Electroweak boson production and searches for aQGC in CMS

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Abstract

The production of electroweak bosons is an important part the Standard Model and it can also shed a light on new physics, in the form of anomalous gauge couplings. This poster presents the study of exclusive or quasi-exclusive $\gamma\gamma \to W^+W^-$ production. The measurement of the process $pp \to p^{(*)} + W^+W^- + p^{(*)} \to p^{(*)} + e^{\pm}\mu^{\mp} + p^{(*)}$ used an integrated luminosity of $19.7\,\mathrm{fb}^{-1}$ of $8\,\mathrm{TeV}$ proton-proton collisions at the LHC. Events are selected by requiring the presence of an electron-muon pair with large transverse momentum $p_{\mathrm{T}}(\mu^{\pm}e^{\mp}) > 30\,\mathrm{GeV}$, and no associated charged particles detected from the same vertex. With this analysis the CMS Collaboration has set upper limits on the values of anomalous quartic gauge coupling coefficients for both dimension-6 and dimension-8 effective field theory operators, giving the most stringent limits to date.

Introduction

The process $\gamma\gamma \to W^+W^-$ occurs at leading order in the Standard Model (SM) via the diagrams shown in Figure 1. This channel is particularly well suited to search for physics beyond the Standard Model, because of the very low contribution of background events. Any deviation from the SM may be quantifiable via anomalous quartic gauge couplings (aQGCs) of effective field theory operators of dimension-6 [1] or dimension-8 [2].

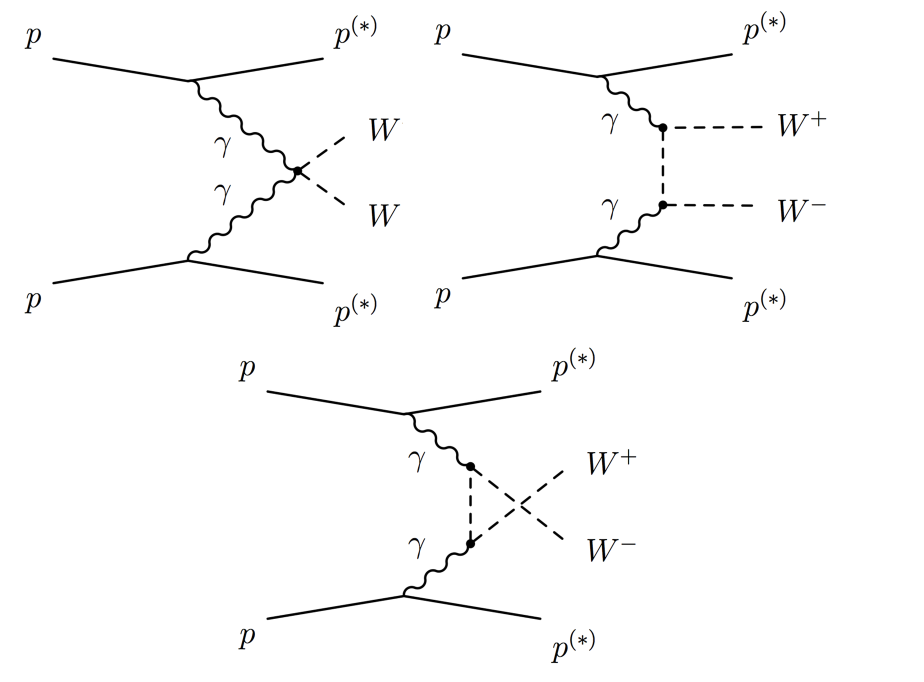

Figure 1: Quartic, t-channel and u-channel diagrams for $\gamma\gamma \to W^+W^-$ in the SM.

Dimension-6 operators can be constructed with couplings $\frac{a_0^W}{\Lambda^2}$ and $\frac{a_C^W}{\Lambda^2}$, where Λ is the scale for new physics. The effective lagrangian terms, originally proposed for LEP are:

$$
\begin{aligned}
\mathcal{L}_6^0 &= -\frac{e^2}{8}\frac{a_0^W}{\Lambda^2}F^{\mu\nu}F_{\mu\nu}W^{+\alpha}W^-_{\alpha} - \frac{e^2}{16c_W^2}\frac{a_0^Z}{\Lambda^2}F^{\mu\nu}F_{\mu\nu}Z^{\alpha}Z_{\alpha} \\
\mathcal{L}_c^6 &= -\frac{e^2}{16}\frac{a_c^W}{\Lambda^2}F^{\mu\alpha}F_{\mu\beta}(W^{+\alpha}W^+_{\beta}) - \frac{e^2}{16c_W^2}\frac{a_c^Z}{\Lambda^2}F^{\mu\alpha}F_{\mu\beta}(Z^{\alpha}Z_{\beta}).
\end{aligned} \tag{1}
$$

Dimension-8 parameters

With the discovery of a light Higgs boson by the CMS and ATLAS Collaborations a linear realization of the $SU(2) \otimes U(1)$ symmetry of the SM – spontaneously broken by the Higgs mechanism – is possible, making dimension-8 the lowest-order operators where new physics may cause deviations in the purely quartic gauge boson couplings. In this formalism there are fourteen operators contributing to γ couplings, which in general will also generate a $WWZ\gamma$ vertex. Adding the constraint that the $WWZ\gamma$ vertex should vanish, a direct relationship between the dimension-8 $f_{M,0,1,2,3}/\Lambda^4$ and the dimension-6 $\frac{a_{0,C}^W}{\Lambda^2}$ couplings can be recovered:

$$
\begin{aligned}
\frac{a_0^W}{\Lambda^2} &= -\frac{4M_W^2}{e^2}\frac{f_{M,0}}{\Lambda^4} = -\frac{8M_W^2}{e^2}\frac{f_{M,2}}{\Lambda^4}, \\
\frac{a_C^W}{\Lambda^2} &= \frac{4M_W^2}{e^2}\frac{f_{M,1}}{\Lambda^4} = \frac{8M_W^2}{e^2}\frac{f_{M,3}}{\Lambda^4}.
\end{aligned} \tag{2}
$$

Considering the $\gamma\gamma \to W^+W^-$ diagram with the inclusion of anomalous quartic gauge couplings, the cross section has a square dependence on the anomalous coupling strength. One alternative to regulate the rising of the cross section at high energies is to multiply both a_0^W and a_C^W parameters by a dipole form factor, where $W_{\gamma\gamma}$ is the energy exchange in the diphoton vertex.

$$
a_{0,C}^W(W_{\gamma\gamma}^2) = \frac{a_{0,C}^W}{\left(1 + \frac{W_{\gamma\gamma}^2}{\Lambda_{\mathrm{cutoff}}^2}\right)^2}. \tag{3}
$$

The results in this analysis are studied with a cutoff energy scale $\Lambda_{\mathrm{cutoff}} = 500\,\mathrm{GeV}$ and with no cutoff (violating unitarity).

Event Selection for Exclusive $\gamma\gamma \to WW$

The preselection of events requires an opposite sign muon-electron pair from a common primary vertex, where each lepton with $p_{\mathrm{T}}(l) > 20\,\mathrm{GeV}$ and $|\eta| < 2.4$, and less than 16 additional tracks at vertex. In order to get rid of the main backgrounds of Inclusive dibosons, Drell-Yan $\tau^+\tau^-$ production and $\gamma\gamma \to \tau^+\tau^-$ additional requirements on the invariant mass of the lepton pair $m(\mu^{\pm}e^{\mp}) > 20\,\mathrm{GeV}$, specific cuts for muon and electron identification, zero extra-tracks at the vertex and the transverse momentum of the lepton pair $p_{\mathrm{T}}(\mu^{\pm}e^{\mp}) > 30\,\mathrm{GeV}$. The effects of this selection on the signal and background expected number of events from simulation is shown in Table 1.

Selection step	Data	Exclusive $\gamma\gamma \to W^+W^-$	Total background	Inclusive diboson	Drell-Yan	$\gamma\gamma \to \tau^+\tau^-$	Other backgrounds
Trigger and Preselection	19406	26.9±0.2	22180±1890	1546±15	7093±75	18.1±0.8	13520±1890
$m(\mu^{\pm}e^{\mp}) > 20\,\mathrm{GeV}$	18466	26.6±0.2	21590±1850	1507±15	7065±75	18.1±0.8	13000±1850
Muon and electron identification	6541	22.5±0.2	6640±93	1306±11	4219±58	12.6±0.7	1102±72
$\mu^{\pm}e^{\mp}$ vertex with no add. tracks	24	6.7±0.2	15.2±2.5	3.7±0.7	6.5±2.3	4.3±0.5	0.7±0.1
$p_{\mathrm{T}}(\mu^{\pm}e^{\mp}) > 30\,\mathrm{GeV}$	13	5.3±0.1	3.9±0.5	2.3±0.4	0.1±0.1	0.9±0.2	0.6±0.1

Table 1: Number of events passing each selection step, for simulation the expected number of signal and background are normalized to an integrated luminosity of $19.7\mathrm{fb}^{-1}$. Uncertainties are statistical only.

Results

The resulting distributions for data and Monte Carlo after selection cuts for the number of extra tracks in events with $p_{\mathrm{T}}(\mu^{\pm}e^{\mp}) > 30\,\mathrm{GeV}$ (right) and for muon-electron transverse momentum in events with zero associated tracks (left) are shown in Figure . Two representative values for anomalous couplings are shown stacked on top of the backgrounds. The first bin in the extra-tracks distribution shows the 13 selected events in data, compatible with SM prediction, which gives a measured cross section of $\sigma(pp \to p^{(*)}W^+W^-p^{(*)} \to p^{(*)}\mu^{\pm}e^{\mp}p^{(*)}) = 10.8^{+5.1}_{-4.1}\mathrm{fb}^{-1}$, resulting in a 3.4σ significance of the SM signal.

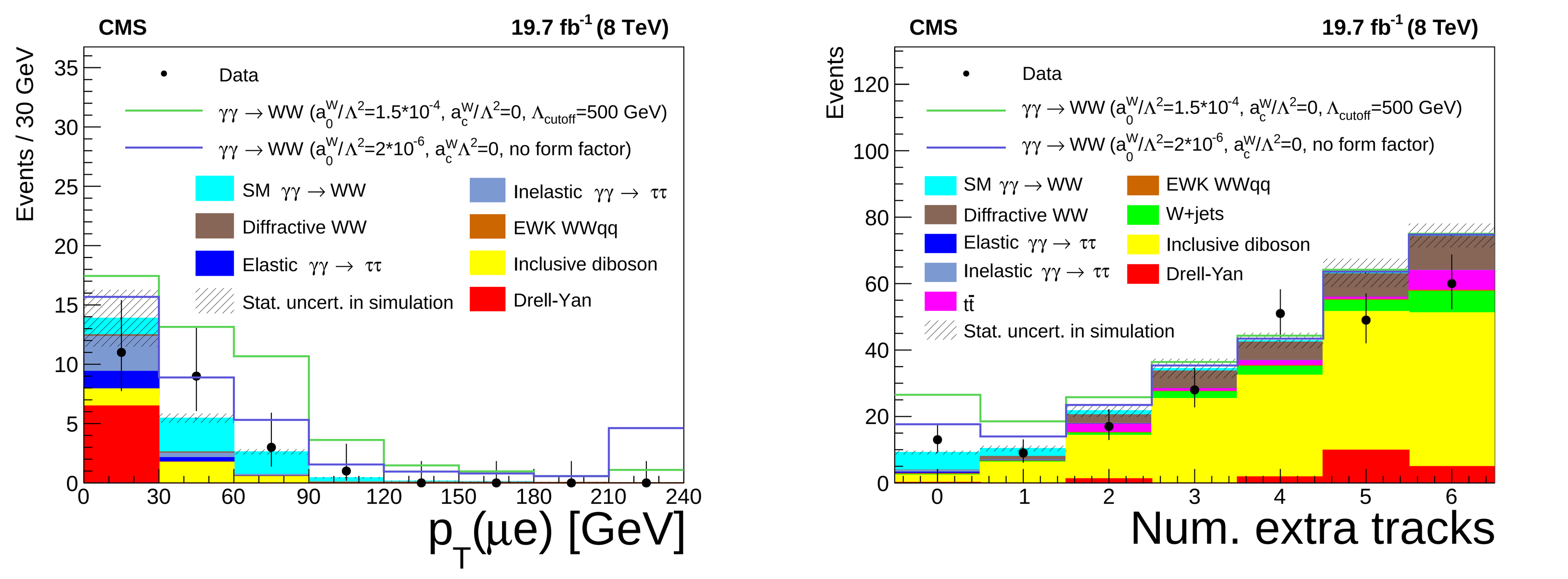

Figure 2: Distributions of the lepton pair p_{T} and extra-tracks multiplicity for events after selection.

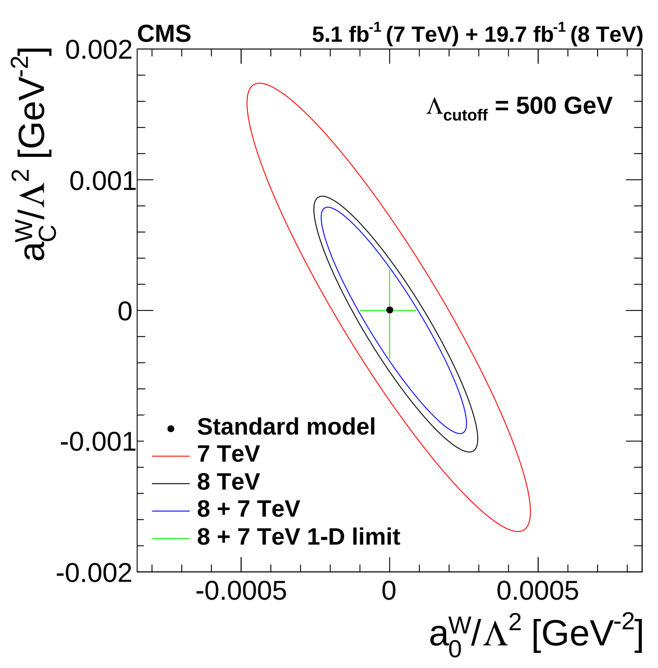

Figure 3: Limits in aQGCs.

The shape of the lepton pair p_{T} distribution above $30\,\mathrm{GeV}$ is used to compute the upper limit on the anomalous cross section [3]. The resulting two dimensional 95% confidence region in the dimension-6 aQGC parameter space is shown in Figure 3 and compared to the 7 TeV result from CMS [4]. The combination of the two measurements is also shown, and the final combined limits computed are:

$$
\begin{aligned}
-0.9 < \ & a_0^W/\Lambda^2 < 0.9\,(\times 10^{-4}\mathrm{GeV}^{-2}) \text{ for } \Lambda_{\mathrm{cutoff}} = 500\,\mathrm{GeV} \\
-3.6 < \ & a_C^W/\Lambda^2 < 3.0\,(\times 10^{-4}\mathrm{GeV}^{-2}) \text{ for } \Lambda_{\mathrm{cutoff}} = 500\,\mathrm{GeV} \\
-1.1 < \ & a_0^W/\Lambda^2 < 1.1\,(\times 10^{-6}\mathrm{GeV}^{-2}) \text{ No form factor} \\
-4.1 < \ & a_C^W/\Lambda^2 < 4.1\,(\times 10^{-6}\mathrm{GeV}^{-2}) \text{ No form factor}
\end{aligned} \tag{4}
$$

Which results in dimension-8 parameter limits:

$$
\begin{aligned}
-3.4 < \ & f_{M,0}/\Lambda^4 < 3.4\,(\times 10^{-10}\mathrm{GeV}^{-4}) \text{ for } \Lambda_{\mathrm{cutoff}} = 500\,\mathrm{GeV} \\
-14 < \ & f_{M,1}/\Lambda^4 < 12\,(\times 10^{-10}\mathrm{GeV}^{-4}) \text{ for } \Lambda_{\mathrm{cutoff}} = 500\,\mathrm{GeV} \\
-4.2 < \ & f_{M,0}/\Lambda^4 < 4.2\,(\times 10^{-12}\mathrm{GeV}^{-4}) \text{ No form factor} \\
-16 < \ & f_{M,1}/\Lambda^4 < 16\,(\times 10^{-12}\mathrm{GeV}^{-4}) \text{ No form factor}
\end{aligned} \tag{5}
$$

Comparisons

Figure 4 shows on the left the expected and measured cross sections for various EW boson production modes. Highlighted in yellow is the exclusive $\gamma\gamma \to W^+W^-$ process which is one of the lowest measured cross-sections at the LHC [5]. The other low-cross section EW production modes also contribute to the searches of anomalous gauge couplings. The plot on the right shows the comparison of the obtained limits for the coefficients of dimension-8 operators of aQGCs in different analyses performed by CMS and ATLAS [6].

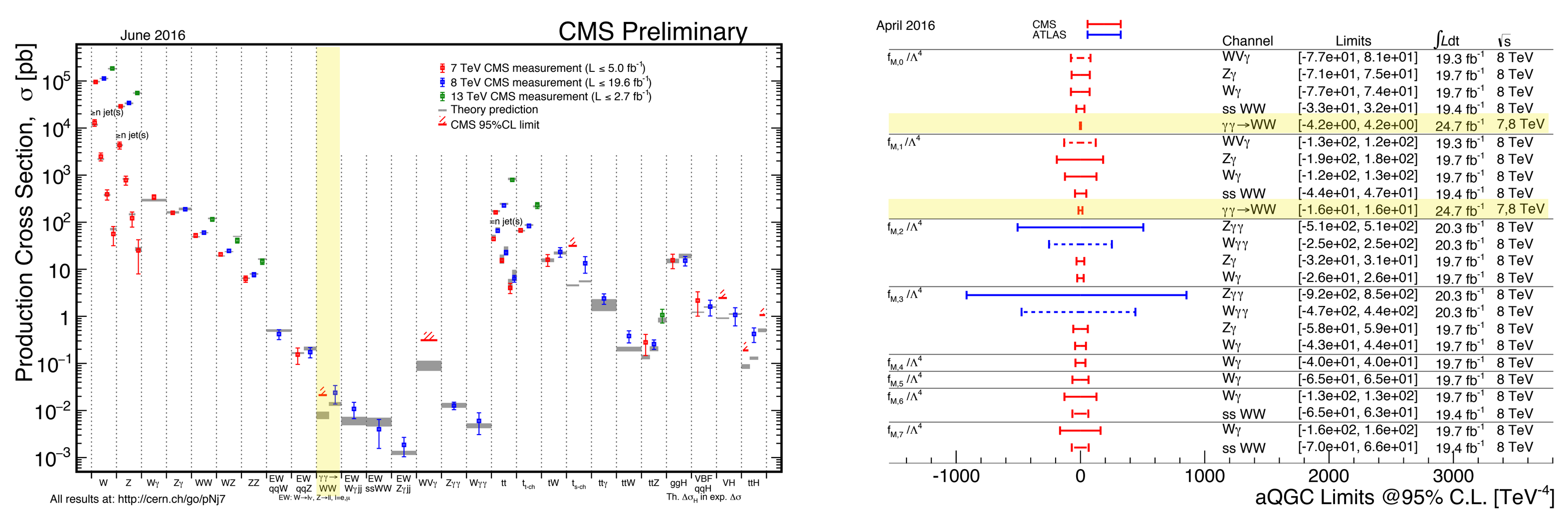

Figure 4: Cross-sections and limits on aQGC parameters for various LHC measurements.

Conclusions

The observed yields and kinematic distributions are consistent with the SM prediction, with a combined significance of 3.4σ. No significant deviations from the SM are observed, and the combined $7 + 8\mathrm{TeV}$ limits are interpreted as improved constraints on dimension-6 and dimension-8 aQGC parameters. These are the most stringent limits for aQGCs in comparison with other LHC analyses.

References

[1] G. Belanger and F. Boudjema. Phys. Lett., B288:pp. 201, 1992. URL http://dx.doi.org/10.1016/0370-2693(92)91978-I.

[2] G. Belanger, et al. Eur. Phys. J., C13:pp. 283, 2000. hep-ph/9908254, URL http://dx.doi.org/10.1007/s100520000305.

[3] CMS Collaboration (CMS). (CMS-PAS-FSQ-13-008), 2016. 1604.04464, URL http://cds.cern.ch/record/2025577.

[4] CMS Collaboration (CMS). JHEP, 01:p. 052, 2012. 1111.5536, URL http://dx.doi.org/10.1007/JHEP01(2012)052.

[5] CMS Collaboration. URL https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsCombine.

[6] CMS Collaboration. URL https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMPaTGC.