PROCEEDINGS OF SCIENCE

Production of W and Z bosons in ATLAS

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The first measurements of the W and Z boson cross sections in proton-proton collisions at $\sqrt{s}$=7 TeV are presented using data recorded with the ATLAS detector. In addition the first observation of hadronically decaying tau leptons in ATLAS is reported. Results are found to be compatible with theoretical predictions based on NNLO QCD calculations.

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1. Introduction and data sample

The W and Z[1] bosons are abundantly produced at $\sqrt{s}$=7 TeV proton-proton (pp) collisions at the LHC and provide the most common source of isolated, high p_{T} leptons. They are therefore an important data sample for understanding the ATLAS detector, in terms of lepton identification, lepton and missing energy scale and resolution, and the trigger performance. The W and Z bosons are also important backgrounds to the beyond the Standard Model searches.

Data were collected during the LHC runs at $\sqrt{s}$ = 7 TeV between March and August 2010 corresponding to an integrated luminosity of about 320 nb^{-1} for the $W \to \ell\nu$ and $Z \to \ell\ell$, ℓ=(e, μ) cross section analysis and of about 550 nb^{-1} for the $W \to \tau_h \nu$ observation. The uncertainty on the luminosity is estimated to be $\pm$11%. Data are compared to theoretical expectations. Electroweak (EW) processes are modeled with PYTHIA Monte Carlo (MC) event generator [1] and subjected to a detailed ATLAS response simulation using GEANT4 program [2]. Events are normalized according to their NNLO cross sections obtained using FEWZ [3] and ZWPROD [4, 5] programs and the integrated luminosity of the data sample. As no reliable prediction can be obtained from a leading order MC simulation for QCD, this background component is for the most part modeled using data driven techniques. Details of the W and Z analyzes described here can be found in [6, 7].

2. Event and lepton selection

The electron and muon samples are selected online using only the first level hardware trigger. The electron trigger requires a narrow cluster of E_{T} >10 GeV to be found in the EM Calorimeter within $|\eta|$<2.5 while the muon trigger searches for patterns of hits compatible with a muon of p_{T} >6 GeV and $|\eta|$<2.4. The $W \to \tau_h \nu$ events are selected exploiting the full three level trigger system. Events which pass the first level calorimeter trigger with a nominal threshold of 5 GeV, have at least one track with p_{T} >6 GeV and the transverse missing energy ($E_{\mathrm{T}}^{\mathrm{miss}}$) greater than 5 GeV at the second level and fulfill $E_{\mathrm{T}}^{\mathrm{miss}}$ >15 GeV requirement at Event Filter are accepted. Collision events are selected by requiring at least one primary vertex of at least three tracks.

Identification of electrons in ATLAS starts from a cluster reconstructed in the EM Calorimeter matched to an Inner Detector (ID) track. Discrimination against backgrounds from jets, heavy quark decays and conversions involves shower shape cuts, basic track quality requirements and impact parameter cut. To further improve the purity of the W analysis, the E/p compatibility between the track and the cluster and additional track quality criteria are added. The analysis requires the electrons to have E_{T} >20 GeV and $|\eta|$<2.47, excluding the barrel-endcap transition region between 1.37<$|\eta|$<1.52.

Muon reconstruction combines tracking information in the ID with the Muon Spectrometer (MS) and is restricted to $|\eta|$<2.4. Decays in flight are rejected by requiring p_{T} >10 GeV on the MS track, and by imposing p_{T} compatibility between ID and MS track reconstructions. Background from cosmic rays is reduced by requiring the muon track to point to the interaction point. Muons from heavy quark decays are suppressed by a track based isolation requirement. Only muons with p_{T} >20 GeV are considered in the analysis.

[1]Throughout this note the label Z refers to Z/γ^*.

Hadronically decaying tau leptons are reconstructed at ATLAS from two seeds: a high quality track in the ID with p_T >6 GeV or a jet reconstructed using topological clusters with E_T >10 GeV. In this analysis taus are required to have both seeds, E_T >25 GeV and $|\eta|$<2.5, excluding the barrel-endcap transition region between 1.37<$|\eta|$<1.52. Discrimination between signal and large QCD background relies upon low track multiplicity as well as narrowness and isolation of calorimeter shower of hadronically decaying taus.

The transverse missing energy and the total transverse energy ($\sum E_T$) reconstruction is based on EM-scale energy deposits in calorimeter cells inside three-dimensional topological clusters. These clusters are corrected for hadronic response, dead material and out-of-cluster losses. The E_T^{miss} is corrected for muons if present in the event. The E_T^{miss} requirement is applied only in the W analysis.

3. Measurements of $W \to \ell\nu$ and $Z \to \ell\ell$, ℓ=(e,μ) cross sections

The $W \to \ell\nu$ candidates are selected with a single electron or muon and missing transverse energy of at least 25 GeV. The transverse mass, m_T, of the ℓ-E_T^{miss} system after the E_T^{miss} cut is shown in Figure 1. A requirement of m_T>40 GeV completes the selection of the W decays. A total of 1069 and 1181 candidates pass these requirements in the electron and the muon channel, respectively.

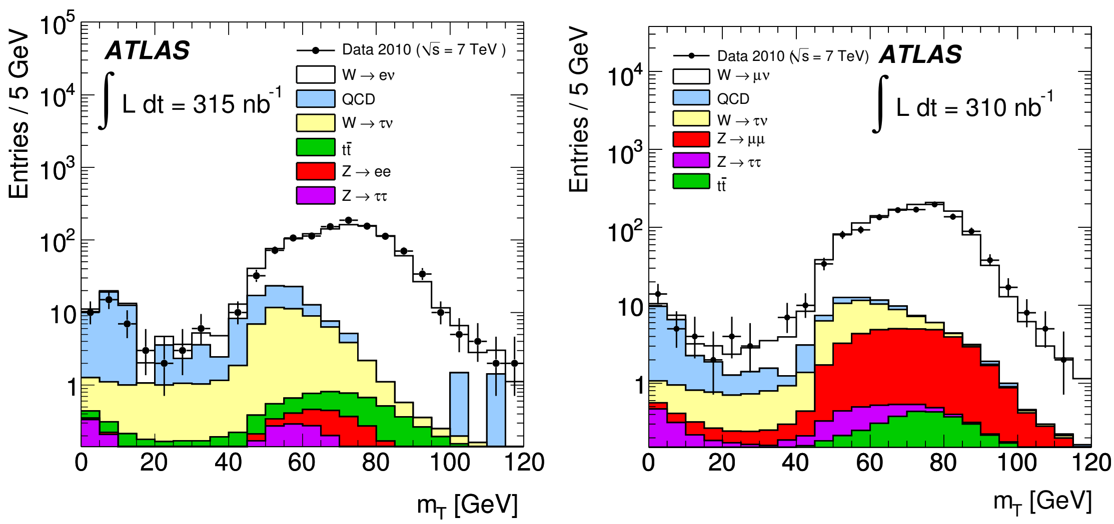

Figure 1: Distributions of the transverse mass of the electron-E_T^{miss} system (left) and muon-E_T^{miss} system (right) for data and MC simulations.

To select $Z \to \ell\ell$ events, an electron and a positron or two muons of opposite sign are required. The invariant mass of the two leptons, m_{ll}, is plotted in Figure 2. A total of 70 candidates in the electron channel and 109 candidates in the muon channel are extracted within the mass window of 66<m_{ll}<116 GeV.

The non-QCD backgrounds for both W and Z measurements are estimated using MC simulations. The main contribution for the $W \to e\nu$ final state comes from $W \to \tau_\ell\nu$ and accounts for

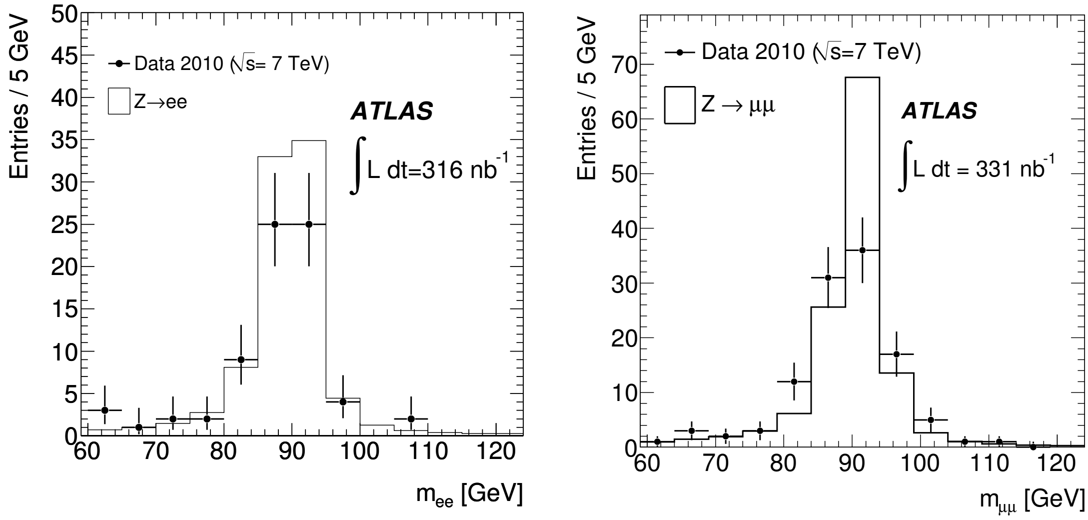

Figure 2: Distributions of the invariant mass of Z candidates in the electron (left) and muon (right) channels for data and MC simulations of signal.

25.9 events. In the muon channel 38.4 and 33.6 events are expected from $Z \to \mu\mu$ and $W \to \tau_\ell \nu$ processes, respectively. The main backgrounds for $Z \to \ell\ell$ are $W \to \ell\nu$, $Z \to \tau\tau$ and $t\bar{t}$ and yield an estimate of 0.11, 0.06 and 0.10 events in the electron and 0.01, 0.09 and 0.11 in the muon channel.

Except for $Z \to \mu\mu$ final state, the QCD background is modeled using data driven techniques. Single electron QCD background in the W analysis is estimated (using a template fit of the missing transverse energy) to be 28.0±3 (stat)±10 (syst) events. The QCD background for $W \to \mu\nu$ channel comes mainly from heavy quark decays and is estimated by comparison of the number of events seen in data after the full W selection, to the number of events observed if the muon isolation requirement is not applied ("Matrix method"). This method yields an estimate of 21.1±4.5(stat)±8.7(syst). The $Z \to ee$ QCD background is extracted from a fit to the invariant mass distribution within the mass window 50<m_{ee}<130 GeV using relaxed electron identification criteria. A rejection factor of relaxing of the lepton identification cuts is determined from data and applied to each lepton in the template. The measured background is 0.91±0.11(stat)±0.41(sys). In the $Z \to \mu\mu$ analysis MC simulations estimate the background to be 0.04 events with 100% systematic uncertainty.

The production cross sections for the W and Z bosons can be expressed as:

$$\sigma_{\mathrm{W(Z)}} \times \mathrm{BR}(\mathrm{W(Z)} \to \ell\nu(\ell\ell)) = \frac{N^{\mathrm{sig}}}{A_{\mathrm{W(Z)}} C_{\mathrm{W(Z)}} L_{\mathrm{W(Z)}}} \tag{3.1}$$

where N^{sig} is the number of background subtracted signal events in a given channel, $A_{\mathrm{W(Z)}}$ is the acceptance for geometrical and kinematical (fiducial) cuts obtained from generator-level Monte Carlo calculations, $C_{\mathrm{W(Z)}}$ is the fraction of generated events within the fiducial acceptance which pass the final selection after reconstruction and $L_{\mathrm{W(Z)}}$ is the integrated luminosity.

The systematic uncertainty on $A_{\mathrm{W(Z)}}$ comes primarily from theoretical uncertainties in the modeling of the boson production and from the limited knowledge of the proton structure functions.

It is estimated to be $\pm 3\%(\pm 4\%)$ for the W(Z) measurement. The total systematic uncertainty on C_W in the electron channel is 7% and comes primarily from the lepton identification efficiency and from the uncertainty in determination of the energy scale. For the muon channel, the total uncertainty is 4% and comes mainly from the lepton reconstruction and trigger efficiencies and the missing transverse energy scale and resolution. In the Z measurement, the total systematic uncertainty on C_Z is 9.4% for the electron case and 5.5% for the muon case, and comes predominantly from the lepton identification/reconstruction efficiencies.

The measured combined cross sections times leptonic branching fraction in the lepton final states are: $\sigma_W \times \mathrm{BR}(W \to \ell\nu)$ =9.96±0.23(stat)±0.50(syst)±1.10(lumi) nb and $\sigma_Z \times \mathrm{BR}(Z \to \ell\ell)$ =0.82±0.06(stat)±0.05(syst)±0.09(lumi) nb. These measurements are compatible with the theoretical predictions calculated at NNLO 10.46±0.52 nb for the W and 0.96±0.05 nb for the Z boson, respectively. The measured and predicted values of the W and Z boson cross sections are shown in Figure 3 and compared to previous measurements carried out at proton-antiproton ($p\bar{p}$) and proton-proton colliders.

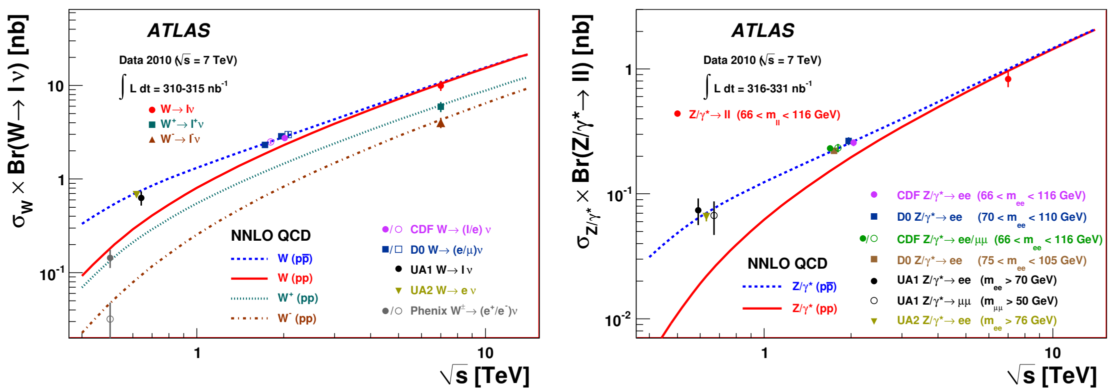

Figure 3: The measured and predicted values of the W boson (left) and Z boson (right) cross section together with results of previous measurements carried out at $p\bar{p}$ and pp colliders.

4. Observation of $W \to \tau_h \nu$ decays

The $W \to \tau_h \nu$ candidates are selected with a single hadronically decaying tau lepton and E_T^{miss} >30 GeV. Events with an electron or a muon are rejected. An additional requirement on the significance of the missing transverse energy $S_{E_T^{\mathrm{miss}}} = \frac{E_T^{\mathrm{miss}}}{0.5\sqrt{\sum E_T}}$>6 is essential to suppress the remaining QCD background. The left plot in Figure 4 shows the $S_{E_T^{\mathrm{miss}}}$ as a function of the transverse mass after E_T^{miss} cut. This selection yields a total of 78 data events.

The MC estimate of the EW and $t\bar{t}$ backgrounds yields 11.8±0.4(stat)±3.7(syst) events. The systematic uncertainty comes primarily from the lepton veto, the uncertainty on the determination of the energy scale and from modeling of the underlying event. The data driven QCD estimate is based on similarity relation in the $S_{E_T^{\mathrm{miss}}}$ and tau identification plane ("ABCD method"). It yields an estimate of 11.1±2.3(stat)±3.2(syst). The dominant systematic uncertainty comes from correlation between the E_T^{miss} significance and tau identification variables.

The total number of observed, background subtracted events is 55.1±10.5(stat.)±5.2(syst.). It is compatible with the Standard Model expectation of 55.3±1.4(stat.)±16.1(syst.) events from $W \longrightarrow \tau_h \nu$ decays estimated at NNLO. The dominant systematic uncertainty on signal comes from the determination of the energy scale as well as from modeling of the underlying event. The right plot in Figure 4 shows the track multiplicity distribution for selected tau leptons from W decays.

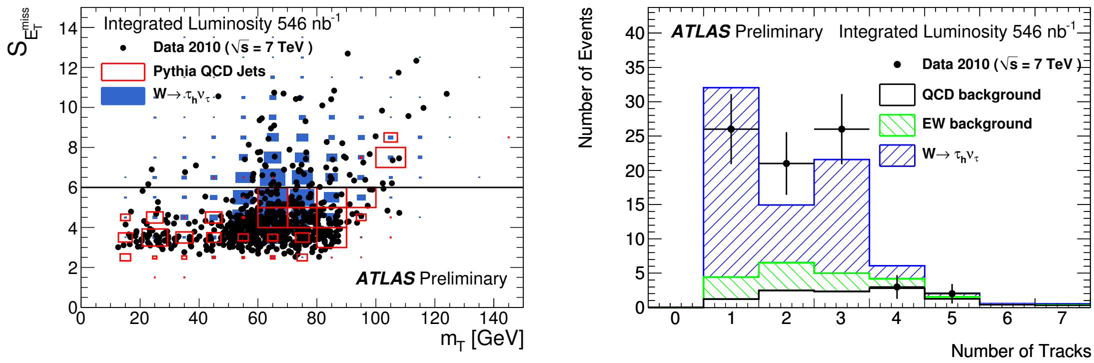

Figure 4: Distribution of events in the $S_{E_{\mathrm{T}}^{\mathrm{miss}}}$ -m_{T} plane after all cuts except that on $E_{\mathrm{T}}^{\mathrm{miss}}$ significance for data, simulated signal events and QCD background (left). Distributions of the τ_{h} track multiplicity for the data, signal and backgrounds (right).

5. Conclusions

The first measurements of the $W \longrightarrow \ell\nu$ and $Z \longrightarrow \ell\ell$, ℓ=(e,μ) production cross sections and the first observation of $W \longrightarrow \tau_h \nu$ decays in pp collisions at $\sqrt{s}$=7 TeV in ATLAS are completed. The results are in agreement with theoretical predictions based on NNLO QCD. The measurements are dominated by systematic uncertainties which are expected to improve with more data.

References

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