Recent electroweak measurements at the LHC

Li Yuan
Kobe University, Japan
On Behalf of the ATLAS and CMS collaborations
August 11~18, 2013
RdV2013

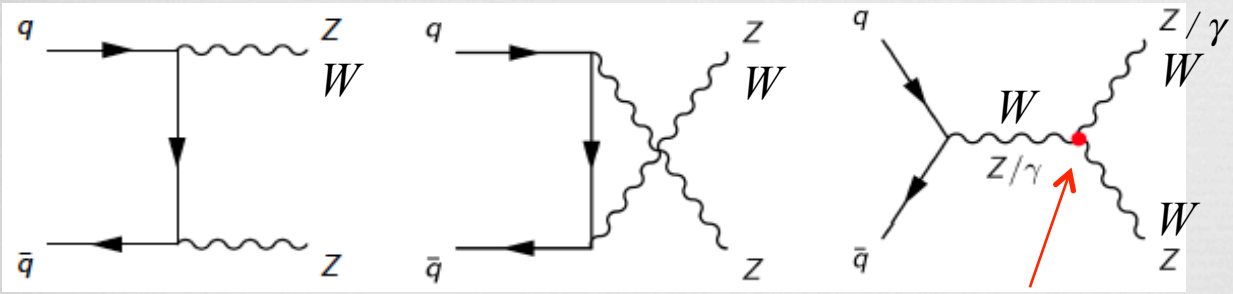
A rich menu of results

- Inclusive W/Z production cross sections and properties
  - Fiducial, total and differential cross sections
  - W charge asymmetry, W polarization, Drell-Yan forward-backward asymmetry …
- W/Z production in association with jets
  - Jet rates, event shape, b and c jet(s)
- Diboson production
  - Fiducial, total and differential cross sections (xs)
  - Search for anomalous Triple Gauge Boson couplings
- Triboson production
  - Search for anomalous Quartic Gauge Boson couplings

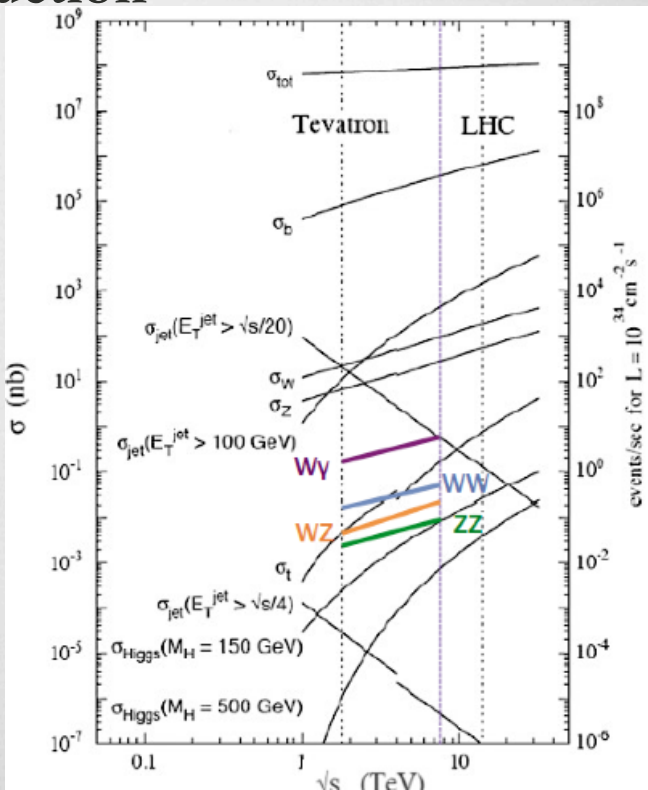
Too many measurements to cover, thus only focus on some of them: diboson and triboson production.

Diboson production

- Motivation:
  - Important test of SM EW sector
  - Sensitive to new phenomena
  - Irreducible background of Higgs production and relevant exotic searches
- Channels: WW, WZ, ZZ, Wγ, Zγ



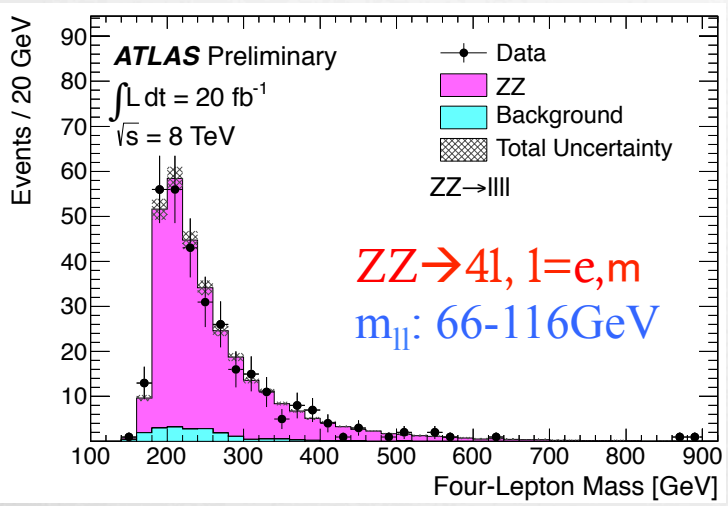
Triple Gauge Coupling (TGC)

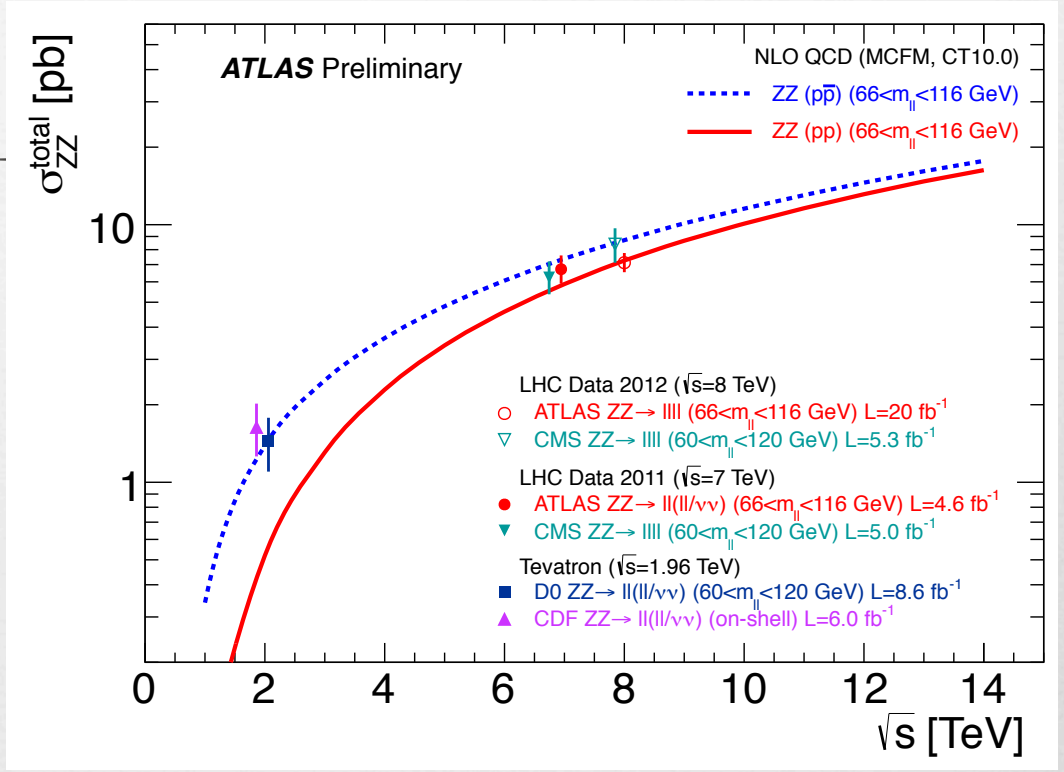


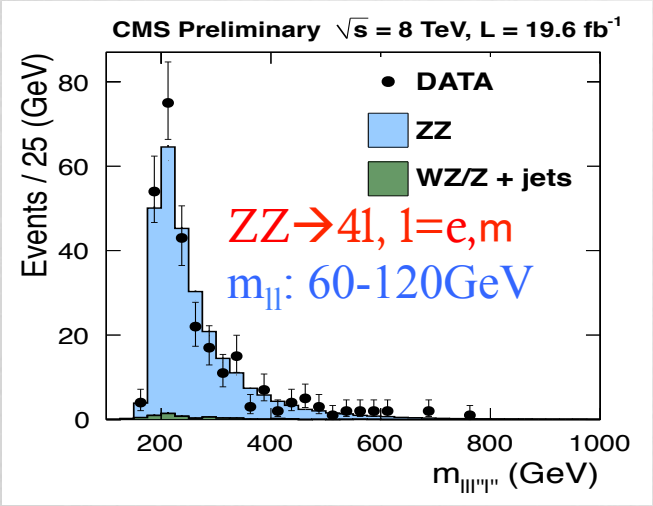
ZZ cross sections @ 8TeV

Both ATLAS and CMS experiments released results with full 2012 data.

ATLAS-CONF-2013-020
CMS-PAS-SMP-13-005



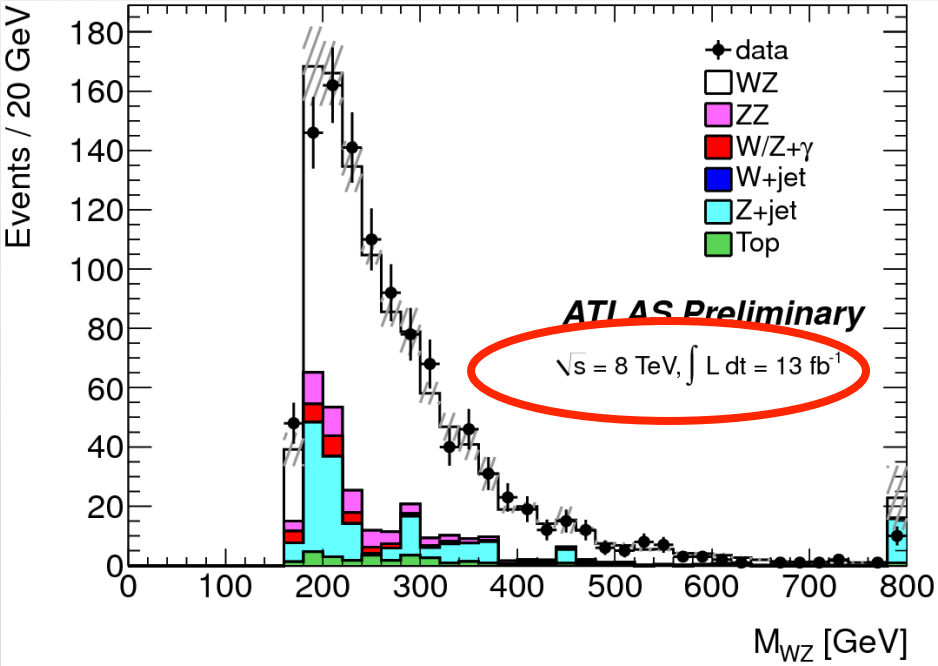




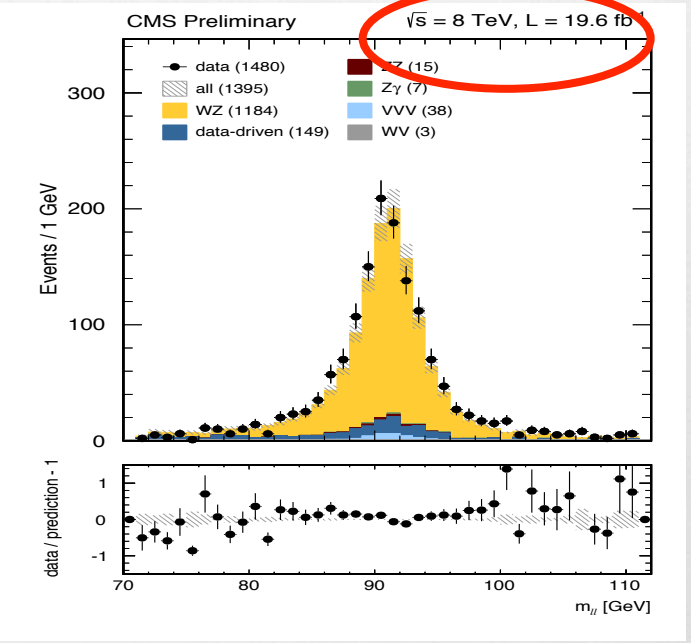
Exp /√s (TeV)	Measured (pb)	MCFM NLO (pb)
ATLAS /7	$6.7\pm0.7_{(stat)}{}^{+0.4}/_{-0.3(syst)}\pm0.3_{(lumi)}$	$5.89^{+0.22}/_{-0.18}$
ATLAS /8	$7.1^{+0.5}/_{-0.4(stat)}\pm0.3_{(syst)}\pm0.2_{(lumi)}$	$7.2^{+0.3}/_{-0.2}$
CMS /7	$6.24^{+0.86}/_{-0.80(stat)}{}^{+0.41}/_{-0.32(syst)}\pm0.14_{(lumi)}$	6.3 ± 0.3
CMS /8	$7.7\pm0.5_{(stat)}\pm{}^{+0.4}/_{-0.5(syst)}\pm0.4_{(lumi)}$	7.7 ± 0.6

WZ cross sections

ATLAS-CONF-2013-021



CMS-PAS-SMP-12-006

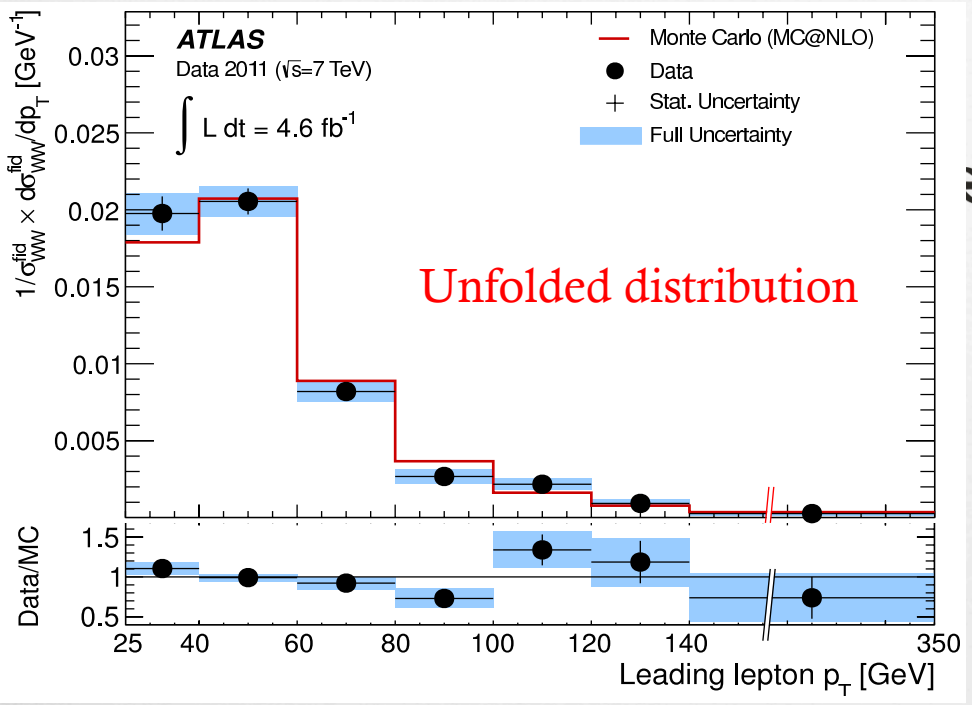


Signal: both W and Z decay leptonically (3 leptons + missing energy)
Main backgrounds: Z+jets, ttbar (jet faking lepton)

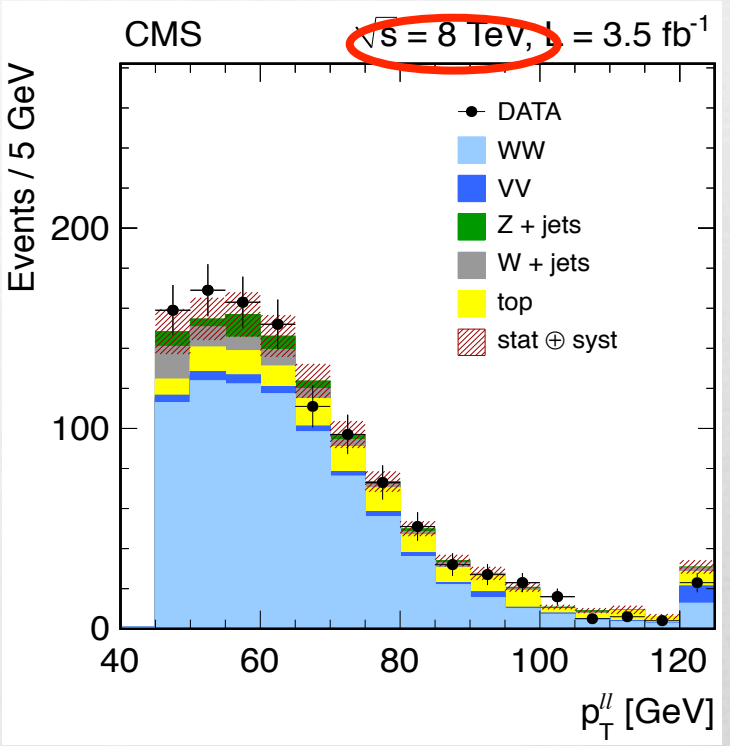
Exp /√s (TeV)	Measured (pb)	MCFM NLO (pb)
ATLAS /7	$20.5^{+3.1}_{-2.8(\text{stat})}{}^{+1.4}_{-1.3(\text{syst})}{}^{+0.9}_{-0.8(\text{lumi})}$	$17.3^{+1.3}_{-0.8}$
ATLAS /8	$20.3^{+0.8}_{-0.7(\text{stat})}{}^{+1.2}_{-1.1(\text{syst})}{}^{+0.7}_{-0.6(\text{lumi})}$	20.3 ± 0.8
CMS /7	$20.76 \pm 1.32_{(\text{stat})} \pm 1.13_{(\text{syst})} \pm 0.46_{(\text{lumi})}$	$17.8^{+0.7}_{-0.5}$
CMS /8	$24.61 \pm 0.76_{(\text{stat})} \pm 1.13_{(\text{syst})} \pm 1.08_{(\text{lumi})}$	$21.9^{+1.2}_{-0.9}$

WW cross sections

ATLAS: PRD 87,112001(2013)



CMS: PLB721(13)190

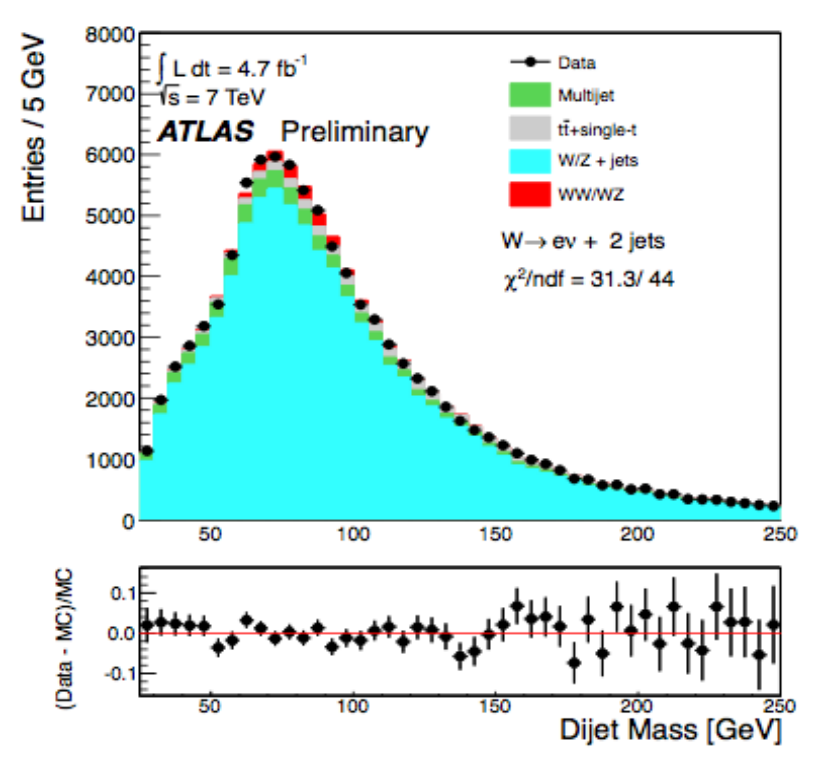


Dominant systematic uncertainty is related to jet veto.
Higgs contribution to the final WW event yield is on the order of 3%.
Measured cross section is slightly above prediction.

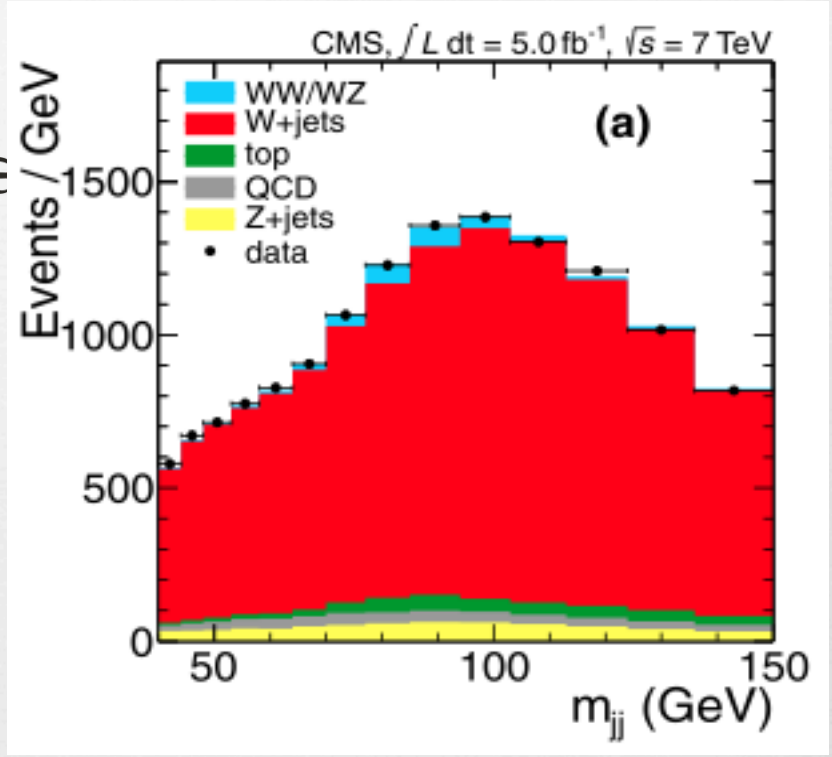
Experiment	√s (TeV)	Measured (pb)	MCFM NLO (pb)
ATLAS	7	$51.9 \pm 2.0_{(stat)} \pm 3.9_{(syst)} \pm 2.0_{(lumi)}$	$44.7^{+2.1}/_{-1.9}$
CMS	7	$52.4 \pm 2.0_{(stat)} \pm 4.5_{(syst)} \pm 1.2_{(lumi)}$	47.0 ± 2.0
	8	$69.9 \pm 2.8_{(stat)} \pm 5.6_{(syst)} \pm 3.1_{(lumi)}$	$57.3^{+2.3}/_{-1.6}$

WW+WZ cross sections with l ν jj channel

ATLAS-CONF-2012-157



CMS: Eur.Phys.J.C 73 (2013 2283)

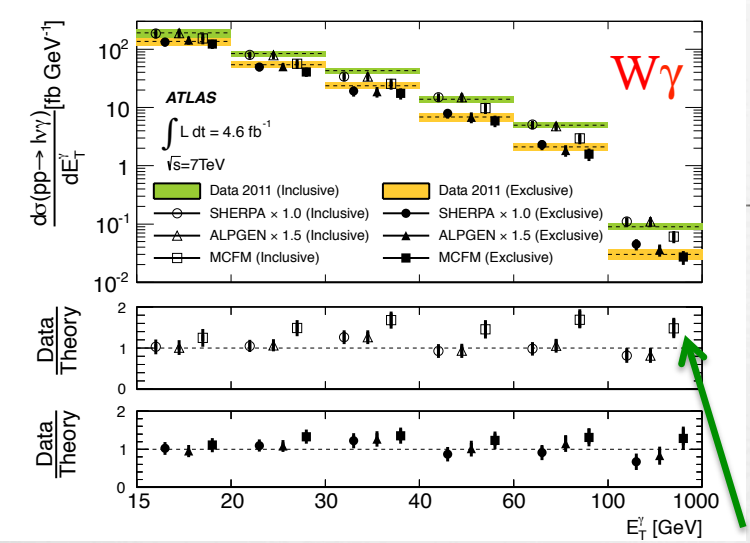


Larger branching fraction than full leptonic decay mode.
Much larger background contamination, especially from W+jets.
Fit on dijet invariant mass to subtract background.

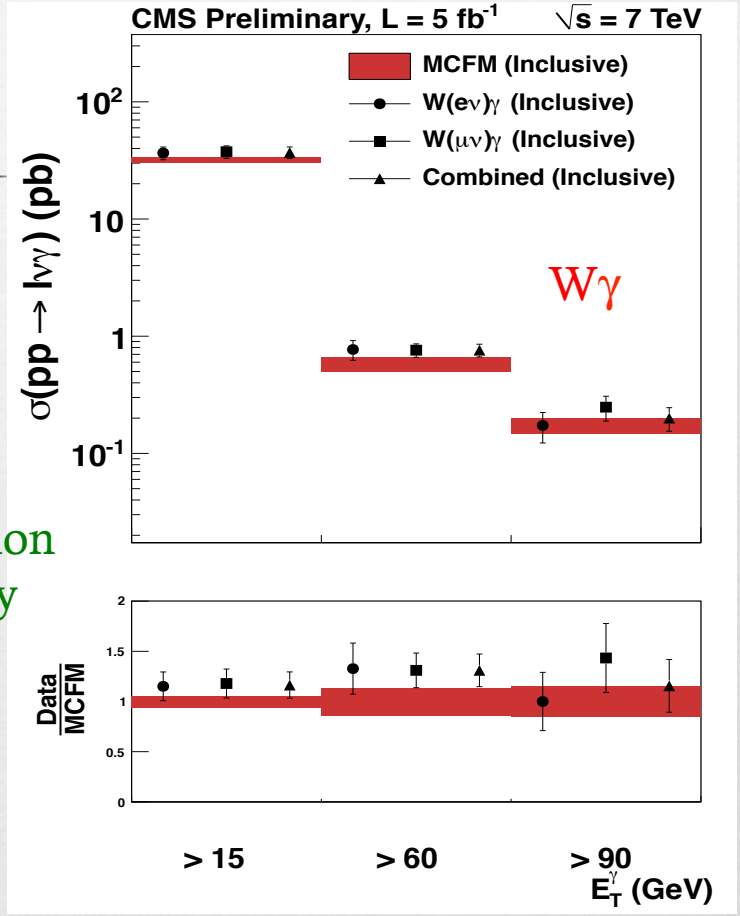
Experiment	√s (TeV)	Measured (pb)	MCFM NLO (pb)
ATLAS	7	$72 \pm 9_{(stat)} \pm 15_{(syst)} \pm 13_{(MC\ stats)}$	63.4±2.6
CMS	7	$68.9 \pm 8.7_{(stat)} \pm 9.7_{(syst)} \pm 1.5_{(lumi)}$	65.6±2.2

Wγ, Zγ Measurements

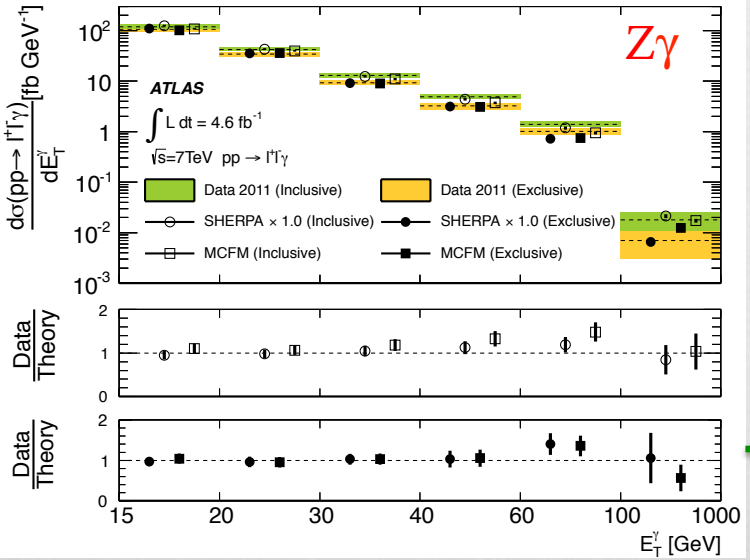
ATLAS: PRD 87,112003 (2013)



CMS-EWK-11-009



Inclusive xs is significantly higher than MCFM prediction due to missing multi q/g emission in MCFM, especially the process of direct photon emission from W boson.



Consistent within uncert. with MCFM prediction. Dominant syst uncertainty is from bkg estimation (template method)

Good agreement also observed in CMS.

Anomalous Triple Gauge Coupling

- Effects of aTGC are Modeled by effective Lagrangian which depends on several parameters
- Modify total production rate and event kinematics, especially increase of cross section at high invariant mass and high transverse momentum if exist

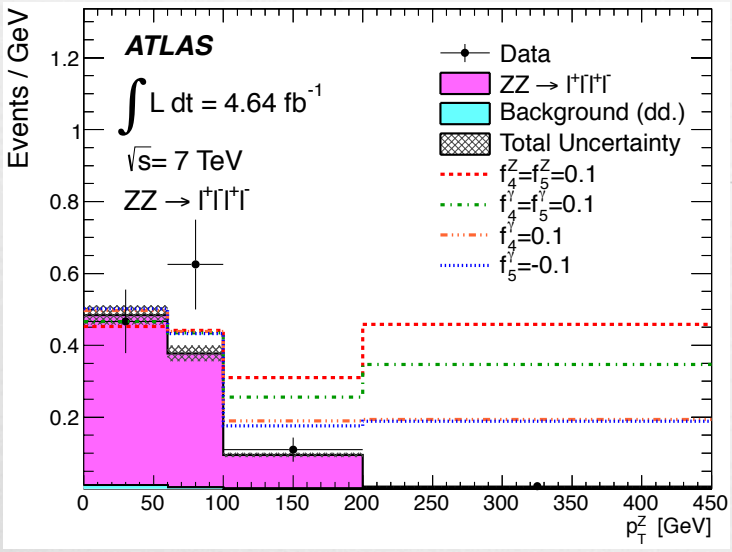
Coupling	Parameters	Channel
$WW\gamma$	$\lambda_\gamma, \Delta\kappa_\gamma$	$WW, W\gamma$
WWZ	$\lambda_Z, \Delta\kappa_Z, \Delta g_1^Z$	WW, WZ
$ZZ\gamma$	h_3^Z, h_4^Z	$Z\gamma$
$Z\gamma\gamma$	h_3^γ, h_4^γ	$Z\gamma$
ZZZ	f_{40}^Z, f_{50}^Z	ZZ
$Z\gamma Z$	$f_{40}^\gamma, f_{50}^\gamma$	ZZ

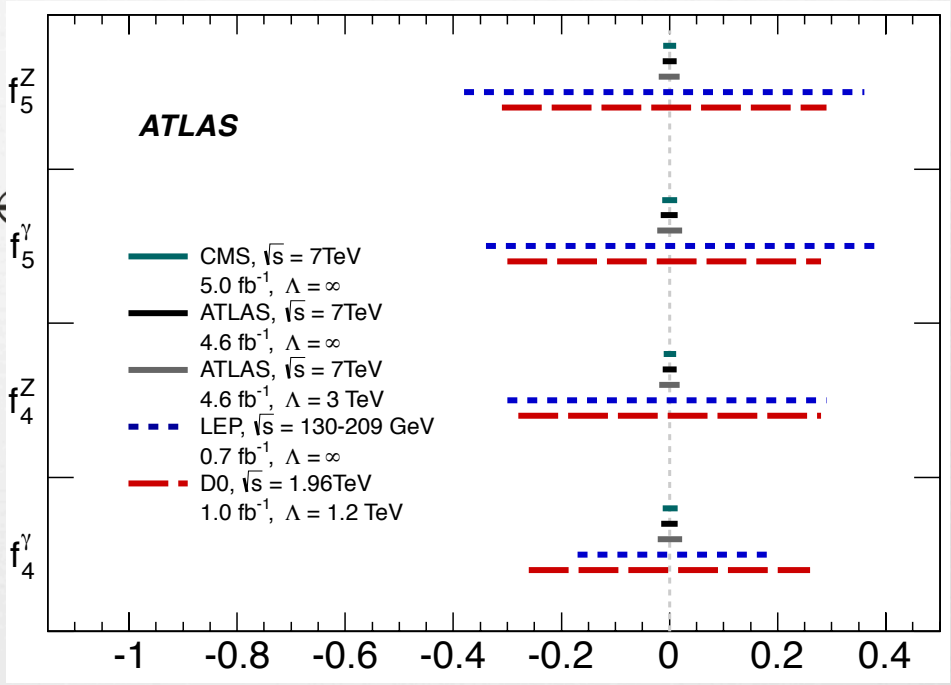
Introduce form-factor Λ to preserve unitarity at high energy

$$\alpha(s) = \frac{\alpha}{(1+\hat{s}/\Lambda^2)^n}$$

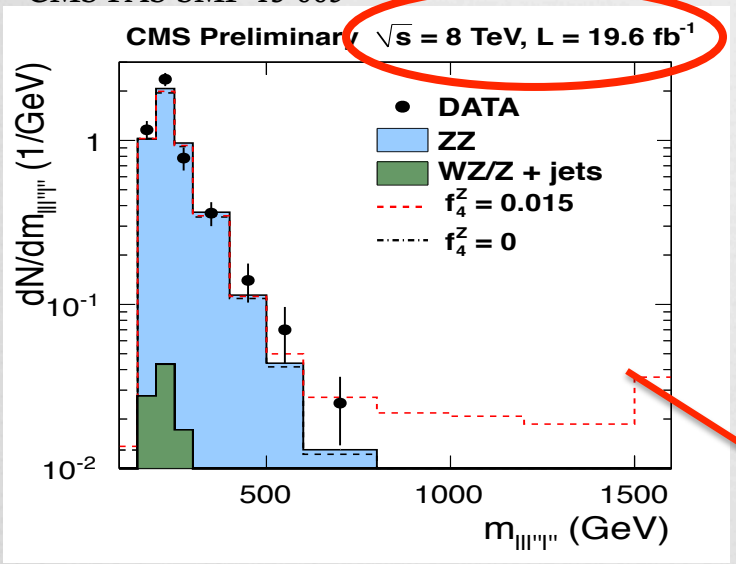
aTGC ZVZ (V=Z, γ) from ZZ Channel

ATLAS: JHEP03(2013)128





CMS-PAS-SMP-13-005



With 7 TeV (2011) data, ATLAS and CMS experiments are already doing better than that of LEP and Tevatron experiments

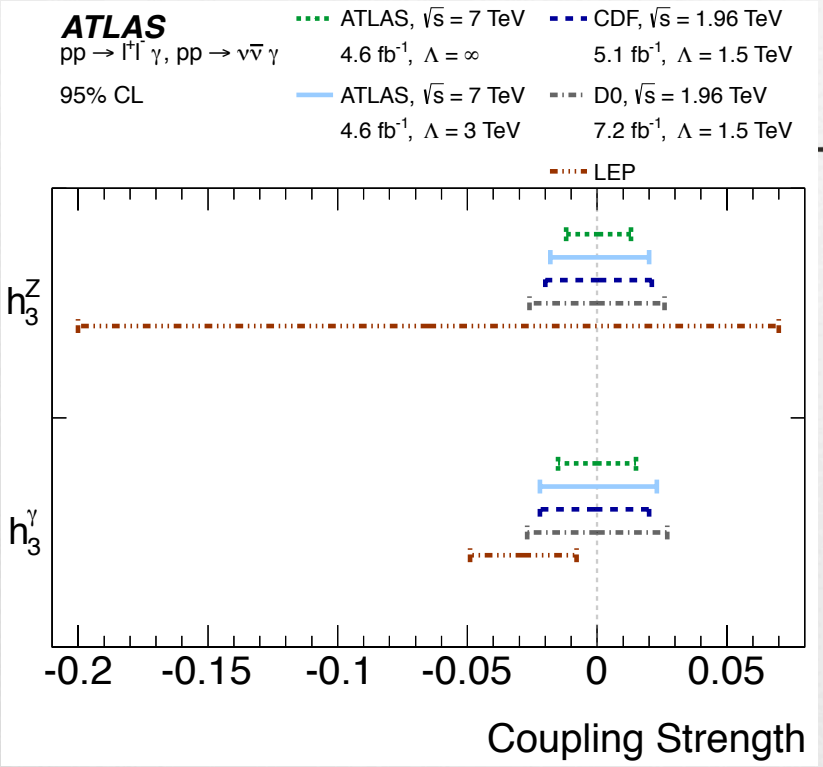
CMS	f_5^Z	f_5^γ	f_4^Z	f_4^γ
7 TeV	[-0.012, 0.012]	[-0.014, 0.014]	[-0.011, 0.012]	[-0.013, 0.015]
8 TeV	[-0.005, 0.005]	[-0.005, 0.005]	[-0.004, 0.004]	[-0004, 0.004]

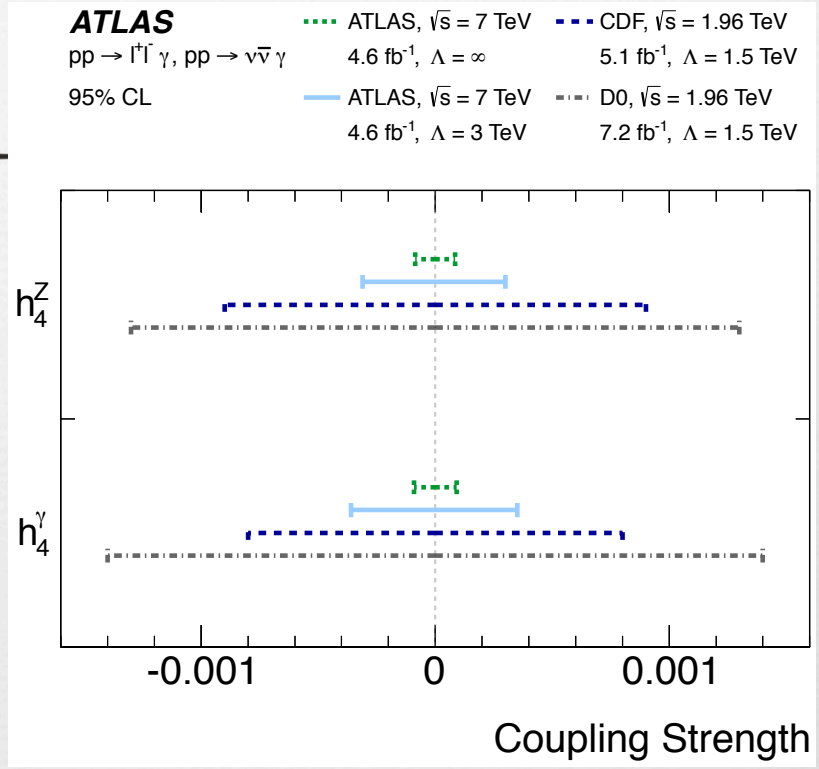
Non-zero aTGCs clearly modify the high tail of the distribution (P_T^Z or m_{4l})

Recent results from 8TeV CMS data, sensitivity improved by a factor of 2~3.

aTGC ZVγ (V=Z, γ) from Zγ Channel

ATLAS PRD 87,112003 (2013)



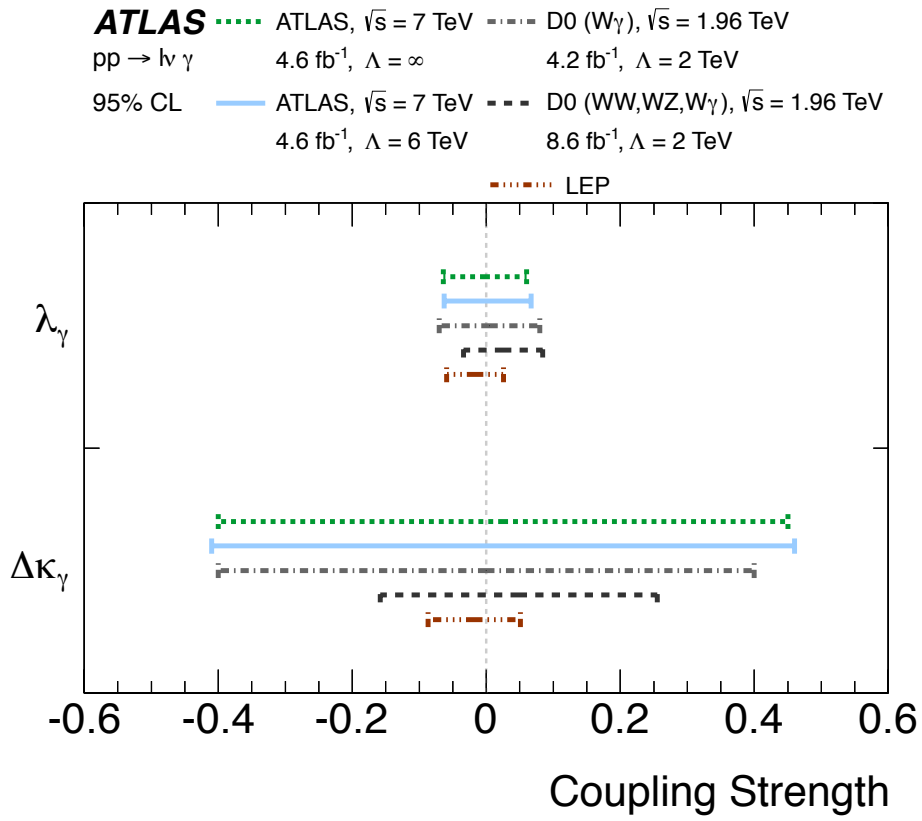


CMS, 7TeV, 5.0 fb^{-1}, CMS-PAS-EWK-11-009, CMS-PAS-SMP-12-020

CMS	h_3^γ	h_3^Z	h_4^γ	h_4^Z
Zγ->llγ	[-0.010, 0.010]	[-8.6, 8.4]×10^{-3}	[-8.8, 8.8]×10^{-5}	[-8.0, 7.9]×10^{-5}
Zγ->ννγ	[-3.2, 3.2]×10^{-3}	[-3.1, 3.1]×10^{-3}	[-1.6, 1.6]×10^{-5}	[-1.4, 1.4]×10^{-5}

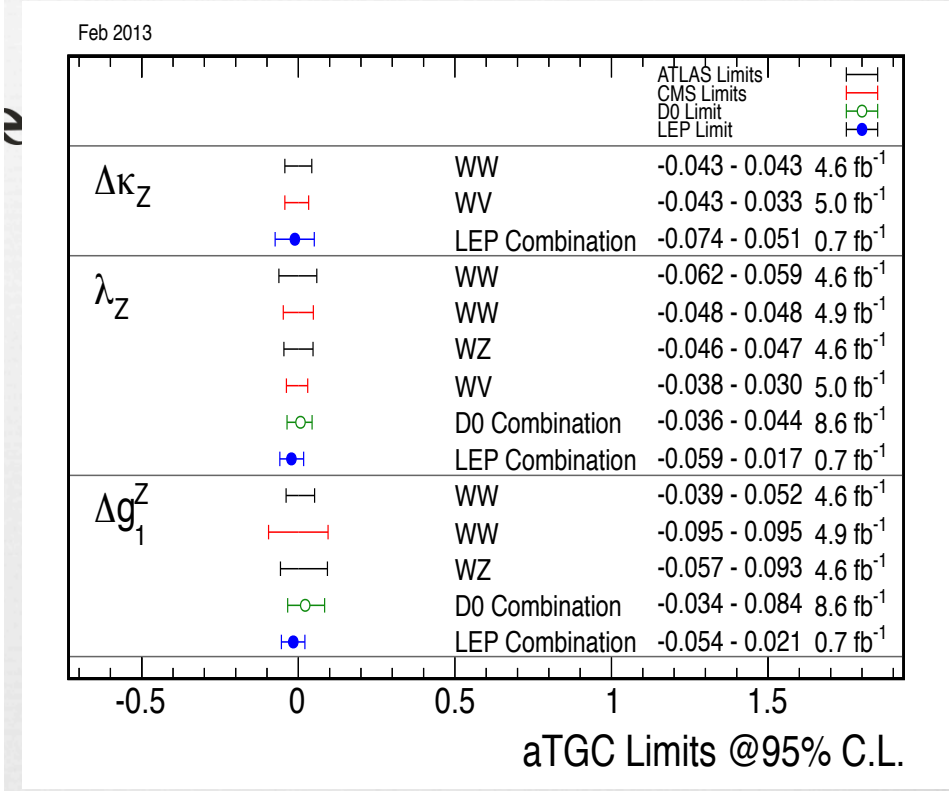
aTGC WWγ, WWZ from Wγ, WW, WZ Channels

ATLAS: PRD 87,112003 (2013)



ATLAS: PRD 87,112001(2013)

CMS-SMP-12-005



CMS, 7TeV, 5.0fb^{-1}, CMS-PAS-EWK-11-009

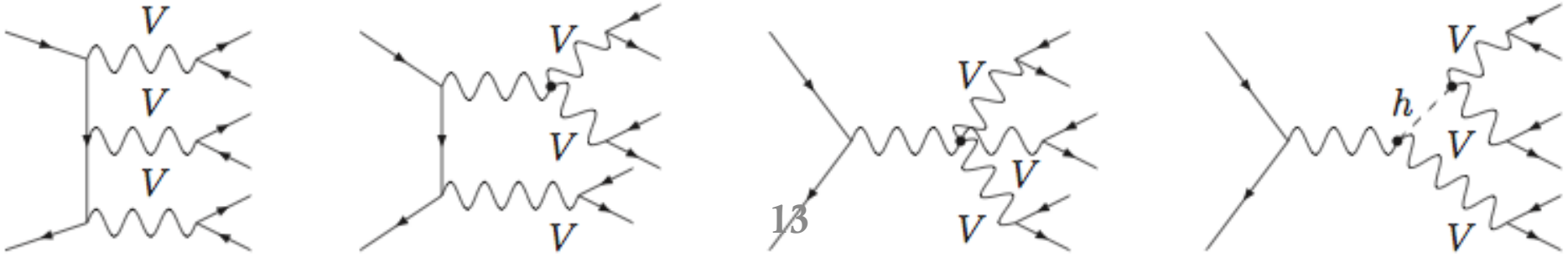
	$\Delta\kappa_\gamma$	λ_γ
$W\gamma \to e\nu\gamma$	[-0.45, 0.36]	[-0.059, 0.046]
$W\gamma \to \mu\nu\gamma$	[-0.46, 0.34]	[-0.057, 0.045]
$W\gamma \to \ell\nu\gamma$	[-0.38, 0.29]	[-0.050, 0.037]

More comparison plots are available at https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMPaTGC

Combination of the various channels is underway within ATLAS and CMS experiments.

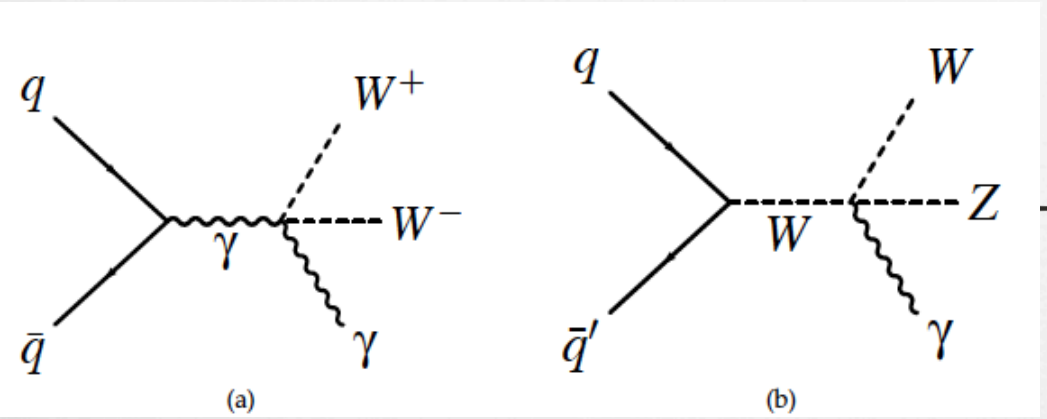
Triboson production

- Motivations:
  - Probe the four-boson coupling predicted by SM
  - Triboson production processes show large gauge cancellations between different topologies and incorporate Higgsstrahlung diagrams.
  - Background to BSM processes with missing transverse momentum and multilepton final states (SUSY searches).
- Difficulties: rather low production rate.



First search for WWγ and WZγ with LHC data

From **CMS**



Events selected:

+ a W boson decaying to leptons,
+ a second boson (W or Z) decaying to two jets
+ an isolated photon

CMS-SMP-13-009

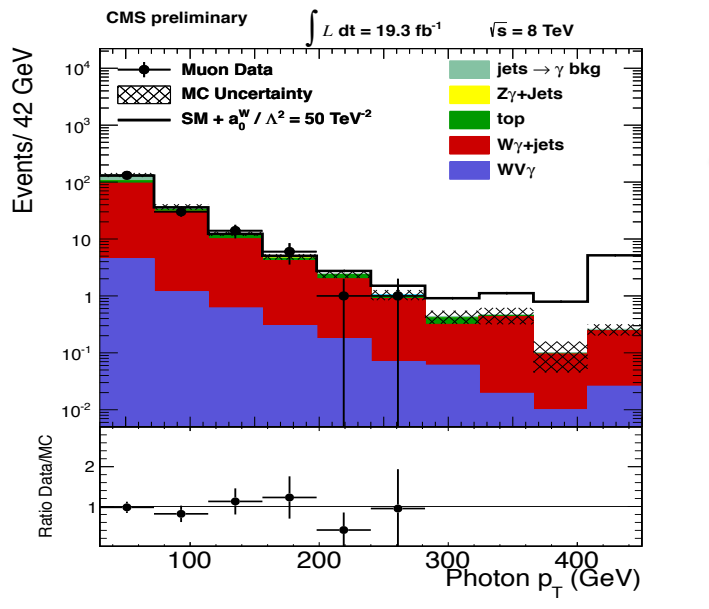
Process	muon channel number of events	electron channel number of events
Wγ+jets	$136.9 \pm 3.5 \pm 9.2 \pm 0.0$	$101.6 \pm 2.9 \pm 8.0 \pm 0.0$
WV+jet, jet→ γ	$33.1 \pm 1.3 \pm 4.6 \pm 0.0$	$21.3 \pm 1.0 \pm 3.1 \pm 0.0$
MC $t\bar{t}\gamma$	$12.5 \pm 0.8 \pm 2.9 \pm 0.5$	$9.1 \pm 0.7 \pm 2.1 \pm 0.4$
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 Zγ+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 WWγ	$6.3 \pm 0.1 \pm 1.5 \pm 0.3$	$4.7 \pm 0.1 \pm 1.1 \pm 0.2$
SM WZγ	$0.6 \pm 0.0 \pm 0.1 \pm 0.0$	$0.5 \pm 0.0 \pm 0.1 \pm 0.0$
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

Background dominated by Wγ+jets.

A binned maximum likelihood fit to the di-jet invariant mass distribution m_{jj} is performed to estimate this background.

Upper limits set for WVγ total cross section: 241 fb with photon $p_T > 10$GeV.

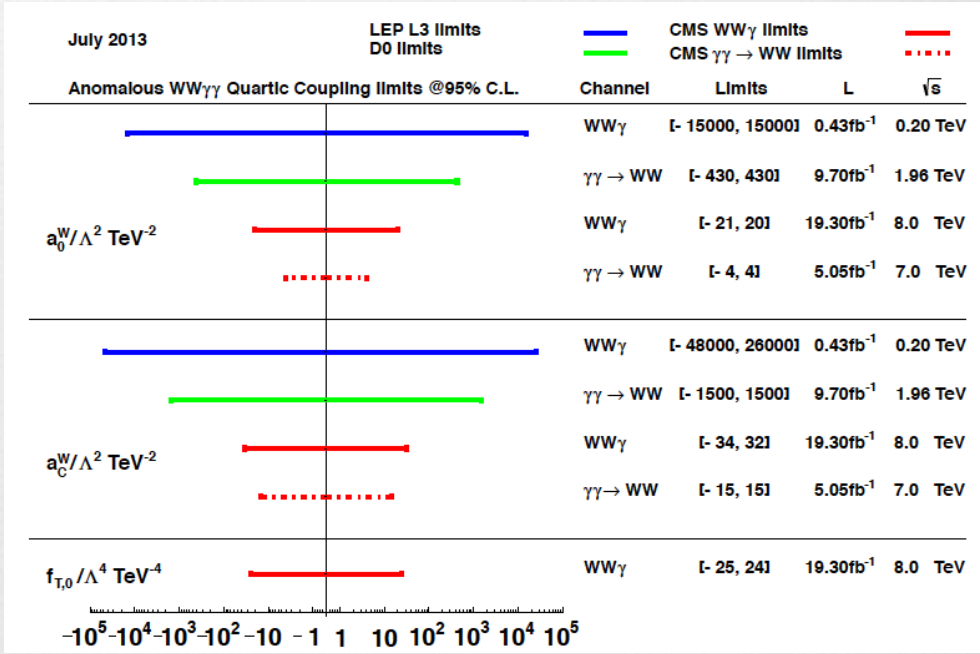
aQGC limits from WVγ channel



Photon p_T is used as the observable for the limit setting with profile asymptotic approximation method with both electron and muon channels.

First ever limits on the pure dimention 8 WWγγ parameter $f_{T,0}{}^{Z}$ and CP conserving WWZγ parameters $\kappa_0{}^{W}$ and $\kappa_C{}^{W}$.

$$-21 < a_0^W/\Lambda^2 < 20\ \text{TeV}^{-2},$$
$$-34 < a_C^W/\Lambda^2 < 32\ \text{TeV}^{-2},$$
$$-25 < f_{T,0}/\Lambda^4 < 24\ \text{TeV}^{-4},$$
$$-12 < \kappa_0^W/\Lambda^2 < 10\ \text{TeV}^{-2}, \text{and}$$
$$-18 < \kappa_C^W/\Lambda^2 < 17\ \text{TeV}^{-2}.$$



Several orders of magnitude more stringent than the best limits obtained at LEP and Tevatron.

Conclusions

- Cross section measurements have been performed in the diboson channels (WW, WZ, ZZ, Wγ, Zγ) by both ATLAS and CMS experiments.
- Stringent limits on aTGCs were obtained and no significant deviations from SM were observed.
- First limits on aQGCs were also obtained.
- Most of the analyses based on full 8 TeV data are still underway, improved precision expected in the coming years.