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Exclusive $\gamma\gamma \to WW$ and Anomalous Quartic Gauge Couplings at CMS

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Recent CMS results sensitive to quartic couplings of gauge bosons are discussed. The signatures investigated are exclusive and quasi-exclusive $\gamma\gamma \to WW$ scattering, and tri-boson production in the $WW\gamma$ and $WZ\gamma$ channels. In the $\gamma\gamma \to WW$ analysis two candidate events pass the selection criteria, consistent with the Standard Model expectation. No deviations from the Standard Model are observed in the high p_T tails of either measurement, and the resulting limits on anomalous quartic gauge couplings are the most stringent to date.

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1. Introduction

The existence of quartic couplings of the gauge bosons, $WW\gamma\gamma$, $WWZZ$, $WWWW$, and $WWZ\gamma$, in conjunction with triple gauge couplings, is a fundamental prediction of the electroweak sector of the Standard Model (SM). While deviations from the SM triple gauge couplings have been extensively searched for at the Large Hadron Collider (LHC) and earlier experiments, the quartic couplings are less constrained experimentally. The high energies and large integrated luminosity available at the LHC greatly improve the sensitivity to beyond SM effects in these interactions, typically parameterized in terms of anomalous quartic gauge couplings (AQGC's).

At the LHC, AQGC's can be investigated through two complimentary approaches: gauge boson scattering, such as $\gamma\gamma \to WW$, and production of tri-boson final states, such as $WW\gamma$ and $WZ\gamma$. First results from both approaches have been obtained at the Compact Muon Solenoid (CMS) experiment in pp collisions at $\sqrt{s} = 7$ TeV and $\sqrt{s} = 8$ TeV.

2. $\gamma\gamma \to WW$ analysis

Exclusive or quasi-exclusive production is characterized by the detection of two W bosons, with no additional activity from the underlying event. This signature may arise when both incident protons remain intact and scatter undetected along the beamline, or, in the case of quasi-exclusive production, when one or both protons dissociate into a low-mass system that goes undetected.

The CMS analysis [1] uses 5.05fb^{-1} of data collected at $\sqrt{s}$ =7 TeV, with a mean of 9 interactions ("pileup") per bunch crossing. In order to reduce the sensitivity to pileup, the exclusive selection is based only on charged tracks associated to a dilepton vertex. Only final states in which the WW pair decays to an electron, muon, and neutrinos are considered when searching for a signal. In the case of same-flavor lepton final states, the contribution from Drell-Yan and direct $\gamma\gamma \to \ell^+\ell^-$ production is more than an order of magnitude larger. Therefore the same-flavor $\mu^+\mu^-$ events are instead used as a control sample to study the backgrounds, the contribution of proton dissociation in high-mass $\gamma\gamma$ interactions, and the effect of pileup on the selection.

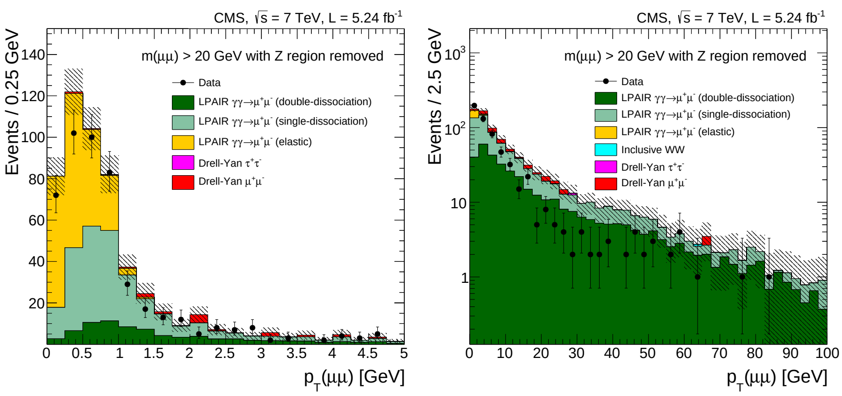

Figure 1: Distribution of $p_T(\mu^+\mu^-)$ for dimuon events with zero extra tracks, for selections enriched in elastic (left) and proton dissociation (right) $\gamma\gamma \to \mu^+\mu^-$ events.

In a kinematic region enhanced in elastic $pp \to p\mu^+\mu^-p$ events, good agreement is observed between data and the prediction from the LPAIR [2, 3] Monte Carlo generator (Fig. 1 left). In a region enhanced in proton dissociation events, a deficit is observed compared to LPAIR, which does not include rescattering corrections. The ratio of the observed $\gamma\gamma \to \mu^+\mu^-$ to the prediction is therefore used to rescale all $\gamma\gamma$ cross sections, including the $\gamma\gamma \to W^+W^-$ signal.

In the μe channel the Standard Model signal region is defined by requiring a μe vertex with zero additional associated tracks, and $p_T(\mu e) > 30$ GeV. The expected background is 0.84 ± 0.15 events, while the expected SM signal is 2.2 ± 0.4 events. In the data two events are observed surviving all selection criteria. The properties of the selected events are consistent with the expectation from the sum of backgrounds and Standard Model $\gamma\gamma \to W^+W^-$ signal (Fig. 2). The results are converted into a cross section times branching fraction of $\sigma(pp \to p^{(*)}W^+W^-p^{(*)} \to p^{(*)}\mu^\pm e^\mp p^{(*)}) = 2.2^{+3.3}_{-2.0}$ fb, with an upper limit of 10.6 fb at 95% confidence level.

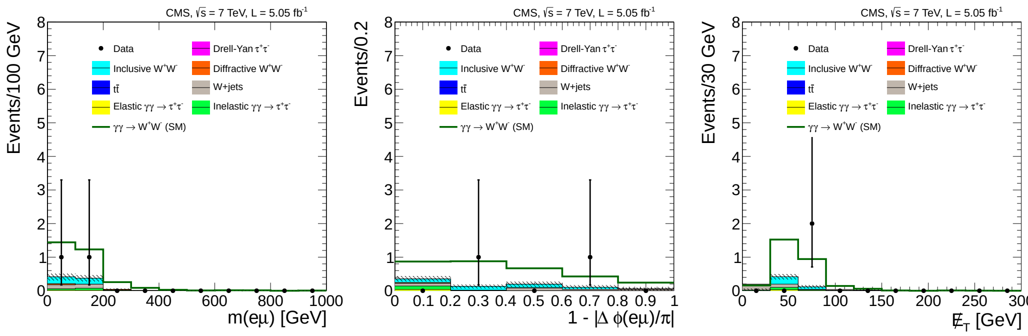

Figure 2: Dilepton invariant mass (left) and acoplanarity (center), and missing transverse energy (right), for μe events with zero associated tracks and $p_T(\mu e) > 30$ GeV. The solid histograms indicate the SM backgrounds, while the open histograms indicate the expected SM signal, stacked on top of the backgrounds.

The p_T of the μe pair is used as the observable to search for evidence of anomalous couplings, by counting events in the region $p_T(\mu e) > 100$ GeV, where the SM background expectation is 0.14 events, dominated by $\gamma\gamma \to W^+W^-$. No events with $p_T(\mu e) > 100$ GeV are observed (Fig. 3), and a model independent upper limit on the partial cross section for $p_T(\mu, e) > 20$ GeV, $|(\eta(\mu, e))| < 2.4$, and $p_T(\mu^\pm e^\mp) > 100$ GeV is set at 1.9 fb at 95% CL.

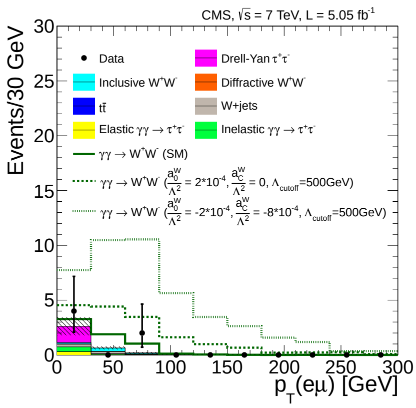

Figure 3: $p_T(\mu e)$ for events with zero extra tracks. The solid histograms indicate the SM backgrounds, while the open histograms indicate the expected $\gamma\gamma \to W^+W^-$ signal for the SM (solid line) and two example AQGC scenarios (dotted and dot-dashed lines).

3. $WV\gamma$ analysis

Tri-boson production in the CMS analysis [4] is probed via $WV\gamma$ events, in which the W decays to a $\mu\nu$ or $e\nu$ final state, and V denotes either a second W or a Z boson decaying to two jets. The analysis uses 19.3fb^{-1} of data collected at $\sqrt{s}$ =8 TeV. The main background after all selections arises from $W\gamma$+jets, which is estimated from data by fitting to the m_{jj} mass distribution outside the W/Z signal region ($70 < m_{jj} < 100$ GeV). Further details of the event selection and backgrounds can be found in Refs. [5, 4].

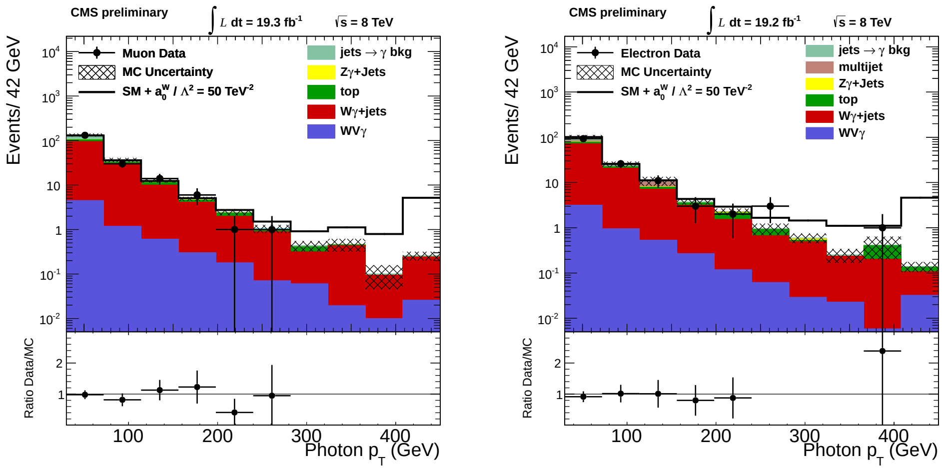

Figure 4: Photon p_T for selected events in the muon (left) and electron (right) channels. The solid histograms indicate the SM signal and backgrounds, while the open histogram shows an example of an AQGC signal.

In the muon channel 183 events pass the final selection criteria, while in the electron channel the number is 139. These values are consistent with the expectations of $193.9 \pm 3.9(\text{stat.}) \pm 10.8(\text{syst.}) \pm 1.0(\text{lumi})$ and $147.6 \pm 4.8(\text{stat.}) \pm 9.6(\text{syst.}) \pm 0.7(\text{lumi})$ in the muon and electron channels, respectively. An upper limit on the combined cross section is set at 241 fb at 95% CL, approximately 3.4 times larger than the SM prediction.

The photon p_T is used as the observable to search for evidence of anomalous couplings (Fig. 4). Fits to binned templates of the $p_T(\gamma)$ distribution are used to compute the limits, with the rightmost bin treated as an overflow. No excess above the SM prediction is observed at high $p_T(\gamma)$.

4. AQGC Results

The results are interpreted in terms of anomalous quartic gauge couplings. In the $\gamma\gamma \to W^+W^-$ analysis the dimension-6 formalism is used [6], while in the $WV\gamma$ analysis limits are given in both the dimension-6 and dimension-8 [7] approaches. The limits from $\gamma\gamma \to W^+W^-$ are obtained both with and without a dipole form factor having $\Lambda_{\text{cutoff}} = 500$ GeV. In the case of the $WV\gamma$ analysis, no form factor is used.

The one- and two-dimensional limits obtained from the $\gamma\gamma \to W^+W^-$ analysis with $\Lambda_{\text{cutoff}} = 500$ GeV are shown in Fig. 5 at left. The resulting limits are approximately 100x more stringent than those obtained at LEP [8, 9, 10, 11, 12, 13], and 20x more stringent than those obtained from $\gamma\gamma \to W^+W^-$ searches at the Tevatron [14] with $\Lambda_{\text{cutoff}} = 500$ GeV.

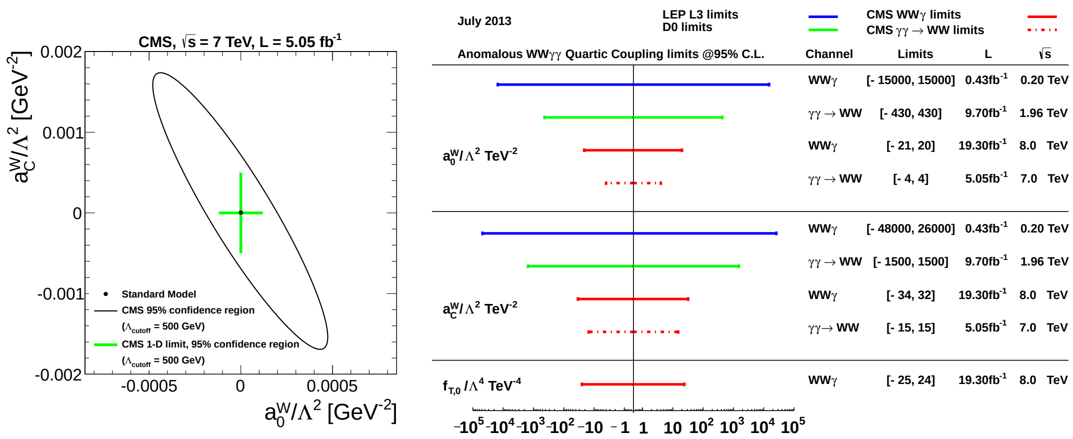

Figure 5: Left: two-dimensional limits on dimension-6 anomalous $WW\gamma\gamma$ quartic couplings from the CMS $\gamma\gamma \to W^+W^-$ analysis, with a form factor of $\Lambda_{\text{cutoff}} = 500$ GeV. Right: Compilation of one-dimensional limits on dimension-6 and dimension-8 anomalous $WW\gamma\gamma$ quartic couplings, with no form factors.

The limits obtained by CMS in the $WV\gamma$ and $\gamma\gamma \to W^+W^-$ analyses with no form factors are shown in Fig. 5 at right, compared to the limits from previous measurements at LEP and the Tevatron. With no form factors, the limits on the dimension-6 anomalous $WW\gamma\gamma$ couplings are up to two orders of magnitude more stringent than previous constraints obtained at the Tevatron with no form factors.

The $WV\gamma$ analysis further derives the first experimental constraints on the CP-conserving anomalous $WWZ\gamma$ coupling parameters κ_0^W/Λ^2 and κ_C^W/Λ^2, finding at 95% CL:

$$-12 < \kappa_0^W/\Lambda^2 < 10\text{TeV}^{-2},$$

$$-18 < \kappa_C^W/\Lambda^2 < 17\text{TeV}^{-2}.$$

5. Summary

The investigation of quartic gauge boson couplings at the LHC has begun, with the first results obtained by CMS in proton-proton collisions at center of mass energies of 7 and 8 TeV. In a search for $\gamma\gamma \to W^+W^-$ production two candidate events are selected, compared to a Standard Model expectation of 0.84 ± 0.15 background with 2.2 ± 0.4 signal. In a search for tri-boson production $WV\gamma$, an upper limit on the cross section is set at 3.4 times the Standard Model prediction. No excess is observed in the high $p_T(\mu e)$ or $p_T(\gamma)$ tails of either analysis, and limits are set on anomalous quartic gauge couplings. The limits on the anomalous $WW\gamma\gamma$ couplings are up to 100 times more restrictive than those obtained at LEP or the Tevatron, while the first limits are set on CP-conserving anomalous $WWZ\gamma$ couplings.

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