Diboson measurements with the CMS detector

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We present studies of diboson production in pp collisions at 7 TeV center-of-mass energy based on data recorded by the CMS detector at the LHC in 2010 and 2011. These include precise measurements of W and Z production in association with a photon and of WW production, WZ and ZZ productions at the LHC. The leptonic decay modes of the W and Z bosons are used. The results are interpreted in terms of constraints on anomalous triple gauge couplings.

1 Introduction

The gauge boson self-interactions appear as vertices involving three or four gauge bosons. The study of diboson production in proton-proton collisions is an important test of the standard model (SM) because of its sensitivity to the self-interaction between gauge bosons via trilinear gauge couplings (TGC). The values of these couplings are fully fixed in the SM by the gauge structure of the $SU(2) \times U(1)$ Lagrangian. Any deviation, manifested as an increased cross section, would indicate new physics. Understanding diboson production is also important for Higgs boson searches, because electroweak WW and ZZ production are irreducible backgrounds for high mass Higgs.

The measurement here described were performed using data recorded by the CMS detector at the LHC in 2010 and 2011. A detailed description of the CMS detector can be found elsewhere [1].

2 WW, WZ, ZZ cross section measurements with 1.1 fb^{-1}

This measurements are based on data taken in 2011 corresponding to an integrated luminosity ($\mathcal{L}$) of 1.1 fb^{-1} and are fully described in Ref. [2].

2.1 Measurement of the $WW \rightarrow l^{+}\nu l^{-}\bar{\nu}$ cross section

The fully leptonic $W^{+}W^{-}$ final state consists of two oppositely charged leptons and large missing energy from the two undetectable neutrinos. Events are selected using triggers that require the presence of one or two high-p_T leptons (electrons or muons). Lepton candidates are then reconstructed offline and events with two oppositely charged (and only two), isolated leptons (ee, $\mu\mu$, $e\mu$) are chosen with extra requirements on E_T^{miss} and invariant mass to reject Drell-Yan. The background from top quarks decays is reduced rejecting events with one jet or more, or that have been tagged as a top-like event using b-jet tagging techniques. A more detailed description can be found here, [2].

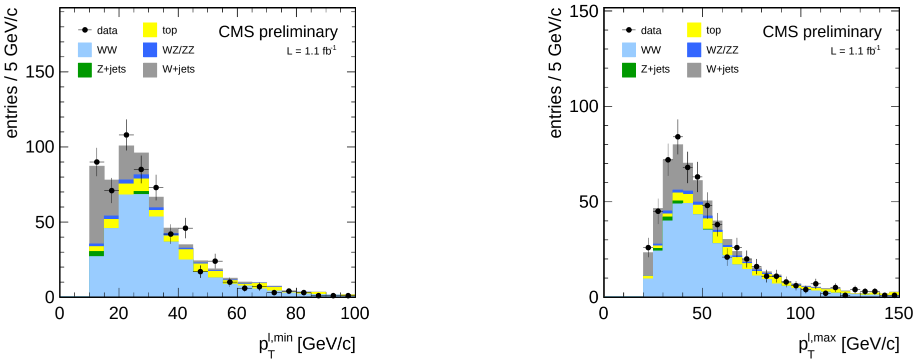

Figure 1: Leading (left) and trailing (right) lepton p_T. Each component in simulation is scaled to data-driven estimates.

The backgrounds include: $W + jets$ and QCD multi-jet events where at least one of the jets is misidentified as a lepton, top production ($t\bar{t}$ and tW), the $Z/\gamma^* \rightarrow ll$ process, and other diboson processes (WZ, ZZ and $W\gamma$). All the backgrounds are estimated from data, except $W\gamma$ and $Z/\gamma^* \rightarrow \tau\tau$ that are estimated from simulation. The W^+W^- yield is calculated from the number of events in the signal region, after subtracting the expected contributions of the various SM background processes. From this yield and the $W \rightarrow l\nu$ branching fraction [3], the W^+W^- production cross section in pp collisions at $\sqrt{s} = 7$ TeV is found to be $\sigma_{W^+W^-} = 55.3 \pm 3.3$ (stat) ± 6.9 (syst) ± 3.3 (lumi) pb. This is consistent with the SM expectation of 43.0 $\pm$ 2.0 pb at NLO [4] within one standard deviation. An update of this measurement using 4.9 fb^{-1} can be found in Ref. [5].

2.2 Measurement of the $WZ \rightarrow l\nu l^+l^-$ cross section

The $WZ \rightarrow l\nu l^+l^-$ decay is characterized by a pair of same-flavor, opposite-charge isolated leptons with an invariant mass corresponding to the Z boson, together with a third isolated lepton and large E_T^{miss}.

Candidate events are selected using a double electron or double muon trigger. The Z boson is reconstructed from two opposite sign, same flavor leptons passing loose identification criteria. We look for the W boson decay by requiring a third isolated lepton and requiring E_T^{miss} in the event to be larger than 30 GeV. In a data sample corresponding to $\mathcal{L} = 1.1$ fb^{-1}, 75 events pass these selection criteria. The invariant mass of the Z candidates for the selected events is shown in Fig. 2. We estimate the $Z + jets$ background using the data sidebands, and the fake-lepton originated backgrounds

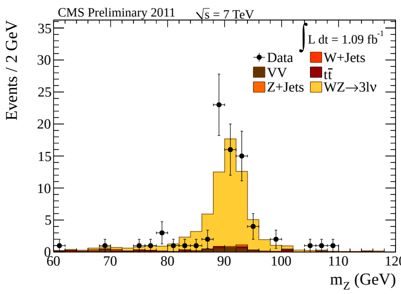

Figure 2: Dilepton invariant mass for events passing the full selection.

by computing the jet to lepton fake rate from $W + jets$ events in data. Similarly, we estimate the tt background contamination within the signal region using data. All other backgrounds are estimated from simulation.

This results in the cross section measurement: $\sigma(pp \to WZ + X) = 17.0 \pm 2.4(\text{stat.}) \pm 1.1(\text{syst.}) \pm 1.0(\text{lumi.})$ pb..The theoretical NLO prediction is 19.79 ± 0.09 [4], which is in good agreement with the measured value. Cross section measurements in the individual channels are consistent with the central value. More details on this measurement are given in Ref [2].

2.3 Measurement of the $ZZ \to l^+l^-l^+l^-$ cross section

The $ZZ \to l^+l^-l'^+l'^-$ process with $l, l' = e, \mu,$ or τ is characterized by two pairs of same flavor, opposite charge, high p_T , isolated leptons, coming from the primary vertex, with an invariant mass corresponding to a Z boson. The process has a clean signature with very little experimental background. We reconstruct each Z boson in the mass range $60 < m_Z < 120$ GeV. One Z is required to decay into a pair of electrons or muons, and the second Z can decay to $\mu\mu, ee$ or $\tau\tau$.

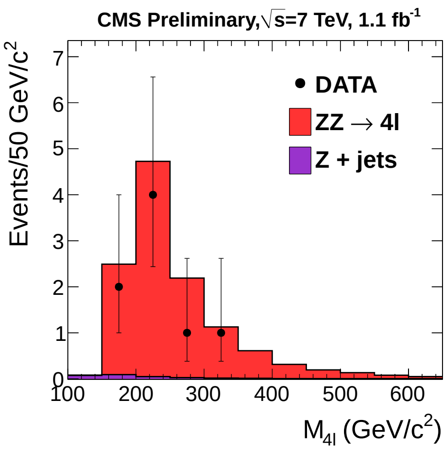

Figure 3: Invariant mass of the 4 leptons ($2e2\mu, 4\mu, 4e$).

For the 4l final state with $l = e, \mu$, we require the that the first Z is reconstructed using a pair of loose identified leptons an invariant mass greater than 60 GeV. For the second lepton pair we require opposite charge and matching flavor with an invariant mass $60 < m_Z < 120$ GeV and such that the reconstructed four-lepton mass satisfies $m_{4l} > 100$ GeV. For the $2l2\tau$ final state, the first Z boson is required to decay to $\mu\mu$or ee as described above, and the second Z decays into a pair of taus. Each tau candidate can decay leptonically, or hadronically. In case the decay is leptonic the p_T should be greater than 10 GeV, we require the hadronic τ to have $p_T > 20$ GeV. The two leptons should be isolated and should have opposite charge. The visible mass should be between 30 and 80 GeV.

The reducible instrumental background is very small or negligible. We estimate any residual background and the associated systematic uncertainty using empirical methods based on experimental data. In the 4l final state, we observe 8 events compared to 12.5 ± 1.1 events expected from the SM. The reconstructed four-lepton invariant mass distribution is shown in Fig. 3. The resulting cross section is $\sigma(pp \to ZZ + X) = 3.8^{+1.5}_{-1.2}(\text{stat.}) \pm 0.2(\text{sys.}) \pm 0.2(\text{lumi.})$ pb, which can be compared to the theoretical NLO prediction 6.4 ± 0.6 pb computed with MCFM[4]. More details on this measurement are given in Ref. [2].

3 Wγ and Zγ measurements

We present a measurement of $W\gamma$ and $Z\gamma$ production in proton-proton collisions at $\sqrt{s} = 7$TeV, based on a data sample recorded by the CMS experiment at the LHC, and corresponding to an integrated luminosity of 36 pb^{-1}. The electron and muon decay channels of the W and Z are used. The total cross sections are measured for photon transverse energy greater than 10 GeV and spatial separation from charged leptons in the plane of pseudorapidity and azimuthal angle greater than 0.7, and with an additional dilepton invariant mass requirement of > 50 GeV for the $Z\gamma$ process. The following cross section times branching fraction values are found: $\sigma(pp \rightarrow W\gamma + X)B(W \rightarrow l\nu) = 56.3 \pm 5.0$ (stat.) $\pm$ 5.0 (syst.) $\pm$ 2.3 (lumi.) pb and $\sigma(pp \rightarrow Z\gamma+X)B(W \rightarrow ll) = 9.4\pm1.0$ (stat.)$\pm$0.6 (syst.)$\pm$0.4 (lumi.) pb. These measurements are in agreement with standard model predictions. The first limits on anomalous $WW\gamma$, $ZZ\gamma$, and $Z\gamma\gamma$ trilinear gauge couplings at $\sqrt{s} = 7$ TeV are set. The details of this analysis are fully documented in Ref. [6].

4 Z to 4l measurements

We present the first observation of the Z boson decaying to 4 leptons in proton-proton collisions. The analyzed dataset corresponds to an integrated luminosity of 4.7 fb^{-1}. We observe a pronounced resonance peak, with the statistical significance of 8.9σ in the distribution of invariant mass of four leptons with its mean and width consistent with the Z boson. With the kinematic requirements imposed in the analysis, we observe 26 events in the mass window of $80-100$ GeV, in agreement with the expected rate of 25.0 events, comprised of 24.6 ± 2.2 $Z \rightarrow 4l$ events and 0.4$\pm$0.1 events from backgrounds. The measured branching fraction of $Z \rightarrow 4l$ decays with a cut on the minimum dilepton mass $m_{2l} > 4GeV$ is $BR(Z \rightarrow 4l) = 4.4^{+1.0}_{-0.8}$ (stat) $\pm$ 0.2 (syst) $\times 10^6$ and agrees with the standard model prediction of 4.45×10^6. The measured cross section times branching fraction is $\sigma \times BR(Z \rightarrow 4l) = 125^{+26}_{-23}$ (stat)$^{+9}_{-6}$(syst)$^{+7}_{-5}$(lumi) fb, also consistent with the standard model prediction of 120 fb. The four-lepton mass peak arising from $Z \rightarrow 4l$ decays provides a natural standard candle for the Higgs boson search in the $H \rightarrow ZZ \rightarrow 4l$ decay mode. The details of this analysis are described in Ref.[7].

References

[1] **CMS** Collaboration, "The CMS experiment at the CERN LHC", JINST **3** (2008) S08004.

[2] **CMS** Collaboration, "Measurement of the WW, WZ and ZZ cross sections at CMS", 201

[3] K. Nakamura *et al.* (Particle Data Group), J. Phys. G 37, 075021 (2010).

[4] J. Campbell, K. Ellis, and C. Williams, "MCFM - Monte Carlo for FeMtobarn processes", 2011

[5] **CMS** Collaboration, "Measurement of WW production rate", 2012

[6] **CMS** Collaboration, Phys. Lett. B **701**, 535 (2011) [arXiv:1105.2758 [hep-ex]].

[7] **CMS** Collaboration, "Observation of Z to 4l production in pp collisions at 7 TeV", 2012