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Measurements of Diboson Production in pp collisions at 7 TeV with the ATLAS detector

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The cross sections of all heavy vector boson pair production processes, namely WW, WZ and ZZ, have been determined with proton-proton collisions at a centre-of-mass energy of 7 TeV with an integrated luminosity of 1.02fb^{-1}. The measured production cross sections are in agreement with prediction from the SM. Limits on anomalous triple gauge boson couplings parameters have been set with ZZ and WZ production cross sections.

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1. Introduction

This note presents a measurement of the WW [1], WZ [2] and ZZ [3] production cross sections and reports limits on anomalous triple gauge boson couplings (TGC) for WZ and ZZ production using 1.02 fb^{-1} of data collected by the ATLAS detector during 2011 at a centre-of-mass energy $\sqrt{s}$ = 7 TeV.

In the standard model (SM) the TGC vertex is completely fixed by the electroweak gauge structure and so a precise measurement of this vertex, through the analysis of diboson production at the LHC, is essential to test the high energy behavior of electroweak interactions and to probe for possible new physics in the bosonic sector. Anomalous gauge boson couplings deviating from gauge constraints might cause a significant enhancement of the production cross section at high diboson invariant mass.

The analyses of heavy vector boson pair production use fully leptonic decay channels involving electrons and muons. The fully leptonic decay offers a very clean signal but has a small branching ratio in the order of a few percent for WW and WZ, and less then a percent for ZZ. The main sources of background are $W/Z\gamma$, W/Z+jets, and top-quark events. The signal and background contributions are modeled with simulation and with data-driven measurements. The signal to background ratio after full selection is about 1.4 for WW, about 4 for WZ and about 30 for ZZ. In the case where a Z boson is produced, mass constrains can be applied which help to effectively reduce backgrounds for WZ and especially ZZ production.

A common phase space is defined to combine the different decay channels and measure a “fiducial” cross section. The phase space is chosen to match closely the analysis cuts and minimizes the dependence on phase space extrapolations from predictions by theory. The common phase space is defined in terms of event four vector (“truth") quantities as transverse momentum $p_{\mathrm{T}}^{\mu,e}(V)$, p_{T}^{ν}, pseudo rapidity[1] and transverse mass[2]. Since the fiducial volume is defined by the lepton kinematics, the cross section definition includes the branching ratios of the bosons decaying into electrons or muons. To measure the total cross section the experimentally accessible phase space is extrapolated to the full phase space.

In the SM the only allowed boson combinations for TGC vertices are $WW\gamma$ and WWZ. Expressions for the most general effective Lagrangian for a TGC vertex with two charged and one neutral vector boson can be found in [4]. The CP conserving anomalous couplings can be parameterized by the three dimensionless parameters g_1^Z, κ^Z and λ. In the SM $g_1^Z = 1$, $\kappa^Z = 1$, $\lambda = 0$. Anomalous TGCs for on-shell ZZ production can be parameterized by two CP-violating (f_4^V) and two CP-conserving (f_5^V) complex parameters ($V = Z, \gamma$) which are zero in the Standard Model [5]. To avoid tree-level unitarity violation at high centre-of-mass energies a form factor with a scale Λ is introduced to damping the effect of anomalous couplings at higher energy scales.

2. WW production

WW events are reconstructed using leptonic decays of the W boson with electrons or muons

[1]The azimuthal angle ϕ is measured around the beam axis and the polar angle θ is the angle from the beam axis. The pseudorapidity is defined as $\eta = \ln \tan(\theta/2)$.

[2]The transverse mass is defined as $M_{\mathrm{T}}^2 = 2E_T^{\ell}E_T^{\nu} - 2\mathbf{p}_T^{\ell}\mathbf{p}_T^{\nu}$.

PoS(EPS-HEP2011)372

in the final state. Sequential decays to electrons and muons via τ leptons are also included as signal. The resulting final state has two high-transverse-momentum (high-p_T) charged leptons and substantial transverse momentum imbalance in the final state due to the neutrinos or antineutrinos escaping detection. The selection criteria require exactly two leptons of opposite charge with $p_\mathrm{T} >$ 20 GeV, the leading electron is required $p_\mathrm{T} > 25$ GeV, dilepton mass for same flavor leptons must be $m_{ll} > 15$ GeV, for mixed flavor leptons $m_{ll} > 10$ GeV. Z events are vetoed with a cut on the dilepton mass around the pole mass of the Z, namely $|m_{ll}| - m_Z < 15$ GeV. Additionally, the orthogonal component of the missing transverse energy wrt. to the nearest lepton is required to exceed 45 (40, 25) GeV for the $\mu\mu$ (ee, $e\mu$) final state. Events containing a jet (anti-k_t, $\Delta R < 0.4$) with $p_\mathrm{T} > 30$ GeV are vetoed, reducing the background from top events.

A total of 414 candidates are selected with an estimated background of 170±28 events. The measured cross section is $48.2 \pm 4.0(\mathrm{stat}) \pm 6.4(\mathrm{syst}) \pm 1.8(\mathrm{lumi})$ pb, consistent with the SM NLO prediction of 46 ± 3 pb. From the number of observed events a fiducial cross section is extracted. The fiducial phase space is defined by the following criteria: muon cuts are $p_\mathrm{T} > 20$ GeV, $|\eta| < 2.4$, electron cuts are $p_\mathrm{T} > 20$ GeV, $|\eta| < 1.37$ or $1.52 < |\eta| < 2.47$, with leading electron in ee channel and electron in $e\mu$ channel $p_\mathrm{T} > 25$ GeV. Jet cuts are $p_\mathrm{T} > 30$ GeV, $|y| < 4.5$, $\Delta R(e,\mathrm{jet}) >$ 0.3. Event cuts are $\mu\mu$ channel $p_{\mathrm{T,Rel}}^{\nu+\bar{\nu}} > 45$ GeV, $m_{\mu\mu} > 15$ GeV and $|m_{\mu\mu} - m_\mathrm{Z}| > 15$ GeV, in the ee channel $p_{\mathrm{T,Rel}}^{\nu+\bar{\nu}} > 40$ GeV, $m_{ee} > 15$ GeV and $|m_{ee} - m_\mathrm{Z}| > 15$ GeV, in the $e\mu$ channel $p_{\mathrm{T,Rel}}^{\nu+\bar{\nu}} > 25$ GeV, $m_{e\mu} > 10$ GeV. The extracted fiducial cross sections per channel are shown in Table 1. The systematic error includes uncertainties due to reconstruction, trigger, and theoretical uncertainties due to parton distribution functions. The uncertainty due to integrated luminosity is listed separately.

Channels	expected σ^{fid} (fb)	measured σ^{fid}(fb)	$\Delta\sigma_{stat}$(fb)	$\Delta\sigma_{syst}$(fb)	$\Delta\sigma_{lumi}$(fb)
$e\nu e\nu$	66.8	90.1	± 18.9	± 11.3	± 3.3
$\mu\nu\mu\nu$	63.8	62.0	± 12.1	± 10.7	± 2.3
$e\nu\mu\nu$	245.1	252.0	± 24.6	± 29.4	± 9.3

Table 1: The predicted and measured fiducial WWproduction cross sections in the three dilepton channels.

3. WZ production

WZ events are selected by requiring at least three reconstructed leptons originating from the same primary vertex, two leptons from a $Z \to \ell\ell$ decay with an invariant mass within 10 GeV of the Z boson mass, and one additional third lepton. The third lepton must pass more stringent identification criteria than the leptons attributed to the Z boson and have $p_\mathrm{T} > 20$ GeV. The transverse mass[3] of the W boson, M_T^W, is formed from the $E_\mathrm{T}^\mathrm{miss}$ and the third lepton. Furthermore, the M_T^W is required to be greater than 20 GeV.

After applying all selection cuts we observe 71 WZ candidates in data with an integrated luminosity of 1.02 fb^{-1}, with 10.5±0.8(stat)$^{+2.9}_{-2.1}$(sys) expected background events. The expected

[3]The transverse mass is defined as $M_\mathrm{T}^2 = 2E_{T\ell}E_{T\nu} - 2\mathbf{p}_{T\ell}\mathbf{p}_{T\nu}$.

signal events include the contribution from τ lepton decays into electrons or muons, which accounts for 1.7 events. The $p_{\mathrm{T}}(Z)$ distribution of the selected events is shown in Figure 1a. The SM expectation for the number of signal events is 49.1±0.4(stat)±3.02(sys).

The different channels are combined by using a common phase space region for which a fiducial cross section is extracted. The common phase space is defined as $p_{\mathrm{T}}^{\mu,e} > 15$ GeV, $|\eta^{\mu,e}| < 2.5$, $p_{\mathrm{T}}^{\nu} > 25$ GeV, $|M_{\ell\ell} - M_{\mathrm{Z}}| < 10$ GeV, and $M_{\mathrm{T}}^{W} > 20$ GeV, to approximate the event selection used in this analysis. The fiducial and total cross sections were determined to be respectively $\sigma_{WZ\to\ell\nu\ell\ell}^{fid} = 118^{+18}_{-16}$(stat) $^{+6}_{-6}$(syst) $^{+5}_{-5}$(lumi) fb and $\sigma_{WZ}^{tot} = 21.1^{+3.1}_{-2.8}$(stat) $^{+1.2}_{-1.2}$(syst) $^{+0.9}_{-0.8}$(lumi) pb. The total cross section is in good agreement with the SM expectation [6] of $17.2^{+1.2}_{-0.8}$ pb.

Limits on the anomalous triple gauge couplings g_1^Z, κ^Z and λ are derived and shown in Table 2 at the 68% and 95% C.I. using a profile log-likelihood method to include systematic uncertainties as nuisance parameters in the fit. A form factor scale on the anomalous couplings of $\Lambda = 3$ TeV is assumed.

Anomalous Coupling	Limits of the 68% C.I.	Limits of the 95% C.I.
Δg_1^Z	$[-0.17,-0.05]\,,[0.13,0.26]$	$[-0.21,0.30]$
$\Delta\kappa^Z$	$[-0.8,-0.2]\,,[0.5,1.0]$	$[-0.9,1.2]$
λ	$[-0.15,-0.06]\,,[0.06,0.15]$	$[-0.18,0.18]$

Table 2: Observed limits at the 68% and 95% C.I. on the anomalous couplings Δg_1^Z, $\Delta\kappa^Z$, and λ.

4. ZZ production

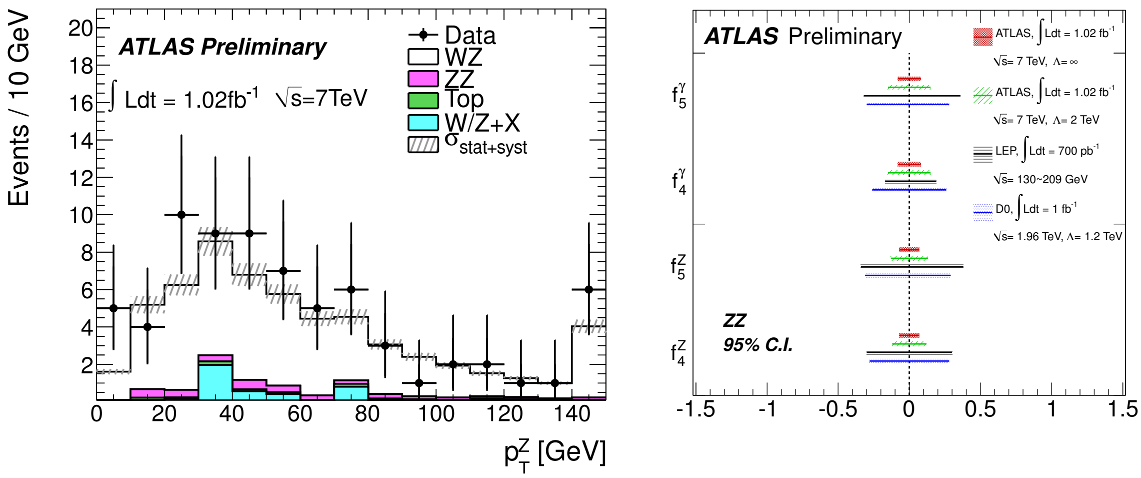
The first measurement of the ZZ production cross-section in LHC proton-proton collisions at $\sqrt{s}$ = 7 TeV has been performed by the ATLAS detector, using electrons and muons in the final state. To ZZ candidate events are characterized by four high-p_{T}, isolated electrons or muons, in three channels: $eeee$, $\mu\mu\mu\mu$ and $ee\mu\mu$. Lepton candidates are required to be consistent with originating from the primary vertex and have $p_{\mathrm{T}} > 15$ GeV. Selected events are required to have exactly four leptons selected as above, to have passed a single-muon or single-electron trigger, and to contain two Z candidates with invariant masses satisfying 66 GeV $< m_{ll} <$ 116 GeV. After all selection cuts total of 12 candidates was observed with a background expectation of $0.3^{+0.9}_{-0.3}$(stat)$^{+0.4}_{-0.3}$(sys). The SM expectation for the number of signal events is 9.1 ± 0.1(stat)±0.3(sys).

The fiducial cross section is defined by the mass of both lepton pairs to be between 66 GeV and 116 GeV and all four leptons to be within the pseudorapidity range $|\eta| < 2.5$ and have transverse momentum (p_{T}) greater than 15 GeV. The total ZZ cross section in the on-shell approximation is obtained from the fiducial cross section using the known $Z \to \ell\ell$ branching ratio and a correction factor for the kinematic and geometrical acceptance. The fiducial and total cross sections were determined to be $\sigma^{\mathrm{fid}}_{ZZ\to\ell\ell\ell\ell} = 19^{+6}_{-5}$ (stat) $^{+1}_{-2}$ (syst) $\pm\,1$ (lumi) fb and $\sigma^{\mathrm{tot}}_{ZZ}= 8.4^{+2.7}_{-2.3}$ (stat) $^{+0.4}_{-0.7}$ (syst) ±0.3 (lumi) pb. The result is statistically consistent with the NLO SM total cross section for this process of $6.5^{+0.3}_{-0.2}$ pb.

One dimensional 95% confidence intervals on the anomalous TGCs were determined using a maximum profile likelihood fit to the observed number of events. The systematic errors were included as nuisance parameters. The resulting limits for each coupling, determined assuming the other couplings fixed at their SM value, are listed in Table 3, and shown in comparison to LEP and Tevatron results in Figure 1b.

Λ	f_4^γ	f_4^Z	f_5^γ	f_5^Z
2 TeV	$[-0.15, 0.15]$	$[-0.12, 0.12]$	$[-0.15, 0.15]$	$[-0.13, 0.13]$
∞	$[-0.08, 0.08]$	$[-0.07, 0.07]$	$[-0.08, 0.08]$	$[-0.07, 0.07]$

Table 3: One dimensional 95% confidence intervals for anomalous neutral gauge boson couplings. Limits are presented for form factor scales of $\Lambda = 2$ TeV and ∞.



(a) (b)

Figure 1: (a) Transverse momentum of the Z in WZ events. (b) Anomalous neutral TGC 95% confidence intervals from ATLAS, LEP (hep-ex/0612034) and Tevatron (PRL100:131801,2008) experiments.

References

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