Recent CMS publications:
CMS-PAS-SMP-17-004 PRL 114 (2015) 051801
CMS-PAS-SMP-16-006 CMS-PAS-SMP-16-004
CMS-PAS-SMP-16-017 CMS-PAS-SMP-16-019
Phys. Lett. B 766 (2017) 268 Eur. Phys. J. C 77 (2017) 236
hep-ex: arXiv:1612.09256 , arXiv:1702.03025, arXiv:1703.06095

The 26th International Workshop on Weak Interactions and Neutrinos (WIN2017)

Recent Multi-boson Cross Section Measurements at CMS

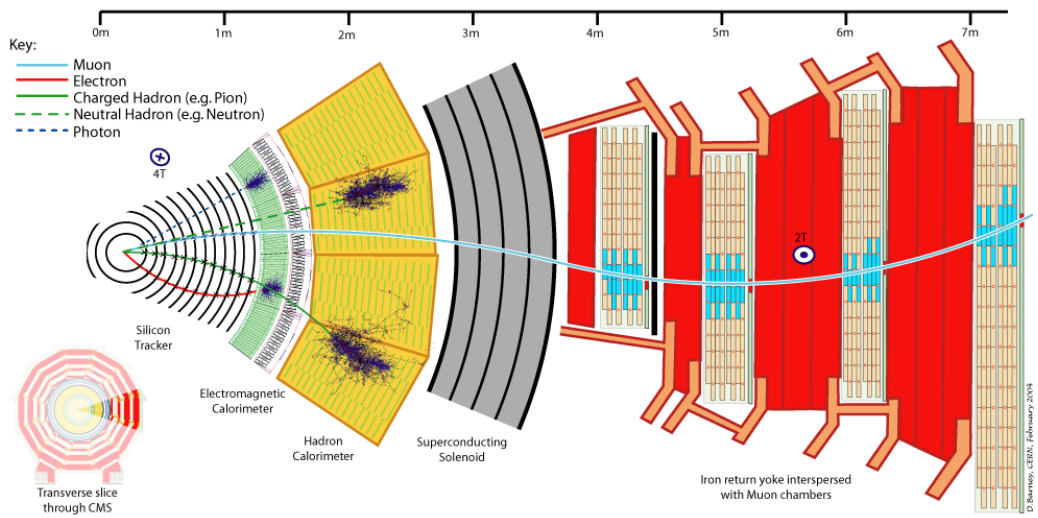
Daneng Yang for the CMS Collaboration

June 20th 2017
Irvine, CA

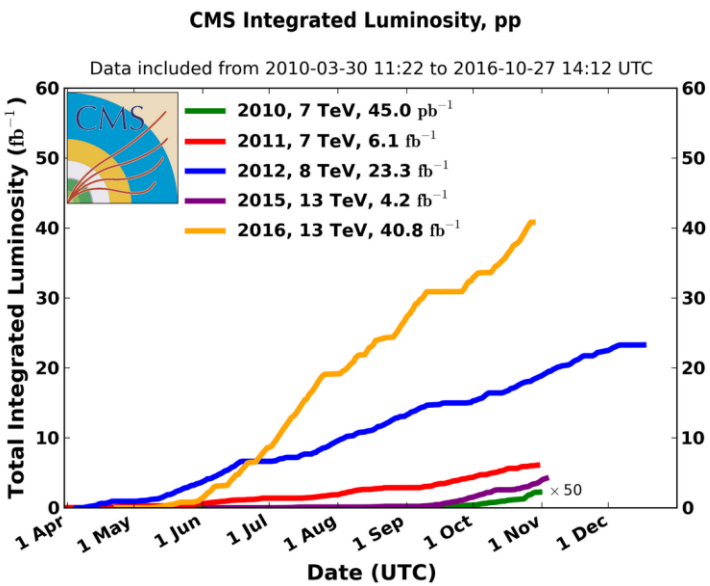
Outline

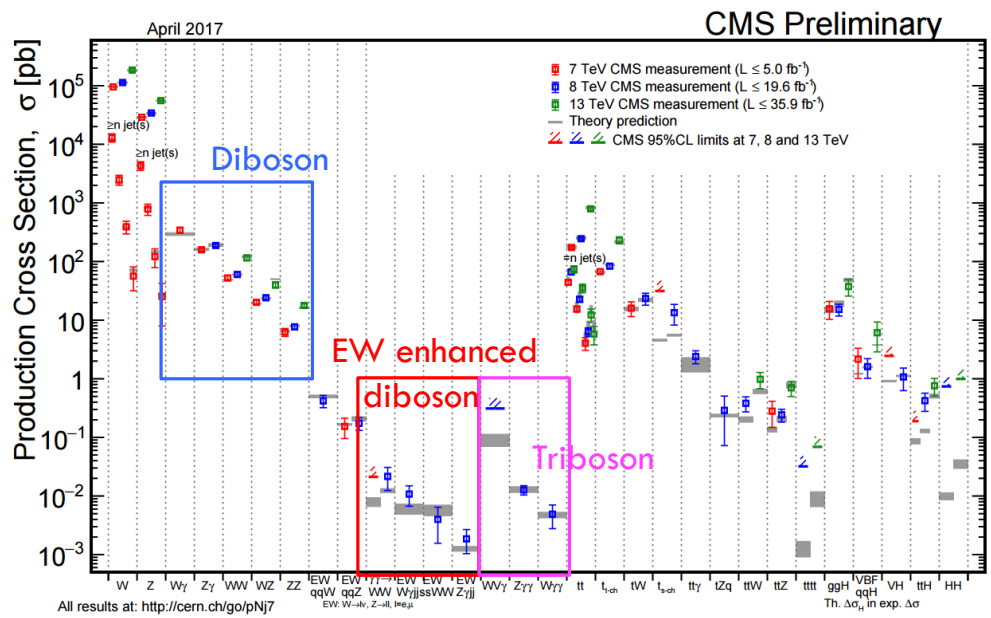
- Introduction: Electroweak physics at CMS
- Resent di-boson measurements
- Resent tri-boson measurements
- Electroweak di-boson measurements
- Limits on anomalous gauge couplings
- Outlook

Electroweak physics at CMS



- High magnetic field, energy resolutions and quality in tracking etc. enable fully reconstruction of final state particles other than neutrino. Particle flow algorithm improves JER and MET resolution.
- LHC has exceeded design Luminosity
- 2016 max peak lumi: 1.5×10^{34} $cm^{-2}s^{-1}$ with pileup ~ 50





Multi-boson cross section measurements at CMS

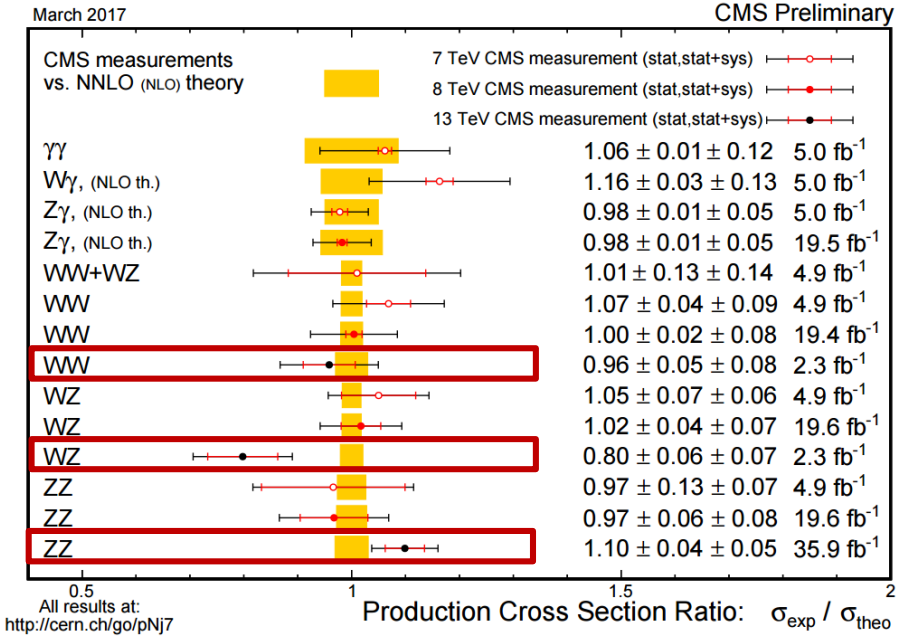
- **Multi-boson productions are important backgrounds for SM Higgs studies and new physics searches**
- **Multi-boson measurements are also probes of non-Abelian gauge structure and EW symmetry breaking**

Theoretical advancement (di-bosons)

- NLO QCD corrections available for all diboson processes, including correlations and off-shell effects
- NNLO QCD predictions available for all diboson processes
- NLO EW corrections implemented in automated way.

For a list of references, see Stefan Kallweit's talk at SM@LHC 2017:https://indico.cern.ch/event/570151/contributions/2524694/attachments/1452009/2239339/Kallweit.pdf

Experimental advancement (di-bosons)



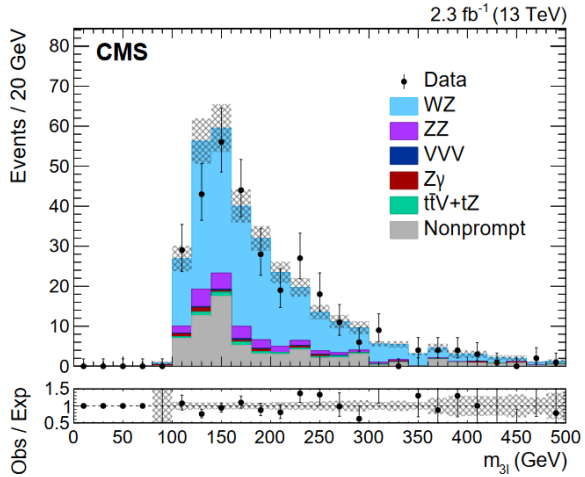
- Several 13 TeV measurements
  - ZZ (full dataset) CMS PAS SMP-16-017
  - W^+W^- (2015 data) CMS PAS SMP-16-006
  - WZ (2015 data) Phys. Lett. B 766 (2017) 268
  - $Z(\nu\nu)\gamma$ (2015 data) CMS PAS SMP-16-004
- $W\gamma$ cross section in agreement with NNLO QCD calculation: arXiv.1504.01330
- All diboson inclusive measurements are systematic uncertainty dominated.

Recent di-boson measurements

Inclusive cross section measurements

13 TeV WZ cross section measurement

(2015 data only) Phys. Lett. B 766 (2017) 268



The fiducial WZ $\to \ell\nu\ell'\ell'$ cross section for $p_T^{\ell'} > 20, 10\,\text{GeV}$, $p_T^{\ell} > 20\,\text{GeV}$, all leptons within $|\eta| < 2.5$, $60 < m_{\ell'\ell'} < 120\,\text{GeV}$, and invariant mass of any same-flavor opposite-sign lepton pair above 4 GeV is

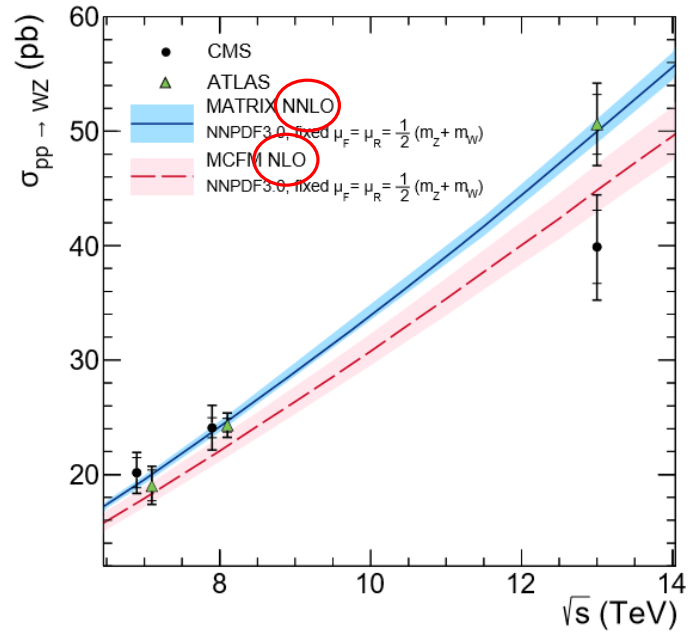
$$\sigma_{\text{fid}}(\text{pp} \to \text{WZ} \to \ell\nu\ell'\ell') = 258 \pm 21\,(\text{stat})^{+19}_{-20}\,(\text{syst}) \pm 8\,(\text{lumi})\,\text{fb},$$

corresponding to a total cross section for the range $60 < m_{\ell'\ell'} < 120\,\text{GeV}$ of

$$\sigma(\text{pp} \to \text{WZ}) = 39.9 \pm 3.2\,(\text{stat})^{+2.9}_{-3.1}\,(\text{syst}) \pm 0.4\,(\text{theo}) \pm 1.3\,(\text{lumi})\,\text{pb}.$$

Inclusive measurement

$$\sigma(\text{pp} \to \text{WZ} + X)\,\mathcal{B}(\text{W} \to \ell\nu)\,\mathcal{B}(\text{Z} \to \ell'\ell') = (1 - f_\tau)\,\frac{N_{\text{obs}} - N_{\text{bkg}}}{\epsilon_{\text{sig}}\,\mathcal{L}},$$



WZ total cross section for different pp c.m. energies. (Eur. Phys. J. C 77 (2017) 236)

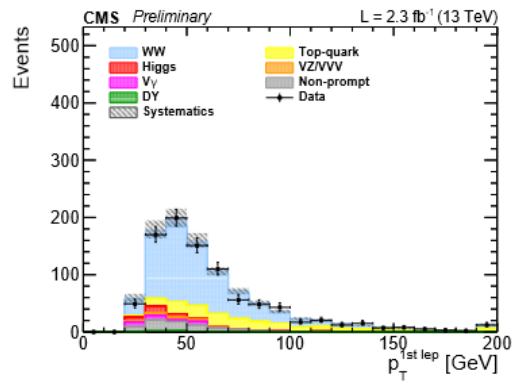
- Stat. uncertainty: inner bars
- Stat. and syst. uncertainties sum in quadrature: outer bars

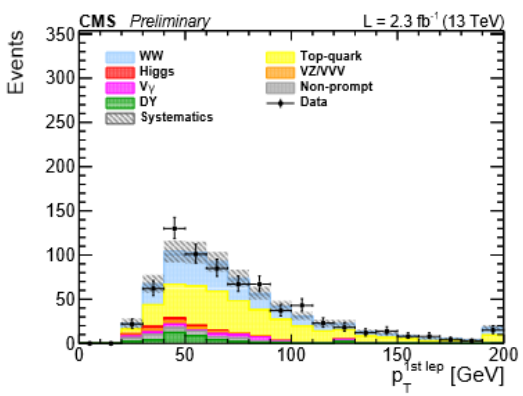
We start taking benifit from NNLO theoretical developments

Inclusive cross section measurements

W^+W^- cross section measurement

(2015 data only) CMS-PAS-SMP-16-006





Measured from 2l2v decay

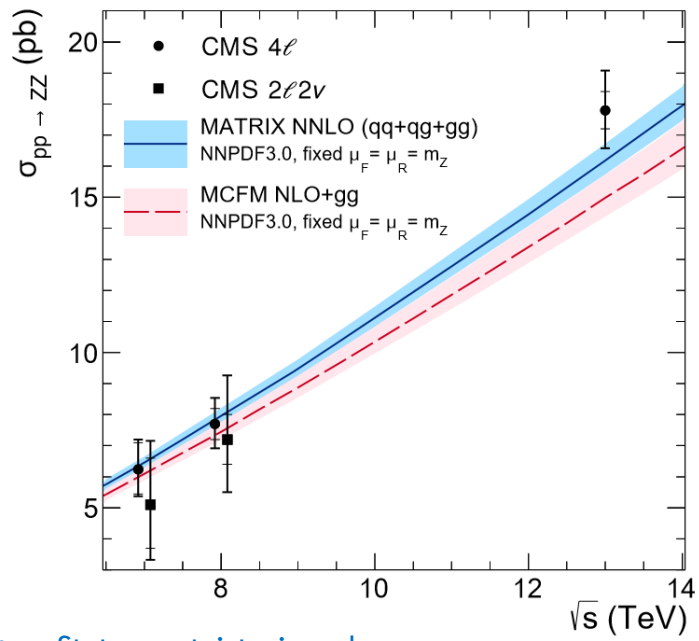
To suppress top background, only 0-jet (upper) and 1-jet (down) categories are considered.

pT^{WW} reweighted to NNLL+NLO prediction

Category	Value ± stat. ± exp. syst. ± theo. syst. ± lumi. [pb]
0-jet	$113.6 \pm 6.3 \pm 5.1 \pm 6.5 \pm 3.3$
1-jet	$135.3 \pm 15.4 \pm 34.0 \pm 14.4 \pm 6.0$
Combination	$115.3 \pm 5.8 \pm 5.7 \pm 6.4 \pm 3.6$

$$\sigma^{\mathrm{NNLO}}(\mathrm{pp} \to \mathrm{W^+W^-}) = 120.3 \pm 3.6 \text{ pb}$$

ZZ cross section measurement



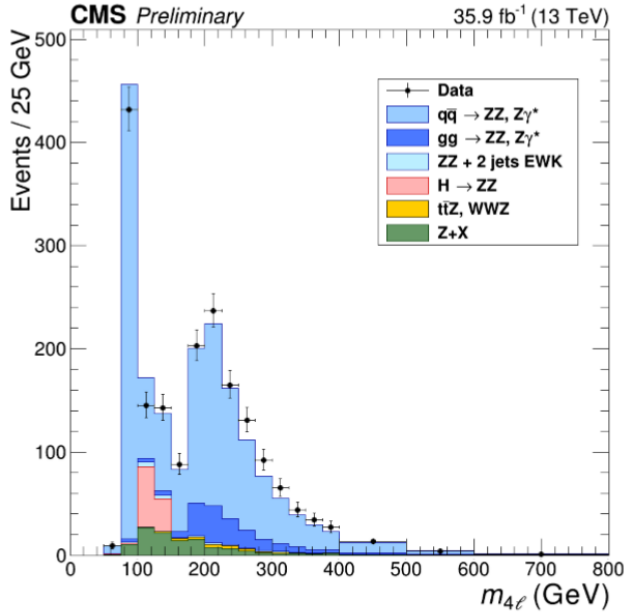
- Stat. uncertainty: inner bars
- Stat. and syst. uncertainties sum in quadrature: outer bars

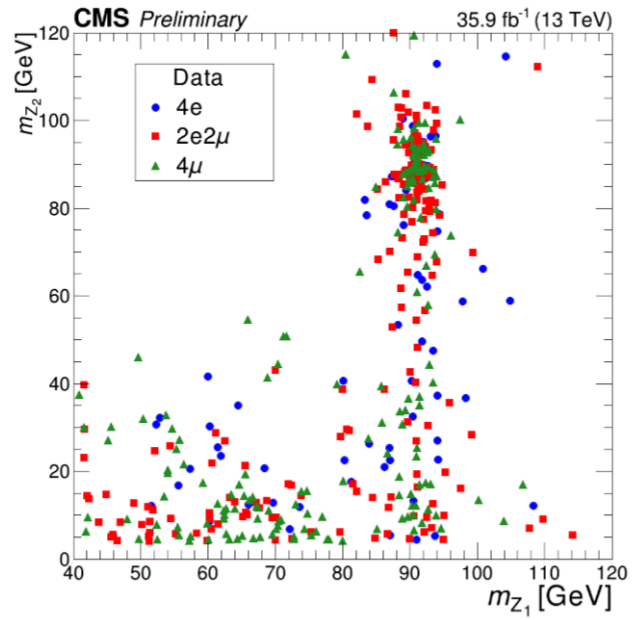
ZZ total cross section for different pp c.m. energies.

ZZ->4l: First diboson measurement with **full 2016 dataset** ($35.9\ fb^{-1}$): CMS-PAS-SMP-16-017

pp→ZZ/Z→4l measurement

ZZ→4l cross section (First diboson measurement with full 2016 dataset)





CMS-PAS-SMP-16-017

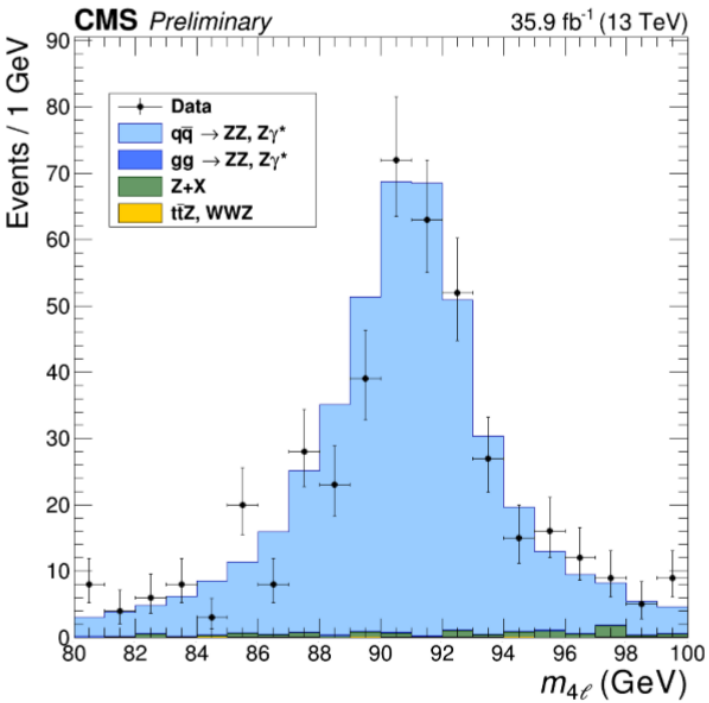
Cross section measurement	Fiducial requirements
Common requirements	$p_T^{\ell_1} > 20\,\text{GeV}$, $p_T^{\ell_2} > 10\,\text{GeV}$, $p_T^{\ell_{3,4}} > 5\,\text{GeV}$,
	$\lvert\eta^\ell\rvert < 2.5$, $m_{\ell^+\ell^-} > 4\,\text{GeV}$ (any opposite-sign same-flavor pair)
$Z \to 4\ell$	$m_{Z_1} > 40\,\text{GeV}$
	$80 < m_{4\ell} < 100\,\text{GeV}$
$ZZ \to 4\ell$	$60 < m_{Z_1}, m_{Z_2} < 120\,\text{GeV}$

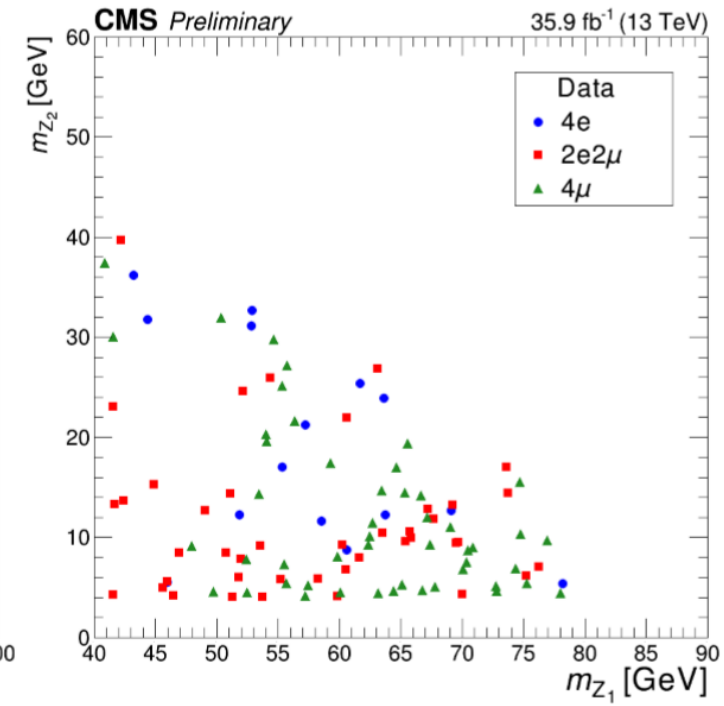
$$\sigma_{\text{fid}}(\text{pp} \to \text{Z} \to 4\ell) = 29.7 \pm 1.4\,(\text{stat})^{+2.0}_{-1.8}\,(\text{syst}) \pm 0.8\,(\text{lumi})\,\text{fb},$$

$$\sigma_{\text{fid}}(\text{pp} \to \text{ZZ} \to 4\ell) = 42.2 \pm 1.4\,(\text{stat})^{+1.6}_{-1.5}\,(\text{syst}) \pm 1.1\,(\text{lumi})\,\text{fb}.$$

pp→ZZ/Z→4l measurement

Z→4l branching fraction measurement $Z \to \ell^+\ell^-\gamma^* \to 4\ell$





$$\sigma(\mathrm{pp} \to \mathrm{Z})\mathcal{B}(\mathrm{Z} \to 4\ell) = 243.8^{+8.3}_{-8.1}\,(\mathrm{stat})^{+9.3}_{-8.8}\,(\mathrm{syst})^{+4.0}_{-4.0}\,(\mathrm{theo}) \pm 6.3\,(\mathrm{lumi})\ \mathrm{fb}.$$ CMS-PAS-SMP-16-017

$$\mathcal{B}(\mathrm{Z} \to 4\ell) = \frac{\sigma(\mathrm{pp} \to \mathrm{Z} \to 4\ell)}{\mathcal{C}^{60\text{–}120}_{80\text{–}100}\,\sigma(\mathrm{pp} \to \mathrm{Z} \to \ell^+\ell^-)/\mathcal{B}(\mathrm{Z} \to \ell^+\ell^-)},$$

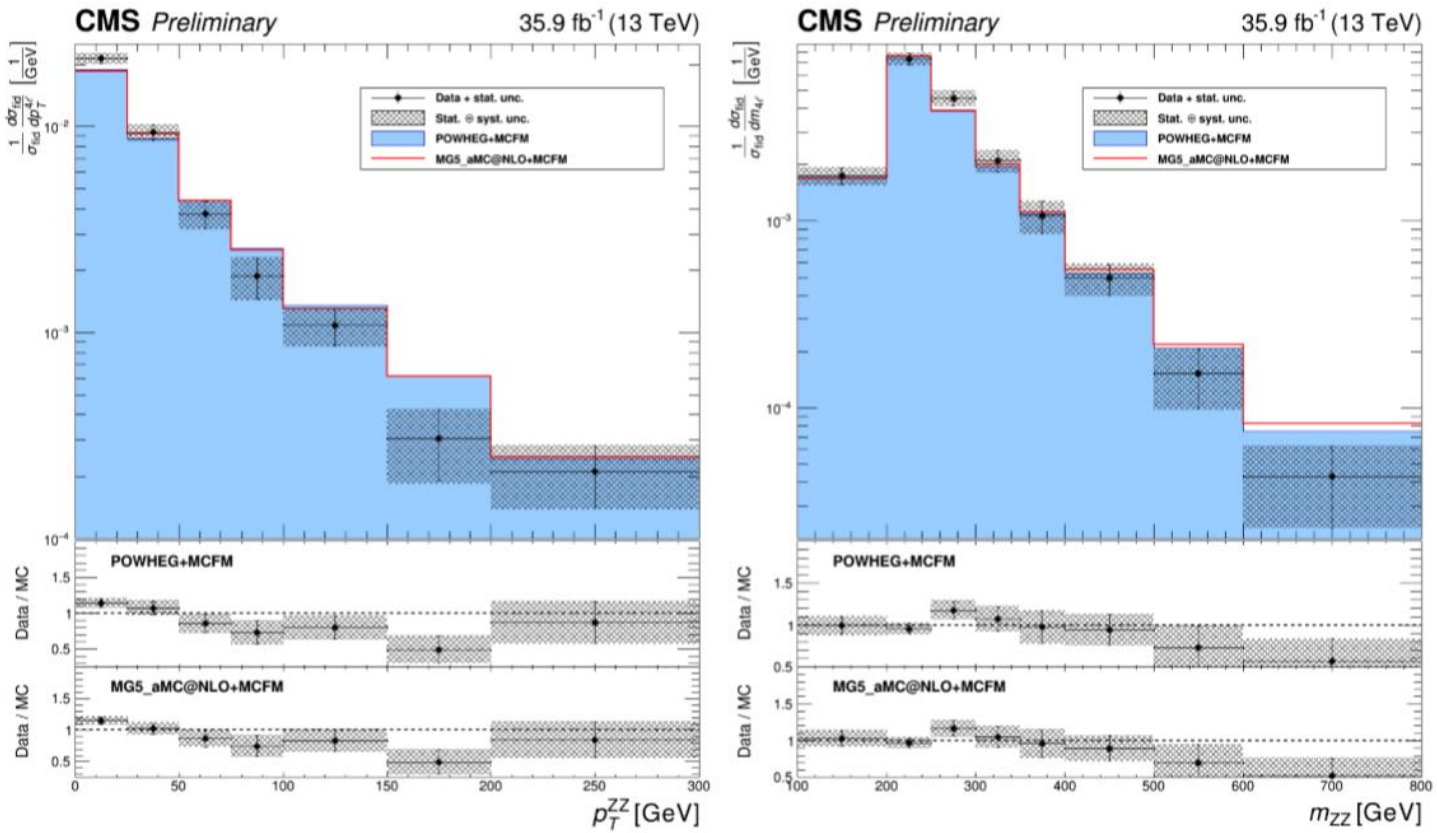
$$\mathcal{B}(\mathrm{Z} \to 4\ell) = 4.74^{+0.16}_{-0.16}\,(\mathrm{stat})^{+0.18}_{-0.17}\,(\mathrm{syst}) \pm 0.08\,(\mathrm{theo}) \pm 0.12\,(\mathrm{lumi}) \times 10^{-6}$$

MG5_aMC@NLO
4.6×10^{-6}

pp→ZZ/Z→4l measurement

Differential cross section measurement

CMS-PAS-SMP-16-017



Resolution dependent binning

pT and mass spectrums of the two Z-bosons

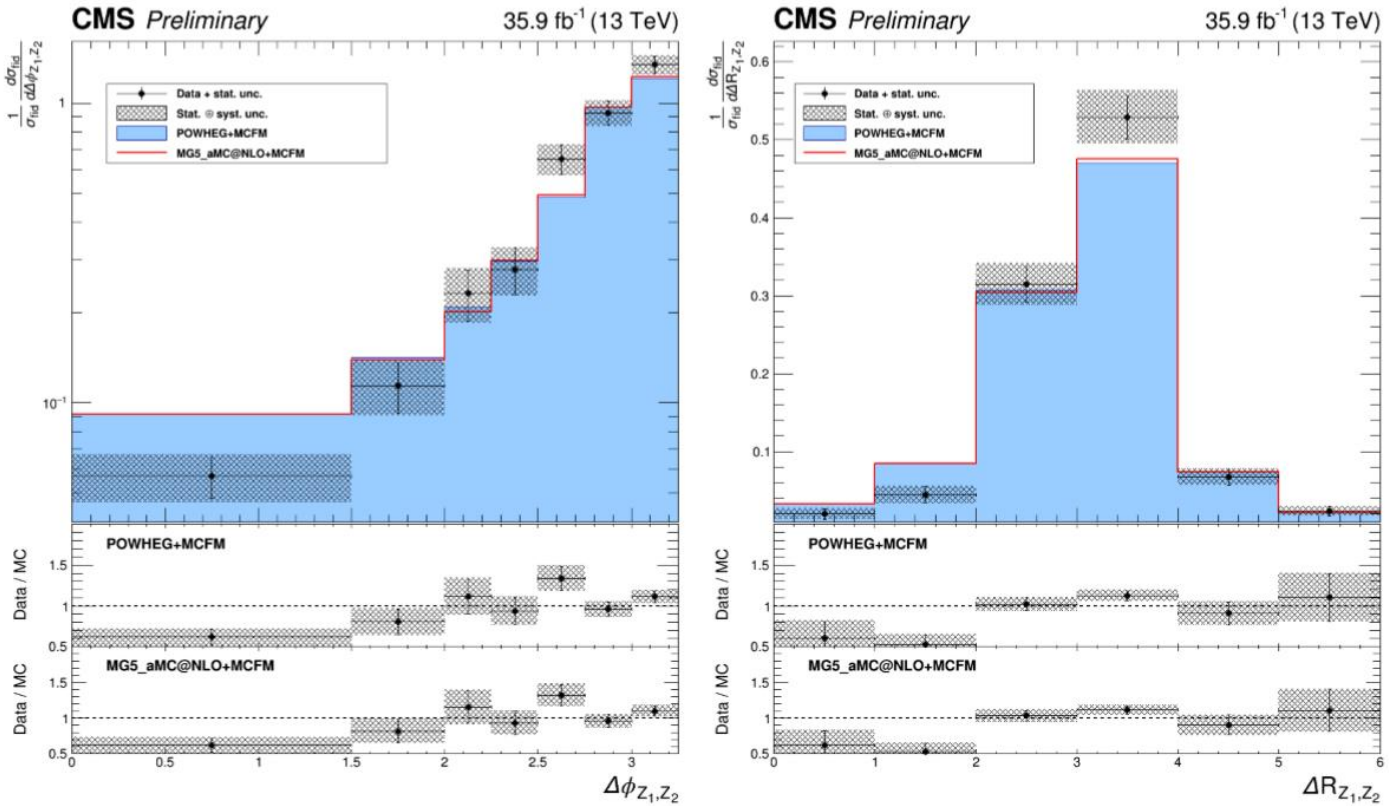
Normalized to fiducial cross section; NLO in QCD, LO in QED

Cross section measurement	Fiducial requirements
Common requirements	$p_T^{\ell_1} > 20\,\text{GeV}$, $p_T^{\ell_2} > 10\,\text{GeV}$, $p_T^{\ell_{3,4}} > 5\,\text{GeV}$,
	$\lvert\eta^\ell\rvert < 2.5$, $m_{\ell^+\ell^-} > 4\,\text{GeV}$ (any opposite-sign same-flavor pair)
$Z \to 4\ell$	$m_{Z_1} > 40\,\text{GeV}$
	$80 < m_{4\ell} < 100\,\text{GeV}$
$ZZ \to 4\ell$	$60 < m_{Z_1}, m_{Z_2} < 120\,\text{GeV}$

pp→ZZ/Z→4l measurement

Differential cross section measurement

CMS-PAS-SMP-16-017



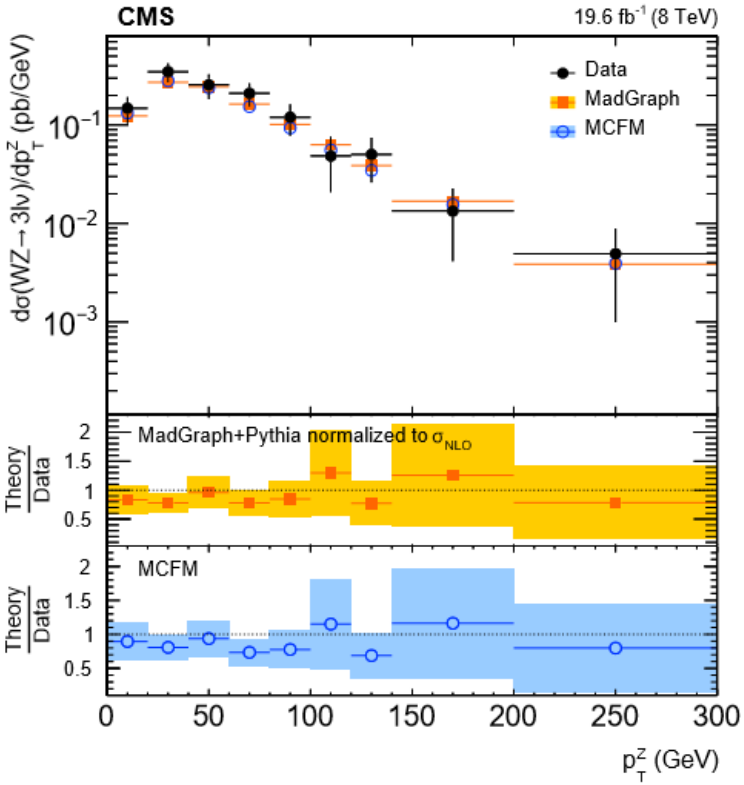
Resolution dependent binning

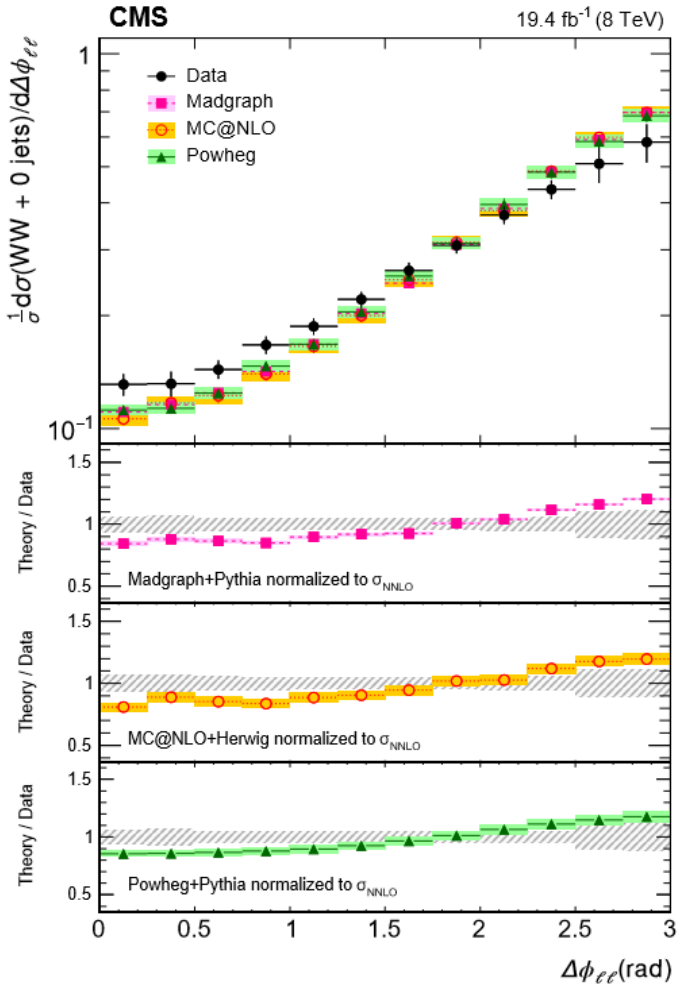
Azimuthal separation and ΔR between the two Z-bosons

Normalized to fiducial cross section; NLO in QCD, LO in QED

Cross section measurement	Fiducial requirements
Common requirements	$p_T^{\ell_1} > 20\,\text{GeV}$, $p_T^{\ell_2} > 10\,\text{GeV}$, $p_T^{\ell_{3,4}} > 5\,\text{GeV}$, $\lvert\eta^\ell\rvert < 2.5$, $m_{\ell^+\ell^-} > 4\,\text{GeV}$ (any opposite-sign same-flavor pair)
$Z \to 4\ell$	$m_{Z_1} > 40\,\text{GeV}$ $80 < m_{4\ell} < 100\,\text{GeV}$
$ZZ \to 4\ell$	$60 < m_{Z_1}, m_{Z_2} < 120\,\text{GeV}$

8 TeV differential measurement





WZ->3lν

Eur. Phys. J. C (2017) 77: 236

Shape in agreement with theory

Data~11% higher than NLO. In good agreement with NNLO calculation.

W^+W^-->lνlν (8 TeV), Eur. Phys. J. C 76 (2016) 401

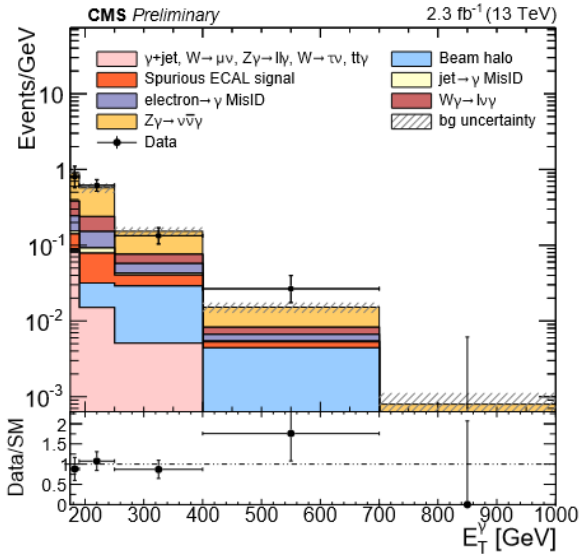
Overall agreement

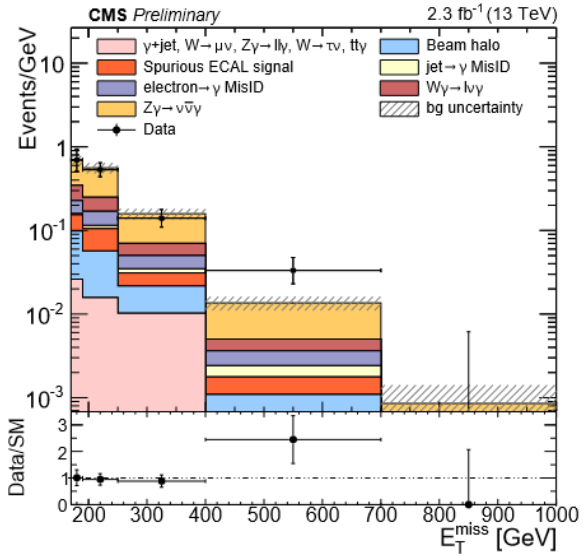
Discrepancy observed in $\Delta\phi_{ll}$ distribution

$Z(\rightarrow\nu\nu)\gamma$ fiducial cross section measurements

13 TeV $Z(\rightarrow \nu\nu)\gamma$ cross section measurement

(2015 data only) CMS-PAS-SMP-16-004





- SM production only from initial state radiation
- Important background for Dark Matter searches (monophoton)

Fiducial selections: pT(γ)>175 GeV, $|\eta(\gamma)|$ <1.44

$$\sigma_{\text{fid}} = 66.5 \pm 13.6\,(\text{stat}) \pm 14.3\,(\text{syst}) \pm 2.2\,(\text{lumi})\,\text{fb}$$

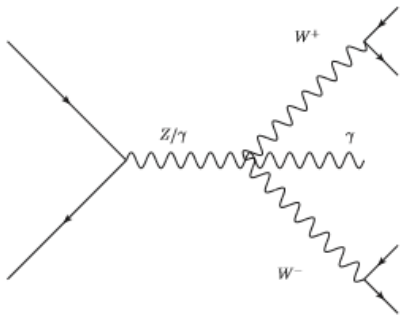
In agreement with NNLO theoretical prediction! (JHEP07(2015)085)

σ_{NNLO}= 65.5$\pm$3.3 fb

Tri-boson measurements

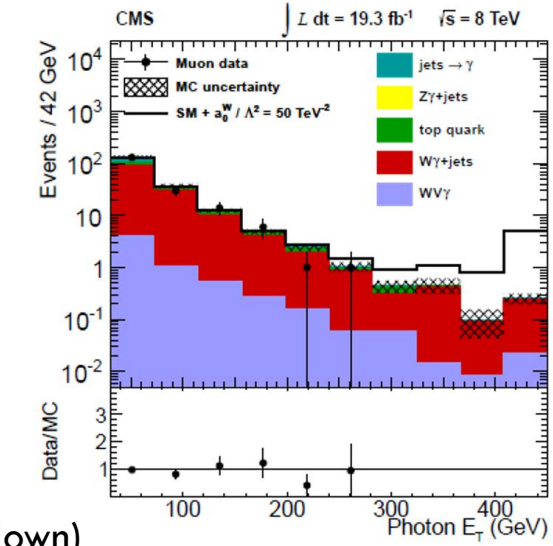
Tri-boson measurements

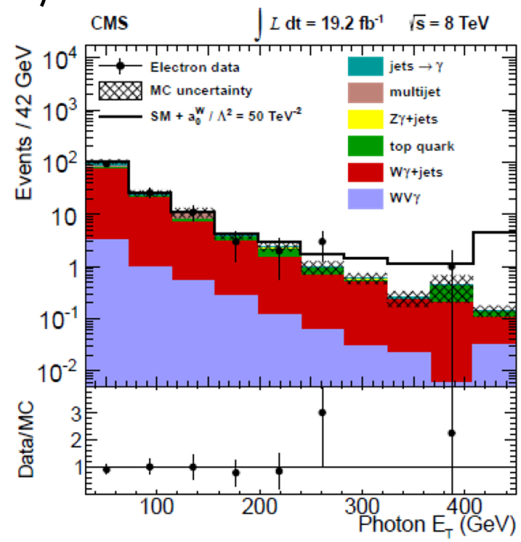
Two tri-boson results from CMS @8 TeV



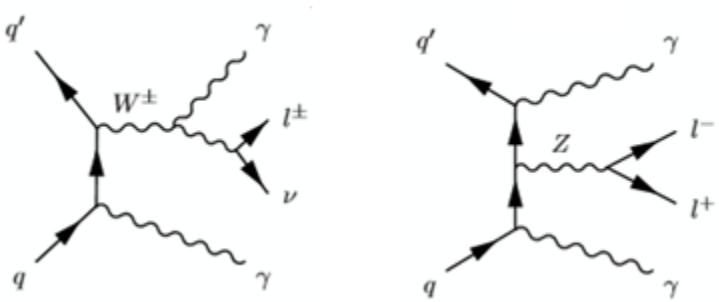
WVγ Production (V=W,Z)
Phys. Rev. D 90, 032008 (2014)

WVγ, muon (up) electron (down) channels





Wγγ Zγγ Observed

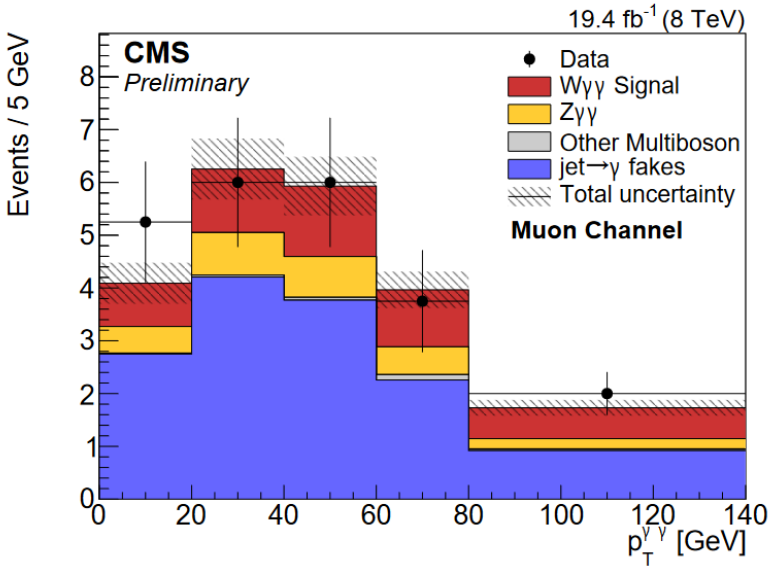


Wγγ and Zγγ productions
CMS-PAS: SMP-15-008

3.4 times upper limit @95% C.L. on the SM cross section

Tri-boson measurements

$W\gamma\gamma$ and $Z\gamma\gamma$ productions
CMS-PAS-SMP-15-008



$W\gamma\gamma$ observed with 2.4 σ

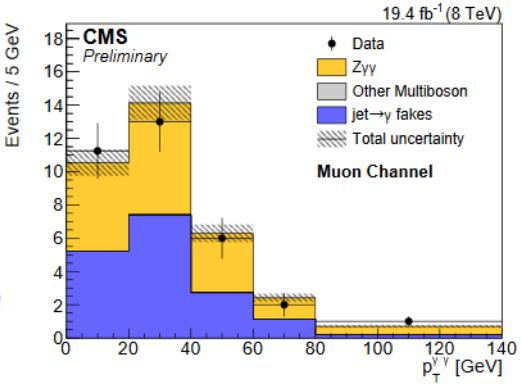
$$\sigma^{\mathrm{NLO}}_{W^{\pm}\gamma\gamma} \cdot \mathrm{BR}\,(W \to \ell\nu) = 4.76 \pm 0.53\,\mathrm{fb} \quad \text{(Madgraph)}$$

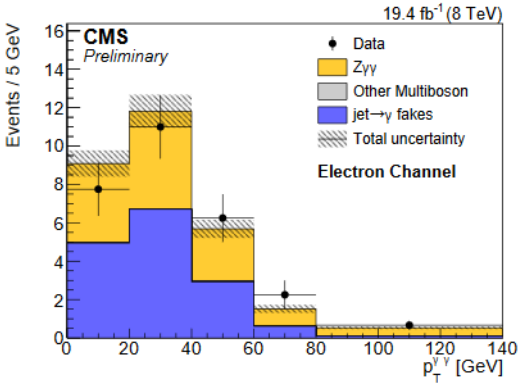
$$\sigma^{\mathrm{fid}}_{W^{\pm}\gamma\gamma} \cdot \mathrm{BR}\,(W \to \ell\nu) = 6.0 \pm 1.8\,(\mathrm{stat}) \pm 2.3\,(\mathrm{syst}) \pm 0.2\,(\mathrm{lumi})\,\mathrm{fb}$$

$Z\gamma\gamma$ observed with 5.9 σ

$$\sigma^{\mathrm{NLO}}_{Z\gamma\gamma} \cdot \mathrm{BR}\,(Z \to \ell\ell) = 12.95 \pm 1.47\,\mathrm{fb} \quad \text{(Madgraph)}$$

$$\sigma^{\mathrm{fid}}_{Z\gamma\gamma} \cdot \mathrm{BR}\,(Z \to \ell\ell) = 12.7 \pm 1.4\,(\mathrm{stat}) \pm 1.8\,(\mathrm{syst}) \pm 0.3\,(\mathrm{lumi})\,\mathrm{fb}$$



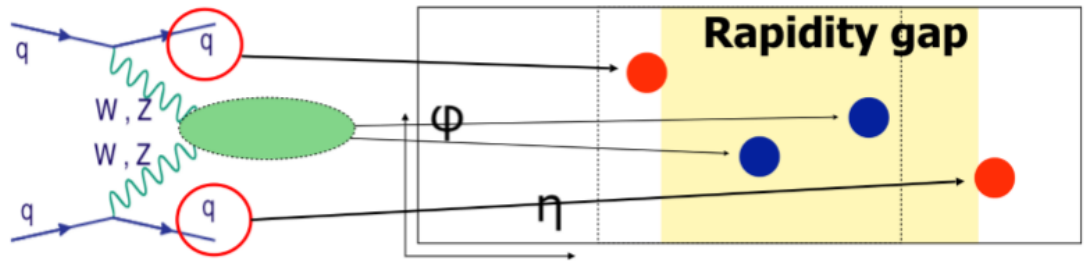


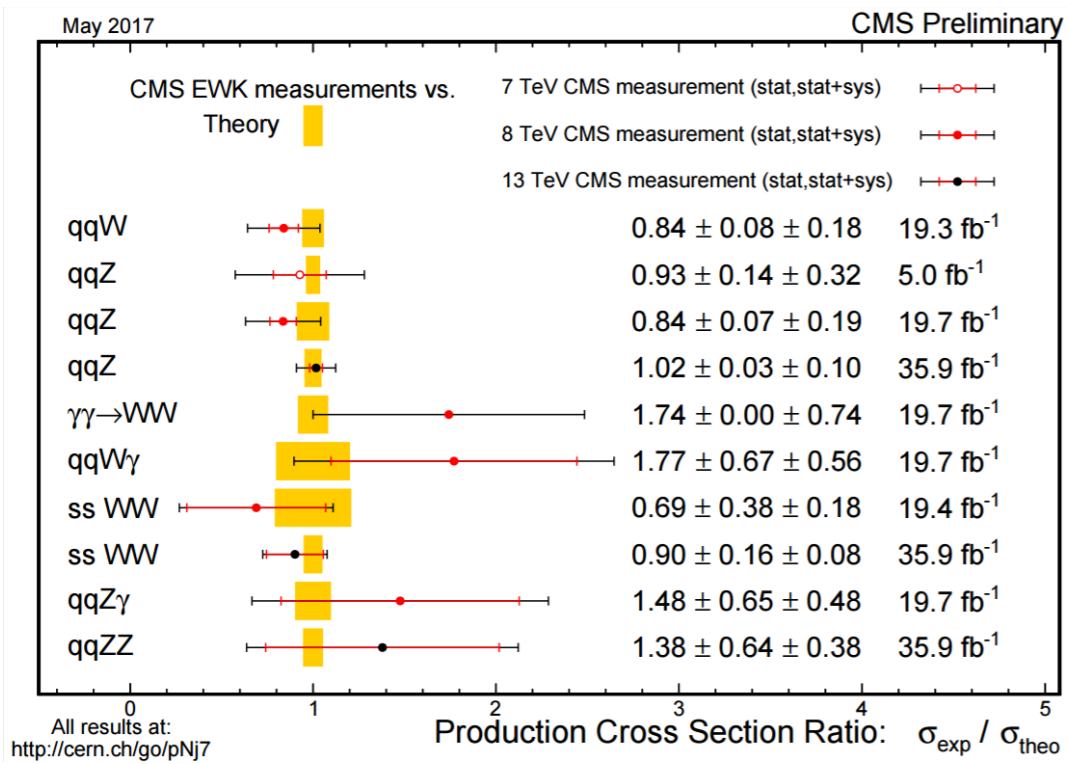
EW di-boson measurements

Electroweak diboson production

Pure EW production is sensitive to the gauge structure of underlying theory and can be sensitive to new physics

- **Large QCD-induced background**
- **Use vector boson fusion/scattering to enhance EW contribution**





EW VV+2jets	CMS 8 TeV
$W^{\pm}W^{\pm}\rightarrow l\nu l\nu$	PRL 114 (2015) 051801 obs. 1.9σ (exp. 2.9σ)
$W\gamma\rightarrow l\nu\gamma$	arXiv:1612.09256 obs. 2.7σ (exp. 1.5σ)
$Z\gamma\rightarrow ll\gamma$	arXiv:1702.03025 **Evidence:** obs. 3.0σ (exp. 2.1σ)

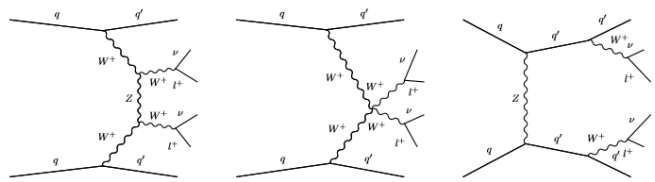
EW VV+2jets	CMS 13 TeV
$W^{\pm}W^{\pm}\rightarrow l\nu l\nu$	**First VBS observation** CMS PAS SMP-17-004
$ZZ\rightarrow 4l$	CMS PAS SMP-16-019 obs. 2.7σ (exp. 1.6σ)

Electroweak diboson production

13 TeV Same sign WW scattering ***First VBS observation!***

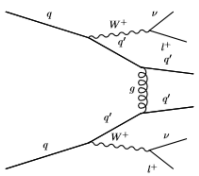
$pp \to W^{\pm}W^{\pm}\ jj$
$\to l^{\pm}\nu\ l^{\pm}\nu\ jj$

Important probe of EWSB mechanism: **Gold-plated modes**
$V_L V_L \to V_L V_L$ unitarized through the presence of the Higgs boson



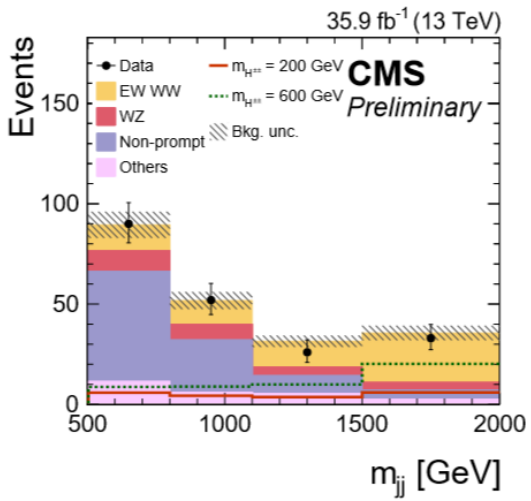
Signal = Electroweak component

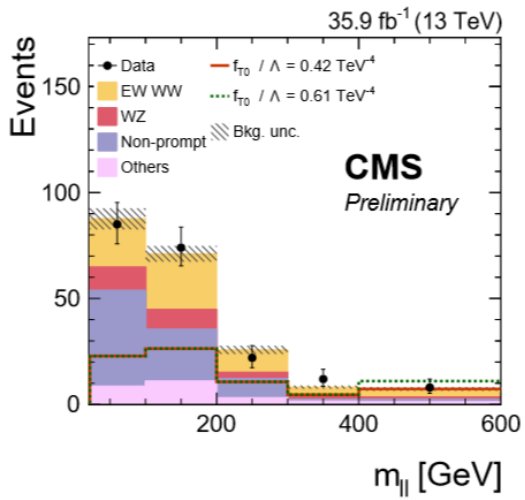
after event selection 7%



QCD component considered as background

Observed significance: 5.5σ
Expected: 5.7σ
Observed signal strength relative to SM prediction: 0.90 $\pm$0.22





Fiducial region:

two tight, same sign leptons (electron or muon) with $p_T > 20$ GeV, $|\eta| < 2.5$
two jets with $p_T > 30$ GeV and $|\eta| < 5.0$
$m_{jj} > 500$ GeV
$\Delta\eta_{jj} > 2.5$
$W \to \tau\nu \to l\nu\nu\nu$ decays are excluded.

Theoretical cross section = 4.25 ± 0.21 fb

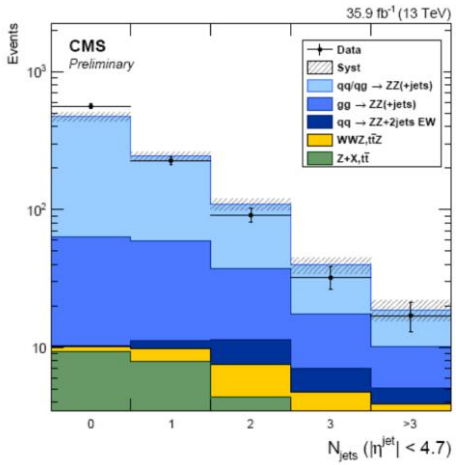
$\sigma_{\text{fiducial}} = 3.83 \pm 0.66$ (stat.) ± 0.35 (syst.) ± 0.12 (lumi.) fb

CMS PAS SMP-17-004

Electroweak diboson production

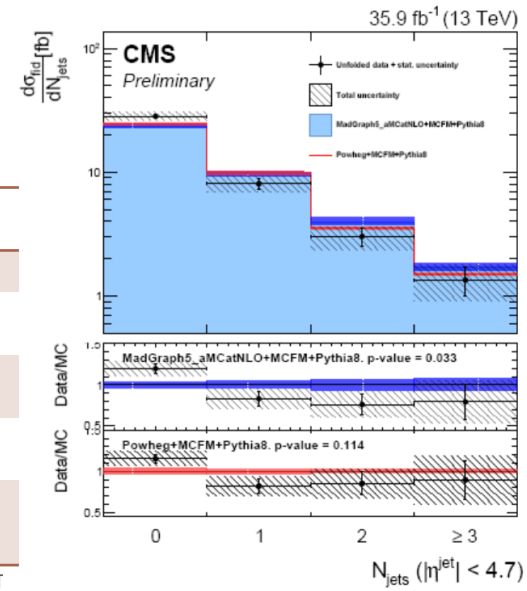
13 TeV **ZZ+jets differential cross section measurement** and **EW ZZ production**

Full 2016 dataset (SMP-16-019)



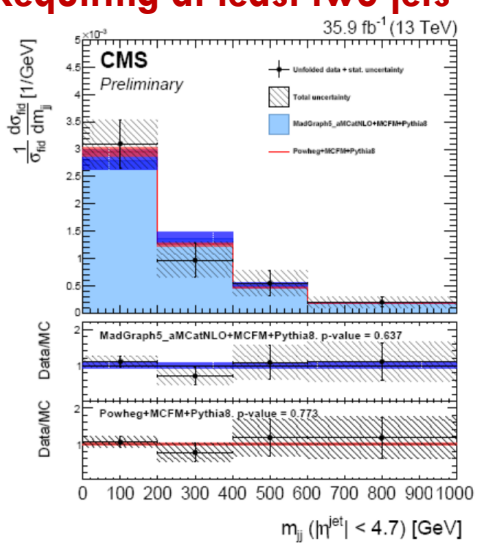
Distribution of reconstructed jet multiplicity.

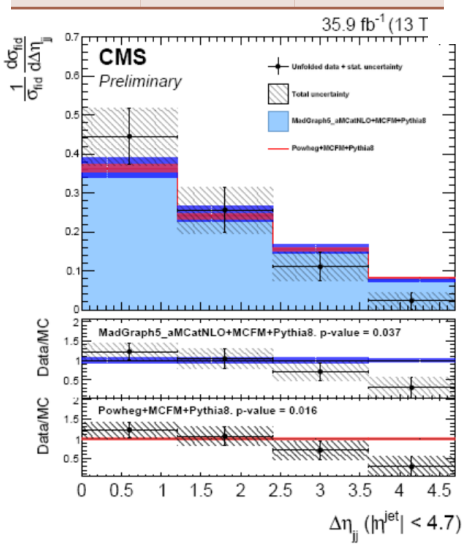
Process	ME Generator	Order/Merging
qq/qg/gg→4l+nj	POWHEG v2	NLO inc.
	MG5_aMC @NLO	≤1 j FxFx
	MadGraph 5.1	≤ 2 j MLM
gg→4l	MCFM 7.0 (6.7)	LO scaled to NLO
qq/qg/gg→4l+2j (EW)	PHANTOM	LO inc.



Differential cross section as a function of the multiplicity

Requiring at least two jets





VBS signal-enriched selection: mjj>400 GeV, $|\eta(j,j)|>2.4$ *+BDT optimization*

$$\sigma_{\rm fid}(\text{EW pp} \to ZZjj \to \ell\ell\ell'\ell' jj) = 0.40^{+0.21}_{-0.16}(\text{stat})^{+0.13}_{-0.09}(\text{syst})\ \text{fb}$$

obs. 2.7σ (exp. 1.6σ)

Electroweak diboson production

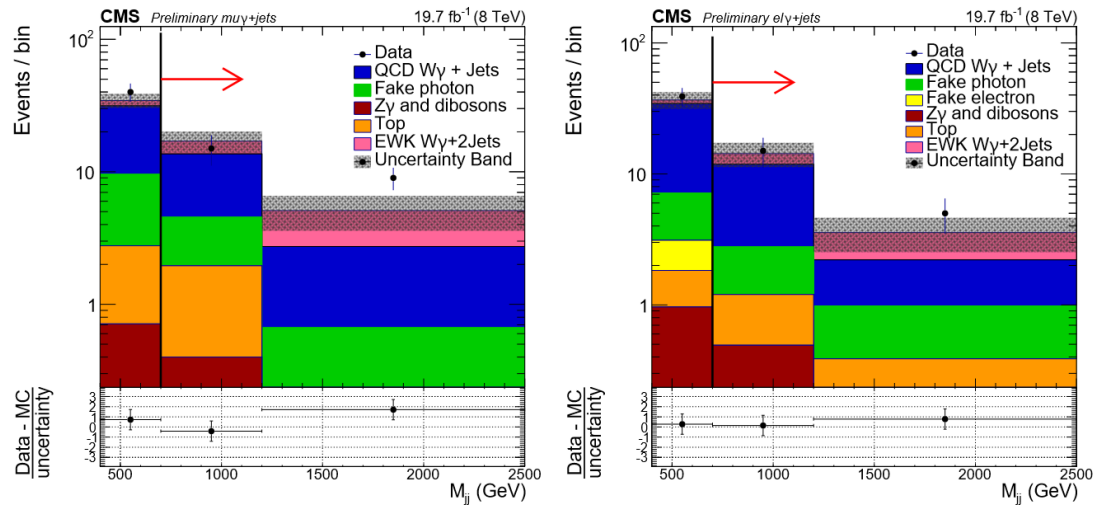
8 TeV Wγ scattering

arXiv:1612.09256

Expected significance: 1.5 σ

Observed significance: 2.7 σ

$$\sigma_{fid} = 10.8 \pm 4.1(stat) \pm 3.4(syst) \pm 0.3(lumi) fb$$



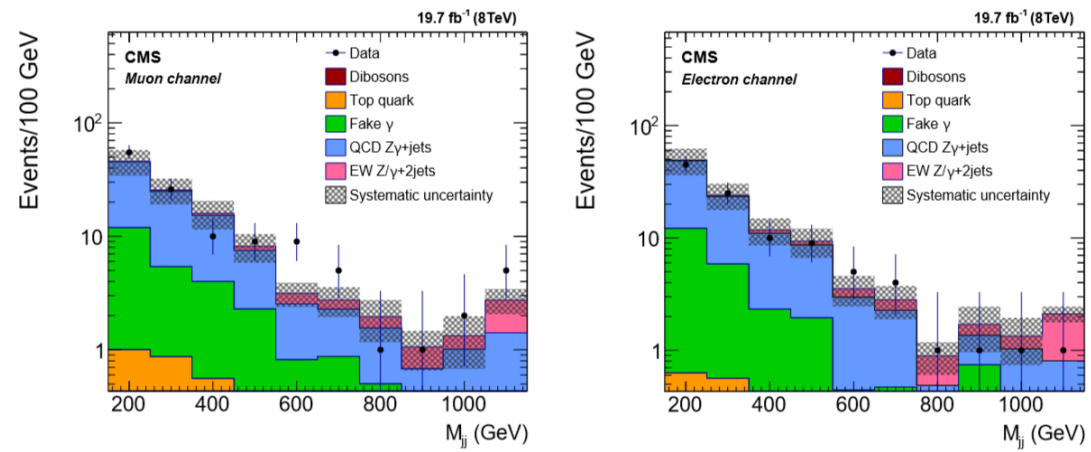
8 TeV Zγ scattering

arXiv:1702.03025

Expected significance: 2.1 σ

Observed significance: 3.0 σ

$$\sigma_{fid} = 1.86^{+0.90}_{-0.75}(stat)^{+0.34}_{-0.26}(syst) \pm 0.05(lumi) fb$$



Limits on anomalous gauge couplings

Anomalous Gauge Couplings

Probing gauge boson self interactions at the LHC

- Within the SM, the Gauge Lagrangian gives 6 vertices. Pure neutral couplings not allowed.
- Extending the SM in effective field theory

$$\mathcal{L}^{NP} = \mathcal{L}^{SM(4)} + \cancel{\frac{1}{\Lambda}\mathcal{L}^5} + \boxed{\frac{1}{\Lambda^2}\mathcal{L}^6} + \cancel{\frac{1}{\Lambda^3}\mathcal{L}^7} + \boxed{\frac{1}{\Lambda^4}\mathcal{L}^8} + \cdots$$

✕ Ignore lepton/baryon number violating terms

Dim-6, search for **aTGCs**

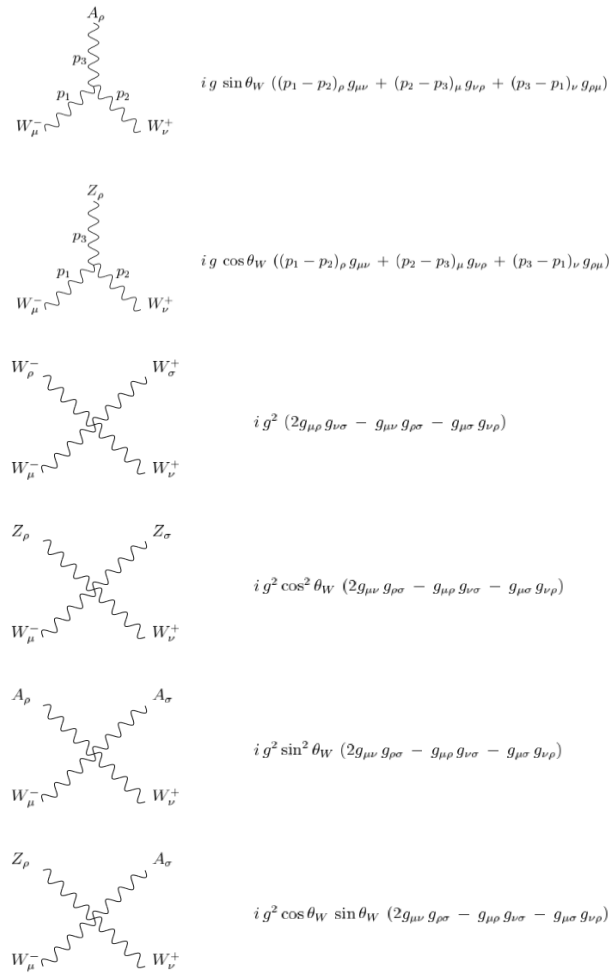
Dim-8, search for **aQGC** assuming no aTGC

- C,P conserving charged aTGCs (arXiv:hep-ph/9601233v1)

$$\Delta g_1^Z \equiv (g_1^Z - 1) \equiv \tan\theta_W \delta_Z \,, \quad \Delta\kappa_\gamma \equiv (\kappa_\gamma - 1) \equiv x_\gamma \,,$$
$$\Delta\kappa_Z \equiv (\kappa_Z - 1) \equiv \tan\theta_W (x_Z + \delta_Z) \,,$$
$$\lambda_\gamma \equiv y_\gamma, \quad \lambda_Z \equiv \tan\theta_W \, y_Z \,.$$

- Constraints from gauge invariance:

$$\Delta\kappa_Z = \Delta g_1^Z - \Delta\kappa_\gamma tan^2\theta_W \quad \lambda_\gamma = \lambda_Z$$



Different approaches: EFT/Vertex function/AC
Translation rules: arxiv:1205.4231

Anomalous Gauge Couplings

Probing gauge boson self interactions at the LHC

Neutral aTGCs

- CP-violating f_4^V, CP-conserving f_5^V (Nucl. Phys. B282 (1987) 253)
- CP-violating h_1^V, h_2^V, CP-conserving h_3^V, h_4^V

aQGCs

- LEP parameterization considers dim-6 anomalous couplings: **not** consistent with a symmetry breaking sector with a Higgs boson.
- Assuming SM gauge symmetry, no TGCs and Dimension 8, we have many QGCs (Phys.Rev.D74:073005,2006)

	WWWW	WWZZ	ZZZZ	WWAZ	WWAA	ZZZA	ZZAA	ZAAA	AAAA
$\mathcal{L}_{S,0}$, $\mathcal{L}_{S,1}$	X	X	X	O	O	O	O	O	O
$\mathcal{L}_{M,0}$, $\mathcal{L}_{M,1}$,$\mathcal{L}_{M,6}$,$\mathcal{L}_{M,7}$	X	X	X	X	X	X	X	O	O
$\mathcal{L}_{M,2}$,$\mathcal{L}_{M,3}$, $\mathcal{L}_{M,4}$,$\mathcal{L}_{M,5}$	O	X	X	X	X	X	X	O	O
$\mathcal{L}_{T,0}$,$\mathcal{L}_{T,1}$,$\mathcal{L}_{T,2}$	X	X	X	X	X	X	X	X	X
$\mathcal{L}_{T,5}$,$\mathcal{L}_{T,6}$,$\mathcal{L}_{T,7}$	O	X	X	X	X	X	X	X	X
$\mathcal{L}_{T8}$,$\mathcal{L}_{T,9}$	O	O	X	O	O	X	X	X	X

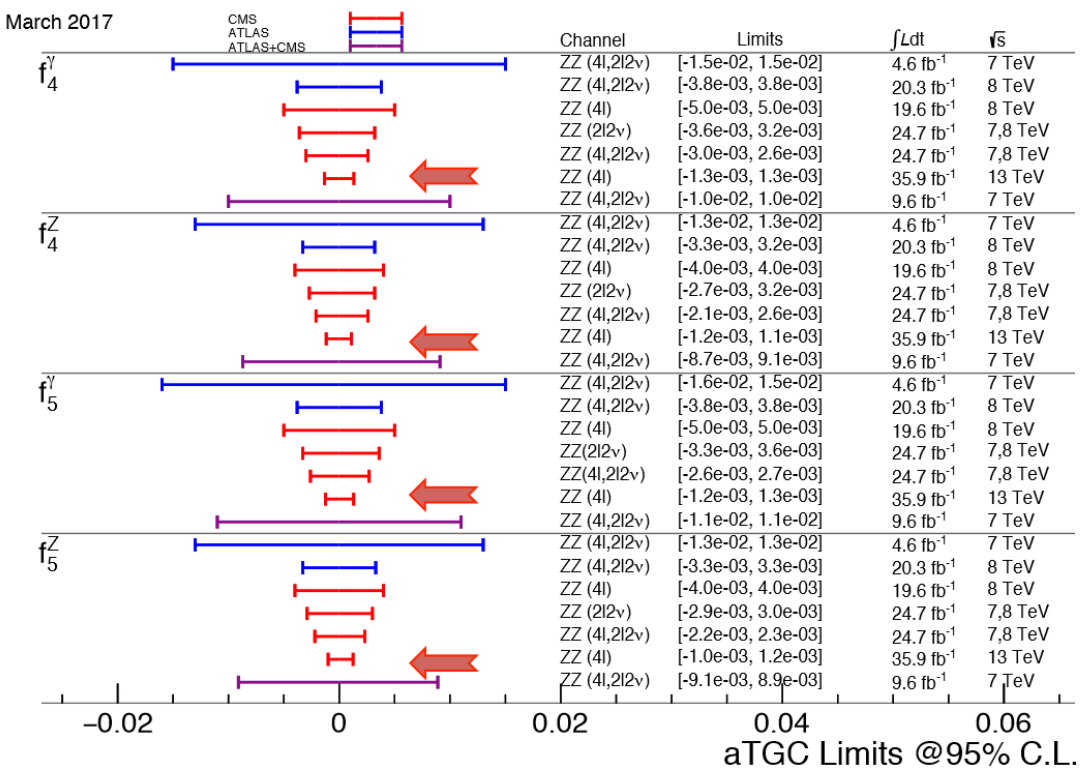
Anomalous Triple Gauge Couplings

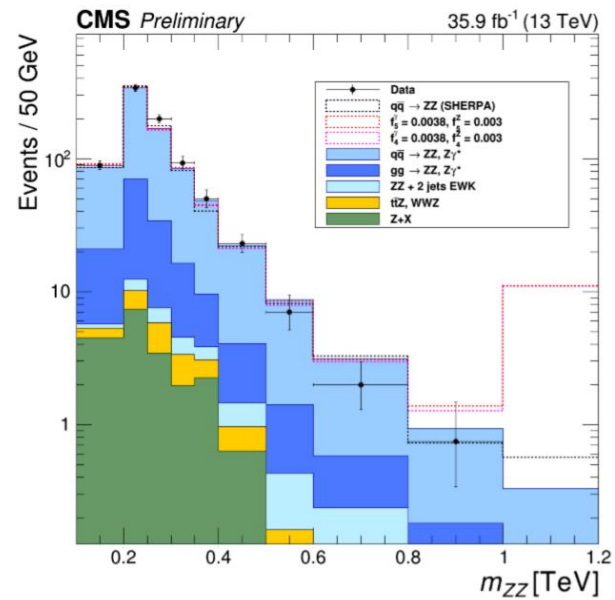
pp→ZZ → 4l CMS-PAS-SMP-16-017

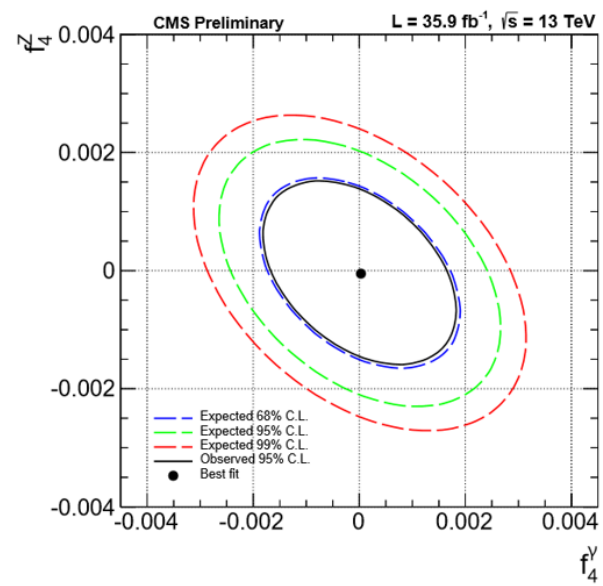
Clean signal:

No Zγγ, ZZγ, ZZZ couplings in the SM at LO

Fit to m_{ZZ} distribution to set the limits.



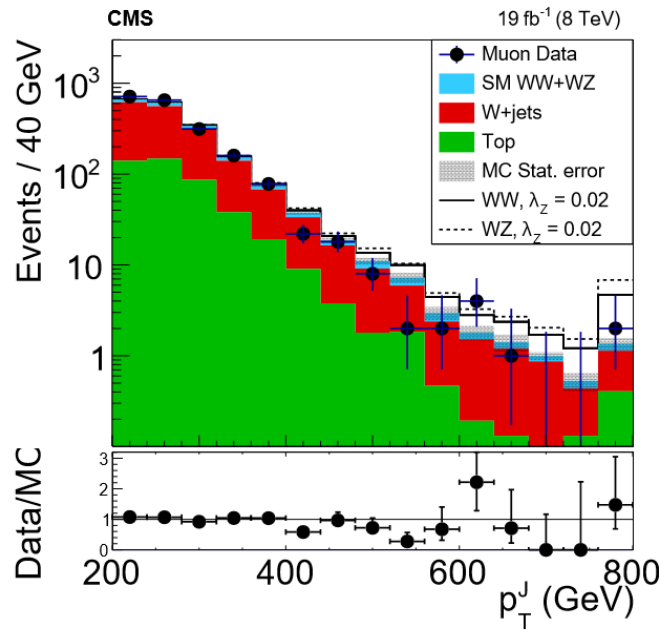




Anomalous Triple Gauge Couplings

Semileptonic WV decay (V=W,Z)

- *Larger rate than pure leptonic channel*
- *Leptonic decaying W can be reconstructed by assigning MET to neutrino*
- *Consider boosted V→qq, increased sensitivity to new physics*



8 TeV limits arXiv:1703.06095

Parameter	Expected Limits	Observed Limits
λ_Z	$[-0.014, 0.013]$	$[-0.011, 0.011]$
$\Delta\kappa_\gamma$	$[-0.068, 0.082]$	$[-0.044, 0.063]$
Δg_1^Z	$[-0.018, 0.028]$	$[-0.0087, 0.024]$

EFT limits (Translated)

	c_{WWW}/Λ^2 (TeV^{-2})	c_B/Λ^2 (TeV^{-2})	c_W/Λ^2 (TeV^{-2})
*	$[-2.7, 2.7]$	$[-14, 17]$	$[-2.0, 5.7]$
[6]	$[-5.7, 5.9]$	$[-29.2, 23.9]$	$[-11.4, 5.4]$
[7]	$[-4.61, 4.60]$	$[-20.9, 26.3]$	$[-5.87, 10.54]$
[43]	$[-4.6, 4.2]$	$[-260, 210]$	$[-4.2, 8.0]$
[44]	$[-3.9, 4.0]$	$[-320, 210]$	$[-4.3, 6.8]$

13 TeV limits (2015 dataset)
CMS-PAS-SMP-16-012

	aTGC	expected limit	observed limit
EFT param.	$\frac{c_{WWW}}{\Lambda^2}$ (TeV^{-2})	[-8.73 , 8.70]	[-9.46 , 9.42]
	$\frac{c_W}{\Lambda^2}$ (TeV^{-2})	[-11.7 , 11.1]	[-12.6 , 12.0]
	$\frac{c_B}{\Lambda^2}$ (TeV^{-2})	[-54.9 , 53.3]	[-56.1 , 55.4]
Vertex param.	λ	[-0.036 , 0.036]	[-0.039 , 0.039]
	Δg_1^Z	[-0.066 , 0.064]	[-0.067 , 0.066]
	$\Delta\kappa_Z$	[-0.038 , 0.040]	[-0.040 , 0.041]

Improvement upon the sensitivity of the fully leptonic 8TeV results and the combined LEP experiments

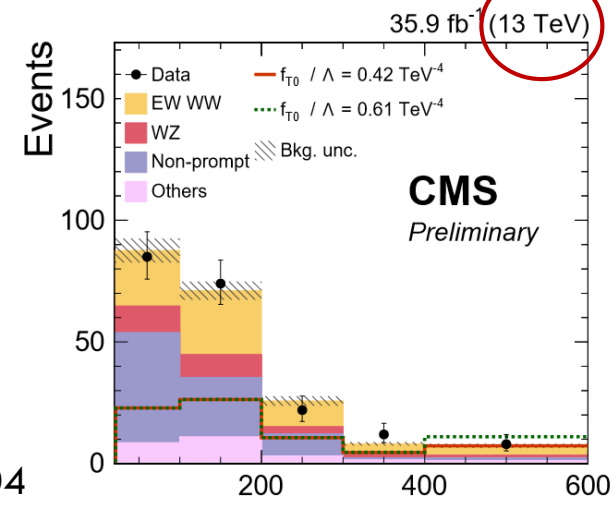
Anomalous Quartic Gauge Couplings

	Observed limits (TeV $^{-4}$)	Expected limits (TeV $^{-4}$)	Run-I limits (TeV $^{-4}$)
f_{S0}/Λ	[-7.7, 7.7]	[-7.0, 7.2]	[-38 , 40] [11]
f_{S1}/Λ	[-21.6,21.8]	[-19.9,20.2]	[-118 , 120] [11]
f_{M0}/Λ	[-6.0, 5.9]	[-5.6, 5.5]	[-4.6 , 4.6] [29]
f_{M1}/Λ	[-8.7 ,9.1]	[-7.9, 8.5]	[-17 , 17] [29]
f_{M6}/Λ	[-11.9,11.8]	[-11.1,11.0]	[-65 , 63] [11]
f_{M7}/Λ	[-13.3,12.9]	[-12.4,11.8]	[-70 , 66] [11]
f_{T0}/Λ	[-0.62,0.65]	[-0.58,0.61]	[-3.8 , 3.4] [30]
f_{T1}/Λ	[-0.28,0.31]	[-0.26,0.29]	[-1.9 , 2.2] [11]
f_{T2}/Λ	[-0.89,1.02]	[-0.80,0.95]	[-5.2 , 6.4] [11]

Significant improvement since Run-I

CMS PAS SMP-17-004

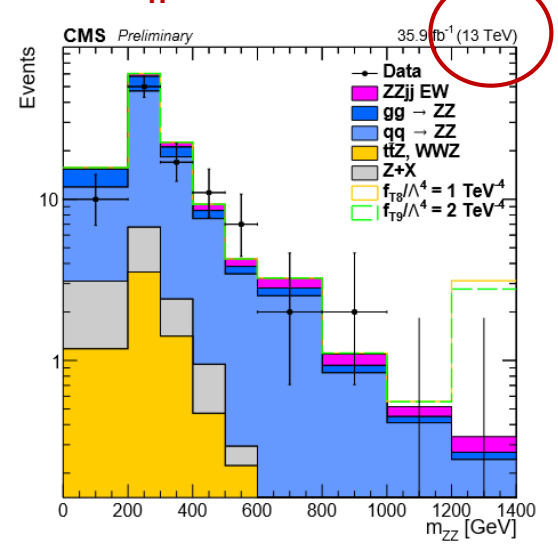
Same sign WW limits



Coupling	Exp. lower	Exp. upper	Obs. lower	Obs. upper	Unitarity bound
f_{T_0}/Λ^4	−0.53	0.51	−0.46	0.44	0.6
f_{T_1}/Λ^4	−0.72	0.71	−0.61	0.61	0.6
f_{T_2}/Λ^4	−1.4	1.4	−1.2	1.2	0.6
f_{T_8}/Λ^4	−0.99	0.99	−0.84	0.84	2.8
f_{T_9}/Λ^4	−2.1	2.1	−1.8	1.8	2.9

CMS PAS SMP-16-019

EW ZZjj limits



Experimental constraint better than the theoretical one

$L_{S,i}$: Operators containing just $D_\mu\Phi$

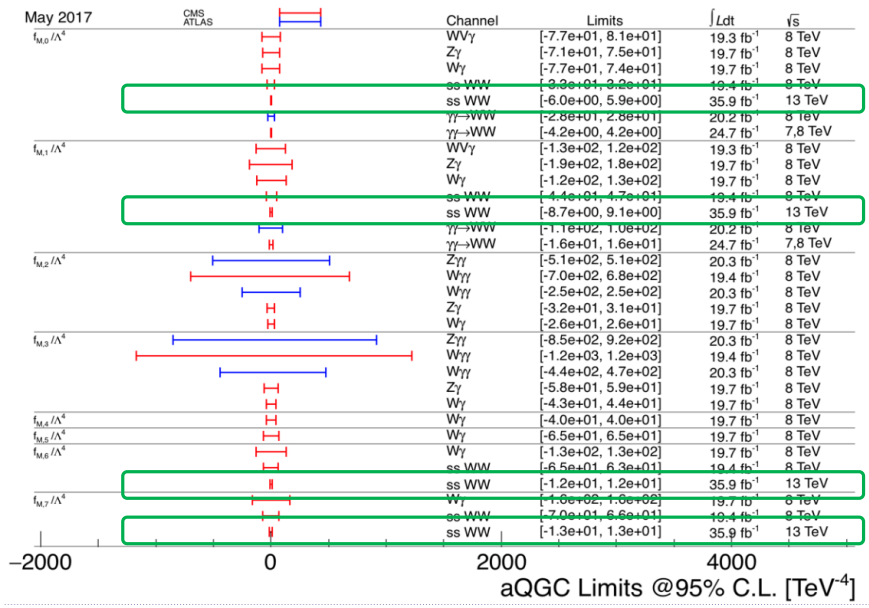
$L_{M,i}$: Operators containing $D_\mu\Phi$ and field strength

$L_{T,i}$: Operators containing just the field strength tensor

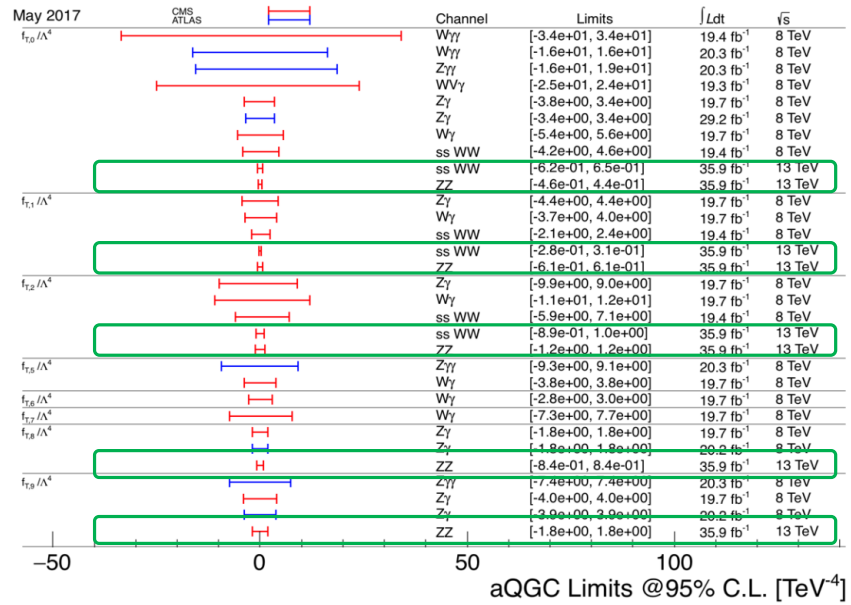
Comparison with existing limits

13 TeV limits significantly better than 8 TeV limits

$L_{M,i}$: Operators containing $D_\mu\Phi$ and field strength



$L_{T,i}$: Operators containing just the field strength tensor



CMS EWK ss WW $\to \ell^{+/-}\ell^{+/-}$qq: using 19.4 fb^{-1} of 8 TeV pp collisions Phys. Rev. Lett. 114, 051801 (2015)

CMS $VW\gamma \to jj\ell\bar{\nu}\gamma$ triboson production with 19.3 fb^{-1} of 8 TeV pp collisions Phys. Rev. D 90, 032008 (2014)

CMS $\gamma\gamma \to W^+W^- \to e^+\mu^-$ scattering with 5.0 fb^{-1} of 7 TeV and 19.7 fb^{-1} of 8 TeV pp collisions Submitted to JHEP

CMS EWK qq $\to Z\gamma qq \to \ell^+\ell^-\gamma$qq: using 19.7 fb^{-1} of 8 TeV pp collisions CMS-PAS-SMP-14-018

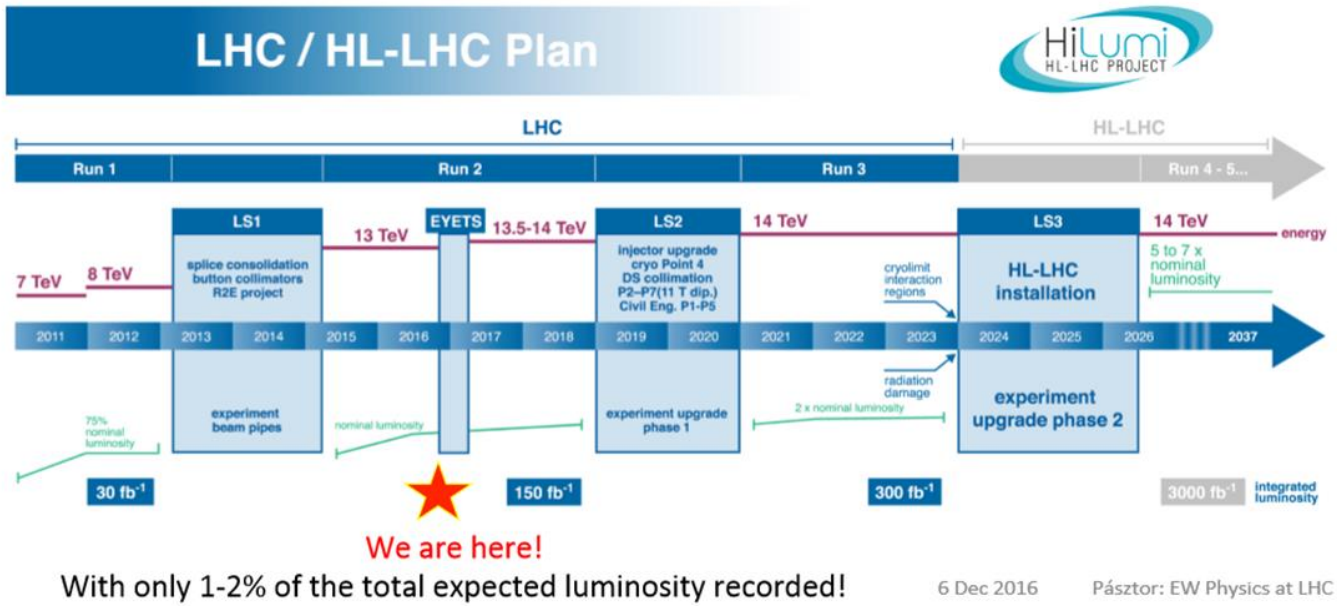
CMS EWK qq $\to W\gamma qq \to \ell^+\nu\gamma$qq: using 19.7 fb^{-1} of 8 TeV pp collisions CMS-PAS-SMP-14-011

CMS $W\gamma\gamma \to \ell\bar{\nu}\gamma\gamma$ and $Z\gamma\gamma \to \ell^+\ell^-\gamma\gamma$triboson production with 19.4 fb^{-1} of 8 TeV pp collisions Submitted to JHEP

ATLAS $W\gamma\gamma \to \ell\bar{\nu}\gamma\gamma$ triboson production with 19.3 fb^{-1} of 8 TeV pp collisions Phys.Rev.Lett. 115 (2015) 3, 031802

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

Outlook



Without hints on new physics, SM precession measurement is becoming more alive.

By LS2, we'll have about 150 fb^{-1} data

- Enable precise measurement of many processes; higher order predictions in QCD maybe also EW can be checked
- Increase sensitivities in probing the nature of EWSB