

ZZ cross section measurement and limits on anomalous Triple Gauge
Couplings at CMS experiment (preliminary results)

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ABSTRACT

The measurement of the *ZZ* production cross section in proton-proton collisions at center-of-mass energies of 7 and 8 TeV from data acquired by the CMS experiment at the LHC is presented. The decay channel $ZZ \rightarrow 2l2\nu$ is selected from data corresponding to an integrated luminosity of 5.1 fb^{-1} at 7 TeV and 19.6 fb^{-1} at 8 TeV.

The measured cross sections,

$\sigma(\text{pp} \rightarrow ZZ) = 5.0_{-1.4}^{+1.5} (\text{stat})_{-1.0}^{+1.3} (\text{syst}) \pm 0.2 (\text{lumi}) \text{ pb}$ at 7 TeV, and
 $\sigma(\text{pp} \rightarrow ZZ) = 6.8_{-0.8}^{+0.8} (\text{stat})_{-1.4}^{+1.8} (\text{syst}) \pm 0.3 (\text{lumi}) \text{ pb}$ at 8 TeV, are in good agreement with the standard model NLO predictions. The selected data are analyzed to search for anomalous triple gauge couplings involving the *ZZ* final state.

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1 Introduction

The measurement of the Z bosons pair production into the $2l2\nu$ final state cross section at 7 and 8 TeV at CMS [1] experiment is presented. In the Standard Model (SM), a Z bosons pair is produced through non-resonant processes or through the decay of a Higgs boson, and the predictions of the SM for this rare electroweak process can be tested with precision for the first time at the LHC.

Vector bosons are expected to couple in triplets (e.g. WWZ) and in quartets (e.g. $WWZZ$) as a consequence of the non-abelian structure of the electroweak gauge theory. All couplings involving the bosons with neutral electric charge are expected to vanish at tree level leading to the absence of triple couplings for $Z\gamma\gamma$, $ZZ\gamma$ and ZZZ . An observation of these anomalous couplings would therefore be an indication of new physics. This new physics can be parametrized as anomalous coupling constants (aTGC) for neutral triple gauge boson interactions γZZ and ZZZ , and it can appear as deviations from the SM, e.g. in the Z boson transverse momentum (p_T) spectrum.

The ZZ production cross section is expected to be $6.46_{-3.3\%}^{+4.7\%}$ pb at $\sqrt{s} = 7$ TeV and $7.92_{-3.0\%}^{+4.7\%}$ pb at $\sqrt{s} = 8$ TeV at next-to-leading order (NLO) [2]. At the tree level, ZZ final states are primarily produced in the t- and u-channels and gluon-gluon fusion. NLO electroweak correction calculations have been recently published [3] and will be applied in next approved results.

Data corresponding to an integrated luminosity of about 5.1 fb^{-1} at 7 TeV and 19.5 fb^{-1} at 8 TeV have been analyzed and the cross-sections measurement is in good agreement with the SM NLO predictions.

2 Event selection

The $2l2\nu$ final state is characterized from the presence of 2 energetic leptons (e/μ) and high transverse missing energy (E_t^{miss}).

To better describe the presence of neutrinos, a new variable, called *reduced* E_t^{miss} , has been defined as done successfully in D0 experiment [4]. The general concept behind a reduced E_t^{miss} is to reduce the instrumental contribution by considering possible contributions to fake missing transverse energy on an event-by-event basis. In each event, E_t^{miss} and jets momentum are decomposed along an orthogonal set of axes in the transverse plane of the detector. One of the axes is defined by the transverse momentum of the charged dilepton system, the other perpendicular to it.

We define the recoil of the dilepton system in two different ways: the clustered recoil (\vec{R}_{clust}), the vectorial sum of the jets reconstructed in the event, and the unclustered recoil (\vec{R}_{uncl}), the sum of all the candidates in the event, with the exception of the two leptons. On each axis i , the reduced- E_t^{miss} projection is defined as:

$$reduced - E_t^{miss^i} = -q_T^i - R_{c-u}^i$$

where R_{c-u}^i is \vec{R}_{clust} or \vec{R}_{uncl} depending on which minimize the absolute value of the *reduced* - E_t^{miss} component. The selection chosen to remove the presence of background is reported in table 1. The cuts have been chosen, among all the possible combinations, to yield the lowest statistical and systematic uncertainty. The selection is identical for 7 and 8 TeV data and for the search of anomalous couplings.

3 Backgrounds estimation

While the WZ background is estimated from simulation, after cross-checking that the simulation agree with the data in a control region with three identified leptons, a data-driven method is applied to estimate the total number of background events from processes which do not involve a Z boson: i.e. WW and top production [5]. In order to measure this contribution, a control sample based on $e\mu$ candidate events is selected by applying the same selection cuts as in the main analysis. The yields in the same-flavour channels (ee and $\mu\mu$) are then obtained by scaling the number of events in the control sample. The re-scaling is done by means of data-driven factors, measured from the side-bands of the Z mass peak region ($55-70 \text{ GeV}/c^2$ and $110-200 \text{ GeV}/c^2$).

The estimation of the Drell-Yan (DY) background requires special care. Although the DY process does not

Table 1: Summary of the optimal signal selection.

Variable	Value
Dilepton invariant mass	$ m(ll) - 91 < 7.5$ GeV
Dilepton p_T	$q_T > 45$ GeV
b-tag veto	based on vertex info. (for jet with $p_T > 20$ GeV)
Jet veto	no jets with $p_T > 30$ GeV
Reduced E_t^{miss}	> 65 GeV
E_t^{miss} balance	$0.4 < B < 1.8$
$\Delta\phi(E_t^{miss}, \text{jet})$	> 0.5 rad
$\Delta\phi(E_t^{miss}, \text{lept.})$	> 0.2 rad
Lepton veto	no additional leptons (e/μ) with $p_T > 10/3$ GeV

include genuine E_t^{miss} from neutrinos, the tail of the reduced- E_t^{miss} distribution can be contaminated by these events due to detector energy resolution, jet energy mis-measurements, pile-up energy fluctuations, and instrumental noise. DY it has been estimated using a process which is topologically similar, with a much higher cross section, as the production of prompt isolated photons in association with jets (i.e. γ +jets). The DY data driven estimation uses the followings steps:

- The kinematic selection to remove processes with real neutrinos, selecting a high purity photon sample in data
- The application of weights to the γ p_T spectrum to match the Z p_T spectrum from the dilepton sample
- The application of the full selection to the weighted photon sample
- The subtraction of the the EWK $\gamma+E_t^{miss}$ events using the simulated predictions

The remaining contribution has been used as DY estimation (light green component of Fig. 1)

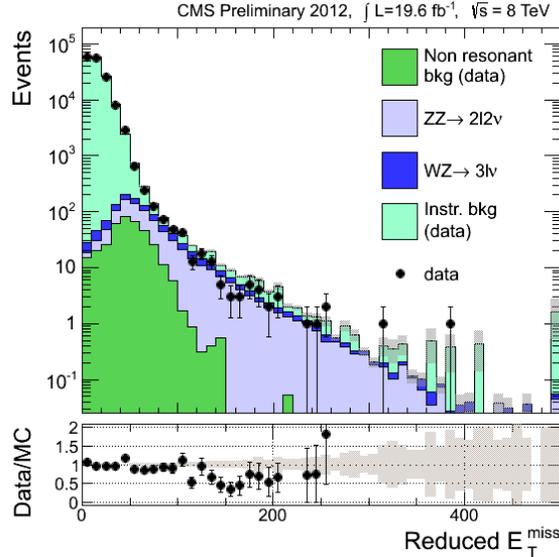


Figure 1: Reduced E_t^{miss} spectrum in the inclusive ll channel at 8 TeV, using the DY-template derived from the photon sample at preselection level.

4 Results

We extract the ZZ production cross section using a profile likelihood fit to the reduced- E_T^{miss} distribution (Fig. 2), which takes into account the expectations for the different background processes and the ZZ signal. Each systematic uncertainty is introduced to the fit as a nuisance parameter with log-normal prior. For the signal we consider a further multiplicative factor, which is the ratio of the cross section to be measured in data to the expected theoretical value. Maximizing the profile likelihood, we obtain the ZZ production cross section from the signal strength fit, as well as optimal fits of the background yields from a fine adjustment of the nuisance parameters.

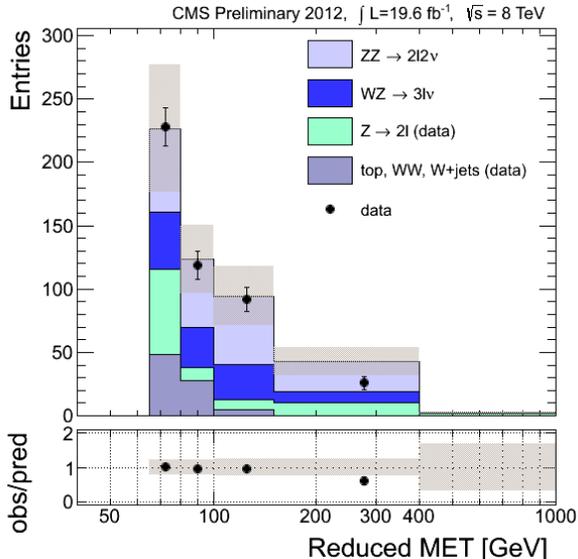


Figure 2: Reduced E_T^{miss} distribution in ll channels, after the full selection, at 8 TeV. DY and non-resonant backgrounds are estimated with data-driven methods. The grey error band includes statistical and systematic uncertainties on the predicted yields. In the bottom plots, error bars and bands are relative to the total predicted yields.

The measured cross sections are:

$$\sigma(\text{pp} \rightarrow ZZ) = 5.0_{-1.4}^{+1.5} (\text{stat})_{-1.0}^{+1.3} (\text{syst}) \pm 0.2 (\text{lumi}) \text{ pb}$$

at 7 TeV, and

$$\sigma(\text{pp} \rightarrow ZZ) = 6.8_{-0.8}^{+0.8} (\text{stat})_{-1.4}^{+1.8} (\text{syst}) \pm 0.3 (\text{lumi}) \text{ pb}$$

at 8 TeV, in good agreement with the SM NLO predictions. Since no deviation from SM have been observed, we search for deviations in the kinematics due to the presence of aTGCs.

Neutral couplings $V^{(*)}ZZ$ ($V = Z, \gamma$) can be described using the following effective Lagrangian:

$$\mathcal{L}_{VZZ} = -\frac{e}{M_Z^2} \left\{ [f_4^\gamma (\partial_\mu F^{\mu\alpha}) + f_4^Z (\partial_\mu Z^{\mu\alpha})] Z_\beta (\partial^\beta Z_\alpha) - [f_5^\gamma (\partial^\mu F_{\mu\alpha}) + f_5^Z (\partial^\mu Z_{\mu\alpha})] \tilde{Z}^{\alpha\beta} Z_\beta \right\}$$

Coefficients f_i^γ and f_i^Z correspond to couplings $\gamma^{(*)}ZZ$ and $Z^{(*)}ZZ$, respectively. All the operators are Lorentz-invariant and $U(1)_{EM}$ gauge-invariant, but not invariant under $SU(2)_L \times U(1)_Y$ gauge symmetry. The terms corresponding to f_4^V parameters violate the CP symmetry, while the terms corresponding to f_5^V parameters conserve CP.

Figure 3 shows the charged dilepton p_T distribution after the full selection, in data and MC, including SHERPA [6] samples with different values of the aTGC parameters.

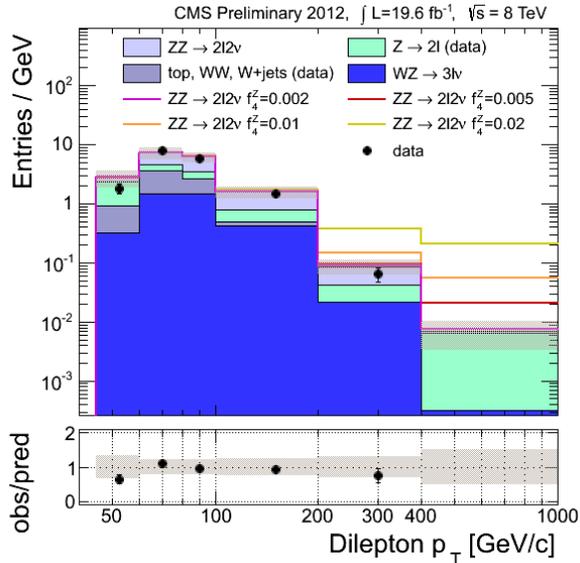


Figure 3: Dilepton transverse momentum distributions at 8 TeV. DY and non-resonant backgrounds are estimated with data-driven methods. The grey error band includes statistical and systematic uncertainties on the predicted yields. In the bottom plots, error bars and bands are relative to the total predicted yields.

In the search for aTGCs, the SM production of ZZ represents a background, while the sole contribution of the aTGCs constitutes the signal. This signal is built from the SHERPA, by subtracting the SM contribution to the charged dilepton p_T .

The limits are calculated with a profile likelihood method. We set one-dimensional limits on the four parameters, i.e. varying independently a single parameter at a time, while fixing the other three to 0. The 95% C.L. one-dimensional limits on the four parameters are reported in Table 2 for 7 TeV and 8 TeV.

Table 2: Summary of 95% C.L. intervals for the neutral aTGC coefficients, set by this analysis using the 7 and 8 TeV CMS datasets. The expected 95% C.L. intervals obtained using the 7 and 8 TeV simulated samples are also shown. No form factor is used.

Dataset	f_4^Z	f_4^γ	f_5^Z	f_5^γ
7 TeV	[-0.0088; 0.0085]	[-0.0098; 0.011]	[-0.0096; 0.0096]	[-0.011 ; 0.010]
8 TeV	[-0.0038; 0.0040]	[-0.0049; 0.0039]	[-0.0041; 0.0038]	[-0.0049; 0.0046]
Combined	[-0.0030; 0.0034]	[-0.0039; 0.0031]	[-0.0036; 0.0032]	[-0.0038; 0.0038]

5 Conclusions

We have measured the ZZ production cross section from proton-proton collisions at center-of-mass energies of 7 and 8 TeV. The data sample selected for our study corresponds to about 5.1 fb^{-1} of integrated luminosity at 7 TeV, and about 19.6 fb^{-1} at 8 TeV. The measured cross section is in good agreement with the SM NLO predictions, and the selected data were also analyzed to search for anomalous triple gauge couplings involving the ZZ final state. In the absence of signs of new physics, we have set limits on the relevant aTGC parameters.

References

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