Measurement of the ZZ production cross section and limits on anomalous neutral triple gauge couplings

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Abstract

The measurement of the Z boson pair production cross section at 7 and 8 TeV in the ZZ $\rightarrow 2l2\nu$ channel is presented. In the Standard Model (SM), a Z boson pair is produced through non-resonant processes or through the decay of a Higgs boson. The SM predictions for this rare electroweak process can be tested precisely at the LHC. In addition, with the ZZ final state, searches for new physics can be performed for instance as resulting from anomalous couplings of neutral gauge bosons (γZZ and ZZZ) which are forbidden at tree level in the SM. Data corresponding to an integrated luminosity of about 5.1 fb^{-1} at 7 TeV and 19.5 fb^{-1} at 8 TeV are analyzed. The sensitivity of the ZZ $\rightarrow 2l2\nu$ and ZZ $\rightarrow 4l$ channels are compared. The latter lead to the most stringent limits published with only 5 fb^{-1} of data at 7 TeV.

1 Current knowledge on ZZ production

The ZZ production cross section is expected to be $6.46^{+4.7\%}_{-3.3\%}$ pb at $\sqrt{s} = 7$ TeV and $7.92^{+4.7\%}_{-3.0\%}$ pb at $\sqrt{s} = 8$ TeV at NLO where the uncertainty includes QCD scale and PDF uncertainties [1].
At the tree level, ZZ final states are primarily produced in the t- and u-channels after the annihilation of a pair of quark and anti-quark. The remaining ZZ pairs are expected to be produced by gluon-gluon fusion through a quark-box diagram (Figure 1).

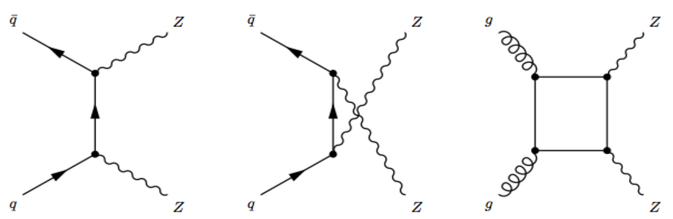

Figure 1: Leading diagrams for the production of ZZ pairs.

The latest public results on the measurement of the ZZ cross section are from $ZZ \rightarrow 4l$ analysis [2]:

$$\sigma(pp \rightarrow ZZ) = 6.24^{+0.86}_{-0.80}(stat.)^{+0.41}_{-0.32}(sys.) \pm 0.14(lum.)\ \text{pb}$$

While neutral bosons are not expected to couple to each other at tree level in the SM, trilinear gauge couplings may be foreseen as possible manifestation of new physics at a higher scale. CP-violating terms are usually parametrized by the f_4^V parameters while CP-conserving terms are usually parametrized by the f_5^V parameters, where V denotes a γ or a Z boson. The current limits [2] on these terms as obtained by CMS are shown in Figure 2 while ATLAS results can be consulted in [3].

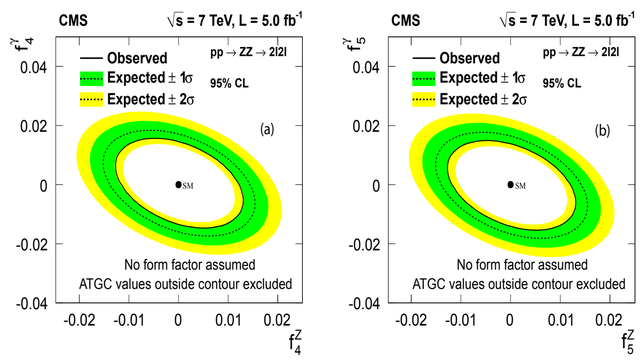

Figure 2: Limits on aTGCs from $ZZ \rightarrow 4l$ events [2].

2 The $2l2\nu$ final state challenge

- ~6 x higher branching ratio with respect to 4l final state
- Lower purity due to instrumental background contamination
- Profit from higher statistics to probe further aTGCs

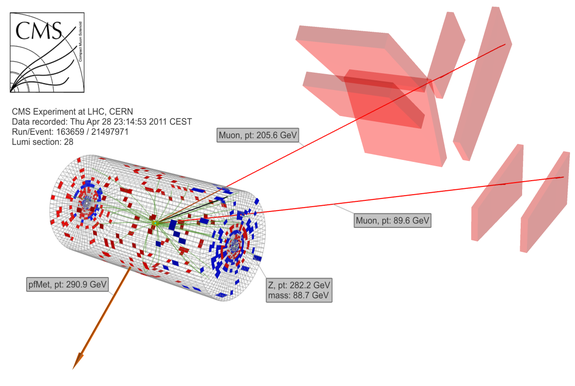

Figure 3: Event display of a $ZZ \rightarrow 2l2\nu$ event.

Several processes can simulate the $2l2\nu$ final state:

- Drell-Yan (DY): di-lepton production: high cross section but no real E_t^{miss}
- Top (pairs and single top): lead to b-jet in the final state
- WW: non-resonant background
- WZ: irreducible background when one lepton fails acceptance

3 Reduced Missing Transverse Energy

Missing transverse energy (E_t^{miss}) is computed from the vector sum of the transverse momenta of all the particle flow (PF) candidates. Its resolution is critical for the extraction of the $ZZ \rightarrow 2l2\nu$ signal given that it is the distinctive hallmark with respect to the DY background.
We follow the approach of constructing a reduced E_t^{miss} variable [4]:

1. Decompose E_t^{miss} , jet and lepton p_T vectors along an orthogonal set of axes defined by the Z boson p_T vector ($\vec{q_T}$)
2. For each axis compute:
   $a^{\vec{jet}} = \sum_j \vec{p_T}(jet_j);\quad a^{\vec{MET}} = \vec{MET} + \vec{q_T}$
3. Build the reduced $E_{t,i}^{miss}$ components as:
   $q_{Ti} + min(a_i^{jet}, -a_i^{MET})$
4. Sum the components in quadrature

We tested this approach to be resilient against instrumental uncertainties such as pileup or jet energy scale.

4 Background estimation

4.1 Drell-Yan background

Since DY is not well modeled from Monte Carlo, a data driven estimation can use a process which is topologically similar but which has much higher cross section, as the production of prompt isolated photons in association with jets (i.e. $\gamma + jets$) [4]:

1. Select a high purity photon sample in data.
2. Weight the γ p_T spectrum (Figure 4 left) to the Z p_T spectrum from di-lepton sample
3. Apply the full selection to the weighted photon sample
4. Subtract the EWK γ+E_t^{miss} events using the simulated prediction
5. Use resulting shape from the photon sample as an estimate for DY (Figure 4 right)

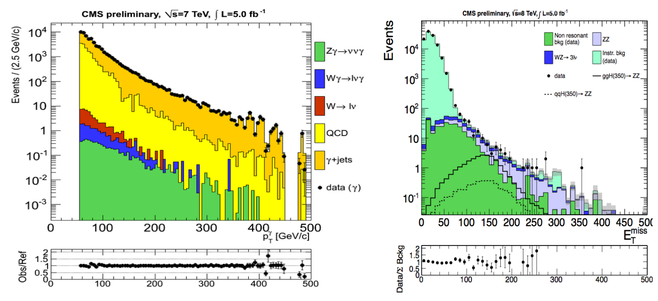

Figure 4: Left: estimated composition of the photon p_T spectrum after re-weigthing to match the Z p_T spectrum. Right: E_t^{miss} distribution in di-lepton events including the DY prediction based on photon events [4].

4.2 Other backgrounds

The WW and top backgrounds are measured from unlike-flavour (eμ) final states exploiting the universal branching ratio of W to leptons.
The WZ background is estimated from simulations after cross-checking that the simulations agree with the data in a control region with three identified leptons.

5 Selection optimization

The final selection is optimized after testing different analysis methods and alternative cuts. The signal yield is eventually estimated from a fit to the reduced E_t^{miss} distribution. For each set of cuts, the cross section is evaluated taking into account all the uncertainties. The cuts are chosen to yield the lowest statistical+systematic uncertainty. The chosen selection is:

1. $|M_{ll} - M_Z| < 7.5$ GeV
2. $q_T > 45$ GeV && Jet-Veto && 3rd Lept.-Veto
3. reduced $E_t^{miss} > 65$ GeV
4. balance $0.4 < q_T/E_t^{miss} < 1.8$

6 Limits on Anomalous Triple Gauge Couplings

After measuring the ZZ production cross section in the $2l2\nu$ final state we search for deviations in the kinematics due to the presence of aTGCs. The q_T distribution is particularly suited for this purpose as you can see in Figure 5.

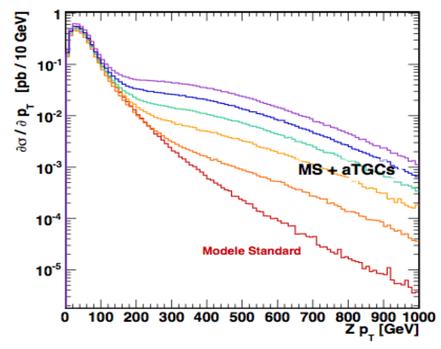

Figure 5: Di-lepton transverse momentum spectrum for different aTGCs values

To evaluate the kinematics induced by aTGCs we have produced a grid of possible f_i^γ and f_i^Z parameters in the [-0.02,0.02] range. Limits for each parameter are computed after a shape analysis of the Z p_T distribution using the CL_S method [5].

7 Next steps

1. We are currently finalizing the $2l2\nu$ analysis (paper to be submitted this year)
2. We plan to measure the fully-corrected differential cross-section $\frac{d\sigma}{dq_T}$
3. Extend the search for VBF ZZ production to set limits on $WWZZ$ quartic couplings
4. Search for invisible Higgs boson decays in associated ZH production mode
5. In the future high-energy LHC run in 2015, we expect sensitivity to standard model loop contributions to the aTGCs

References:

[1] M. Campbell, Vector boson pair production at the LHC, JHEP 1107 (2011) 018, doi:10.1007/JHEP07(2011)018, arXiv:1105.0020v1.

[2] CMS Collaboration, "Measurement of the ZZ production cross section and search for anomalous couplings in 2l2l final states in pp collisions at $\sqrt{s}$ = 7 TeV", J. High Energy Phys. 01 (2013) 063.

[3] ATLAS, "Measurement of ZZ production in pp collision at $\sqrt{s}$ = 7 TeV and limits on anomalous ZZZ and $ZZ\gamma$ couplings with the ATLAS detector", arXiv:121:6096

[4] CMS Collaboration, "Search for the standard model Higgs boson in the $H \rightarrow ZZ \rightarrow 2l2\nu$ channel in pp collisions at $\sqrt{s}$ = 7 and 8 TeV", HIG-12-023

[5] L. Read, "Modified frequentist analysis of search results (The CL(s) method)", http://inspirehep.net/record/532313