The potential for the observation and study of $pp \rightarrow WW \rightarrow ll\nu\nu$, $pp \rightarrow WZ \rightarrow ll\nu\nu$, and $pp \rightarrow ZZ \rightarrow llll$ ($l = e, \mu$) production are investigated using fully simulated signal and background Monte Carlo samples at the LHC. Due to the relatively high cross sections at the LHC energy ($\sqrt{s} = 14$ TeV) and the clean signature of multi-lepton final states, these productions could potentially be observed in the early phase of the experiment ($100 \text{ pb}^{-1} \sim 1 \text{ fb}^{-1}$). The limits on the anomalous triple gauge couplings are also studied and could be significantly improved over the Tevatron results.

1. Introduction
The study of multiple gauge-boson production at the LHC provides a direct test of the non-Abelian structure of the standard model (SM) at energy scales never reached before. Only the charged triple gauge-boson couplings (TGC’s), such as $WWZ$ and $WW\gamma$, are allowed in the SM at tree level. The existence of neutral TGC’s, such as $ZZ\gamma$ and $ZZZ$, is forbidden in the SM. The presence of anomalous couplings would increase the cross sections and alter the production kinematics. Any deviations from the expected values would indicate the presence of new physics beyond the SM. The cross sections of diboson production at the LHC is 10 times or more higher than Tevatron. In the near future, the LHC will be the primary source of diboson production with higher reach in invariant mass, where the new physics effects might become evident, and high statistics. The diboson production is also an important and irreducible background to the search of the new physics such as SM Higgs boson and SUSY. Therefore, a detailed understanding of diboson production is needed in the first phase of LHC data-taking before any new discovery can be made. This proceeding briefly summarizes the studies using the fully simulated data on the diboson production in fully-leptonic decay channel at the LHC.

2. Monte Carlo data
In CMS, the signal samples are generated using the PYTHIA event generator with GEANT-based detector simulation. The $Z\bar{b}b$ background process is modeled with the COMPHEP program, the $t\bar{t} \rightarrow 2l + X$ process with the TOPREX program, and all the others with PYTHIA. Underlying events are included in the simulation, as well as a number of additional inelastic or diffractive $pp$ interactions (pile-up). In the low luminosity phase of the LHC ($\mathcal{L} = 2 \times 10^{33} \text{cm}^{-2}\text{s}^{-1}$), the average number of pile-up interactions on top of the signal collision is expected to be 5.
In ATLAS, the diboson signal and $t\bar{t}$ background samples are generated with MC@NLO(v2.3)+Herwig/Jimmy. One of the bosons or top quark is forced to decay leptonically and the other decays to all allowed final states. Except for $t\bar{t}$, background samples are produced by PYTHIA. The pile-up effect is not included in the simulation.

3. Preliminary results

3.1. WW

$W$ pair production receives contributions from both the WWZ and WW$\gamma$ coupling and has been extensively studied by the LEP experiments in $e^+e^-$ collisions up to $\sqrt{s} = 209$ GeV [1] and Tevatron experiments in $p\bar{p}$ collision up to $\sqrt{s} = 1.96$ TeV [2, 3]. The results have been shown to agree well with the SM expectation. ATLAS studied the WW production in the dilepton decay channel $W^+W^- \rightarrow l^+\nu l^-\bar{\nu}$ ($l = e, \mu$). The signature is two isolated high-$p_T$ leptons of opposite charge and large missing transverse energy, $E_T$, from the undetected neutrinos. After the selection cuts, the significant backgrounds to signal production are from Drell-Yan (DY) with large $E_T$, $Z$+jet where one lepton escapes detection and a jet fakes an isolated lepton, and $W$+jets where the jet fakes an isolated lepton. The background contribution of $t\bar{t}$ events is reduced by requiring minimal jet activity. The signal and background yield of each channel are listed in Table 1. The $ee$ channel has excellent detection sensitivity for the signal because the rejection of background from DY process can be well controlled.

|      | $ee$ | $\mu\mu$ | $e\mu$ |
|------|------|----------|--------|
| $N_S$ | 36.7 | 37.6     | 284.4  |
| $N_B$ | 188.6| 112.1    | 59.4   |
| $S_L$ | 2.59 | 3.38     | 25.3   |
| $N_S/\sqrt{N_B}$ | 2.67 | 3.55     | 36.9   |

Table 1. Expected WW signal and background yield for an integrated luminosity of 1 $fb^{-1}$. $S_L = \sqrt{2m_QQ = (1+N_S/N_B)^{N_S+N_B}e^{-N_S}}$ is used to assess the significance of the signal observation.

The production of $WZ$ proceeds mainly through $s$-channel quark annihilation and allows for the direct measurement of WWZ coupling independent of the WW$\gamma$ coupling. WZ process is not available at tree level at LEP. The recent results from the Tevatron experiments [4, 5] have shown no deviation from the SM prediction.

In CMS, events with three charged leptons ($e$ or $\mu$) with $p_T > 10$ GeV/$c$ and $|\eta| < 2.5$, are selected. Events are retained if there is a $Z$ candidate found with a mass within 20 GeV/$c^2$ of nominal $Z$ mass, $m_Z$. The background from ZZ final state is reduced by rejecting events with a second $Z$ candidate with a mass within 40 GeV/$c^2$ of $m_Z$. The remaining lepton is associated with the $W$ boson decay and requires $p_T$ larger than 20 GeV/$c$. This requirement effectively suppresses background from $Zbb$ events. For 1 $fb^{-1}$, a yield of 97 signal for 22 background events is expected. Figure 1 shows the expected signal significance as a function of integrated luminosity. $WZ \rightarrow llll\nu$ channel can be observed with a significance of 5, including systematic effects, in an integrated luminosity of 150 $pb^{-1}$. ATLAS selects events with three charged leptons with $p_T > 10$ GeV/$c$. The third high $p_T$ lepton with $E_T > 25$ GeV gives the $W$ signal. Events with more than one jet with energy larger than 30 GeV in $|\eta| < 3$ are not considered. A yield of 76 signal for 6 background events is expected at the first 1 $fb^{-1}$.
3.3. ZZ

The $s$-channel contribution to ZZ production is strongly suppressed. The production mainly proceeds via the $t$-channel $q\bar{q}$ scattering. CMS studied ZZ $\rightarrow 4e$ channel. Four electron candidates ordered by $p_T$ must satisfy $p_T > 30, 20, 15, 10$ GeV/$c$ and $|\eta| < 2.5$. The Z candidates are formed with invariant mass between 50 and 120 GeV. For 1 $fb^{-1}$, the expected yield is 3.6 signal for 0.28 background events. The total systematic uncertainties on the cross section determination is 12.9 %. Figure 2 shows the $e^+e^-$ mass distribution found by the ZZ selection from CMS as expected in 10 $fb^{-1}$. ATLAS studied ZZ $\rightarrow llll$ channel. The Z candidate is formed by the same-flavor opposite-charge lepton pairs, separated by $\Delta R(l^+l^-) > 0.2$. The highest-$p_T$ lepton associated to the Z boson must satisfy $p_T > 15$ GeV. The invariant mass of lepton pairs must satisfy $|M_{l^+l^-} - m_Z| < 12$ GeV. A yield of 13 signal events with negligible background is expected at the first 1 $fb^{-1}$.

![Figure 1](image1.png)

**Figure 1.** Significance for the WZ signal observation from CMS. The solid line shows the case of ideal simulation of the lepton efficiencies. The dashed line presents the result of a decrease of this efficiency of 2% per lepton. The dotted line shows the effect of systematic uncertainties.

![Figure 2](image2.png)

**Figure 2.** The $e^+e^-$ invariant mass distribution, two entries per event, with 10 $fb^{-1}$ of integrated luminosity from CMS. The contributions of three main backgrounds, $Z\gamma^*$, $tt$, and $Zbb$, are indicated.

3.4. Triple gauge boson couplings

The most general Lorentz and gauge invariant TGC which conserves charge and parity is described by an effective Lagrangian [6]. Table 2 lists the TGC limits from CDF [7] at Tevatron and ATLAS fast simulation data. With the much higher collision energy at LHC, the TGC’s measurements could be improved up to two orders of magnitude over Tevatron.

References

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