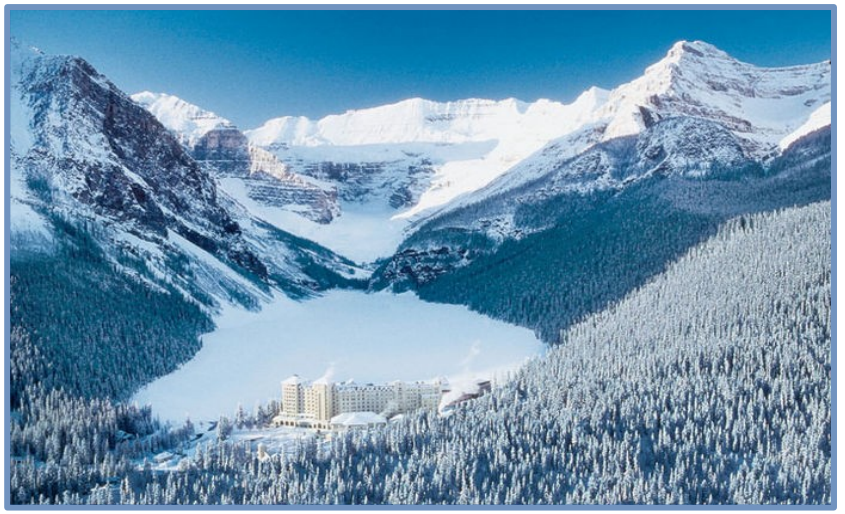
Recent Multiboson Production Results from CMS

Lake Louise Winter Institute 2015



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On behalf of CMS collaboration

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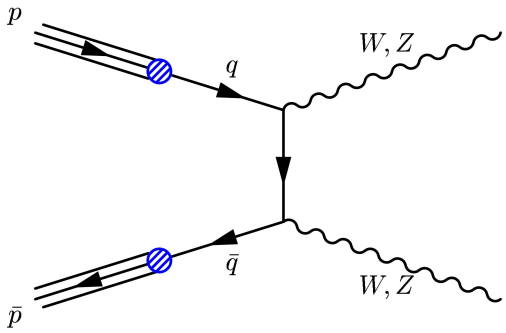
16/02/2015

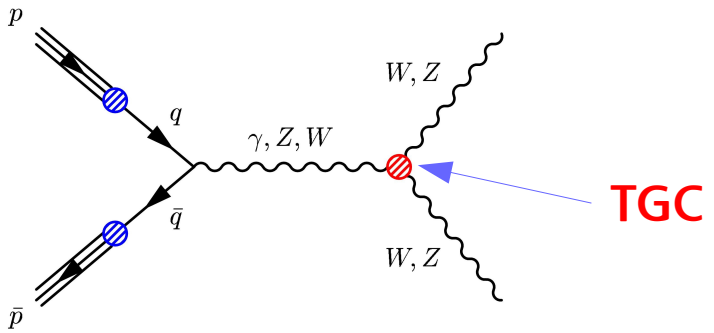
Introduction

- **Diboson production results**:
  - Recent CMS measurements using 8 TeV data.
  - Analyses in the ZZ, WZ and WW channels.
  - Cross section measurements and limits on aTGCs.

- **Vector Boson Scattering (VBS)**:
  - Recent CMS measurement using data collected at 8 TeV
  - Important process to be studied at LHC.
  - Limits on aQGCs and on doubly-charged Higgs boson.

Diboson production





- Important for testing the gauge sector of the Standard Model.
- Constitute irreducible backgrounds for Higgs boson analyses and searches.
- Also good tests for new physics beyond the SM.

- Deviations interpreted in terms of anomalous Triple Gauge Couplings (aTGCs).
  - Couplings defined by operators in an effective Lagrangian.
  - Typically evident in high tails of observable's distribution.

ZZ→lll'l' at 8 TeV

CMS-PAS-SMP-13-005
Phys. Lett. B 740 (2015) 250

Signature

- Two lepton pairs peaking at M_Z.
- l=e,μ l'=e,μ,τ

Selections

- Two same-flavor and opposite-sign isolated leptons from each Z.
- Lepton pair retained if $60<M_{ll}<120$ GeV.
- At least one lepton with $p_T>20$ GeV and one with $p_T>10$ GeV.

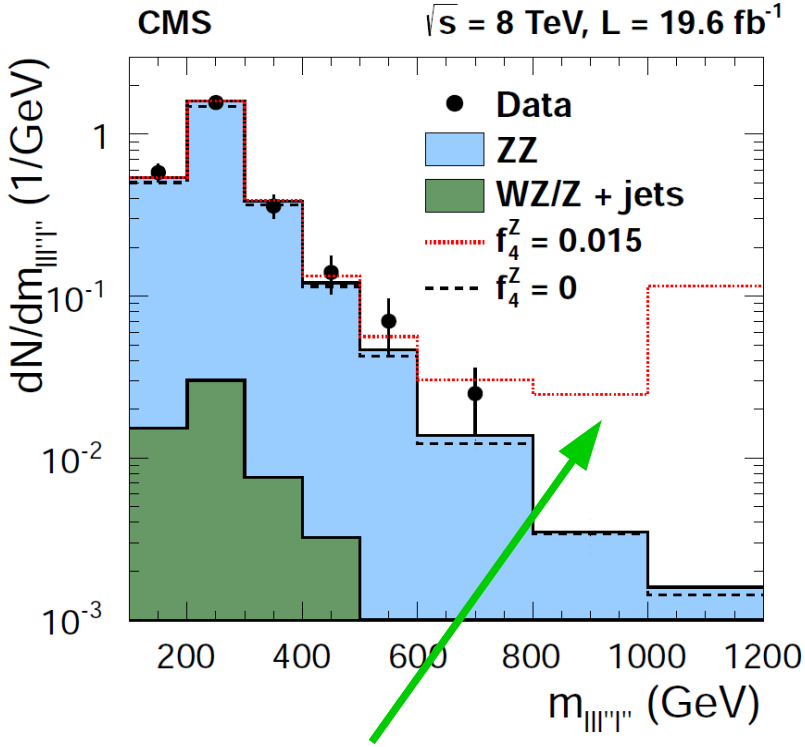
Backgrounds

- Mostly rejected by isolation and identification criteria.
- The remnants are Z/WZ+jets.

ZZ→2l2ν: expected to be published within next few weeks.

$$\sigma = 7.7 \pm 0.5(stat)^{+0.5}_{-0.4}(syst) \pm 0.4(theo) \pm 0.2(lumi)\ pb$$

Cross section in agreement with MCFM NLO expectation.



Anomalous couplings effects simulated with SHERPA and used to set limits on ZZZ and ZZγ couplings.

$W^+W^- \to 2l2\nu$ at 8 TeV

CMS-PAS-SMP-12-024

Phys. Lett. B 721 (2013) 190–211

Signature

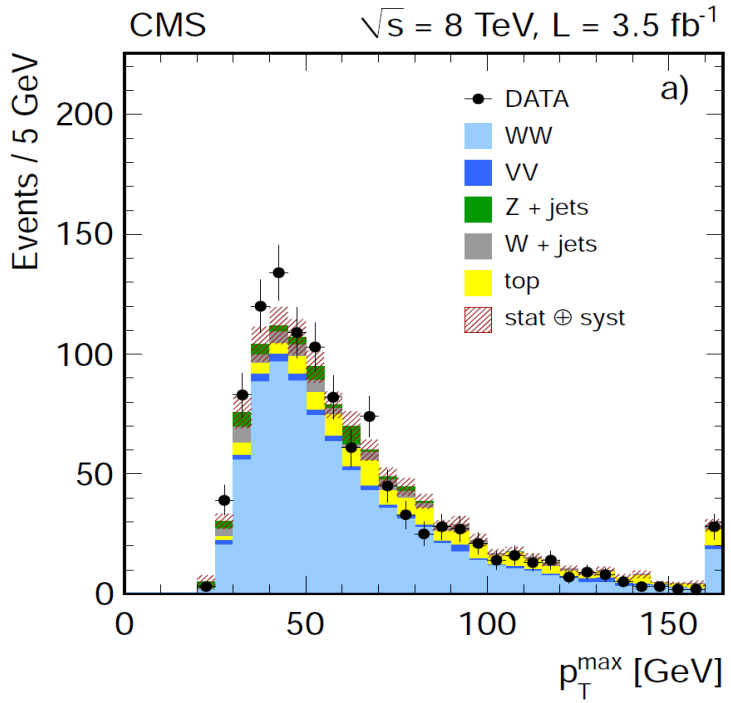
- Two oppositely charged electrons or muons with p_T>20 GeV plus MET.

Selections

- Jet veto and anti top-tagging to suppress top background.
- E_T^{miss}>45 GeV in same flavor final state to suppress DY.
- E_T^{miss}>20 GeV in opposite flavor.
- Extra lepton veto.

Backgrounds

- $t\bar{t}$ and tW
- VV
- Z/W + jets



$$\sigma = 69.9 \pm 2.8(stat) \pm 5.6(syst) \pm 3.1(lumi)\ pb$$

Inclusive cross section slightly higher than the SM NLO expectation of $57.3^{+2.3}_{-1.6}$ pb.

ATLAS result

$$\sigma = 71.4 \pm 1.2(stat) \pm 5.0(syst) \pm 2.2(lumi)\ pb$$

$VZ \rightarrow V+2$ b-jets

CMS-PAS-SMP-13-011

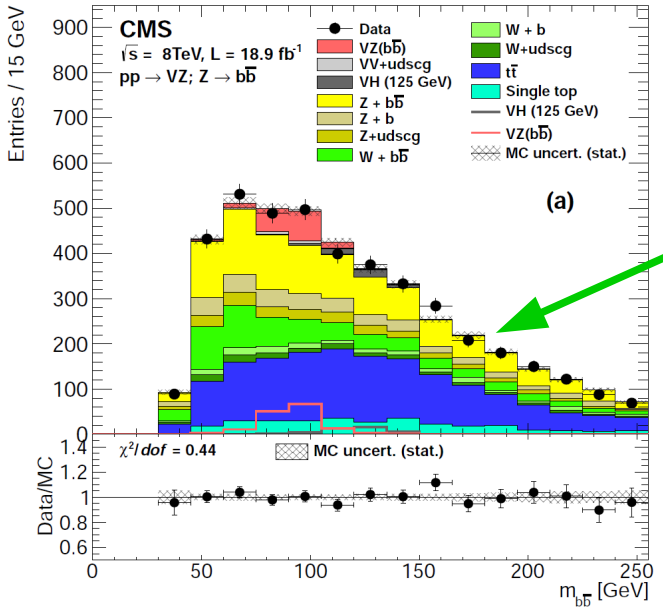
EPJC 74 (2014) 2973

Signature

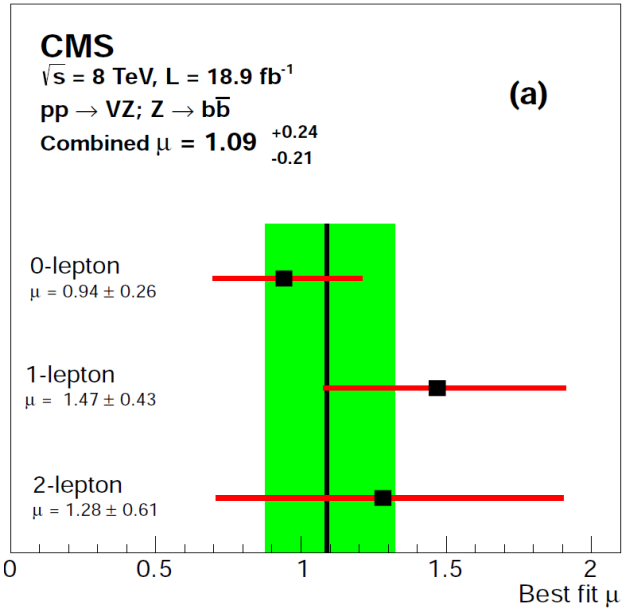
- Very similar to VH analysis with $H \rightarrow b\bar{b}$.
- Two b-tagged jets from Z decay.
- V detected through leptonic decay.

Selections

- Analysis divided into three lepton categories.
- $Z \rightarrow ll$: isolated and oppositely charged leptons with $60<M_{ll}<120$ GeV.
- $W \rightarrow l\nu$: single isolated lepton + $E_T^{miss}>45$ GeV
- $Z \rightarrow \nu\nu$: $E_T^{miss}>100$ GeV.
- $p_T^V>100$ GeV in each channel.



Main backgrounds are $t\bar{t}$ and V+jets

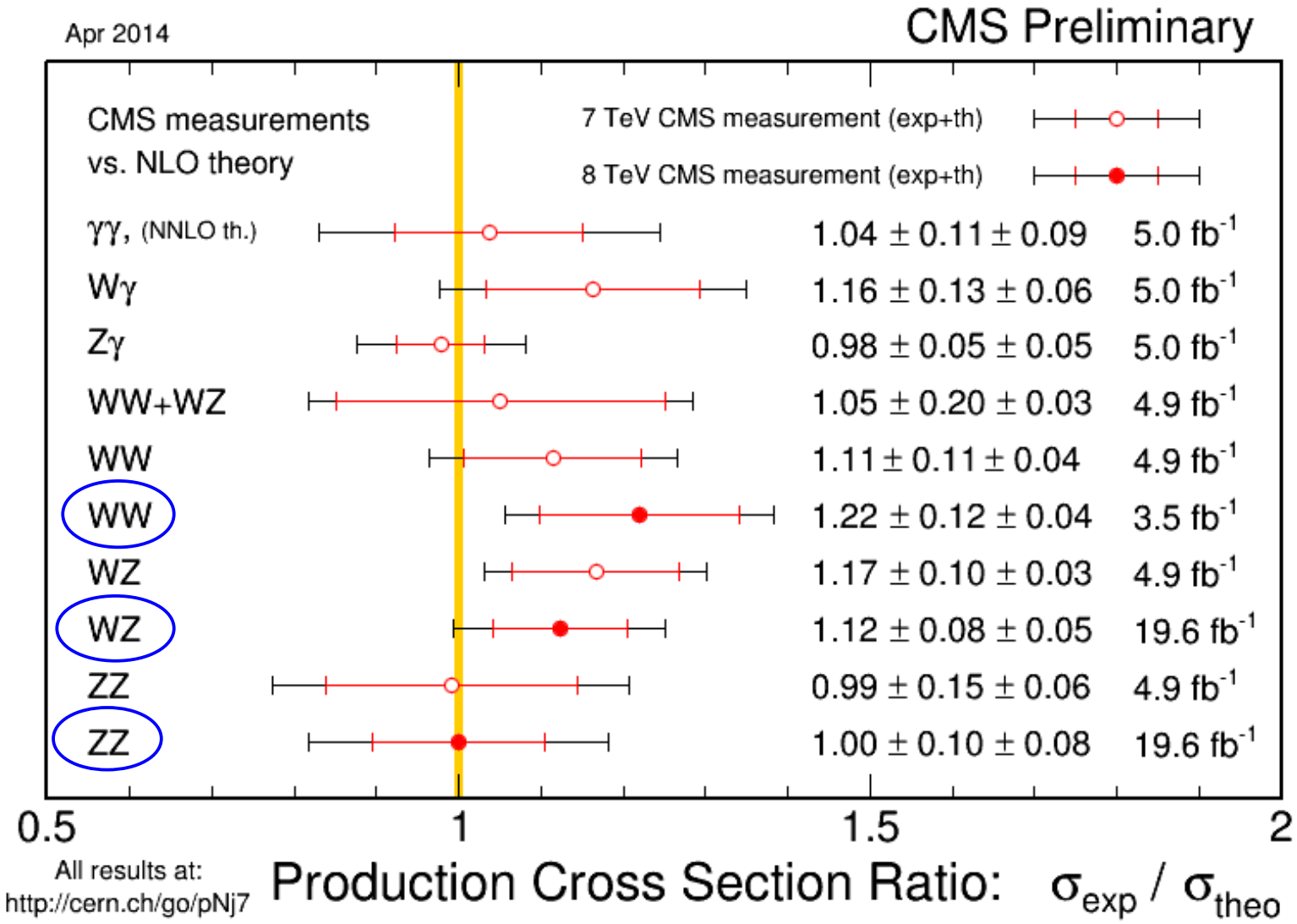


$$\sigma(WZ)=30.7\pm9.3(stat)\pm7.1(syst)\pm4.1(theo)\pm1.0(lumi)\,pb$$

MCFM NLO cross section = 22.3 ± 1.1 pb

In agreement also with $WZ \rightarrow 3l\nu$ channel

Diboson cross sections results

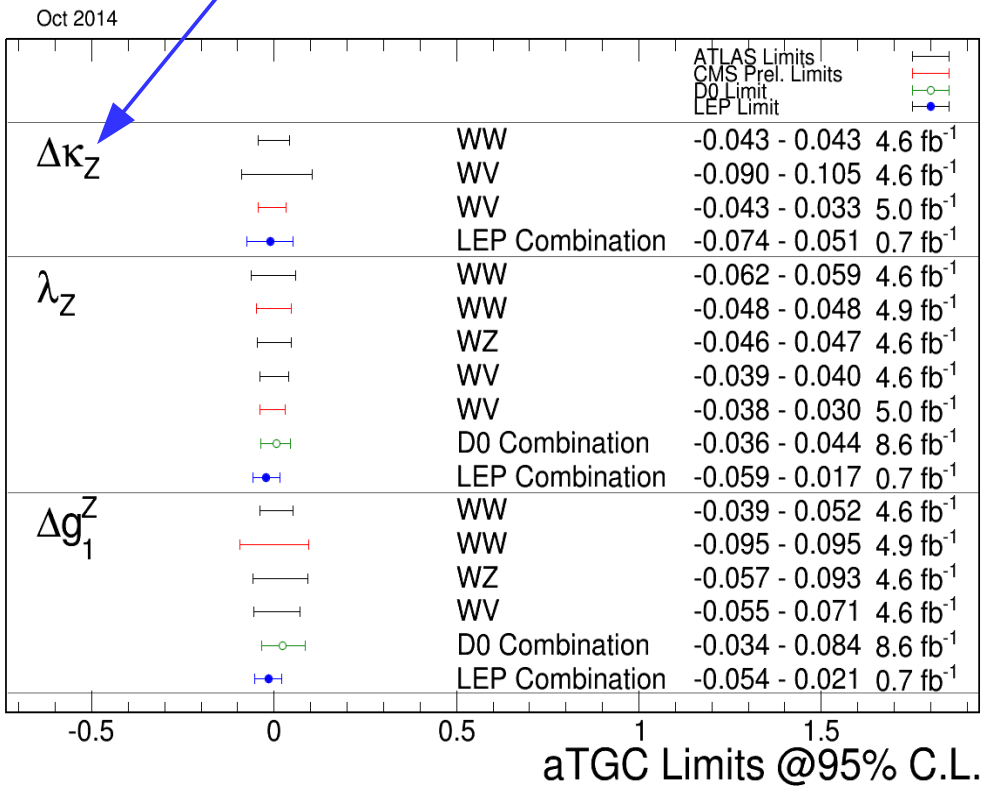


aTGCs results

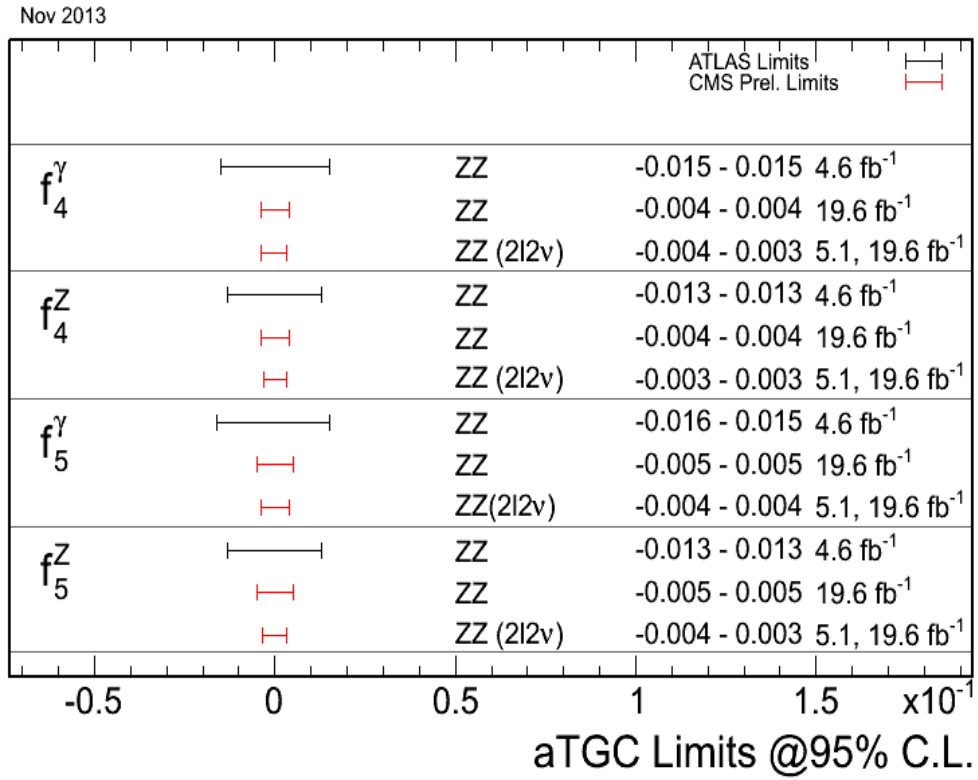
Charged aTGCs described using the LEP parameterization.

arXiv:hep-ph/9601233

WWZ vertex parameters



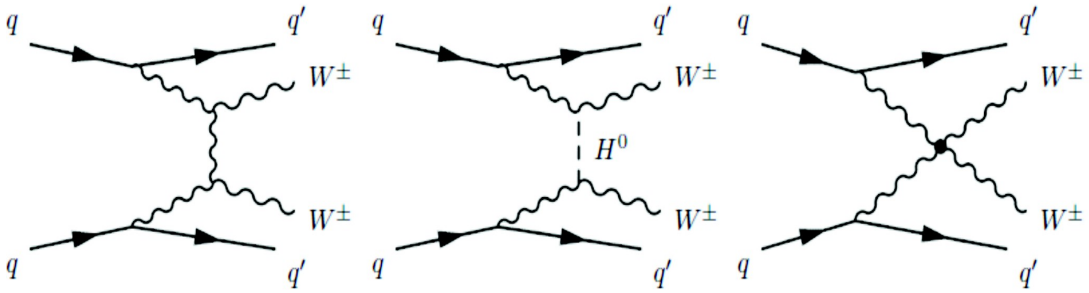
In SM all neutral TGCs are zero at tree level.
Limits are set on ZZZ and ZZγ couplings using anomalous parameters f_4^V and f_5^V.

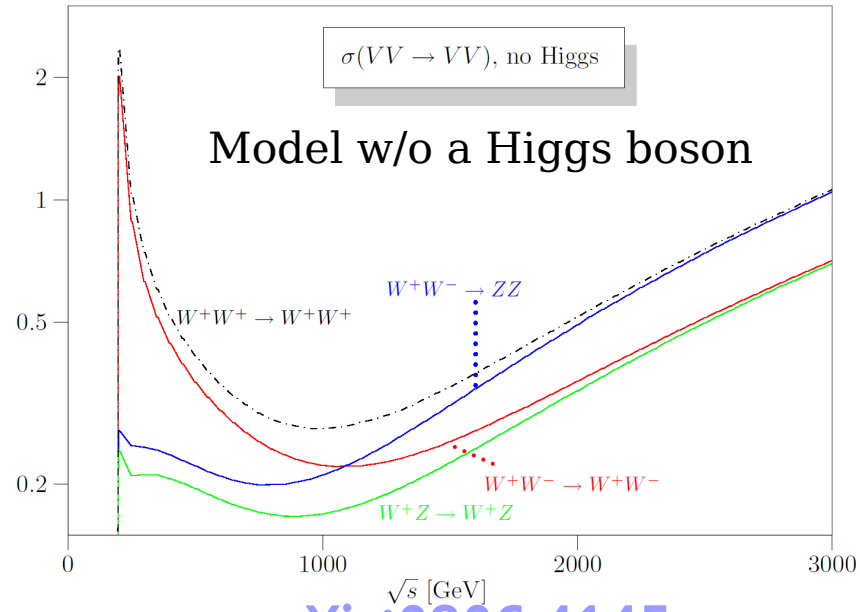


No evidence of anomalous triple gauge couplings is observed

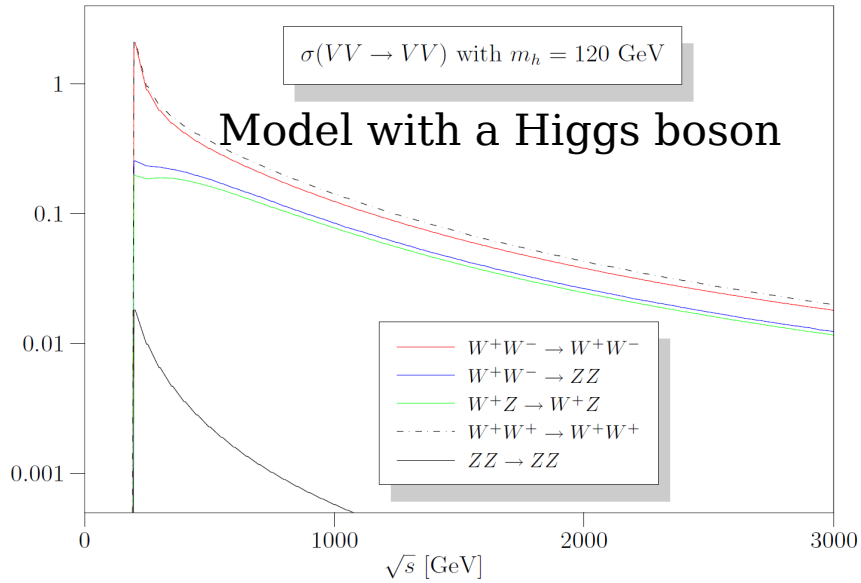
Vector Boson Scattering (VBS)

- Important process to probe the EWSB mechanism.
- The role of the Higgs boson in EWSB is essential to preserve the unitarity of VBS cross section.
- Same sign VBS provides the best S/B.





arXiv:0806.4145



VBS in $W^{\pm}W^{\pm}jj$

CMS-PAS-SMP-13-015

Signature & selections

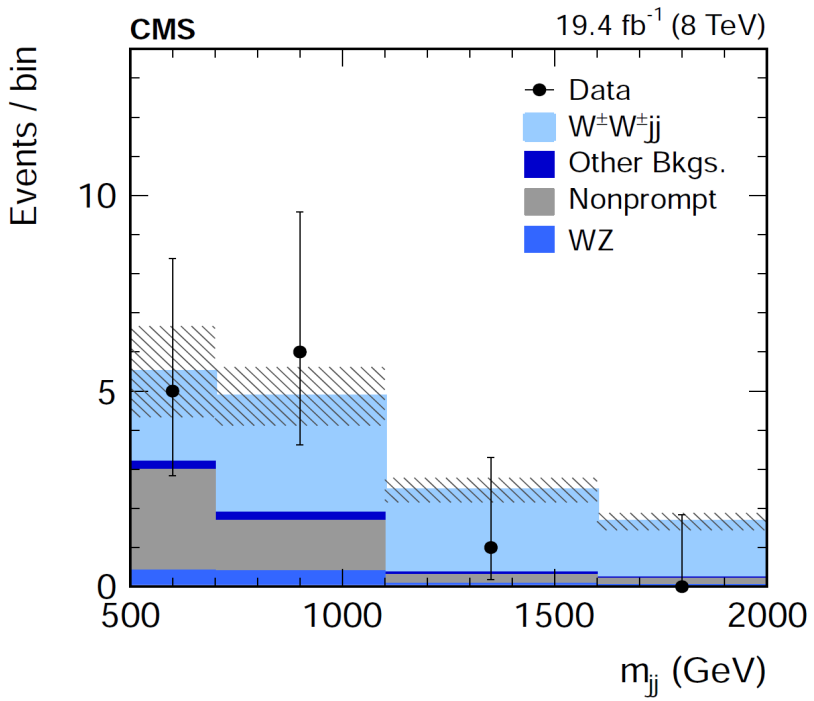
- Similar to $H \to WW$ analysis in VBF channel.
- Two leptons with same charge.
- Two forward jets with M_{jj}>500 GeV and $|\Delta\eta_{jj}|$>2.5.
- M_{ll}>50 GeV to reduce W+jets and top backgrounds.
- E_T^{miss} > 40 GeV.
- Z/top veto.

Backgrounds

- Nonprompt leptons (75%).
- $WZ \to 3l\upsilon$ (15%).
- Wrong-sign, DPS and VVV (10%).

$$\sigma_{fid}\left(W^{\pm}W^{\pm}jj\right) = 4.0^{+2.4}_{-2.0}\left(stat\right)^{+1.1}_{-1.0}\left(syst\right) fb$$

MadGraph+VBFNLO correction: 5.8 ± 1.2 fb



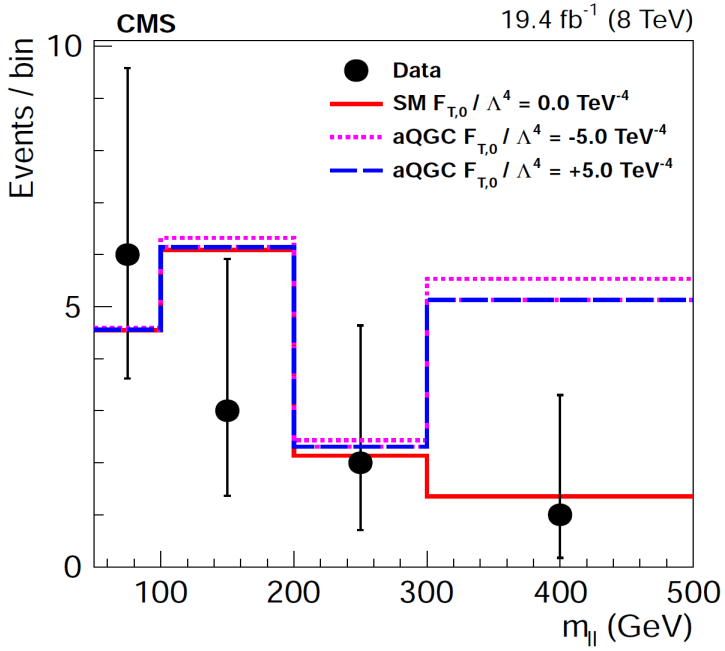
Results

- Results in agreement with SM with an observed (expected) significance of the $W^{\pm}W^{\pm}jj$ process of **2.0σ** (3.1σ).

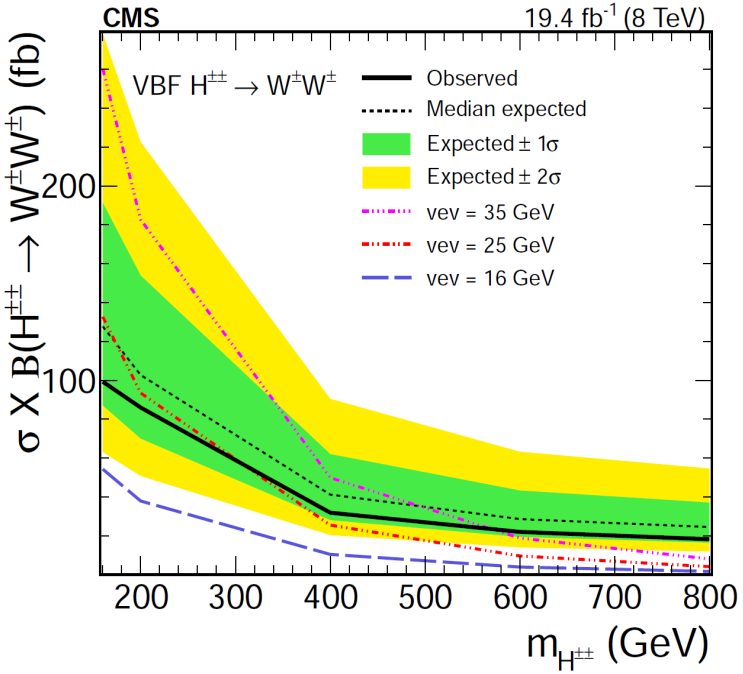
VBS in $W^{\pm}W^{\pm}jj$

Limits on alternative models

- An excess of events could be also interpreted in terms of aQGCs or models with doubly-charged Higgs boson.



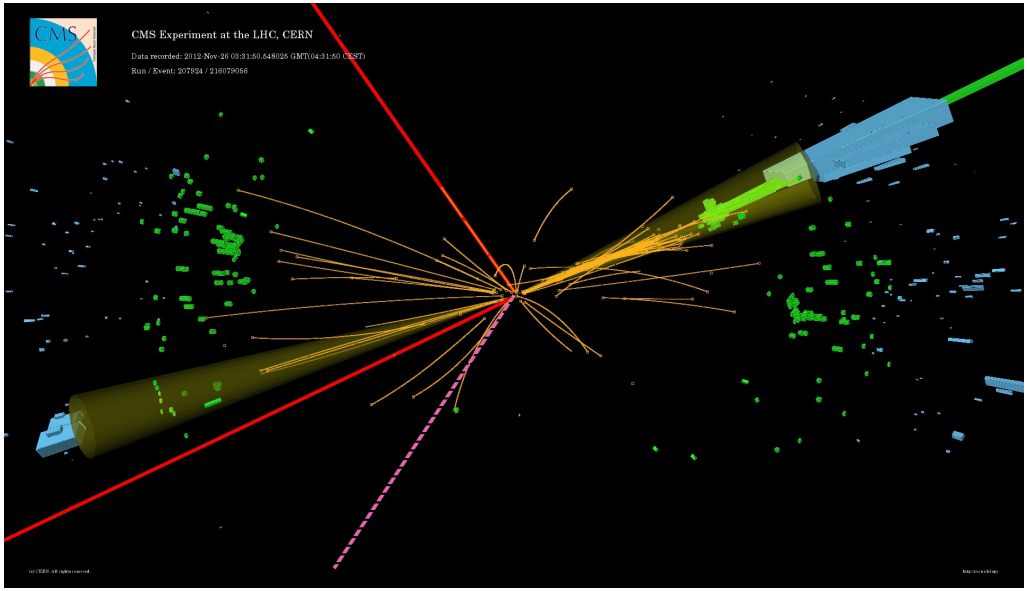
M_{ll} distribution most sensitive to aQGCs.



Upper limit on doubly-charged Higgs cross section

No evidence of aQGCs is observed

Conclusions



Candidate VBS event in the di-muon channel recorded by CMS

- CMS provided precise cross sections measurements for diboson processes using 7 and 8 TeV data.
- Limits on charged and neutral aTGCs have been set and no evidence of deviations from SM is found.
- ATLAS and CMS reported the first evidence of VBS at LHC.
- Run2 data taking is essential to achieve higher significance on same sign VBS.

BACKUP

Analyses references

	DIBOSON PROCESSES		VECTOR BOSON SCATTERING
PAS	ZZ	SMP-13-005	SMP-13-015
	WW	SMP-12-024	
	WZ	SMP-13-011	
Luminosity and Energy	ZZ	19.4 fb^{-1} (8 TeV)	19.4 fb^{-1} (8 TeV)
	WW	3.5 fb^{-1} (8 TeV)	
	WZ	18.9 fb^{-1} (8 TeV)	
Results	Cross section and aTGCs limits		aQGCs and H^{++} limits

Signature & Selections

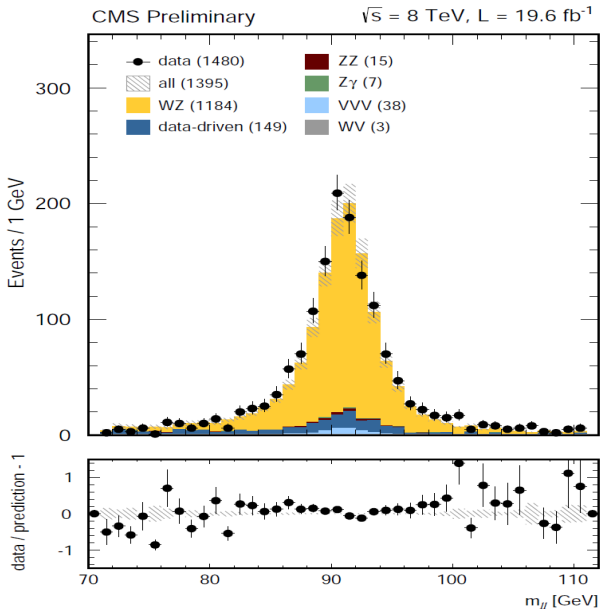
- Events with 3 leptons in the final state.
- Two oppositely charged e or μ peaking at M_Z, from the Z boson decay.
- One isolated lepton plus MET from the W decay.

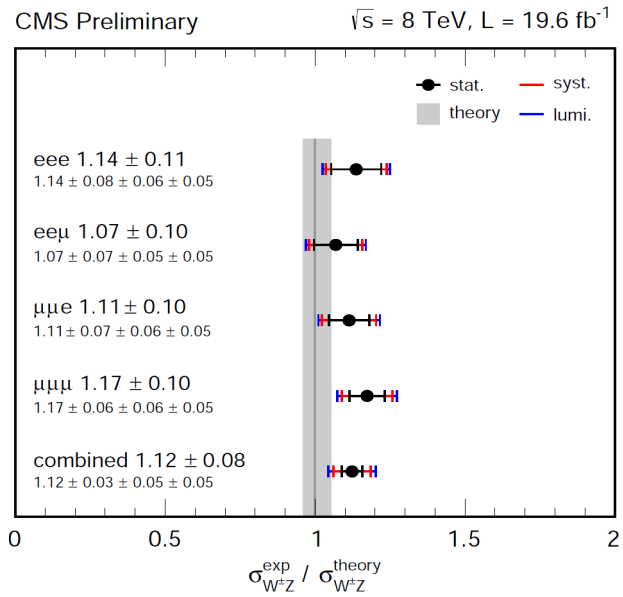
Backgrounds

- Non-peaking: $t\bar{t}$.
- Z+fake lepton: fake laptons from jets or photons.
- Z+prompt lepton: $ZZ \rightarrow 4l$ events with a non detected lepton.

$$\sigma = 24.61 \pm 0.76\,(stat) \pm 1.13\,(syst) \pm 1.08\,(lumi)\ pb$$

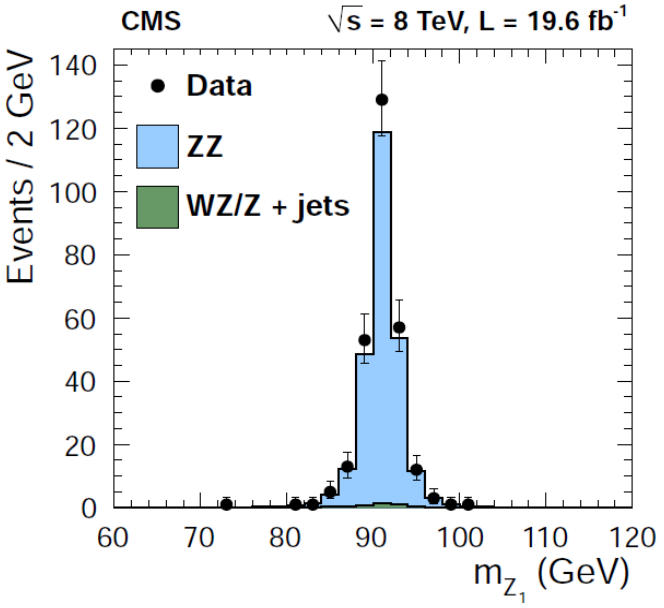
MCFM cross section = 22.3 ± 1.1 pb





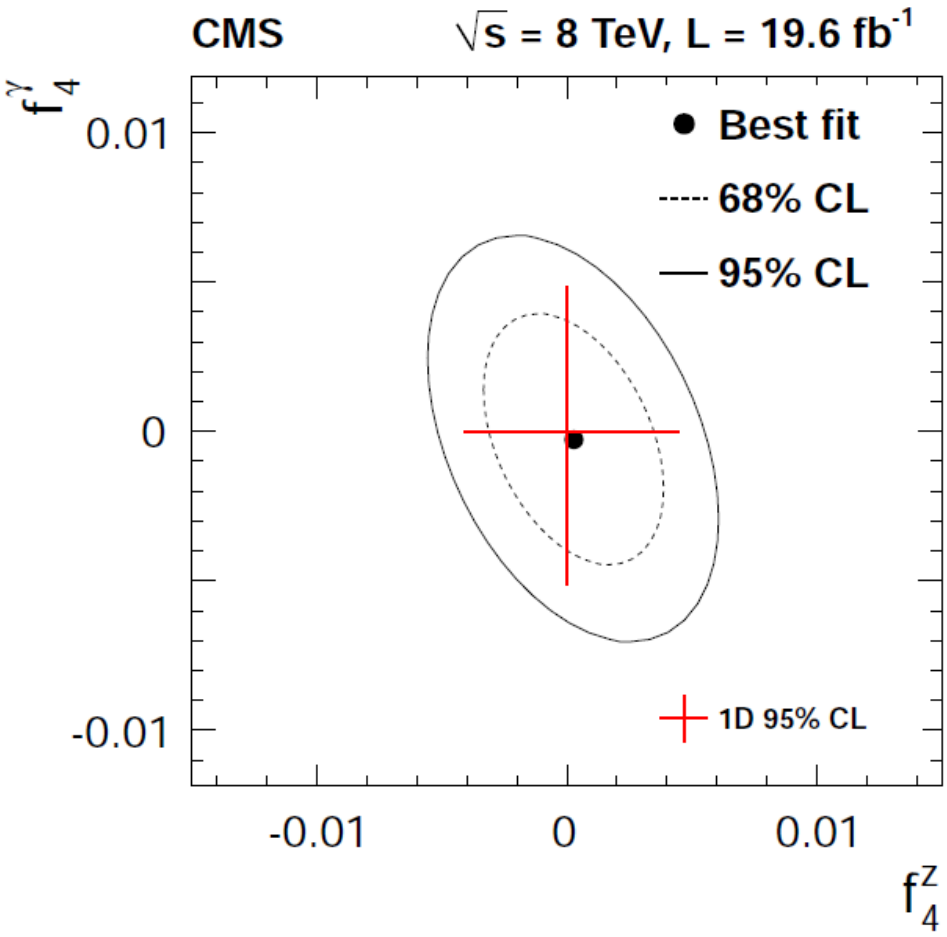
$ZZ \to 4l$ yields

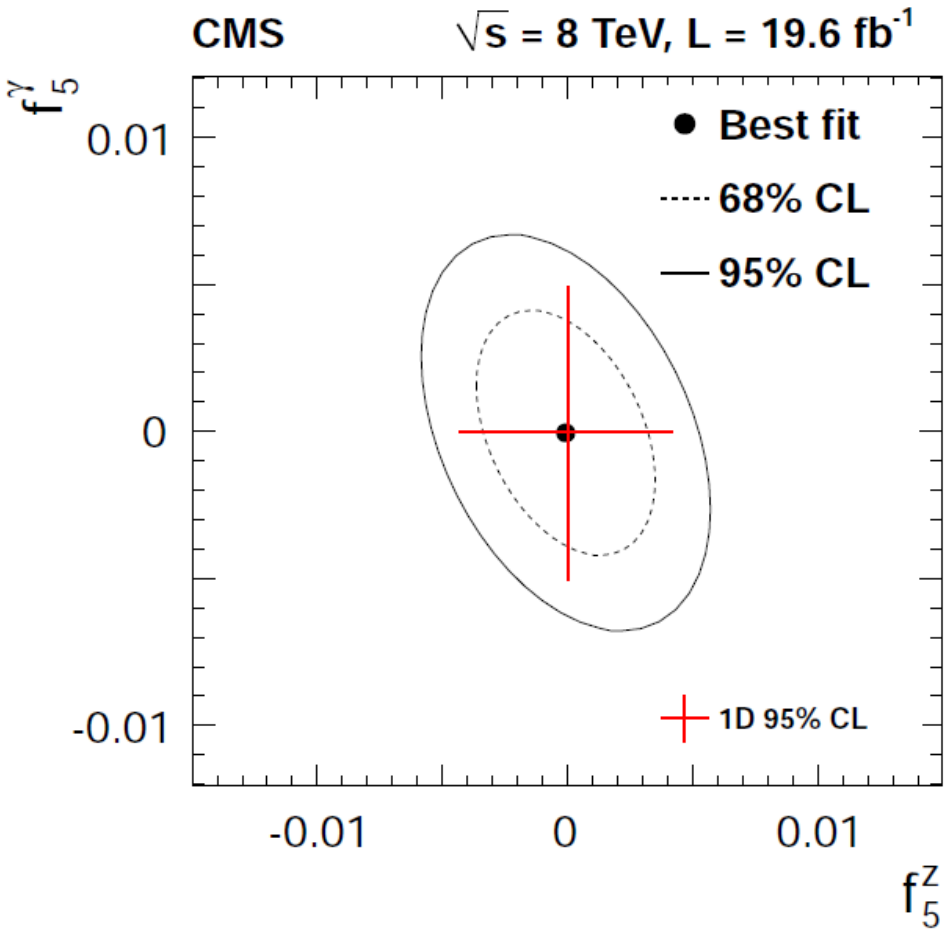
Decay channel	Expected ZZ yield	Background	Total expected	Observed
4e	$55.28 \pm 0.25 \pm 7.64$	$2.16 \pm 0.26 \pm 0.88$	$57.44 \pm 0.37 \pm 7.69$	54
4μ	$77.32 \pm 0.29 \pm 10.08$	$1.19 \pm 0.36 \pm 0.48$	$78.51 \pm 0.49 \pm 10.09$	75
$2e2\mu$	$136.09 \pm 0.59 \pm 17.50$	$2.35 \pm 0.34 \pm 0.93$	$138.44 \pm 0.70 \pm 17.52$	148
$ee\tau_h\tau_h$	$2.46 \pm 0.03 \pm 0.32$	$3.46 \pm 0.34 \pm 1.04$	$5.92 \pm 0.36 \pm 1.15$	10
$\mu\mu\tau_h\tau_h$	$2.80 \pm 0.03 \pm 0.34$	$3.89 \pm 0.37 \pm 1.17$	$6.69 \pm 0.39 \pm 1.30$	10
$ee\tau_e\tau_h$	$2.79 \pm 0.03 \pm 0.36$	$3.87 \pm 1.26 \pm 1.16$	$6.66 \pm 1.34 \pm 1.29$	9
$\mu\mu\tau_e\tau_h$	$2.87 \pm 0.03 \pm 0.37$	$1.49 \pm 0.67 \pm 0.60$	$4.36 \pm 0.71 \pm 0.73$	2
$ee\tau_\mu\tau_h$	$3.27 \pm 0.03 \pm 0.42$	$1.47 \pm 0.41 \pm 0.44$	$4.74 \pm 0.43 \pm 0.63$	2
$\mu\mu\tau_\mu\tau_h$	$3.81 \pm 0.03 \pm 0.50$	$1.55 \pm 0.43 \pm 0.46$	$5.36 \pm 0.46 \pm 0.70$	5
$ee\tau_e\tau_\mu$	$2.23 \pm 0.03 \pm 0.29$	$3.04 \pm 1.32 \pm 1.50$	$5.27 \pm 1.40 \pm 1.61$	4
$\mu\mu\tau_e\tau_\mu$	$2.41 \pm 0.03 \pm 0.32$	$0.74 \pm 0.51 \pm 0.37$	$3.15 \pm 0.54 \pm 0.51$	5
Total $\ell\ell\tau\tau$	$22.65 \pm 0.05 \pm 2.94$	$19.51 \pm 2.15 \pm 5.85$	$42.16 \pm 2.28 \pm 6.87$	47



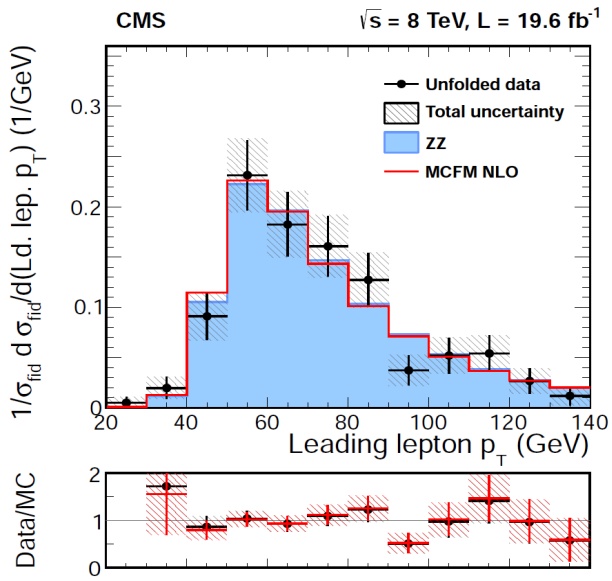
Decay channel	Total cross section, pb
4e	$7.2\,^{+1.0}_{-0.9}\,(\text{stat})\,^{+0.6}_{-0.5}\,(\text{syst}) \pm 0.4\,(\text{theo}) \pm 0.2\,(\text{lumi})$
4μ	$7.3\,^{+0.8}_{-0.8}\,(\text{stat})\,^{+0.6}_{-0.5}\,(\text{syst}) \pm 0.4\,(\text{theo}) \pm 0.2\,(\text{lumi})$
$2e2\mu$	$8.1\,^{+0.7}_{-0.6}\,(\text{stat})\,^{+0.6}_{-0.5}\,(\text{syst}) \pm 0.4\,(\text{theo}) \pm 0.2\,(\text{lumi})$
$\ell\ell\tau\tau$	$7.7\,^{+2.1}_{-1.9}\,(\text{stat})\,^{+2.0}_{-1.8}\,(\text{syst}) \pm 0.4\,(\text{theo}) \pm 0.2\,(\text{lumi})$
Combined	$7.7 \pm 0.5\,(\text{stat})\,^{+0.5}_{-0.4}\,(\text{syst}) \pm 0.4\,(\text{theo}) \pm 0.2\,(\text{lumi})$

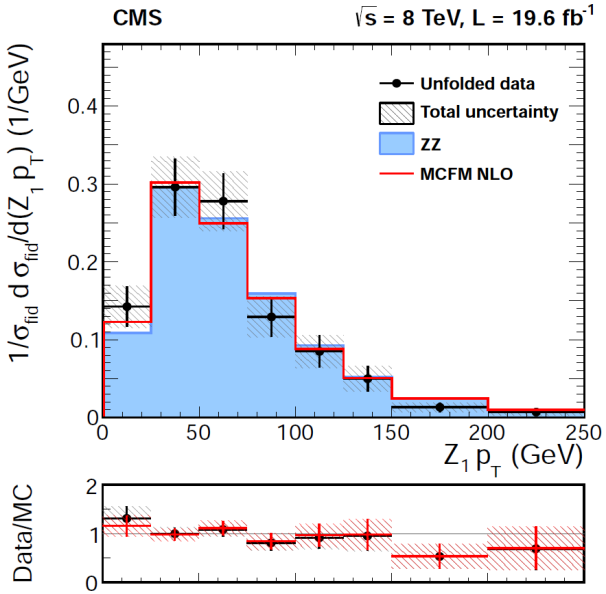
ZZ→4l aTGC limits

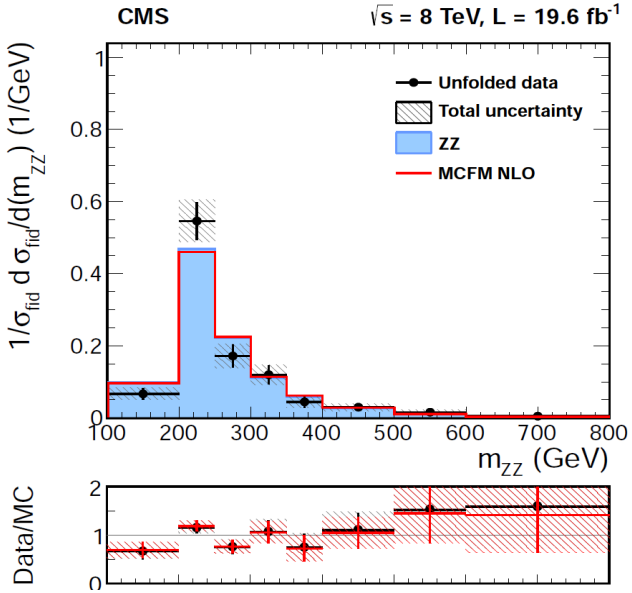


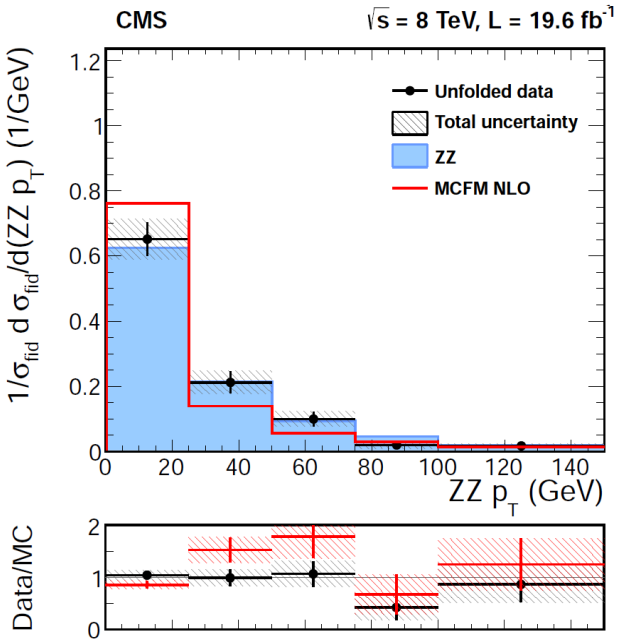


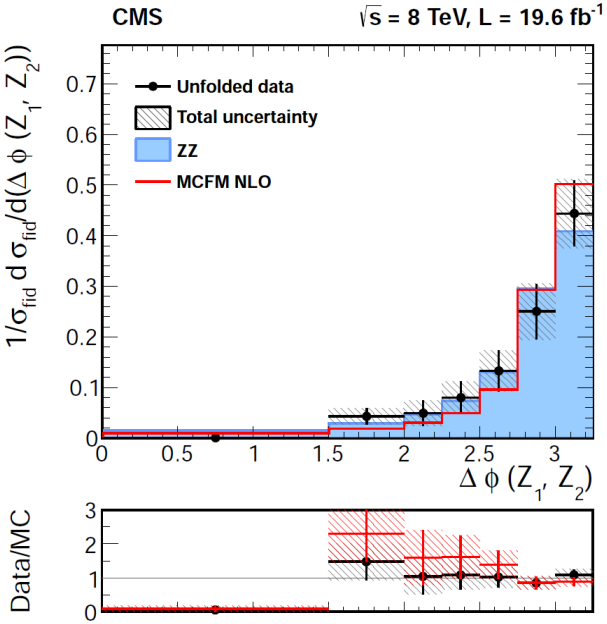
$ZZ \to 4l$ differential cross sections

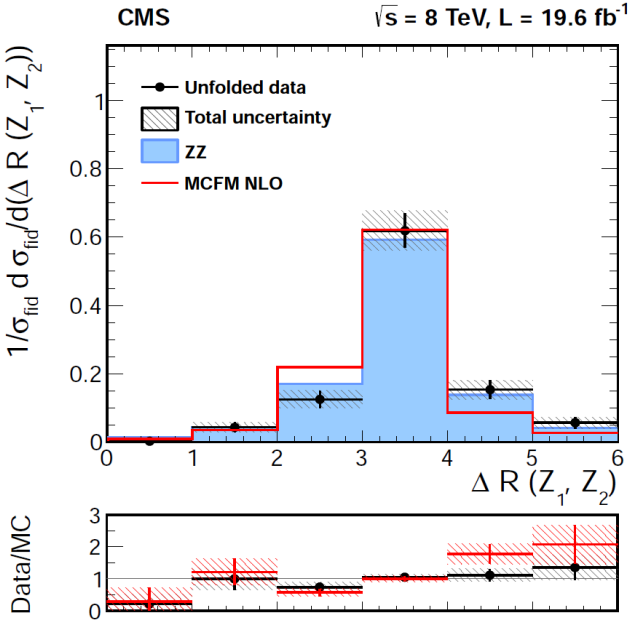






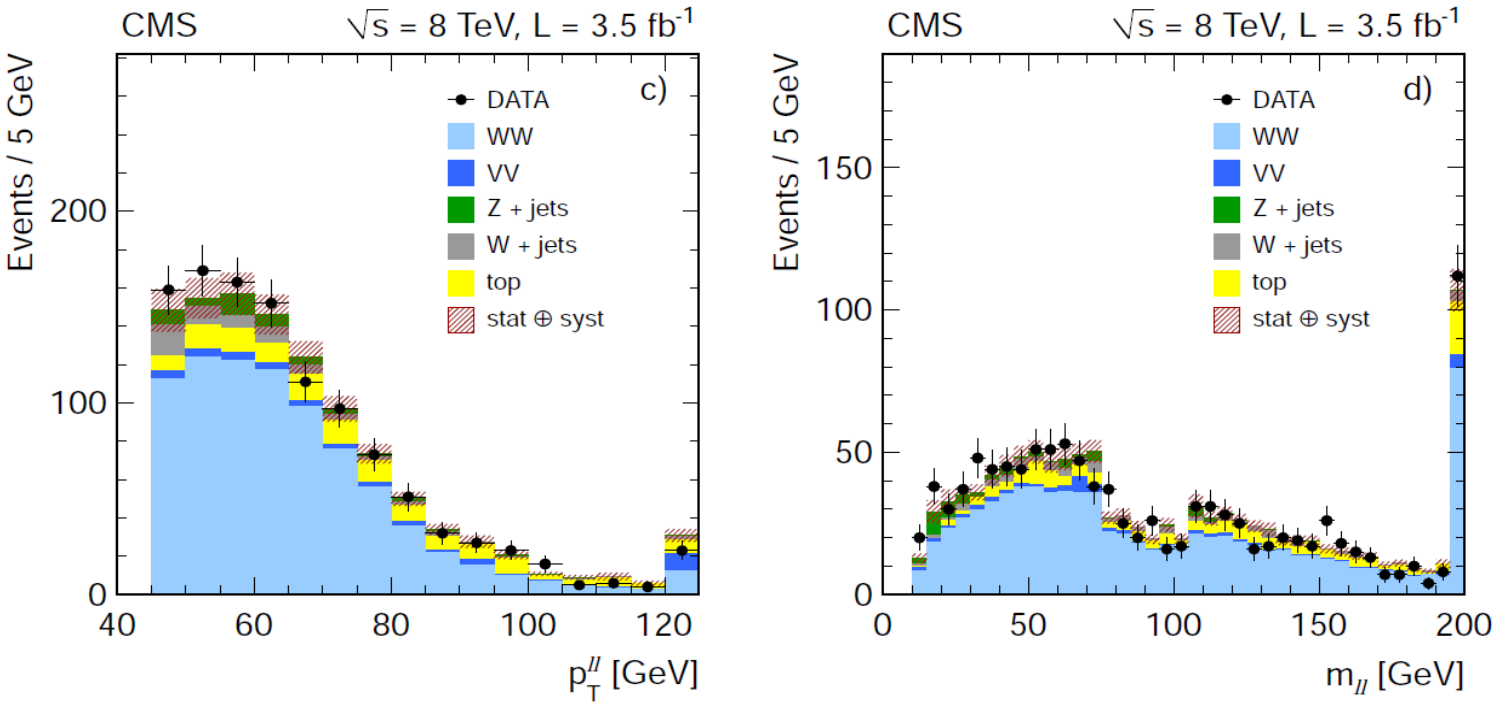




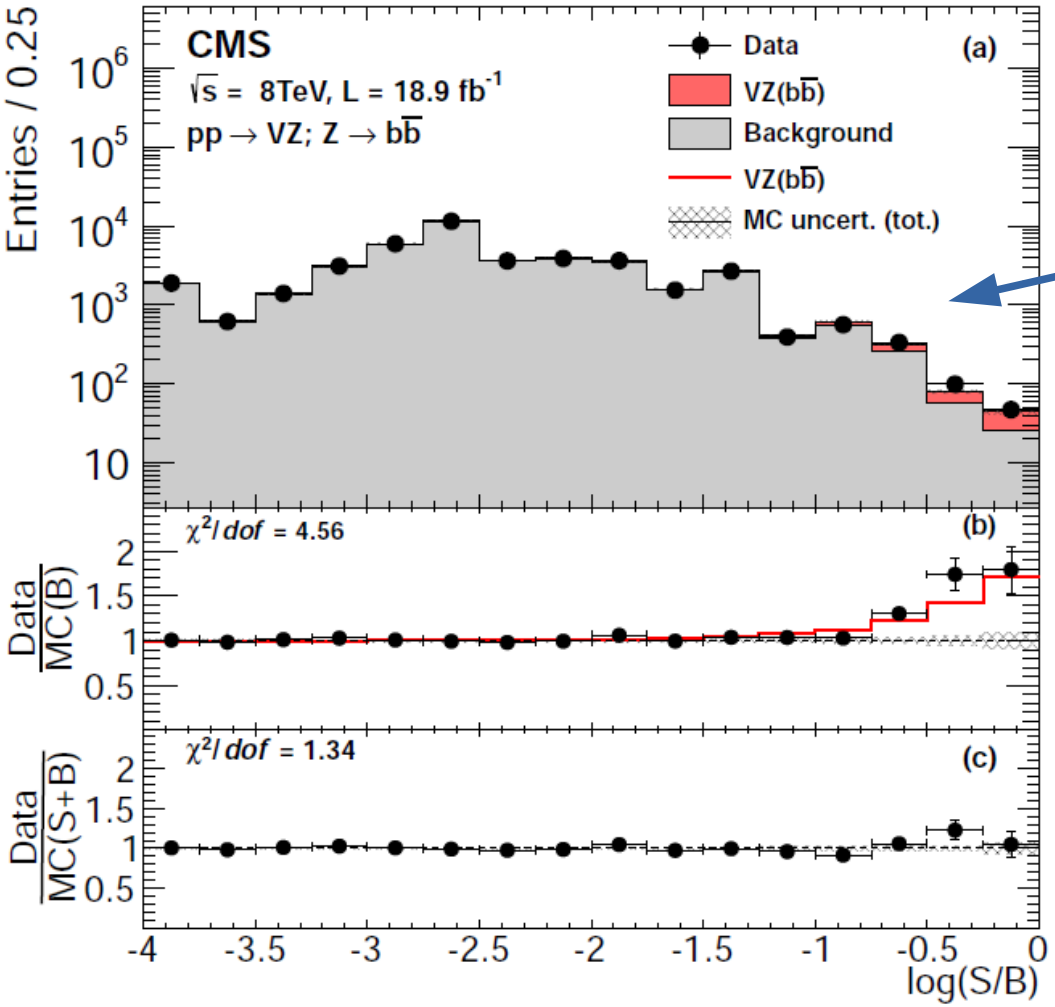


$W^+W^- \to 2l2\nu$ yields

Channel	$\ell'\nu\ell''\nu$
W^+W^-	684 ± 50
$t\bar{t}$ and tW	132 ± 23
W+jets	60 ± 22
WZ and ZZ	27 ± 3
Z/γ^*+jets	43 ± 12
$W\gamma^{(*)}$	14 ± 5
Total background	275 ± 35
Signal + background	959 ± 60
Data	1111

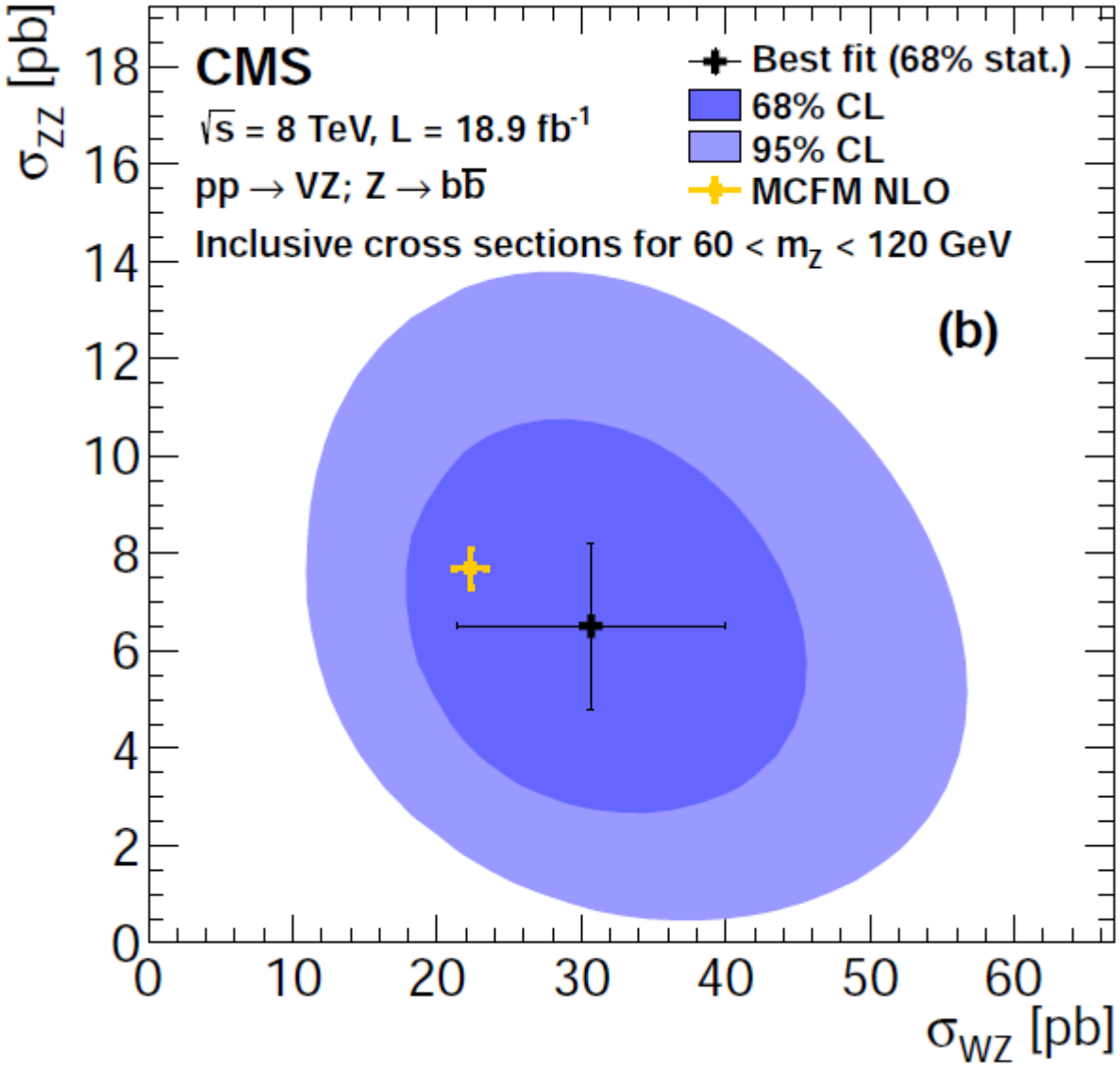


VZ→V+2 b-jets MVA



Combined distribution for all channels in the value of the logarithm of the ratio of signal to background (S/B) discriminants in data and in MC simulations, based on the outputs of the S and B BDT discriminants for each event.

VZ→V+2 b-jets contour plot



aTGCs parameterization

- LEP parameterization: respects SU(2)xU(1) gauge invariance and conserves the charge conjugation and and parity symmetries.
- Involves 5 parameters:

  1) $\Delta g_1^Z = g_1^Z - 1$

  2) $\Delta k_\gamma = k_\gamma - 1$

  3) $\Delta k_Z = k_Z - 1$

  4) λ_γ

  5) λ_Z

$$\begin{aligned}\mathcal{L} \;=\; & ig_{WWV}\Big(g_1^V(W^+_{\mu\nu}W^{-\mu} - W^{+\mu}W^-_{\mu\nu})V^\nu + \kappa_V W^+_\mu W^-_\nu V^{\mu\nu} + \frac{\lambda_V}{M_W^2}W^{\nu+}_\mu W^{-\rho}_\nu V^\mu_\rho \\ & + ig_4^V W^+_\mu W^-_\nu(\partial^\mu V^\nu + \partial^\nu V^\mu) - ig_5^V\epsilon^{\mu\nu\rho\sigma}(W^+_\mu\partial_\rho W^-_\nu - \partial_\rho W^+_\mu W^-_\nu)V_\sigma \\ & + \tilde\kappa_V W^+_\mu W^-_\nu \tilde V^{\mu\nu} + \frac{\tilde\lambda_V}{m_W^2}W^{\nu+}_\mu W^{-\rho}_\nu \tilde V^\mu_\rho\Big)\end{aligned}$$

- Because of gauge invariance only 3 parameters are independent:

  1) $\Delta k_Z = \Delta g_1^Z - \Delta k_\gamma \tan^2\theta_W$

  2) $\lambda_\gamma = \lambda_Z$

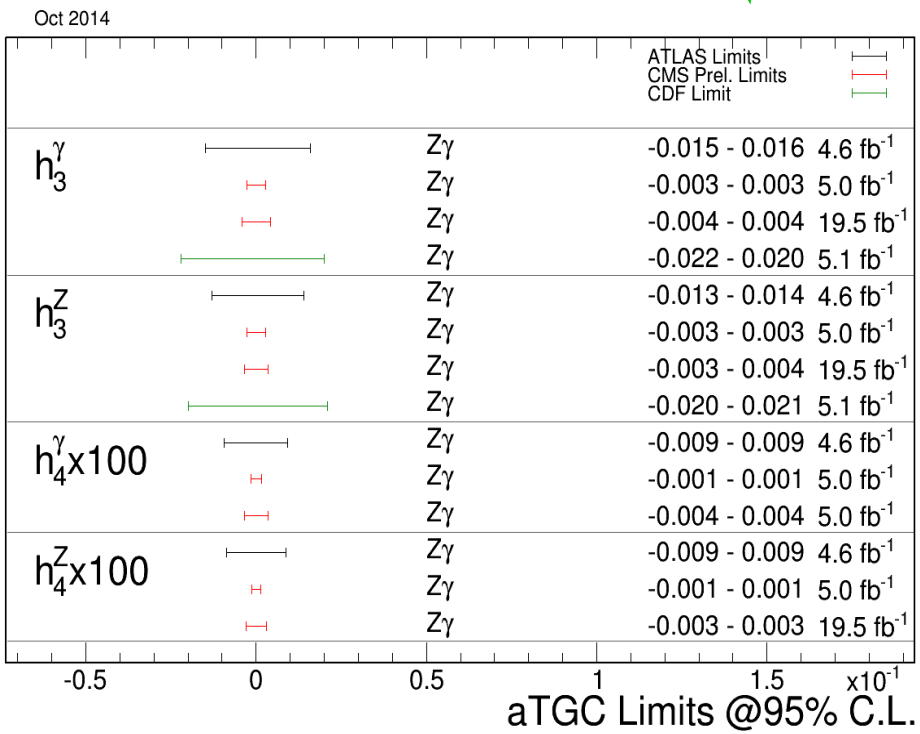
aQGCs parameterization

$$\mathscr{L}_{\text{eff}} = \mathscr{L}_{\text{SM}} + \sum_{\text{dimension } d} \sum_{i} \frac{c_i^{(d)}}{\Lambda^{d-4}} \mathcal{O}_i^{(d)}$$

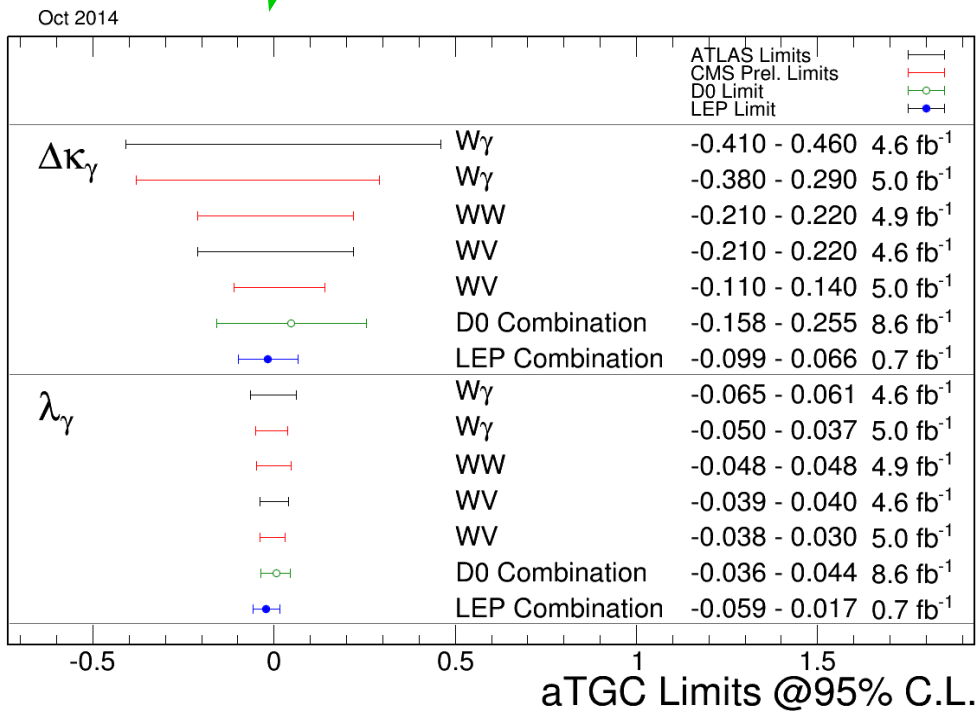
- Effective field theory approach: put new physics in higher dimension terms.
- New physics appear as anomalous QGC.
- It is a model independent approach, complementary to direct searches.
- Different parameterizations = dimension-6 or dimension-8 operators.

aTGCs summary

Limits on neutral aTGCs for ZZγ and Zγγ

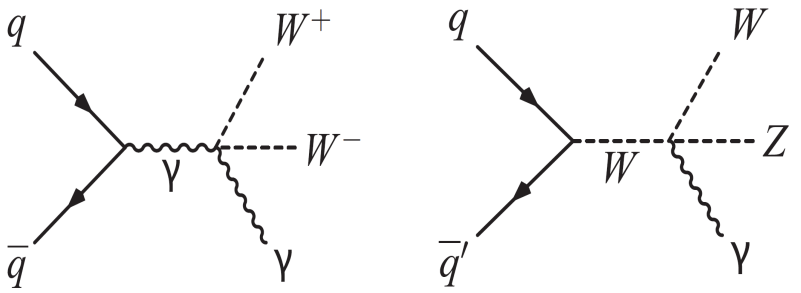


Limits on charged aTGCs for WWγ



Triple-boson processes

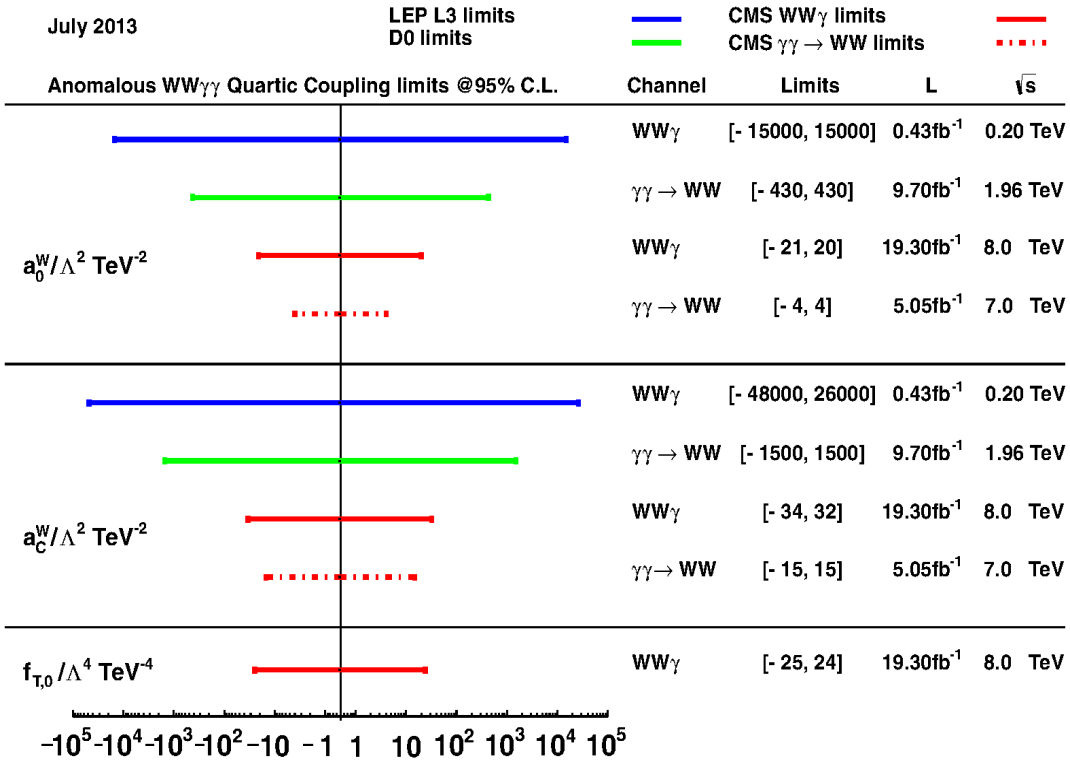
- Diboson final states in scattering topologies and triboson final states can be used to set limits on quartic gauge couplings (aQGCs).



Observed Limits	Expected Limits
$-21\ (\text{TeV}^{-2}) < a_0^W/\Lambda^2 < 20\ (\text{TeV}^{-2})$	$-24\ (\text{TeV}^{-2}) < a_0^W/\Lambda^2 < 23\ (\text{TeV}^{-2})$
$-34\ (\text{TeV}^{-2}) < a_C^W/\Lambda^2 < 32\ (\text{TeV}^{-2})$	$-37\ (\text{TeV}^{-2}) < a_C^W/\Lambda^2 < 34\ (\text{TeV}^{-2})$
$-25\ (\text{TeV}^{-4}) < f_{T,0}/\Lambda^4 < 24\ (\text{TeV}^{-4})$	$-27\ (\text{TeV}^{-4}) < f_{T,0}/\Lambda^4 < 27\ (\text{TeV}^{-4})$
$-12\ (\text{TeV}^{-2}) < \kappa_0^W/\Lambda^2 < 10\ (\text{TeV}^{-2})$	$-12\ (\text{TeV}^{-2}) < \kappa_0^W/\Lambda^2 < 12\ (\text{TeV}^{-2})$
$-18\ (\text{TeV}^{-2}) < \kappa^W/\Lambda^2 < 17\ (\text{TeV}^{-2})$	$-19\ (\text{TeV}^{-2}) < \kappa^W/\Lambda^2 < 18\ (\text{TeV}^{-2})$

First experimental limits

- a_0^W, a_C^W : dimension-6 parameters associated with WWγγ vertex.
- k_0^W, k^W : dimension-6 parameters associated with WWZγ vertex.
- $f_{T,0}$: dimension-8 parameter associated to both verices.



WWγ and WZγ

CMS-PAS-SMP-13-009

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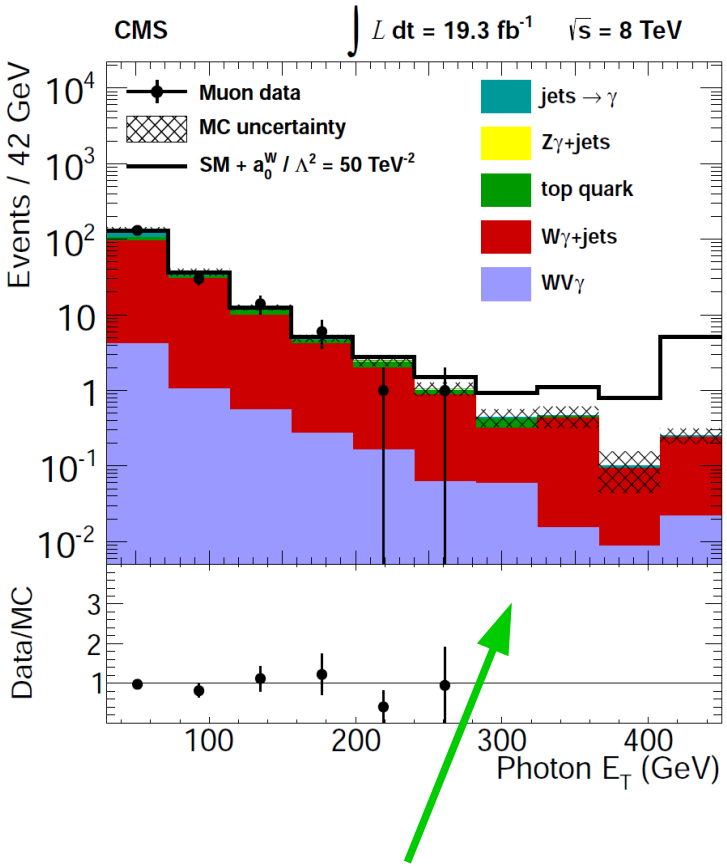

aQGCs limits extracted from photon E_T distribution.

Signal signature

- Events with one photon and a pair of vector bosons (WV).
- One W is required to decay to leptons and the other boson (W or Z) decays hadronically.

Selections

- Similar to the previous analyses.
- Photon required to have ET>30 GeV.
- Events with photon candidates in the endcaps are rejected.

Results

- Only upper limit of 311 fb at 95% CL on Wvg cross section (3.4 times larger than SM prediction).
- No evidence for anomalous WWgg and WWZg QGCs is found.

VBS in $W^{\pm}W^{\pm}jj$

Signal and background yields in same sign *WWjj*

	Nonprompt	WZ	VVV	Wrong sign	WW DPS	Total bkg.	$W^{\pm}W^{\pm}jj$	Data
W^+W^+	2.1 ± 0.6	0.6 ± 0.1	0.2 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	3.1 ± 0.6	7.1 ± 0.1	10
W^-W^-	2.1 ± 0.5	0.4 ± 0.1	0.1 ± 0.1	—	—	2.6 ± 0.5	1.8 ± 0.1	2
$W^{\pm}W^{\pm}$	4.2 ± 0.8	1.0 ± 0.1	0.3 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	5.7 ± 0.8	8.9 ± 0.1	12

Upper and lower limits on on the nine dimension-8 parameters affecting QGCs between weak gauge bosons.

Operator coefficient	Exp. lower	Exp. upper	Obs. lower	Obs. upper	Unitarity limit
$F_{S,0}/\Lambda^4$	−42	43	−38	40	0.016
$F_{S,1}/\Lambda^4$	−129	131	−118	120	0.050
$F_{M,0}/\Lambda^4$	−35	35	−33	32	80
$F_{M,1}/\Lambda^4$	−49	51	−44	47	205
$F_{M,6}/\Lambda^4$	−70	69	−65	63	160
$F_{M,7}/\Lambda^4$	−76	73	−70	66	105
$F_{T,0}/\Lambda^4$	−4.6	4.9	−4.2	4.6	0.027
$F_{T,1}/\Lambda^4$	−2.1	2.4	−1.9	2.2	0.022
$F_{T,2}/\Lambda^4$	−5.9	7.0	−5.2	6.4	0.08

VBS in $W^{\pm}W^{\pm}jj$

Fiducial region

- Two same sign leptons with p_T^l>10 GeV and $|\eta_l|$<2.5.
- Two jets with p_T^j>20 GeV and $|\eta_l|$<5.0.
- M_{jj}>300 GeV
- $|\Delta\eta_{jj}|$>2.5