Production of multiple electroweak bosons at CMS

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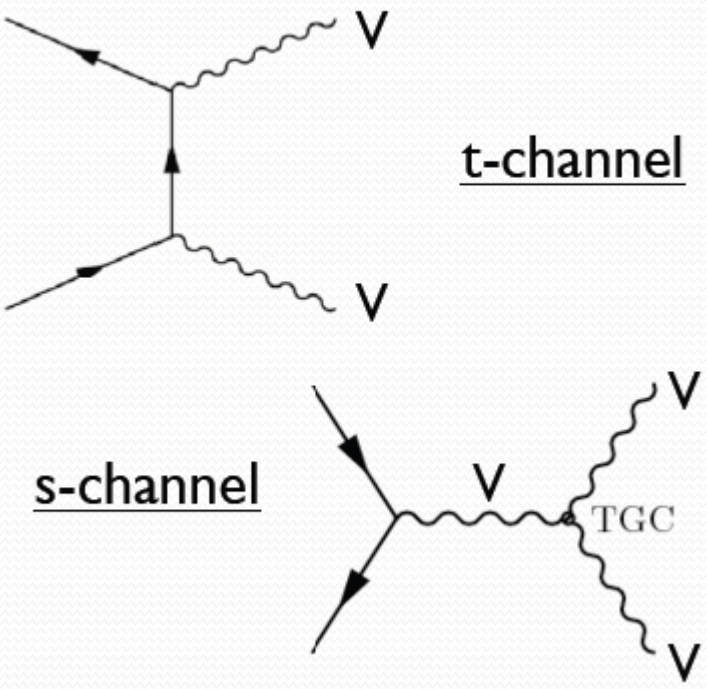
Overview

- Standard Model diboson measurements are crucial to check the gauge structure of the standard model
  - **Irreducible background to new physics searches and Higgs boson analyses**

Main diboson production mechanism

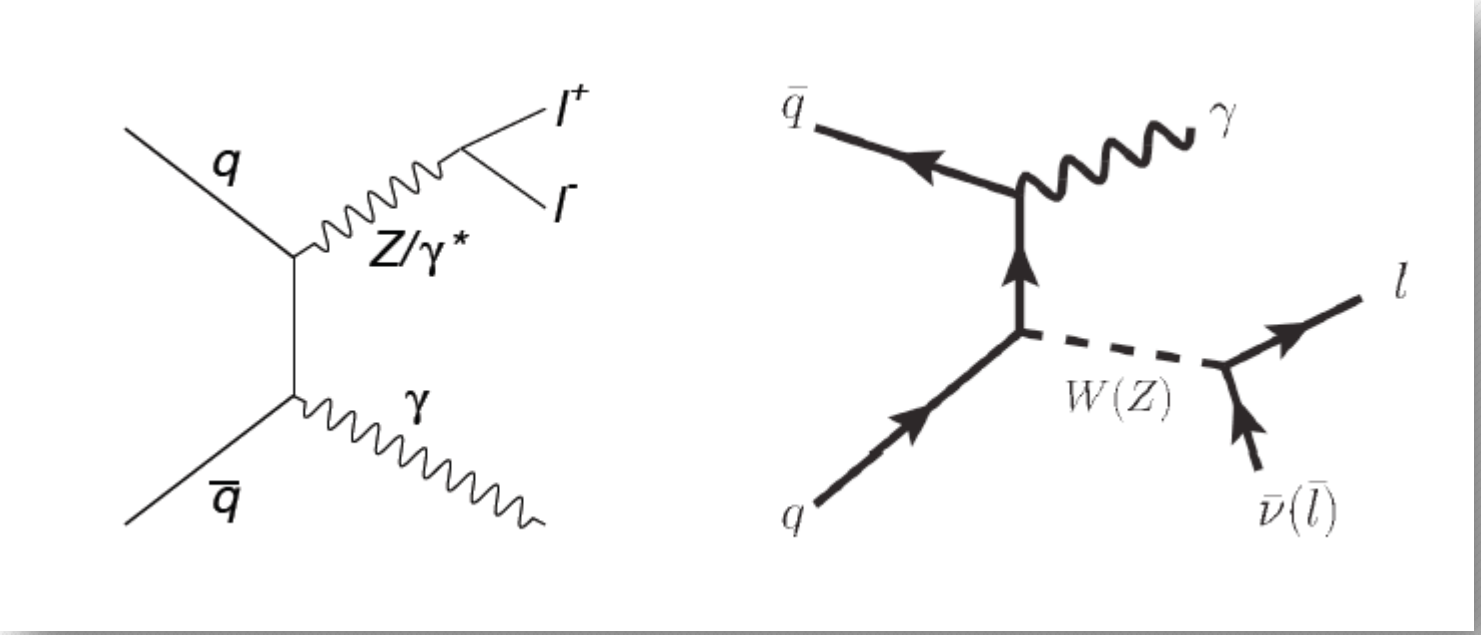


→ Cross Section results

- **Wγ/Zγ Production**
- **WW/WZ Production**
- **ZZ production**

→ aTGC results

Wγ/Zγ production cross section

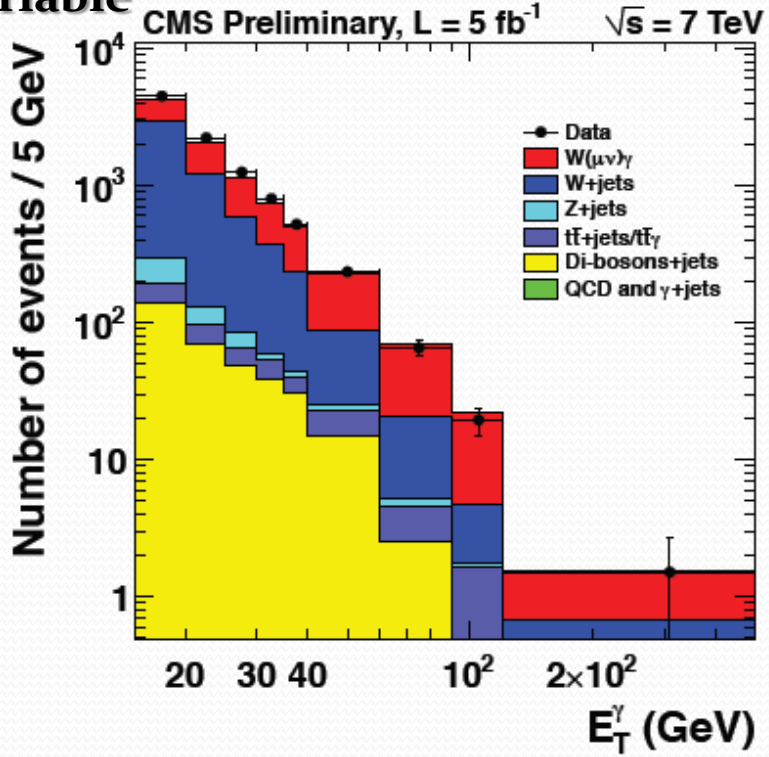


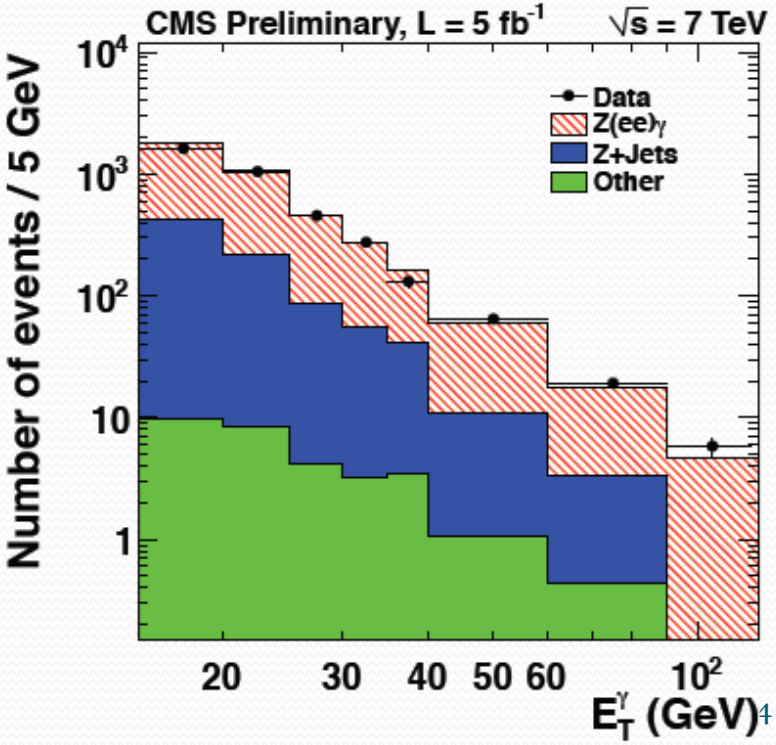
$W\gamma \rightarrow l\nu\gamma / Z\gamma \rightarrow ll\gamma$

Main selection cuts:

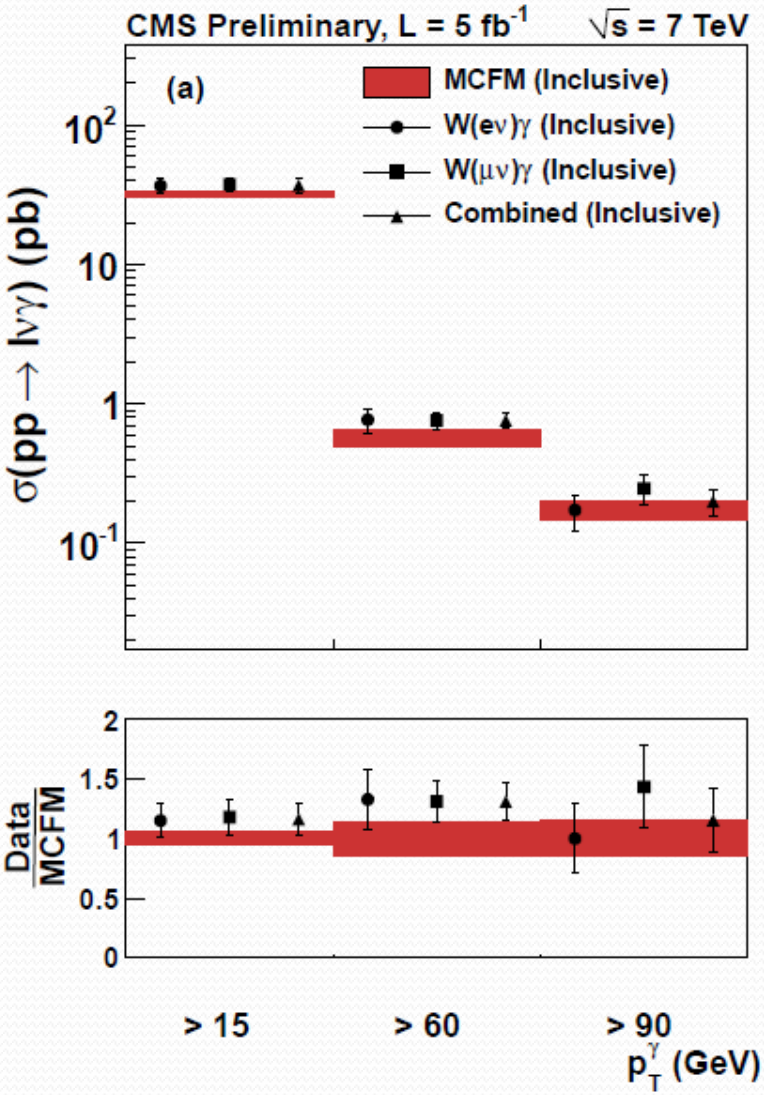
- **lepton $p_T > 20$ GeV for Z and 35 GeV for $W \rightarrow l\nu$ | γ $p_T > 15$ GeV**
- **$m_T^W > 70$ GeV to remove background without true MET and surpass electron trigger turn-on.**

Background due to mis-identified photons from a template fit to a shower shape variable

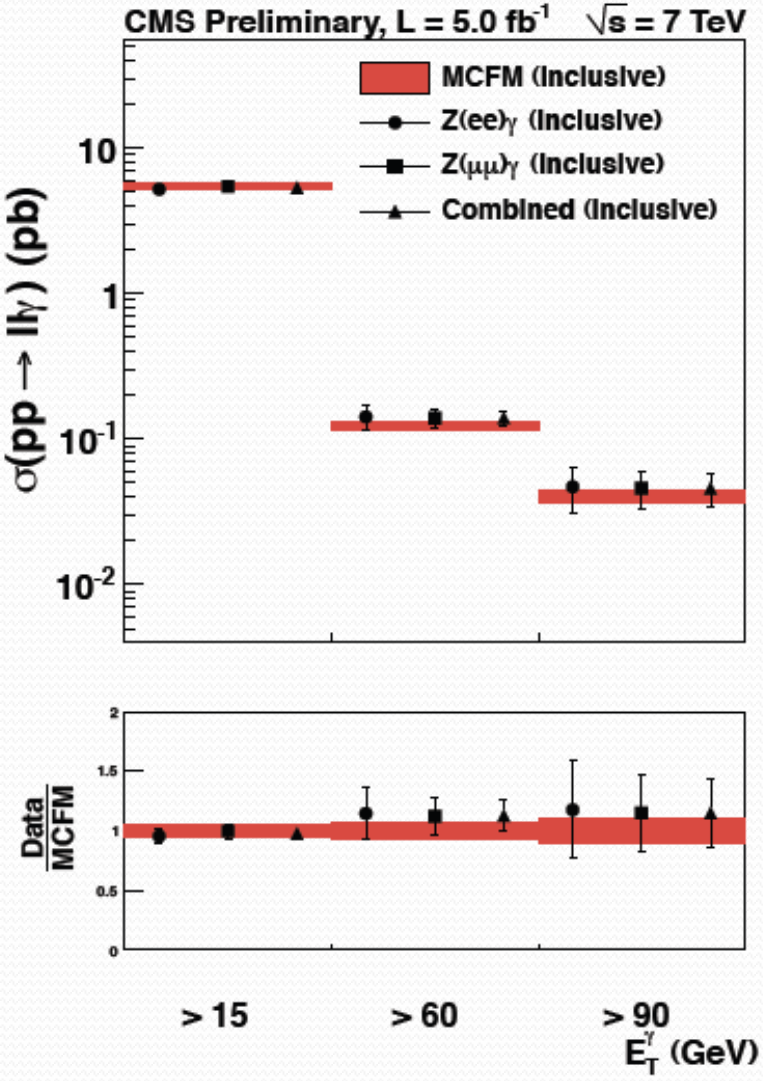




Wγ → lνγ/Zγ → llγ



→ Fair agreement with expectations (at one sigma level)



→ Good agreement with the standard model

$Z\gamma \rightarrow \nu\nu\gamma$

- First measurement of $Z\gamma \rightarrow \nu\nu\gamma$ at $\sqrt{s}$= 7 TeV
- Experimentally challenging final state due to large instrumental and non-collision backgrounds.
- Most backgrounds and efficiencies are estimated with data-driven methods

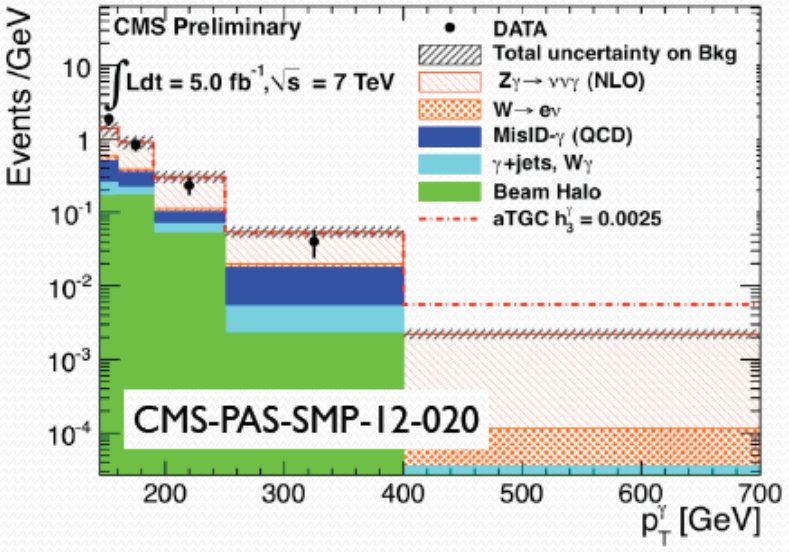
photon (η) < 1.4, E_T > 145 GeV
MET > 130 GeV

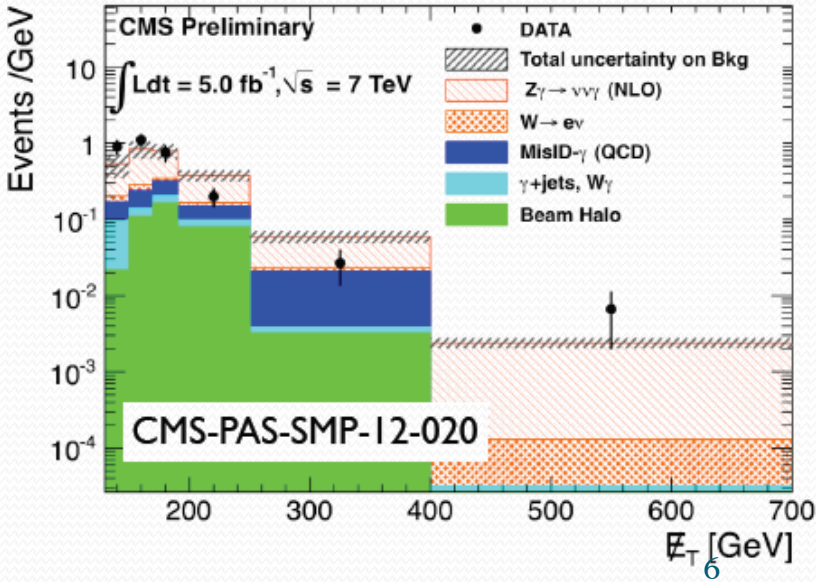
Experimental cross section:

21.3 ± 4.2 (stat.) ± 4.3 (syst.) ± 0.5 (lumi) fb

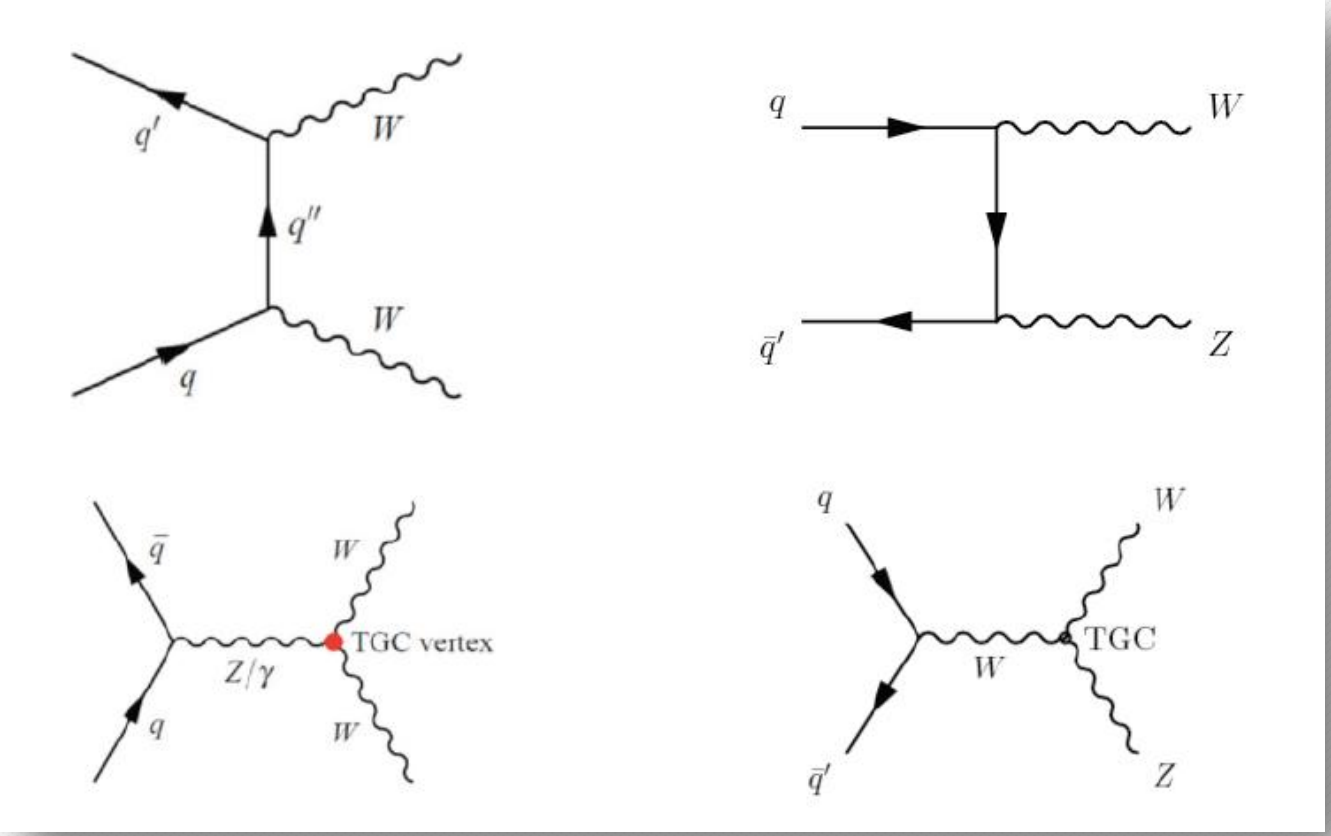
Theoretical prediction:

21.9 ± 1.1 fb





WW/WZ production cross section

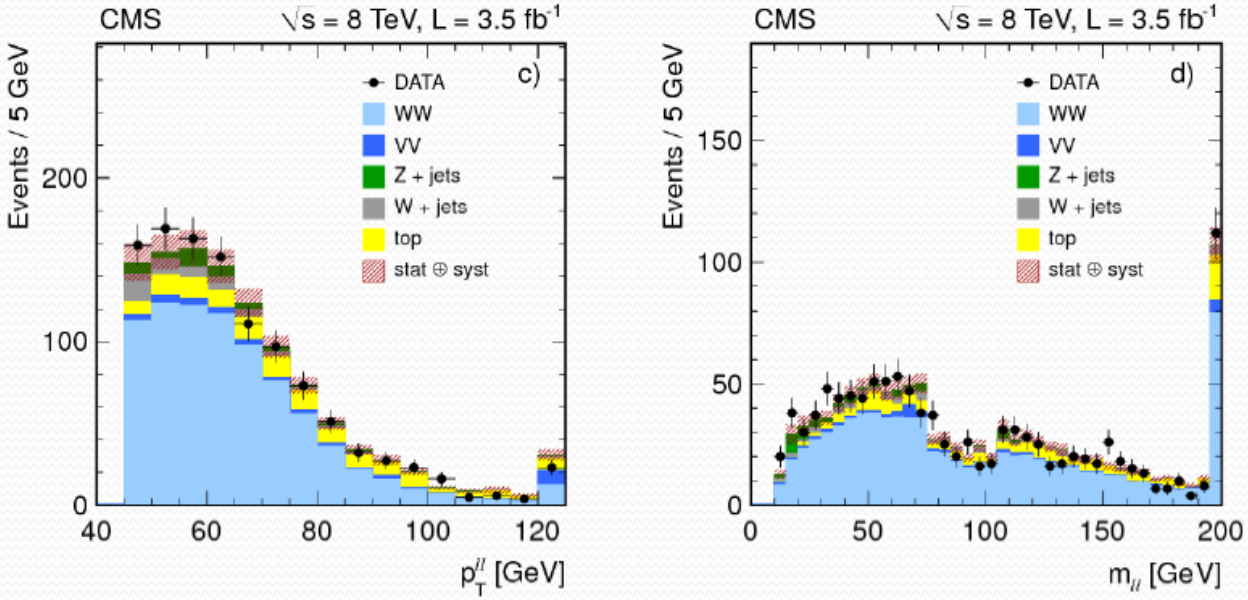


WW production xs

(Physics Letters B. Volume 721, Issues 4–5, 25 April 2013, Pages 190–211)

- 2 high p_T leptons (> 20 GeV)
- m_{ll} > 20 GeV → remove low mass resonances
- Z_{veto} → reduce the DY and WZ background
- No high p_T jet in the event
- b quark veto (only for low pT jets) → top background
- Tight MET cut → DY background
- No third lepton → WZ/ZZ background

→ **Main backgrounds estimated from data-driven methods**



WW production xs

7 TeV

Sample	Yield ± stat. ± syst.
gg→WW	46.03 ± 0.60 ± 14.16
$q\bar{q}$ →WW	750.86 ± 4.11 ± 53.13
$t\bar{t}$ +tW	128.46 ± 12.79 ± 19.55
W+jets	59.45 ± 3.93 ± 21.40
WZ+ZZ	29.40 ± 0.43 ± 2.03
Z/γ^*	10.98 ± 5.05 ± 2.59
W+γ	18.84 ± 2.84 ± 4.68
$Z/\gamma^* \to \tau\tau$	0.0 ± 1.0 ± 0.1
Total Background	247.13 ± 14.62 ± 29.54
Signal + Background	1044.02 ± 15.20 ± 62.41
Data	1134

$\sigma_{WW} = 52.4 \pm 2.0$ (stats.) ± 1.2 (lumi.) ± 4.5 (syst.) pb

8 TeV

sample	yield ± stat. ± syst.
gg → WW	43.3 ± 1.0 ± 13.4
qq → WW	640.3 ± 4.9 ± 47.4
$t\bar{t}$+tW	131.6 ± 12.7 ± 19.5
W+jets	60.0 ± 4.3 ± 21.6
WZ+ZZ	27.4 ± 0.5 ± 2.9
Z/γ^*	42.5 ± 6.0 ± 9.9
Wγ + Wγ^*	13.6 ± 2.4 ± 4.3
total background	275.2 ± 14.9 ± 31.2
signal + background	958.8 ± 15.7 ± 58.3
data	1111

$\sigma_{WW} = 69.86 \pm 2.79$ (stat.) ± 5.58 (syst.) ± 3.07 (lumi.) pb

To be compared with:

$\sigma(gg \to WW + q\bar{q} \to WW) = 47.04$ pb $\left(^{+4.3\%}_{-3.2\%}\right)$

To be compared with:

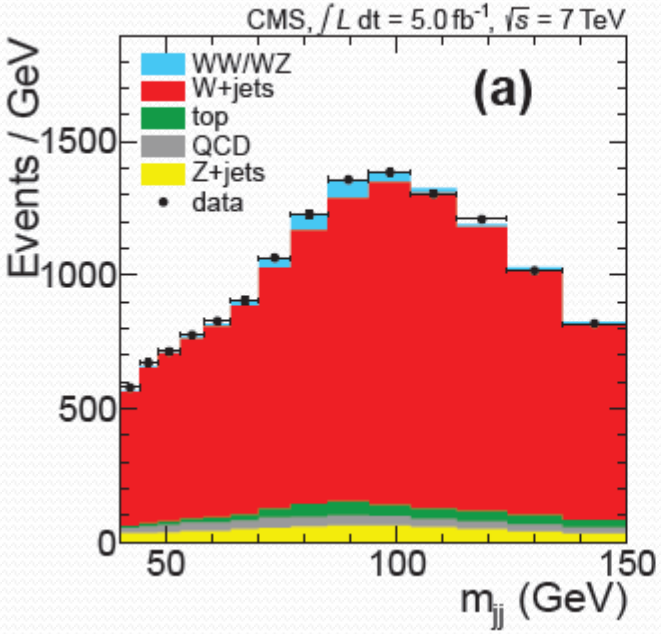
$\sigma(gg \to WW + qq \to WW) = 57.25$ pb $\left(^{+4.1\%}_{-2.8\%}\right)$

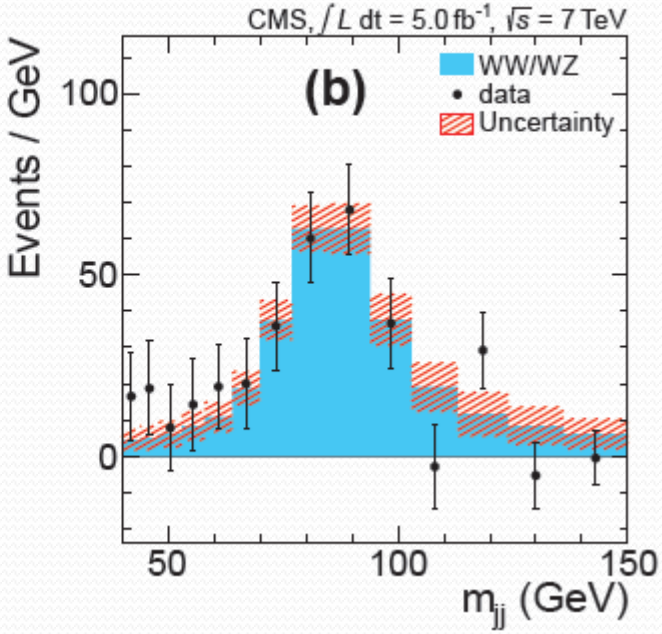
WW+WZ production xs

Measurement of WW+WZ diboson production in pp collisions in the semileptonic final state:

Eur.Phys.J. C73 (2013) 2283

- One W boson decays leptonically ($l\nu$ with l = e,μ)
- The other boson (W or Z) decays hadronically (jj)
  - Two energetic jets in the final state.



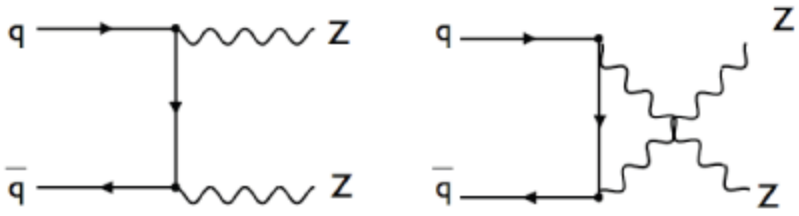


$\sigma(pp \rightarrow WW + WZ) = 68.9 \pm 8.7\ (stat.) \pm 9.7\ (syst.) \pm 1.5\ (lum.)$ pb

To be compared with:

$\sigma(pp \rightarrow WW + WZ) = 65.6 \pm 2.2$ pb

ZZ production cross section



Standard Model Production

ZZ production cross section

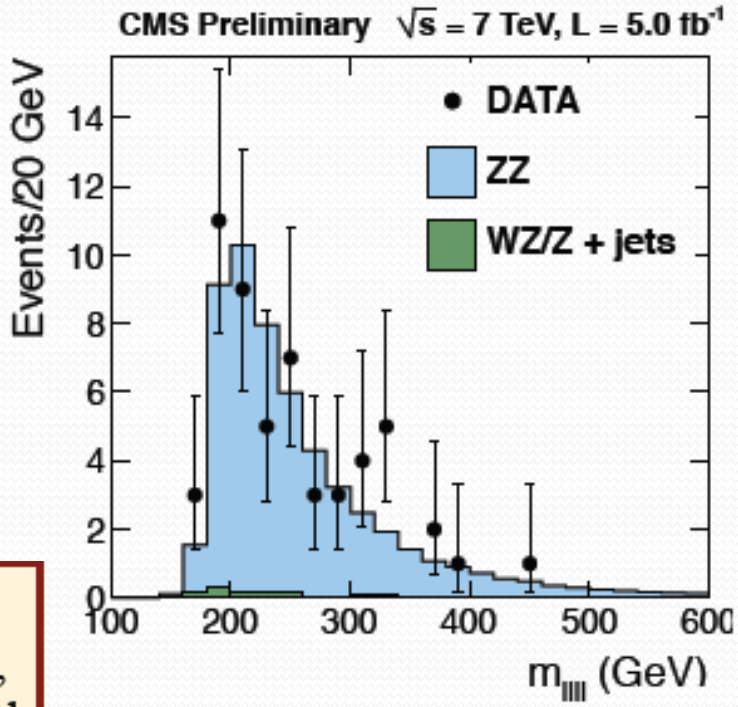
(Physics Letters B. Volume 721, Issues 4–5, 25 April 2013, Pages 190–211)

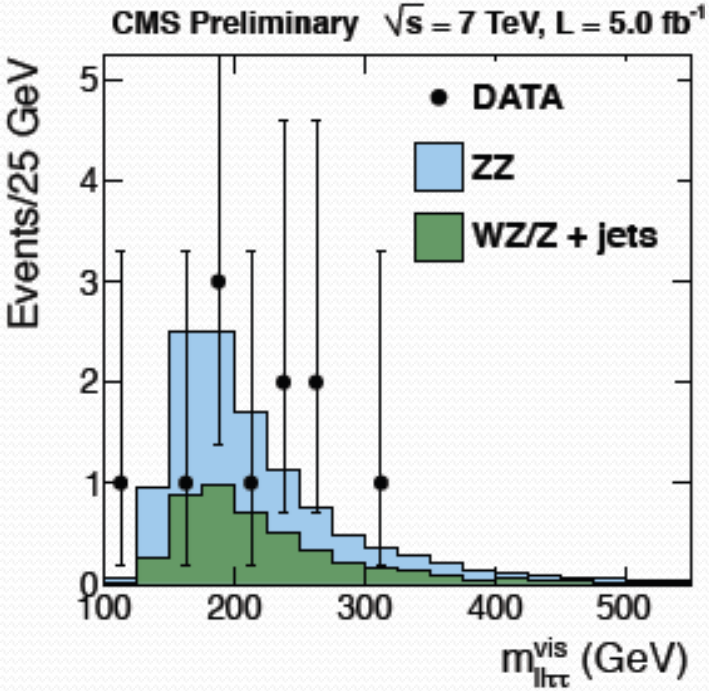
- ZZ cross section is measured in the ZZ → 2l2l' channel, where l=e/μ and l'=e/μ/τ
- $60 < m_{ll} < 120$ GeV/c^2 for the two Z bosons
  → Lepton pair closest to m_Z considered as Z_1.
- Leptons coming from Z_1: $p_T > 10/20$
- For the Z_2 , taus are also considered: $30 < m_{\tau\tau} < 90$ GeV/c^2
- Very little background (even for ZZ → 2l2τ the S/B ≥ 1)
- Main background: QCD W/Z+jets and WZ+jets
- Estimated from data: define control samples where one or two leptons fail the isolation/identification criteria.

ZZ production cross section

7 TeV

JHEP 1301 063 (2013)





4ℓ Total:
54 observed,
54.6 expected
(53.2+1.4)

2ℓ2τ Total:
11 observed,
11.5 expected
(7.1+4.4)

$\sigma(pp \rightarrow ZZ) = 6.24 \pm 0.86\ (stat.) \pm 0.41(syst.) \pm 0.14\ (lum.)$ pb

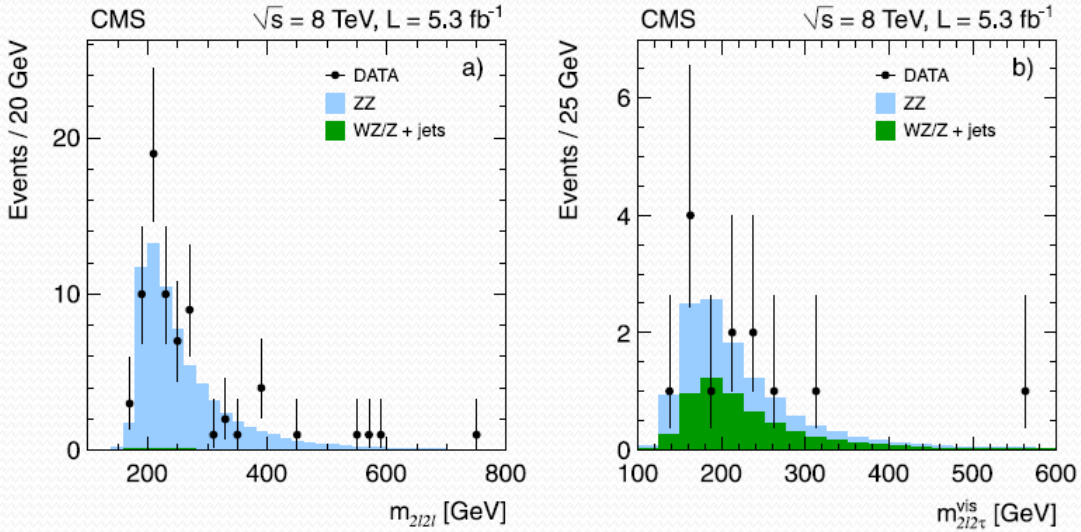
Consistent with the SM prediction at 7 TeV:

$\sigma(pp \rightarrow ZZ) = 6.3 \pm 0.4$ pb

ZZ production cross section

8 TeV

Channel	4e	4μ	2e2μ	2ℓ2τ
ZZ	11.6 ± 1.4	20.3 ± 2.2	32.4 ± 3.5	6.5 ± 0.8
Background	0.4 ± 0.2	0.4 ± 0.3	0.5 ± 0.4	5.6 ± 1.4
Signal + background	12.0 ± 1.4	20.7 ± 2.2	32.9 ± 3.5	12.1 ± 1.6
Data	14	19	38	13

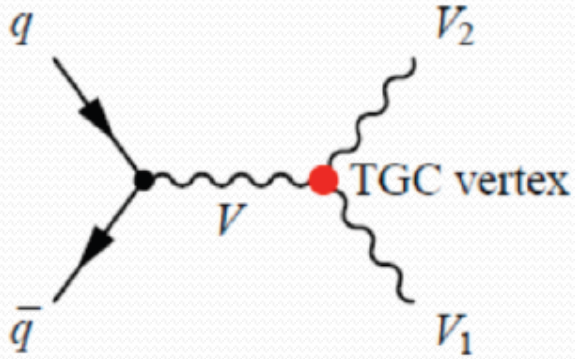


$\sigma(pp \rightarrow ZZ) = 8.4 \pm 1.0\ (stat.) \pm 0.7(syst.) \pm 0.4\ (lum.)\ pb$

Consistent with the SM prediction at 8 TeV :

$\sigma(pp \rightarrow ZZ) = 7.7 \pm 0.4\ pb$

Triple Gauge Couplings



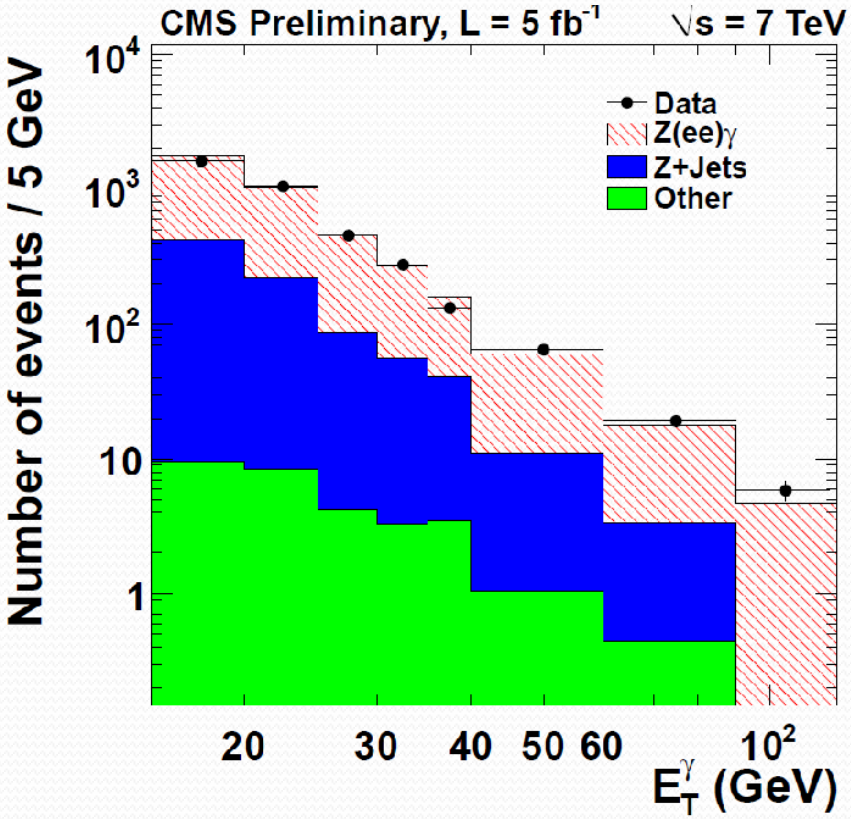
Coupling	Parameters	Channel
WWγ	$\Delta\kappa_\gamma$, λ_γ	WW, Wγ
WWZ	Δg_1^Z, $\Delta\kappa_Z$, λ_Z	WW, WZ
ZZγ	h_3^Z, h_4^Z	Zγ
Zγγ	h_3^γ, h_4^γ	Zγ
ZZZ	f_4^Z, f_5^Z	ZZ
ZγZ	f_4^γ, f_5^γ	ZZ

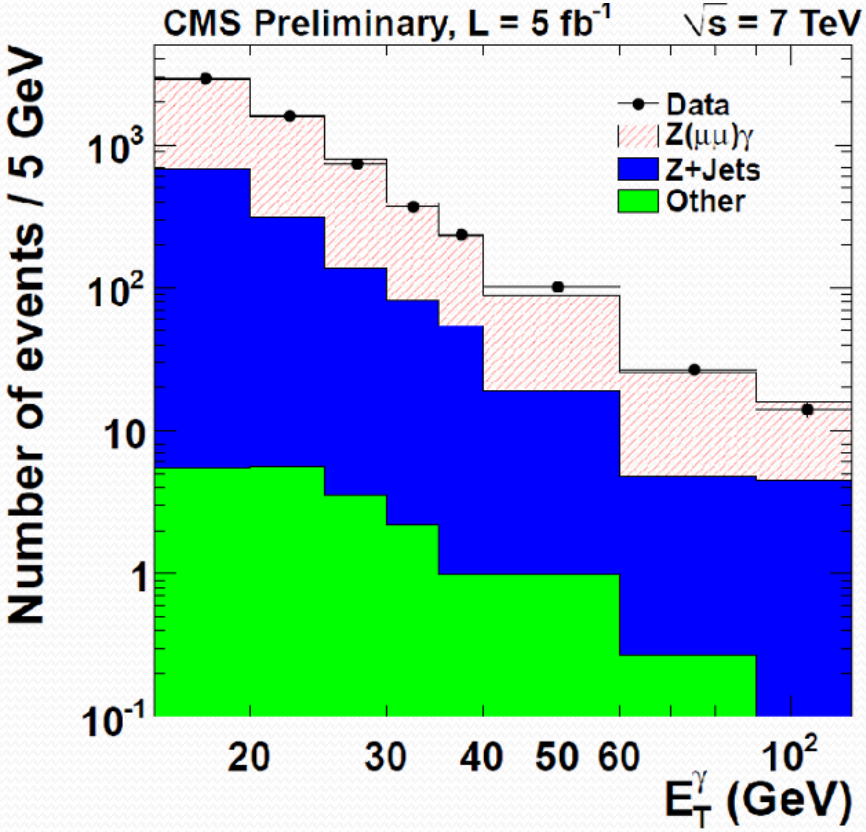
- Predicted by the Gauge structure of the Standard Model
- Neutral TGC couplings are forbidden at tree level by the SM
- Non-SM values would increase the cross section at high mass,p_T

TGC limits from Zγ (llγ)

→ **Determined from events with high p_T photon**

	h_3^γ	h_4^γ	h_3^Z	h_4^Z
$Z\gamma \to ee\gamma$	-0.013, 0.013	-1.1, 1.1 $\times 10^{-4}$	-0.011, 0.011	-9.9, 9.5 $\times 10^{-5}$
$Z\gamma \to \mu\mu\gamma$	-0.013, 0.013	-1.1, 1.2 $\times 10^{-4}$	-0.011, 0.011	-1.0, 1.1 $\times 10^{-4}$
$Z\gamma \to \ell\ell\gamma$	-0.010, 0.010	-8.8, 8.8 $\times 10^{-5}$	-8.6, 8.4 $\times 10^{-3}$	-8.0, 7.9 $\times 10^{-5}$



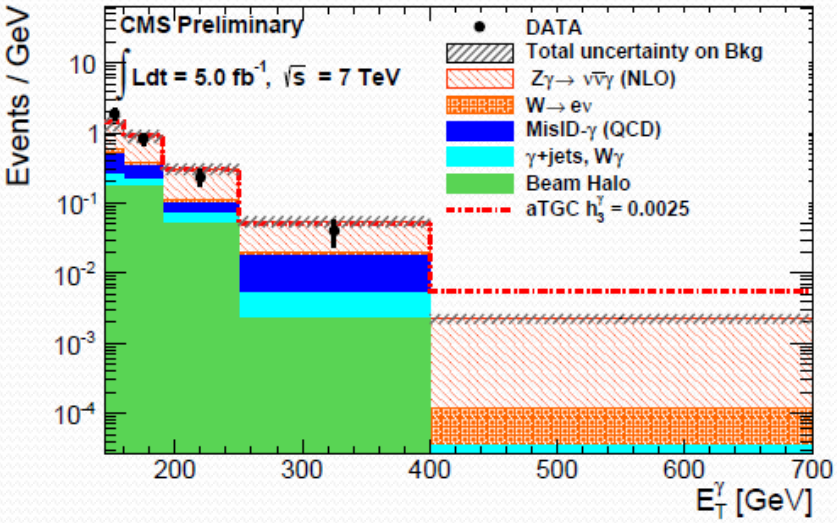


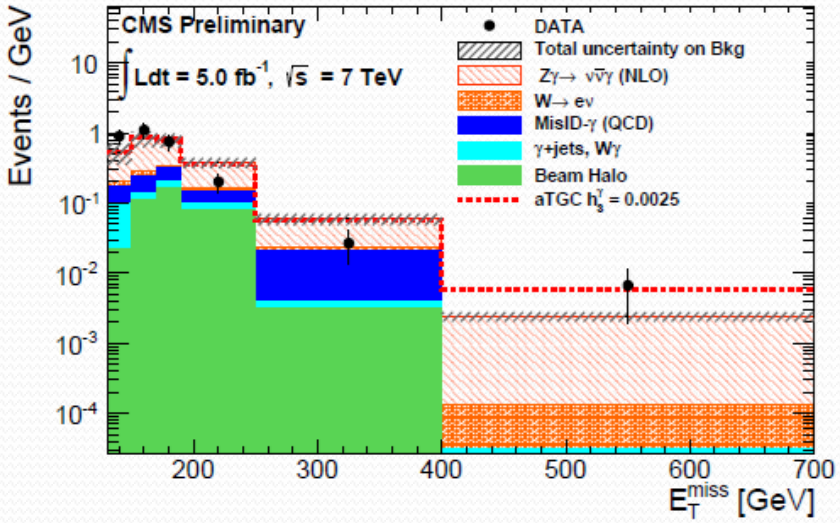
TGC limits from Zγ (MET+γ)

Most stringent limits on trilinear gauge couplings set to date:

$$|h_3^\gamma| < 2.9 \times 10^{-3} \qquad |h_4^\gamma| < 1.5 \times 10^{-5} \qquad \text{Z}\gamma\gamma \text{ couplings}$$

$$|h_3^Z| < 2.7 \times 10^{-3} \qquad |h_4^Z| < 1.3 \times 10^{-5} \qquad \text{ZZ}\gamma \text{ couplings}$$

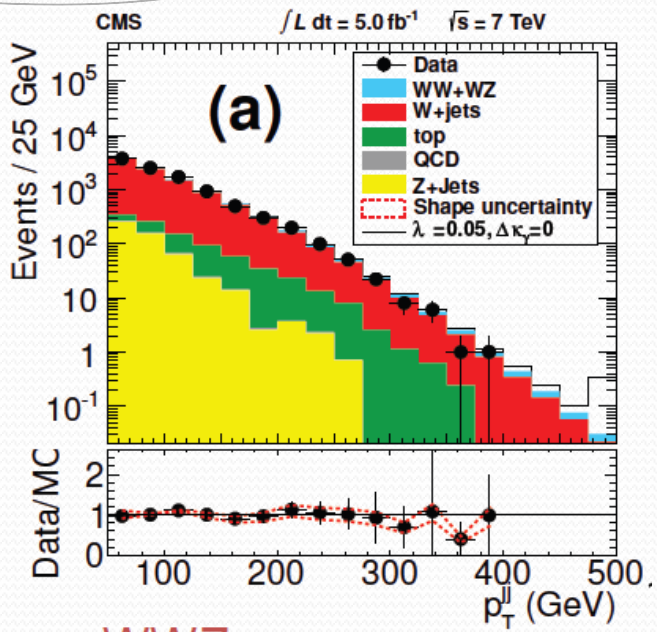




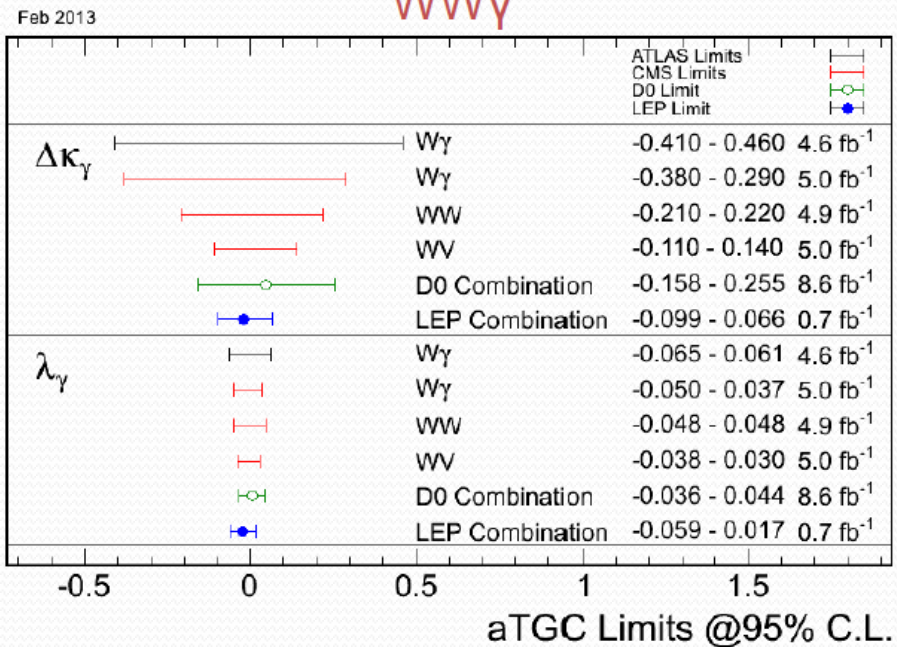
WWγ and WWZ TGC

Limits determined from p_T spectrum:

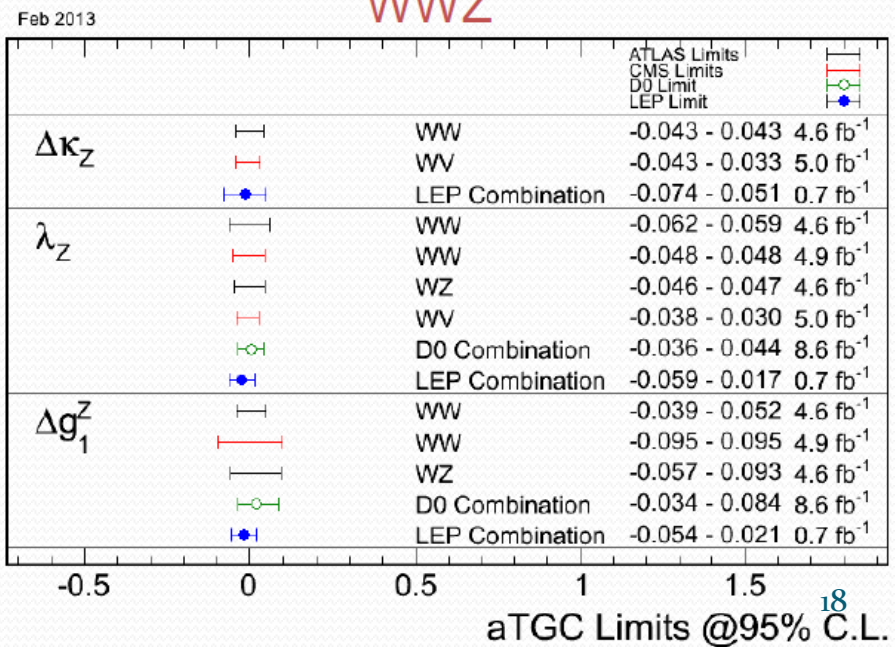
- Photon in Wγ
- Leading lepton in WW → lνlν
- Z boson in WZ → lνll
- Dijet system in WW/WZ → lνjj



WWγ



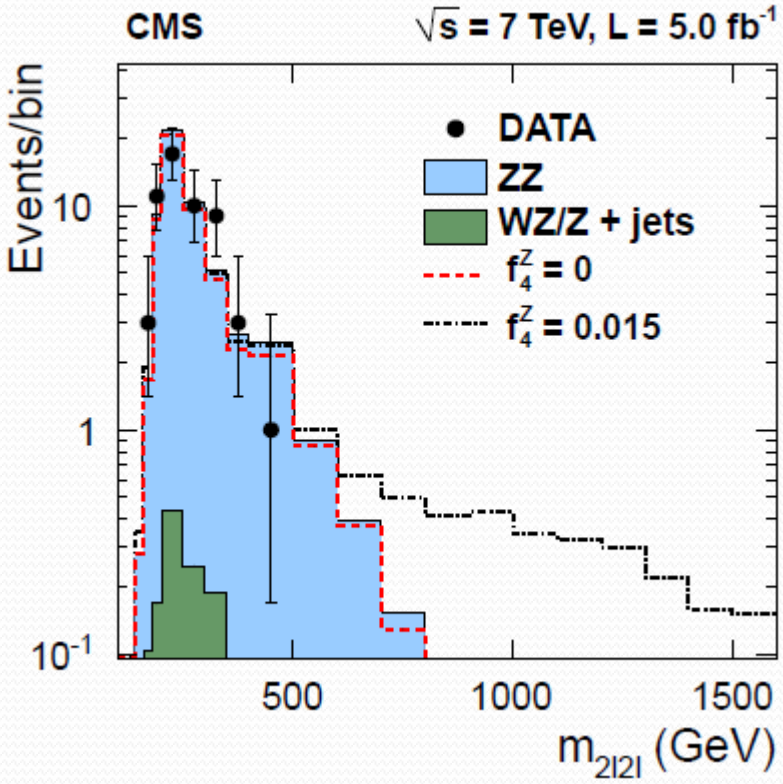
WWZ



TGC limits from ZZ

CMS JHEP 1301 (2013) 063

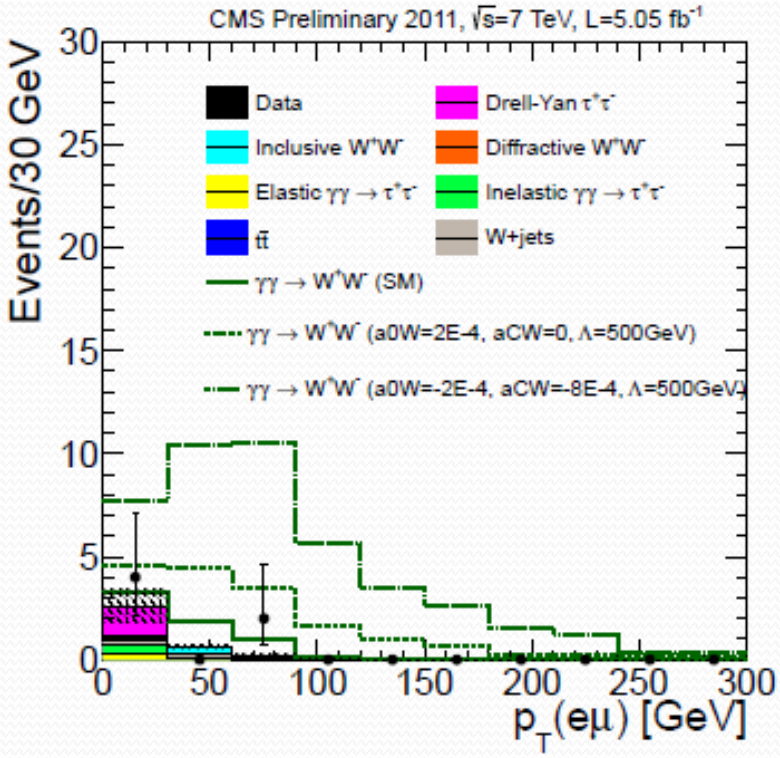
- Determined from the four lepton invariant mass distribution:

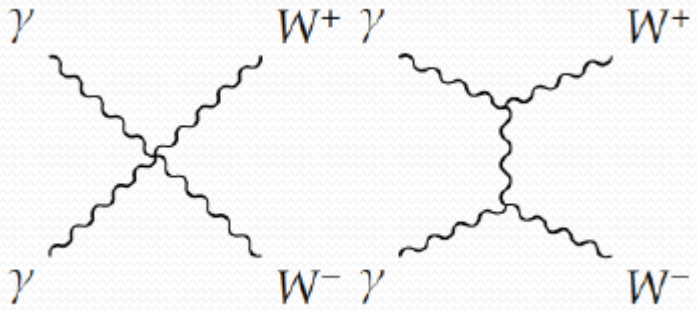


$$-0.011 < f_4^Z < 0.012,\ -0.012 < f_5^Z < 0.012,\ -0.013 < f_4^\gamma < 0.015,\ -0.014 < f_5^\gamma < 0.014.$$

Anomalous Quartic Couplings

CMS PAS FSQ-12-010





- First limits on anomalous quartic couplings at LHC from CMS measurement of exclusive two photon production of WW

pp → p(*)WWp(*) → p(*)μep(*)

Observed 2 events
SM: 2.2 ± 0.5 events
Background 0.84 ± 0.13

Cross section:
Measured: $2.1\ ^{+3.0}_{-1.9}$
SM: 3.8 ± 0.9

Λ	$\lvert a_0^W/\Lambda^2\rvert$ / GeV^{-2}	$\lvert a_C^W/\Lambda^2\rvert$ / GeV^{-2}
500 GeV	< 0.00017	< 0.0006
∞	2.8 x 10^{-6}	1.02 x 10^{-2}

- Limits set from number of events with $p_T(\mu e) > 100$ GeV

→ Limits about 1 order of magnitude better than DO and 100x than LEP

Conclusions

- Cross section calculated for the different diboson channel
  - No significant deviation from the SM observed
- Limits set on anomalous gauge boson couplings
  - No evidence is found for physics beyond the SM
- Plans:
  - Update all the analysis with the full luminosity at 8 TeV