Measurements of dibosons with the ATLAS detector and associated constraints on new physics

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Diboson cross sections have been measured for all combinations of W,Z and isolated photons, using the ATLAS detector at the LHC. The cross sections are measured in kinematic regions defined by the decay kinematics, in some cases including vetoes on additional jets. The measurements are also extrapolated to the full phase space using theoretical calculations of the acceptance, and are additionally used to place constraints on triple-gauge boson couplings.

1 Introduction

At the end of the 2011 proton-proton run of the LHC, the delivered luminosity was increased by a factor of $\sim$5 from the $\sim 1\,\text{fb}^{-1}$ dataset used for summer 2011 conference results. New measurements using the full $\sim 5\,\text{fb}^{-1}$ dataset are presented here. The larger dataset implies a significant reduction of statistical errors, and therefore more precise tests of the Standard Model.

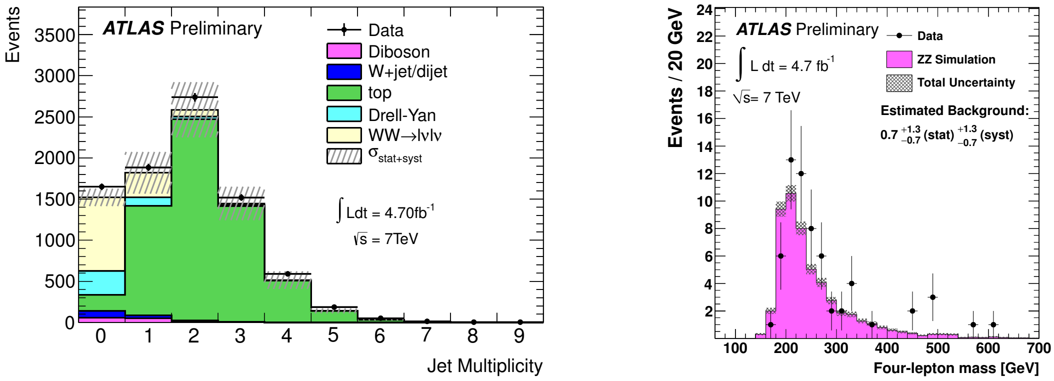
The diboson production processes presented here are sensitive to triple gauge couplings (TGCs), which are allowed in the Standard Model only for specific vertices. Anomalous triple gauge couplings, differing from those expected in the Standard Model, could manifest as modifications of the cross section or kinematics of diboson production. These diboson production processes are also important backgrounds in searches for the Higgs boson. The WW and ZZ processes could happen both through decays of a Standard Model Higgs boson, or through direct production, which acts a large background in the search for the Higgs.

2 The ATLAS experiment

The ATLAS detector is a general purpose detector at the LHC, CERN. It consists of an inner detector for charged tracking, surrounded by electromagnetic and hadronic calorimeters, and finally a muon detector system. The detector and its performance are described in detail in [1].

3 Event selection and cross-section measurements

The production of a high p_{T} photon in association with a W or Z boson is the highest cross-section process considered here. As with the other diboson channels, measurements of this



(a) (b)

Figure 1: (a) Jet multiplicity distribution for candidate WW events, before the final jet veto cuts [4] (b) Four-lepton invariant mass distribution for ZZ events after the full selection [7].

process can probe anomalous TGCs. The analysis is performed only for the case of the W/Z boson decaying fully leptonically, and the main backgrounds consist of jets produced in association with a W or Z boson, where a jet fakes either a photon or a charged lepton [2]. Events are selected by requiring one (for the Wγ case) or two (for the Zγ case) leptons (electron or muon, denoted ℓ) with transverse momentum (p_{T}) of at least 15 GeV. In addition, an isolated photon must be reconstructed, with transverse energy (E_{T}) of at least 15 GeV. The photon must be separated from each lepton[1] by $\Delta R > 0.7$. Finally, for the Wγ channel, missing transverse energy ($E_{\mathrm{T}}^{\mathrm{miss}}$) of at least 25 GeV is required, and the transverse mass of the W must exceed 40 GeV; for Zγ, the dilepton invariant mass must be greater than 40 GeV. The results of the cross-section measurements will be given at the end of this section.

The production of two W bosons of opposite charge, with both W bosons decaying leptonically, is another process which has been measured using the ATLAS dataset from 2011 [4]. This is again sensitive to anomalous TGCs, and is one of the most important backgrounds in the search for a Standard Model Higgs boson via the H$\rightarrow$WW decay. The main backgrounds are the production of jets in association with a Z boson, and top quark production. The former is reduced by vetoing dilepton masses within 15 GeV of the nominal Z mass and by requiring large missing transverse energy[2]; the latter is reduced by requiring events to contain zero jets with $p_{\mathrm{T}} > 25$ GeV, and zero jets with $p_{\mathrm{T}} > 20$ GeV that contain a b-hadron. Figure 1(a) shows the jet multiplicity after the missing transverse energy cut, and before the jet veto cuts.

Increasing the required number of leptons from two to three, the diboson production process WZ has also been measured [5]. This analysis is again sensitive to anomalous TGCs, and searches for a charged Higgs boson. The analysis is much cleaner than the WW analysis, with the main backgrounds being caused by the reconstruction of a jet as a charged lepton, or by a true charged lepton not being detected. These main backgrounds are production of jets in association with a single Z boson, and ZZ diboson production, and top quark production. Events are selected by first requiring two isolated leptons (either two electrons or two muons)

[1] ΔR is the sum in quadrature of the separation in azimuth and pseudorapidity, $(\Delta R)^2 = (\Delta\phi)^2 + (\Delta\eta)^2$

[2] We use the variable $E_{\mathrm{T,rel}}^{\mathrm{miss}}$, which is the component of the $E_{\mathrm{T}}^{\mathrm{miss}}$ vector which is perpendicular to the closest lepton or jet if this closest object is separated by $\Delta\phi \leq \frac{\pi}{2}$; otherwise, if $\Delta\phi > \frac{\pi}{2}$, then $E_{\mathrm{T}}^{\mathrm{miss}}$ is used.

Process	$\int\mathcal{L}dt$	$\sigma_{\rm fid}$ [fb]	(stat.)	(syst.)	(lumi.)	$\sigma_{\rm tot}$ [pb]	(stat.)	(syst.)	(lumi.)	Reference
Wγ	1 fb^{-1}	4.60	±0.11	±0.64	±0.17					[2]
Zγ	1 fb^{-1}	1.29	±0.05	±0.15	±0.05					[2]
WW	1 fb^{-1}	*by channel: see reference*				54.4	±4.0	±3.9	±2.0	[3]
WW	5 fb^{-1}	*by channel: see reference*				53.4	±2.1	±4.5	±2.1	[4]
WZ	1 fb^{-1}	102	$^{+15}_{-14}$	$^{+7}_{-6}$	$^{+4}_{-4}$	20.5	$^{+3.1}_{-2.8}$	$^{+1.4}_{-1.3}$	$^{+0.9}_{-0.8}$	[5]
ZZ$\to\ell\ell\ell\ell$	1 fb^{-1}	19.4	$^{+6.3}_{-5.2}$	$^{+0.9}_{-0.7}$	±0.7	8.5	$^{+2.7}_{-2.3}$	$^{+0.4}_{-0.3}$	±0.3	[6]
ZZ$\to\ell\ell\ell\ell$	5 fb^{-1}	21.2	$^{+3.2}_{-2.7}$	$^{+1.0}_{-0.9}$	±0.8	7.2	$^{+1.1}_{-0.9}$	$^{+0.4}_{-0.3}$	±0.3	[7]
ZZ$\to\ell\ell\nu\nu$	5 fb^{-1}	12.2	$^{+3.0}_{-2.8}$	±1.9	±0.5	5.4	$^{+1.3}_{-1.2}$	$^{+1.4}_{-1.0}$	±0.2	[8]

Table 1: Summary table of cross-section measurements. Results are given both for the fiducial volume defined by the selection cuts, $\sigma_{\rm fid}$, and extrapolated to the total cross section, $\sigma_{\rm tot}$.

with $p_{\rm T} > 15$ GeV, with a dilepton mass within 10 GeV of the nominal Z mass, then requiring a third lepton with $p_{\rm T} > 20$ GeV attributed to the W. In addition, $E_{\rm T}^{\rm miss} > 25$ GeV is required, and the transverse mass of the W boson is required to be greater than 40 GeV.

Measurements have been made of ZZ diboson production in two final states: firstly with both Z bosons decaying into charged leptons, and secondly with one Z decaying into charged leptons and the other Z boson decaying to a pair of neutrinos (sharing the final state with the WW diboson measurement described above). The latter final state gives a gain in branching fraction compared to the former, but also suffers from increased background.

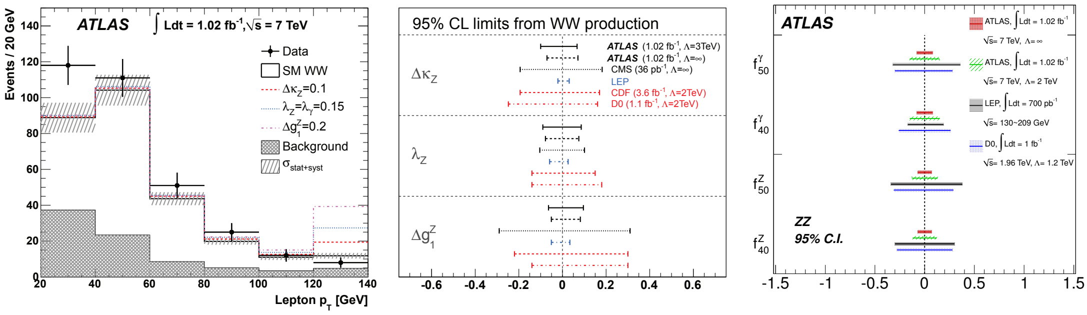
For the $\ell^-\ell^+\ell^-\ell^+$ final state, four isolated leptons are required, with $p_{\rm T}$>7 GeV [7]. The leptons are required to form two pairs, each with dilepton invariant mass within 15 GeV of the nominal Z mass. The four-lepton mass distribution of selected events is shown in figure 1(b).

For the $\ell^-\ell^+\nu^-\nu^+$ final state, two leptons with $p_{\rm T}$ >20 GeV and with $m_{\ell\ell}$ within 15 GeV of the nominal Z mass are required [8]. Large missing transverse energy is also required. For this the axial $E_{\rm T}^{\rm miss}$ is used, requiring the component of the $E_{\rm T}^{\rm miss}$ parallel to the dilepton vector in the plane transverse to the beam to be greater than 80 GeV. Finally, the events are required to contain zero jets with $p_{\rm T}$>25 GeV, and the fractional $p_{\rm T}$ difference between $E_{\rm T}^{\rm miss}$ and dilepton is required to be small: $|E_{\rm T}^{\rm miss} - p_{\rm T}^{\ell\ell}|/p_{\rm T}^{\ell\ell}<0.6$.

The results of all the above cross-section measurements are presented in table 1. For each analysis, the most recent ATLAS result is given. All measurements agree with the Standard Model prediction within the respective uncertainties. In the case of WW and ZZ$\to\ell^-\ell^+\ell^-\ell^+$, the previous cross-section result is also given, as these have been used to derive the TGC limits discussed in the next section. More details on the measurements can be found in the reference for each analysis in the table.

4 Limits on anomalous triple gauge couplings

The final selected events in each of the analyses described above can be used further, to derive limits on anomalous triple gauge couplings (TGCs). Anomalous TGCs can result in deviations of the cross sections and kinematics of these processes, and therefore cross-section measurements, or kinematic distributions, can be used to impose limits on these couplings. Figure 2(a) shows the example of the WW analysis, where the leading-lepton $p_{\rm T}$ spectrum is very sensitive to anomalous TGCs, particularly at large values. The distribution observed in data is used



(a) (b) (c)

Figure 2: (a) Leading-lepton p_{T} spectrum of WW events, for data and MC with various TGCs ($\Delta\kappa_{\mathrm{z}}$, λ_{z} and Δg_1^{z} are all equal to zero in the SM) [3]. This spectrum is used to derive the limits on anomalous TGCs shown in (b). (c) Limits on anomalous TGCs computed from the cross-section measurement of ZZ$\rightarrow\ell^-\ell^+\ell^-\ell^+$ [6].

to compute the limits on anomalous TGCs shown in figure 2(b). Figure 2(c) shows the limits computed using ZZ$\rightarrow\ell^-\ell^+\ell^-\ell^+$ events. Anomalous TGC limits have also been derived using Wγ, Zγ [2] and WZ [5] events.

5 Summary

Cross sections have been measured for a number of diboson production processes, both extrapolated to the total phase space, and within a fiducial volume given by the detector acceptance and event selection cuts. These measurements have been made for production of Wγ, Zγ, WW, WZ and ZZ, using part or all of the ATLAS dataset from the 2011 run of the LHC at $\sqrt{s} = 7\,$TeV. These analyses form precise tests of the Standard Model, and have been used to place stringent limits on anomalous triple gauge couplings.

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