Vector Boson Pair Production at LHC and Tevatron

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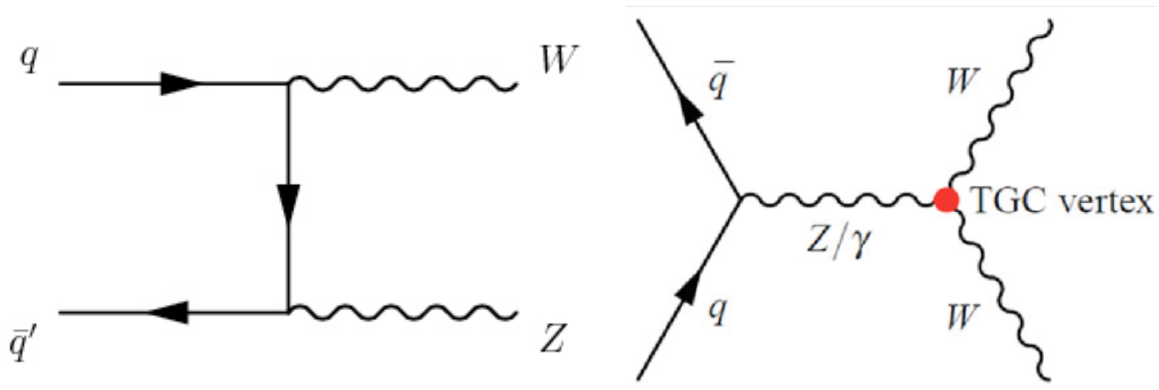
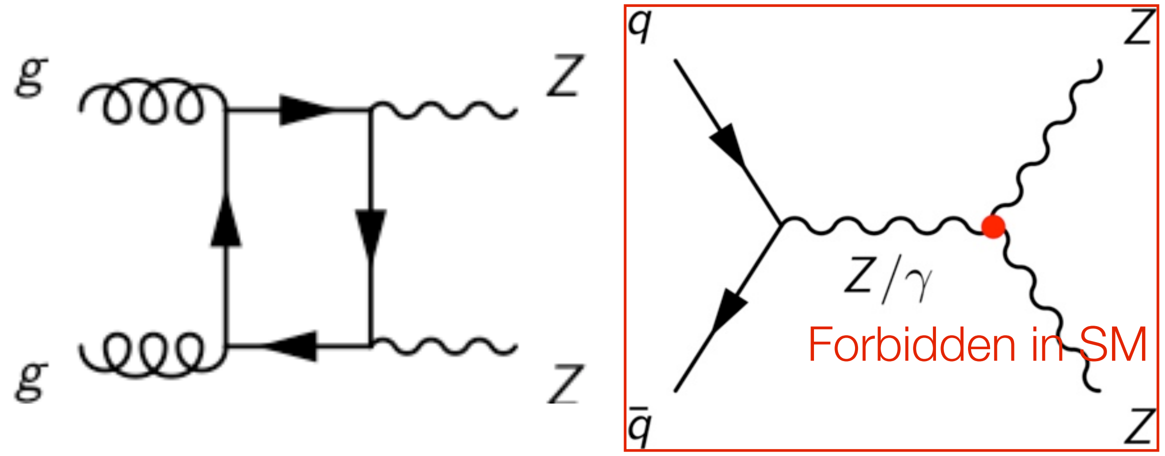
On behalf of ATLAS/CMS/CDF/D0 collaborations

Introduction

- The study of diboson production provides an important test of the Standard Model at TeV energy scale
- Sensitive to self-interaction among vector bosons via triple gauge couplings (TGC)
  - Neutral TGC is forbidden at tree level in SM
  - New physics would induce changes in TGC
- Irreducible background to Higgs boson
  - See J. Branson's H->VV talk tomorrow





Data and Analysis

- Tevatron: proton-antiproton collisions at 1.96 TeV, up to 9.8 fb^{-1}
- LHC: proton-proton collisions at 7, 8 TeV up to 5, 20 fb^{-1}
- W, Z decay modes
  - W->lv, Z->ll: leptons are isolated; experimentally clean
  - Neutrino inferred by imbalance of transverse energy: Missing ET
  - W/Z->jj, Z->vv: higher branching fractions; larger backgrounds
- Theoretical predictions on diboson cross sections: NLO QCD (e.g. MCFM)
- Focusing on new results in the past year

Cross section measurements

Cut and count in most cases

Data-driven when possible

$$\sigma_S = \frac{N - N_B}{A_S \cdot \epsilon_S \cdot \mathcal{L}}$$

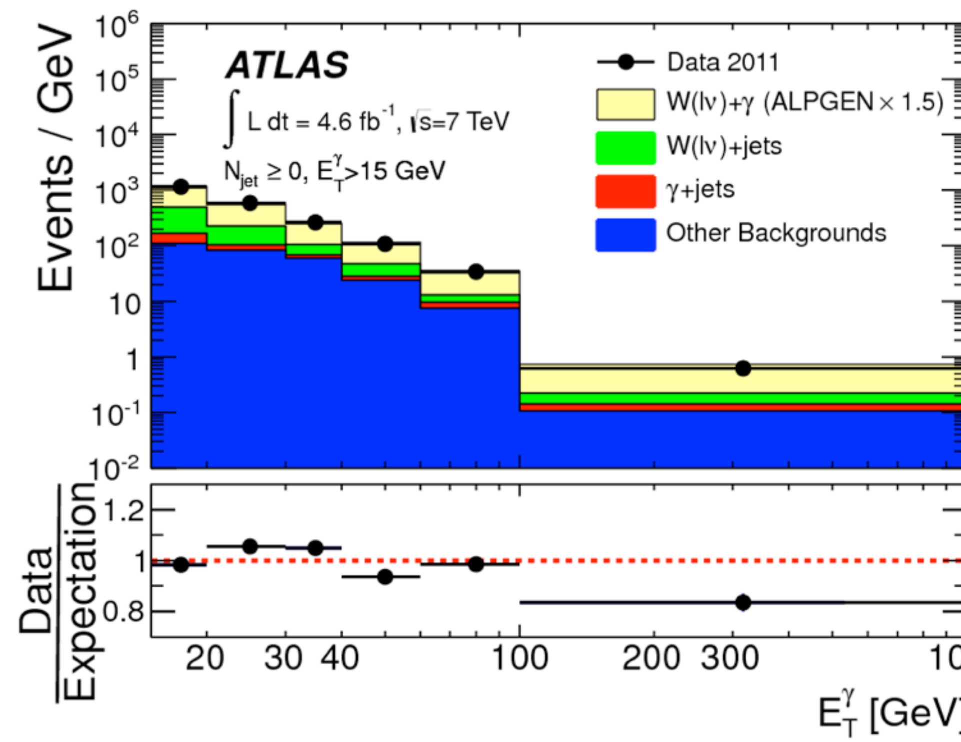
Determined from MC, corrected for data/MC efficiency differences

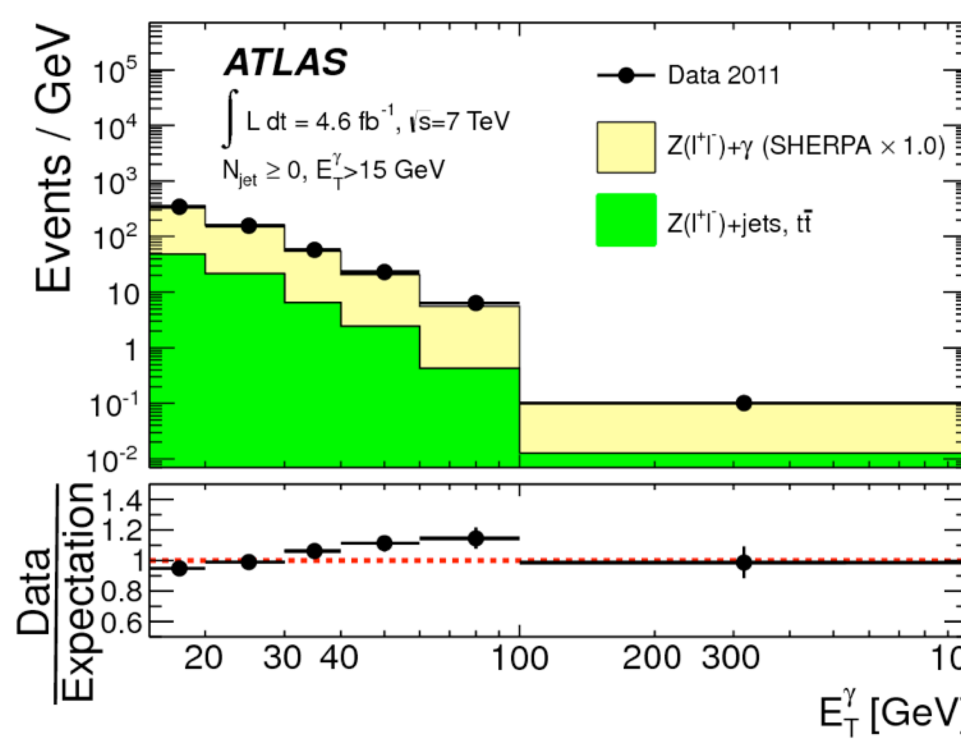
In following slides: Wγ, Zγ, WW, WZ, ZZ

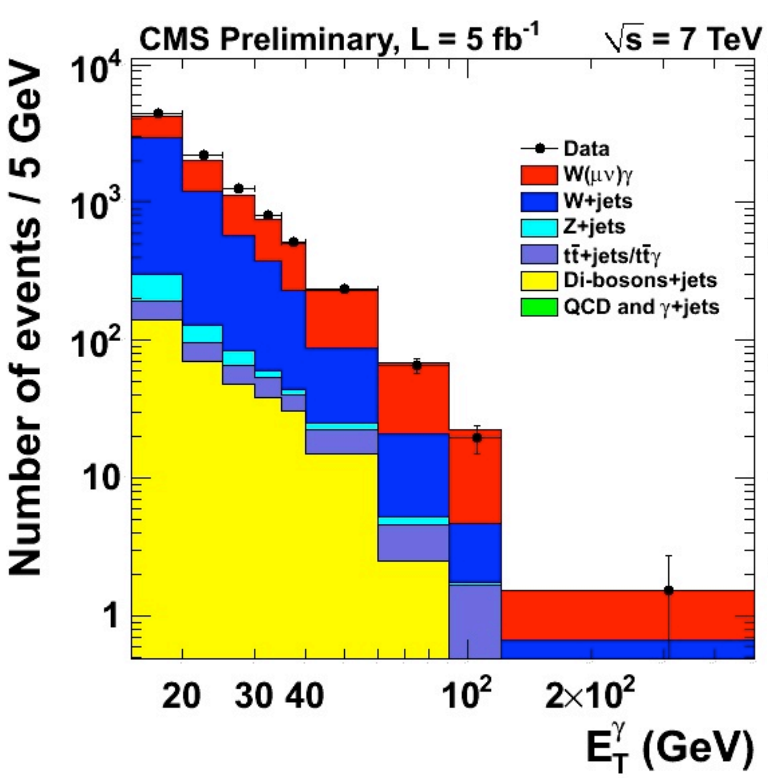
arXiv:1308.6832 (submitted to PRD)
Phys. Rev. D 87, 112003 (2013)

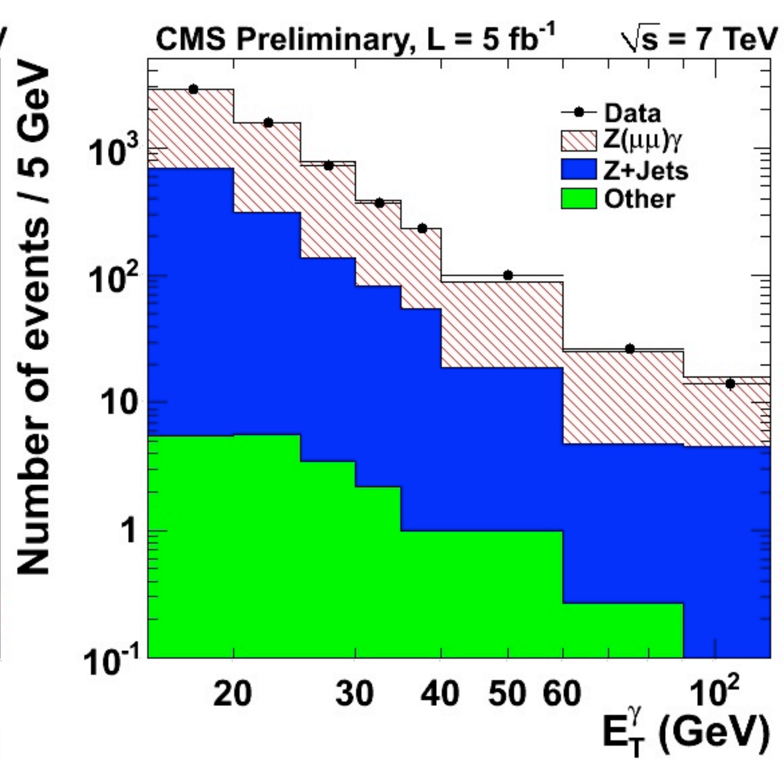
Wγ->lνγ, Zγ->llγ

- Lepton+Missing ET or dilepton
- Photon pT > 15 GeV
- Good S/B
- Main backgrounds: W+jets, Z+jets (jet faking photon)

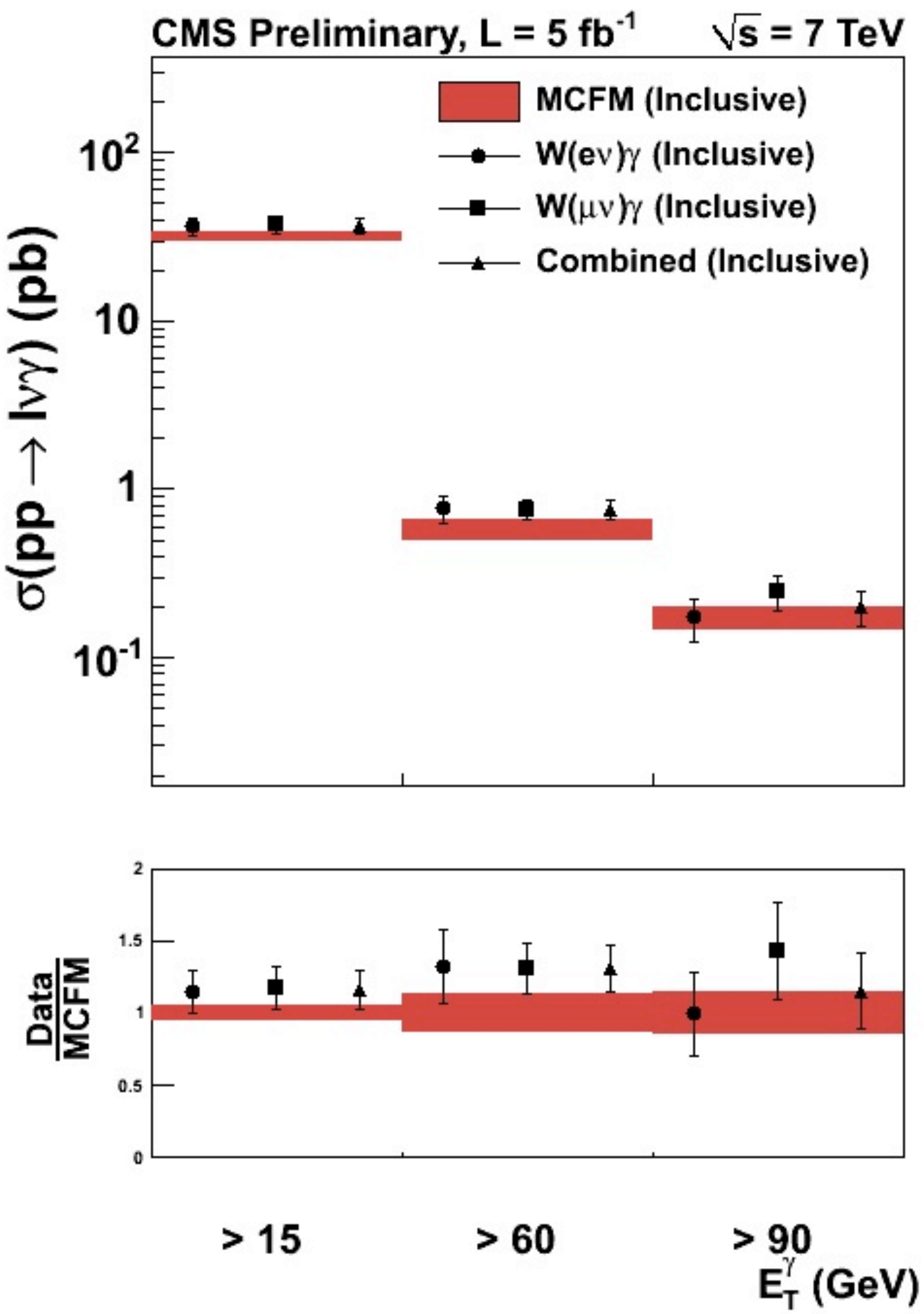


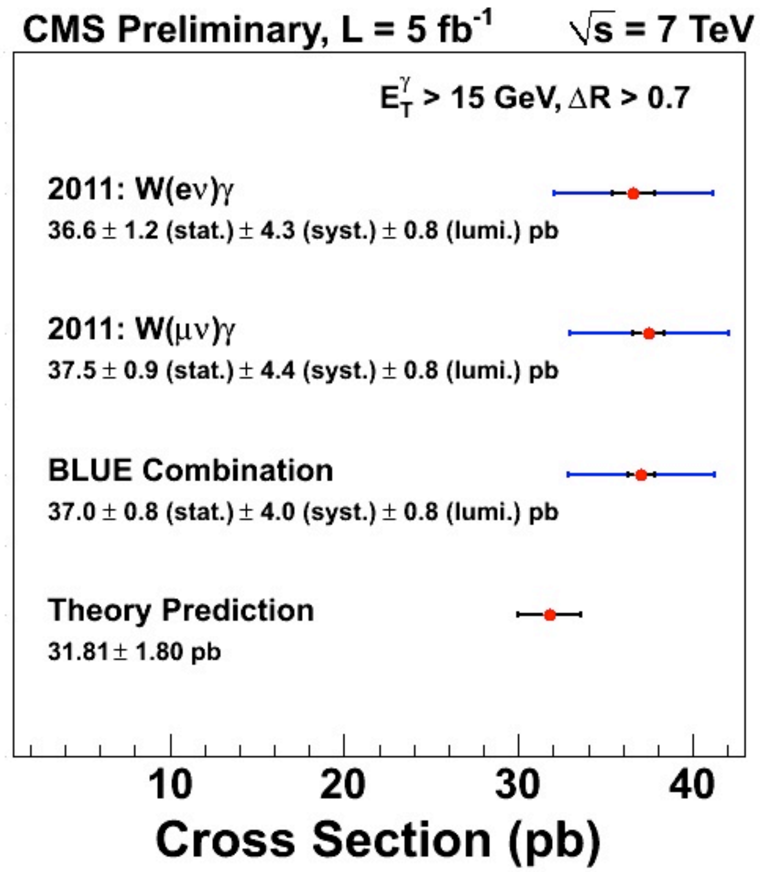


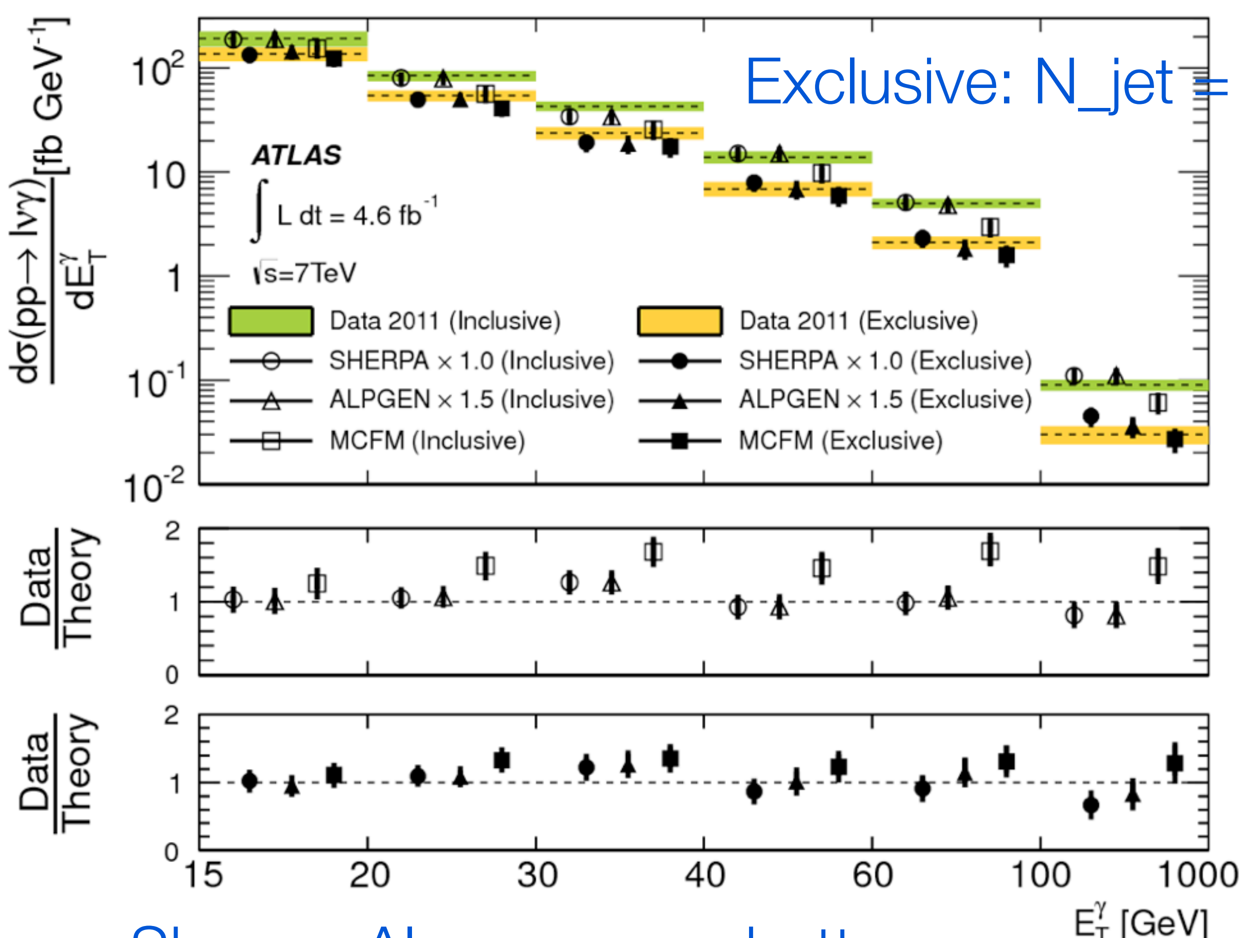




Wγ->lνγ



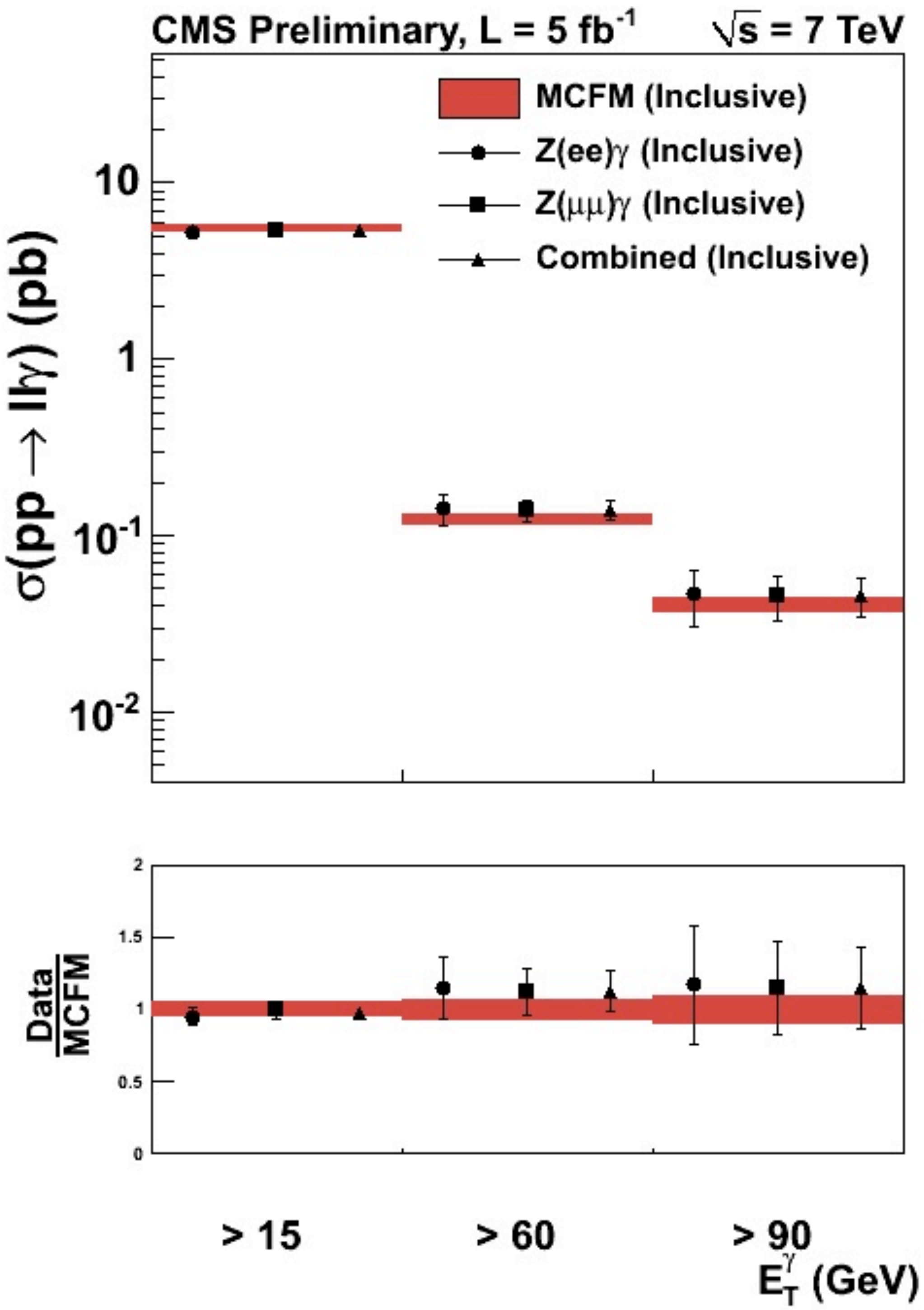


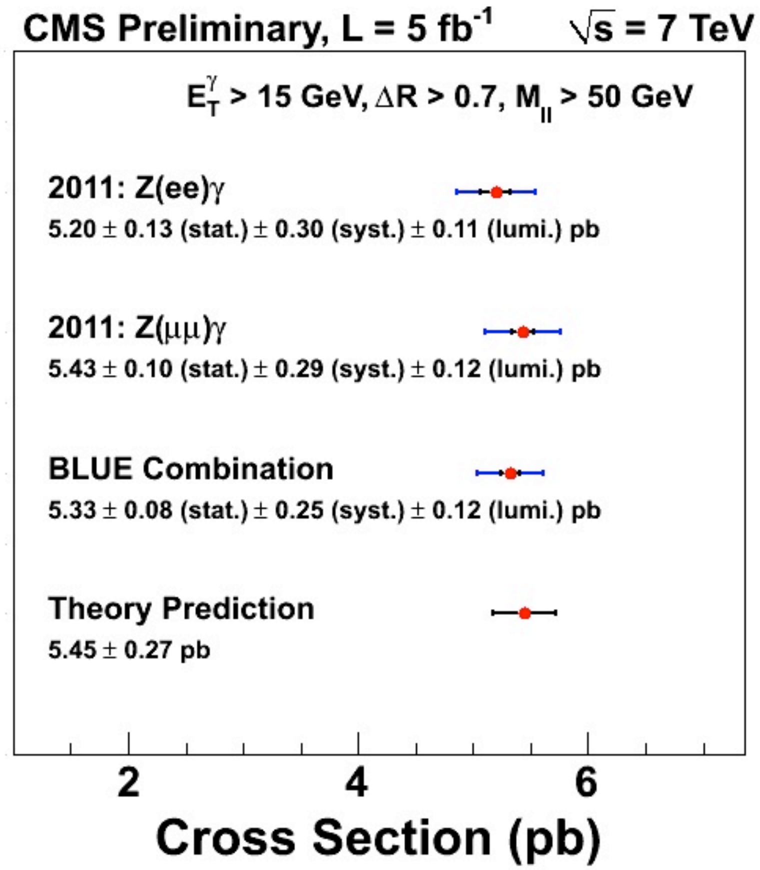


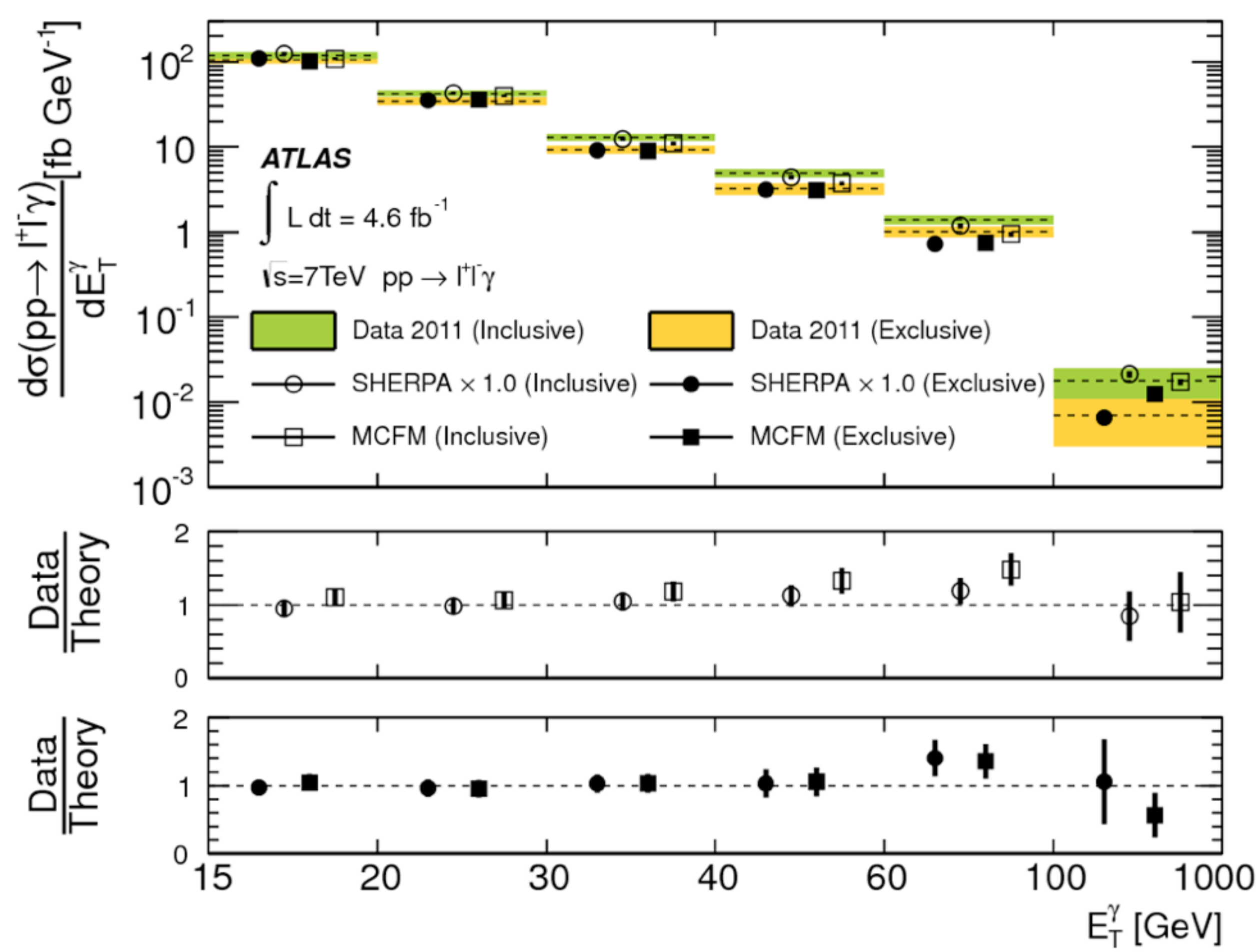
Exclusive: N_jet = 0

Sherpa, Alpgen agree better

Zγ->llγ





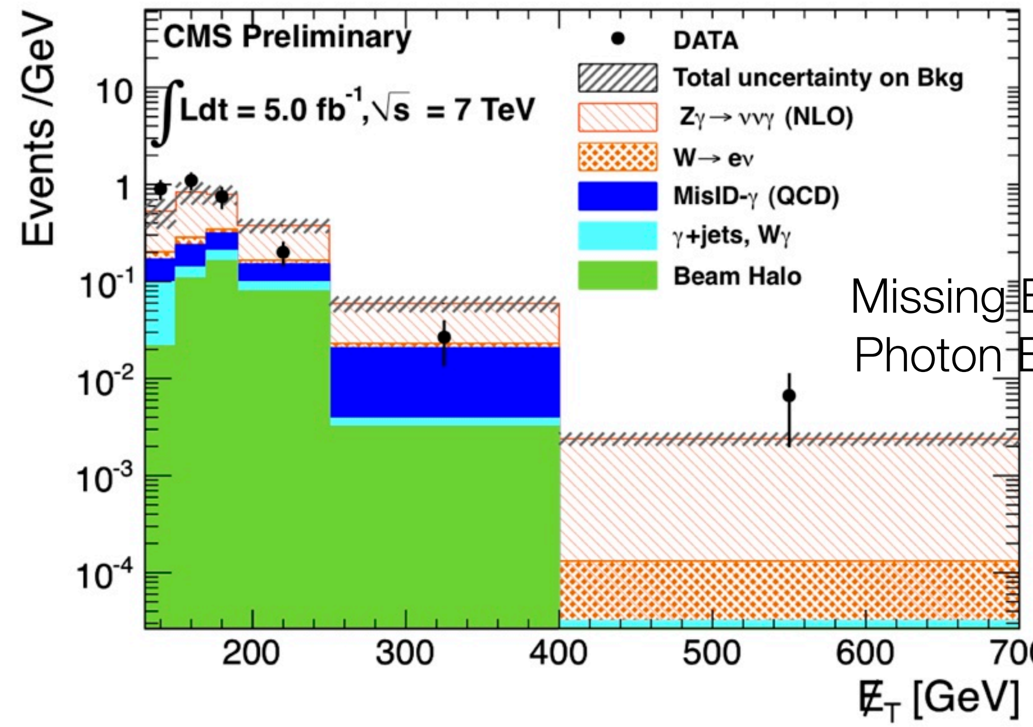


Good agreement with MCFM

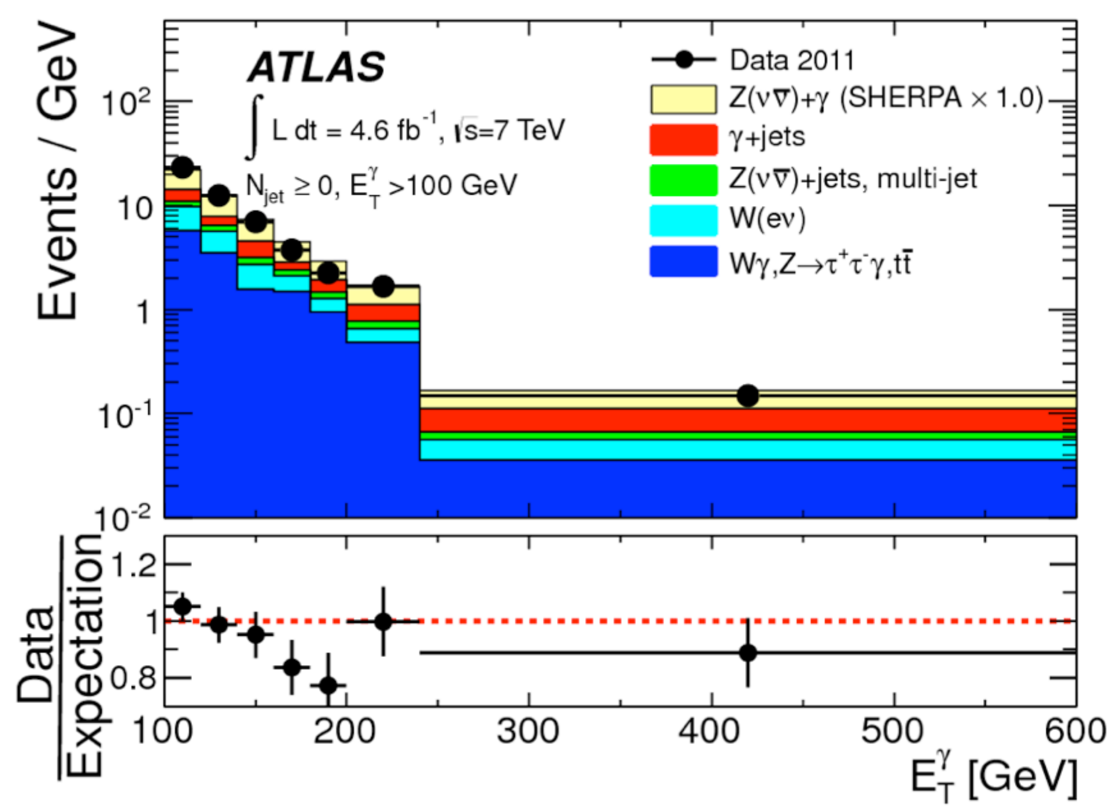
CMS-PAS-SMP-12-020
Phys. Rev. D 87, 112003 (2013)

Zγ->ννγ

- Missing ET + isolated photon
- Pros: larger branching fraction and acceptance
- Cons: larger backgrounds; Blind to low pT
- Main Backgrounds
  - W->eν, Z(νν)+jets, QCD
- Photon timing is used to reduce non-collision backgrounds



Missing ET > 130 GeV
Photon ET > 145 GeV



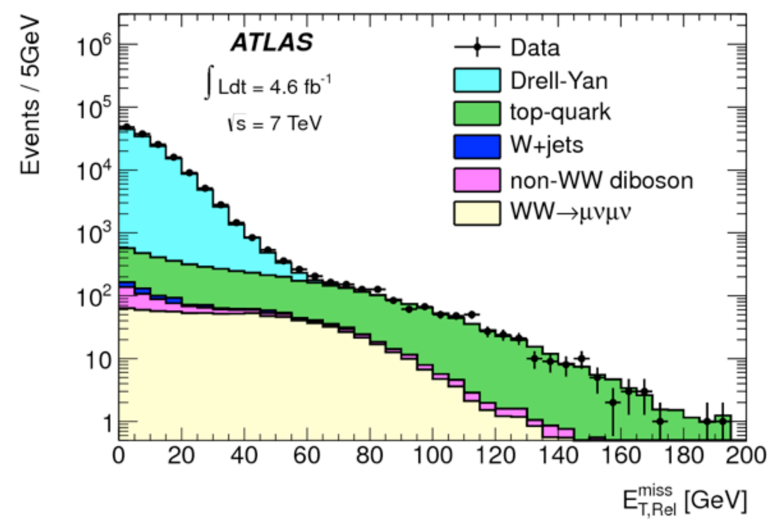
Phys. Rev. D 87, 112001 (2013)

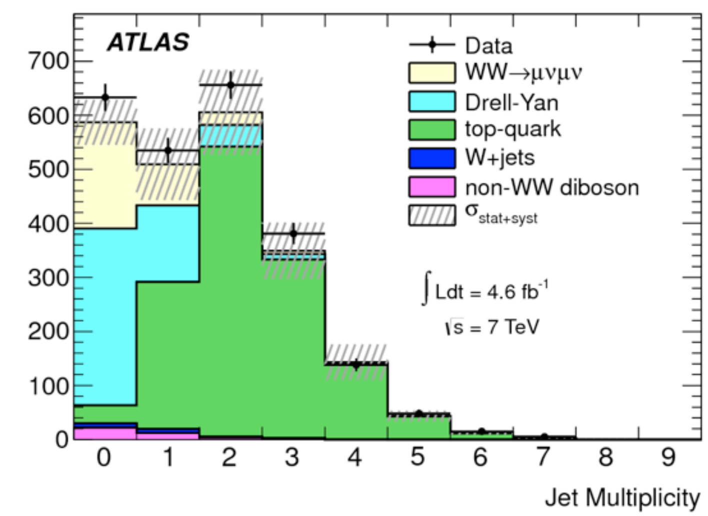
WW->lvl'v'

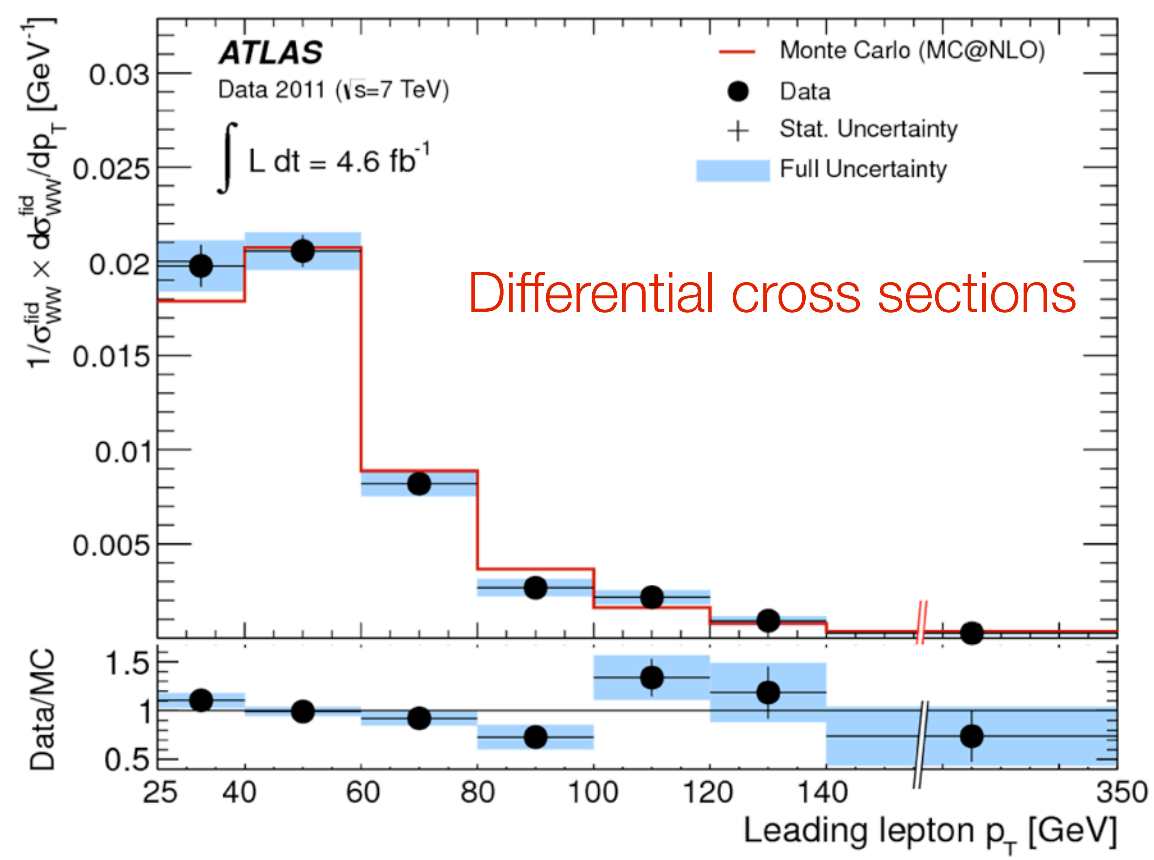
- Two opposite sign leptons, pT > 25/20 GeV; significant Missing ET
- Main backgrounds
  - top, Z+jets
- Systematics dominate
  - Jet veto
  - Background estimation

$$E_{\mathrm{T,Rel}}^{\mathrm{miss}} = \begin{cases} E_{\mathrm{T}}^{\mathrm{miss}} \times \sin(\Delta\phi) & \text{if } \Delta\phi < \pi/2 \\ E_{\mathrm{T}}^{\mathrm{miss}} & \text{if } \Delta\phi \geq \pi/2 \end{cases}$$

$\Delta\phi$ wrt to the closest lepton







7 TeV 4.6 fb^{-1}

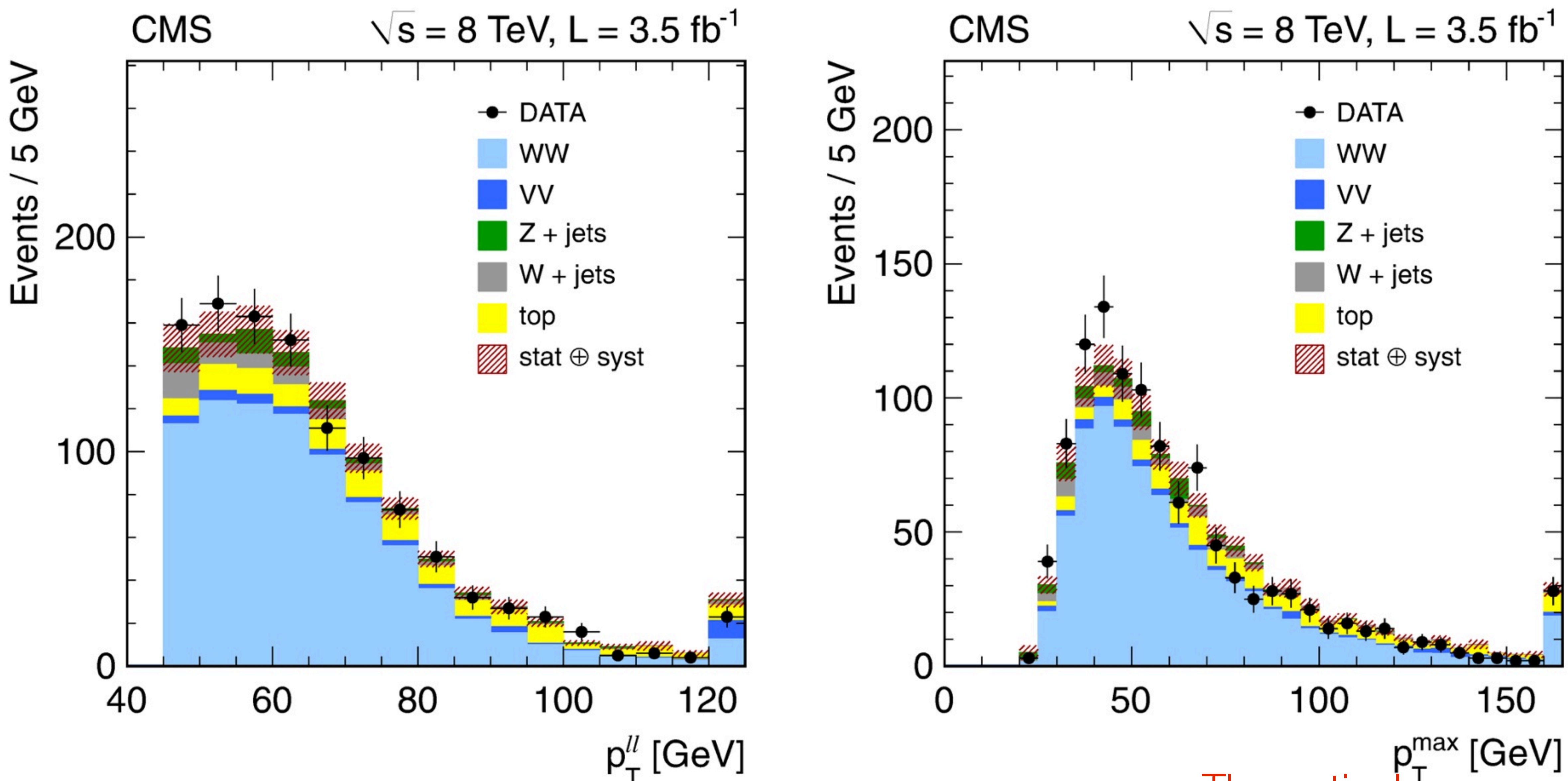
$51.9 \pm 2.0(\mathrm{stat}) \pm 3.9(\mathrm{sys}) \pm 2.0(\mathrm{lumi})$

Theoretical $44.7^{+2.1}_{-1.9}$ pb

arXiv:1306.1126 (submitted to EPJC)
Phys. Lett. B 721 (2013) 190–211

WW->lvl'v'

Two opposite charged leptons, pT > 20 GeV

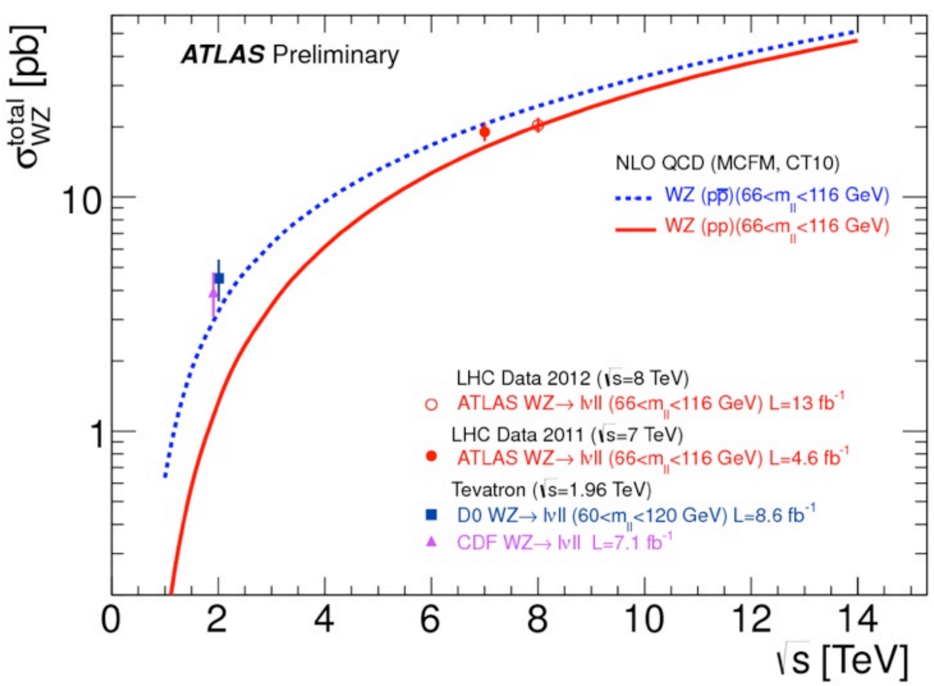


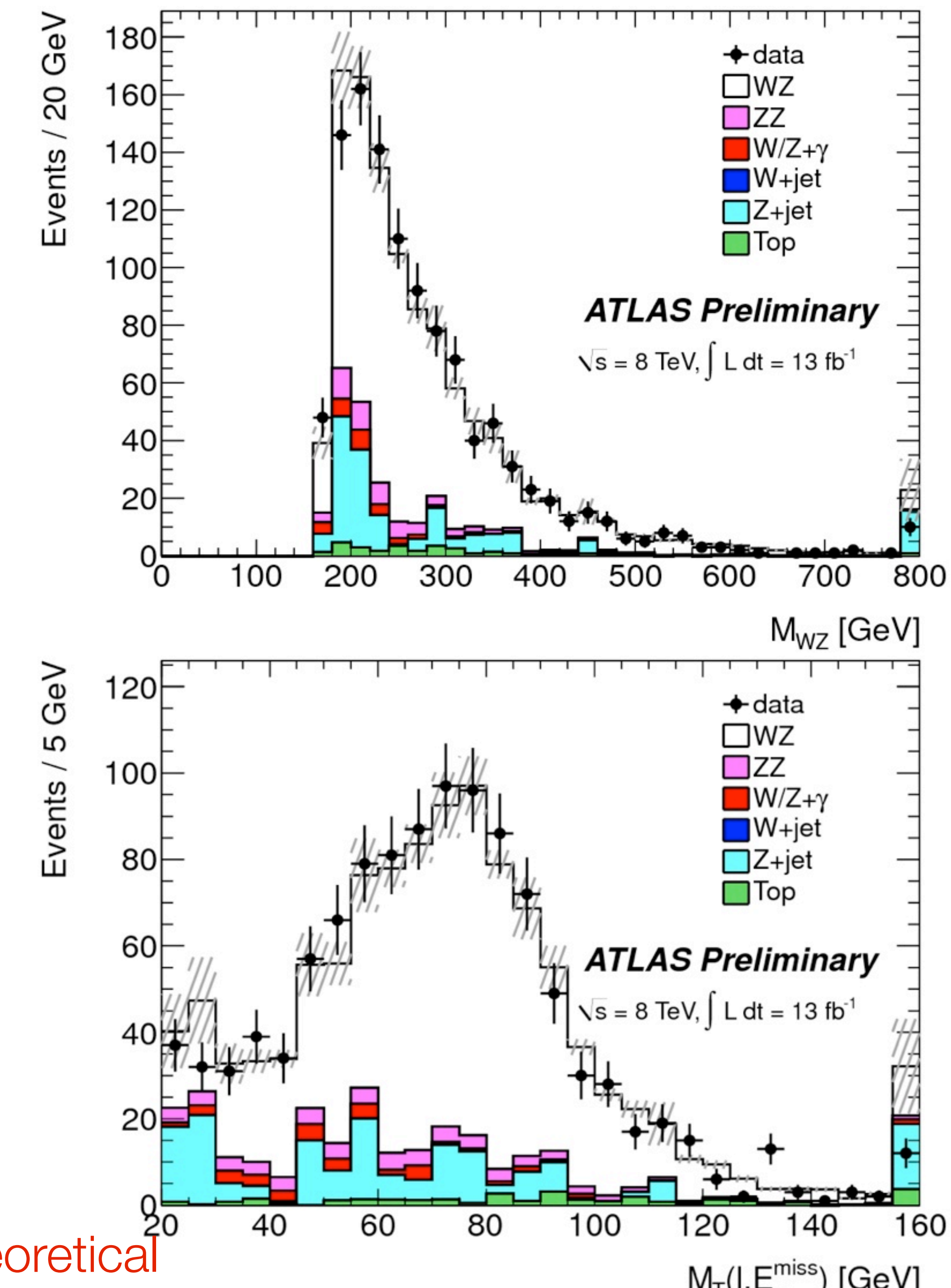
		Theoretical
7 TeV 4.9 fb^{-1}	$52.4 \pm 2.0\,(\text{stat.}) \pm 4.5\,(\text{syst.}) \pm 1.2\,(\text{lum.})$ pb	47.0±2.0 pb
8 TeV 3.5 fb^{-1}	$69.9 \pm 2.8\,(\text{stat.}) \pm 5.6\,(\text{syst.}) \pm 3.1\,(\text{lum.})$ pb	$57.3^{+2.3}_{-1.6}$ pb

Eur. Phys. J. C (2012) 72:2173
ATLAS-CONF-2013-021
Phys. Rev. D 86 (2012) 031104
Phys. Rev. D 85 (2012) 112005

WZ->lνl'l'

- Exactly 3 leptons, a pair of which from Z; significant missing ET
- Very low background
- Main background: Z+jets (jet faking lepton)





66 GeV < M(l^+l^-) < 116 GeV

Theoretical

7 TeV 4.6 fb^{-1} $19.0^{+1.4}_{-1.3}$(stat.) $\pm$ 0.9(syst.) $\pm$ 0.4(lumi.) pb $17.6^{+1.1}_{-1.0}$ pb

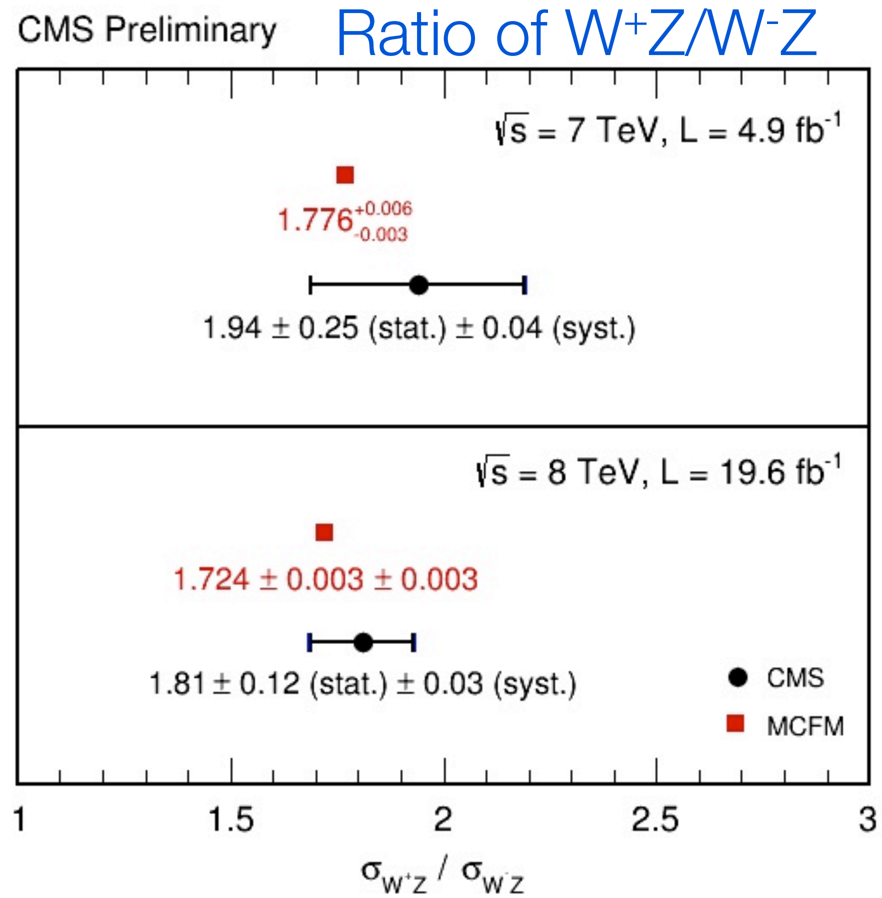
8 TeV 13 fb^{-1} $20.3^{+0.8}_{-0.7}$(stat.) $^{+1.2}_{-1.1}$(syst.) $^{+0.7}_{-0.6}$(lumi.) pb 20.3±0.8 pb

WZ->lνl'l'

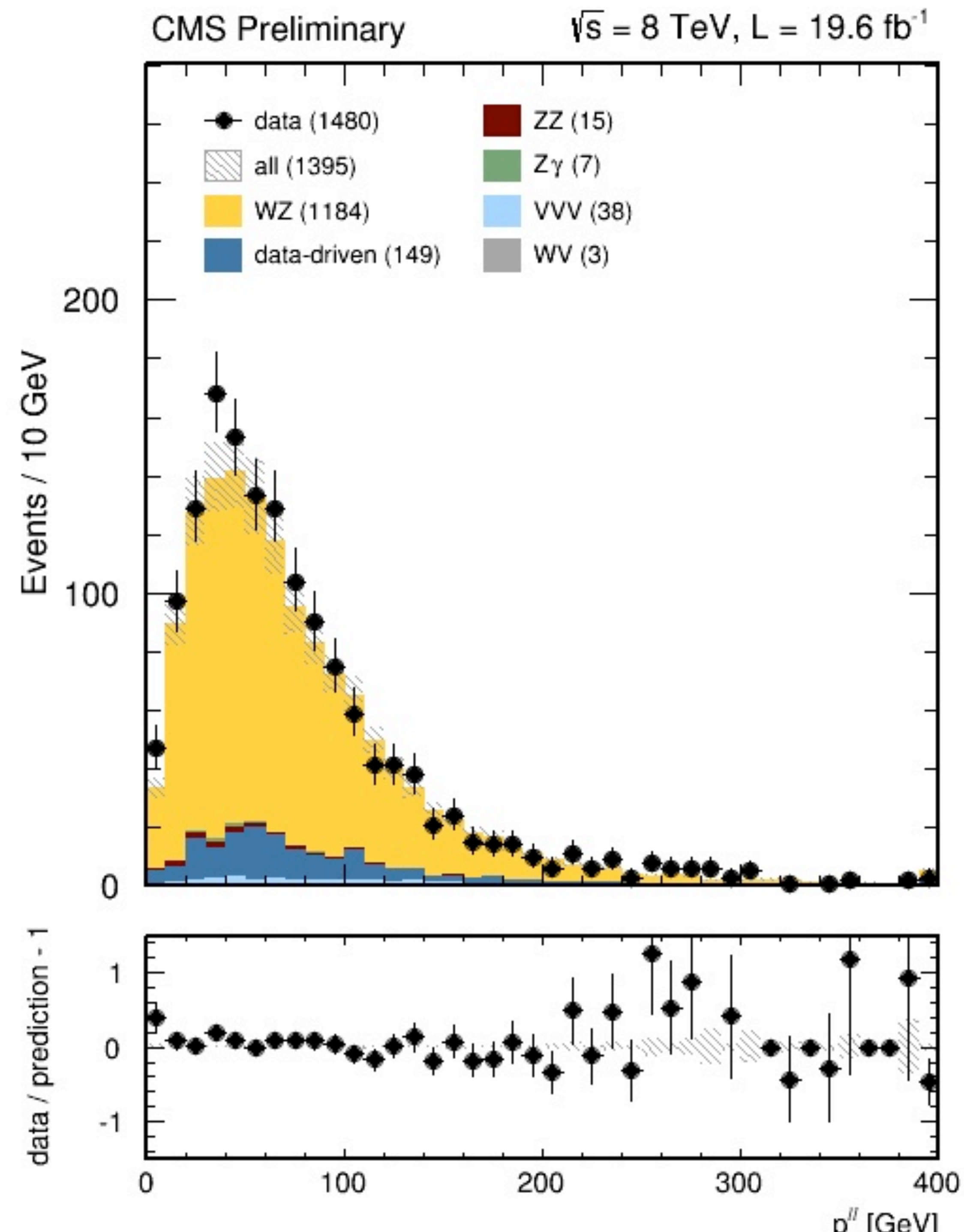
NEW

Leptons pT > 20/10/20 GeV
Missing ET > 30 GeV

Ratio of W^+Z/W^-Z



CMS-PAS-SMP-12-006



71 GeV < M(l^+l^-) < 111 GeV

Theoretical

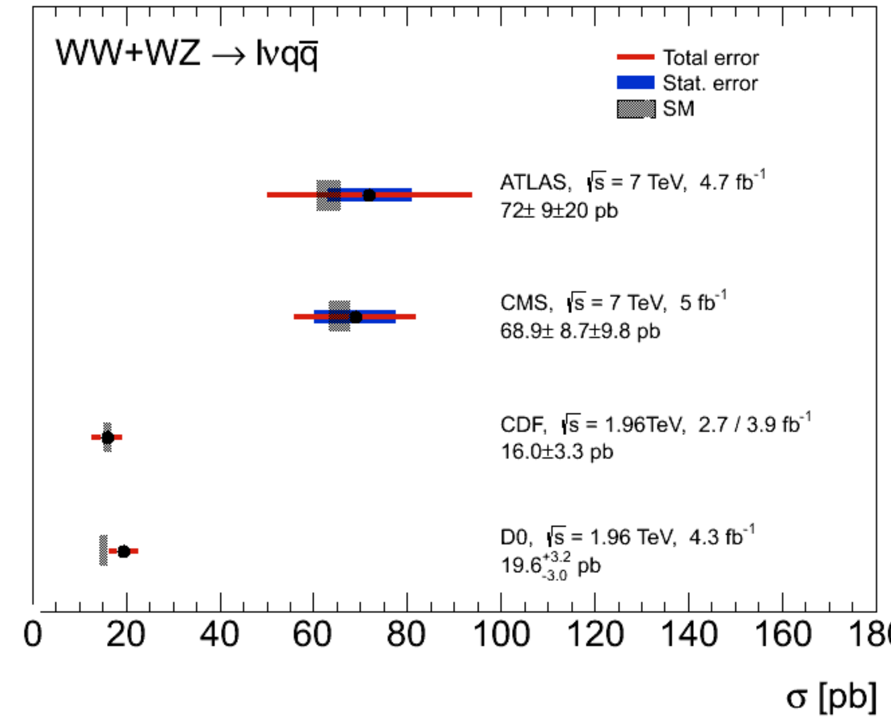
4.9 fb^{-1} $\sigma(pp \to WZ + X; \sqrt{s} = 7\,\text{TeV}) = 20.76 \pm 1.32\,(\text{stat.}) \pm 1.13\,(\text{syst.}) \pm 0.46\,(\text{lumi.})\,\text{pb}$ — $17.8^{+0.7}_{-0.5}$ pb

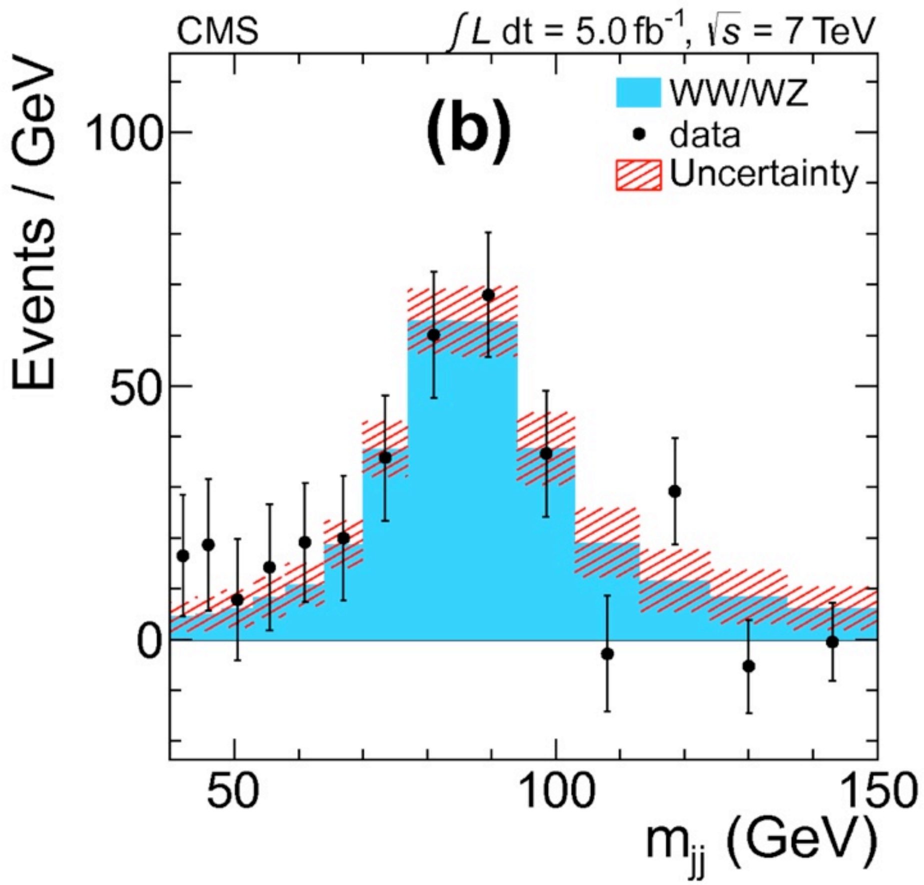
19.6 fb^{-1} $\sigma(pp \to WZ + X; \sqrt{s} = 8\,\text{TeV}) = 24.61 \pm 0.76\,(\text{stat.}) \pm 1.13\,(\text{syst.}) \pm 1.08\,(\text{lumi.})\,\text{pb}$ — $21.91^{+1.17}_{-0.88}$ pb

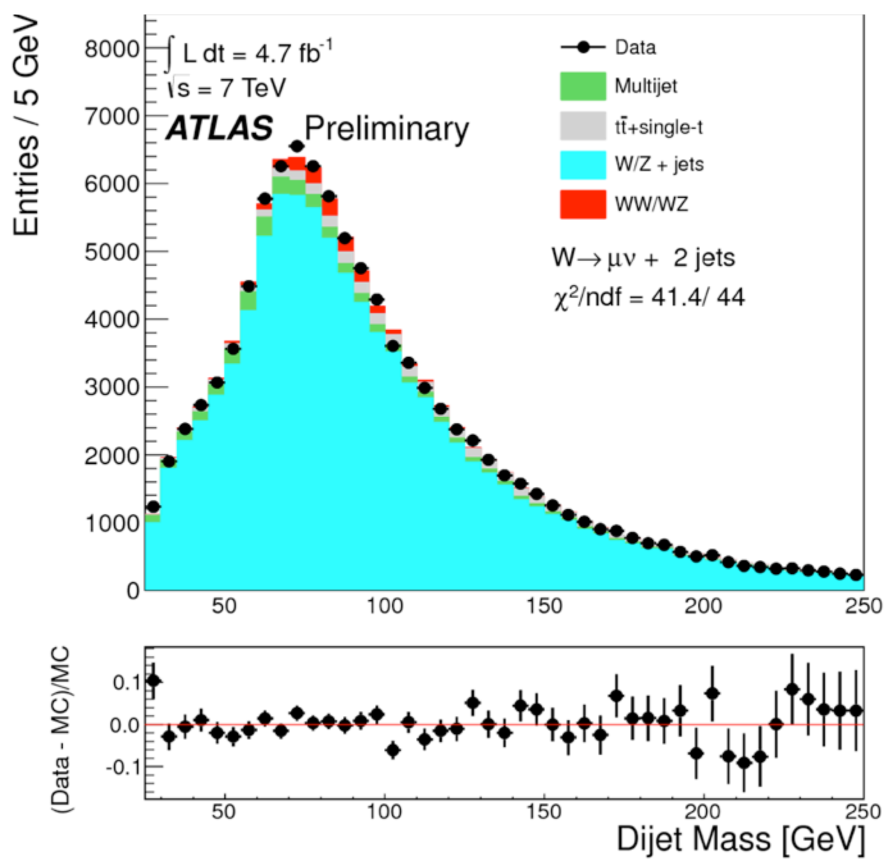
Eur.Phys.J. C73 (2013) 2283
ATLAS-CONF-2012-157

WW/WZ->lvjj

- Trigger on a W and look at the di-jet spectrum; cannot distinguish WW from WZ
- Main background: W/Z+jets
- Challenge: background estimation, jet energy scale/resolution







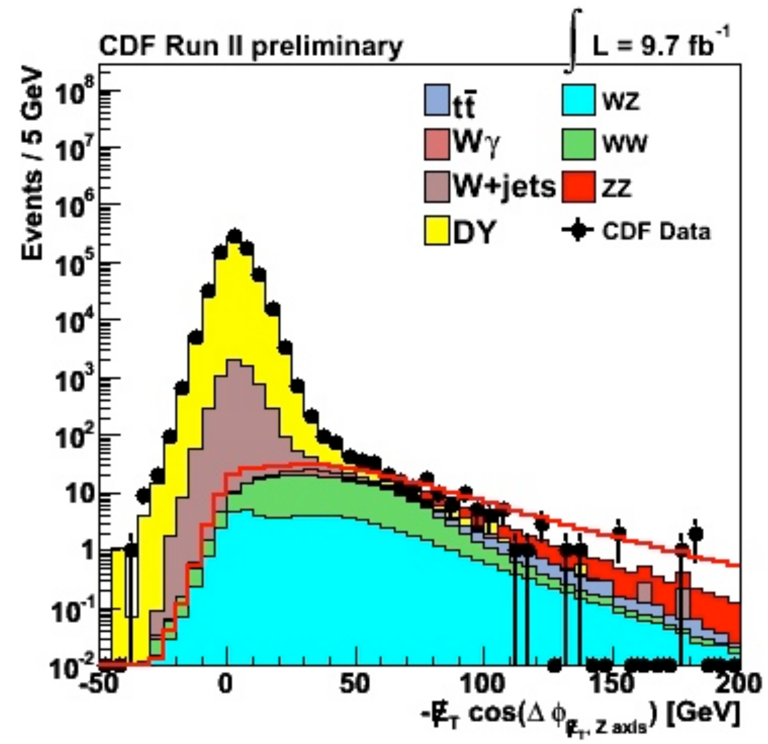
Signal and background yields obtained from fit on M(jj)

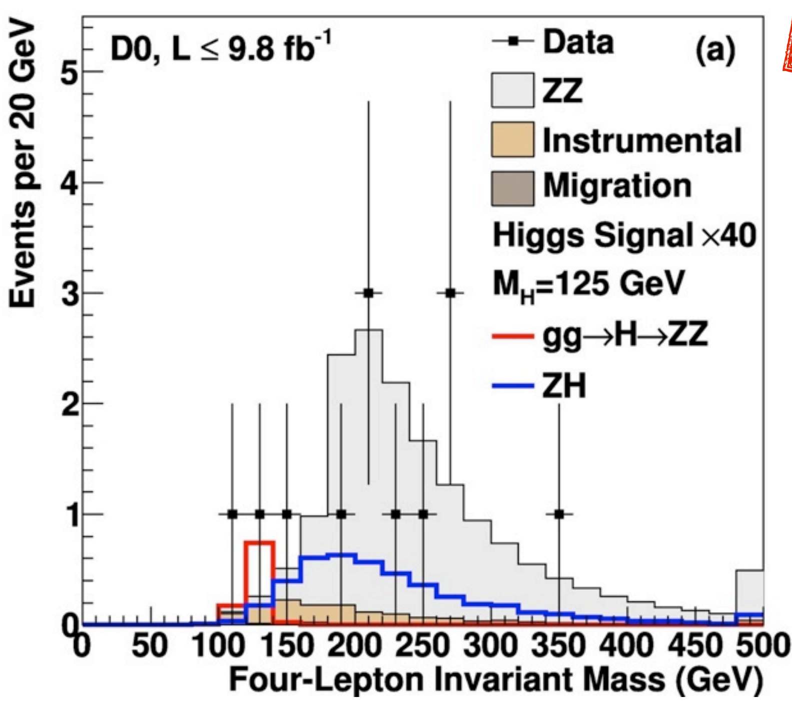
CDF note 10957

Phys. Rev. D 88, 032008 (2013)

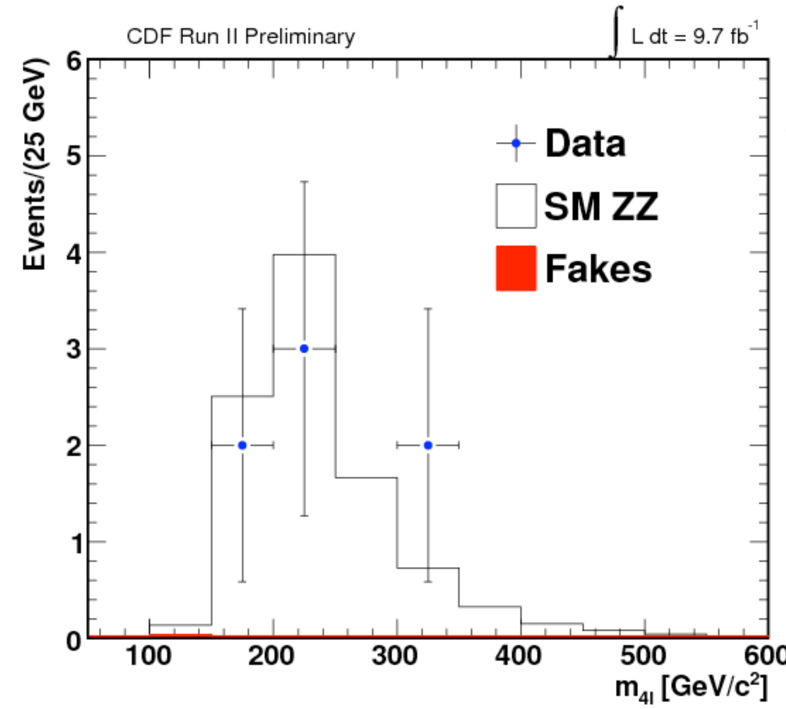
ZZ->lll'l', llνν

- lll'l': distinct signature, completely reconstructable
- llνν: large branching fraction
- Combined assuming standard BF





NEW



NEW

$1.32^{+0.29}_{-0.25}\,(\mathrm{stat}) \pm 0.12\,(\mathrm{syst}) \pm 0.04\,(\mathrm{lumi})$ pb

$1.04^{+0.28}_{-0.24}(\mathrm{stat.})^{+0.15}_{-0.08}(\mathrm{syst.})$ pb = $1.04^{+0.32}_{-0.25}$ pb

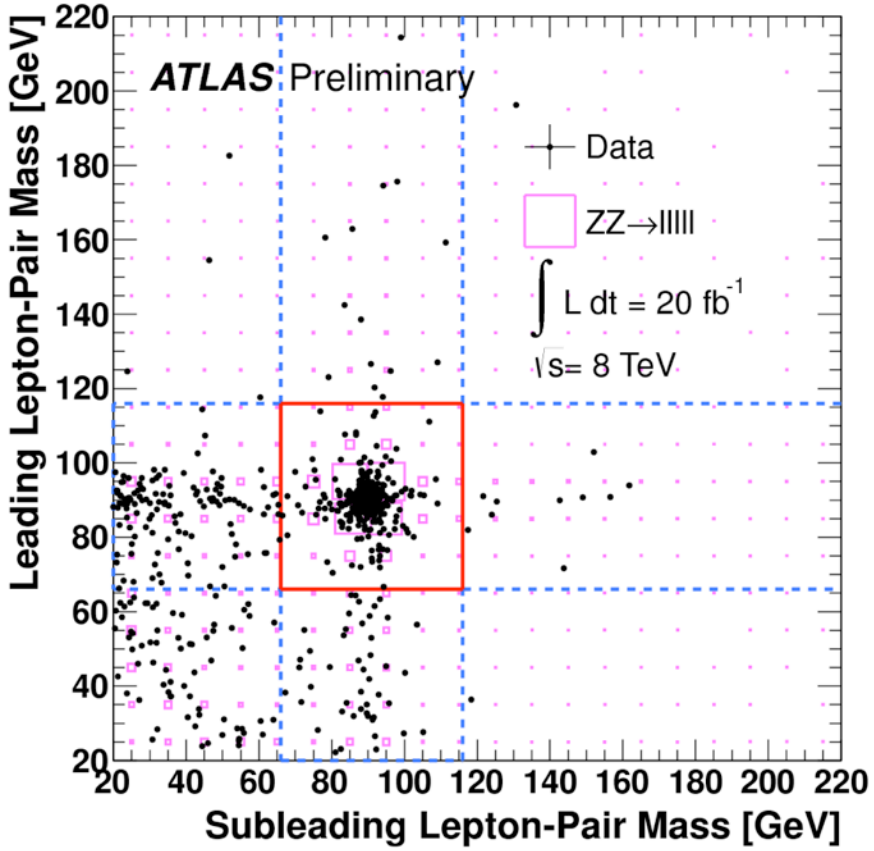
$M(l^+l^-) > 30$ GeV

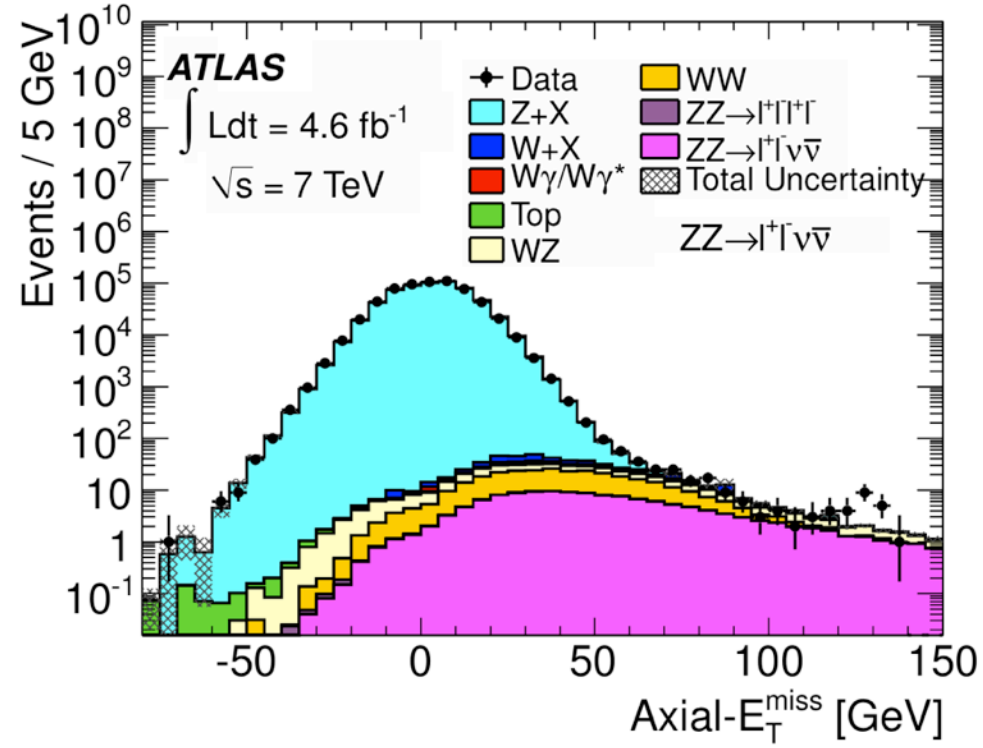
Theoretical 1.4±0.1 pb

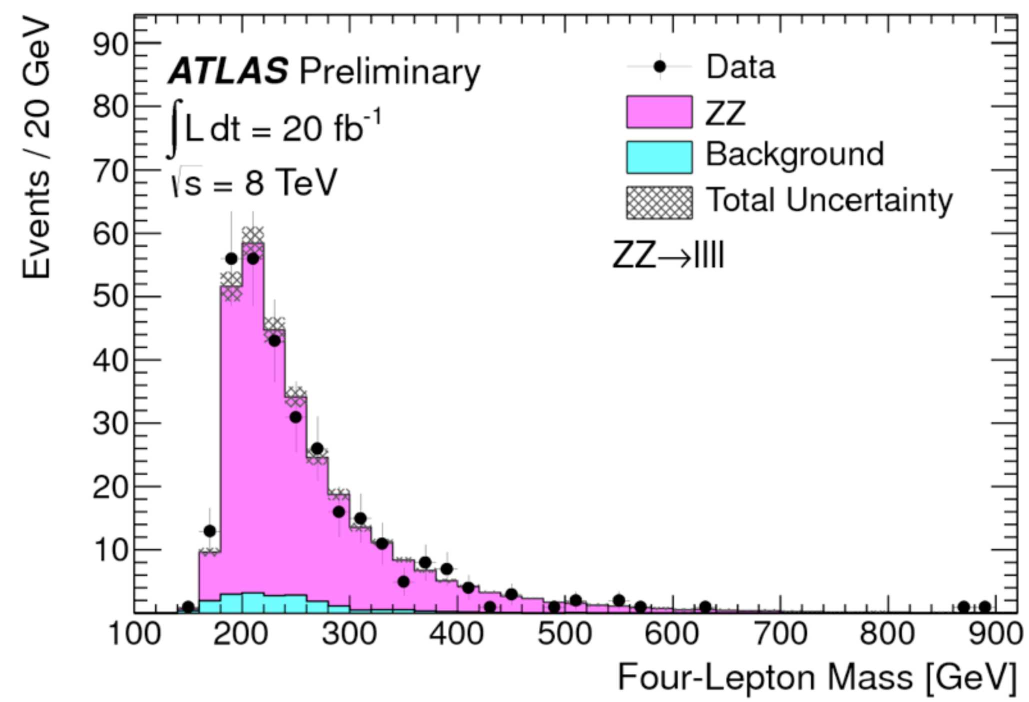
ATLAS-CONF-2013-020
JHEP03(2013)128

ZZ->lll'l', llνν

- Very low backgrounds
- Optimized for lepton efficiency, especially at low pT







66 GeV < M(l^+l^-) < 116 GeV

		Theoretical
7 TeV 4.6 fb^{-1}	$6.7 \pm 0.7\ (\text{stat.})\ ^{+0.4}_{-0.3}\ (\text{syst.}) \pm 0.3\ (\text{lumi.})$ pb	$5.89^{+0.22}_{-0.18}$ pb
8 TeV 20 fb^{-1}	$7.1^{+0.5}_{-0.4}(\text{stat.}) \pm 0.3(\text{syst.}) \pm 0.2(\text{lumi.})$ pb	$7.2^{+0.3}_{-0.2}$ pb

NEW

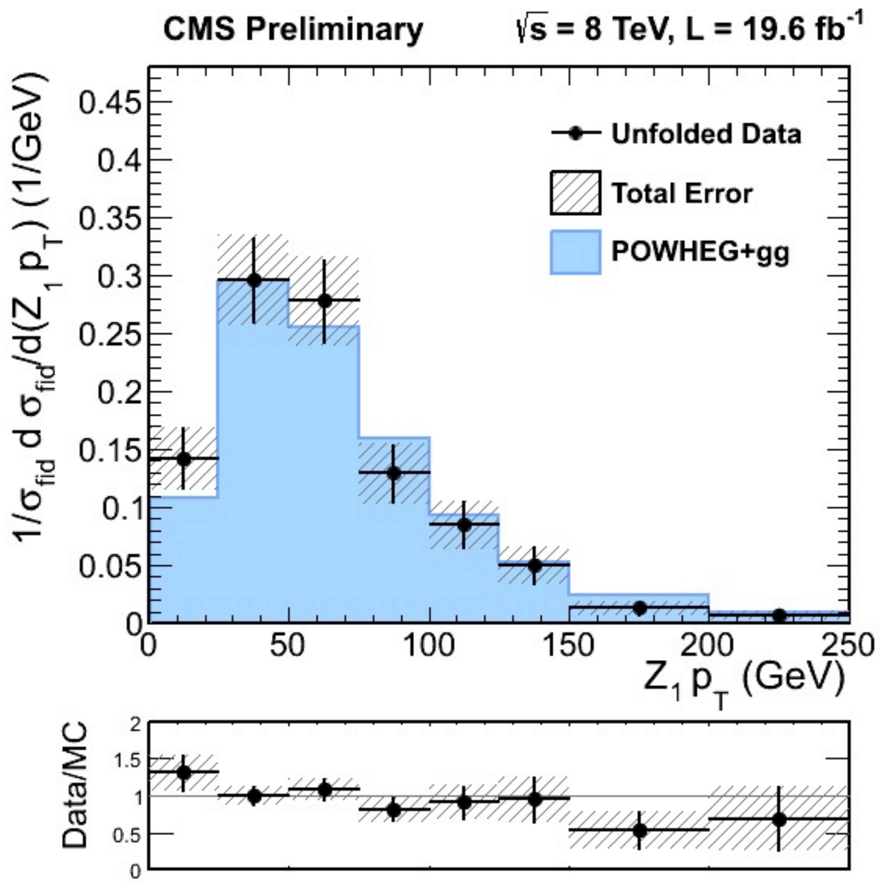
ZZ->lll'l'

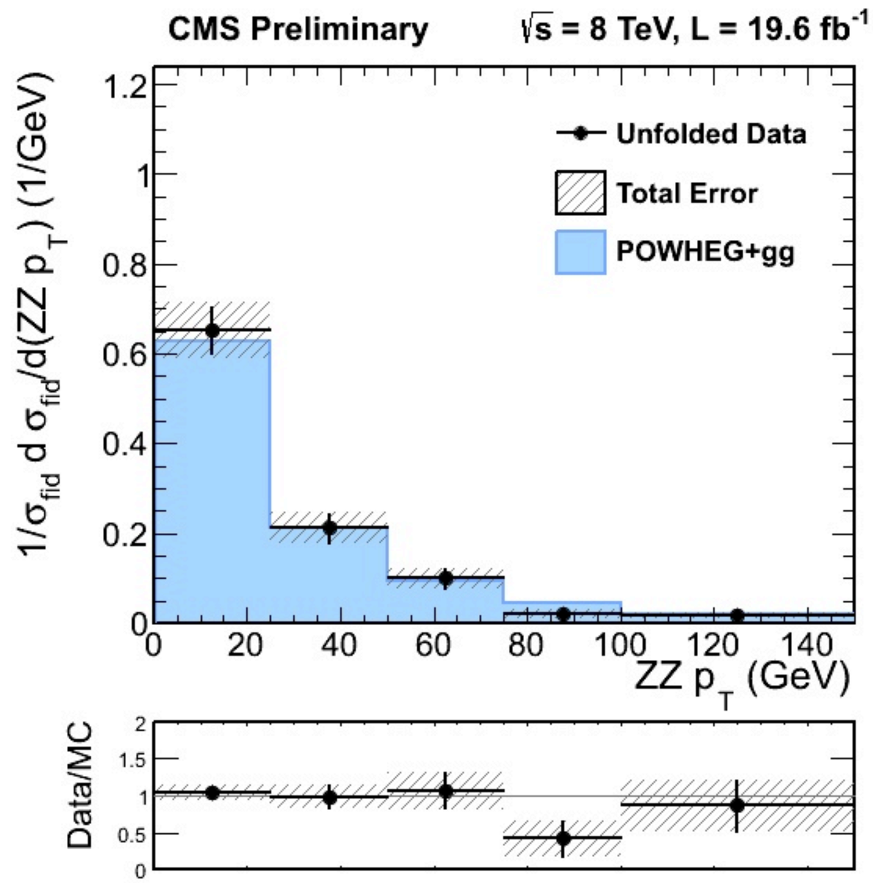
$l = e, \mu; l' = e, \mu, \tau$

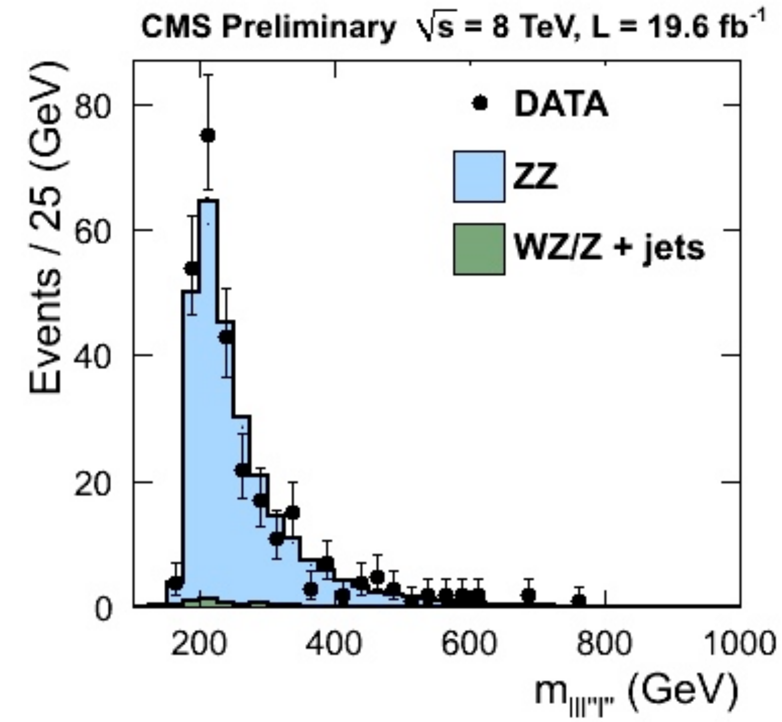
CMS-PAS-SMP-13-005
Phys. Lett. B 721 (2013) 190-211
J. High Energy Phys. 01 (2013) 063

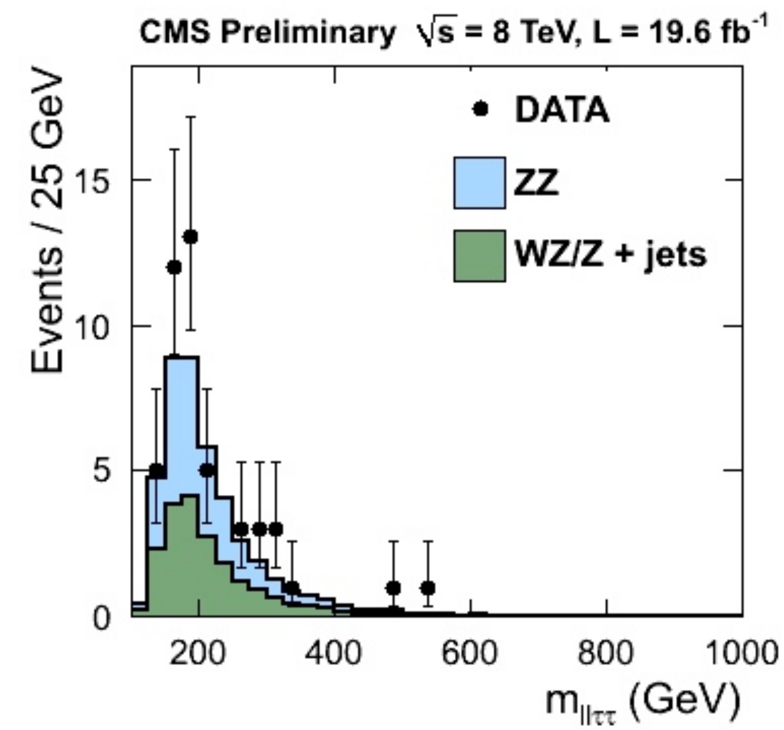
Lepton pT > 20/10/7/5 GeV

Differential cross sections









Cross sections obtained from simultaneous fit to event yields in all studied channels

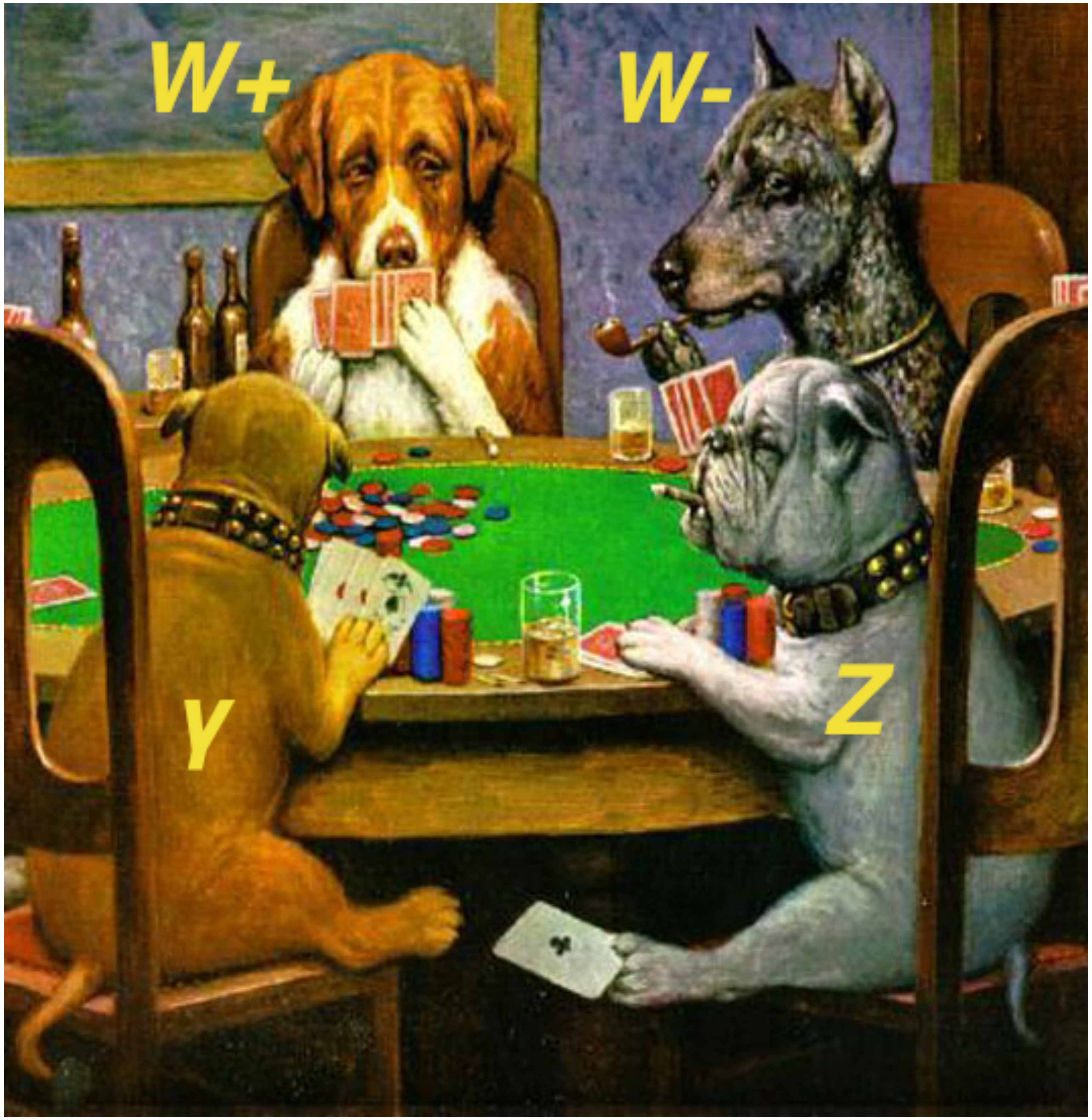
60 GeV < $M(l^+l^-)$ < 120 GeV

		Theoretical
7 TeV 5.0 fb^{-1}	$6.24^{+0.86}_{-0.80}\,(\text{stat.})\,^{+0.41}_{-0.32}\,(\text{syst.}) \pm 0.14\,(\text{lumi.})\,\text{pb}$	6.3±0.4 pb
8 TeV 19.6 fb^{-1}	$7.7^{+0.5}_{-0.5}\,(\text{stat.})^{+0.5}_{-0.4}\,(\text{syst.}) \pm 0.4\,(\text{theo.}) \pm 0.3\,(\text{lum.})\,\text{pb}$	7.7±0.6 pb

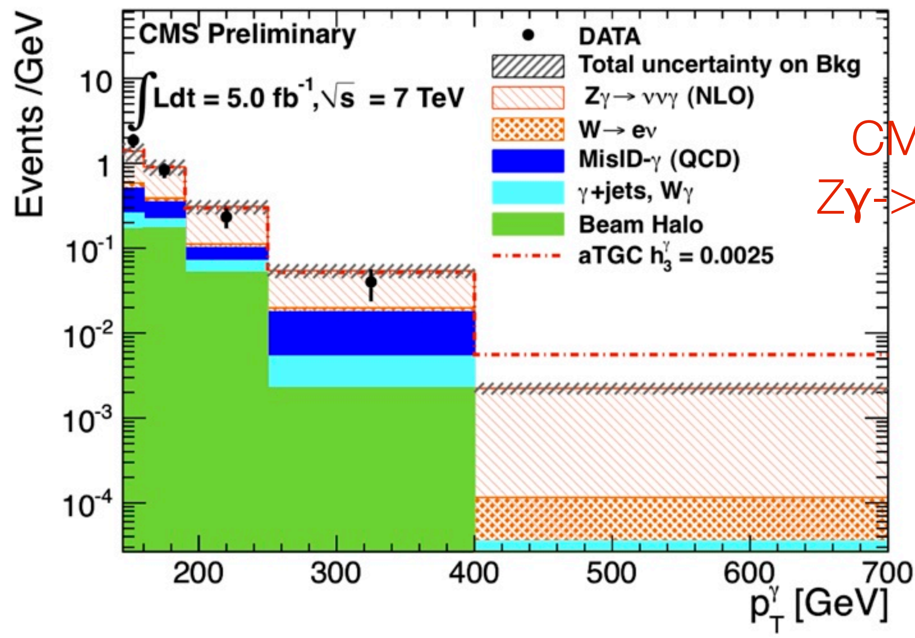
Anomalous Triple Gauge Couplings

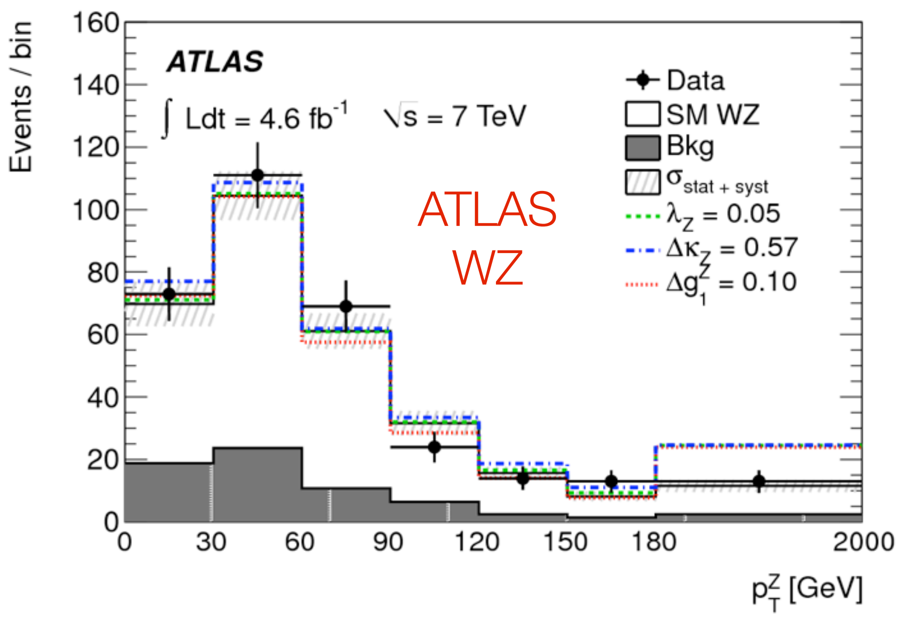
- SM describes exactly how vector bosons interact with each other
  - Even new physics at a higher energy scale will have indirect effects on TGC
- aTGC are modeled using effective Lagrangian depending on some parameters, which are all zero in SM

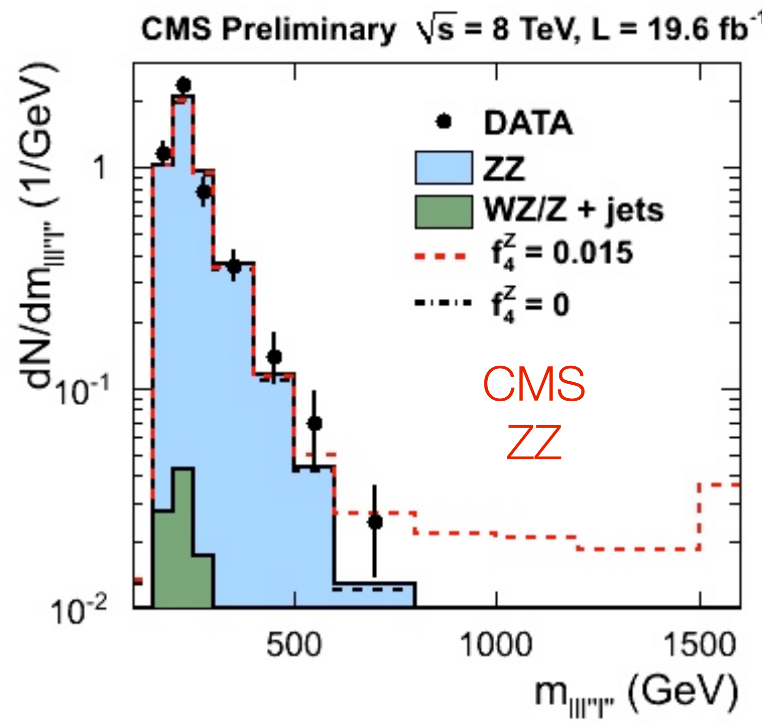
Coupling	Parameters	Channel
WWγ	$\Delta\kappa_\gamma$, λ_γ	WW, Wγ
WWZ	Δg_1^Z, $\Delta\kappa_Z$, λ_Z	WW, WZ
ZZγ	h_3^Z, h_4^Z	Zγ
Zγγ	h_3^γ, h_4^γ	Zγ
ZZZ	f_4^Z, f_5^Z	ZZ
ZγZ	f_4^γ, f_5^γ	ZZ

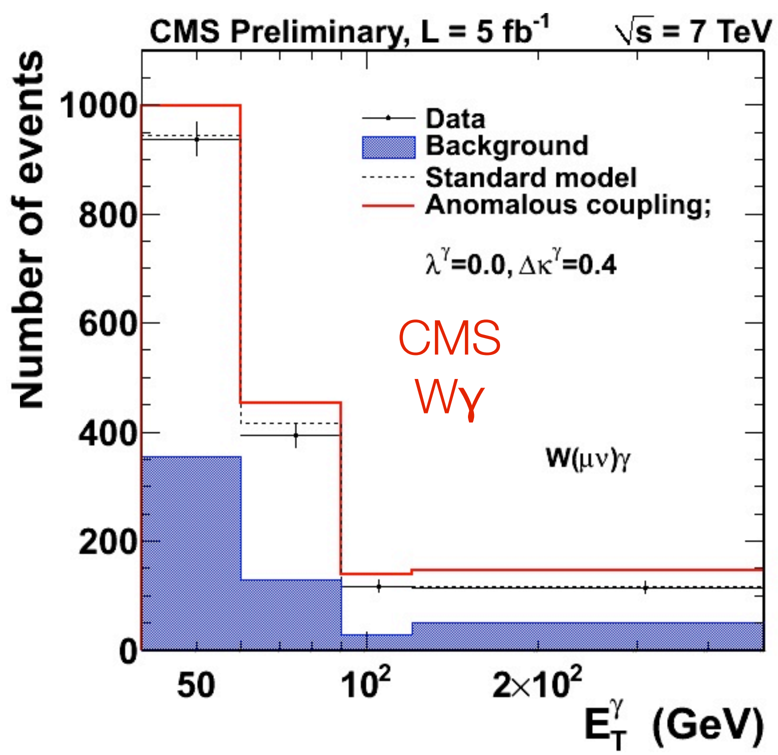


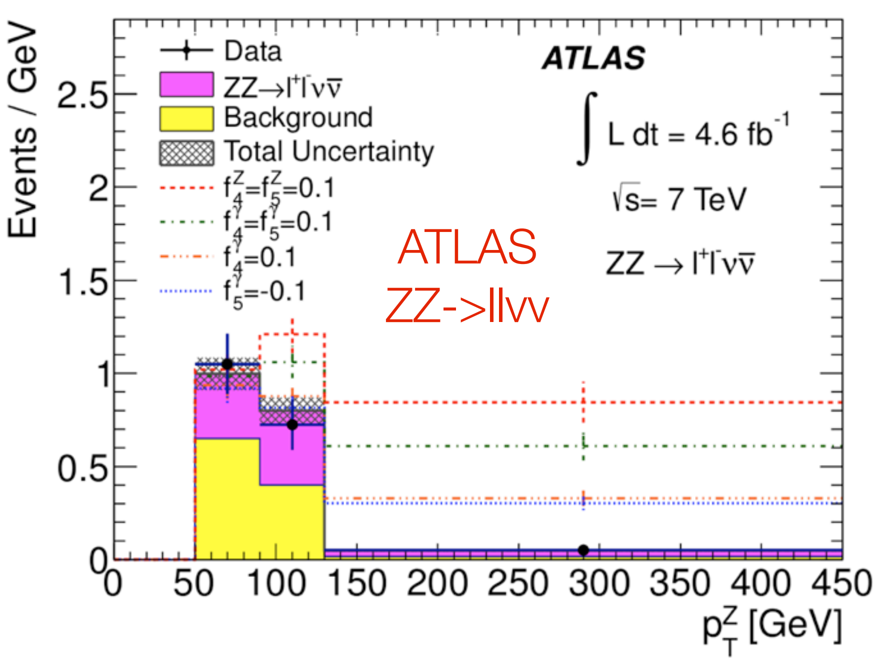
To interact by the rules or not?

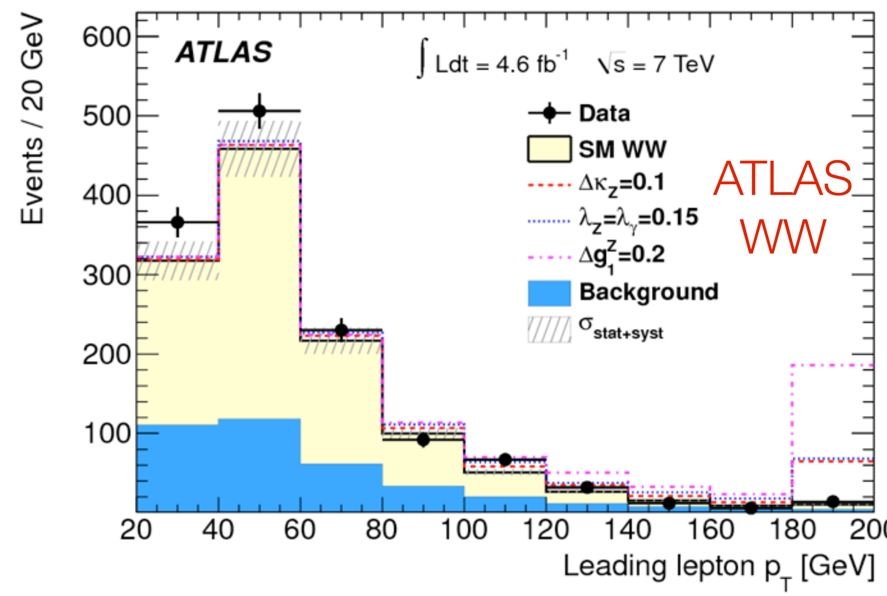










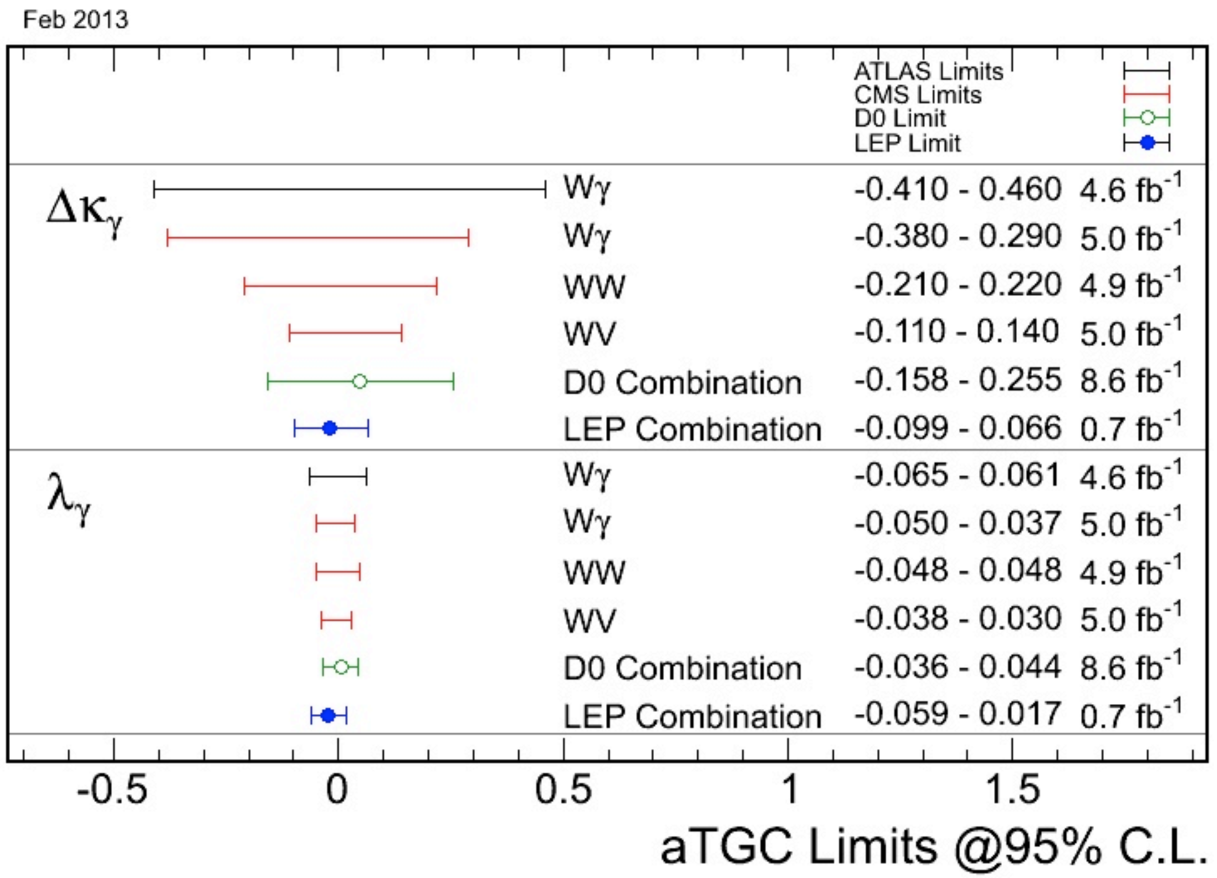


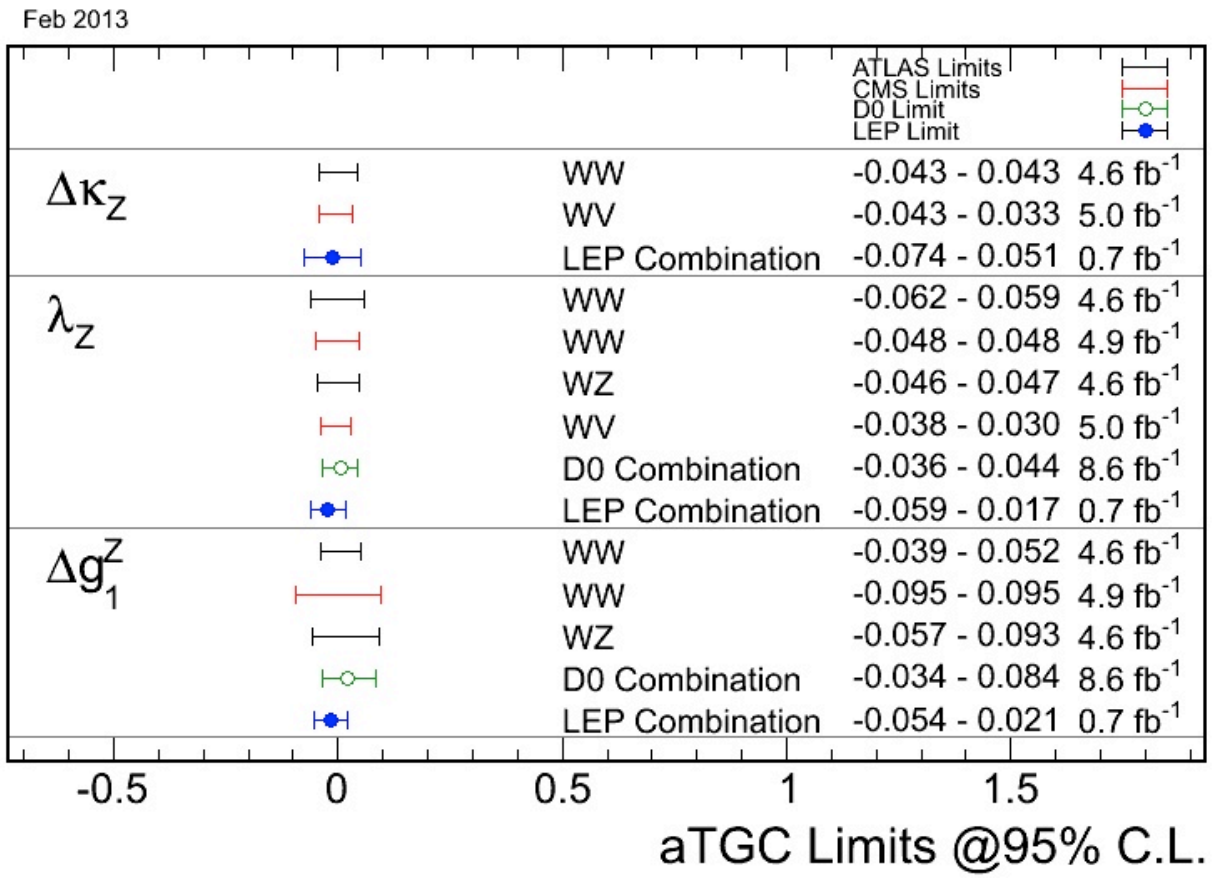
aTGC would increase cross section at high end of M(VV), and its proxies, e.g. pT

The tail drives sensitivity!

Charged aTGC (WWγ, WWZ)

Phys. Rev. D 87, 112003 (2013)
arXiv:1308.6832 (submitted to PRD)
arXiv:1306.1126 (submitted to EPJC)
Eur.Phys.J. C73 (2013) 2283
Phys.Lett. B718 (2012) 451-459
arXiv:1302.3415
Phys. Rev. D 87, 112001 (2013)
Eur.Phys.J. C72 (2012) 2173



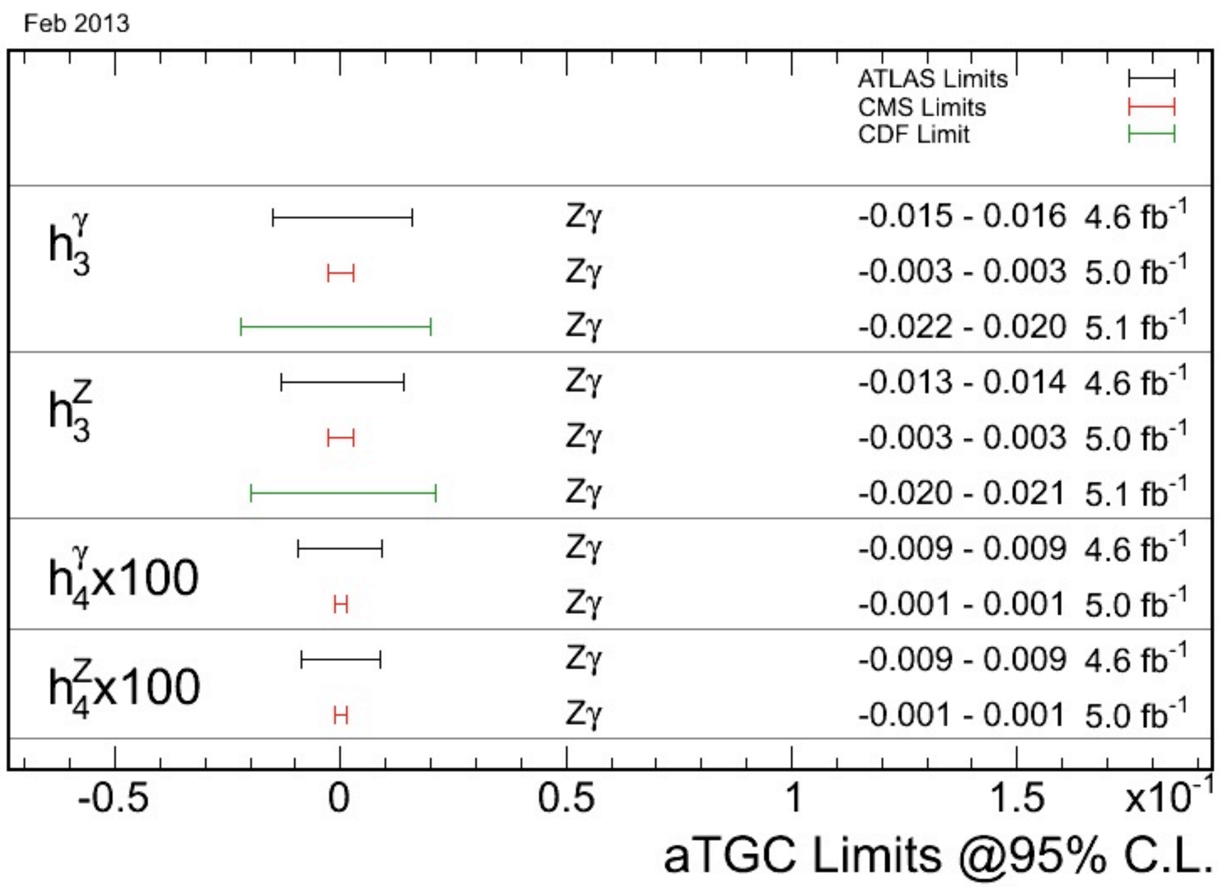


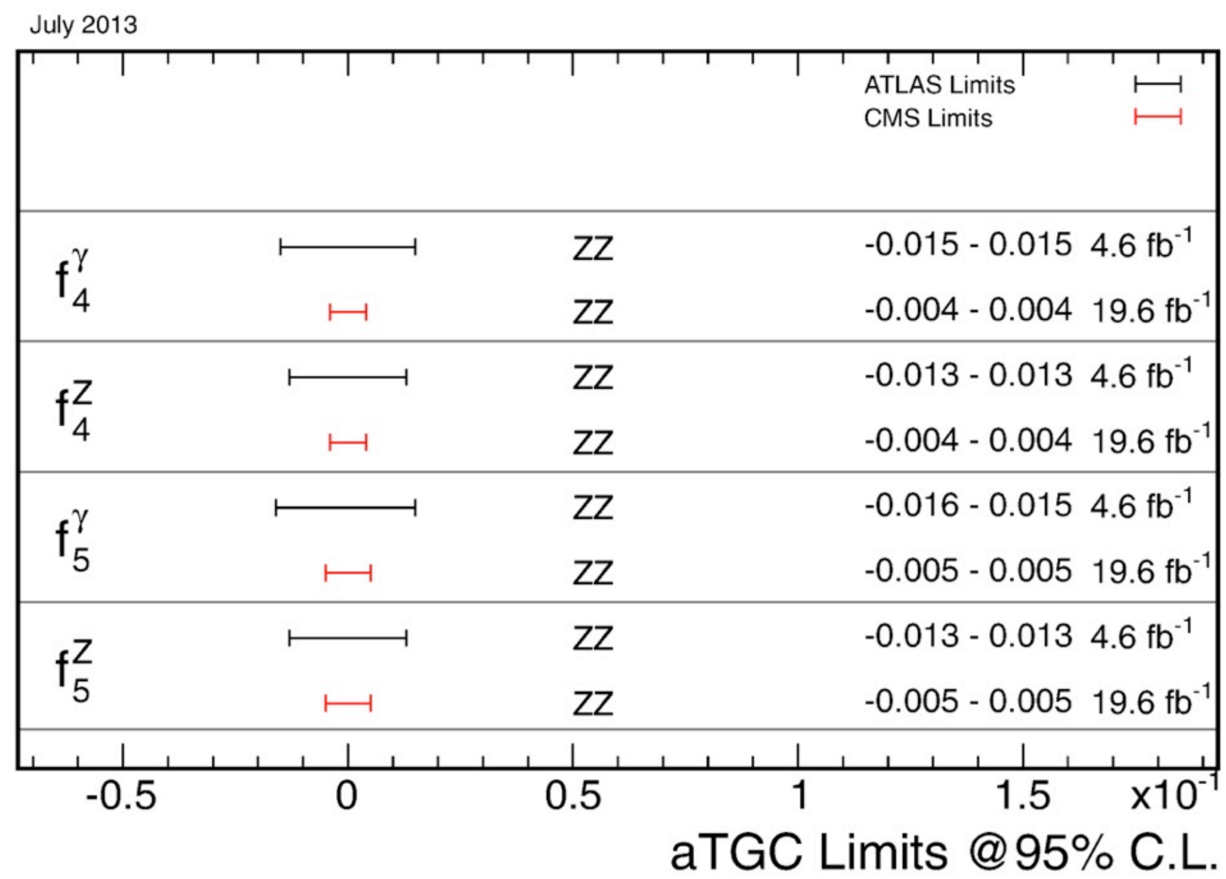
LEP remains most competitive here
WV->lvjj doing well

LHC approaching LEP sensitivities

Neutral aTGC (Zγγ, ZZγ, ZZZ)

Phys. Rev. D 87, 112003 (2013)
arXiv:1308.6832 (submitted to PRD)
CMS-PAS-SMP-12-020
Phys. Rev. Lett. 107, 051802, 2011
JHEP03(2013)128
CMS-PAS-SMP-13-005



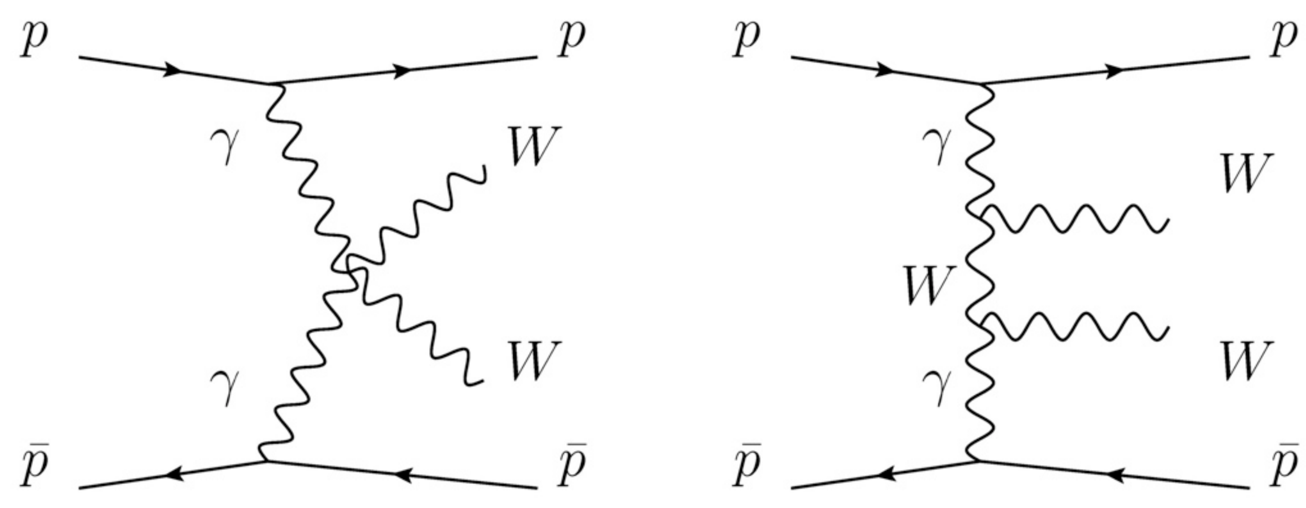


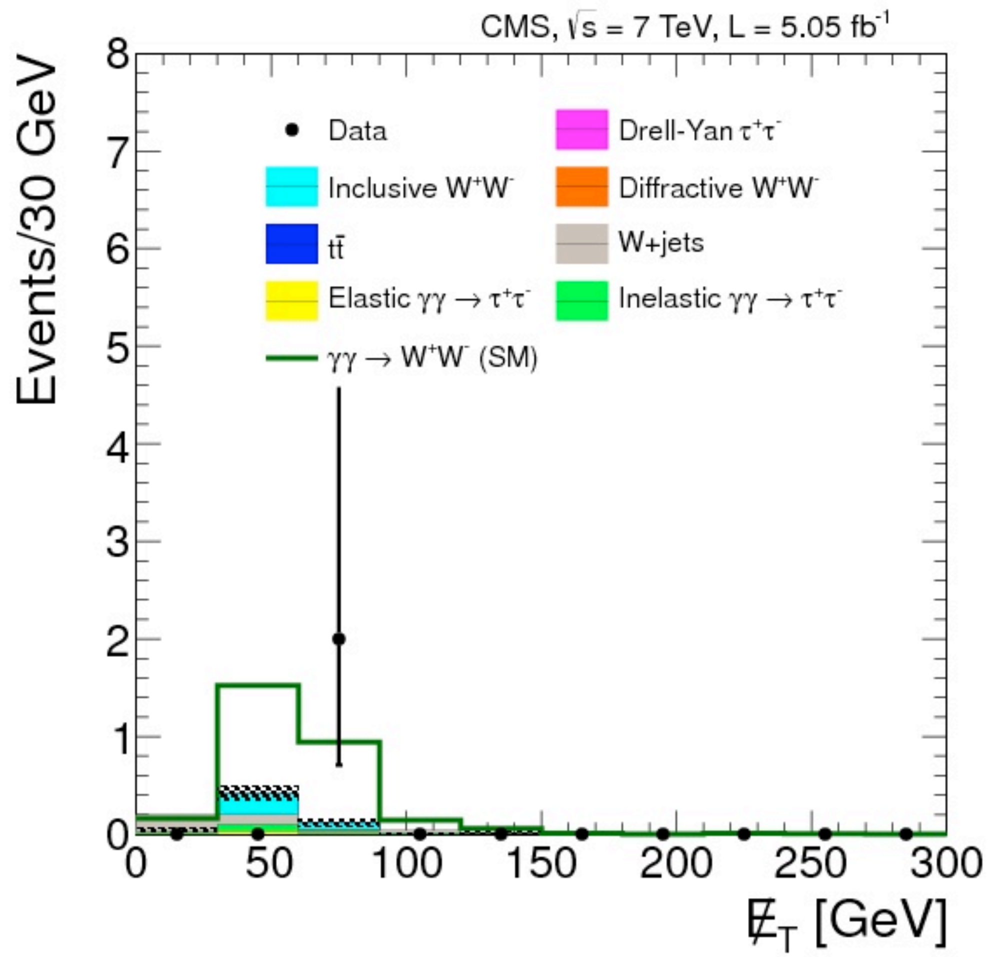
LHC dominates on neutral aTGC limits
Sensitivity mostly from ννγ

Loops contribute 10^{-4}; Some new models predict 10^{-4} to 10^{-3}
Limits are already at interesting region!

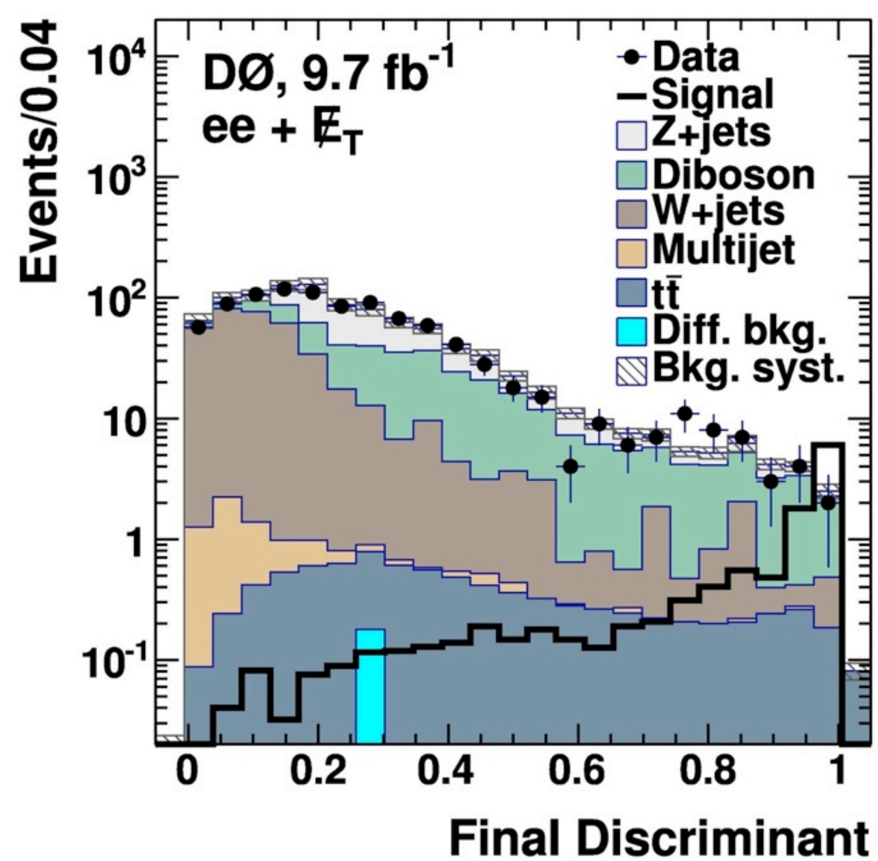
JHEP 1307 (2013) 116
Phys. Rev. D 88, 012005

γγ->WW->lνlν





NEW



- Opposite charged eμ vertex 0 extra track, pT(eμ) > 30 GeV
- 7TeV 5 fb^{-1}: 2 events observed (expected: 2.2 signal, 0.84 background)

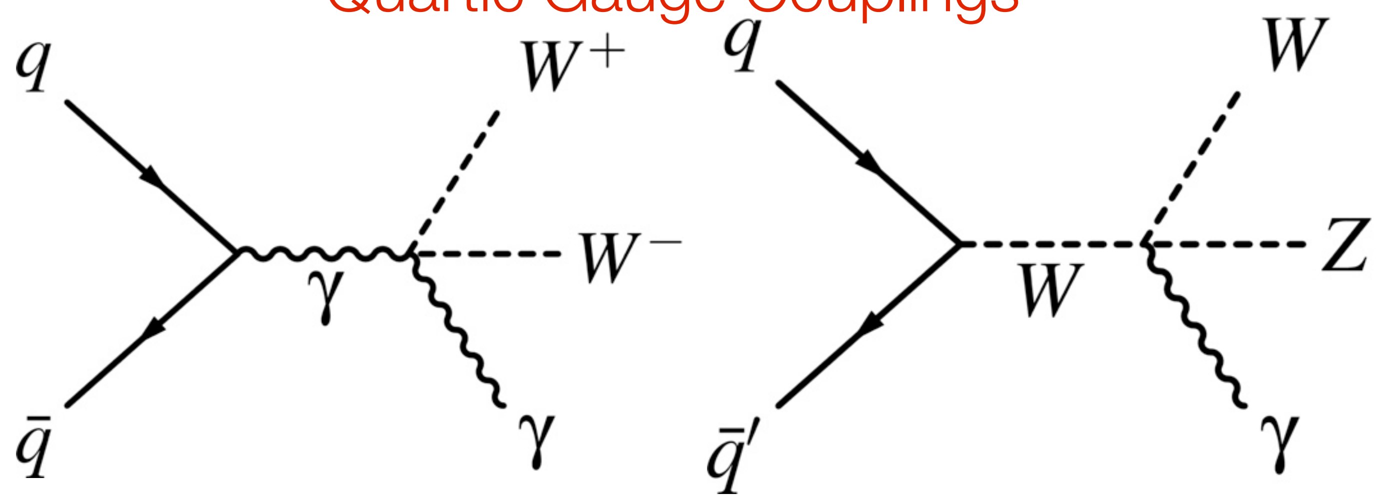
CMS-PAS-SMP-13-009

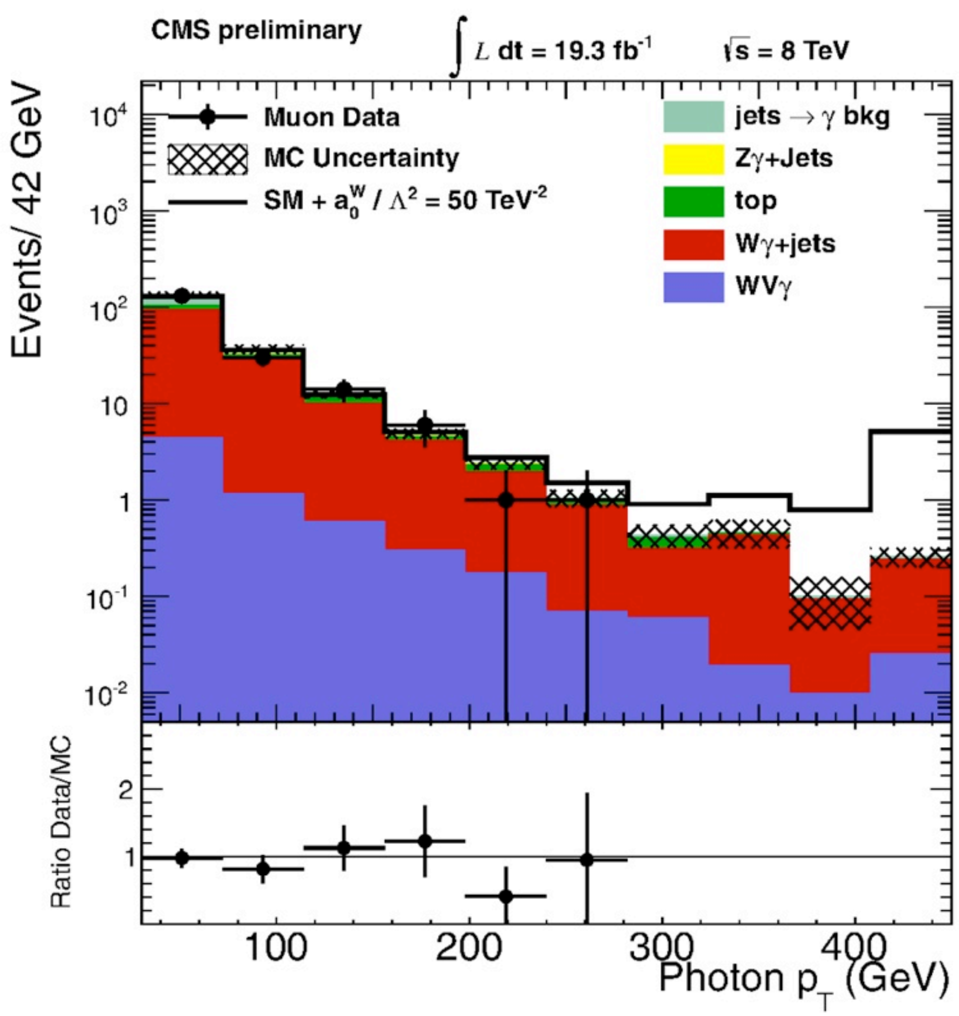
Tri-boson: WVγ

NEW

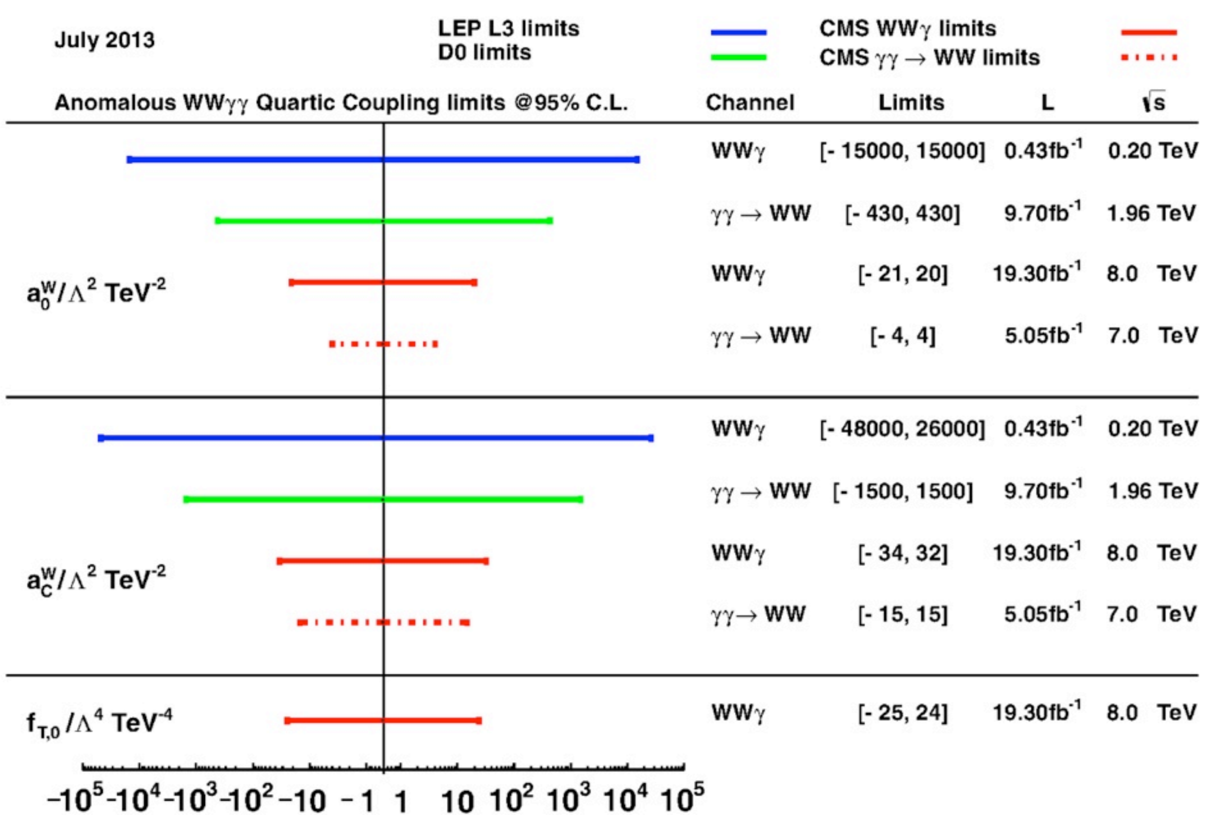
- W->lν; V: W/Z->jj
- σ(WVγ) < 241 fb, 3.4 times SM (photon pT > 10 GeV)

Quartic Gauge Couplings





γγ->WW and tri-boson are used to set limits on anomalous Quartic Gauge Couplings



Summary

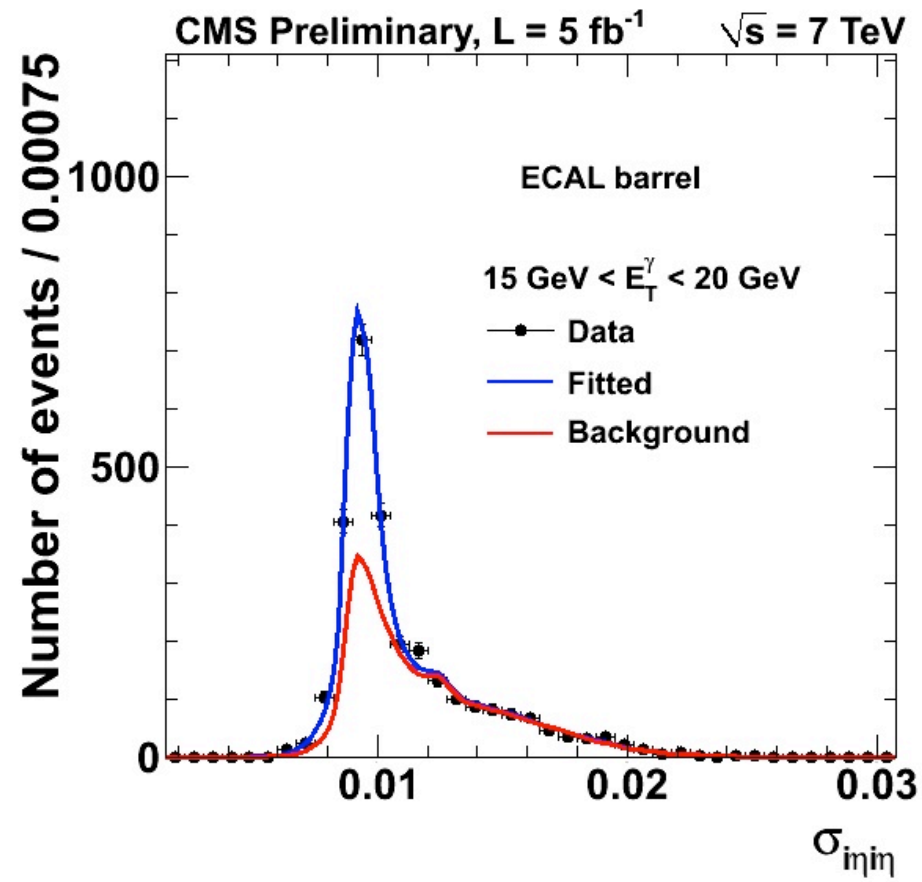
- Measurements are presented of diboson production cross sections
  - Proton-antiproton collisions at 1.96 TeV at Tevatron
  - Proton-proton collisions at 7 TeV and 8 TeV at LHC
- The measured cross sections are consistent with SM predictions
  - Differential cross sections are also measured in some channels
- Limits set on anomalous Triple Gauge Couplings. No evidence for new physics
- The study of Quartic Gauge Couplings has started
- Full statistics 8 TeV measurement in all channels at LHC will continue. Looking forward to 2015 run

Backup

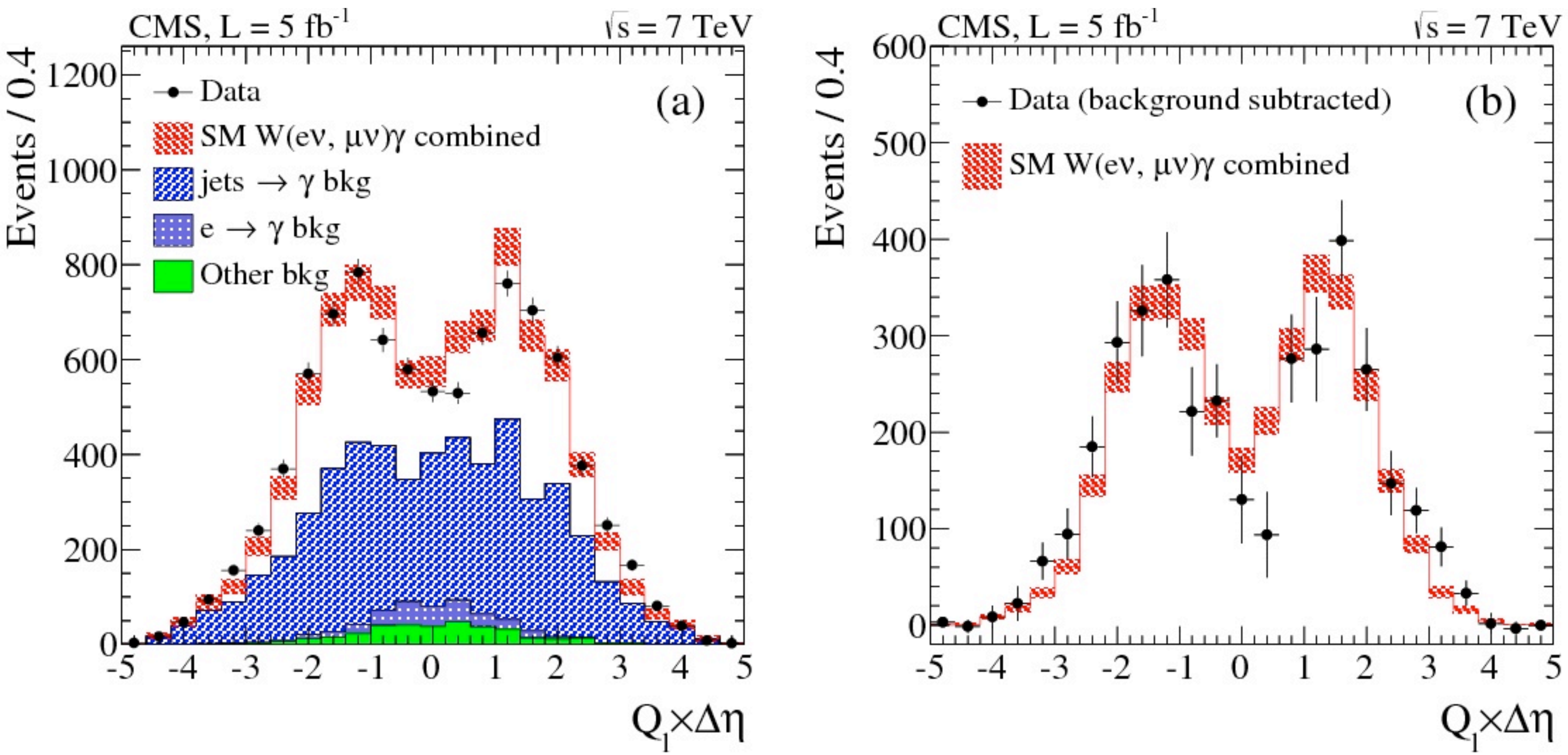
CMS Vγ

Table 2: Summary of selection criteria used to define the $W\gamma$ and $Z\gamma$ samples.

Selection	$W\gamma \to e\nu\gamma$	$W\gamma \to \mu\nu\gamma$	$Z\gamma \to ee\gamma$	$Z\gamma \to \mu\mu\gamma$
Trigger	single electron	single muon	dielectron	dimuon
p_T^ℓ (GeV)	>35	>35	>20	>20
$\|\eta^\ell\|$	EB or EE	<2.1	EB or EE	<2.4
p_T^γ (GeV)	>15	>15	>15	>15
$\|\eta^\gamma\|$	EB or EE	EB or EE	EB or EE	EB or EE
$\Delta R(\ell,\gamma)$	>0.7	>0.7	>0.7	>0.7
M_T^W (GeV)	>70	> 70		
$m_{\ell\ell}$ (GeV)			>50	>50
Other criterion	only one lepton	only one lepton		



Radiation Amplitude Zeros



CMS Zγ->vvγ 7 TeV

Source	Number of selected events
Misidentified jets	11.2 ± 2.8
Beam-gas processes	11.1 ± 5.6
Misidentified electrons	3.5 ± 1.5
Wγ	3.3 ± 1.0
$\gamma\gamma$	0.6 ± 0.3
γ+jet	0.5 ± 0.2
Total	30.2 ± 6.5
$Z\gamma \rightarrow \nu\bar{\nu}\gamma$ (NLO)	45.3 ± 6.9
data	73

WW

CMS 8 TeV

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
$Z/\gamma^* +$ jets	43 ± 12
$W\gamma^{(*)}$	14 ± 5
Total background	275 ± 35
Signal + background	959 ± 60
Data	1111

ATLAS 7 TeV

Selection criteria
Exactly two opposite-sign leptons
$m_{\ell\ell'} > 15, 15, 10$ GeV
$\lvert m_{\ell\ell'} - m_Z \rvert > 15, 15, 0$ GeV
$E_{T,Rel}^{miss} > 45, 45, 25$ GeV
Jet veto
$p_T(\ell\ell') > 30$ GeV

	ee	$\mu\mu$	$e\mu$	Combined
Data	174	330	821	1325
WW	$100 \pm 2 \pm 9$	$186 \pm 2 \pm 15$	$538 \pm 3 \pm 45$	$824 \pm 4 \pm 69$
Top	$22 \pm 12 \pm 3$	$32 \pm 14 \pm 5$	$87 \pm 23 \pm 13$	$141 \pm 30 \pm 22$
W + jets	$21 \pm 1 \pm 11$	$7 \pm 1 \pm 3$	$70 \pm 2 \pm 31$	$98 \pm 2 \pm 43$
Drell-Yan	$12 \pm 3 \pm 3$	$34 \pm 6 \pm 10$	$5 \pm 2 \pm 1$	$51 \pm 7 \pm 12$
Other dibosons	$13 \pm 1 \pm 2$	$21 \pm 1 \pm 2$	$44 \pm 2 \pm 6$	$78 \pm 2 \pm 10$
Total background	$68 \pm 12 \pm 13$	$94 \pm 15 \pm 13$	$206 \pm 24 \pm 35$	$369 \pm 31 \pm 53$
Total expected	$169 \pm 12 \pm 16$	$280 \pm 16 \pm 20$	$744 \pm 24 \pm 57$	$1192 \pm 31 \pm 87$

WZ 8 TeV

CMS

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

ATLAS

Final State	eee	$ee\mu$	$e\mu\mu$	$\mu\mu\mu$	Combined
Observed	192	270	298	334	1094
ZZ	10.3±0.6	14.7±0.8	12.8±0.7	18.8±1.0	56.6±1.6
Z + jets	37±3±11	33±4±10	57±4±11	47±5±14	188±8±24
Top		6.3±0.5±3.4		9.1±0.7±4.9	
$W/Z + \gamma$	13±3	1.3±0.6	17±3	–	32±5
Bkg (total)	60±4±11	55±4±10	87±5±11	75±5±14	277±9±24
Expected signal	144±12	199±16	200±16	276±21	819±34
Expected S/B	2.4	3.7	2.3	3.7	3.0
$A \times C$	0.144	0.188	0.199	0.276	-

WV->Wjj 7 TeV

CMS

Process	Muon channel	Electron channel
Diboson (WW+WZ)	1900 ± 370	800 ± 310
W plus jets	67380 ± 590	31640 ± 850
$t\bar{t}$	1660 ± 120	950 ± 70
Single top	650 ± 30	310 ± 20
Drell–Yan+jets	3610 ± 160	1410 ± 60
Multijet (QCD)	300 ± 320	4190 ± 870
Data	75419	39365
Fit χ^2/N_{dof} (probability)	9.73/12 (0.64)	5.30/12 (0.95)
Acceptance $\times$ efficiency ($\mathcal{A}\varepsilon$)	$(5.15 \pm 0.24) \times 10^{-3}$	$(2.63 \pm 0.12) \times 10^{-3}$
Expected WW+WZ yield from simulation	1700 ± 60	870 ± 30

ATLAS

Process	e	μ
WW	1250 ± 60	1360 ± 70
WZ	276 ± 19	306 ± 21
W + light jets	$(67 \pm 13) \times 10^3$	$(71 \pm 14) \times 10^3$
W/Z + heavy flavor jets	$(19 \pm 4) \times 10^3$	$(20 \pm 4) \times 10^3$
$t\bar{t}$	$(24.8 \pm 2.5)\times 10^2$	$(24.6 \pm 2.5)\times 10^2$
single top	$(13.5 \pm 1.3)\times 10^2$	$(13.7 \pm 1.4)\times 10^2$
multijet	$(50 \pm 15)\times 10^2$	$(39 \pm 12)\times 10^2$
Z + jets	$(35 \pm 7)\times 10^2$	$(32 \pm 6)\times 10^2$
Wγ + ZZ	383 ± 19	464 ± 23
Total SM prediction	$(100 \pm 14)\times 10^3$	$(103 \pm 15)\times 10^3$
Total Data	100055	103627
Signal efficiency for $60 < m_{jj} < 120$ GeV	0.7%	0.9%
Signal to background ratio for $60 < m_{jj} < 120$ GeV	2.6%	2.8%

CMS ZZ 8 TeV

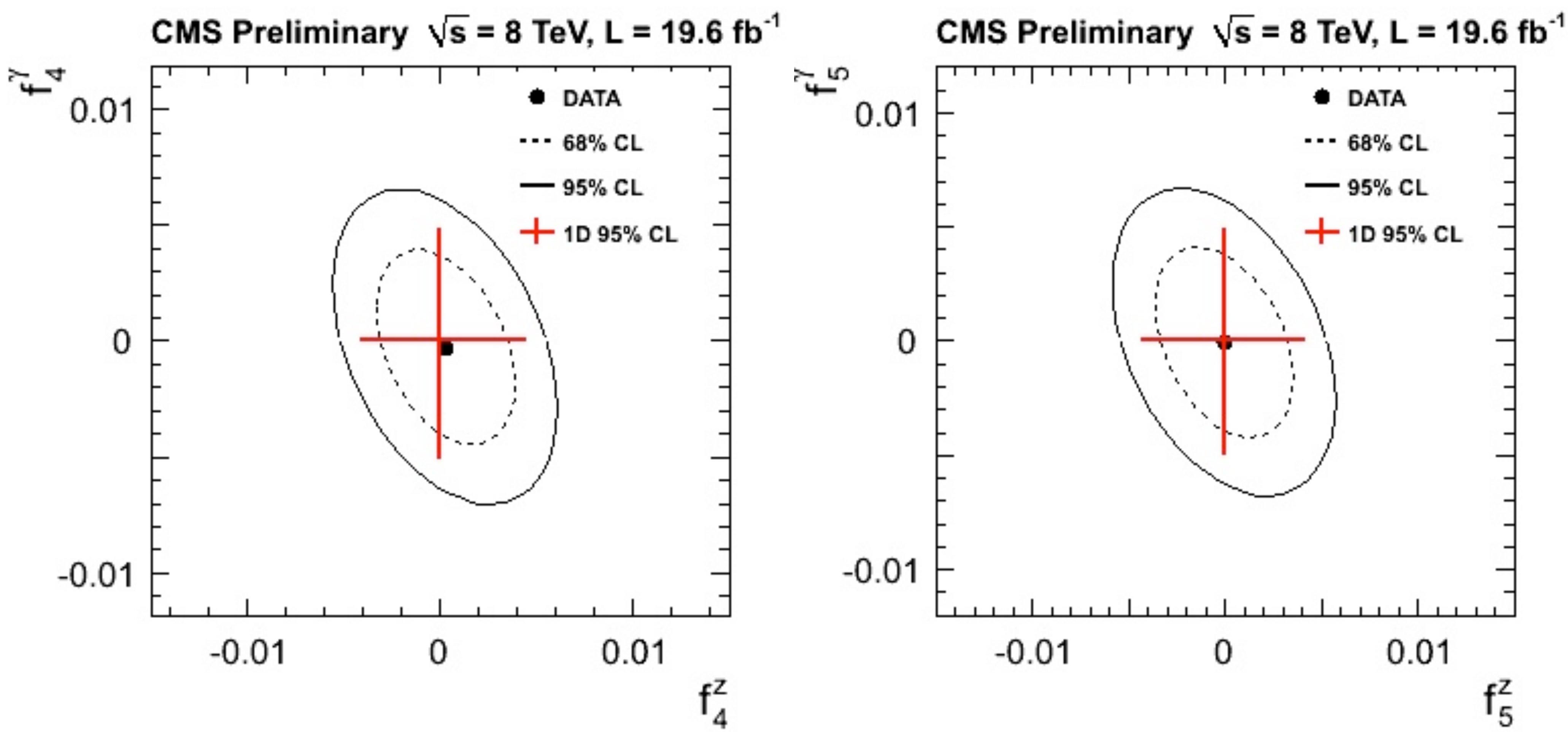
Decay channel	N_{ZZ}^{exp}	Background	Total expected	Observed
$\mu\mu\mu\mu$	$77.32 \pm 0.29 \pm 10.08$	$1.19 \pm 0.36 \pm 0.48$	$78.51 \pm 0.49 \pm 10.09$	75
eeee	$55.28 \pm 0.25 \pm 7.64$	$2.16 \pm 0.26 \pm 0.88$	$57.44 \pm 0.37 \pm 7.69$	54
$\mu\mu$ee	$136.09 \pm 0.59 \pm 17.50$	$2.35 \pm 0.34 \pm 0.93$	$138.44 \pm 0.70 \pm 17.52$	148
$\mu\mu\tau_h\tau_h$	$2.80 \pm 0.03 \pm 0.34$	$3.89 \pm 0.37 \pm 1.17$	$6.69 \pm 0.39 \pm 1.30$	10
$ee\tau_h\tau_h$	$2.46 \pm 0.03 \pm 0.32$	$3.46 \pm 0.34 \pm 1.04$	$5.92 \pm 0.36 \pm 1.15$	10
$ee\tau_e\tau_h$	$2.79 \pm 0.03 \pm 0.36$	$3.87 \pm 1.26 \pm 1.16$	$6.66 \pm 1.34 \pm 1.29$	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
$\mu\mu\tau_\mu\tau_h$	$3.81 \pm 0.03 \pm 0.50$	$1.55 \pm 0.43 \pm 0.46$	$5.36 \pm 0.46 \pm 0.70$	5
$ee\tau_\mu\tau_h$	$3.27 \pm 0.03 \pm 0.42$	$1.47 \pm 0.41 \pm 0.44$	$4.74 \pm 0.43 \pm 0.63$	2
$ee\tau_e\tau_\mu$	$2.23 \pm 0.03 \pm 0.29$	$3.04 \pm 1.32 \pm 1.50$	$5.27 \pm 1.40 \pm 1.61$	4
$\mu\mu\tau_\mu\tau_e$	$2.41 \pm 0.03 \pm 0.32$	$0.74 \pm 0.51 \pm 0.37$	$3.15 \pm 0.54 \pm 0.51$	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

Table 1: The observed and expected yield of ZZ events, and estimated yield of background events obtained from data are shown for each decay channel and are summed in the total expected yield ("Total expected.").

ATGC

- To stop unitarity violation, may use form factor: $\alpha(s)=\alpha(0)/(1+s/\Lambda)^n$

$$\mathcal{L}_{WWV}^{\text{eff}} = ig_{WWV}[g_1^V(W_{\mu\nu}^+ W^{-\mu} - W^{+\mu}W_{\mu\nu}^-)V^\nu + \kappa_V W_\mu^+ W_\nu^- V^{\mu\nu} + \frac{\lambda_V}{M_W^2} W_\mu^{+\nu} W_\nu^{-\rho} V_\rho^{\mu}],$$



CMS WVγ

Process	muon channel number of events	electron channel number of events
$W\gamma$+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$\rightarrow \gamma$	$33.1 \pm 1.3 \pm 4.6 \pm 0.0$	$21.3 \pm 1.0 \pm 3.1 \pm 0.0$
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 $Z\gamma$+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 $WW\gamma$	$6.3 \pm 0.1 \pm 1.5 \pm 0.3$	$4.7 \pm 0.1 \pm 1.1 \pm 0.2$
SM $WZ\gamma$	$0.6 \pm 0.0 \pm 0.1 \pm 0.0$	$0.5 \pm 0.0 \pm 0.1 \pm 0.0$
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