( W^{+} \) to electron/muon candidates are shown.

For the \( Z \rightarrow e^{+}e^{-}/\mu^{+}\mu^{-} \) channels, the signature is two opposite charged leptons. Therefore in this case the event selection requires the presence of two reconstructed leptons with opposite charge and the invariant mass of the lepton pair in the range \( 66 < m_{\ell\ell} < 116 \) GeV. In Figures 6 and 7 the distributions of the invariant mass of the Z boson candidates are shown, both in the electron and in the muon channels.

For the two analyses the main backgrounds come from QCD jets and other electroweak processes. The estimation of the electroweak background is taken from Monte Carlo, while for the QCD background the estimation is extracted directly from data. As seen in Figures 4-7, the
Figure 6. Invariant mass distribution of candidate $Z \rightarrow ee$ events [2].

Figure 7. Invariant mass distribution of candidate $Z \rightarrow \mu\mu$ events [2]. The QCD background is found to be negligible.

amount of residual background, after the event selections described before, is small both for $W$ and $Z$ channels.

The main systematics affecting the cross section measurement come from the uncertainty on the electron reconstruction and identification ($\sim 1.5/3\%$) and the uncertainty on the missing energy scale ($2\%$ for $W$ channels). It has to be noticed that the resulting systematic uncertainty is already smaller than the systematic on luminosity ($3.4\%$) [3].

The systematic on the acceptance ($\sim 3/4\%$) is dominated by the uncertainties on the PDFs and on showering models. It is evaluated taking into account three contributions:

- uncertainties within one PDF set, which are derived using the CTEQ 6.6 PDF [4],
- uncertainties between different PDF sets (the maximal difference between the MRST LO* [5], CTEQ 6.6 and HERAPDF 1.0 [6] sets is taken as a systematic),
- difference between the PYTHIA [7] and MC@NLO [8] simulations, using the same PDF set, CTEQ 6.6.

The results of the measurement of the $W$ and $Z/\gamma^*$ cross sections are reported in Table 1.

| $\sigma_{W\pm}^{tot} \cdot \text{BR}(W \rightarrow \ell\nu\ell)$ [nb] | $\sigma_{Z/\gamma^*}^{tot} \cdot \text{BR}(Z/\gamma^* \rightarrow \ell\ell)$ [nb], $66 < m_{\ell\ell} < 116$ GeV |
|---|---|
| $W^+$ | $6.257 \pm 0.017$ (stat.) $\pm 0.152$ (syst.) $\pm 0.213$ (lumi.) $\pm 0.188$ (acc.) |
| $W^-$ | $4.149 \pm 0.014$ (stat.) $\pm 0.102$ (syst.) $\pm 0.141$ (lumi.) $\pm 0.124$ (acc.) |
| $W$ | $10.391 \pm 0.022$ (stat.) $\pm 0.238$ (syst.) $\pm 0.353$ (lumi.) $\pm 0.312$ (acc.) |
| $Z/\gamma^*$ | $0.945 \pm 0.006$ (stat.) $\pm 0.011$ (syst.) $\pm 0.032$ (lumi.) $\pm 0.038$ (acc.) |

Figure 8 summarizes the results on the cross section measurements showing the measured and predicted $W/Z$ cross section ratio. Good agreement with predictions is observed. Figure 9
shows the measured and predicted $W^-$ vs. $W^+$ cross sections times leptonic branching ratios: already with the 2010 amount of data, the $W$ cross section measurement has sensitivity to PDFs and some constraints can be set.

**Figure 8.** Measured and predicted $W/Z$ cross section ratio. The experimental uncertainty of the measurement includes statistical and experimental systematic uncertainties [2].

**Figure 9.** Measured and predicted $W^-$ vs. $W^+$ cross sections times leptonic branching ratios. The projections of the ellipse to the axes correspond to one standard deviation uncertainty of the cross sections. The uncertainties of the predictions are the PDF uncertainties [2].

### 2.2. $W^+$jets and $Z/\gamma^*$+jets cross sections

The study of massive vector boson production in association with one or more jets is an important test of QCD. Moreover, $W/Z$+jets processes are a significant background to studies of Standard Model processes such as $t\bar{t}$ or single-top production, as well as searches for the Higgs boson and for physics beyond the Standard Model. Therefore the measurements of the cross section and kinematic properties of $W/Z$+jets processes and comparisons to theoretical predictions are of significant interest.

ATLAS has measured the cross sections for the $W$+jets production [9] and $Z/\gamma^*$+jets production [10] with the boson decaying either in the electron or the muon channel.

Jets are reconstructed with the anti-$k_t$ algorithm [11] with a radius parameter $R = 0.4$. All jets considered in the analysis for the $W$+jets ($Z/\gamma^*$+jets) cross section measurement are required to have a transverse momentum $p_T > 20 (30)$ GeV and a pseudorapidity in the range $|\eta| < 2.8$. In addition, a lepton-jet overlap removal is applied: if a jet and a lepton passing some identification requirements are within $\Delta R = \sqrt{\Delta \eta^2 + \Delta \phi^2} < 0.5$, the jet is removed, regardless of the jet $p_T$ or $\eta$.

Both in the $W$+jets and $Z/\gamma^*$+jets analyses, events are required to fire a single lepton trigger. Then, for the $W$+jets channel, the event selection is based on the presence of one isolated lepton (with $E_T > 20$ GeV). The events must not have any additional identified lepton. Moreover, events are required to have $E_T^{\text{miss}} > 25$ GeV, and transverse mass $m_T > 40$ GeV, as in the analysis for the $W$ inclusive cross section measurement. For the $Z/\gamma^*$+jets analysis instead,
the presence of two opposite charge leptons with $E_T > 20$ GeV is required. Furthermore, the invariant mass of the lepton pair must be $66 < m_{\ell\ell} < 116$ GeV.

The backgrounds are estimated with different techniques for the different analyses and also depending on the channel. For example, in the $W+$jets analysis, the number of QCD background events was estimated by fitting, in each jet multiplicity bin, the $E_T^{\text{miss}}$ distribution in the data (without the $E_T^{\text{miss}}$ cut) to a sum of two templates: one for the QCD background and another which included signal and the leptonic backgrounds. In both muon and electron channels, the shapes for the latter template were obtained from simulation. While in the muon channel the template for the QCD background was obtained from simulation, in the electron channel it was obtained from the data because the mechanisms by which a jet fakes an electron are difficult to simulate.

The main systematics affecting the measurements come from the jet energy scale, which is smaller in the $W+$jets channel ($\sim 9\%$) while is more important for the $Z/\gamma^*+$jets ($\sim 10 - 20\%$, depending on the $p_T$ and $\eta$ of the jet). Another important systematic for the $W+$jets channel comes from the treatment of pile-up: it amounts to $\sim 7\%$.

**Figure 10.** $W+$jets cross section as a function of the inclusive jet multiplicity for electron channel. Also shown are predictions from ALPGEN, SHERPA, PYTHIA, MCFM and BLACKHAT−SHERPA, and the ratio of theoretical predictions to data (PYTHIA is not shown in the ratio) [9].

**Figure 11.** $W+$jets cross section as a function of the $p_T$ of the first jet in the event for the electron channel. The $p_T$ of the first jet is shown separately for events with $\geq 1$ jet to $\geq 4$ jet. The $\geq 2$ jet, $\geq 3$ jet and $\geq 4$ jet distributions have been scaled down by factors of 10 and 100, 1000 respectively. Also shown are predictions from ALPGEN, SHERPA, MCFM and BLACKHAT−SHERPA, and the ratio of theoretical predictions to data for $\geq 1$ jet and $\geq 2$ jet events [9].
The results of the measurements are shown in Figures 10 to 13. In Figure 10 the \(W+\)jets cross section as a function of jet multiplicity for the electron channel is shown, while Figure 11 shows the \(W+\)jets cross section as a function of the \(p_T\) of the leading jet in the event for the electron channel, separately for events with \(\geq 1\) jet to \(\geq 4\) jet. The cross sections are quoted in the limited kinematic region: \(E_T^{j} > 20\ \text{GeV}, \ |\eta^j| < 2.8,\ E_T^{\ell} > 20\ \text{GeV}, \ |\eta^{\ell}| < 2.47\) (excluding \(1.37 < |\eta^{\ell}| < 1.52),\ |\eta^\nu| < 2.4,\ p_T^\nu > 25\ GeV,\ M_T > 40\ GeV,\ \Delta R^{\ell j} > 0.5\), where \(\ell, \ j, \text{ and } \nu\) denote lepton, jet and neutrino, respectively. Along with data, the predictions from ALPGEN [12], SHERPA [13], PYTHIA, MCFM [14] and BLACKHAT–SHERPA [15], and the ratio of theoretical predictions to data are also displayed. Good agreement is observed with the predictions of the multi-parton matrix element generators ALPGEN and SHERPA. Calculations based on NLO matrix elements in MCFM and in BLACKHAT–SHERPA are also in good agreement with the data.

![Figure 10](image1.png)

**Figure 12.** \(Z/\gamma^*+\text{jets}\) cross section as a function of the inclusive jet multiplicity for the muon channel. The measurements are compared to NLO pQCD predictions from MCFM (only available in the first two bins and including uncertainties), as well as the predictions from ALPGEN, SHERPA, and PYTHIA (\(\times 1.17\)) [10].

![Figure 13](image2.png)

**Figure 13.** \(Z/\gamma^*+\text{jets}\) cross section as a function of the \(p_T\) of the jet for the muon channel. The measurements are compared to NLO pQCD predictions from MCFM, as well as the predictions from ALPGEN and SHERPA [10].

Figure 12 shows the measured \(Z/\gamma^*+\text{jets}\) production cross section in the muon channel as a function of the inclusive jet multiplicity, while Figure 13 shows the measured inclusive cross section as a function of the \(p_T\) of the jet, in events with at least one jet with \(p_T^j > 30\ \text{GeV and } |\eta^j| < 2.8\) in the final state, and normalized to \(Z/\gamma^*\) Drell-Yan cross section. The results are defined in a limited kinematic range for the \(Z/\gamma^*\) decay products. In the muon channel the measurements are presented in the region: \(66 < m_{\mu\mu} < 116\ \text{GeV},\ p_T^{\ell} > 30\ \text{GeV, } |\eta^{\ell}| < 2.4,\ \text{and } \Delta R^{\ell \mu} > 0.5\). The measurements are compared to NLO pQCD predictions from MCFM, as well as the predictions from ALPGEN and SHERPA. The measured cross sections are described by the NLO pQCD predictions, which include non-perturbative corrections, as well as by the
predictions from LO matrix elements supplemented by parton showers, as implemented in the ALPGEN and SHERPA Monte Carlo generators.

2.3. W charge asymmetry
The measurement of the W boson charge asymmetry is sensitive to quark distribution via the dominant production process $u\bar{d}(\bar{u}d) \rightarrow W^{+}(\rightarrow \mu^{-}\nu_{\mu})$. It provides complementary information to that obtained from measurements of inclusive deep inelastic scattering cross sections at the HERA $ep$ collider, as the HERA data do not strongly constrain the ratio between $u$ and $d$ valence quarks in the kinematic regime of low $x$, where $x$ is the proton momentum fraction carried by the parton. In particular the measurement of the $W$ charge asymmetry at the LHC can contribute to the understanding of PDFs in the parton momentum fraction range $10^{-3} \lesssim x \lesssim 10^{-1}$.

The charge asymmetry has been studied in ATLAS in the muon channel [16]. The event selection is very similar to the selection used in the $W \rightarrow \mu\nu$ cross section measurement described before.

The asymmetry varies significantly as a function of the pseudorapidity $\eta_{\mu}$ of the charged decay lepton due to its strong correlation with the momentum fraction $x$ of the partons producing the $W$ boson. It is defined from the cross sections for $W \rightarrow \mu\nu_{\mu}$ production $d\sigma_{W\mu^{\pm}}/d\eta_{\mu}$ as:

$$A_{\mu} = \frac{d\sigma_{W\mu^{+}}/d\eta_{\mu} - d\sigma_{W\mu^{-}}/d\eta_{\mu}}{d\sigma_{W\mu^{+}}/d\eta_{\mu} + d\sigma_{W\mu^{-}}/d\eta_{\mu}}$$

where the cross sections include the event kinematical cuts used to select $W \rightarrow \mu\nu_{\mu}$ events.

Systematic effects on the $W$ production cross-section measurements are typically the same for positive and negative muons, mostly canceling in the asymmetry. All systematic uncertainties on the asymmetry measurement are determined in each $|\eta_{\mu}|$ bin accounting for correlations between the charges. The dominant sources of systematic uncertainties on the asymmetry come from trigger and reconstruction efficiencies.

The measured differential charge asymmetry in eleven bins of muon absolute pseudorapidity is shown in Figure 14. Also shown are expectations from $W$ predictions at NLO with different PDF sets: CTEQ 6.6, HERA 1.0 and MSTW 2008 [17]; all predictions are presented with 90% confidence-level error bands.

![Figure 14. The muon charge asymmetry from W boson decays in bins of absolute pseudorapidity. The data (shown with error bars including the statistical and systematic uncertainties) are compared to MC@NLO predictions with different PDF sets [16].](image)

A $\chi^{2}$ comparison using the measurement uncertainty and the central value of the PDF predictions yields values per number of degrees of freedom of 9.16/11 for the CTEQ 6.6 PDF.
set, 35.81/11 for the HERA 1.0 PDF set and 27.31/11 for the MSTW 2008 PDF set. Whereas none of the predictions are inconsistent with these data, the predictions are not fully consistent with each other since they are all phenomenological extrapolations in $x$. The input of the data presented here is therefore expected to contribute to the determination of the next generation of PDF sets, helping to reduce PDF uncertainties, particularly the shapes of the valence quark distributions in the low-$x$ region.

3. Diboson production

In the following, some measurements of diboson production cross sections are presented. In Section 3.1 the measurements of $W\gamma$ and $Z\gamma$ cross sections are presented. The analysis of $W^+W^-$ production is described in Section 3.2 while in Section 3.3 the measurement of $W^\pm Z$ production is shown.

3.1. $W\gamma$ and $Z\gamma$ cross section measurements

The measurement of $W$ and $Z$ bosons in association with high energy photons provides important tests of the Standard Model. In fact, physics beyond the Standard Model, such as composite structure of $W$ and $Z$ bosons, new vector bosons, and techni-mesons would enhance those production cross sections and alter the event kinematics.

ATLAS studies [18] use measurements of $pp \rightarrow \ell\nu\gamma + X$ and $pp \rightarrow \ell^+\ell^-\gamma + X$ with an integrated luminosity of approximately 35 pb$^{-1}$. Events are selected by requiring the presence of a $W$ or $Z$ boson candidate along with an associated isolated photon having a transverse energy $E_T > 15$ GeV and being separated from the closest electron or muon $\ell$ by $\Delta R_{\ell\gamma} > 0.7$.

The event selection is based on the presence of one high $p_T$ lepton and one high $E_T$ photon. In addition, for the $W\gamma$ channel the event is required to have $E_T^{\text{miss}} > 25$ GeV and $m_T > 40$ GeV, while for the $Z\gamma$ channel events with $m_{\ell\ell} > 40$ GeV are selected. The suppression of photons from final state radiation FSR is done by means of an isolation cut.

A total of 192 $W\gamma$ candidates (95 in the electron and 97 in the muon channel) and 48 $Z\gamma$ candidates (25 in the electron and 23 in the muon channel) pass all the requirements. In Figure 15 the three body transverse mass$^2$ of those $W\gamma$ candidate events, considering both the electron and muon channels, is shown. In Figure 16 the three body invariant mass for the $Z\gamma$ candidate events is shown, again for electron and muon channels together. In both distributions a good agreement between data and predictions can be observed.

The summary of the measurements of the $W\gamma$ and $Z\gamma$ cross section is reported in Table 2, along with the NLO theoretical predictions. The main systematic uncertainties affecting the measurements come from photon reconstruction and identification efficiency ($\sim 11\%$). While the current measurements are not strongly sensitive to possible new physics, the distributions of kinematic variables determined from the leptons and photons are consistent with the predictions from the Standard Model in a new kinematic regime.

The ratio of the $W\gamma$ to $Z\gamma$ cross sections, defined as

$$R = \frac{\sigma_{pp\rightarrow\ell^+\nu\gamma}}{\sigma_{pp\rightarrow\ell^+\ell^-\gamma}}$$

(4)

can be measured with a higher relative precision than the individual cross sections since both experimental and theoretical uncertainties partially cancel. This ratio is a test of the $WW\gamma$ triple gauge coupling predicted by the Standard Model. In Figure 17 the measured ratio of the production cross sections of $W\gamma$ and $Z\gamma$, together with the Standard Model prediction are reported.

$^2$ defined as $m_T^2(\ell, \nu, \gamma) = (\sqrt{M_T^2 + |p_T(\gamma) + p_T(\ell)|^2 + E_T^{\text{miss}}})^2 - |p_T(\gamma) + p_T(\ell) + E_T^{\text{miss}}|^2$. 

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3.2. $W^+W^-$ production
The $W^+W^-$ process plays an important role in electroweak physics. The production rate and kinematic distributions of $W^+W^-$ are sensitive to the triple gauge couplings of the $W$ boson and $W^+W^-$ production is an important background to Standard Model Higgs boson searches.

ATLAS has measured the $W^+W^-$ production cross section [19]. Candidate $W^+W^-$ events are reconstructed in the fully leptonic decay channel (including the channels with taus decaying
leptonically), looking for $\ell^+\nu_\ell\ell^-\nu_\ell$ events. This final state has a better signal to background ratio than the semi-leptonic or hadronic channels. In Figure 18 the event display of a $W^+W^-$ candidate is shown: in this case one $W$ decays in $e\nu_e$ and the other in $\mu\nu_\mu$. In the event display the electron and muon can be seen together with the direction of missing energy.

![Event display of a \(WW\rightarrow e\nu_e\mu\nu_\mu\) candidate.](image)

The event selection starts from the requirement that the event has fired a single lepton trigger. The signal selection requires two opposite sign leptons with a $p_T > 20$ GeV and missing energy.

The main backgrounds for the fully leptonic channel are $W$+jets, Drell-Yan production, top production (both $t\bar{t}$ and $Wt$) and other diboson processes. The main sources of background have been evaluated from Monte Carlo, except from the background from $W$+jets. This background was estimated directly from data, as the rate at which hadronic jets are mis-identified as leptons may not be accurately described in the Monte Carlo. The $W$+jets background is derived by defining a control region, similar to $W^+W^-$ signal selection, that is enriched in $W$+jets events due to the use of an alternative lepton definition. The selected events are then required to pass the full $W^+W^-$ event selection, where the jet is treated as if it was a fully identified lepton. The $W$+jets background is then estimated by scaling this control sample by a measured fake factor.

To reject the background from $Z$ bosons, a cut on the dilepton invariant mass is applied, removing events with $|m_{\ell\ell} - m_Z| < 10$ GeV and $m_{\ell\ell} < 15$ GeV. Events are required to have a large amount of missing energy, where the missing energy in this case is defined as:

$$E_{T,rel}^{miss} = \begin{cases} E_T^{miss} \times \sin(\Delta\phi) & \text{if } \Delta\phi < \pi/2 \\ E_T^{miss} & \text{if } \Delta\phi \geq \pi/2 \end{cases}$$

where $\Delta\phi$ is the difference in the azimuthal angle $\phi$ between the $E_T^{miss}$ and the nearest lepton or jet. This definition of $E_{T,rel}^{miss}$ helps in rejecting more efficiently those events for which missing energy is likely to have been mis-measured.

For the $ee$ and $\mu\mu$ channels the requirement is $E_{T,rel}^{miss} > 40$ GeV, while for the $e\mu$ channel it is $E_{T,rel}^{miss} > 20$ GeV. Another important requirement to suppress background, in particular the $t\bar{t}$ contribution, is to veto events with reconstructed jets. The effect of this selection can be seen by comparing Figures 19 and 20: the distribution of $E_{T,rel}^{miss}$ for events passing the full event selection apart from the cut on $E_{T,rel}^{miss}$ are reported. In Figure 19 the jet veto is not applied, while in Figure 20 it is: the $t\bar{t}$ background is highly suppressed.

After the selection, 8 candidate events are selected in data: 1 in the $e^+e^-$ channel, 2 in the $\mu^+\mu^-$ channel and 5 in the $e^\pm\mu^\mp$ channel. In Figure 21 the distribution of the dilepton system $p_T$ for these $W^+W^-$ candidates is shown.
ATLAS measures a cross section of $\sigma_{\text{tot}}^{W^+W^-} = 41^{+20}_{-16}\,(\text{stat.}) \pm 5(\text{syst.}) \pm 1(\text{lumi.})\,\text{pb}$. This is in agreement with the NNLO theoretical prediction, which is $44.3 \pm 3\,\text{pb}$. Note that the systematic uncertainty on the measurement is far smaller than the statistical uncertainty. This measurement will therefore profit from the high integrated luminosity collected in the year 2011.

3.3. $W^\pm Z$ production

ATLAS has also measured the $W^\pm Z$ production cross section [20]. The analysis uses four channels with leptonic decays ($W^\pm Z \rightarrow \ell
ell
ell$) involving electrons and muons: $\ell\ell\ell\ell$, $e\ell\mu\mu$ or $\mu\mu\ell\ell$ (including secondary $e$ or $\mu$ leptons from the decay of $\tau$ leptons) plus missing transverse energy, $E_T^{\text{miss}}$. The results are based on an integrated luminosity of 205 pb$^{-1}$ collected in early 2011. The main sources of background to the leptonic $W^\pm Z$ signal are $ZZ$, $Z\gamma$, $Z/\gamma^*+\text{jets}$, and top events. The signal and background contributions are mainly modeled with Monte Carlo simulation and validated with data-driven techniques.

At least one single lepton trigger is required to fire in order to select the event. Events with two leptons of the same flavour and opposite charge with an invariant mass within 10 GeV of the $Z$ boson mass are selected. This reduces much of the background from QCD and top production, and some diboson backgrounds.

Events are then required to have at least 3 reconstructed leptons originating from the same
primary vertex, two leptons from a $Z \rightarrow \ell\ell$ decay and an additional third lepton. This requirement reduces the $Z/\gamma^*+\text{jets}$, top, and some diboson backgrounds. Next, the $E_T^{\text{miss}}$ in the event is required to be greater than 25 GeV and the transverse mass of the system formed from the third lepton and the $E_T^{\text{miss}}$ is required to be greater than 20 GeV. These cuts suppress the remaining backgrounds from $Z$ and diboson production.

Figures 22 and 23 show the transverse momentum of $W$ and $Z$ bosons for the selected events.

**Figure 22.** Transverse momentum of the $W$ in $W^\pm Z$ candidate events [20].

**Figure 23.** Transverse momentum of the $Z$ in $W^\pm Z$ candidate events [20].

ATLAS observes 12 $W^\pm Z$ candidates in data, with $9.1 \pm 0.2(\text{stat}) \pm 1.3(\text{sys})$ signal and $2.0 \pm 0.3(\text{stat}) \pm 0.7(\text{sys})$ background events expected. The signal definition includes the contribution from tau decays into electrons or muons, which accounts for about 0.5 events.

The final results for the combined total inclusive cross section measurement for the $W^\pm Z$ bosons decaying directly into electrons and muons excluding contributions from tau decays is: $\sigma_{WZ}^{\text{tot}} = 18_{-6}^{+7}(\text{stat})_{-3}^{+3}(\text{syst})_{-1}^{+1}(\text{lumi}) \text{pb}$. This measurement is found to be in agreement with the NNLO theoretical prediction, which is 16.9 pb. Also in this case, the main uncertainty on the measurement comes from the amount of data available for the measurement. Therefore also this measurement will profit from the high statistic collected during the full 2011 period.

4. Conclusions
To conclude, in this paper the recent electroweak results of the ATLAS Experiment with 2010 data have been presented. They are summarized in Figure 24.

**Figure 24.** Summary of the ATLAS cross-section measurements from the 2010 and early 2011 datasets, including inclusive $W$ and $Z$, diboson $W\gamma$ and $Z\gamma$, $W^+W^-$, $W^\pm Z$ and $t\bar{t}$ production. The dark error bar represents the statistical uncertainty. The red error bar represents the full uncertainty, including systematics and luminosity uncertainties.
In 2011, already more than 1 fb⁻¹ of pp collisions has been collected. Such amount of data will give the possibility to improve those measurements for which the statistical error is the dominating uncertainty, like the measurements of the diboson production. With these data it will also be possible to measure differential cross sections. Moreover new analyses will be possible with the increased statistics, for example the measurement of the W/Z+b in W/Z+jets events and the ZZ production cross section.

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