PROCEEDINGS OF SCIENCE

WW, WZ, and ZZ production at CMS

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We present the WW, WZ and ZZ production cross sections measurements and constraints on anomalous triple-gauge boson couplings performed by the CMS collaborations using proton-proton collisions produced at a centre-of-mass energy of 7 and 8 TeV at LHC. Several measurements have been updated using the full available luminosity for the 7 TeV and 8 TeV runnings, in particular WZ at 7 TeV and ZZ at 8 TeV. A CMS's new WZ cross-section measurement at 8 TeV is presented and the cross section ratio $\sigma(W^+Z)/\sigma(W^-Z)$ is measured for the first time. Also new world leading sensitivity constrains on anomalous triple gauge couplings are set on the ZZ mode.

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1. Introduction

The diboson production processes WW, ZZ and WZ are expected to take place at the LHC and their cross sections, as well as detailed kinematic differential distributions, are precisely predicted in the framework of the Standard Model (SM). The cross section measurement provide excellent tests of the Quantum Cromodynamics (QCD) and the Electroweak (EW) sectors. Any measured deviation from the SM predictions of the diboson production rates or kinematic distributions would indicate the presence of anomalous triple-gauge boson couplings (aTGC) or other physics processes beyond the SM. Furthermore, the diboson processes are themselves sources of background to the SM Higgs searches, as well as searches for new phenomena. Therefore, it is mandatory to have precise diboson production cross section measurements as well as reliable and accurate theoretical predictions of these processes.

In this note, we present the 7 TeV and 8 TeV measurements of WW, WZ and ZZ diboson production based in the proton-proton collision data collected by CMS detectors at LHC in 2011 and 2012. We present also searches for aTGC using the WW, WZ and ZZ channels.

2. Cross section measurements

The $pp \to WW + X$ production cross section has been measured in the $WW \to \ell\nu\ell\nu$ channel at 7 TeV [1] using 4.9 fb^{-1} and at 8 TeV [2] using 3.5 fb^{-1} integrated luminosity of data. The signal region is selected by requiring two isolate leptons with opposite charge and large $E_{\mathrm{T}}^{\mathrm{miss}}$. The QCD and W+Jets production can mimic the signal when a jet is mis-identified as a lepton producing a fake lepton. This background is rejected by defining the lepton objects with a tight requirement in isolation and identification and estimated using standard data-driven methods. The Drell-Yan background is reduced by applying a Z-veto and high amount of $E_{\mathrm{T}}^{\mathrm{miss}}$ and by requiring than any jet with $E_T > 15$ GeV and the two-lepton system are almost back-to-back in the transverse plane, $\Delta\phi(\ell\ell, jet) > 165^o$. In addition a jet veto is applied to reduced the top background. The cross section at 7 TeV was measured to be $52.5 \pm 2.0(\mathrm{stat.}) \pm 4.5(\mathrm{syst.}) \pm 1.2(\mathrm{lumi.})$ pb. The theoretical prediction at next-to-leading (NLO) order provided by MCFM [3] and MSTW08 parton distribution functions is 47.0 ± 2.0 pb. The measured cross section at 8 TeV $69.9 \pm 2.8(\mathrm{stat.}) \pm 5.6(\mathrm{syst.}) \pm 3.1(\mathrm{lumi.})$ pb is compared with the predicted one at NLO with the same MCFM+MSTW08, $57.3^{+2.4}_{-1.6}$ pb. The measurements are slightly higher than the prediction in both cases. Notice that the expected contribution of the decay product of the SM Higgs, $H \to WW$, is around 4% and it is not included in the theoretical prediction.

The measurement of a diboson production using a hadronic decay for one boson can exploits the higher branching ratio with respect to the full leptonic decay, which is around 6 times lower. In return, the jet resolution does not allow to separate the W and Z mass, however it is possible to measure the total cross section for $WW + WZ$ decaying semileptonically $\ell\nu jj$. The measurement at 7 TeV [4] performed in CMS using 5.0 fb^{-1}, selects the signal region by requiring exactly two high-p_t jets and one isolated lepton in addition to high amount of $E_{\mathrm{T}}^{\mathrm{miss}}$. This selection requirements mitigate the Drell-Yan, QCD and top backgrounds, but the W+jets background is still huge compared to signal, see Figure 1, and a binned maximum-likelihood fit to the dijet invariant mass has been used to extract the signal yield and measures the cross section.

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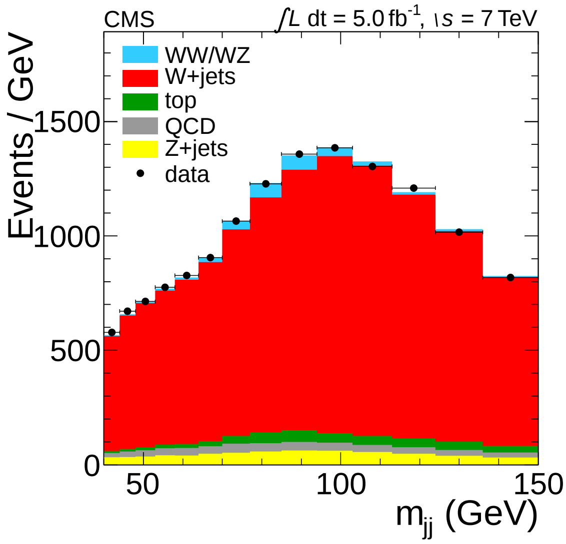
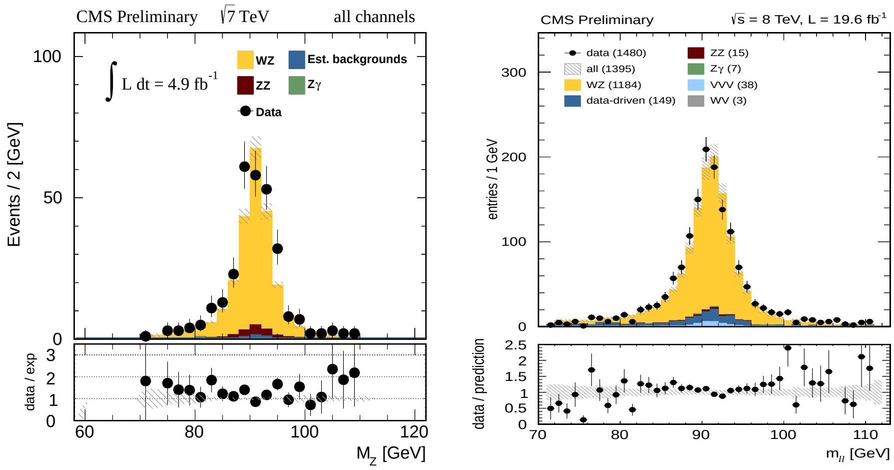


Figure 1: Dijet invariant mass for the WW+WZ cross section analysis

The $pp \to WZ + X$ cross section has been measured at 7 TeV using 4.9 fb^{-1} and at 8 TeV using 19.6 fb^{-1} in the $WZ \to \ell\nu\ell\ell$ channel [5]. The leptonic channel is a clean signature which requires three high-p_t isolated leptons and high amount of $E_{\mathrm{T}}^{\mathrm{miss}}$ for the undetected neutrino. Furthermore, there is small backgrounds due to instrumental effects: particles (jets especially) mis-identified as leptons. These fakes leptons are rejected by requiring tight identification and isolation criteria. Although is small compared with the signal, the only irreducible background is coming from the $ZZ \to 2\ell2\ell'$, when a lepton was lost due to detector acceptance. The Figures 2a and 2b show the invariant mass of the Z dilepton system for 7 and 8 TeV, respectively; it can be appreciated the high signal over background ratio. The cross section at 7 TeV was measured to be $20.8 \pm 1.3(\text{stat.}) \pm 1.1(\text{syst.}) \pm 0.5(\text{lumi.})$ pb to be compared with the NLO prediction with MCFM+MSTW08 of $17.8^{+0.7}_{-0.5}$ pb. The 8 TeV measurement was obtained to be $24.7 \pm 0.8(\text{stat.}) \pm 1.1(\text{syst.}) \pm 1.1(\text{lumi.})$ pb and the NLO prediction is $22.0^{+1.2}_{-0.8}$ pb. Both measurements are slightly higher than the SM predictions.

The same signal definition but split into two regions regarding the charge of the W-lepton candidate, has been used to evaluated the production cross section ratio $\sigma(pp \to W^+Z + X)/\sigma(pp \to W^-Z + X)$. The observable takes advantage of the cancelation for the luminosity uncertainty and of the high reduction of some systematics related with the background estimation. However, a new source of systematic has to be introduced to take into account the efficiency ratio between opposite charged leptons, although the effect in the ratio measurement is small (around 3%). The expected ratio is sensitive to the parton distribution function ratio of positive versus negatively charged quark in the proton with increased sensitivity to the sea quark contributions at higher energies. The ratio $\sigma(pp \to W^+Z + X)/\sigma(pp \to W^-Z + X)$ has been measured to be $1.94 \pm 0.25(\text{stat.}) \pm 0.04(\text{syst.})$ at 7 TeV and the SM prediction at NLO using using MCFM+MSTW08 is $1.776^{+0.006}_{-0.003}$. The 8 TeV measurement was $1.81 \pm 0.12(\text{stat.}) \pm 0.03(\text{syst.})$ and the prediction 1.724 ± 0.003. Both reported results are in good agreement with the SM predictions.

The cross section measurement of the $pp \to ZZ + X$ has been performed in the full leptonic



(a) 7 TeV (b) 8 TeV

Figure 2: Dilepton invariant mass for the WZ cross section analysis

channel both in 7 TeV [6] and 8 TeV [7] using an integrated luminosity of 5.0 fb^{-1} and 19.6 fb^{-1}, respectively. The signal region selection requires two pairs of high-p_t, opposite charged, same flavor and isolated leptons compatibles with two on-shell Z bosons. The signal region is expanded by including the $ZZ \rightarrow \tau\tau$ decay mode. The main source of background is instrumental, due to particles mis-identified as leptons, mimicking the signal mainly in WZ+jets or Z+jets events. This background is highly reduced using tight identification and isolation criteria. The measured cross section at 7 TeV was $6.2^{+0.9}_{-0.8}(stat.)^{+0.4}_{-0.3}(sys.) \pm 0.1(lumi.)$ pb and the NLO prediction using MCFM+MSTW08 is 6.3 ± 0.4 pb. The 8 TeV cross section was measured to be $7.7 \pm 0.5(stat.) \pm 0.6(syst.) \pm 0.3(lumi.)$, and the NLO SM predicts 7.7 ± 0.4 pb. Both measurements are in good agreement with the SM predictions.

3. Anomalous triple-gauge boson couplings

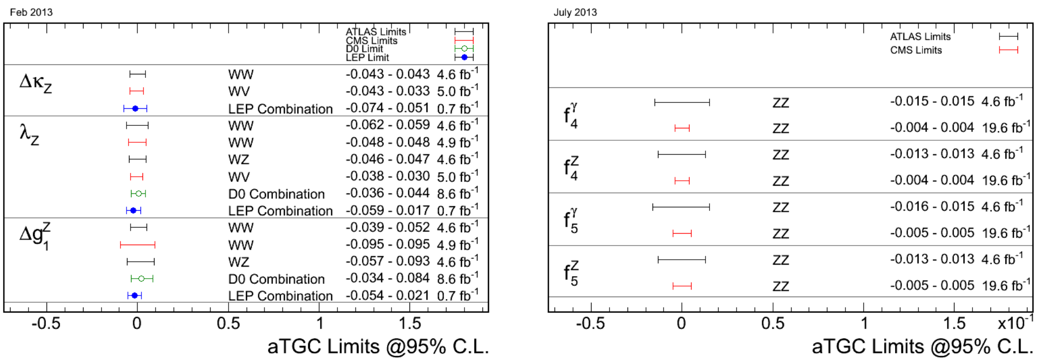
Any deviation from the triple-gauge boson couplings fixed in the SM by the gauge structure of the EW theory indicates new physics. It is possible to deduce a effective lagrangian featuring such anoumalous triple-gauge boson couplings (aTGC) and be compared to the experimental data. We use an $SU(2) \times U(1)$ gauge respecting of aTGCs [8] with parameters given in Table 1. In this parametrization the following relationships exist $\lambda_\gamma = \lambda_Z$ and $\Delta\kappa_Z = \Delta g_1^Z - \Delta\kappa_\gamma tan^2(\theta_W)$ leading to three independent parameters. All these parameters are equal to zero in the SM.

Coupling	Parameters	Channels
$WW\gamma$	λ_γ,$\Delta\kappa_\gamma$	WW
WWZ	λ_Z, $\Delta\kappa_Z$, Δg_1^Z	WW,WZ
$Z\gamma Z$	f_4^Z, f_5^Z	ZZ
ZZZ	f_4^γ, f_5^γ	ZZ

Table 1: List of aTGC parameters used for searches

The aTGC are expected to modify the total production rates as well as kinematics distributions, in particular, the boson transverse momentum and the diboson invariant mass, both at high values. The expected number of signal events can be written as function of the SM cross section plus some aTGC parameters. The searches for aTGC using the channels WW, WZ and ZZ have found no deviation from the SM values, and in absence of deviations, upper limmits on the aTGC parameters have been set.

The WW [1] [2] and $WW+WZ$ [4] modes have been used to probe the WWV ($V=Z,W$) vertex, setting limits on the respective parameters . The limits was set using the transverse momentum of the diboson system, p_t^{jj}, for the $WW+WZ$ and the transverse momentum of the leading lepton in the WW case. Figure 3a shows the limits obtained at 95% confidence level together with previous results from LEP, D0 and ATLAS. The neutral vertex ZVZ ($V=Z,\gamma$) has been tested using



(a) Limits on WWZ and WWW (b) Limits on $Z\gamma Z$ and ZZZ

Figure 3: Anomalous triple-gauge bosons limits at 95% confidence level

the full 19.6 fb^{-1} data from the 8 TeV run, considerably improving previous limits in the related parameters. The limits have been extracted using the invariant mass of the four lepton system. These limits are shown in Figure 3b at 95% of confidence level.

4. Summary

Measurements of the WW, WZ and ZZ cross section production have been presented for the 7 TeV and 8 TeV center of mass energy. The WZ analysis at 7 TeV has been released with the full available luminosity, 4.9 fb^{-1}, updating the previous one [9] at 1.1 fb^{-1}, whereas the 8 TeV is a new measurement at CMS. The ratio $\sigma(W^+Z)/\sigma(W^-Z)$ has been measured at 7 and 8 TeV for the first time. Also, this note shows the updated results for the ZZ cross section at 8 TeV using 19.6 fb^{-1} of integrated luminosity. Figure 4 summarizes the diboson production measurements performed at CMS to date, the WW, $WW+WZ$ and ZZ cross section, among other SM productions, are compared with to their theoretical prediction. The WW, WZ and ZZ modes have been used to perform searches for aTGC, obtaining no deviations from SM predictions. Limits on aTGC are set in these channels.

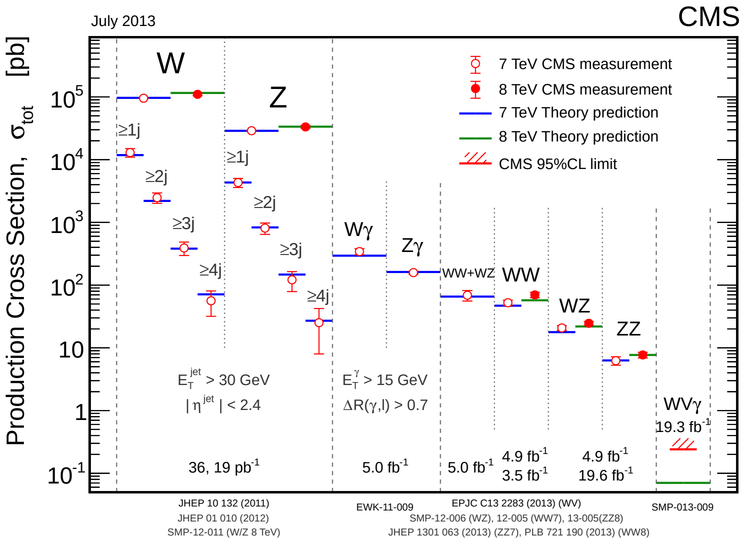


Figure 4: Cross section measurements at CMS and their theoretical predictions

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