Measurement of the cross section and constraints on anomalous quartic couplings from VBS Zγ with CMS detector

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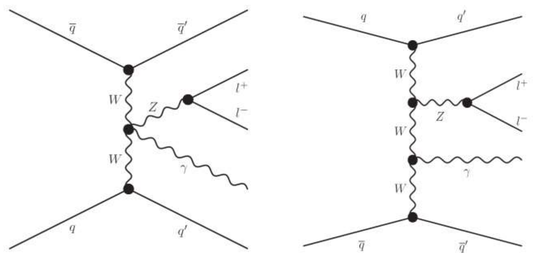
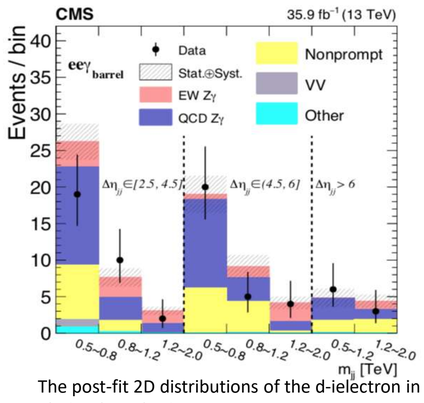
Introduction

- Final states: Z to ee and Z to μμ plus a photon with two jets.
- VBS Signature: large dijet mass and large η separation between the jets.
- For 2016 data sets, main results are:
  - ➢ Signal significance: 4.7 σ observed/5.5 σ *(after combination with 2012 analysis)*
  - ➢ Fiducial cross-section measurement
  - ➢ Limits on anomalous couplings.

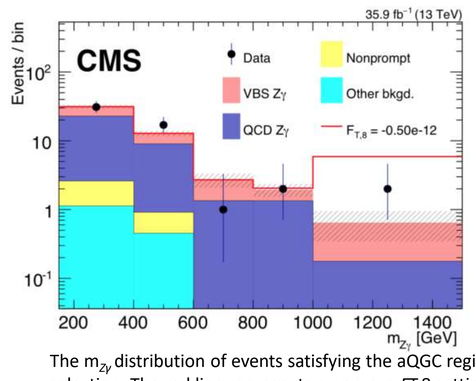


$$\sigma_{EW}^{fid} = 3.2 \pm 0.2(\text{lumi}) \pm 1.1(\text{stat}) \pm 0.6(\text{syst})\ \text{fb} = 3.2 \pm 1.2\ \text{fb}$$

$$\sigma_{EW+QCD}^{fid} = 14.3 \pm 0.4(\text{lumi}) \pm 1.1(\text{stat}) \pm 2.7(\text{syst})\ \text{fb} = 14.3 \pm 3.0\ \text{fb}$$



The post-fit 2D distributions of the d-ielectron in photon barrel category



The $m_{Z\gamma}$ distribution of events satisfying the aQGC region selection. The red line represents a nonzero *FT*,8 setting, which would significantly enhance the yields at high $m_{Z\gamma}$

Sample

- The measurement is based on data collected at the CMS experiment at $\sqrt{s}$ = 13 TeV
- Integrated luminosity: 35.9 fb^{-1}
- Signal: Electroweak production of Z and γ.
- Backgroud:
  - ➢ Irreducible background Zγ plus QCD jets estimated from simulation
  - ➢ Non-prompt photon contributions estimated from Data
  - ➢ Di-boson and single top estimated from simulation

Object reconstruction and event selection

Object reconstruction

Working points efficiency:

Loose muon	highly efficient
Tight muon	additional muon-quality cuts

Medium photon	80%
Medium electron	80%
Veto electron	95%

Good Muon selection
- Tight muon
- Relative Particle-Flow isolation <0.15
- pT > 20 GeV, |η| < 2.4

Good Electron selection
- Medium electron
- pT > 25 GeV, |η| < 2.5

Good Photon selection
- Medium photon
- Conversion-safe electron veto
- pT > 20 GeV and $|\eta_{sc}|$ < 1.4442 or 1.566 < $|\eta_{sc}|$< 2.5

Loose Muon selection
- Loose muon
- Relative Particle-Flow isolation <0.25
- pT > 20 GeV, |η| < 2.4

Veto Electron selection
- Veto electron
- pT > 20 GeV, |η| < 2.5, $|\eta_{sc}|$ < 1.4442 or 1.566 < $|\eta_{sc}|$< 2.5 **Third lepton veto**

Jets
- Particle-Flow Jets and AK4CHS
- pT>30 GeV
- |η| < 4.7

Event selection

- Two and only two same-flavor good leptons
- Third lepton veto
- One good photon with pT > 20 GeV
- Two jets with pT > 30 GeV
- 70 GeV < M_{ll} < 110 GeV
- $M_{ll\gamma}$ > 100 GeV

Basic event selection

- 150 GeV < M_{jj} < 400 GeV **Low M_{jj} control region**

- M_{jj} > 500 GeV
- $\Delta\eta(j_1, j_2)$ > 2.5

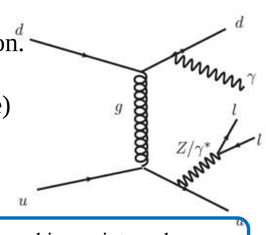
Signal region selection

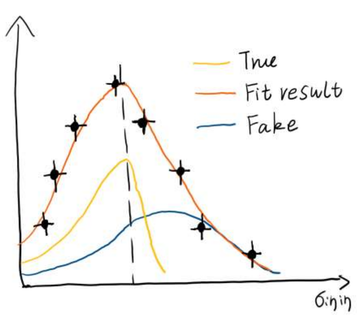
- Zepp = $|\eta_{Z\gamma} - (\eta_{j1} + \eta_{j2})/2|$ < 2.4
- dphi = $|\phi_{Z\gamma} - \phi_{j1,j2}|$ > 1.9

Optimization selection

Background estimation

- Background processes estimated from simulation are normalized to the best theoretical cross section prediction and all of them are reweighted to correct pileup, lepton, photon and trigger efficiencies.
- Irreducible background QCD Zγ normalization is significantly constrained by data in a low M_{jj} control region.
- A data-driven method is used to estimation non-prompt photon contribution.
  - ➢ A fit was performed using the shape of $\sigma_{i\eta i\eta}$ (the shower shape variable) from data, true and fake photon





True photon is from QCD Zγ with medium photon working points and matched to generator-level

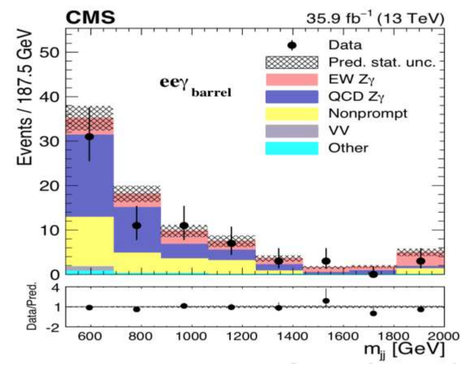
Fake photon is from data by inverting charged isolation between 5 and 10 GeV
Closure test was done to select a best charged isolation sideband

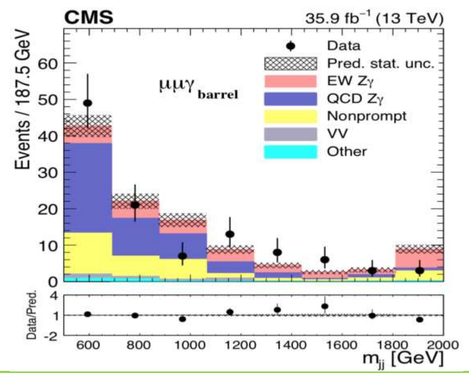
Data is from data with medium working points photon

- ➢ Build non-prompt sample by inverting one of medium cut-based photon variable with corresponding loose cut-based value while keep others invariant.
- ➢ For each event in this non-prompt sample, a photon p_T dependent weight is applied

$$W_{p_T^\gamma} = \frac{h_{data} -> GetBinContent(p_T^\gamma)}{h_{plj} -> GetBinContent(p_T^\gamma)} \times FakeFraction(p_T^\gamma)$$

Data VS MC in signal region (with optimization cuts)

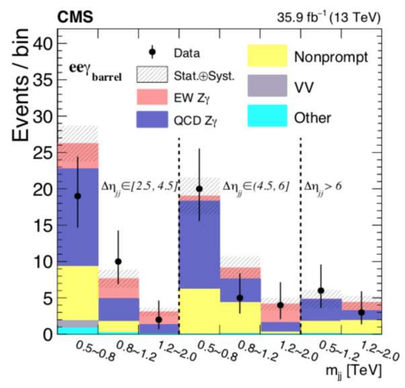


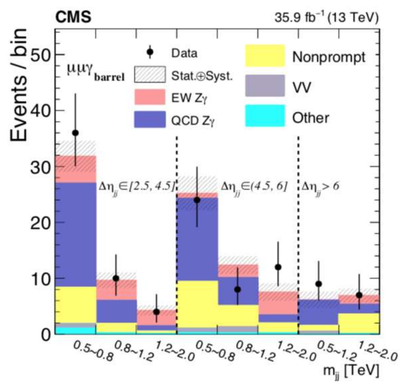


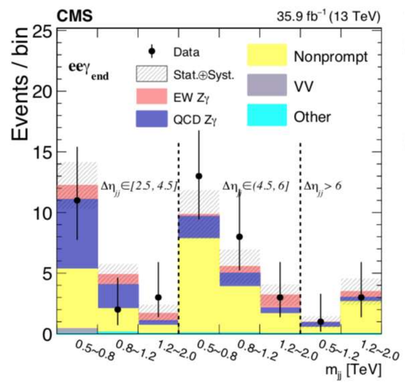
Significance calculation

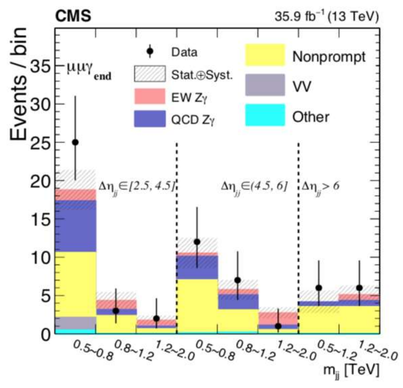
The significance is calculated using a simultaneous fit in the signal region with 2D mjj-Δηjj binning and the control region in 4 categories for muon/electron choice and barrel photon/endcap photon choice.

- The expected significance based on 2016 data is 5.2 σ and the observed significance is 3.9 σ
- After the combination with 8 TeV data, the expected significance is 5.5 σ and the observed significance is 4.7 σ









Fiducial cross section

$$\sigma_{fiducial-region} = \sigma_{generator} \cdot \mu_{signal-strength} \cdot \epsilon_{generator-to-fiducial}$$

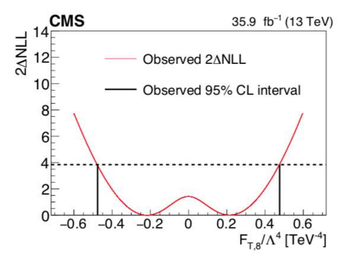
- $\mu_{signal\text{-}strength}$ is the best-fit signal strength which is 0.65 ±0.24 for EWK and 0.91 ± 0.19 for EWK+QCD.
- $\sigma_{generator}$ is the cross section computed by the generator (MadGraph5_aMC@NLO) which is 4.97 ± 0.25 (scale) ± 0.14 (PDF) for EWK and 15.7 ± 1.7 (scale) ± 0.2 (PDF) fb for EWK+QCD within the fiducial region acceptance.
- $\varepsilon_{generated\ to\ fiducial}$ is the efficiency to go from the generator cuts to the fiducial cuts

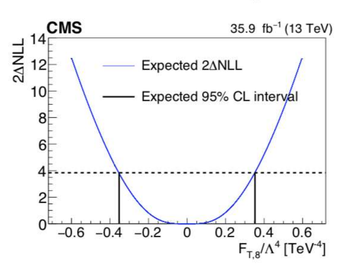
Limits on anomalous quartic gauge couplings

SM lagrangian can be extended with higher dimensional operators maintainng SU(2)×U(1) gauge symmetry:

$$\mathscr{L}_{eff} = \mathscr{L}_{SM} + \sum_{n=5}^{\infty} \frac{f_n}{\Lambda^{n-4}} \mathcal{O}_n$$

- Operator: $LT_{0\text{-}2}$, $LT_{5\text{-}9}$ and $LM_{0\text{-}7}$ were considered.
- For each aQGC value, the ratio of AQGC/SM was computed for every $m_{Z\gamma}$ bin and a fit was performed.
- Considering a test statistics test: $t_{\alpha_{test}} = -2ln\frac{\mathcal{L}(\alpha_{test},\hat{\hat{\theta}})}{\mathcal{L}(\hat{\alpha},\hat{\theta})}$ follows χ^2 distribution.
- Extract the limits directly using the delta log-likelihood function $\Delta NLL = t_{\alpha test}/2$.
- The 95% CL limit on a one dimensional aQGC parameter corresponds a value of 3.84.





Observed Limits [TeV^{-4}]	Expected Limits [TeV^{-4}]	Unitarity Bound
$-19.5 < f_{M0}/\Lambda^4 < 20.3$	$-15.0 < f_{M0}/\Lambda^4 < 15.0$	1.0
$-40.5 < f_{M1}/\Lambda^4 < 39.5$	$-30.0 < f_{M1}/\Lambda^4 < 29.9$	1.2
$-8.22 < f_{M2}/\Lambda^4 < 8.10$	$-6.09 < f_{M2}/\Lambda^4 < 6.06$	1.3
$-17.7 < f_{M3}/\Lambda^4 < 17.9$	$-13.1 < f_{M3}/\Lambda^4 < 13.2$	1.4
$-15.3 < f_{M4}/\Lambda^4 < 15.8$	$-11.7 < f_{M4}/\Lambda^4 < 11.7$	1.4
$-25.1 < f_{M5}/\Lambda^4 < 24.5$	$-19.0 < f_{M5}/\Lambda^4 < 18.1$	1.8
$-38.9 < f_{M6}/\Lambda^4 < 40.6$	$-29.9 < f_{M6}/\Lambda^4 < 30.0$	1.0
$-60.3 < f_{M7}/\Lambda^4 < 62.5$	$-45.9 < f_{M7}/\Lambda^4 < 46.1$	1.3
$-0.74 < f_{T0}/\Lambda^4 < 0.69$	$-0.56 < f_{T0}/\Lambda^4 < 0.51$	1.4
$-0.98 < f_{T1}/\Lambda^4 < 0.96$	$-0.72 < f_{T1}/\Lambda^4 < 0.72$	1.4
$-1.97 < f_{T2}/\Lambda^4 < 1.86$	$-1.47 < f_{T2}/\Lambda^4 < 1.37$	1.4
$-0.70 < f_{T5}/\Lambda^4 < 0.75$	$-0.51 < f_{T5}/\Lambda^4 < 0.57$	1.7
$-1.64 < f_{T6}/\Lambda^4 < 1.68$	$-1.23 < f_{T6}/\Lambda^4 < 1.26$	1.6
$-2.59 < f_{T7}/\Lambda^4 < 2.82$	$-1.91 < f_{T7}/\Lambda^4 < 2.12$	1.7
$-0.47 < f_{T8}/\Lambda^4 < 0.47$	$-0.36 < f_{T8}/\Lambda^4 < 0.36$	1.5
$-1.27 < f_{T9}/\Lambda^4 < 1.27$	$-0.94 < f_{T9}/\Lambda^4 < 0.94$	1.5

95% CL exclusion limits in units of TeV−4 The unitarity bounds is determined using the VBFNLO framework.

Conclusion

Measurements of electroweak Zγjj analysis using 2016 data

- Observed (expected) significance after combination with previous analysis of 2012 data: 4.7 σ (5.5 σ)
- Observed (expected) significance with only 2016 data: 3.9 σ (5.2 σ)
- Limits on anomalous couplings, the results are competitive or more stringent than previous constraints
- Fiducial cross section measurement

Reference: http://cds.cern.ch/record/2682214?ln=en

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