MEASUREMENTS OF STANDARD MODEL PROCESSES AT ATLAS

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With over 45 pb^{-1} of 7 TeV pp collisions recorded, the ATLAS Standard Model physics program is well under way. These proceedings survey the latest tests of the Standard Model at this unprecedented energy scale. An overview of recent ATLAS results is given. Measurements of the W boson charge asymmetry, di–boson production, and single top–quark production are highlighted.

1 Introduction

Measurements of Standard Model (SM) processes have been the flagship of the ATLAS[1] physics program in 2010. These measurements cover a wide range of topics from soft QCD measurements of particle multiplicities and the total pp inelastic cross section, through QCD measurements of inclusive jet production, photon production, and top-quark pair production, to electro-weak measurements of vector–boson properties, di–boson production, and single top–quark production.

In addition to being a rich source of physics, Standard Model processes serve as standard candles from which the detector performance can be understood. The expected SM signals can be used to commission the detector and refine analysis techniques in preparation for the unexpected. The physics objects used in SM measurements - charged leptons, missing transverse energy, photons, and jets - are critical for all physics analyses. The understanding of these objects, gained initially through SM measurements, is of wide–ranging importance for all the physics done at ATLAS.

These proceedings will focus on recent electro–weak measurements. The measurement of the W boson charge asymmetry is presented in Section 2, followed by the measurement of the $W\gamma$ and $Z\gamma$ cross sections in Section 3. Section 4 presents the measurement of the WW production cross section and results on single top–quark production are given in Section 5. As can be seen in Figure 1, the electro–weak measurements presented in these proceedings span several orders of magnitude in production cross section. The varying amounts of signal and sources of background across this broad spectrum pose unique challenges to the different analyses presented here.

2 W boson Charge Asymmetry

The W boson charge asymmetry is particularly interesting because it is sensitive to the parton distributions functions, PDFs, of the proton. A precision measurement of the asymmetry can

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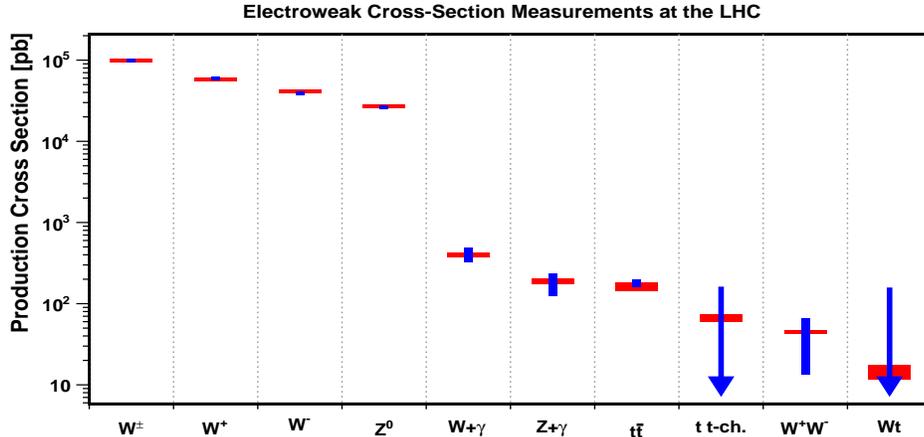[a]on behalf of the ATLAS Collaboration

Figure 1: Electro–weak production cross sections at the LHC. Theoretical predictions are shown in red, the corresponding ATLAS measurements are given in blue. See references [2-6] for cross section measurements.

be used to constrain the PDFs of the valance quarks in the $10^{-3} - 10^{-4}$ region of momentum fraction.[7]

The W boson charge asymmetry has been measured by ATLAS in the muon decay channel as a function of the muon pseudo–rapidity, η_μ.[7] The asymmetry, defined as

$$A_\mu = \frac{\frac{\mathrm{d}\sigma_{W_\mu^+}}{\mathrm{d}\eta_\mu} - \frac{\mathrm{d}\sigma_{W_\mu^-}}{\mathrm{d}\eta_\mu}}{\frac{\mathrm{d}\sigma_{W_\mu^+}}{\mathrm{d}\eta_\mu} + \frac{\mathrm{d}\sigma_{W_\mu^-}}{\mathrm{d}\eta_\mu}}, \tag{1}$$

consists of the ratio of production cross sections, which has the advantage that many of the experimental uncertainties cancel. The measurement was performed by selecting events containing reconstructed muons with transverse momentum, p_T, above 20 GeV, and missing transverse energy, E_T^{miss}, above 25 GeV. The events were additionally required to contain a reconstructed W boson candidate with a transverse mass, m_T of more than 40 GeV. This selection led to 1.3×10^5 W boson candidates, with an estimated background of seven percent predominantly from background from other electro–weak processes.

The measured W boson asymmetry is shown as a function muon pseudo–rapidity in Figure 2(a). The asymmetry rises with η_μ, as predicted by theory, with statistical and systematic uncertainties that are comparable in each η_μ-bin. The limiting systematic uncertainties come from uncertainties on the trigger and muon identification efficiencies, which vary across η_μ from 1–7%. These systematics are currently limited by statistics in control regions and will decrease with further data taking.

The predicted W boson asymmetry from several global fits to the proton PDF are also shown in Figure 2(a). The current experimental uncertainty of the ATLAS measurement is already comparable to those of the global fits. Future measurements of the W boson asymmetry will constrain the proton PDFs.

3 $W\gamma$ and $Z\gamma$ Cross Sections

ATLAS has performed the measurement of the $W\gamma$ and $Z\gamma$ cross sections in the leptonic decay channels of the W and Z bosons[3][b]. The measurement of these $W\gamma$ and $Z\gamma$ processes provides

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[b]Here, and in the rest of these proceedings, the leptonic decay channels only refer to the decays of W or Z bosons to electrons or muons, including the decays to electrons and muons through τs. Decays to hadronically decaying τs have been neglected.
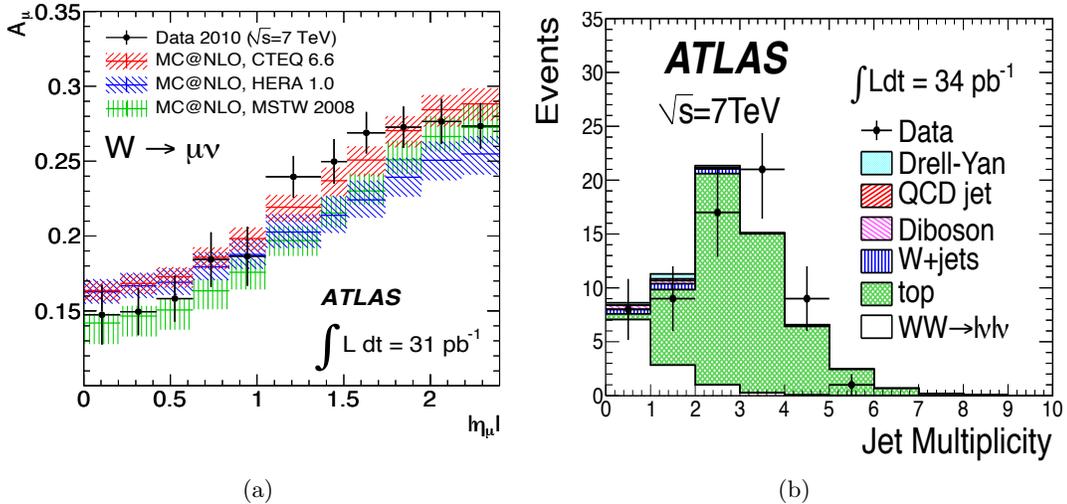
Figure 2: (a) The W boson asymmetry as a function of muon pseudo–rapidity.[7] The measurement is shown in black along with theoretical predictions from several parametrizations of the parton distribution function. (b) The jet multiplicity distribution for events satisfying the di–lepton plus E_T^{miss} selection in the WW cross section analysis.[6] The zero–jet bin is used for the signal extraction.

a test of the electro–weak model. A photon can be produced in association with a W boson or a Z boson through the initial state radiation (ISR) of a photon off of an incoming quark, or by the final state radiation (FSR) of a photon off of the W boson or Z boson decay products. The $W\gamma$ process can also be produced through an additional diagram in which the photon is directly radiated from the W boson. This diagram is sensitive to the triple gauge coupling (TGC) predicted by the Standard Model.

Events were selected containing a W or Z boson candidate and an isolated reconstructed photon with transverse energy, E_T, greater than 15 GeV. The W boson candidates were required to have an electron or muon with E_T greater than 20 GeV, E_T^{miss} greater than 25 GeV, and m_T above 40 GeV. Z boson candidates were required to have two electrons or muons, each with E_T greater than 20 GeV, and having an invariant mass above 40 GeV. The reconstructed photons were required to be well isolated and to be separated from the reconstructed lepton by more than 0.7 in ΔR.[c] The event yields and estimated backgrounds are given in Tables 1 and 2. The W+jet background in the $W\gamma$ analysis is derived from control regions in the data.

$W\gamma$	electron-channel	muon-channel
Event Yield	95	97
W boson + jet Bkg	$16.9 \pm 5.3 \pm 7.3$	$16.9 \pm 5.3 \pm 7.4$
EW Bkg	$10.3 \pm 0.9 \pm 0.7$	$11.9 \pm 0.8 \pm 0.8$

Table 1: $W\gamma$ yields and background estimates. The W+jet background is derived from control regions in the data, whereas the remaining electro–weak background is taken from simulation.

The results of the $W\gamma$ and $Z\gamma$ cross section measurements are presented in Tables 3 and 4. The limiting systematic uncertainties are from uncertainties associated to the photon reconstruction and identification, uncertainties on the background predictions, and uncertainties associated with the signal acceptance. The measured cross sections are in good agreement with the NLO SM prediction. Future measurements of the $W\gamma$ and $Z\gamma$ processes will constrain new physics in

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[c]ΔR^2 is defined as $\Delta R^2 = \Delta\phi^2 + \Delta\eta^2$, where $\Delta\phi(\Delta\eta)$ is the difference in $\phi(\eta)$ between the photon and the lepton.

$Z\gamma$	electron-channel	muon-channel
Event Yield	25	23
Background	3.7 ± 3.7	3.3 ± 3.3

Table 2: $Z\gamma$ yields and background estimates. The background estimates are taken from simulation.

anomalous TGCs.

$W\gamma$	Cross Section [pb]
e-channel	48.9 ± 6.6 (stat) ± 8.3 (sys) ± 1.7 (lumi)
μ-channel	38.7 ± 5.3 (stat) ± 6.4 (sys) ± 1.3 (lumi)
SM NLO Prediction	42.1 ± 2.7 (sys)

Table 3: The measured $W\gamma$ cross sections in electron and muon channel compared to the SM NLO predictions. The cross sections are reported for $E_T^\gamma > 15$ GeV and $\Delta R(l, \gamma) > 0.7$.

$Z\gamma$	Cross Section [pb]
e-channel	9.0 ± 2.5 (stat) ± 2.1 (sys) ± 0.3 (lumi)
μ-channel	5.6 ± 1.4 (stat) ± 1.2 (sys) ± 0.2 (lumi)
SM NLO Prediction	6.9 ± 0.5 (sys)

Table 4: The measured $Z\gamma$ cross sections in electron and muon channel compared to the SM NLO predictions. The cross sections are reported for $E_T^\gamma > 15$ GeV and $\Delta R(l, \gamma) > 0.7$.

4 *WW* Cross Section

Similar to the $W\gamma$ and $Z\gamma$ processes, another process which tests the electro–weak model is WW di–boson production. The WW final state is produced primarily through quark annihilation at the LHC, and includes a diagram sensitive to the WWZ TGC predicted by the SM. In addition to being sensitive to new physics through anomalous TGCs, the WW process is also important because it is the dominant background to searches for the Higgs boson in which the Higgs decays to pairs of W bosons.

ATLAS has performed the WW cross section measurement in the fully leptonic decay channels of the W's .[6] The event signature is two high–p_T isolated leptons with large missing energy. The jet multiplicity distribution of events satisfying the di–lepton plus E_T^{miss} selection[d] is shown in Figure 2(b).

The large remaining background from top–quark production is reduced by requiring that the event contain no reconstructed high p_T jets within the ATLAS acceptance. Eight signal candidates pass the full selection, one in the ee-channel, two in the $\mu\mu$-channel, and five in the $e\mu$-channel. The background estimation is provided in Table 5. The W+jet estimate is made from control regions in the data, whereas the remaining electro–weak backgrounds are taken from simulation and cross checked with data–driven procedures.

The measured WW cross section is $41^{+20}_{-16}(stat.) \pm 5(syst.) \pm 1(lumi.)$ pb, which is to be compared to the SM NLO prediction of 44 ± 3 pb. The dominant uncertainty on the cross section measurement is the statistical uncertainty on the number signal events, 44%. The

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[d]The E_T^{miss} requirement is on the E_T^{miss} relative to the nearest lepton, $E_T^{miss,Rel}$. $E_T^{miss,Rel}$ is defined as $E_T^{miss,Rel} = sin(\phi) \times E_T^{miss}$, if $\phi < \frac{\pi}{2}$, otherwise $E_T^{miss,Rel} = E_T^{miss}$. ϕ is the angle between the missing energy and the nearest lepton. Events are required to have greater than 40 GeV relative E_T^{miss} in the ee and $\mu\mu$ channels, and greater than 25 GeV in the $e\mu$ channel.

Background	Events
Drell-Yan	0.23 ± 0.15 (stat) ± 0.17 (sys)
Top Quark	0.53 ± 0.12 (stat) ± 0.28 (sys)
W+jet	0.54 ± 0.32 (stat) ± 0.21 (sys)
Other Di-boson	0.38 ± 0.04 (stat) ± 0.04 (sys)
Total Bkg.	1.68 ± 0.37 (stat) ± 0.42 (sys)

Table 5: The estimated background for the WW cross section measurement. The background from W+jet was estimated from control regions in data, whereas the other background as estimated from simulation and cross checked by data-driven methods.

systematic uncertainty is 16%, and is dominated by uncertainties on the background modeling and signal acceptance. Further studies of the WW process will constrain new physics through measurements of anomalous TGCs and will be critical for understanding the background in the search for the Higgs boson.

5 Single Top-Quark Production

Single top-quark production is a direct probe of the CKM element V_{tb}. A precise measurement of the single top-quark cross section will provide a determination of V_{tb} without relying on unitarity constraints. Single top-quark production proceeds through three modes, each with a distinct experimental signature. The t-channel production has the largest expected contribution, $\sim$65 pb, and leads to a top quark and either a u or d-quark in the final state. Wt-production is expected to have the second largest contribution, $\sim$15 pb, and has a top-quark and a W boson in the final state. The s-channel is the smallest expected single top-quark contribution at the LHC, $\sim$4 pb, and produces a top quark and bottom quark in the final state. Each of the individual single top-quark production modes is sensitive to different forms of new physics.[8] With the 2010 data set, ATLAS has performed searches for the single top-quark in both the t-channel and Wt-production modes.[5]

The t-channel single top-quark analysis has been performed in the leptonic decay mode of the top-quark. Events were selected with one high-p_T electron or muon, large E_T^{miss}, and two jets, one of which was identified as a b-quark. The m_T of the lepton and E_T^{miss} system was required to be consistent with coming from a W boson and the reconstructed top-quark mass was required to be between 130 and 210 GeV. To enhance sensitivity, the analysis was performed separately in the positive and negative lepton channels. The event yield and background estimation of the t-channel analysis is given in Table 6. The background prediction was made using a combination of data-driven and simulation based estimates.

	l^+ channel	l^- channel
t-channel Expectation	10.3 ± 1.8	4.4 ± 0.8
Background Prediction	12.4 ± 3.3	8.8 ± 1.8
Event Yield	21	11

Table 6: Event yield and background estimation for the t-channel single top-quark analysis.

The result of the t-channel analysis is a signal significance of 1.6 σ. An excess over background that is consistent with t-channel production was seen. An upper limit of 162 pb was placed on the cross section at the 95% confidence level. The systematic uncertainties in the t-channel analysis are limited by uncertainties on the jet energy scale, b-quark identification, and background modeling. Many of these systematic uncertainties are limited by statistical uncertainties in control regions and are expected to improve with the addition of more data.

Single top-quark production in the Wt-channel gives rise to two W bosons in the final state: one directly produced with the top quark and the other the result of the top-quark decay. ATLAS has searched for Wt production in both the single and di-lepton final states. The single lepton Wt analysis is similar to the t-channel analysis with the additional requirement of extra jets in the event. The di-lepton analysis requires two high p_T leptons, large E_T^{miss}, and exactly one reconstructed jet in the final state. The event yields and background estimations for the Wt-channel analysis are given in Table 7. The background prediction was made using a combination of data-driven and simulation–based estimates.

	single lepton channel	di-lepton channel
Wt Expectation	12.6 ± 0.9	2.8 ± 0.5
Background Prediction	262.0 ± 22.8	12.7 ± 2.8
Event Yield	294	15

Table 7: Event yield and background estimation for the Wt single top-quark analysis.

The analysis of the Wt channel placed a combined upper limit of 158 pb on the Wt single top-quark cross section. As in the t-channel analysis the current systematic uncertainty is limited by uncertainties on the jet energy scale, b-quark identification, and background modeling, which are expected to improve with the addition of more data.

6   Conclusion

These proceedings have presented electro-weak measurements made by the ATLAS experiment with the 45 pb^{-1} of integrated luminosity collected during the 2010 data taking. These initial Standard Model measurements have allowed ATLAS to understand its detector performance and have provided the first electro-weak physics results at 7 TeV.

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