

Laurent Chevalier CEA-Saclay, eps-hep 2015, Vienna 22-29 July

LHC measurements → Standard Model: almost perfect?





 $W\gamma, Z\gamma$ cross section

WZ, ZZ cross section

WW+WZ semi-leptonic

WW cross section

VBF/VBS See talk N.L. Martinez

aTGC

Summary

SM Non-Abelian structure of $SU(2)_{1} \times U(1)_{2}$ allow TGC(charged only) & QGC (charged only) W TGC QGC aTGC parameters coupling channel W (All = 0 in SM)aTGC $WW\gamma$ $\lambda_{\gamma}, \Delta \kappa_{\gamma}$ $WW, W\gamma$ aTGC WWZ $\lambda_Z, \Delta \kappa_Z, \Delta g_1^Z$ WW, WZTGC h_3^Z, h_4^Z $ZZ\gamma$ $Z\gamma$ $Z\gamma\gamma$ $h_3^{\gamma}, h_4^{\gamma}$ $Z\gamma$ $f_{40}^{\gamma}, f_{50}^{\gamma}$ $Z\gamma Z$ ZZ f_{40}^Z, f_{50}^Z ZZZ ZZEFT Λ : scale of new physics $\mathcal{O}_i^{(d)}$: new operators of higher dimensions (d) $\mathcal{L}_{eff} = \mathcal{L}_{SM} + \sum_{d} \sum_{i} \frac{c_i^{(d)}}{\Lambda^{d-4}} \mathcal{O}_i^{(d)}$ => Modify differential and total cross sections

Wγ,Ζγ cross section

WZ, ZZ cross section

WW+WZ semi-leptonic

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Summary

$W\gamma / Z\gamma \rightarrow I\nu\gamma, II\gamma, \nu\nu\gamma$

- high E^T isolated photon
- high p^T isolated lepton
- $\Delta R_{(lepton, photon)} > 0.7$ •

BKG

 10^{2}

10

10

 10^{-2}

0

0 15

dσ(pp→ lvγ)[fb GeV⁻¹]

dĒ₁

<u>Data</u> Theory

<u>Data</u> Theory

- W/Z+jets
- γ +jets
- $W \rightarrow ev$

ATLAS

L dt = 4.6 fb

Data 2011 (Inclusive

ACFM (Inclusive)

20

x 1.5 (Inclusive)

30

Remarks:

Wγ

Data 2011 (Exclusive)

60

40

100

- Z γ fair agreement
- Wγ measurement above NLO
- NNLO QCD corrections are needed (see next slide)



$W\gamma \& Z\gamma$ cross sections at 7 TeV

Phys. Rev. D 87,112003



6/15



WZ & ZZ cross sections at 7 and 8 TeV





$W\gamma, Z\gamma$ cross section

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aTGC

Summary

WW cross section at 8 TeV

ATLAS-CONF-2014-033







Wγ,Zγ cross section

WZ, ZZ cross section

WW+WZ semi-leptonic

WW cross section

VBF/VBS See talk N.L. Martinez

aTGC

Summary

aTGC

Anomalous couplings:

- · increase cross sections and modification of kinematic distributions
- Anomalous effect from beyond SM
- physics can be modelled (SM+higher dimension operators)

Oct 2014			
WW	8		ATLAS Limits CMS Prel. Limits D0 Limit LEP Limit
Δr –		Wγ	-0.410 - 0.460 4.6 fb ⁻¹
Διγ μ		Wγ	-0.380 - 0.290 5.0 fb ⁻¹
	HI	WW	-0.210 - 0.220 4.9 fb ⁻¹
	↓t	WV	-0.210 - 0.220 4.6 fb ⁻¹
	HH	WV	-0.110 - 0.140 5.0 fb ⁻¹
	⊢	D0 Combinati	on -0.158 - 0.255 8.6 fb ⁻¹
	—	LEP Combina	tion -0.099 - 0.066 0.7 fb ⁻¹
2		Wγ	-0.065 - 0.061 4.6 fb ⁻¹
Ny	—	Wγ	-0.050 - 0.037 5.0 fb ⁻¹
	H	WW	-0.048 - 0.048 4.9 fb ⁻¹
	\vdash	WV	-0.039 - 0.040 4.6 fb ⁻¹
	⊢	WV	-0.038 - 0.030 5.0 fb ⁻¹
	⊢o⊣	D0 Combinati	on -0.036 - 0.044 8.6 fb ⁻¹
	H	LEP Combina	tion -0.059 - 0.017 0.7 fb ⁻¹
-0.5		0.5	1 15
0.0	Ū		
		argo	Limits @95% C.L
Nov 2013			
	777		ATLAS Limits
82Z	,		
٤Y	H	ZZ	-0.015 - 0.015 4.6 fb ⁻¹
4	⊢–(ZZ	-0.004 - 0.004 19.6 fb ⁻¹
	H	ZZ (2l2v)	-0.004 - 0.003 5.1, 19.6 fb ⁻¹
•7	H	ZZ	-0.013 - 0.013 4.6 fb ⁻¹
r_4^-	H	77	-0.004 - 0.004 19.6 fb ⁻¹
	H	ZZ (2 2v)	$-0.003 - 0.003 - 51.19.6 \text{ fb}^{-1}$
-7		77	$-0.016 - 0.015 4.6 \text{ fb}^{-1}$
f ₅		77	$-0.005 - 0.005 + 0.6 \text{ fb}^{-1}$
0		77(2121)	-0.003 - 0.003 - 19.0 fb
		22(212V)	-0.004 - 0.004 5.1, 19.6 lb
f	F=====	22	-0.013 - 0.013 4.6 m
5	H	ZZ	-0.005 - 0.005 19.6 fb"
n		ZZ (2l2v)	-0.004 - 0.003 5.1, 19.6 fb ⁻¹
_0.5	0	0.5	1 15 v10
-0.5	U	0.5	1 1.5 XIU
		ATCC	Limita @050/ CI

Oct 2014			
WWZ	7		ATLAS Limits CMS Prel. Limits D0 Limit LEP Limit
$\Delta \kappa_{-}$	<u> </u>	WW	-0.043 - 0.043 4.6 fb ⁻¹
ANZ	H	WV	-0.090 - 0.105 4.6 fb ⁻¹
	—	WV	-0.043 - 0.033 5.0 fb ⁻¹
	⊢ ●−+	LEP Combination	-0.074 - 0.051 0.7 fb ⁻¹
λ		WW	-0.062 - 0.059 4.6 fb ⁻¹
~Z		ww	-0.048 - 0.048 4.9 fb ⁻¹
	Ш.	WZ	-0.046 - 0.047 4.6 fb ⁻¹
	<u> </u>	VV V	-0.039 - 0.040 4.6 fb ⁻⁺
	H	WV DO Combination	-0.038 - 0.030 5.0 fb ⁻¹
	HOH	LED Combination	
. 7			$-0.059 - 0.017 0.7 \text{ fb}^{-1}$
Δg_{\perp}^{2}			$-0.039 - 0.052 4.0 \text{ fb}^{-1}$
- 1		WZ	$-0.057 - 0.093 4.9 \text{ fb}^{-1}$
		ŴŹ	$-0.055 - 0.071 4.6 \text{ fb}^{-1}$
	<u>⊢o</u> ⊣	D0 Combination	-0.034 - 0.084 8 6 fb ⁻¹
	H•H	LEP Combination	-0.054 - 0.021 0.7 fb ⁻¹
-0.5	0	0.5 1	1.5
		algoli	mits (0)95% C.L.
ZγZ,Z	Ζγγ	-	ATLAS Limits
ΖγΖ,Ζ	Ζγγ	Ζγ	ATLAS Limits CMS Prel. Limits CDF Limit -0.015 - 0.016 4.6 fb ⁻¹
ΖγΖ,Ζ h ₃	ZXX	Ζγ Ζγ	ATLAS Limits CMS Prel. Limits CDF Limit -0.015 - 0.016 4.6 fb ⁻¹ -0.003 - 0.003 5.0 fb ⁻¹
ΖγΖ,Ζ h ₃	ZXX	Ζγ Ζγ Ζγ Ζγ	ATLAS Limits CMS Prel. Limits CDF Limit -0.015 - 0.016 4.6 fb ⁻¹ -0.003 - 0.003 5.0 fb ⁻¹ -0.004 - 0.004 19.5 fb ⁻¹
ΖγΖ,Ζ h ₃	ZXX	Ζγ Ζγ Ζγ Ζγ Ζγ	ATLAS Limits CMS Prel. Limits -0.015 - 0.016 4.6 fb ⁻¹ -0.003 - 0.003 5.0 fb ⁻¹ -0.004 - 0.004 19.5 fb ⁻¹ -0.022 - 0.020 5.1 fb ⁻¹
ΖγΖ,2 h ₃	ZXX	Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ	ATLAS Limits CMS Prel. Limits CDF Limit -0.015 - 0.016 4.6 fb ⁻¹ -0.003 - 0.003 5.0 fb ⁻¹ -0.004 - 0.004 19.5 fb ⁻¹ -0.022 - 0.020 5.1 fb ⁻¹ -0.013 - 0.014 4.6 fb ⁻¹
ΖγΖ,2 h ^γ ₃	ZXX	Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ	ATLAS Limits CMS Prel. Limits CDF Limit -0.015 - 0.016 4.6 fb ⁻¹ -0.003 - 0.003 5.0 fb ⁻¹ -0.004 - 0.004 19.5 fb ⁻¹ -0.022 - 0.020 5.1 fb ⁻¹ -0.013 - 0.014 4.6 fb ⁻¹ -0.003 - 0.003 5.0 fb ⁻¹
ΖγΖ,2 h ^γ ₃		Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ	ATLAS Limits CMS Prel. Limits CDF Limit -0.015 - 0.016 4.6 fb ⁻¹ -0.003 - 0.003 5.0 fb ⁻¹ -0.004 - 0.004 19.5 fb ⁻¹ -0.022 - 0.020 5.1 fb ⁻¹ -0.013 - 0.014 4.6 fb ⁻¹ -0.003 - 0.003 5.0 fb ⁻¹ -0.003 - 0.004 19.5 fb ⁻¹
ΖγΖ,2 h ^γ ₃		Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ	ATLAS Limits CMS Prel. Limits CDF Limit -0.015 - 0.016 4.6 fb ⁻¹ -0.003 - 0.003 5.0 fb ⁻¹ -0.004 - 0.004 19.5 fb ⁻¹ -0.022 - 0.020 5.1 fb ⁻¹ -0.013 - 0.014 4.6 fb ⁻¹ -0.003 - 0.003 5.0 fb ⁻¹ -0.003 - 0.004 19.5 fb ⁻¹ -0.003 - 0.004 19.5 fb ⁻¹
ZγZ,Z h ^γ ₃ h ^Z ₃		Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ	ATLAS Limits CMS Prel. Limits CDF Limit -0.015 - 0.016 4.6 fb ⁻¹ -0.003 - 0.003 5.0 fb ⁻¹ -0.004 - 0.004 19.5 fb ⁻¹ -0.022 - 0.020 5.1 fb ⁻¹ -0.013 - 0.014 4.6 fb ⁻¹ -0.003 - 0.003 5.0 fb ⁻¹ -0.003 - 0.004 19.5 fb ⁻¹ -0.020 - 0.021 5.1 fb ⁻¹
ΖγΖ,2 h ^γ ₃ h ^Z ₃		Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ	ATLAS Limits CMS Prel. Limits CDF Limit -0.015 - 0.016 4.6 fb ⁻¹ -0.003 - 0.003 5.0 fb ⁻¹ -0.004 - 0.004 19.5 fb ⁻¹ -0.022 - 0.020 5.1 fb ⁻¹ -0.013 - 0.014 4.6 fb ⁻¹ -0.003 - 0.003 5.0 fb ⁻¹ -0.003 - 0.004 19.5 fb ⁻¹ -0.020 - 0.021 5.1 fb ⁻¹ -0.009 - 0.009 4.6 fb ⁻¹ -0.009 - 0.009 4.6 fb ⁻¹
ΖγΖ,2 h ^γ ₃ h ^Z ₃		Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ	ATLAS Limits CMS Prel. Limits CDF Limit -0.015 - 0.016 4.6 fb ⁻¹ -0.003 - 0.003 5.0 fb ⁻¹ -0.004 - 0.004 19.5 fb ⁻¹ -0.022 - 0.020 5.1 fb ⁻¹ -0.013 - 0.014 4.6 fb ⁻¹ -0.003 - 0.003 5.0 fb ⁻¹ -0.003 - 0.004 19.5 fb ⁻¹ -0.020 - 0.021 5.1 fb ⁻¹ -0.009 - 0.009 4.6 fb ⁻¹ -0.001 - 0.001 5.0 fb ⁻¹
ΖγΖ,Ζ h ^γ ₃ h ^z ₃ h ^γ ₄ x100		Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζ	ATLAS Limits CMS Prel. Limits CDF Limit -0.015 - 0.016 4.6 fb ⁻¹ -0.003 - 0.003 5.0 fb ⁻¹ -0.004 - 0.004 19.5 fb ⁻¹ -0.022 - 0.020 5.1 fb ⁻¹ -0.013 - 0.014 4.6 fb ⁻¹ -0.003 - 0.003 5.0 fb ⁻¹ -0.003 - 0.004 19.5 fb ⁻¹ -0.020 - 0.021 5.1 fb ⁻¹ -0.009 - 0.009 4.6 fb ⁻¹ -0.001 - 0.001 5.0 fb ⁻¹ -0.004 - 0.004 5.0 fb ⁻¹
h_3^{γ} h_3^{γ} h_4^{γ} x100 h^{z} x100		Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζ	ATLAS Limits CMS Prel. Limits CDF Limit -0.015 - 0.016 4.6 fb ⁻¹ -0.003 - 0.003 5.0 fb ⁻¹ -0.004 - 0.004 19.5 fb ⁻¹ -0.022 - 0.020 5.1 fb ⁻¹ -0.013 - 0.014 4.6 fb ⁻¹ -0.003 - 0.003 5.0 fb ⁻¹ -0.003 - 0.004 19.5 fb ⁻¹ -0.009 - 0.009 4.6 fb ⁻¹ -0.001 - 0.001 5.0 fb ⁻¹ -0.004 - 0.004 5.0 fb ⁻¹ -0.009 - 0.009 4.6 fb ⁻¹
ΖγΖ,2 h ^γ ₃ h ⁷ ₃ h ⁷ ₄ x100		Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζ	ATLAS Limits CMS Prel. Limits CDF Limit -0.015 - 0.016 4.6 fb ⁻¹ -0.003 - 0.003 5.0 fb ⁻¹ -0.004 - 0.004 19.5 fb ⁻¹ -0.022 - 0.020 5.1 fb ⁻¹ -0.013 - 0.014 4.6 fb ⁻¹ -0.003 - 0.003 5.0 fb ⁻¹ -0.003 - 0.004 19.5 fb ⁻¹ -0.009 - 0.009 4.6 fb ⁻¹ -0.001 - 0.001 5.0 fb ⁻¹ -0.009 - 0.009 4.6 fb ⁻¹ -0.001 - 0.001 5.0 fb ⁻¹
ΖγΖ,2 h ^γ ₃ h ⁷ ₃ h ^γ ₄ x100 h ² ₄ x100		Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζ	ATLAS Limits CMS Prel. Limits - -0.015 - 0.016 4.6 fb ⁻¹ -0.003 - 0.003 5.0 fb ⁻¹ -0.004 - 0.004 19.5 fb ⁻¹ -0.013 - 0.014 4.6 fb ⁻¹ -0.022 - 0.020 5.1 fb ⁻¹ -0.003 - 0.003 5.0 fb ⁻¹ - -0.003 - 0.004 19.5 fb ⁻¹ -0.009 - 0.009 4.6 fb ⁻¹ -0.001 - 0.001 5.0 fb ⁻¹ -0.004 - 0.004 5.0 fb ⁻¹ -0.009 - 0.009 4.6 fb ⁻¹ -0.004 - 0.004 5.0 fb ⁻¹ -0.009 - 0.009 4.6 fb ⁻¹ -0.001 - 0.001 5.0 fb ⁻¹ -0.003 - 0.003 19.5 fb ⁻¹
ΖγΖ,2 h ^γ ₃ h ⁷ ₃ h ^γ ₄ x100 h ⁷ ₄ x100		Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζγ Ζ	ATLAS Limits CMS Prel. Limits CDF Limit -0.015 - 0.016 4.6 fb ⁻¹ -0.003 - 0.003 5.0 fb ⁻¹ -0.004 - 0.004 19.5 fb ⁻¹ -0.022 - 0.020 5.1 fb ⁻¹ -0.013 - 0.014 4.6 fb ⁻¹ -0.003 - 0.003 5.0 fb ⁻¹ -0.003 - 0.004 19.5 fb ⁻¹ -0.000 - 0.021 5.1 fb ⁻¹ -0.009 - 0.009 4.6 fb ⁻¹ -0.004 - 0.004 5.0 fb ⁻¹ -0.009 - 0.009 4.6 fb ⁻¹ -0.001 - 0.001 5.0 fb ⁻¹ -0.003 - 0.003 19.5 fb ⁻¹ -0.003 - 0.003 19.5 fb ⁻¹ -0.003 - 0.003 19.5 fb ⁻¹
$rac{2}{8}$ $rac{2}{7}$ $rac{$			ATLAS Limits CMS Prel. Limits CDF Limit -0.015 - 0.016 4.6 fb ⁻¹ -0.003 - 0.003 5.0 fb ⁻¹ -0.004 - 0.004 19.5 fb ⁻¹ -0.022 - 0.020 5.1 fb ⁻¹ -0.013 - 0.014 4.6 fb ⁻¹ -0.003 - 0.003 5.0 fb ⁻¹ -0.003 - 0.004 19.5 fb ⁻¹ -0.009 - 0.009 4.6 fb ⁻¹ -0.001 - 0.001 5.0 fb ⁻¹ -0.009 - 0.009 4.6 fb ⁻¹ -0.009 - 0.009 4.6 fb ⁻¹ -0.001 - 0.001 5.0 fb ⁻¹ -0.003 - 0.003 19.5 fb ⁻¹ -0.004 - 0.004 -

No Deviation from SM

Introduction	Summary of cross section Data (pb)	Theory (pb)
Wγ,Zγ	Di-boson in ATLAS:	
cross section	• W γ , Z γ cross section at 7 TeV (4.6fb ⁻¹ ,NNLO)	
	• $W\gamma \rightarrow I\nu\gamma$ 2.77 ±0.03 (stat) ±0.33(syst) ±0.14 (lumi)	2.456 ±0.006
W7 77	• $Z\gamma \rightarrow II\gamma$ 1.31 ±0.02 (stat) ±0.11(syst) ±0.05 (lumi)	1.305 ±0.003
cross section	• MZ cross section	
	• 7 TeV 4.6fb ⁻¹ 19.0 ^{+1.4} (stat.) ± 0.9 (syst.) ± 0.4 (lumi)	17.6 ^{+1.1}
\\/\//+\//7	• 8 TeV 13.0fb ⁻¹ 20.3 ^{+0.8} (stat.) ^{+1.2} (syst.) ^{+0.7} (lumi)	20.3±0.8
semi-leptonic	• ZZ cross-section	
	 7 TeV 4.6fb⁻¹ 6.7 ±0.7(stat.) ^{+0.4} (syst.) ±0.3(lumi) 	5.89 +0.22 -0.18
	 8 TeV 20.3fb⁻¹ 7.1 +0.5 -0.4(stat.) ±0.3(syst.) ±0.2(lumi) 	7.2 +0.3 -0.2
cross section	$\sim 10/10/7$ comi lontonio	
	• $7 \text{ TeV} = 4.6 \text{ fb}^{-1} = 68. \pm 7 (\text{stat.}) \pm 19(\text{syst.})$	61.1±2.2
VBF/VBS		
See talk N.L. Martinez	WW cross-section	
	• 7 TeV 4.6fb ⁻¹ 51.9 ± 2.0 (stat.) ± 3.9(syst.) ±2.0(lumi) 9 TeV 20 2fb ⁻¹ 71.4 ± 4.2 (stat.) ±50 (syst.) ±22 (lumi)	44.7
	• 8 IEV 20.310 $^{\circ}$ 71.4 \pm 1.2 (stat.) $^{\circ}$ (syst.) $^{\circ}$ (umi)	58.7
alge	• $\sim 2.1 \sigma$ higher than SM	↑
	• aTGC	Including Higgs
Summary	No deviation	

 $W\gamma, Z\gamma$ cross section

WZ, ZZ cross section

WW+WZ semi-leptonic

WW cross section

VBF/VBS See talk N.L. Martinez

aTGC

Summary

Summary

- Run-1 allowed to explore di-boson production processes:
 SM consistent
- Most di-boson measurements are systematically limited.
- Tri-boson and VBS processes are accessible.
- Promising Run-2 analysis!





backup

ction Measurements	Status: March 20	015	∫£ dt [fb ^{−1}]	Reference
= 44.0 + 3.2 - 4.2 pb (data) 2γNNLO (theory)	ΔΤΙΔ	Preliminary	4.9	JHEP 01, 086 (2013)
= 2.77 ± 0.03 ± 0.36 pb (data) NNLO (theory)	AILAO		4.6	PRD 87, 112003 (2013) arXiv:1407.1618 [hep-ph]
= 1.76 ± 0.03 ± 0.22 pb (data) NNLO (theory)	Run 1	$\sqrt{s} = 7, 8 \text{ leV}$	4.6	PRD 87, 112003 (2013)
= 1.31 ± 0.02 ± 0.12 pb (data) NNLO (theory)			4.6	PRD 87, 112003 (2013) arXiv:1407.1618 [hep-ph]
= 1.05 ± 0.02 ± 0.11 pb (data) NNLO (theory)			4.6	PRD 87, 112003 (2013)
= 6.1 + 1.1 - 1.0 ± 1.2 fb (data) MCFM NLO (theory)		A	20.3	arXiv:1503.03243 [hep-ex]
= 2.9 + 0.8 - 0.7 + 1.0 - 0.9 fb (data) MCFM NLO (theory)	A		20.3	arXiv:1503.03243 [hep-ex]
= 1.37 ± 0.14 ± 0.37 pb (data) MC@NLO (theory)			4.6	JHEP 01, 049 (2015)
= 1.3 ± 0.4 ± 0.2 fb (data) PowhegBox (theory)			20.3	PRL 113, 141803 (2014)
= 51.9 ± 2.0 ± 4.4 pb (data) MCFM (theory) = 71.4 ± 1.2 + 5.5 - 4.9 pb (data) MCFM (theory)			4.6 20.3	PRD 87, 112001 (2013) ATLAS-CONF-2014-033
= 56.4 ± 6.8 ± 10.0 fb (data) MCFM (theory)			4.6	PRD 87, 112001 (2013)
= 73.9 ± 5.9 ± 7.5 fb (data) MCFM (theory)			4.6	PRD 87, 112001 (2013)
= 262.3 ± 12.3 ± 23.1 fb (data) MCFM (theory)		Theory Theory	4.6	PRD 87, 112001 (2013)
= 563.0 ± 28.0 + 79.0 - 85.0 fb (data) MCFM (theory)		Observed	4.6	arXiv:1407.0573 [hep-ex]
= 19.0 + 1.4 - 1.3 ± 1.0 pb (data) MCFM (theory) = 20.3 + 0.8 - 0.7 + 1.4 - 1.3 pb (data)		stat stat+syst	4.6 13.0	EPJC 72, 2173 (2012) ATLAS-CONF-2013-021
= 99.2 + 3.8 - 3.0 + 6.0 - 6.2 fb (data) MCFM (theory)			13.0	ATLAS-CONF-2013-021
= 6.7 ± 0.7 + 0.5 − 0.4 pb (data) MCFM (theory) = 7.1 + 0.5 − 0.4 ± 0.4 pb (data) MCFM (theory)			4.6 20.3	JHEP 03, 128 (2013) ATLAS-CONF-2013-020
= 76.0 ± 18.0 ± 4.0 fb/(data) Powheg (theory) = 107.0 ± 9.0 ± 5.0 fb (data) Powheg (theory)		Observed	4.5 20.3	arXiv:1403.5657 [hep-ex] arXiv:1403.5657 [hep-ex]
= 25.4 + 3.3 - 3.0 + 1.6 - 1.4 fb (data) PowhegBox & gg2ZZ (theory) = 20.7 + 1.3 - 1.2 ± 1.0 fb (data) MCEM (theory)	•	▲ stat stat+syst	4.6 20.3	JHEP 03, 128 (2013) ATLAS-CONF-2013-020
= 29.8 + 3.8 - 3.5 + 2.1 - 1.9 fb (data) PowhegBox & gg2ZZ (theory)			4.6	JHEP 03, 128 (2013)
= 12.7 + 3.1 - 2.9 ± 1.8 fb (data) PowhegBox & gg2ZZ (the /)			4.6	JHEP 03, 128 (2013)
.2 0.4 0.6 0.8 1.0 1.2 1	.4 1.6 1.8	2.0 2.2 2.4 2.6		
	obs	erved/theorv		
	ction Measurements 44.0 + 3.2 - 4.2 pb (data) 2/NNLO (theory) 2.77 + 0.03 ± 0.36 pb (data) NNLO (theory) 1.76 ± 0.03 ± 0.22 pb (data) NNLO (theory) 1.31 ± 0.02 ± 0.12 pb (data) NNLO (theory) 1.31 ± 0.02 ± 0.11 pb (data) NNLO (theory) 1.37 ± 0.14 ± 0.37 pb (data) MCFM NLO (theory) 1.37 ± 0.14 ± 0.37 pb (data) MCFM NLO (theory) 1.37 ± 0.14 ± 0.37 pb (data) MCFM (theory) 51.9 ± 2.0 ± 4.4 pb (data) MCFM (theory) 73.9 ± 5.9 ± 7.5 tb (data) MCFM (theory) 262.3 ± 12.3 ± 23.1 tb (data) MCFM (theory) 262.3 ± 12.3 ± 23.1 tb (data) MCFM (theory) 99.2 ± 3.8 - 0.7 + 1.4 - 1.3 pb (data) MCFM (theory) 99.2 ± 3.3 - 3.0 + 0.0 - 6.2 tb (data) MCFM (theory) 99.2 ± 3.3 - 3.0 + 0.0 tb (data) MCFM (theory) 20.3 + 0.8 + 0.0 4 pb (data) MCFM (theory) 20.4 + 0.4 pb (data) MCFM (theory) 20.3 + 0.8 + 0.0 4 bb (data) MCFM (theory) 20.4 + 0.1 4 bb (data) MCFM (theory) 20.4 + 0.4 0 bb (data) MCFM (theory) 20.4 + 0.4 0 bb (data) MCFM (theory) 20.4 + 0.4 0 bb (data) PowhegBox & gg2ZZ	ction Measurements Status: March 2 440 + 32 + 42 bb (data) ATLAS 2.77 + 0.03 + 0.22 pb (data) Run 1 1.31 + 0.02 - 0.12 pb (data) Run 1 1.31 + 0.02 - 0.12 pb (data) ATLAS NNLO (theory) ATLAS 1.31 + 0.02 - 0.12 pb (data) ATLAS NNLO (theory) ATLAS 1.31 + 0.02 - 0.12 pb (data) ATLAS NNLO (theory) ATLAS 1.37 + 0.14 + 0.37 pb (data) ATLAS MCFM NLO (theory) ATLAS 1.37 + 0.14 + 0.37 pb (data) ATLAS MCFM (theory) ATLAS MCFM (theory)	Cition Measurements Status: March 2015 44.0 ± 3.4.0.2 (Buog) ATLAS Preliminary 27.7 ± 0.3 ± 0.35 ± 0.45 ± 0.44m) Run 1 √5 = 7, 8 TeV 1.31 ± 0.02 ± 0.12 ± 0.44m) Run 1 √5 = 7, 8 TeV 1.31 ± 0.02 ± 0.12 ± 0.44m) Run 1 √5 = 7 TeV Motor (Meory) Run 1 √5 = 7 TeV 1.31 ± 0.02 ± 0.12 ± 0.44m) Run 1 √5 = 7 TeV Motor (Meory) Run 1 √5 = 8 TeV Motor (Meory) Run 1 Ø = 20 + 41 + 51 + 51 + 51 + 51 + 51 + 51 + 51	Cition Measurements Status: March 2015 $\begin{bmatrix} f_c dt \\ [tb^-1] \end{bmatrix}$ 44.0 - 3.3 (4.2 pb (dm)) ATLAS Preliminary 2.77 + 0.03 + 0.25 pb (dm) ATLAS Preliminary 1.76 + 0.03 + 0.25 pb (dm) ATLAS Preliminary 1.76 + 0.03 + 0.25 pb (dm) 4.6 1.76 + 0.03 + 0.25 pb (dm) 4.6 1.76 + 0.03 + 0.25 pb (dm) 4.6 1.76 + 0.02 + 0.12 bb (dm) 4.6 1.77 + 0.02 + 0.02 bb (dm) 4.6 1.76 + 0.02 + 0.01 bb (dm) 4.6 1.77 + 0.02 + 0.02 bb (dm) 4.6 1.76 + 0.02 + 0.01 bb (dm) 4.6 1.77 + 0.02 + 0.01 bb (dm) 4

22/07/2015

Signature

- Leptons/photons
 - High-pT
 - Isolated
- Z Bosons
 - Invariant mass in windows around the Z pole
- W Bosons
 - Large Missing ET to account for the neutrino
 - Transverse mass selection

Background

Estimated with data driven methods

- V+jets
 - Genuine high-pt leptons from boson decay
 - Leptons from heavy flavour decaysJets misidentified as leptons/photons
 - Particles outside the detector acceptance => Missing ET
- tt(bar) and single top
 - Prompt isolated leptons from W leptons
 - Large Missing ET





Wγ,Ζγ cross section

WZ.ZZ cross section

• $Z\gamma \rightarrow I\nu\nu$

WW/W7 semi-leptonic

WW cross section

VBF/VBS See talk N.L. Martinez

aTGC

Summary

$W\gamma \& Z\gamma$ cross sections at 7 TeV

• W γ , Z γ cross section at 7 TeV (4.6fb⁻¹)

• $W\gamma \rightarrow I\nu\gamma$ 2.77 ±0.03 (stat)

• $Z\gamma \rightarrow II\gamma$ 1.31 ±0.02 (stat)

Mar / Zer Jan Har sum				
$VV\gamma / Z\gamma \rightarrow IV\gamma, II\gamma, VV\gamma$	Cuts	$pp ightarrow \ell u \gamma$	$pp ightarrow \ell^+ \ell^- \gamma$	$pp \rightarrow \nu \bar{\nu} \gamma$
 Electrons: 20-22 GeV 	Lepton	$p_{\rm T}^{\ell} > 25 \; {\rm GeV}$	$p_{\rm T}^{\ell} > 25 \; {\rm GeV}$	_
Muons: 18 GeV		$ \eta_{\ell} < 2.47$	$ \eta_{\ell} < 2.47$	—
 Photons: 80 GeV Id0 I/σd0 < 10(3) e(u) 		$N_{\ell} = 1$	$N_{\ell^+} = 1, N_{\ell^-} = 1$	$N_{\ell} = 0$
• z0 < 1mm		$p_{\rm T}^{\nu} > 35~{\rm GeV}$	_	_
 Calorimeter isolation in cone AR < 0.3 less than 6 GeV (e) 	Boson		$m_{\ell^+\ell^-} > 40 \text{ GeV}$	$p_{\mathrm{T}}^{\nu\bar{\nu}} > 90 \text{GeV}$
• pT isolation in cone $\Delta R < 0.3$	Photon	$E_{\rm T}^{\gamma} > 15 { m ~GeV}$	$E_{\mathrm{T}}^{\gamma} > 15 \text{ GeV}$	$E_{\rm T}^{\gamma} > 100 { m ~GeV}$
less than 15% of the μ pT		$ \eta^{\gamma} $	$ < 2.37, \Delta R(\ell, \gamma)$	> 0.7
• W Y modelled with ALPGEN (CTEQ6L1)			$\epsilon_h^p < 0.5$	
 Ż γ, vvγ modelled with Sherpa 	Jet	$E_{ m T}^{ m je}$	t > 30 GeV, $ \eta^{\text{jet}} $.	< 4.4
(CTEQ6.6W)		1	$\Delta R(e/\mu/\gamma, \text{jet}) > 0$).3
		Inclusive :	$N_{\rm jet} \ge 0$, Exclusiv	$re: N_{ m jet} = 0$
	-			
NLO				

 $0.133 \pm 0.01 (stat) \pm 0.02 (syst)$

 $\pm 0.33(syst)$

±0.11(syst)

±0.14 (lumi)

±0.05 (lumi)

±0.05 (lumi)

1.96 ±0.17 1.18 ±0.05 0.156 ±0.012 21/15

Introduction	Wγ & Zγ cros	s sections at pb (data)	7 TeV		pb (theory)
Wγ,Ζγ cross section	Di-boson in AT • Wγ , Zγ cross	LAS: section at 7 TeV (4	↓.6fb⁻¹)		
WZ, ZZ cross section	• $W\gamma \rightarrow I\nu\gamma$ • $Z\gamma \rightarrow II\gamma$ • $Z\gamma \rightarrow I\nu\nu$	2.77 ±0.03 (stat) 1.31 ±0.02 (stat) 0.133 ±0.01 (stat)	±0.33(syst) ±0.11(syst) ±0.02(syst)	±0.14 (lumi) ±0.05 (lumi) ±0.05 (lumi)	1.96 ±0.17 1.18 ±0.05 0.156 ±0.012
WW/WZ semi-leptonic					
WW cross section					
VBF/VBS See talk N.L. Martinez					
aTGC					

Summary

 $W\gamma, Z\gamma$ cross section

WZ, ZZ cross section

WW+WZ semi-leptonic

WW cross section

VBF/VBS See talk N.L. Martinez

aTGC

WZ & ZZ cross sections at 7 and 8 TeV

Backgrounds to $ZZ \rightarrow II_{VV}$:

- WZ→IvII: MC based, validated using trilepton control region
- WW/top/Z $\tau\tau$: real E_T^{miss} , data driven, flavor symmetry
- Z+jets: fake E_T^{miss} , estimated with γ +jets events
- W+jets/QCD: fake lepton, matrix method and fake-factor method
- Others: ZZ→4I



$W\gamma, Z\gamma$ cross section

WZ, ZZ cross section

WW+WZ semi-leptonic

WW cross section

VBF/VBS See talk N.L. Martinez

aTGC

WZ & ZZ cross sections at 7 and 8 TeV

Electrons

Muons

Requirement	$\ell^+\ell^-\nu\bar{\nu}$ final state	Requirement	$\ell^+\ell^-\nu\bar{\nu}$ final state
Central Electron Selection		Standard Muons	
1. e: Type	author==1 or 3	1. μ : type	Combined, "loose" STACO muons,
2. e: Quality	(OQ AND 1446 == 0)	2. μ : $p_{\rm T}$ and η	$p_{\rm T} > 25 { m GeV}, \eta < 2.5$
3. e: ID cut	Medium++	3. μ : ID hits	MCP recommendations
4. e: η	$ \eta < 2.47$	4. μ : $z_0 * sin(\theta)$	$ z_0 * sin(\theta) < 0.5 \text{ mm}$
5. $e: E_T$	$E_T > 25 \text{ GeV}$	5. μ : d_0	$ d_0 /\sigma(d_0) < 3.0$
6. e: $z_0 * sin(\theta)$	$ z_0 * sin(\theta) < 0.5 \text{ mm}$	6. μ : track iso	$\Sigma p_{\rm T}(\Delta R < 0.2)/p_{\rm T} < 15\%$
7. $e: d_0$	$ d_0 /\sigma(d_0) < 6$	7. μ : calo iso	$\Sigma E_T (\Delta R < 0.2) / E_T < 15\%$
8. e: Track isolation	$\Sigma p_{\rm T} (\Delta R < 0.2) / p_{\rm T} < 15\%$		
9. e: Calo isolation	$\Sigma E_T (\Delta R < 0.2) / E_T < 15\%$		
10. e: Overlap removal	a) Remove <i>e</i> if $\Delta R < 0.1$ from μ		
	b) Remove lowest $E_T e$ in		
	$\Delta R < 0.1$ from another e		

Jets

Requirement	$\ell^+ \ell^- \nu \bar{\nu}$ final state
AntiKT4LCTopo Jets	
1. jet: $p_{\rm T}$ and η	$p_{\rm T} > 25 { m GeV}, \eta < 4.5$
2. jet: Bad Jets	Remove events with "LooserBad" jets
3. jet: JVF	$ JVF > 0.5 \text{ or } \eta > 2.4 \text{ or } p_T > 50 \text{ GeV}$
4. jet: Overlap removal	Remove jets if overlapped with selected leptons, $\Delta R < 0.3$

MET: RefFinal

Summary

 $W\gamma, Z\gamma$ cross section

WZ, ZZ cross section

WW+WZ semi-leptonic

WW cross section

VBF/VBS See talk N.L. Martinez

aTGC

Summary

WZ & ZZ cross sections at 7 and 8 TeV

Total phase-space: 66 < m_{z1}, m_{z2} < 116 GeV

Fiducial phase-space:

- 2 pairs of opposite sign same flavor leptons
- $\circ p_T^\ell$ > 7 GeV
- \circ 66 < m_Z < 116 GeV
- $\Delta R(\ell, \ell) > 0.2$ (all leptons)
- $4\mu: |\eta_{\mu}| < 2.7$
- ο 2e2μ:
 - $\begin{array}{l} \circ \ |\eta_{\mu}| < 2.7 \\ \circ \ |\eta_{e}| < 2.5 \ (\text{both } e) \ , \text{OR} \\ |\eta_{e_{1}}| < 2.5 \ \text{and} \ |\eta_{e_{2}}| < 4.9 \end{array}$

• 4e:

 \circ $|\eta_e|$ < 2.5 (all *e*), OR $|\eta_e|$ < 2.5 (3*e*) and $|\eta_{e_4}|$ < 4.9

- 2 same-flavor opposite sign leptons
- \circ 76 GeV < m_Z < 106 GeV
- $\circ p_T^{\ell}$ > 25 GeV
- Axial- $E_{\rm T}^{\rm miss}$ > 90 GeV

$$\sum \frac{|p_{\mathrm{T}}^{\nu\overline{\nu}} - p_{\mathrm{T}}^{Z}|}{p_{\mathrm{T}}^{Z}} < 0.4$$

$$\circ |\eta^{\ell}| < 2.5$$

• No jets with $p_{\rm T}$ > 25 GeV and $|\eta| < 4.5$ (remove jets with electrons $\Delta R = 0.3$)

MetAs

Met

 $\circ \quad \Delta R(\ell,\ell) > 0.3$

 $W\gamma, Z\gamma$ cross section

WZ, ZZ cross section

WW/WZ semi-leptonic

WW cross section

VBF/VBS See talk N.L. Martinez

aTGC

Summary

WW & WZ in semi-leptonic mode at 7 TeV

WW/WZ→Ivjj

- Exactly one high-pT isolated lepton pT>25 GeV
- $|d0 / \sigma(d0)| < 3$ (10) for muons (electrons)
- |z0| <1 mm
- ETmiss > 30 GeV, mT,W > 40 GeV
- Exactly two jets with pT > 25 GeV and $|\eta| < 2.8$ (pT > 30 GeV for the leading jet)
- Azimuthal angular separation between the leading jet pT and the Etmiss vectors must fulfil |Δφ(ETmiss,j1)| > 0.8
- $|\Delta \eta(j1,j2)| < 1.5$, $\Delta R(j1,j2) > 0.7$ if pT of the dijet system is less than 250 GeV
- 25 < mjj < 250 GeV



 $W\gamma, Z\gamma$ cross section

WZ, ZZ cross section

WW/WZ semi-leptonic

WW cross section

VBF/VBS See talk N.L. Martinez

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Summary

WW production at 8 TeV

WW→lvlv (in 0-jet bin)

- Lowest order:W±W± + 2jets, there is no SM inclusive W±W±
- for EW+strong measurement ("inclusive signal phase space")
 - exactly 2 high pT same-sign leptons with pT > 25 GeV in $|\eta|$ < 2.5
 - mll>20 GeV, ΔRll>0.3
 - \geq 2 jets with pT>30 GeV, $|\eta|$ < 4.5
 - ETmiss > 40 GeV (from W decays)
 - veto events containing b-jets
 - Z-veto in ee channel: mee mZ | > 10 GeV
 - mjj >500GeV
- for EW-only measurement ("VBS signal phase space")
 - additional cut on $|\Delta Yjj| > 2.4$



NNLO corrections: up to 10% (arXiv:1408.5243)

Summary

• re summation at large logs: partially explain excess (arXiv:1407.4537,1407.4481,1507.02565v1)

28/15

WW production at 7 & 8 TeV



CMS $60.1 \pm 0.9 \text{ (stat.)} \pm 3.2 \text{ (exp.)} \pm 3.1 \text{ (th.)} \pm 1.6 \text{ (lum.) pb.}$

ATLAS and CMS in agreement.

ATLAS 71.4^{+1.2}_{-1.2} (stat) $^{+5.0}_{-4.4}$ (syst) $^{+2.2}_{-2.1}$ (lumi) pb

<u>Theoretical predictions cited:</u> 59.8 ± 1.2 pb (CMS) NNLO "qqbar+qq" (no H)

58.7 ± 2.9 pb (ATLAS) NLO qqbar + LO gg + NNLO H

VBS Phys. Rev. Lett. 113, 141803

30

25

20

Vector Boson Scattering topology: unitary issue Pair of same charge W with 2 jets Quartic Gauge Vertex contribution W in leptonic mode: $W \rightarrow I_V$ (I=e,µ)





1507.02565v1

Transverse-momentum resummation for vector-boson pair production at NNLL+NNLO Massimiliano Grazzini, Stefan Kallweit, Dirk Rathlev, Marius Wiesemann

