Multi-boson production and searches for anomalous gauge couplings at CMS

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On behalf of the CMS Collaboration

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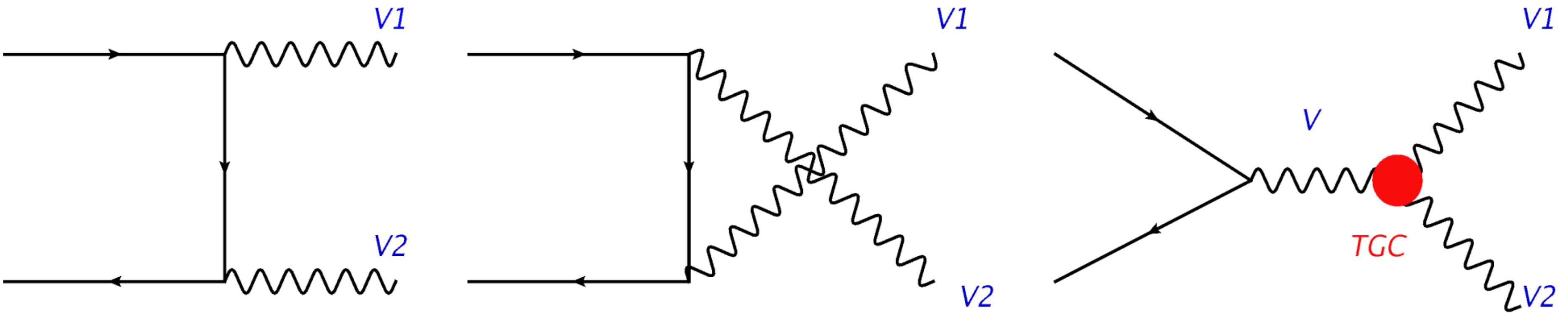
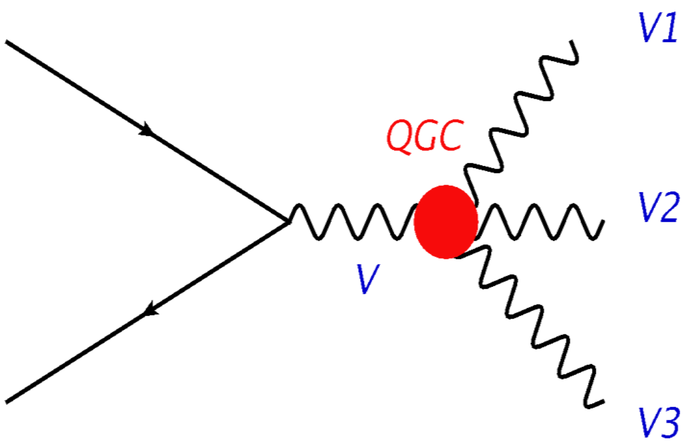
Physics Motivations



- Crucial test of the SM:
  e.g. on the non-Abelian gauge symmetry part of the SM

- Important backgrounds to Higgs and new physics searches

- Sensitive to anomalous Triple (Quartic) Gauge Couplings
  Indirect probe on new physics



Overview of CMS results

$$\sigma_S = \frac{N_S}{A_S \cdot \epsilon_S \cdot L}$$

Process (l=e,μ)	Int. Luminosity(fb^{-1}) @7TeV	Int. Luminosity(fb^{-1}) @8TeV	Xsec Measurement Phase space	aTGC/QGC
Wγ→ lνγ	5.0	-	E_T^{γ} >15/60/90GeV & ΔR(l, γ)>0.7	WWγ
Zγ→ llγ	5.0	-	E_T^{γ} >15/60/90GeV & ΔR(l, γ)>0.7 & M_{ll}>50GeV	ZZγ, Zγγ
Zγ→ ννγ	5.0	-	E_T^{γ} >145GeV & $\lvert\eta^{\gamma}\rvert$ <1.4	ZZγ, Zγγ
WW+WZ→lνjj	5.0	-	Full	WWγ, WWZ
WW→lνlν	4.9	3.5	Full	WWγ, WWZ
WZ→ 3lν	4.9	**19.6**	71GeV<MZ<111GeV	WWZ
ZZ→4l, 2l2τ	4.9	**19.6**	60GeV<$MZ_{1,2}$<120GeV	ZZZ, ZZγ
WWγ+WZγ →lνjjγ	-	**19.3**	E_T^{γ} >15GeV & ΔR(l, γ)>0.7	WWγγ, WZγγ
γγ	**5.0**	-	$E_T^{\gamma 1,2}$ >40,25GeV, ΔR(γ,γ)>0.7 $\lvert\eta_\gamma\rvert < 1.44$ or $1.57 < \lvert\eta_\gamma\rvert < 2.5$	

Exclusive γγ → W^+W^- not covered here, but will be shown in aQGC comparison

Wγ→ lνγ (l=e,μ) 7TeV

CMS-PAS-EWK-10-008, Phys. Lett. B 701 (2011) 535, arXiv:1105.2758; CMS-PAS-EWK-11-009, arXiv:1308.6832, submitted to Phys. Rev. D

Events selections:

① **Exactly one isolated lepton**:
Single Lepton trigger & P_T^l>35GeV & ($|\eta^e|<2.5$ || $|\eta^\mu|<2.1$)

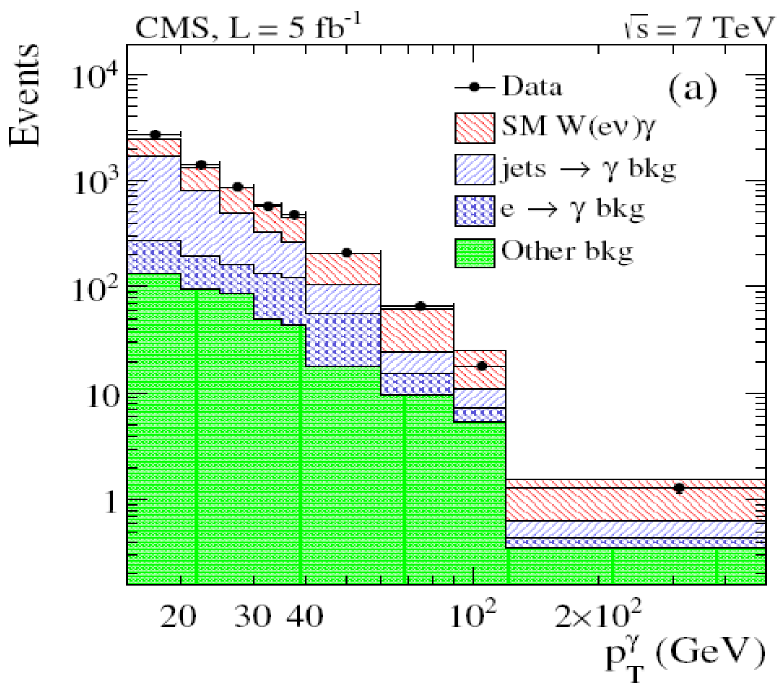
② **One isolated photon**:
E_T^γ >15GeV & $|\eta^\gamma|<2.5$ & $\Delta R(l, \gamma)>0.7$

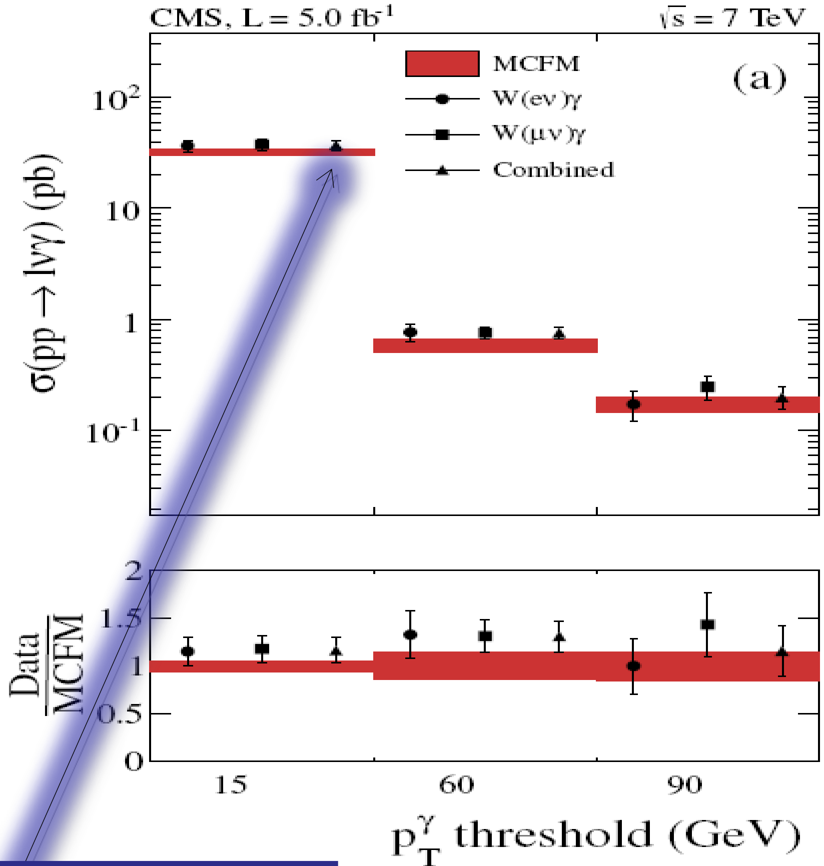
③ **Veto 2nd same flavor Lepton**

④ **Large W transversemass**: M_T^W>70GeV

Main Backgrounds from Data-Driven:

- **W+Jets: Jet fake photon**
  → dominate systematics
- **DY, VV: Electron fake photon**





MCFM NLO: 31.8±1.8pb

$$\sigma(pp \to W\gamma) \times \mathcal{B}(W \to \ell\nu) = 37.0 \pm 0.8\,(\text{stat.}) \pm 4.0\,(\text{syst.}) \pm 0.8\,(\text{lum.})\,\text{pb.}$$

$Z\gamma \rightarrow ll\gamma$ 7TeV

CMS-PAS-EWK-10-008, Phys. Lett. B 701 (2011) 535, arXiv:1105.2758; CMS-PAS-EWK-11-009, arXiv:1308.6832, submitted to Phys. Rev. D

Events selections:

① **Two isolated lepton**:
Double Lepton trigger & P_T^l>20GeV & ($|\eta^e|$<2.5 || $|\eta^\mu|$<2.4)

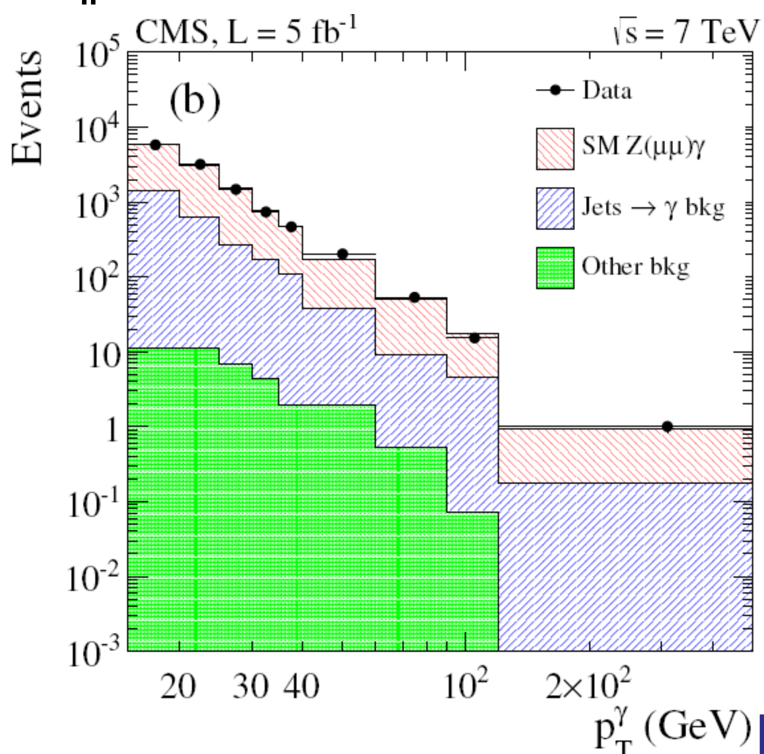
② **One isolated photon**:
E_T^γ >15GeV & $|\eta^\gamma|$<2.5 & $\Delta R(l, \gamma)$>0.7

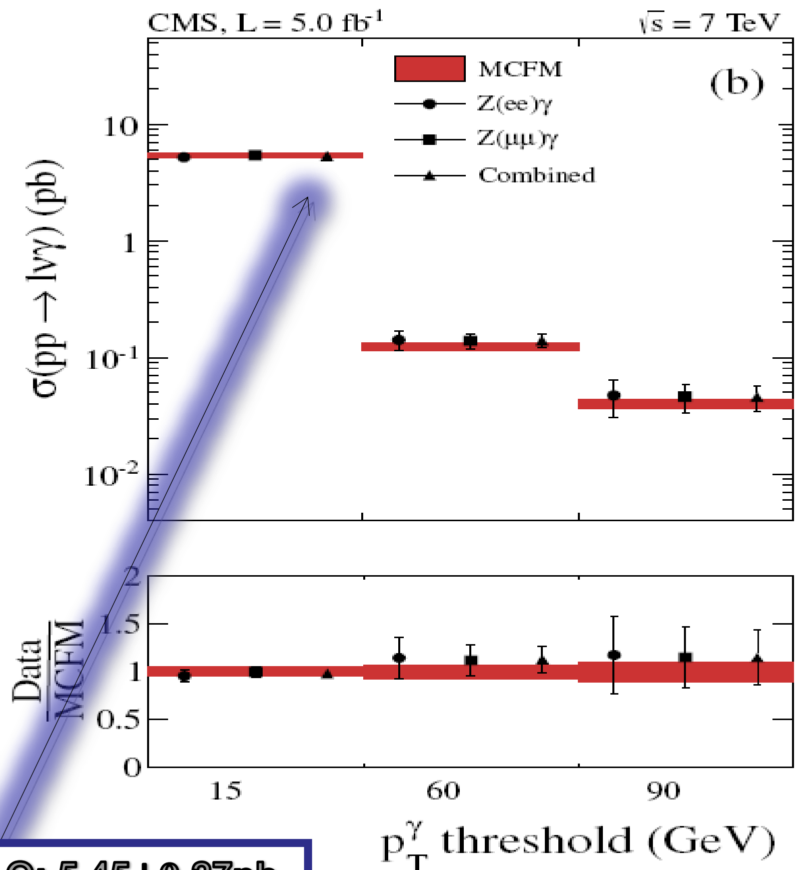
③ **M_{ll}>50GeV**

Main Backgrounds from Data-Driven:

➢ **Z+Jets: Jet fake photon**

Lep ID/ISO Unc. → dominate systematics





MCFM NLO: 5.45±0.27pb

$$\sigma(pp \rightarrow Z\gamma) \times \mathcal{B}(Z \rightarrow \ell\ell) = 5.33 \pm 0.08\,(\text{stat.}) \pm 0.25\,(\text{syst.}) \pm 0.12\,(\text{lum.})\,\text{pb}.$$

7TeV

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

Events selections:

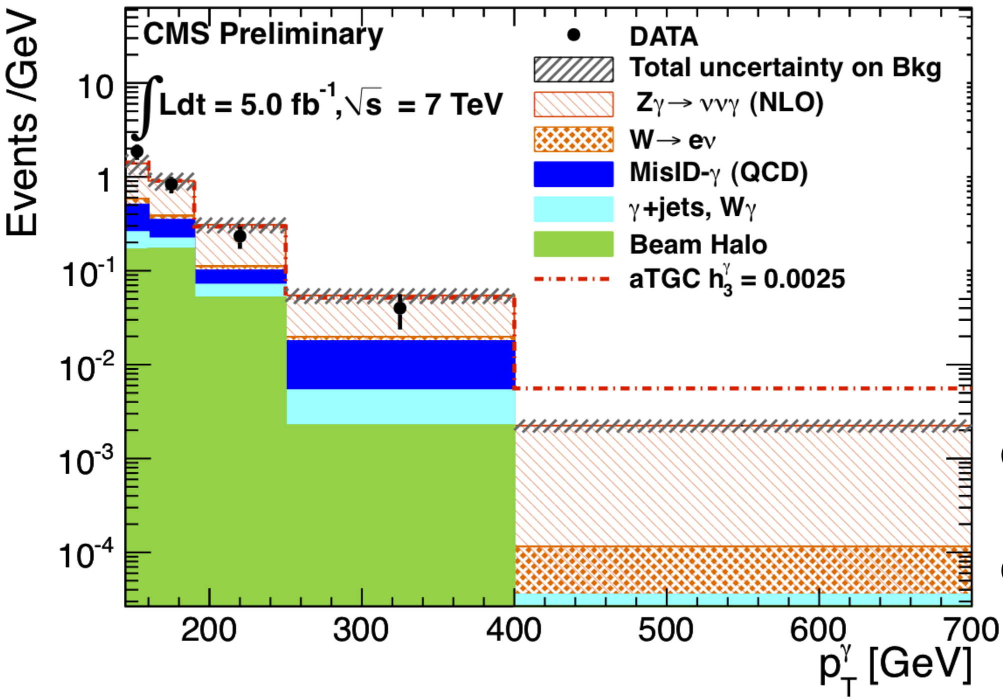
① **One isolated photon**:

Single γ Trigger & E_T^{γ} >145GeV & $|\eta^{\gamma}|$ <1.4

② **MET>130GeV**

③ **Veto additional energetic track**

④ **Veto additional energetic Jets near γ**



Main Backgrounds from Data-Driven:

- **Multi-Jets: Jet fake photon**
- **Beam-gas**
- **W→ *eν* with e fake photon**

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
$Z\gamma \rightarrow \nu\nu\gamma$ (NLO)	45.3 ± 6.9
data	73

$\sigma_{CMS}(pp \rightarrow \nu\nu\gamma) = 21.3 \pm 4.2$ (stat.) ± 4.3 (syst.) ± 0.5 (lumi.) fb

$\sigma_{NLO}(pp \rightarrow \nu\nu\gamma) = 21.9 \pm 1.1$fb (**from BAUR**)

WW+WZ→lνjj

7TeV

EPJC73 (2013) 2283, arXiv:1210.7544

Events selections:

① **Exactly one isolated lepton**:
Single Lepton trigger &
(P_T^e>35GeV & $|\eta^e|$<2.5) ||
(P_T^μ>25GeV & $|\eta^\mu|$<2.1)

② **Exactly two PF AK5 Jets with b veto**:
P_T^j >35GeV & $|\eta^j|$<2.4

③ **MET>25 (30) GeV for μ (e) channel**

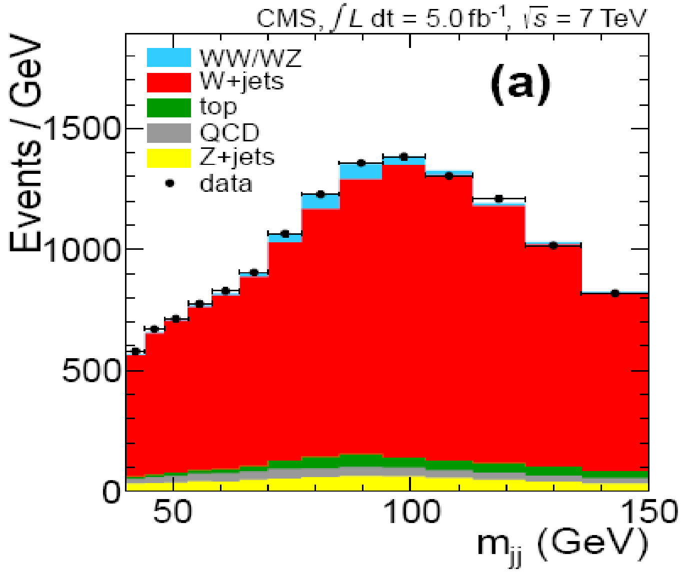
④ **Veto additional loose lepton:**
P_T^j >10 (20) GeV for μ (e) channel

⑤ **M_T^W>30 (50) GeV for μ (e) channel**

Large Branch Ratio
Large Background
Due to Jet resolution, can't distinguish WW from WZ

Signal and background yields determined with an unbinned likelihood fit to the dijet mass spectrum

σ_{CMS} (pp→WW+WZ) = 68.9 ± 8.7 (stat.) ± 9.7 (syst.) ± 1.5 (lumi.) pb
σ_{NLO} (pp→WW+WZ) = 65.6 ± 2.2pb (**from MCFM**)



Process	Shape	Constraint on normalization
Diboson (WW+WZ)	MC	Unconstrained
W+jets	MC	31.3 nb ± 5% (NLO) [30]
$t\bar{t}$	MC	163 pb ± 7% (NLO) [31]
Single top	MC	85 pb ± 5%(NNLL) [32–34]
Drell–Yan+jets	MC	3.05 nb ± 4.3% (NNLO) [35]
Multijet (QCD)	data	E_T^{miss} fit in data

W+jets: float factorization/renorm & ME-PS matching scales to get good modeling of data

7 & 8TeV
qqb, gg(3%) → WW→lνlν

CMS-PAS-SMP-12-013, Phys. Lett. B 721 (2013) 190, arXiv:1301.4698; CMS-PAS-SMP-12-005, arXiv:1306.1126, submitted to EPJC; CMS-PAS-EWK-10-009, Phys. Lett. B 699 (2011) 25, arXiv:1102.5429; CMS-PAS-EWK-11-010

Events selections:

① **Two oppositely Charged isolated lepton**:
Single/Double Lepton trigger &
P_T^l>20GeV & ($|\eta^e|$<2.5 || $|\eta^\mu|$<2.4)

② **Veto any Jets with**:
P_T^j >30GeV & $|\eta^j|$<4.7

③ **Projected MET>45 (20) GeV for OF (SF) channel**

④ **Veto additional loose lepton:**
P_T^j >10 GeV

⑤ **Reject el consistent with a photon conversion**

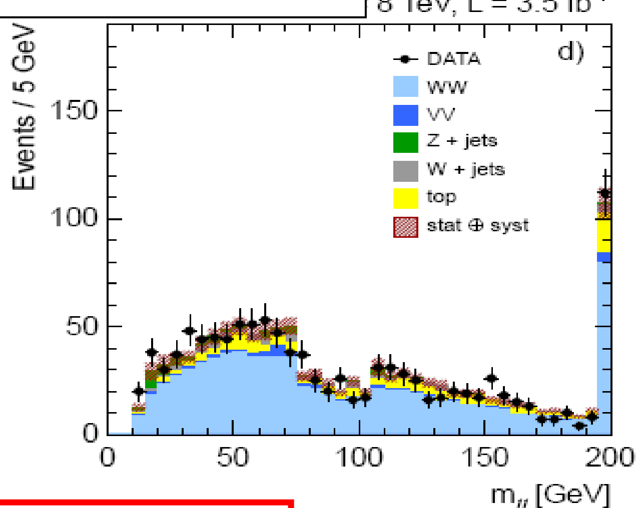
⑥ **Φ(ll,J1)<165degree, with J1 as the hardest Jet with** P_T^j >15GeV

⑦ **Veto $|M_{ll}-M_Z|$<15GeV or M_{ll}<12GeV**

⑧ **Veto top bkg with b-veto (arXiv:1211.4462)**

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

Sys. dominated by Jet veto eff ~4.6%



Main Backgrounds :

- **V+Jets:** ③ ⑥⑦
- **Top:** ② ⑧
- **Di-Boson:** ④⑤
- **Driven/Corrected by DATA**

Inclusive WW cross section:

	σ_{CMS} [pb]	σ_{NLO} [pb] (MCFM)
7 TeV	$52.4 \pm 2.0_{stat} \pm 4.5_{syst} \pm 1.2_{lumi}$	47.0 ± 2.0
8 TeV	$69.9 \pm 2.8_{stat} \pm 5.6_{syst} \pm 3.1_{lumi}$	$57.3^{+2.4}_{+1.6}$

Contributions from Higgs ~4% Not included

7 &8 TeV NEW

$WZ \to 3l\nu$

CMS-PAS-SMP-12-006

Events selections:

① **Two SF & OC leptons**:

Double Lepton trigger

P_{Tl1} >20 GeV & P_{Tl2} >10 GeV & $|M_{ll}-M_Z|$<20GeV

In case of multi-Z, choose the one closest to M_Z

② **A 3rd lepton** P_{Tl3}>20GeV

③ **MET>30 GeV**

- **Main Backgrounds from Data-Driven:**

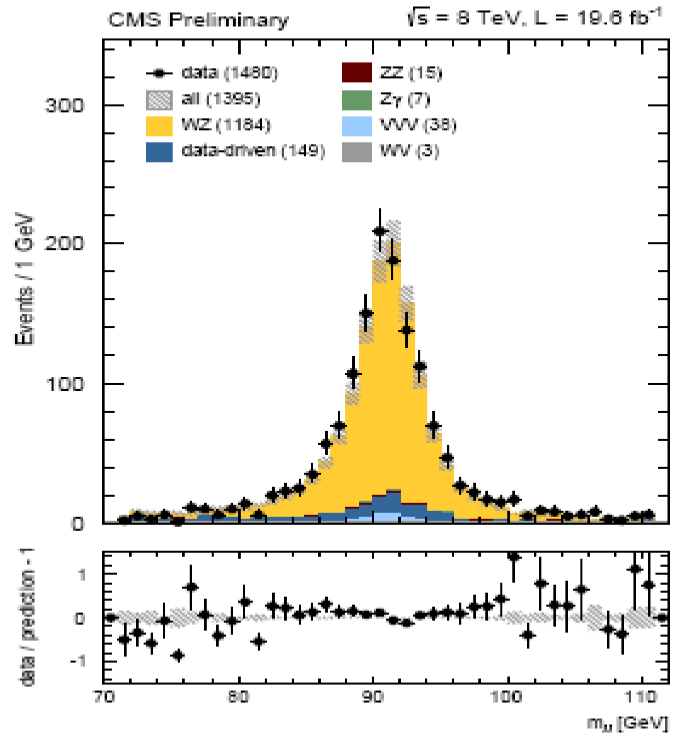
  Z+Jets: fake or non-isolated lepton from Jets

  ZZ → 4l with one lepton lost

- **ZZ/ Zγ /VVV from MC**

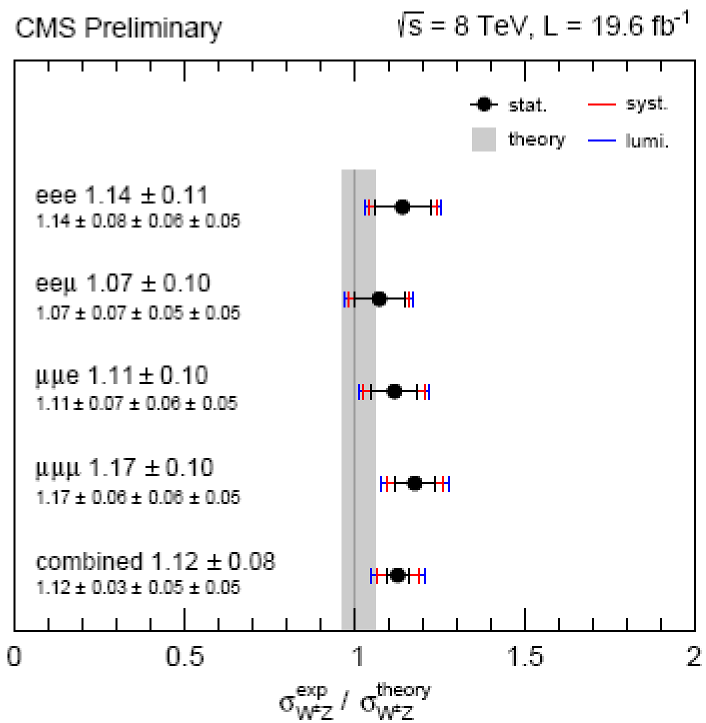
Yields of selected events in data at 8 TeV

sample	eee	$ee\mu$	$\mu\mu e$	$\mu\mu\mu$
Z+jets	9.8 ± 4.4	16.9 ± 6.0	14.5 ± 5.4	13.8 ± 4.5
top	1.4 ± 0.4	2.7 ± 0.3	6.2 ± 0.7	9.1 ± 1.0
ZZ	2.4 ± 0.1	3.1 ± 0.1	3.9 ± 0.1	5.8 ± 0.1
$Z\gamma$	2.4 ± 0.9	0.4 ± 0.4	3.8 ± 1.2	0
WV	0.1 ± 0.1	0.1 ± 0.1	0.2 ± 0.1	2.2 ± 0.7
VVV	6.1 ± 0.3	7.9 ± 0.3	10.4 ± 0.4	13.4 ± 0.4
WZ	193.9 ± 1.4	245.8 ± 1.6	315.9 ± 1.9	428.0 ± 2.2
total MC	216.0 ± 4.7	277.0 ± 6.3	354.9 ± 6.0	472.3 ± 5.2
data-driven	14.8 ± 1.4	27.1 ± 2.9	47.9 ± 3.4	59.0 ± 4.6
data	235	288	400	557



7 &8 TeV NEW

WZ→ 3lν



$$\left(\frac{\sigma_{W+Z}}{\sigma_{W-Z}}\right)_{7\ \text{TeV}} = 1.94 \pm 0.25\ (\text{stat.}) \pm 0.04\ (\text{syst.})$$

$$\left(\frac{\sigma_{W+Z}}{\sigma_{W-Z}}\right)_{8\ \text{TeV}} = 1.81 \pm 0.12\ (\text{stat.}) \pm 0.03\ (\text{syst.})$$

The SM prediction for this ratio

at $\sqrt{s} = 7$ TeV is $1.776^{+0.006}_{-0.003}$,

1.724 ± 0.003 at $\sqrt{s} = 8$ TeV

71GeV<MZ<111GeV

Statistical Uncertainty dominates

MCFM NLO

$\sigma\left(pp \to WZ + X; \sqrt{s} = 7\,\text{TeV}\right) = 20.76 \pm 1.32\ (\text{stat.}) \pm 1.13\ (\text{syst.}) \pm 0.46\ (\text{lumi.})$ pb

$17.8^{+0.7}_{-0.5}$ pb

$\sigma\left(pp \to WZ + X; \sqrt{s} = 8\,\text{TeV}\right) = 24.61 \pm 0.76\ (\text{stat.}) \pm 1.13\ (\text{syst.}) \pm 1.08\ (\text{lumi.})$ pb

$21.91^{+1.17}_{-0.88}$ pb

ZZ→4l, 2l2τ

CMS-PAS-SMP-13-005; CMS-PAS-SMP-12-014, Phys. Lett. B 721 (2013) 190, arXiv:1301.4698; JHEP 01(2013)063, arXiv:1211.4890; CMS-PAS-EWK-11-010

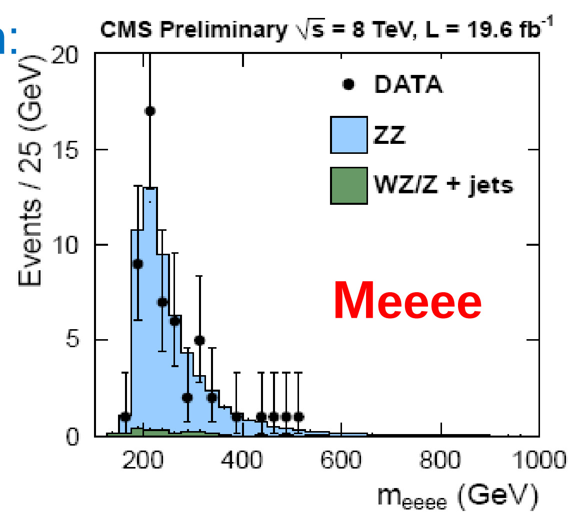
4l	2l2τ
Double lepton or Triple-electron triggers	
60GeV<$MZ_{1,2}$<120GeV M_{ll}>4GeV	60GeV<M_{ll}<120GeV 20(30)GeV<$M^{vis}{\tau\tau}$<120GeV for $\tau_e\tau_\mu$ (all others)
P_T^{l1}>20GeV, P_T^{l2}>10GeV,	P_T^{l1}>20GeV, P_T^{l2}>10GeV, $P_T(\tau_{e,}\ \tau_\mu)$>10GeV, $P_T(\tau_h)$>20GeV
FSR Photon Recovered with $M_{ll\gamma}$<100GeV	No FRS photon recovery

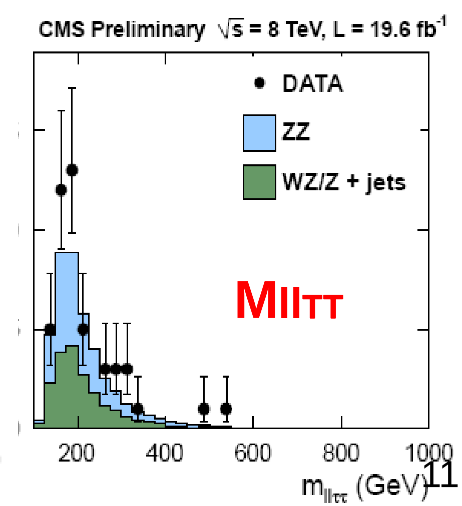
Main Backgrounds from Data-Driven:

- **Z/WZ+Jets:**
  Jet fake l or τ
- **Ttbar and Zbb:**
  Heavy Flavor Jets

Main systematic uncertainty:

tau reconstruction



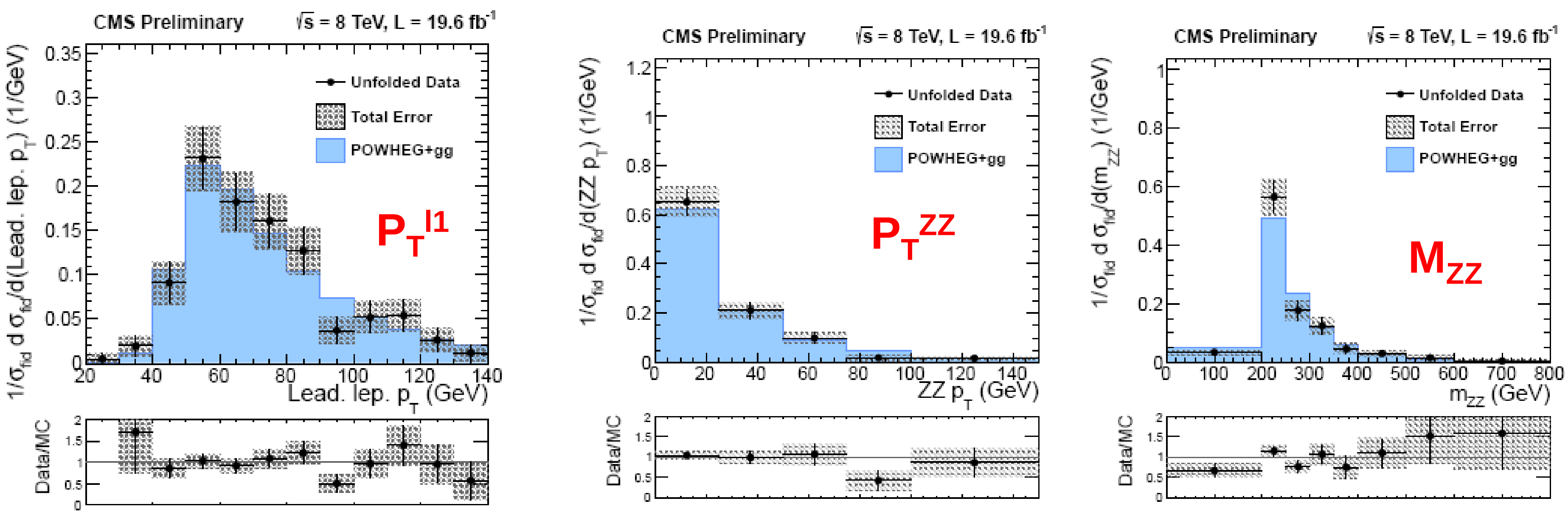


7 &8 TeV NEW

ZZ→4l, 2l2τ

		MCFM NLO qq + LO gg	
7 TeV	$6.24^{+0.86}_{-0.80}(stat.)^{+0.41}_{-0.32}(sys.) \pm 0.14(lumi.)$	**6.3 ± 0.4**	**pb**
8 TeV	$7.7 \pm 0.5(stat.) \pm 0.6(syst.) \pm 0.4(theo.) \pm 0.3(lumi.)$	**7.7 ± 0.6**	**pb**

The differential distributions normalized to fiducial cross sections



(a)

8 TeV NEW

WWγ+WZγ →lνjjγ

CMS-PAS-SMP-12-006

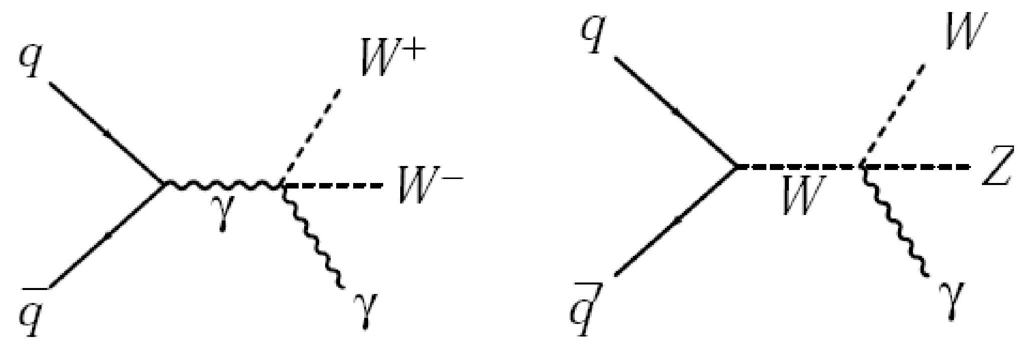
Events selections:

① **Exactly one isolated lepton**:

Single Lepton trigger &

(P_T^e>35GeV & $|\eta^e|$<2.5) ||

(P_T^μ>25GeV & $|\eta^\mu|$<2.1)



② **Two PF AK5 Jets with b veto**:

P_T^j >30GeV & $|\eta^j|$<2.4

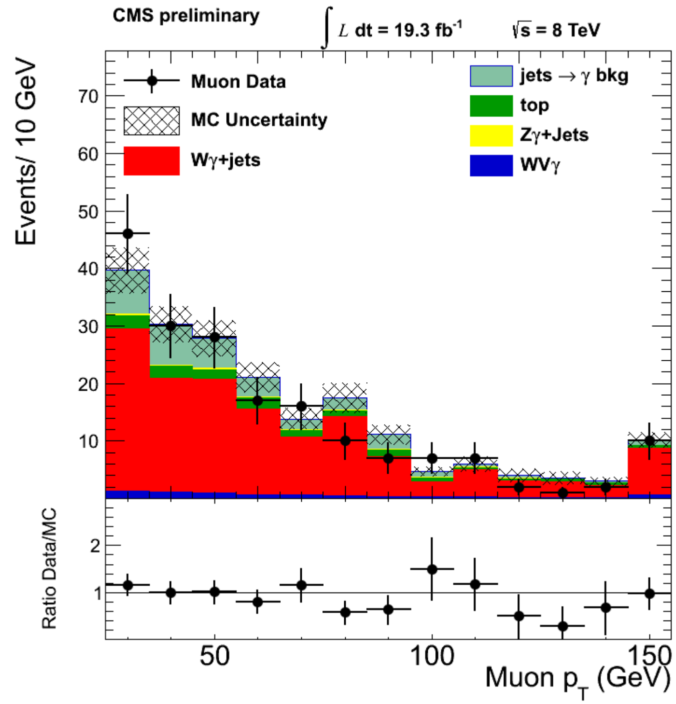
③ **MET>35 GeV**

④ **Δφ(MET,J1)>0.4, $R_{j\gamma}$>0.5, $R_{l\gamma}$>0.5**

⑤ **M_T^W>30 GeV**

⑥ **$|M_{\gamma e}-M_z|$>10GeV**

⑦ **$|\Delta\eta_{jj}|$<1.4, 70GeV<M_{jj}<110GeV**



Main Backgrounds from Data-Driven:

- Wγ+Jets : **sideband**
- **Fake Photon: ratio method**

σ(WV γ)< 241fb, 3.4 times SM (70.3fb)
E_T^γ >15GeV

CMS-PAS-SMP-13-001

γγ

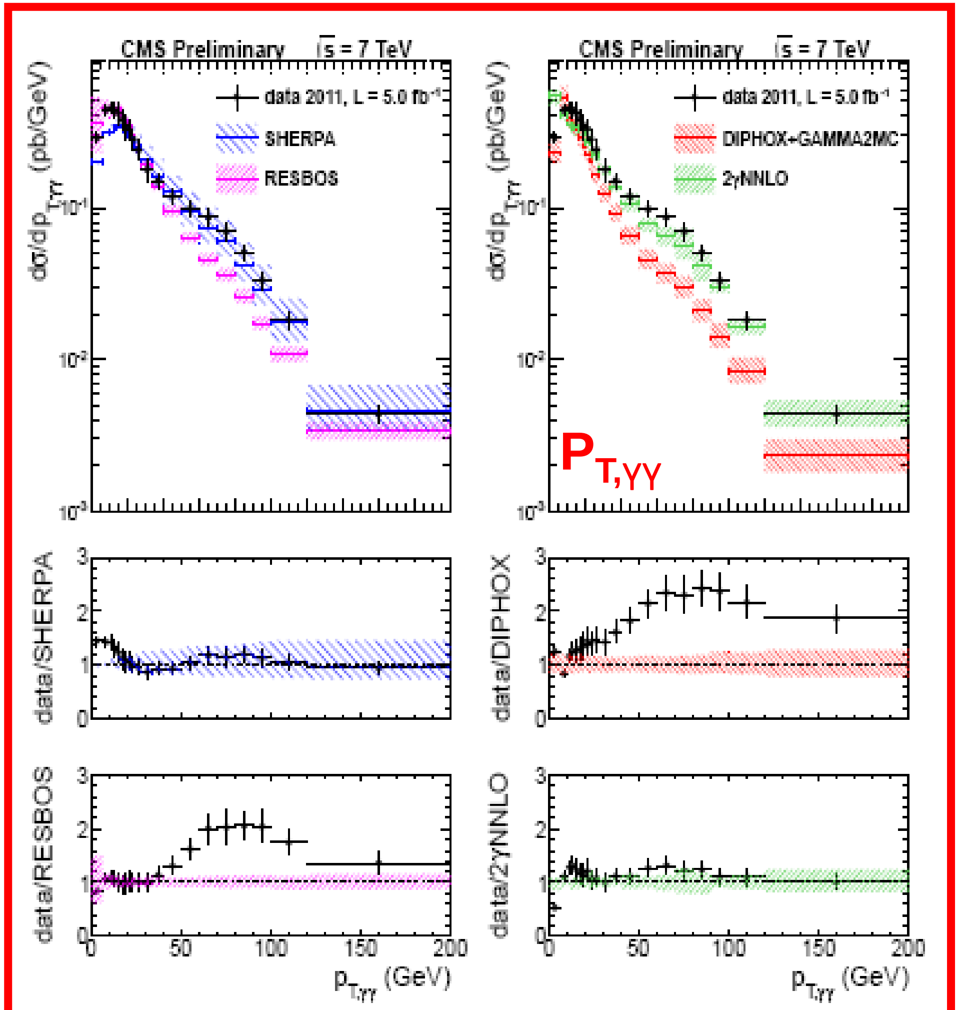
$$\sigma_{data} = 16.8 \pm 0.2\ (\text{stat.}) \pm 1.8\ (\text{syst.}) \pm 0.4\ (\text{lumi})\ \text{pb}$$

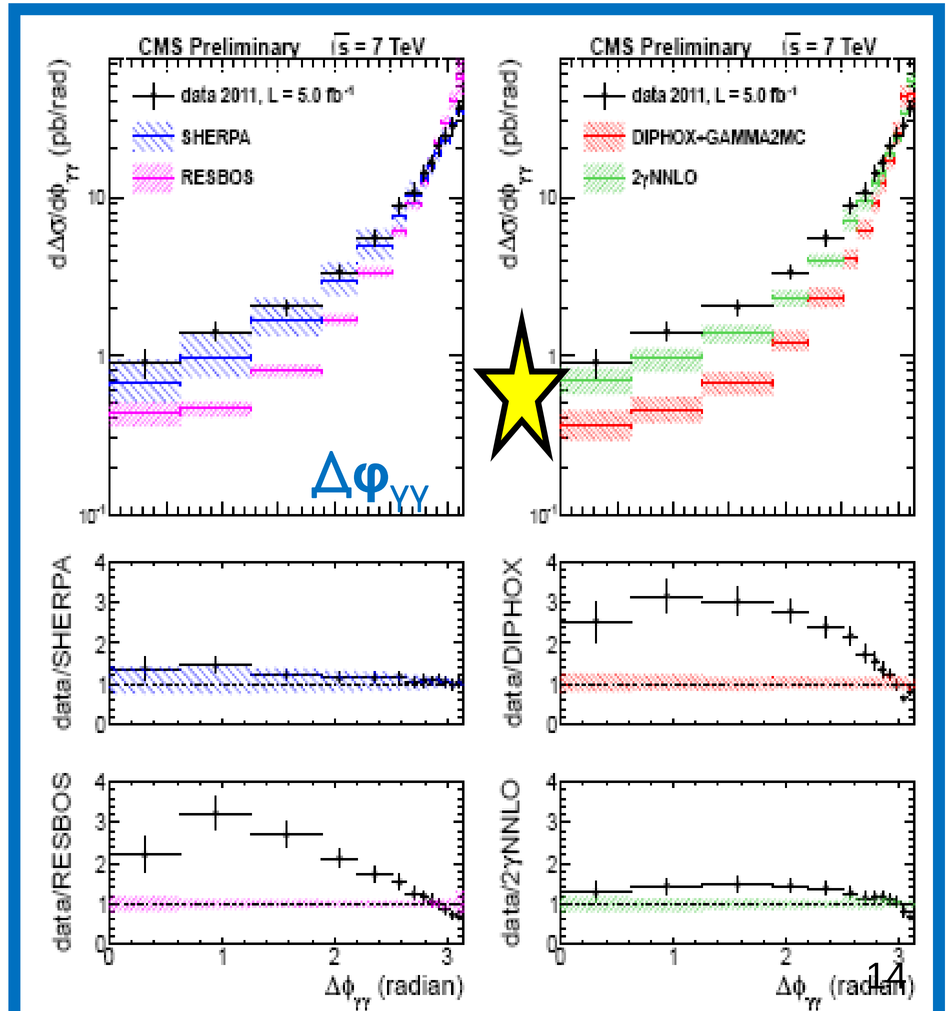
$$\sigma_{\text{NNLO}}(2\gamma\text{NNLO}) = 16.2^{+1.5}_{-1.3}(\text{scale})\ \text{pb}$$

$$\sigma_{\text{NLO}}(\text{DIPHOX+GAMMA2MC}) = 12.8^{+1.6}_{-1.5}(\text{scale})^{+0.6}_{-0.8}(\text{pdf}+\alpha_s)\ \text{pb}$$

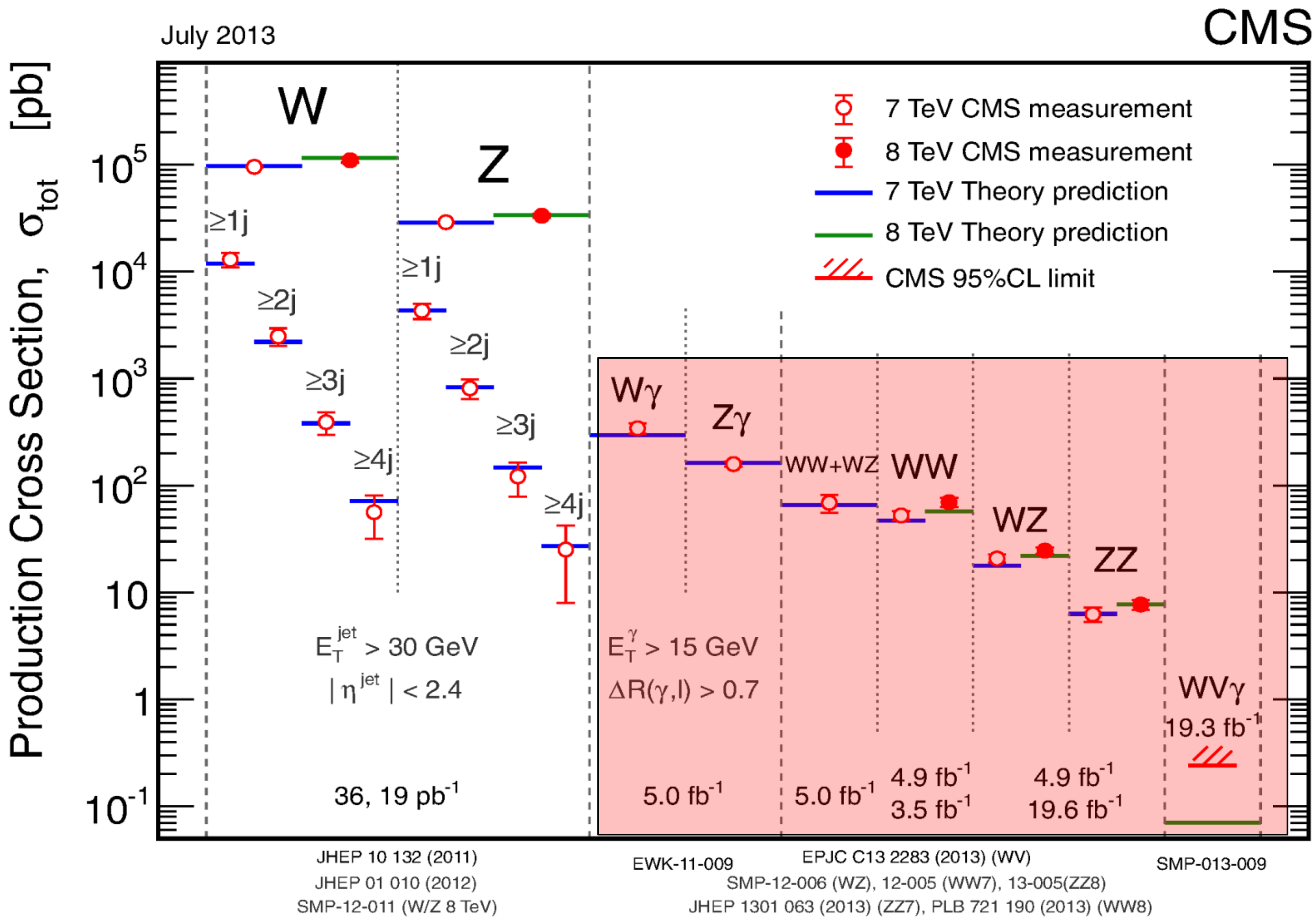
$$\sigma_{\text{NLO}}(\text{RESBOS}) = 14.9^{+2.2}_{-1.7}(\text{scale}) \pm 0.6(\text{pdf}+\alpha_s)\ \text{pb}$$

$$\sigma_{\text{LO}}(\text{SHERPA}) = 15.2^{+3.2}_{-1.9}(\text{scale})\ \text{pb}$$





Summary of the Xsec Measurement



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

Triple and Quartic Anomalous Gauge Couplings

- **ATGC and AQGC are less well measured in EWK**
- **They are signature of New Physics**
- **At hard tail of phase space, they increase Xsec significantly**

Charged aTGCs WWγ/WWZ
HISZ (LEP) parametrization

$\lambda_\gamma = \lambda_Z = \lambda$

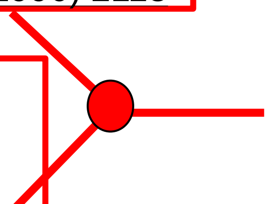
$\Delta K_Z = \Delta g^Z_1 - \Delta K_\gamma . \tan^2\theta_W$

NPB282 (1987) 253; PRD41 (1990) 2113

Neutral aTGCs

Zγ channel: Zγγ/ZZγ
$h_3^{Z,\gamma}$, $h_4^{Z,\gamma}$
PRD47 (1993) 4889

ZZ channel: ZZγ/ZZZ
$f_4^{Z,\gamma}$, $f_5^{Z,\gamma}$
NPB282 (1987) 253

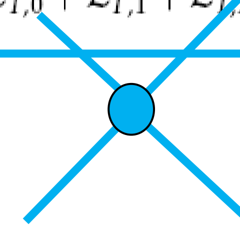


aQGCs WWγγ/WWZγ EPJC 13 (2000) 283

Now under Dim8 Framework, where operators can be recombined to get the same Lorentz structure Dim6 operators as in LEP

a_0^W, a^W_c **as well as other pure Dim8 ones:**

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

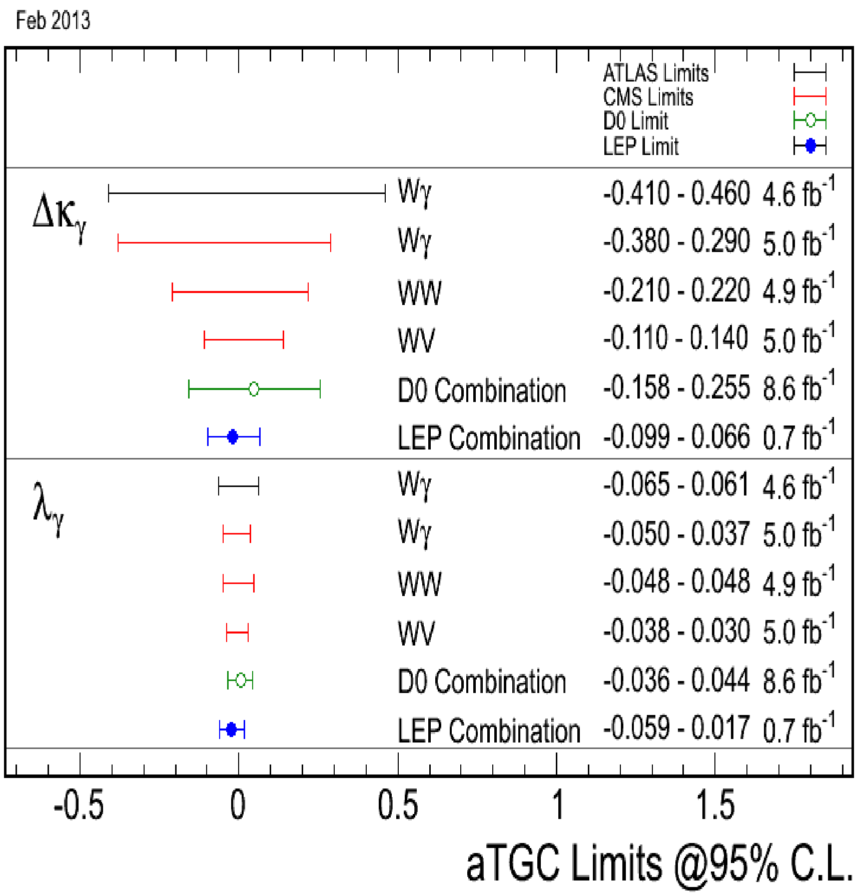


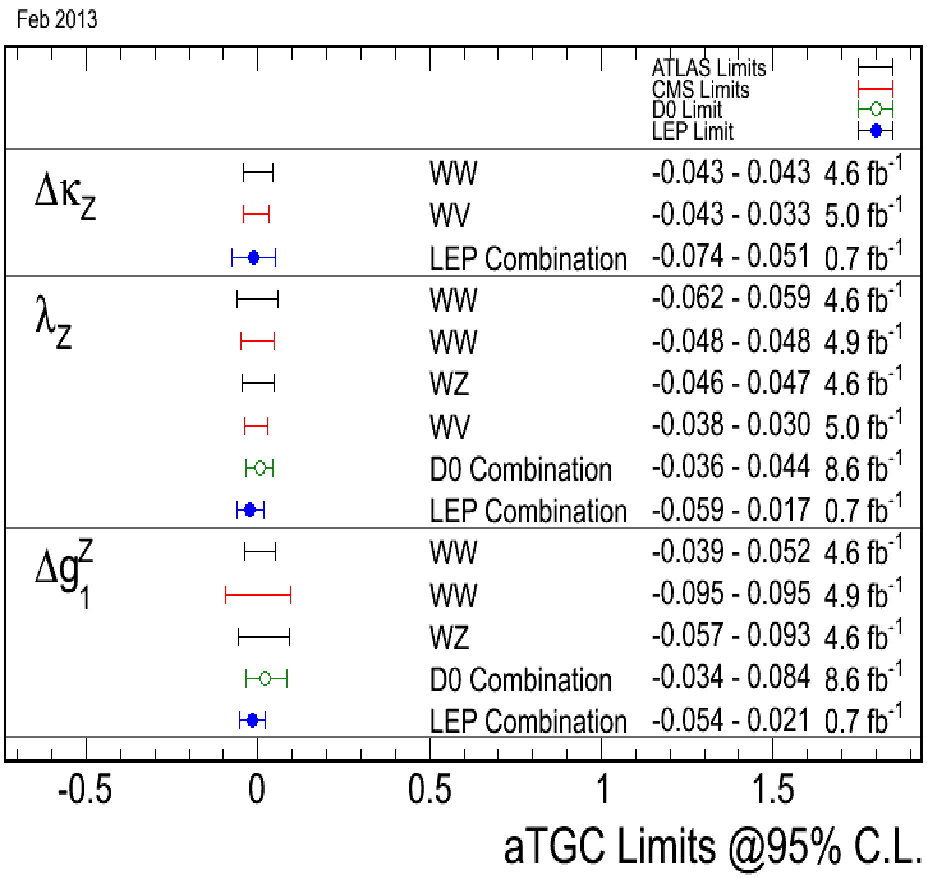
- *Without Form factor for aTGC*
- *With and Without for aQGC*
- *CLs and profile likelihood methods used to set the upper limit*

Triple and Quartic Anomalous Gauge Couplings

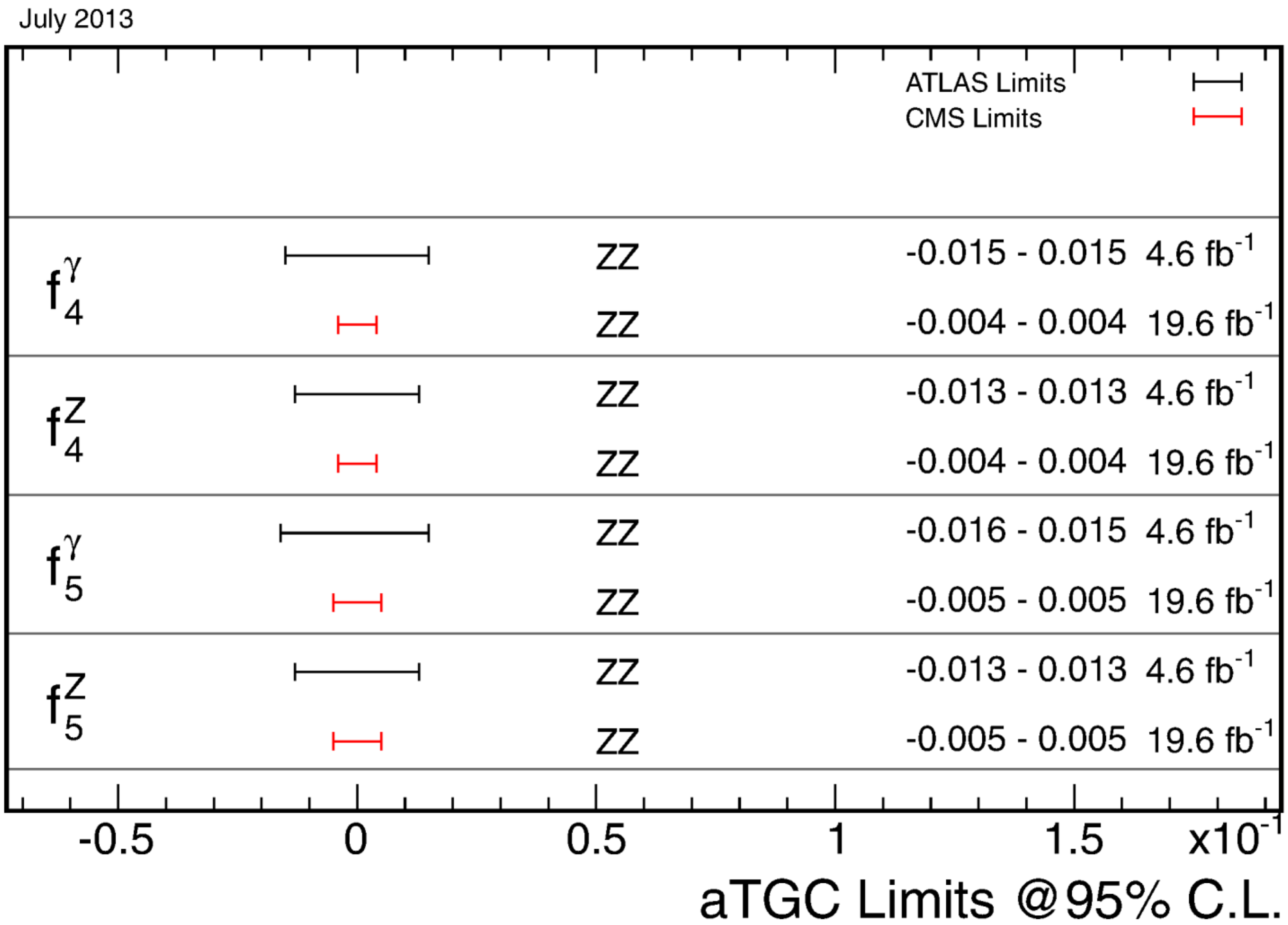
Process (l=e,μ)	aTGC/QGC Parameters		Limit Setting variable
$W\gamma \to l\nu\gamma$	WWγ	$\boldsymbol{\lambda_{\gamma}, \Delta K_{\gamma}}$	E_T^{γ}
$Z\gamma \to ll\gamma$	ZZγ, Zγγ	$\boldsymbol{h_3^{Z,\gamma}, h_4^{Z,\gamma}}$	E_T^{γ}
$Z\gamma \to \nu\nu\gamma$	ZZγ, Zγγ	$\boldsymbol{h_3^{Z,\gamma}, h_4^{Z,\gamma}}$	E_T^{γ}
$WW+WZ \to l\nu jj$	WWγ, WWZ	$\boldsymbol{\lambda_{Z}, \Delta K_{\gamma}}$	P_T^{jj}
$WW \to l\nu l\nu$	WWγ, WWZ	$\boldsymbol{\lambda_{Z}, \Delta K_{\gamma}, \Delta g^{Z}_{1}}$	Max P_T^{l}
$ZZ \to 4l, 2l2\tau$	ZZZ, ZZγ	$\boldsymbol{f_4^{Z,\gamma}, f_5^{Z,\gamma}}$	M_{4l}
$WW\gamma+WZ\gamma \to l\nu jj\gamma$	WWγγ, WZγγ	$\boldsymbol{a_0^W, a^W_c}$, $\boldsymbol{f0_T}$, K_0^W, K_c^W	E_T^{γ}
$\gamma\gamma \to$ **W^+W^-**	WWγγ	$\boldsymbol{a_0^W, a^W_c}$	P_T^{ll}

Charged aTGCs

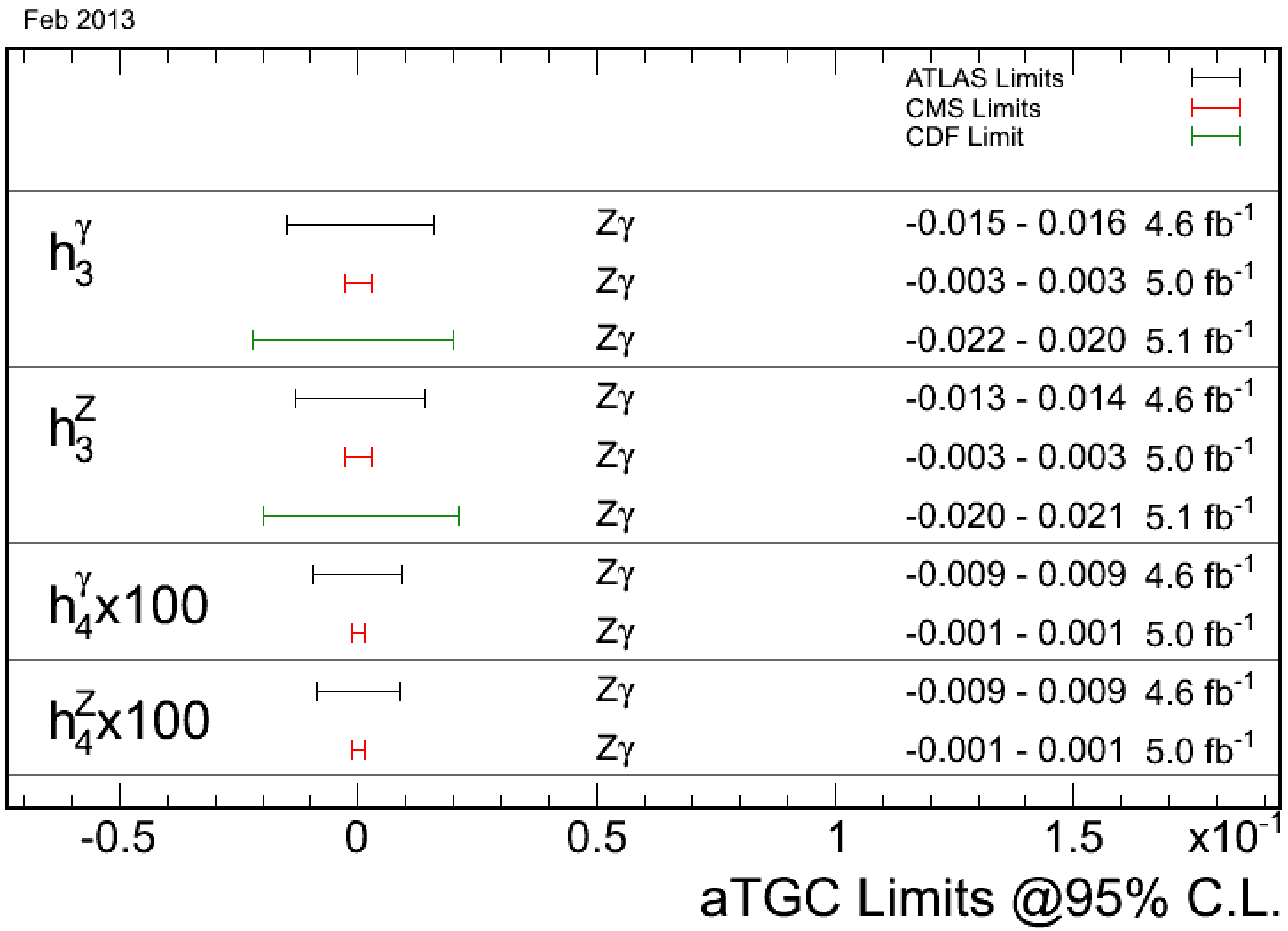




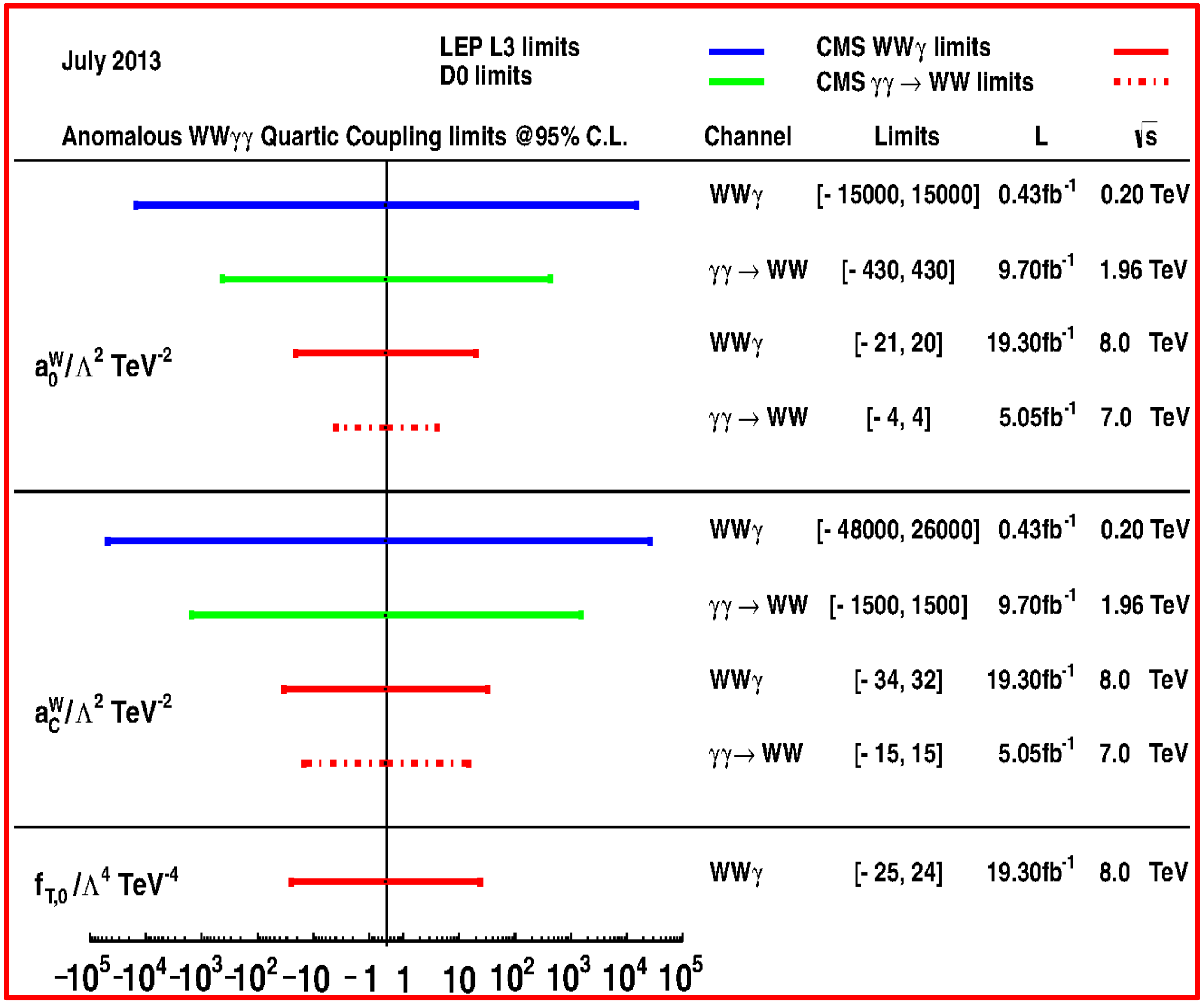
Neutral aTGCs



Neutral aTGCs



aQGCs



WWγ+WZγ →lνjjγ

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

Summary

- **Various Multi (2 or 3) boson processes have been measured by CMS with 2011 or 2012 dataset.**

  WZ/ZZ updated with 8TeV full dataset

  γγ 7TeV measurement public now

  Xsec in agreement with NLO/NNLO theoretical results

  First measurement on triple gauge boson productions: WVγ

- **Stringent limits set on charged and neutral aTGC**

- **First measurement on aQGC at the LHC from two channels**

  First ever limits on f^{0}_{T}, K_{0}^{W}, K_{c}^{W}

Backup

CMS bkg from data determination methods

Used for:

Fake rate method (often used for fake leptons, jets misidentified as leptons)
- Select data control sample dominated with background to measure the probability ("fake rate"=FR) for a loose lepton object (fake lepton) to pass the tight requirements used in the selection
- Use the FR to extrapolate the yield from a loose lepton sample (background enriched) to the fully selected leptons

WW (W+jet bkg)
ZZ (Z+jet, WZ+jet, tt bkg)

Template fit method (often used for fake photons, jets misidentified as photons)
- Perform a two component fit using the signal and background templates in discriminating observable

Vgamma (V+jet bkg)
WW+WZ->2l2j (W+jets bkg)

Data/MC scale factor
- Using the data control sample dominated with background to rescale the simulation

WW (Wγ bkg)*

Measurement of efficiency
- Measurement of the selection efficiency and applying it to background dominated data control sample

WW (tt bkg)

Wγ→ lνγ (l=e,μ)

CMS-PAS-EWK-10-008, Phys. Lett. B 701 (2011) 535,
arXiv:1105.2758; CMS-PAS-EWK-11-009, arXiv:1308.6832,
submitted to Phys. Rev. D

RAZ (Radiation-amplitude Zero) Measurement:

Veto Jets with P_T>30GeV,
M_T(l γ MET)>110GeV

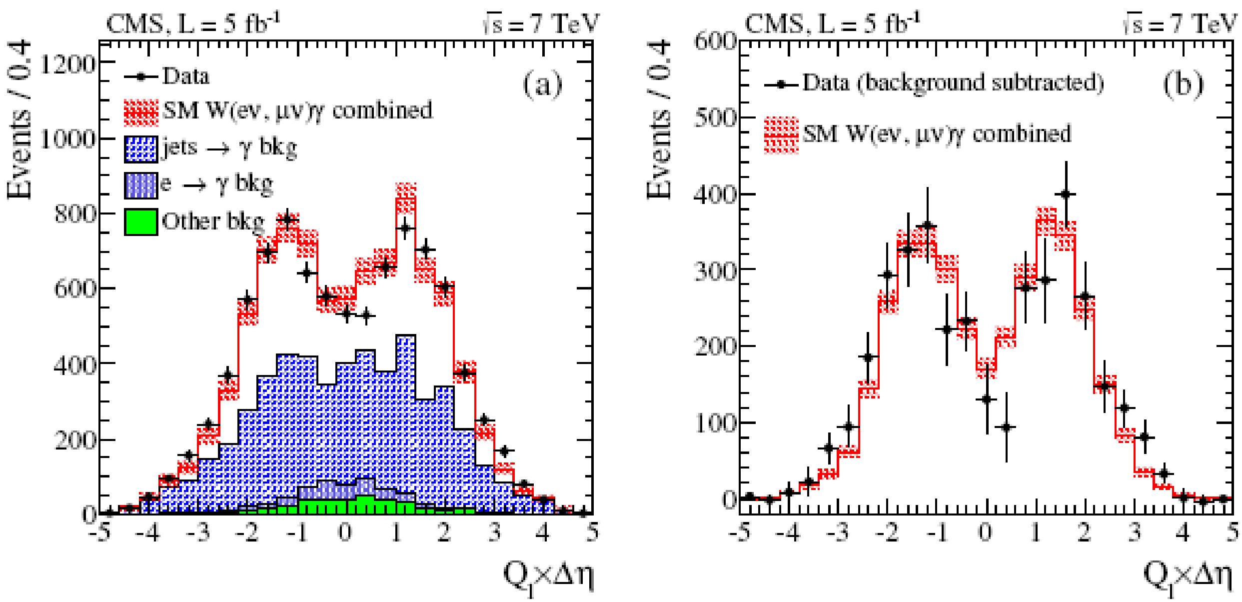
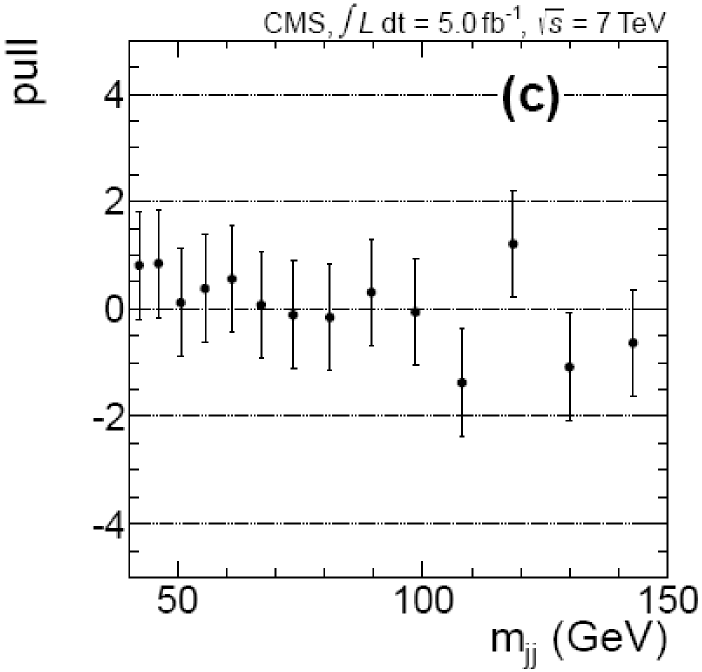


Figure 7: Charge-signed rapidity difference $Q_\ell \times \Delta\eta$ between the photon candidate and a lepton for Wγ candidates in data (filled circles) and expected SM signal and backgrounds (shaded regions) normalized to (a) data, and (b) background-subtracted data. The hatched bands illustrate the full uncertainty in the MC prediction.

WW+WZ→lνjj

EPJC73 (2013) 2283, arXiv:1210.7544



W+jets: float factorization/renorm & ME-PS matching scales to get good modeling of data

$$F_{\mathrm{W+jets}} = \alpha\,\mathcal{F}_{\mathrm{W+jets}}(\mu_0^2, q'^2) + \beta\,\mathcal{F}_{\mathrm{W+jets}}(\mu'^2, q_0^2) + (1-\alpha-\beta)\,\mathcal{F}_{\mathrm{W+jets}}(\mu_0^2, q_0^2)\,,$$

validate the fit procedure by performing pseudo-experiments.

where $\mathcal{F}_{\mathrm{W+jets}}$ denotes the m_{jj} shape from simulation. The parameters μ_0 (μ') and q_0 (q') correspond to the default (alternative) values of μ and q, respectively. The parameters α and β are free to vary during the fit and remain within the physical ranges ($0 \leq \alpha, \beta \leq 1$ and $1-\alpha-\beta \geq 0$). We take $\mu' = 2\mu_0$ or $0.5\mu_0$ ($q' = 2q_0$ or $0.5q_0$), depending on which alternative sample provides a better fit to the data. Thus, the fit probes variations of a factor of two in both μ and q (with the corresponding shape fluctuations accounted for when setting exclusion limits).

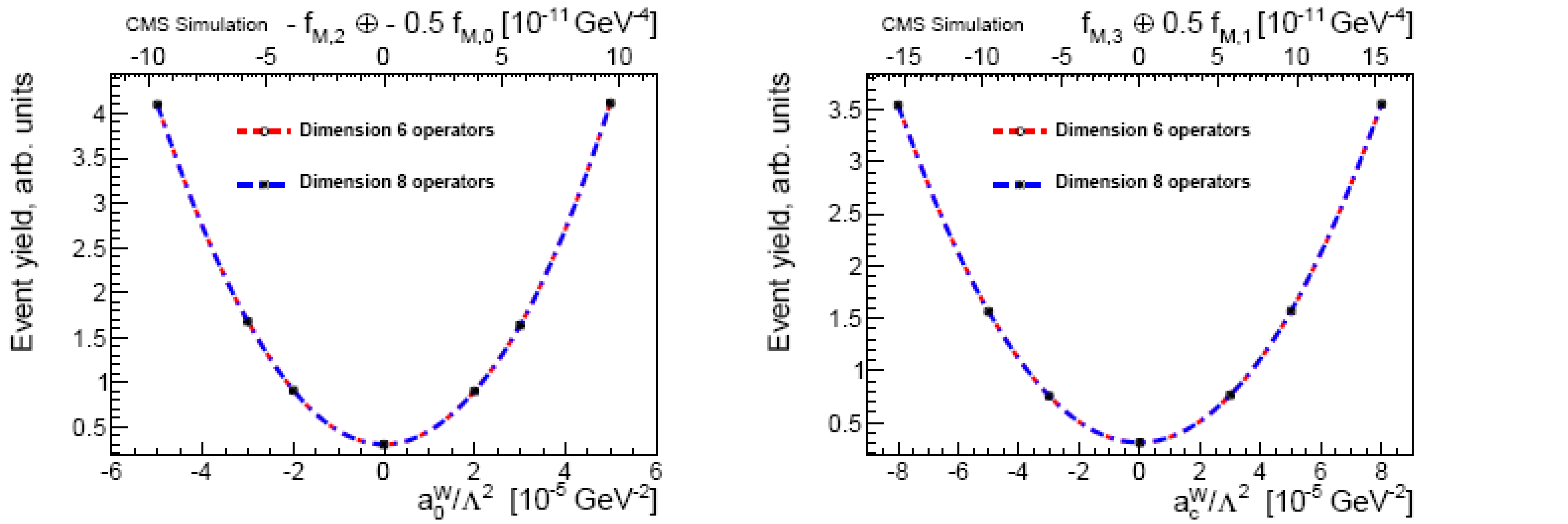
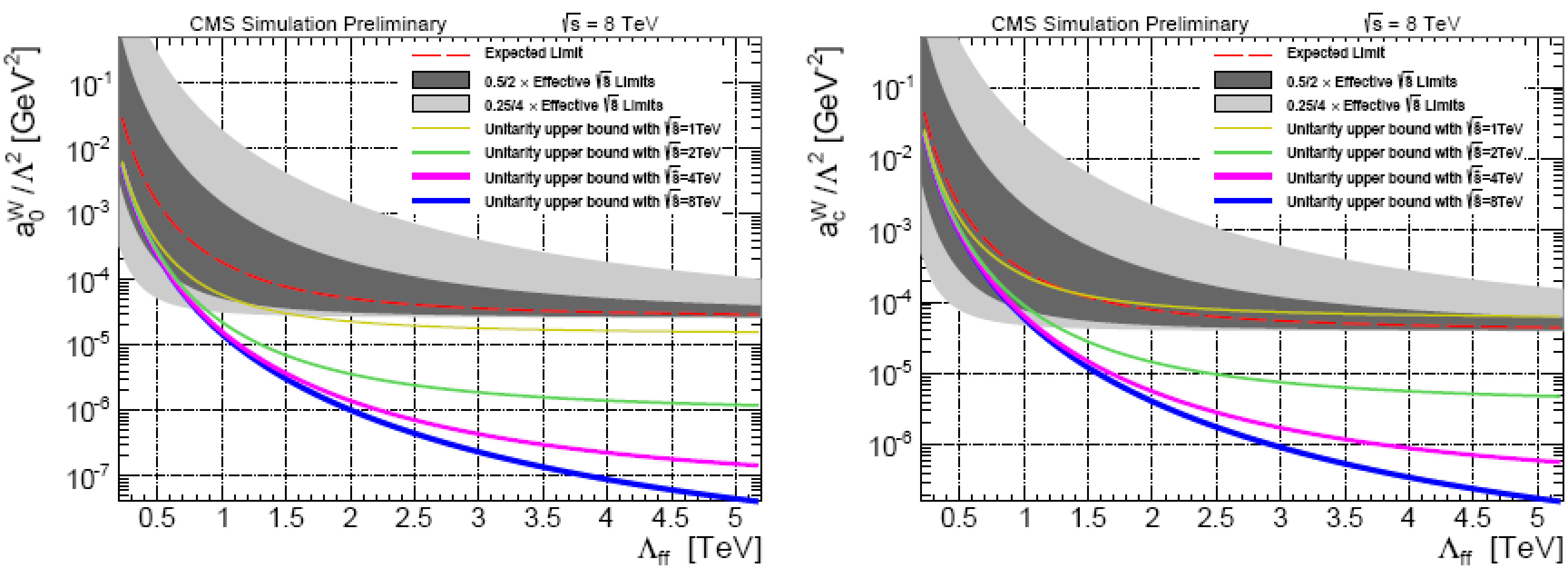
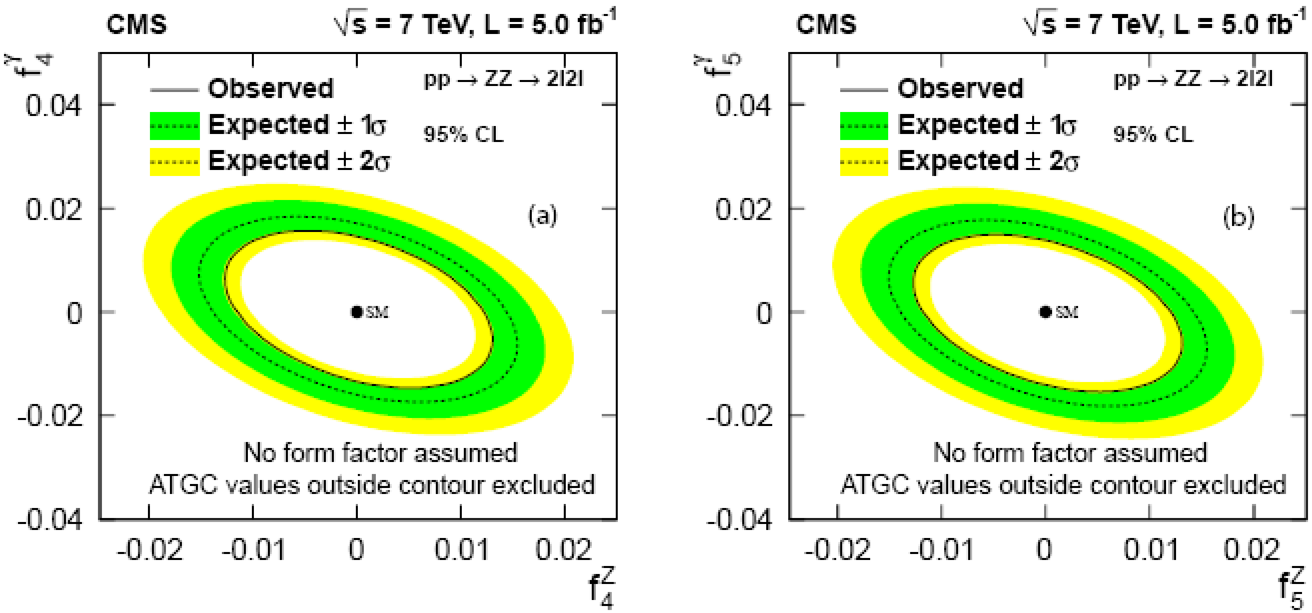
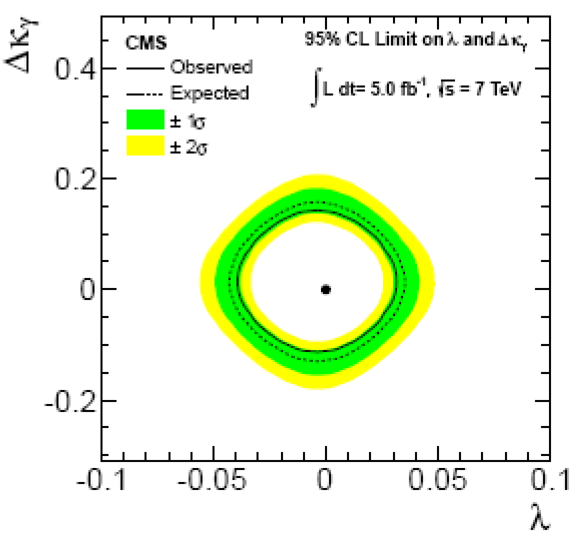
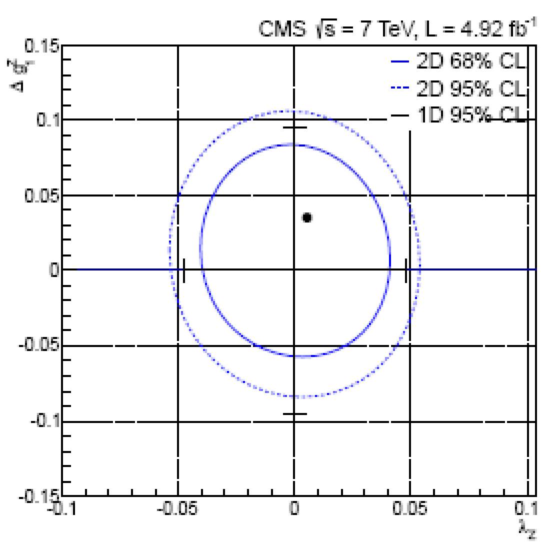


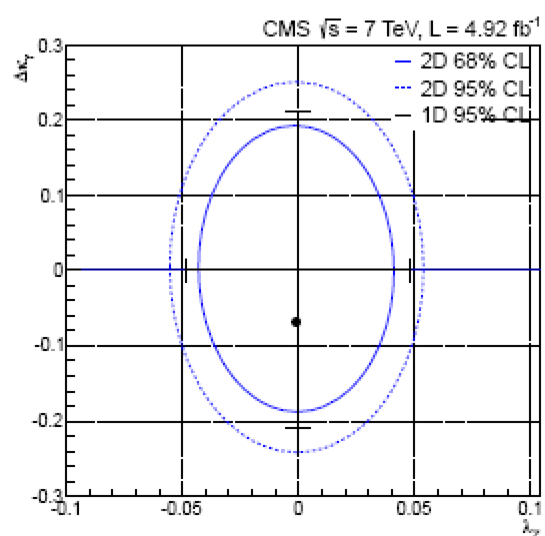
Figure 2: Dimension 8 parameters $f_{M,i}$ are related to dimension 6 parameters a_0^W, a_C^W via a simple linear transformation.




CMS
$\sqrt{s}$ = 7 TeV, L = 5.0 fb^{-1}
Observed
Expected ± 1σ
Expected ± 2σ
pp → ZZ → 2l2l
95% CL
(a)
(b)
SM
No form factor assumed
ATGC values outside contour excluded
f_4^γ
f_4^Z
f_5^γ
f_5^Z


CMS
95% CL Limit on λ and Δκγ
Observed
Expected
± 1σ
± 2σ
∫L dt= 5.0 fb^{-1}, $\sqrt{s}$ = 7 TeV
Δκγ
λ


CMS $\sqrt{s}$ = 7 TeV, L = 4.92 fb^{-1}
2D 68% CL
2D 95% CL
1D 95% CL
λ_Z


CMS $\sqrt{s}$ = 7 TeV, L = 4.92 fb^{-1}
2D 68% CL
2D 95% CL
1D 95% CL
$\Delta\kappa_\gamma$
λ_Z