DIBOSON PRODUCTION CROSS SECTION AT $\sqrt{s} = 7$ TEV

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We present the latest measurements of diboson production cross sections in pp collisions at a center-of-mass energy of 7 TeV, based on data recorded by the ATLAS and CMS detectors at the LHC in 2010 and 2011. New measurements are highlighted. Updated WW and ZZ production cross-sections are presented. The search for a resonant enhancement in the dijet mass spectrum in W plus 2 or 3 jets events and the first observation of Z decaying to 4 leptons at hadron colliders are shown. The results are compared to SM predictions.

1 Introduction

The Standard Model (SM) gauge sector stands explicitely the interactions between gauge bosons. Triple terms and quartic terms appear in the lagrangian density after the spontaneous electroweak symmetry breaking and determine the gauge structure of the interactions between bosons. The strength of these interactions is a non trivial prediction of the electroweak theory and a unique signature of the non abelian nature of the gauge symmetry. Anomalous effects in triple gauge couplings (TGCs) would lead to an increase of the diboson production cross-section with regard to the SM, specially for large invariant masses of the diboson system. Diboson production measurement is thus a direct probe of the Standard Model. Diboson production is also a major background in many searches, namely the SM Higgs boson search in four leptons.

Production cross sections of WW, $W\gamma$ and $Z\gamma$ were measured by both ATLAS and CMS for Moriond 2011 [1] with approximately 35 pb^{-1}. For summer conferences, with 1 fb^{-1}, WW production measurement was updated [2] and WZ and ZZ production cross sections were measured [3]. These results are in good agreement with the SM. We focus here on updates of WW and ZZ production cross sections by ATLAS [4,5]. The study of the dijet mass spectra and the observation of $Z \to 4\ell$ by CMS [7,6] are also shown. These results are based on 4.7 fb^{-1}.

Despite their small branching ratio, the boson decays considered in these analyses are leptonic decays, as they have clean signatures and low QCD backgrounds. The main backgrounds are QCD multijets or W plus jets with jets faking leptons, top ($t\bar{t}$ or Wt, $t \to Wb$), Drell-Yan and other diboson modes. Major backgrounds are determined with data-driven techniques.

2 Update on WW production with 4.7 fb^{-1} (ATLAS)

The signal is selected in three different channels: ee, $e\mu$ and $\mu\mu$, with leptons of opposite charges and $p_T > 20$ GeV. The event is required to have large M_{ET} from the undetected neutrinos. The leading lepton p_T has to be greater than 25 GeV for the ee and $\mu\mu$ modes, whereas the electron p_T has to be greater than 25 GeV in the $e\mu$ mode. QCD and W+jets backgrounds are reduced by tight lepton identification and isolation criteria. Drell-Yan and other diboson backgrounds are suppressed by applying a veto on events with a dilepton invariant mass around the Z mass ±15 GeV for same flavor events. The top background is reduced by requiring no jet with $p_T > 25$ GeV ("jet veto"), and further suppressed by requiring no b-tagged jet with $p_T > 20$ GeV ("top veto"). Backgrounds from jets faking leptons are estimated from a fake rate measurement in data used to extrapolate the background yield from a W+jets control region to the signal region. The top background is estimated with Monte-Carlo (MC) and corrected with a data/MC factor for the jet veto efficiency. The Drell-Yan is also taken from MC with a data/MC correction determined from the M_{ET} tail in the Z peak region. The acceptance and efficiencies from simulation are corrected with data/MC ratio for lepton ID and jet veto efficiencies determined on Z events with the "tag-and-probe" method. The systematic uncertainty is about 8% and comes mainly from the W+jets and top backgrounds knowledge ($\simeq$ 5%) and the signal efficiencies ($\simeq$ 7%). The measured cross section is given in equation 1 and is in good agreement with previous measurements [1,2] and with the prediction from theory: $\sigma_{WW}^{\text{theo}} = 45.1 \pm 2.8$ pb.

$$\sigma_{WW} = 53.4 \pm 2.1\ (\text{stat.}) \pm 4.5\ (\text{syst.}) \pm 2.1\ (\text{lumi.})\ \text{pb} \tag{1}$$

3 Update on ZZ production with 4.7 fb^{-1} (ATLAS)

The ZZ production cross section is measured using the four-lepton decay channel, where the term lepton is used for electrons and muons. Events are selected by requiring four leptons with $p_T > 7$ GeV, forming two opposite-sign same-flavour lepton pairs with $66 < m_{\ell^+\ell^-} < 116$ GeV, with the leading lepton required to have $p_T > 20\,(25)$ GeV if it is a muon (electron). Leptons are required to be isolated and well identified. Heavy flavor decays are rejected by cutting on the leptons impact parameters. The sample after selection is almost background free, as it is shown in figure 1. The number of observed candidate events in the acceptance is 62 for a background expectation of 0.7 ± 1.8. The efficiencies are determined from MC and corrected for eventual differences with data using the "tag-and-probe" method on Z events. The systematic uncertainty is about 5%. The total ZZ production cross section measurement, extrapolated to the full phasespace using SM predicted kinematic distributions and corrected for the $ZZ \to \ell^+\ell^-\ell^+\ell^-$ branching fraction, is given by equation 2 and is consistent with the SM prediction: $\sigma_{ZZ}^{\text{tot, theo}} = 6.5 \pm 0.3$ pb.

$$\sigma_{ZZ}^{\text{tot}} = 7.2^{+1.1}_{-0.9}\ (\text{stat.})^{+0.4}_{-0.3}\ (\text{syst.}) \pm 0.3\ (\text{lumi.})\ \text{pb} \tag{2}$$

4 Dijet mass spectra in W plus 2 or 3 jets events 4.7 fb^{-1} (CMS)

This section presents the study of the invariant mass spectrum m_{jj} of the two jets with the highest transverse momentum in events with two or three jets produced in association with a W boson. In events with a lepton plus jets, the CDF collaboration reported evidence for an excess around 150 GeV over the m_{jj} distribution expected from the SM processes [8]. The D0 collaboration did not confirm this result [8]. The analysis is performed in the e and μ W boson decay channels. The muon (electron) is required to have $p_T > 25\,(35)$ GeV, with $M_{ET} > 25\,(30)$ GeV, and a transverse mass $m_T = \sqrt{2p_T^{\ell} M_{ET}(1 - cos(\Delta\phi(\ell, M_{ET})))} > 50$ GeV. Events with a second lepton passing looser quality criteria and with $p_T > 10\,(20)$ GeV for muon (electron) are disregarded to reduce the Drell-Yan contribution. Furthermore, we require the presence of exactly two or three jets in the event with $p_T > 40$ GeV for the leading p_T jet and $p_T > 30$ GeV for the second and third jets. The selected jets and the lepton from the W decay are required to originate from the same primary vertex. Jet energy corrections are applied versus p_T and η to account for jet energy resolution variations and pile-up. The selected data sample is dominated

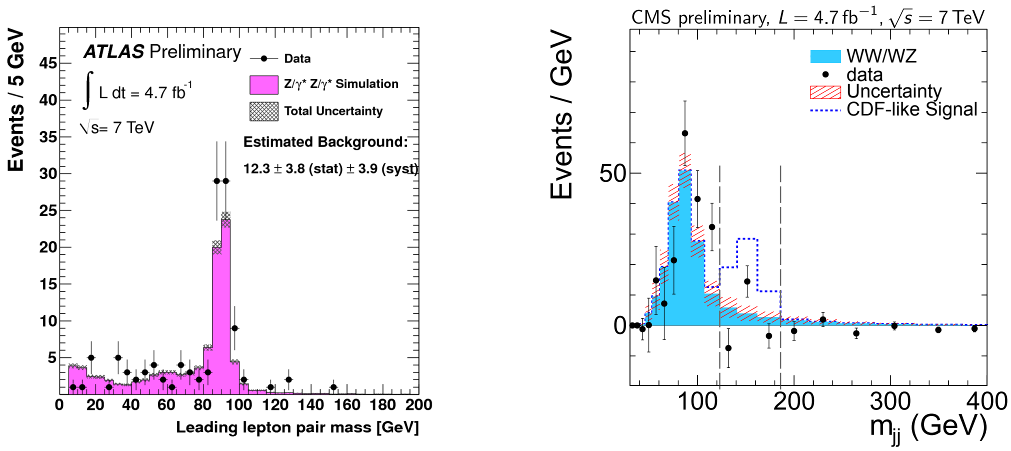

Figure 1: Leading lepton pair mass distribution for ZZ candidates in all four-lepton channels (left), without applying the dilepton mass requirements. Dijet invariant mass spectrum after substraction of the major backgrounds (right): the diboson signal is the only background left and there is no evidence for a resonant enhancement.

by events with W plus two or more jets. Smaller contributions come from top pairs, single top, Drell-Yan plus two or more jets, and multijet production. A small fraction of events is due to WW and WZ diboson production. We determine the relative contribution of the known SM processes to the observed m_{jj} spectrum using an unbinned maximum likelihood fit in the range between 40 GeV and 400 GeV.

The m_{jj} region between 123 and 186 GeV is excluded from this fit. The templates used in the fit are taken from MC except for the multijets background taken from a control sample with the lepton failing the isolation criteria. The normalisation of the W+jets background is free in the fit. As shown on the right in figure 1, there is no evidence for a resonant enhancement in the background substracted dijet mass spectrum.

The dominant systematic uncertainties arise from the jet energy scale, the M_{ET} resolution and the trigger and lepton ID efficiencies. A potential signal is excluded by testing a generic gaussian signal hypothesis around 150 GeV, with a width 15 GeV corresponding to a CDF-like signal with the CMS resolution. An upper limit on the cross section times branching fraction is set at 95% of confidence level at 1.3 pb, to be compared with the CDF excess of 3.4 pb.

5 First observation of $Z \to 4\ell$ at hadron colliders with 4.7 fb^{-1} (CMS)

All four LEP collaborations reported observations of four-fermion production $e^+e^- \to 4f$, which includes $e^+e^- \to Z \to 4f$ [9]. However, the observation of $Z \to 4\ell$ decays in pp collisions is of special interest. The clean resonant peak in the four-lepton invariant mass distribution at $m_{4\ell} = m_Z$ can be used as a standard candle for direct calibration of the four-lepton mass scale, the four-lepton mass resolution, and the overall four-lepton reconstruction efficiency in phase space similar to the Higgs boson four-lepton decays, $H \to ZZ \to 4\ell$.

The main irreducible background, $q\bar{q} \to Z\gamma^\star \to 4\ell$ is an initial state radiation whereas the signal $q\bar{q} \to Z \to 4\ell$ is a final state radiation. The interference term between signal and background is negligible in the analysis range, which allows to discuss the two production mechanisms separately. We define signal events as those with four leptons ($4e$, 4μ, $2e2\mu$), with $80 < m_{4\ell} < 100$ GeV and di-lepton masses for all pairings of leptons satisfying $m_{\ell\ell} > 4$ GeV. Lepton are selected with $p_T > 7\,(5)$ GeV and $|\eta| < 2.5\,(2.4)$ GeV for $e(\mu)$. The two hardest leptons are required to have a p_T greater than 20 GeV and 10 GeV. Isolation requirement are applied, after correcting the isolation for pile-up and other leptons. Heavy-flavour decays are rejected by cutting on the leptons impact parameters. We observe 26 events, in agreement with

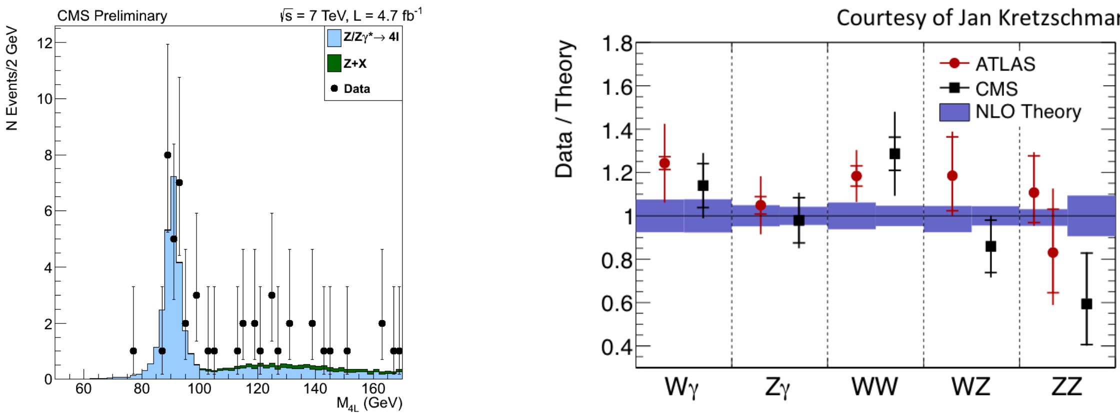

Figure 2: Left: four lepton mass distribution in data (black points) and simulation (blue). Right: up-to-date data over theory ratio for several diboson channels and both experiments.

the expected rate of 25.0 events, this analysis being almost background free (0.4 ± 0.1 expected background events). A pronounced resonance peak is observed in the $m_{4\ell}$ distribution (figure 2, right). The efficiencies are determined from MC and corrected with data using Z events and the "tag-and-probe" technique. The measured cross section times branching fraction is given in equation 3 and is consistent with the standard model prediction of 120 fb. The measured branching fraction of $Z \to 4\ell$ decays with a cut on the minimum dilepton mass $m_{2\ell} > 4$ GeV is given in equation 4 and agrees with the SM expectation 4.45×10^{-6}. With the current data, a fit to the observed four lepton mass leads to a precision on the mass scale of about 0.5%.

$$(\sigma \times BR)_{Z\to 4\ell} = 125^{+26}_{-23}\ (\text{stat.})^{+9}_{-6}\ (\text{syst.})^{+7}_{-5}\ (\text{lumi.})\ \text{fb} \quad (3)$$

$$BR_{Z\to 4\ell} = 4.4^{+1.0}_{-0.8}\ (\text{stat.}) \pm 0.2\ (\text{syst.}) \times 10^{-6} \quad (4)$$

6 Conclusion

Diboson studies at the LHC are now beyond the observation phase and all the results are in good agreement with SM expectations so far (see figure 2, right). With more statistics, precision will keep on increasing and interpretations of the latest results in terms of limits on TGCs are still to come.

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