EPS HEP 2013 Stockholm

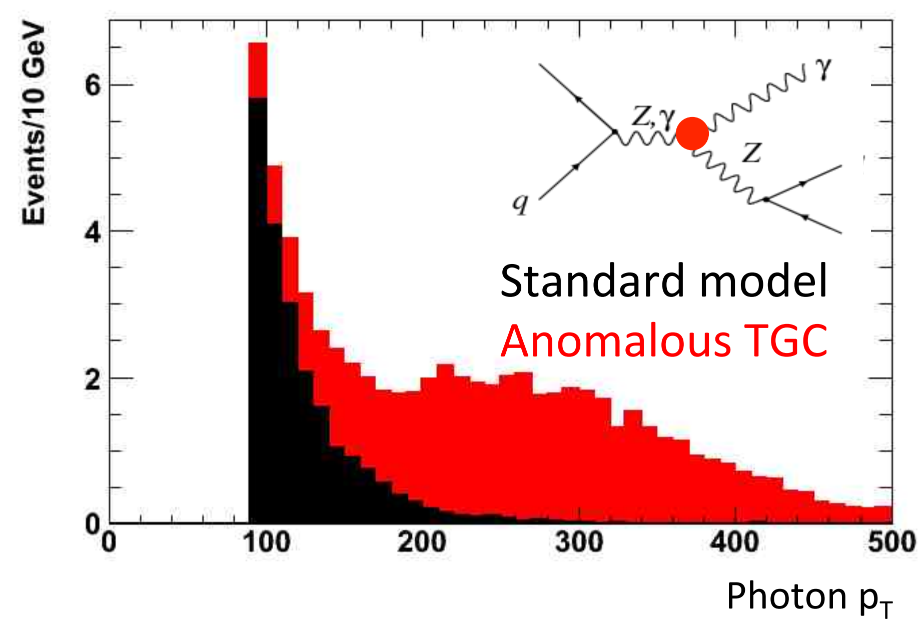
Stockholm, Sweden
July 18, 2013

Vector boson plus photon production at CMS

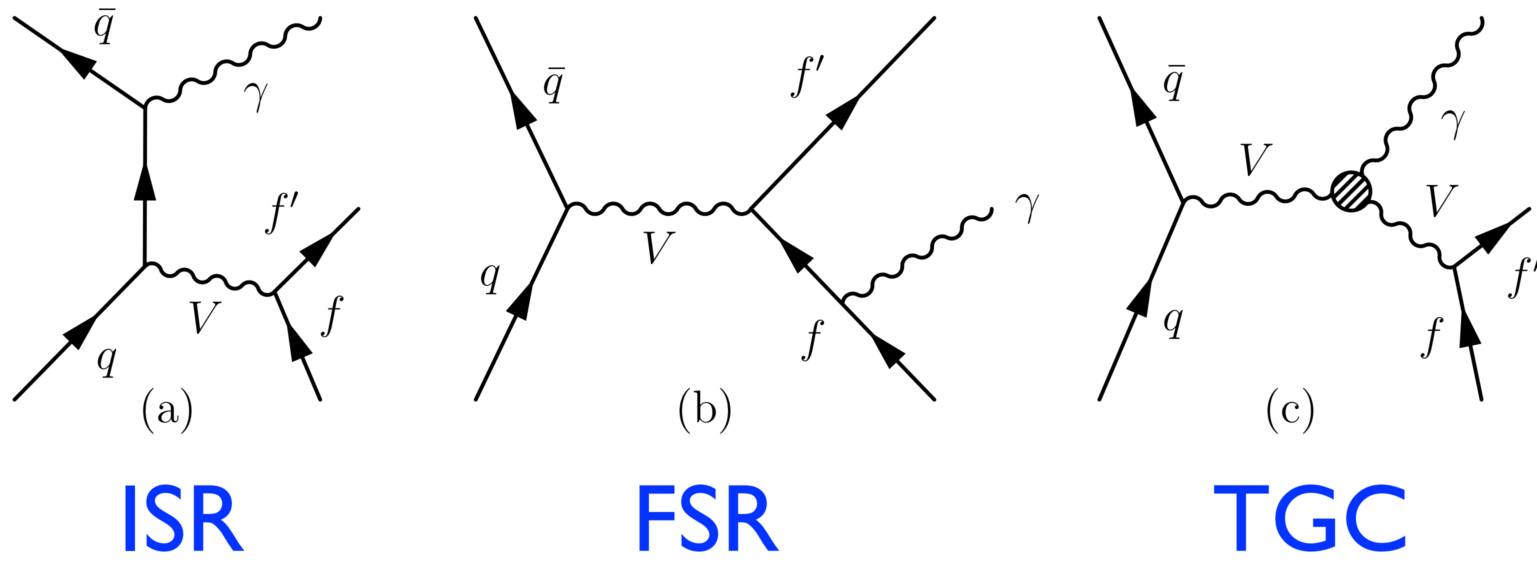
Chia Ming, Kuo
National Central University, Taiwan

Motivation of multiboson physics

- The measurements of diboson ($W\gamma$, $Z\gamma$, WW, WZ, ZZ) and triboson ($WW\gamma$, $WZ\gamma$, WWW and so on) are an important test of the Standard Model (SM)
- Multiboson processes present the primary backgrounds to Higgs and new physics search
- The self-interactions of electroweak gauge bosons are fundamental prediction of SM resulting from non-Abelian nature of SU(2)xU(1) gauge theory
  - values of triple and quartic gauge boson couplings (TGCs, QGCs) are fully fixed in the SM
  - new phenomena can induce changes in TGCs/QGCs so that cross sections and kinematics deviate from SM prediction
    - provides an indirect search for new physics

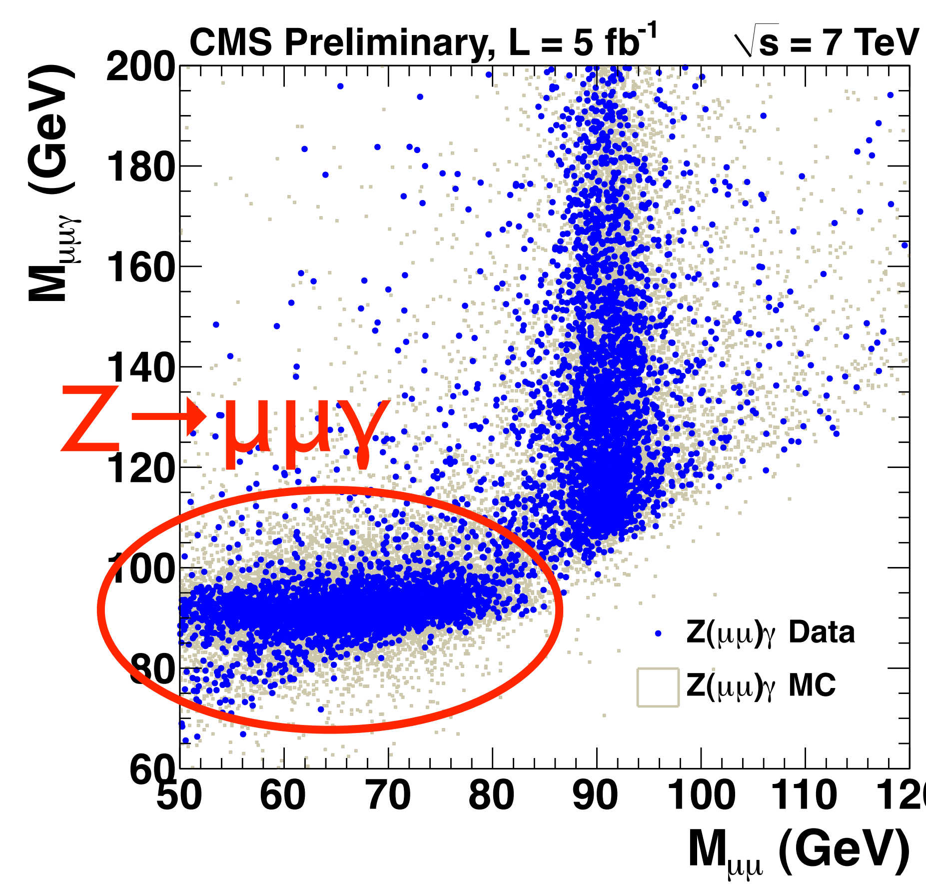


Wγ and Zγ signature



WWγ vertex is allowed in SM
ZZγ, Zγγ vertex are not allowed

- Measurements based on leptonic W and Z boson decays: eνγ, μνγ, eeγ, μμγ, ννγ
  - for ννγ, only ISR diagram exists in SM
  - using 5/fb of 7 TeV data
  - CMS PAS EWK-11-009 and SMP-12-020
- FSR Z→llγ process provides pure photon control sample
  - photon energy scale and resolution from data
  - check photon selection efficiency

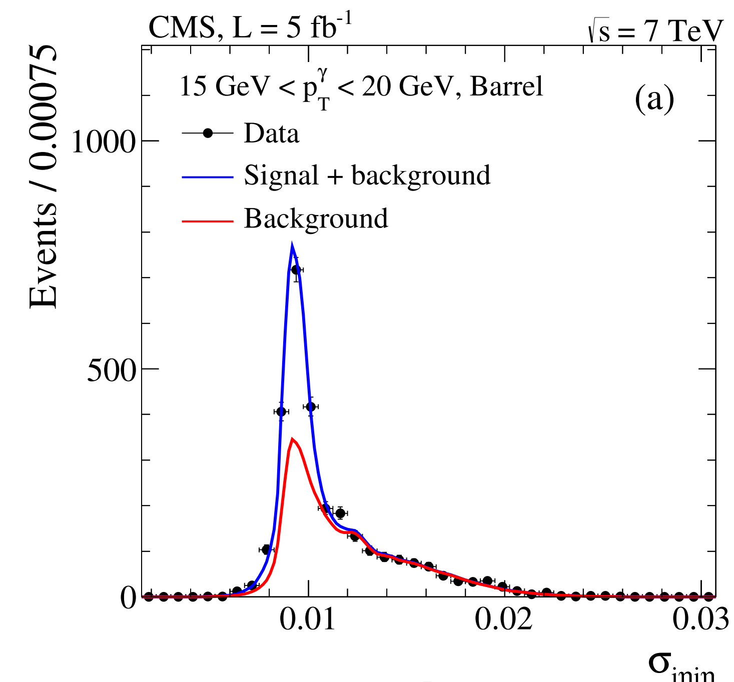


Wγ/Zγ event selection

	Wγ→lνγ (l = e, μ)	Zγ→llγ (l = e, μ)	Zγ→ννγ (γ+MET)
Trigger	Single lepton	Dilepton	Single photon
Lepton Selection	$p_T > 35$ GeV	$p_T > 20$ GeV	
Photon Selection	$P_T > 15$ GeV $\Delta R(l, \gamma) > 0.7$ $\|\eta^{\gamma}\| < 2.5$ excluding ECAL GAP	$P_T > 15$ GeV $\Delta R(l, \gamma) > 0.7$ $\|\eta^{\gamma}\| < 2.5$ excluding ECAL GAP	$P_T > 145$ GeV $\|\eta^{\gamma}\| < 1.4$
Presence of ν	$M_T^W > 70$ GeV		MET > 130 GeV
additional requirements	no second lepton	$M_{ll} > 50$ GeV	- no other significant activity in the event: jets, leptons. etc. - ECAL timing/shape requirement on photons to remove non-collision backgrounds

Backgrounds for Wγ and Zγ→llγ

- Major background arises from events in which jets, originating mostly from W+jets and Z+jets events, are misidentified as photons
  - Use η-width of the photon candidate as a discriminant and then perform two-component fit using the signal and background templates



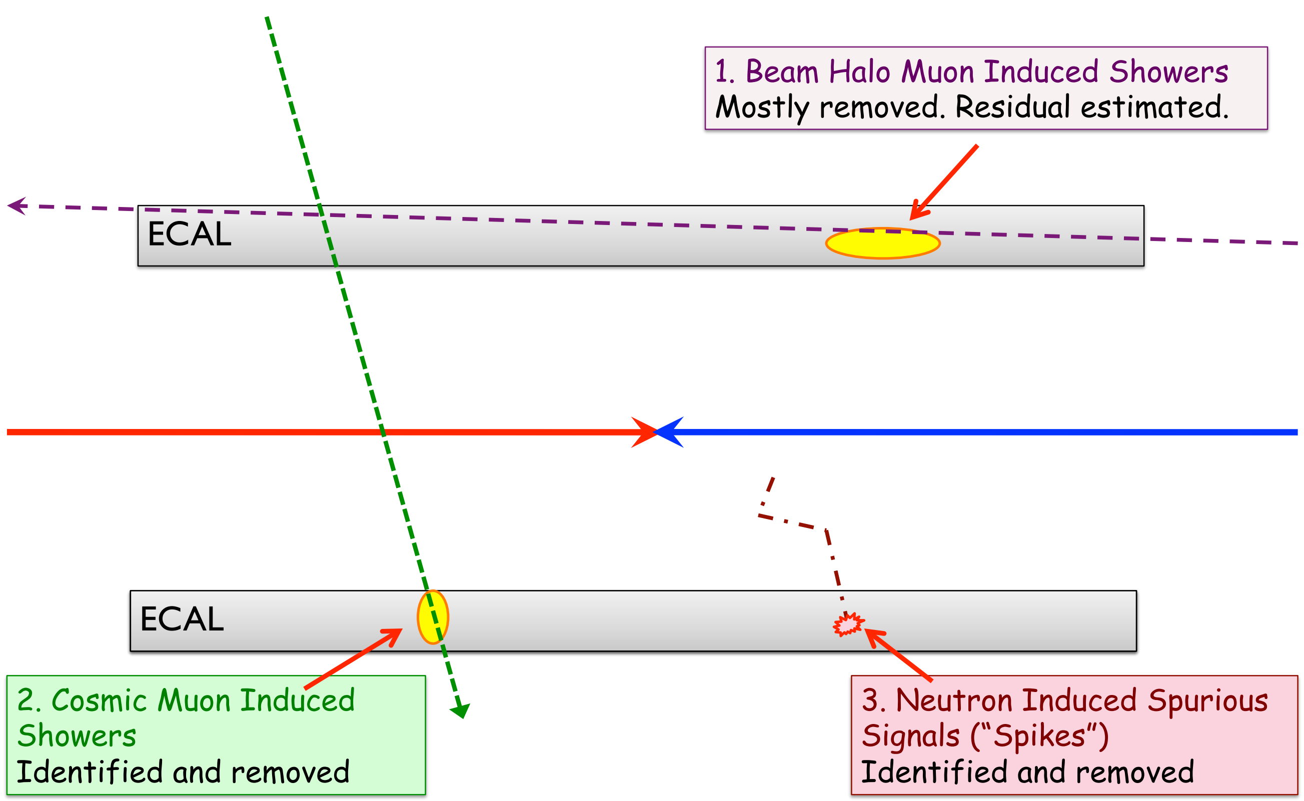
- Second major background to Wγ is the processes where an electron is misidentified as a photon such as Z+jets, WZ, etc.
  - Measured in data using Z→ee process
- Other sources are small and estimated from simulation

Backgrounds for Zγ→ννγ

- jet→γ misidentification estimated from data using "ratio method" : use QCD enriched sample to determined the ratio of isolated fake photon to non-isolated fake photon

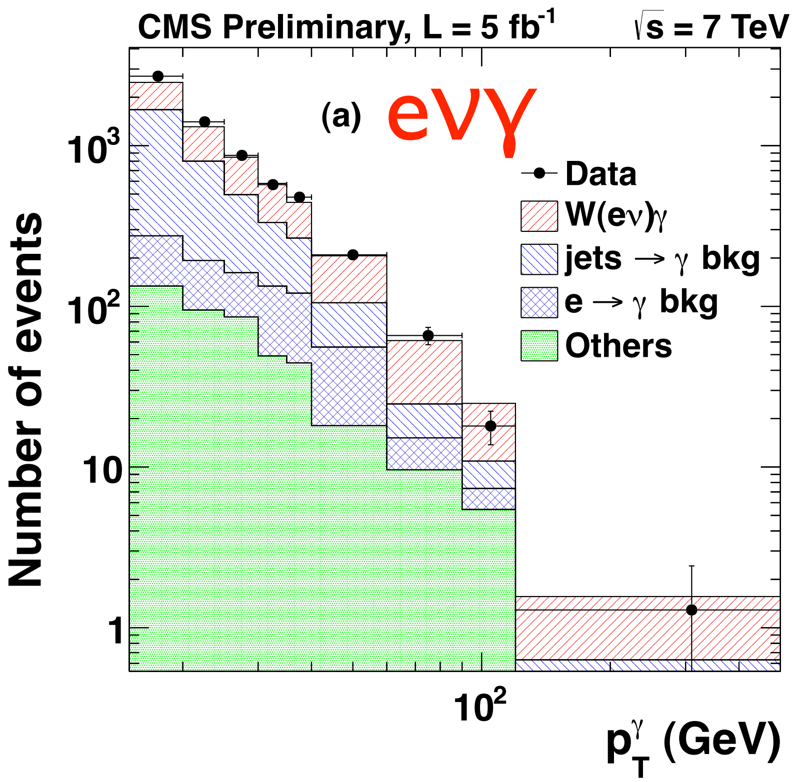
$$N_{V+jets} = \frac{N_{isolated\ \gamma\ in\ QCD}}{N_{non\text{-}isolated\ \gamma\ in\ QCD}} \times N_{V+non\text{-}isolated\ \gamma}$$

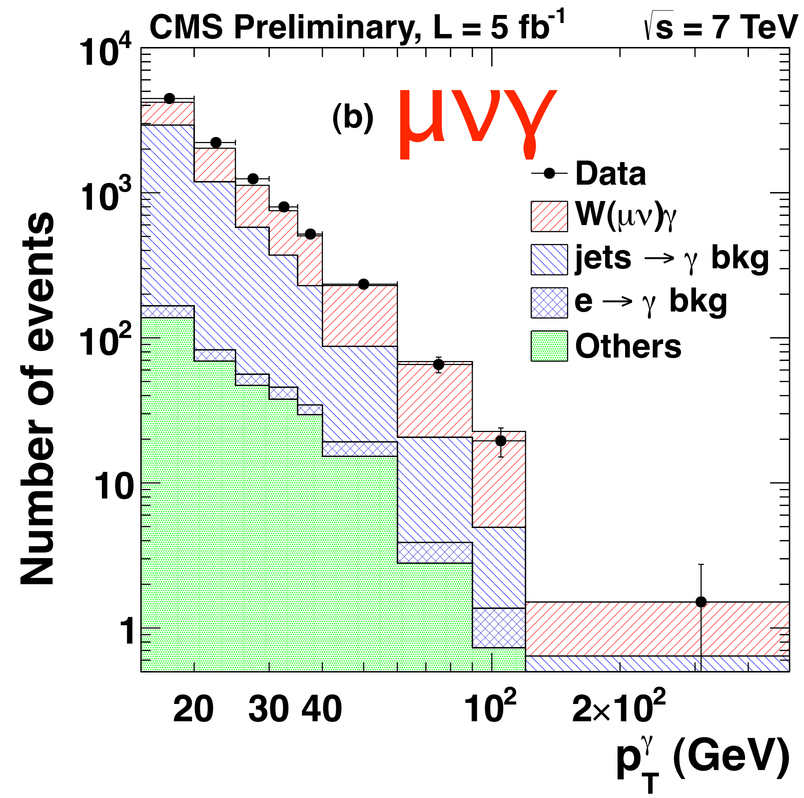
- The residual non-collision background (mainly beam-halo) is estimated from data
- e→γ misidentification estimated from data
- Other sources (Wγ, γγ, γ+jets) are estimated from simulation

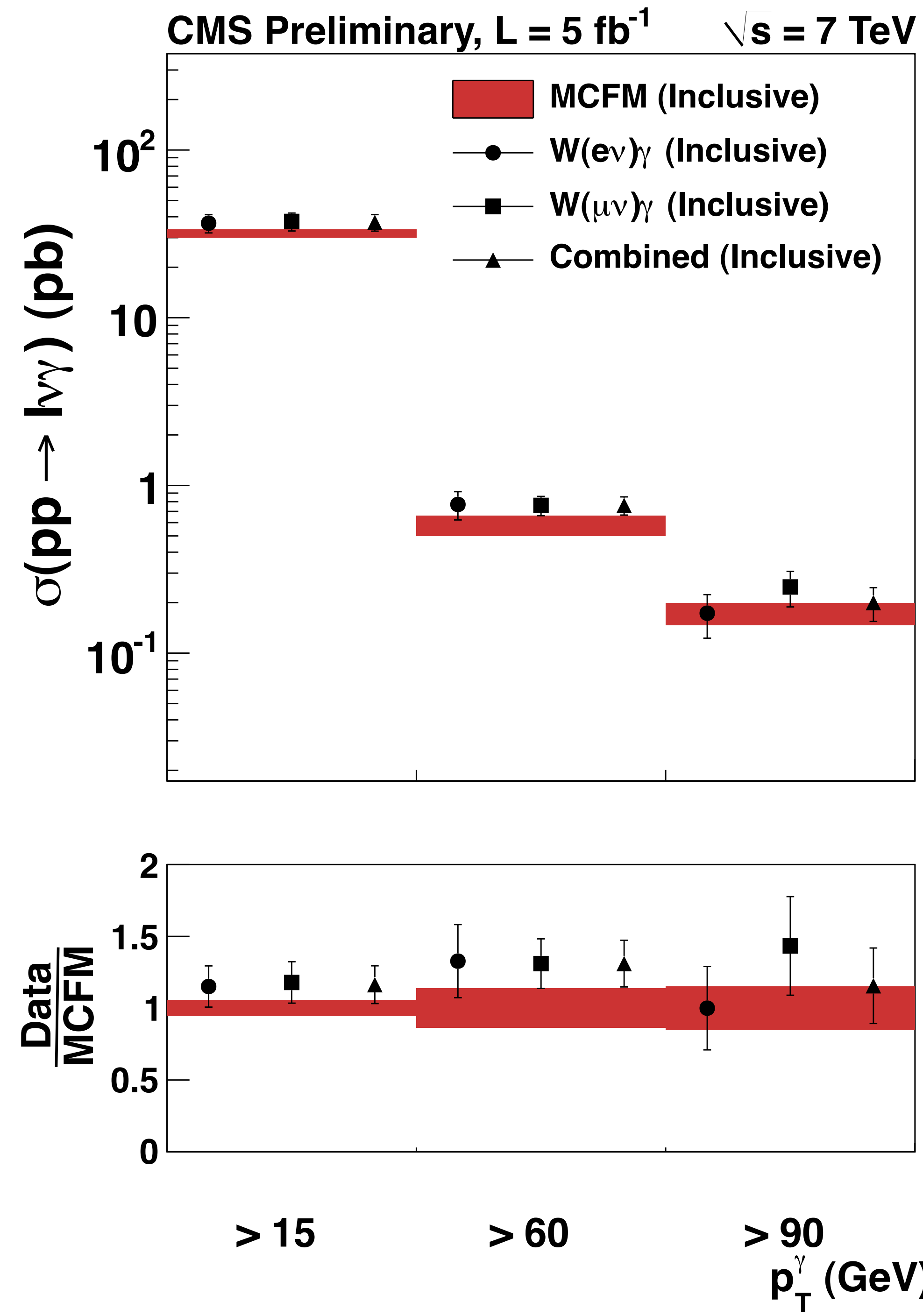


Source	Estimate
Misidentified jets	11.2 ± 2.8
Beam-gas processes	11.1 ± 5.6
Misidentified electrons	3.5 ± 1.5
$W\gamma$	3.3 ± 1.0
$\gamma\gamma$	0.6 ± 0.3
γ+jet	0.5 ± 0.2
Total	30.2 ± 6.5
$Z\gamma \to \nu\nu\gamma$ (NLO)	45.3 ± 6.9
data	73

Wγ results



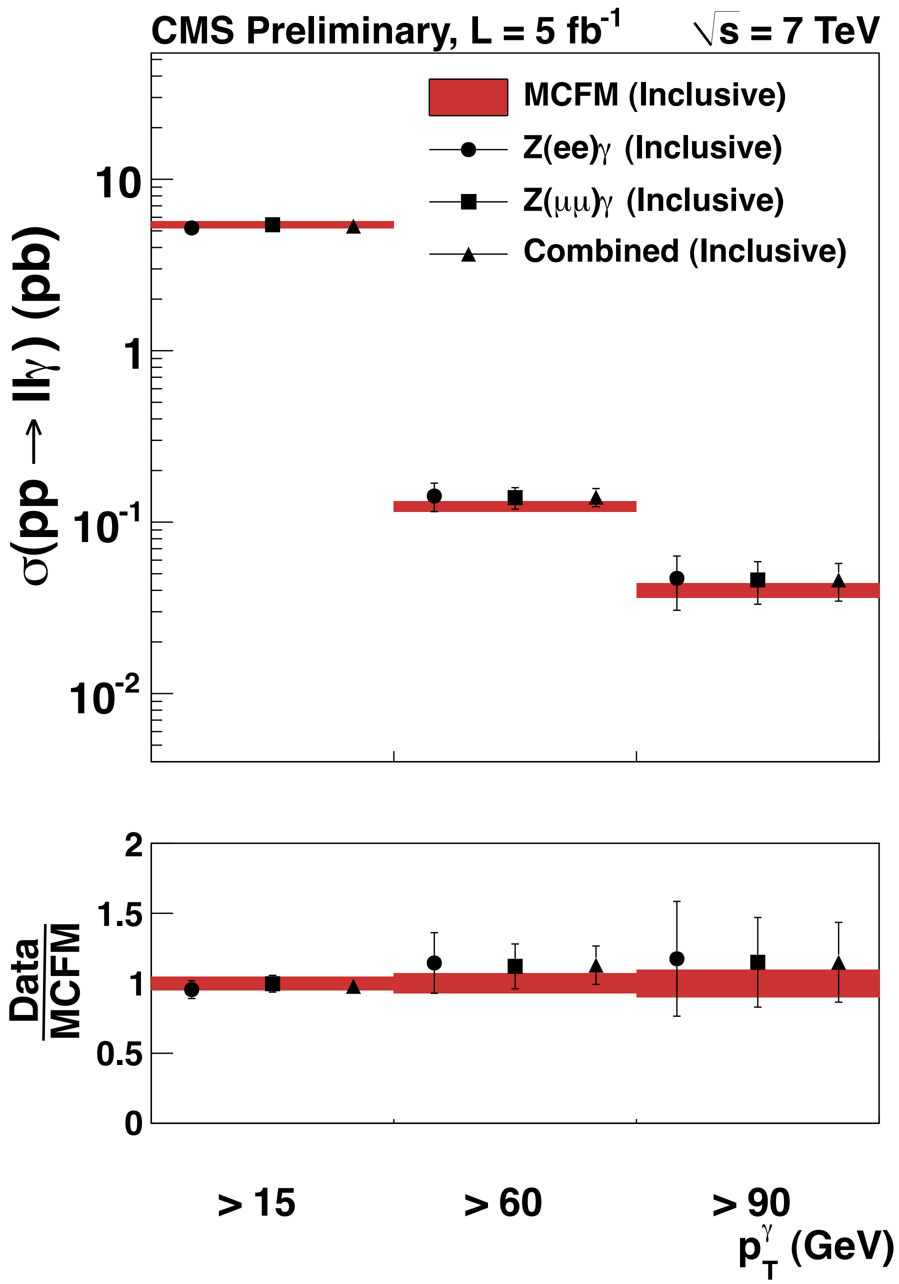


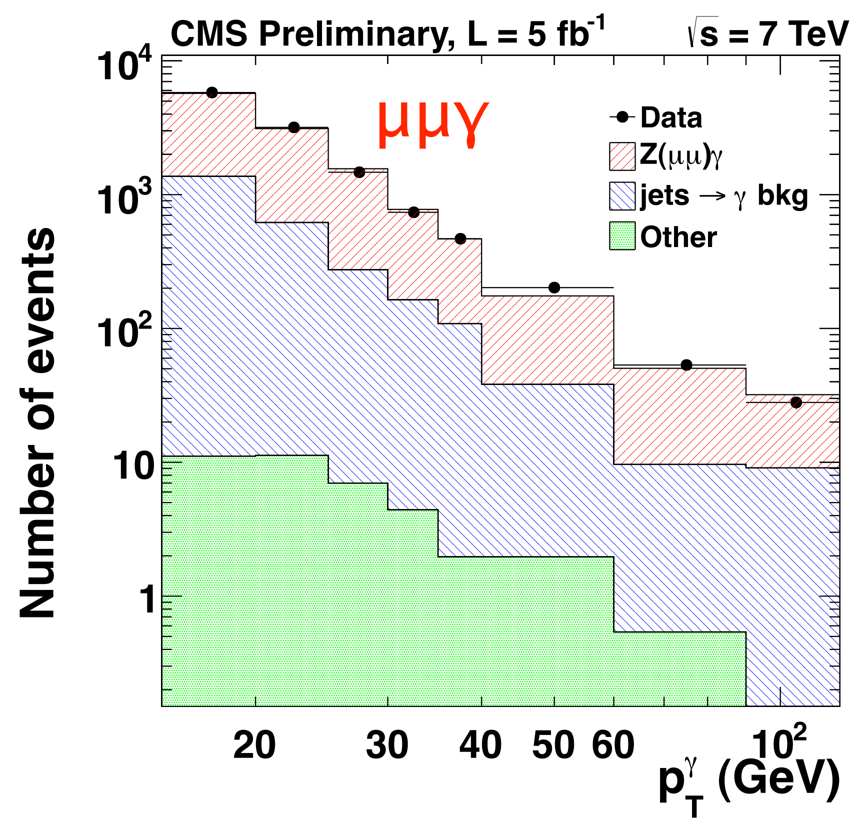


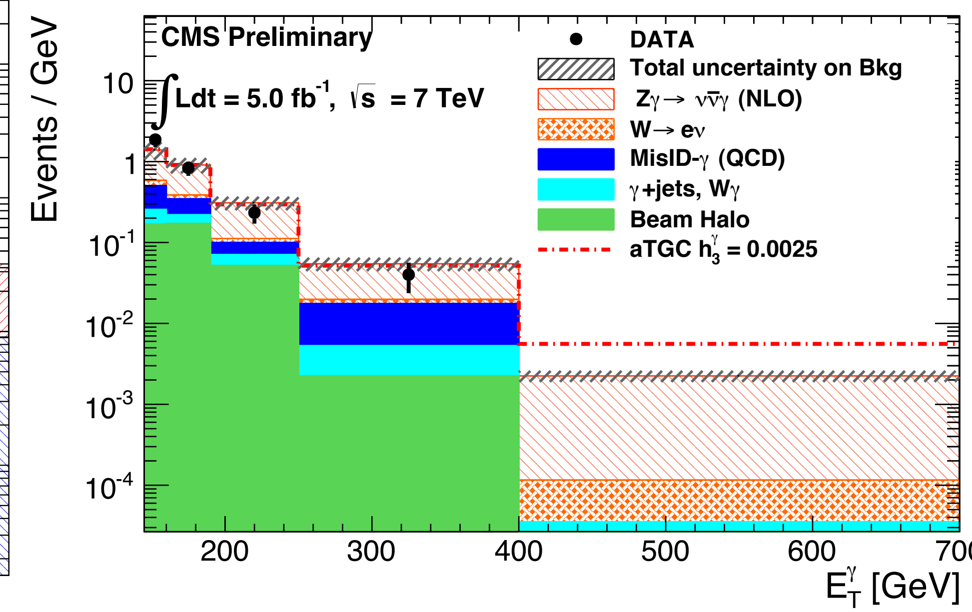
CMS measurement (P_T^γ > 15 GeV)	MCFM prediction
37.0 ± 0.8 (stat) ± 4.0 (syst) ± 0.8 (lumi) pb	31.8 ±1.8 pb

- Measured cross sections are in agreement with SM NLO predictions from MCFM

Zγ results





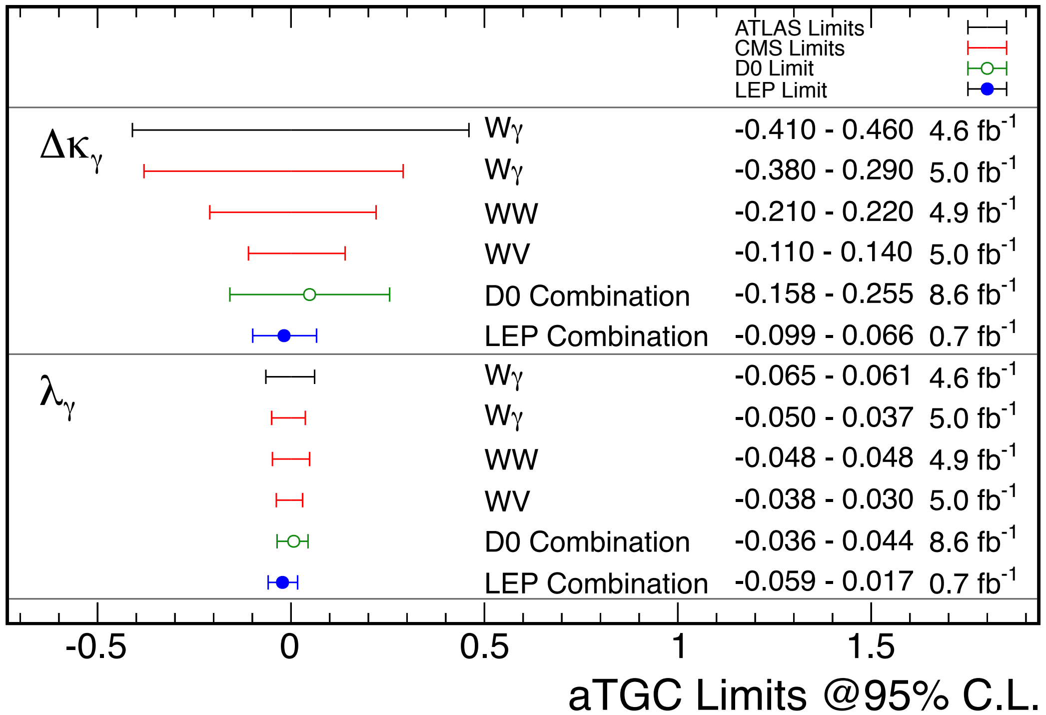


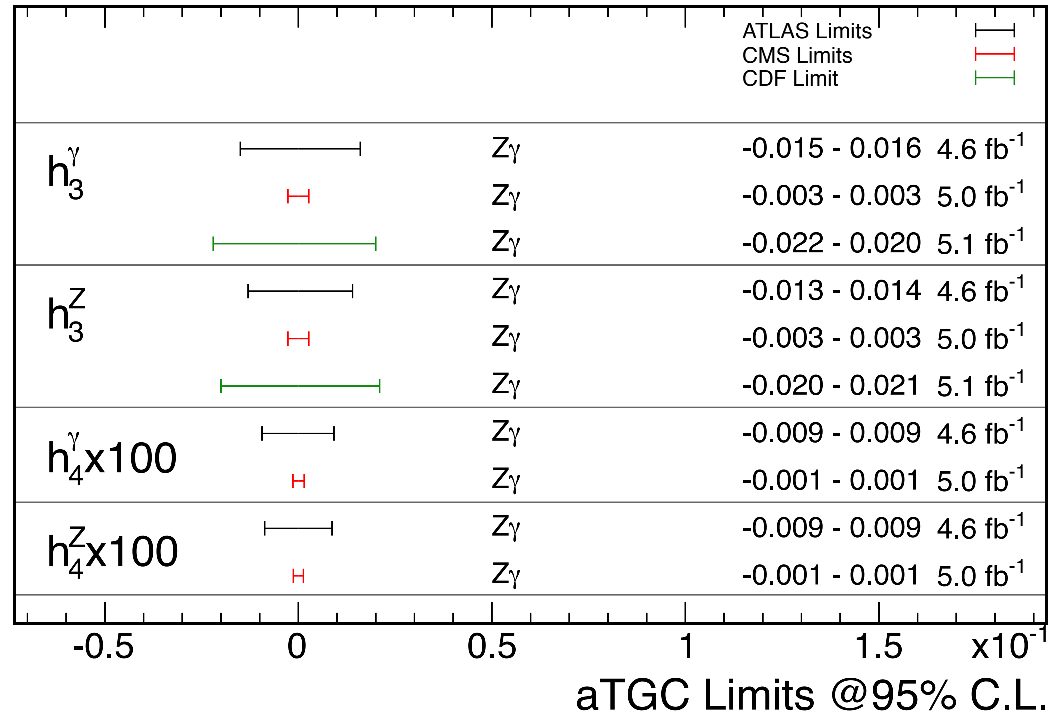
	llγ (P_T^γ > 15 GeV)	ννγ (P_T^γ > 145 GeV)
CMS measurement	5.33 ± 0.08 (stat) ± 0.25 (syst) ± 0.12 (lumi) pb	0.021 ± 0.004 (stat) ± 0.004 (syst) ± 0.001 (lumi) pb
NLO prediction	5.45 ± 0.27 pb	0.022 ± 0.001 pb

- Measured cross sections are in agreement with SM NLO predictions

anomalous TGC results

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMPaTGC



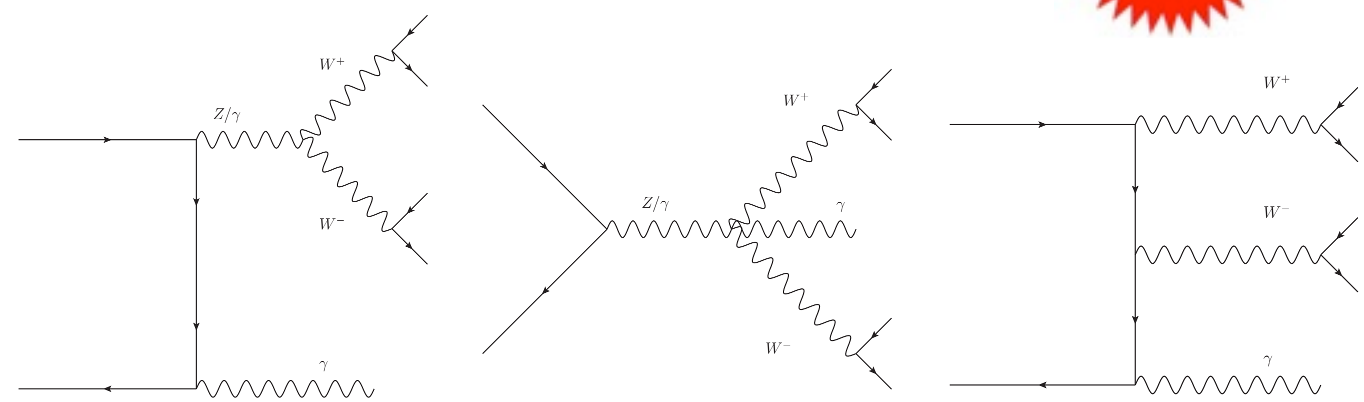


- To model generic new physics signal, we work with the effective Lagrangian
  - Example : WWV vertex (V = Z, γ)
  - The number of coupling parameters can be reduced if one takes some assumptions (e.g. C and P conservation)
- Use P_T^γ shape to extract limits on aTGC
- λ_γ results competitive with most sensitive measurements
- Results of neutral TGC are world's most sensitive
- No evidence observed for physics beyond the SM

$$
\begin{aligned}
L_{WWV}/g_{WWV} = {} & i g_1^V (W^\dagger_{\mu\nu} W^\mu V^\nu - W^\dagger_\mu V_\nu W^{\mu\nu}) + i\kappa_V W^\dagger_\mu W_\nu V^{\mu\nu} \\
& + i\frac{\lambda_V}{m_W^2} W^\dagger_{\lambda\mu} W^\mu_\nu V^{\nu\lambda} - g_4^V W^\dagger_\mu W_\nu (\partial^\mu V^\nu + \partial^\nu V^\mu) \\
& + g_5^V \epsilon^{\mu\nu\lambda\rho} (W^\dagger_\mu \partial_\lambda W_\nu - \partial_\lambda W^\dagger_\mu W_\nu) V_\rho \\
& + i\tilde{\kappa}_V W^\dagger_\mu W_\nu \tilde{V}^{\mu\nu} + i\frac{\tilde{\lambda}_V}{m_W^2} W^\dagger_{\lambda\mu} W^\mu_\nu \tilde{V}^{\nu\lambda}
\end{aligned}
$$

$W W\gamma$ and $W Z\gamma$ signature and event selections

- Measurements based on final state of $WV\gamma \rightarrow l\nu$+dijet+$\gamma$ (l = e,μ)
  - using 19.3/fb of 8 TeV data
  - CMS PAS SMP-13-009
- single lepton trigger
- $p_T^e > 30$ GeV, $p_T^\mu > 25$ GeV
- Minimum of 2 jets with $p_T > 30$ GeV and $|\eta| < 2.4$
- MET > 35 GeV, $\Delta\Phi$(MET, leading jet) > 0.4, $M_T^W > 30$ GeV
- $p_T^\gamma > 30$ GeV, ECAL barrel only, and well separated from jets and lepton
- Exactly one lepton, anti-b tag for jets
- $|\Delta\eta_{jj}| < 1.4$, $70 < M_{jj} < 100$ GeV, and $|M_{\gamma e} - M_Z| > 10$ GeV

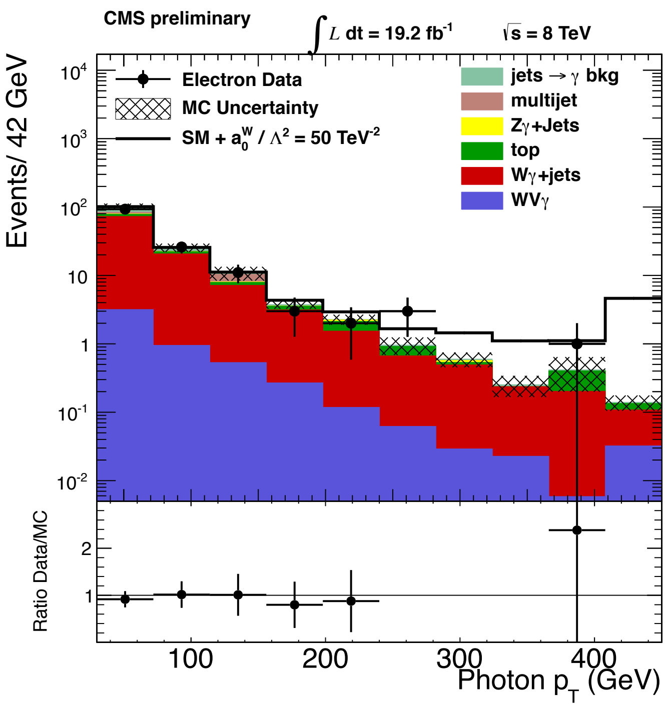


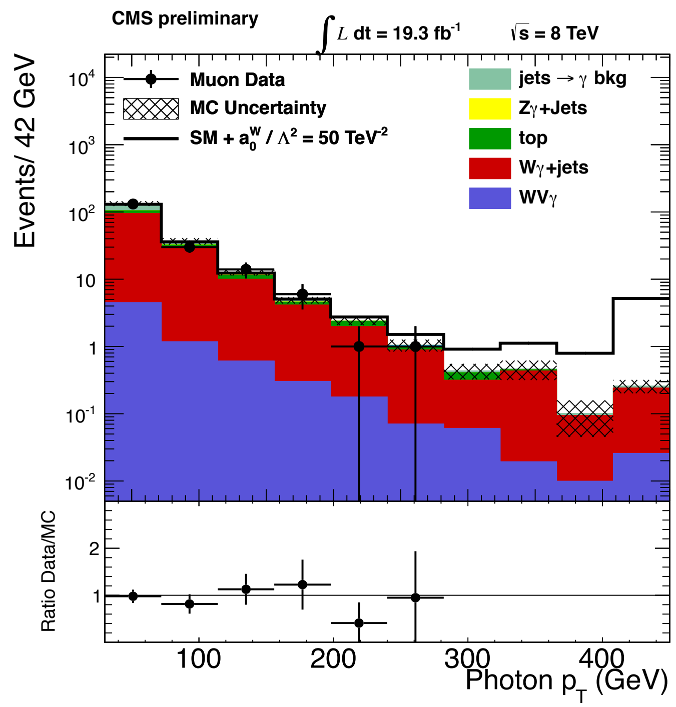
TGC QGC QED radiation

Backgrounds for WVγ

- Major background : Wγ + jets
  - Data and MC dijet mass sidebands (0-70 and 100-190 GeV) used to estimate the data-driven Wγ+jets normalization
- jet→γ : WV+jets
  - estimated from data using "ratio method"
- Others (tt+γ, t, Zγ+jets, QCD) are estimated from simulation

WVγ results



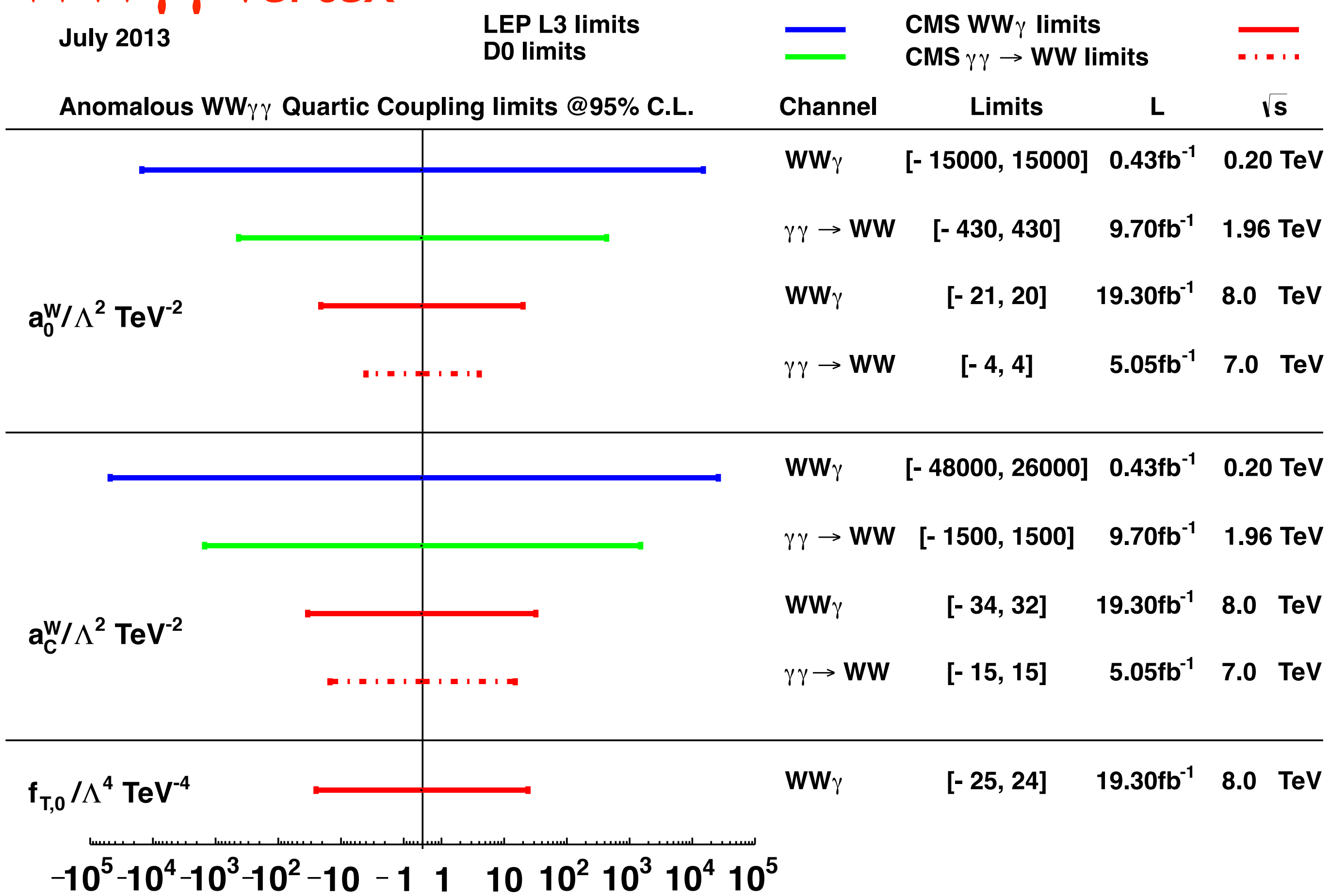


Process	muon channel number of events	electron channel number of events
$W\gamma$+jets	$136.9 \pm 3.5 \pm 9.2 \pm 0.0$	$101.6 \pm 2.9 \pm 8.0 \pm 0.0$
WV+jet, jet→ γ	$33.1 \pm 1.3 \pm 4.6 \pm 0.0$	$21.3 \pm 1.0 \pm 3.1 \pm 0.0$
MC $t\bar{t}\gamma$	$12.5 \pm 0.8 \pm 2.9 \pm 0.5$	$9.1 \pm 0.7 \pm 2.1 \pm 0.4$
MC single top	$2.8 \pm 0.8 \pm 0.2 \pm 0.1$	$1.7 \pm 0.6 \pm 0.1 \pm 0.1$
MC $Z\gamma$+jets	$1.7 \pm 0.1 \pm 0.1 \pm 0.1$	$1.5 \pm 0.1 \pm 0.1 \pm 0.1$
multijets	$<0.2 \pm 0.0 \pm 0.1 \pm 0.0$	$7.2 \pm 3.6 \pm 3.6 \pm 0.0$
SM $WW\gamma$	$6.3 \pm 0.1 \pm 1.5 \pm 0.3$	$4.7 \pm 0.1 \pm 1.1 \pm 0.2$
SM $WZ\gamma$	$0.6 \pm 0.0 \pm 0.1 \pm 0.0$	$0.5 \pm 0.0 \pm 0.1 \pm 0.0$
Total predicted	$193.9 \pm 3.9 \pm 10.8 \pm 1.0$	$147.6 \pm 4.8 \pm 9.6 \pm 0.7$
Data	183	139

- good agreement between measurements and predictions
- an upper limit for WWγ and WZγ cross section, 241 fb, is set at 95% C.L. for p_T^γ > 10 GeV
  - about 3.4 times larger than SM prediction, 70.3 fb, from aMC@NLO

anomalous QGC results

WWγγ vertex



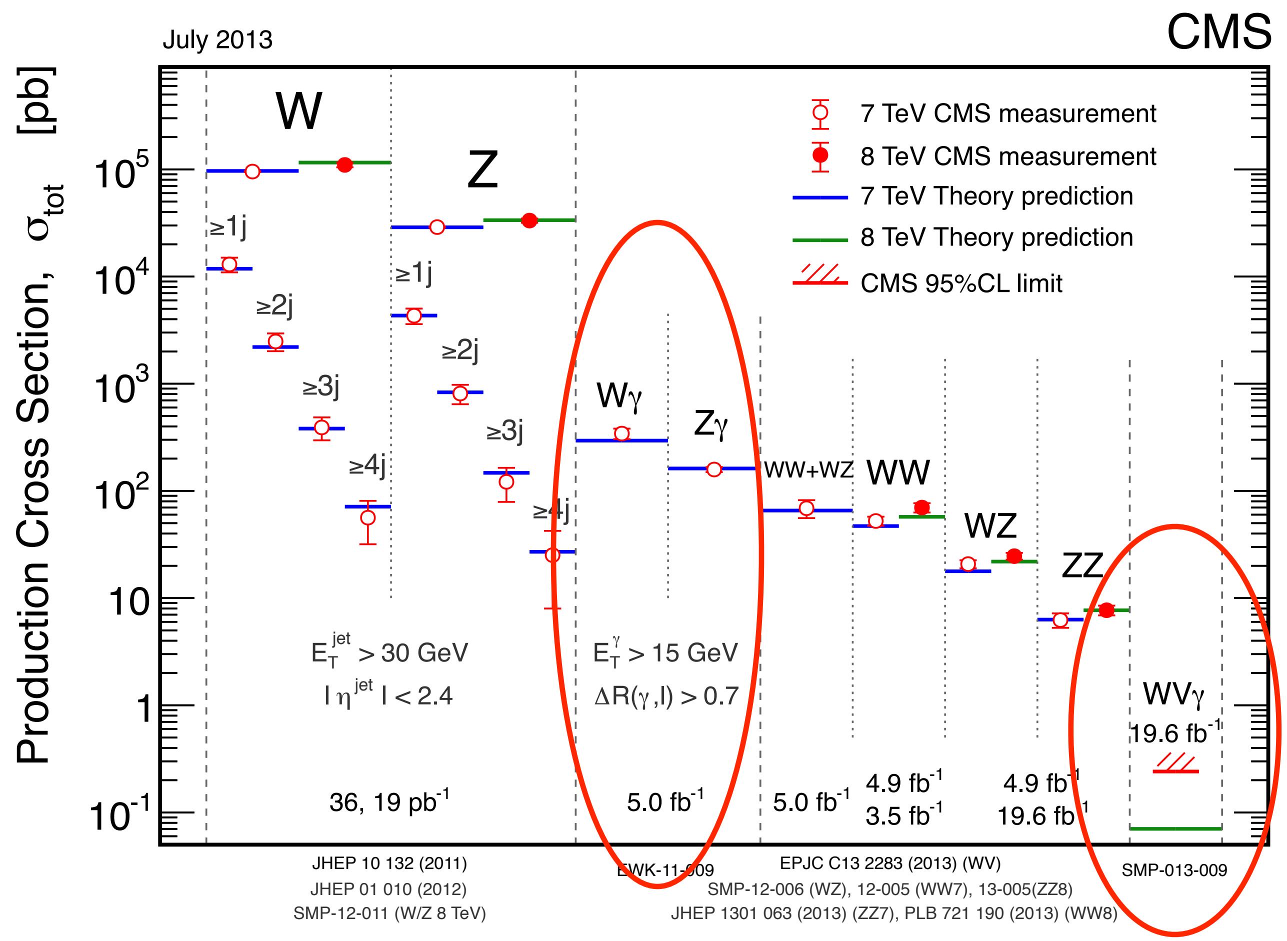
$$\mathcal{L}_{aQGC} = \frac{a_0^W}{4g^2}\mathcal{W}_0^\gamma + \frac{a_C^W}{4g^2}\mathcal{W}_c^\gamma + \sum_i k_i^W \mathcal{W}_i^Z + \mathcal{L}_{T,0} + \mathcal{L}_{T,1} + \mathcal{L}_{T,2}$$

WWZγ vertex	
κ_0^W/Λ^2	[-12, 10] TeV^{-2}
κ_C^W/Λ^2	[-18, 17] TeV^{-2}

See Jonathan Hollar's talk for CMS γγ→WW results

- Use P_T^γ shape to extract limits on anomalous quartic gauge couplings
- focus on anomalous vertices that may be associated to dimension 6 and 8 effective operators
- first constraint on the κ_0^W and k_C^W parameter of WWZγ vertex
- No evidence of anomalous QGC is found

Summary



- Wγ and Zγ cross sections agree with SM NLO predictions
- World's most sensitive analysis for a triboson final state performed. No evidence for WVγ production found
- No evidence for anomalous TGCs/QGCs, but much more improved limits
  - most stringent limits on ZZγ and Zγγ vertex and WWZγ vertex
- More results with ~20/fb of 8TeV data to come ! Stay tuned !