

Diboson production at ATLAS and CMS

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on behalf of the ATLAS and CMS collaborations



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focus on well-known and recent results of fully leptonic decays of dibosons:

- cross section measurements
- interpretation as anomalous triple/quartic gauge couplings

\sqrt{s}	experiment	ZZ	$W^{\pm}W^{\mp}$	$W^{\pm}Z$	$(Z/W^{\pm})\gamma$	$\gamma\gamma \to W^\pm W^\mp$
	ATLAS	JHEP 03 (2013) 128	PRD 87, 112001 (2013)	EPJC 72 (2012) 2173	PLB 717 (2012) 49	
$7 { m TeV}$	CMS	JHEP 01 (2013) 063	EPIC 73 (2013) 2610		JHEP 10 (2013) 164	JHEP 07 (2013) 116
	Child				PRD 89 (2014) 092005	
	ATLAS	ATLAS-CONF-2013-020	arXiv:1603.01702	PRD 93, 092004 (2016)	arXiv:1604.05232	preliminary plots
		PLB 721 (2013) 190			CMS-PAS-SMP-14-018	
$8 { m TeV}$	CMS	120 /21 (2013) 190	orViv:1507.02268		JHEP 04 (2015) 164	
	CIND	PL P 740 (2015) 250	arxiv:1507.05200		CMS-PAS-SMP-14-011	
		FLB /40 (2013) 250			arXiv:1602.07152	
$7/8 { m TeV}$	CMS	EPJC 75 (2015) 511		CMS-PAS-SMP-12-006		arXiv:1604.04464
13 TeV	ATLAS	PRL 116, 101801 (2016)		preliminary plots		
10 164	CMS	CMS-PAS-SMP-16-001		CMS-PAS-SMP-16-002		

results of semi-leptonic decays and like-sign WW production are not presented

\sqrt{s}	experiment	WW/WZ	WZ/ZZ	$W^{\pm}W^{\pm}$
7 TeV	ATLAS	JHEP 01 (2015) 049		
. 101	CMS	EPJC 73 (2013) 2283		
8 TeV	ATLAS			PRL 113, 141803 (2014)
0 100	CMS		EPJC 74 (2014) 2973	PRL 114, 051801 (2015)



- measurement of total and differential cross sections to ...
 - ... probe validity of Standard Model at TeV scale
 - ... compare with modeling of higher order QCD and EW effects
 - ... understand irreducible diboson background in Higgs analyses



- exploration of self-coupling structure of gauge bosons will ...
 - improve our understanding of electroweak symmetry breaking and unitarity
 intersect with determination of Higgs
 - couplings
 - ... indicate new physics if anomalous triple/quartic couplings are present

effective Lagrangian:

$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm SM} + \sum_{\rm dimension d} \sum_{i} \frac{c_i^{(d)}}{\Lambda^{d-4}} \mathcal{O}_i^{(d)}$$

Cross Section Measurements With Fully Leptonic Final States ZZ production at 7, 8 and 13 TeV

- production mechanisms:
 - ▶ $q\bar{q}$ annihilation via *t*-channel
 - ▶ with gg initial state and box diagram or s-channel Higgs (contributing together O(4 - 10)% depending on the center-of-mass energy)
- two pairs of oppositely charged, pairwise same flavor leptons (τ only for CMS at 7/8 TeV)
 - minimal background of < 1% to 5%
 - small experimental uncertainties
 - slightly different fiducial selections between experiments (mass window, pairing, ...)
- total measured cross sections at 13 TeV

 $\sigma(p\,p\,\rightarrow\,Z\,Z)\,[{\rm fb}]$

ATLAS

$$16.7^{+2.2}_{-2.0}(\text{stat})^{+0.9}_{-0.7}(\text{syst})^{+1.0}_{-0.7}(\text{lumi})$$

 CMS
 $14.6^{+1.9}_{-1.8}(\text{stat})^{+0.5}_{-0.3}(\text{syst}) \pm 0.2(\text{theo}) \pm 0.4(\text{lumi})$





Cross Section Measurements With Fully Leptonic Final States ZZ production at 7, 8 and 13 TeV

- $e^+e^-/\mu^+\mu^-$ plus missing transverse energy
 - elaborated fiducial phase space definitions
 - jet veto in common for both experiments
 - ▶ more than O(50%) background dominated by WZ and Z+jets
 - increased experimental uncertainties
- measurements still agree within uncertainties with SM predictions at NLO QCD accuracy:
 - ► recent calculations at NNLO QCD show cross section enhancement of $q\bar{q}$ initial state
 - production via gg is predicted to increase
 \$\mathcal{O}(70\%)\$ at higher orders in QCD
 - ▶ higher order electroweak effects decrease production via qq̄ initial state by O(8%)
 - predictions for other diboson pairs suggest similar effects





Cross Section Measurements With Fully Leptonic Final States W^+W^- production at 7 and 8 TeV

- production mechanisms:
 - ▶ $q\bar{q}$ annihilation via *t*-channel or *s*-channel
 - ▶ with gg initial state and box diagram [O(5%)] (or s-channel Higgs [O(3%)])
- event selection and backgrounds:
 - ▶ pair of isolated leptons: e^+e^- , $\mu^+\mu^-$, $\mu^\pm e^\mp$
 - missing transverse energy
 - ► m(ℓ⁺ℓ⁻)/p_T(ℓ⁺ℓ⁻) cut to reduce Drell-Yan and Z+jets (remaining 1 - 7%)
 - ▶ jet-veto to reduce $t\bar{t}$ (remaining 11 18%)
 - ▶ requirements on combined quantities (remaining W+jets 1 − 6%, other diboson 2 − 5%)
- supplementary for CMS analysis
 - ▶ 1-jet fiducial volume enters the analysis
 - Higgs portion is not considered as signal





Cross Section Measurements With Fully Leptonic Final States *WZ production at* 7, 8 *and* 13 TeV

- production mechanisms:
 - ▶ $q\bar{q}$ annihilation via *t*-channel or *s*-channel
 - EW or QCD production of WZ + 2jets
 - no gg initial state at NNLO QCD
- various fiducial volumes:
 - ► three leptons ℓ^{(')±}ℓ⁺ℓ⁻ with ℓ = e,µ assigned to gauge bosons by basic algorithm up to "resonant shape" approach
 - multiple jet requirements particularly for measurements at 8 TeV
 - *b*-jet veto (to suppress $t\bar{t}$ background)
 - di-jet orientation/separation to optimize for VBS production or aQGC sensitivity
- dominant backgrounds are ZZ (prompt leptons) as well as V+jets and $t\bar{t}$ (lepton misidentification)







Cross Section Measurements With Fully Leptonic Final States *WZ production at* 7, 8 *and* 13 TeV

- unfolded differential cross sections sensitive to W polarization or WZ helicity amplitude as well as further differential distributions are available for 8 TeV center-of-mass energy
- measurement of WZ + 2jet production:
 - CMS in fiducial volume inspired by "W[±]W[±]+2jet" analysis: σ^{fid}_{WZjj} = 10.8 ± 4.0(stat) ± 1.3(syst) fb expected: 14.4 ± 4.0 fb
 - ATLAS translates observed events in VBS fiducial phase space in cross section for electroweak production:

$$\begin{split} \sigma^{\rm fid}_{WZjj-\rm EW \to \ell' \nu \ell \ell} &= 0.29^{+0.14}_{-0.12} (\rm stat)^{+0.09}_{-0.1} (\rm syst) \ \rm fb \\ & \text{expected: } 0.13 \pm 0.01 \ \rm fb \end{split}$$



Cross Section Measurements With Fully Leptonic Final States $(Z/W^{\pm})\gamma$ production at 7 and 8 TeV

- production mechanisms:
 - \blacktriangleright V plus initial/final state photon radiation
 - ▶ V plus final state quark fragmentation
 - electroweak production via VBS
- multiple fiducial volumes:
 - visible (invisible) $Z \to e^+ e^- / \mu^+ \mu^- (\to \nu \nu)$ or
 - ► W decay to e/µ and missing transverse energy
 - isolated photon
 - ATLAS: exclusive $(N_{jets} = 0)$ and inclusive
 - CMS: various VBS di-jet selections
- measured $\sigma_{\rm fiducial}(pp \to \nu \nu \gamma)$ in fb

$$\begin{aligned} & {}_{\rm exclusive}^{\rm ATLAS} = 43 \pm 2({\rm stat}) \pm 10({\rm syst}) \pm 1({\rm lumi}) & [49.21^{+0.61}_{-0.52}] \\ & \sigma^{\rm CMS} = 52.7 \pm 2.1({\rm stat}) \pm 6.4({\rm syst}) \pm 1.4({\rm lumi}) & [50.6^{+2.4}_{-2.2}] \end{aligned}$$

• electroweak $W\gamma$ production with significance of 2.67 (expected 1.52) measured by CMS:

 $\sigma^{\rm CMS}_{\rm fiducial\,EWK} = 10.8 \pm 4.1 ({\rm stat}) \pm 3.4 ({\rm syst}) \pm 0.3 ({\rm lumi})\,{\rm fb}$

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- measurement of total and differential cross sections to ...
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- exploration of self-coupling structure of gauge bosons will ...
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effective Lagrangian:

$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm SM} + \sum_{\rm dimension \, d} \sum_{i} \frac{c_i^{(d)}}{\Lambda^{d-4}} \mathcal{O}_i^{(d)}$$

- neutral trilinear couplings f_4^V (*CP*-violating) and f_5^V (*CP*-conserving) with V = Z, γ are forbidden on tree-level in the Standard Model
- CMS interprets measured p_T^{ℓ+ℓ[−]} distributions for ZZ → 2ℓ2ν and p_T^{4ℓ} for ZZ → 4ℓ:
 - combined results of 7 and 8 TeV data
 - SM prediction includes higher order EW effects
 - no form factor scaling of couplings applied
 - 1-/2-dim. 95% confidence intervals available

	$f_4^Z [imes 10^{-3}]$	$f_4^{\gamma} [imes 10^{-3}]$	$f_5^Z [imes 10^{-3}]$	$f_5^{\gamma} [imes 10^{-3}]$
combined	[-2.2, 2.6]	[-2.9, 2.6]	[-2.3, 2.3]	[-2.6, 2.7]
expected	[-3.6, 3.9]	[-4.6, 4.1]	[-3.6, 3.7]	[-4.3, 4.3]

• CMS results by factor $\mathcal{O}(4-9)$ tighter than ATLAS interpretation of differential $p_T^{\text{leading }\ell^+\ell^-}$ measurement at 7 TeV or CMS limits at 7 TeV



Anomalous Triple Gauge Couplings Studies Of $(Z/\gamma)\gamma Z$ Coupling Using $pp \to Z\gamma$

- limits expressed in terms of *CP*-conserving parameters $h_{(3/4)}^V$ with $V = Z, \gamma$ since *CP*violating couplings do not interfere and have similar sensitivity to aTGCs
- both experiments interpret high energy tail of differential E^γ_T measurement in terms of anomalous couplings
 - ATLAS: exclusive $(N_{jets} = 0)$ fiducial selection
 - CMS: central photon with $|\eta^{\gamma}| < 1.44$
- limits are available as 1-/2-dim. 95% confidence intervals and as function of form factor Λ_{FF}





- CMS (ATLAS) interprets differential $m(\ell^+\ell^-)$ $(p_T(\text{leading }\ell))$ results at 8 TeV in context of
 - ► coefficients C_{WWW}/Λ^2 , C_W/Λ^2 , C_B/Λ^2 of C-/Pconserving effective dimension-6 operators
 - different (constrained) scenarios of coupling (deviations) Δg_1^Z , Δk^Z , Δk^γ , λ^γ and λ^Z with form factor Λ (ATLAS)
- 95% confidence intervals on couplings are given 2-dimensional and 1-dimensional:

	$\frac{\mathcal{C}_{WWW}}{\Lambda^2}$ [TeV ⁻²]	$rac{\mathcal{C}_W}{\Lambda^2}$ [TeV ⁻²]	$\frac{\mathcal{C}_B}{\Lambda^2}$ [TeV ⁻²]
CMS	[-5.7, 5.9]	[-11.4, 5.4]	[-29.2, 23.9]
ATLAS	[-4.61, 4.60]	[-5.87, 10.54]	[-20.9, 26.3]
world	5.5 ± 4.8	$-3.9^{+3.9}$	$-1.7^{+13.6}$
average		-4.8	

• results are more stringent than for 7 TeV and competitive with LEP findings



- complementary probe of triple and quartic couplings via WZ because access to other phase space regions
- ATLAS uses m_T^{WZ} to place limits on ETF coefficients for aTGCs and provides 1-/2-dim. 95% confidence intervals

	$\frac{\mathcal{C}_{WWW}}{\Lambda^2}$ [TeV ⁻²]	$\frac{\mathcal{C}_W}{\Lambda^2}$ [TeV ⁻²]	$\frac{\mathcal{C}_B}{\Lambda^2}$ [TeV ⁻²]
observed	[-3.9, 4.0]	[-4.3, 6.8]	[-320, 210]
expected	[-3.9, 3.8]	[-3.6, 7.6]	[-270, 180]

• further optimized selection of VBS fiducial volume of ATLAS WZ analysis is used to investigate coefficients $\alpha_{4/5}$ of linear independent dimension-4 operators of effective ZWZW coupling





Anomalous Quartic Gauge Couplings Studies Using $pp \to (W)V\gamma$, $W^{\pm}W^{\pm}$, $\gamma\gamma \to WW$



- interpretation of high transverse momentum tail p^W_T in Wγ analysis as dimension-8 couplings
- differential $p_T^{e\mu}$ obtained in exclusive $\gamma\gamma \rightarrow W(\rightarrow e^{\pm}\nu)W(\rightarrow \mu^{\mp}\nu)$ analysis used to constrain couplings $\alpha_{(0,C)}^W/\Lambda^2$



bril 2016	CMS				
	ATLAS	Channel	Limits	∫Ldt	ſs
$f_{T,0}/\Lambda^4$		Wyy	[-3.8e+01, 3.8e+01]	19.4 fb ⁻¹	8 TeV
		Ziri	[-1.6e+01, 1.9e+01]	20.3 fb ⁻¹	8 TeV
		Wyy	[-1.6e+01, 1.6e+01]	20.3 fb ⁻¹	8 TeV
	J	WVy	[-2.5e+01, 2.4e+01]	10.3 fb ⁻¹	8 TeV
	. H	Zγ	[-3.8e+00, 3.4e+00]	19.7 fb ⁻¹	8 TeV
		Wy	[-5.4e+00.5.6e+00]	10.7 fb ⁻¹	8 TeV
	1-1	ee 10/10/	[-4 2e+00 4 6e+00]	10.4 0-1	8 TeV
5- /A ⁴		Wry	[-4.6e+01_4.7e+01]	10.4 fb ⁻¹	8 TeV
• •	i	7.4	[-4.4e+00.4.4e+00]	10.7 8-1	8 TeV
		Wy	[-3.7e+00_4.0e+00]	10.7 (b)1	8 TeV
		00 1000	[2.10100, 3.40100]	10.7 10	O TOV
r (4 ⁴		7.	[+2.10+00, 2.40+00] [-9.90+00.9.00+00]	19.4 ID 10.7 Ib ⁻¹	0 TeV
T,2 /A		2-1 Mar	[-5.50+00, 5.00+00]	19.7 10	8 TeV
		***	[-1.10+01, 1.20+01]	19.7 10	o Tev
	1	SS VVVV	[-5.9e+00, 7.1e+00]	19.4 lb	orev
r _{7,6} /Λ ⁻		277	[-9.38+00, 9.18+00]	20.3 fb ⁻¹	8 TeV
	H	ννγ	[-3.0e+00, 3.8e+00]	19.7 fb ⁻¹	8 IeV
T _A /A	H .	ννγ	[-2.08+00, 3.08+00]	19.7 fb"	o ieV
f _{1,2} /Λ ⁴		Wγ	[-7.3e+00, 7.7e+00]	19.7 fb ⁻¹	8 TeV
$t_{T,R}/\Lambda^n$	н	2γ	[-1.8e+00, 1.8e+00]	19.7 fb	8 TeV
$t_{T,9}/\Lambda^n$		Zγγ	[-7.4e+00, 7.4e+00]	20.3 fb ⁻¹	8 TeV
	H	Zγ	[-4.0e+00, 4.0e+00]	19.7 fb ⁻¹	8 TeV
1					
-50	0 50	aQO	100 GC Limits @95	150 % C.L.	[TeV
-50 pril 2016		aQC	100 GC Limits @95	150 % C.L.	(TeV
		aQC	100 GC Limits @95	150 % C.L. <u>j_{Ldt}</u> 19.3 fb ⁻¹	[TeV Is 8 TeV
-50		aQ0	100 GC Limits @95 Limits [-7.7e+01, 8.1e+01] [-7.1e+01, 7.5e+01]	150 % C.L. <u>J_{Ldt}</u> 19.3 fb ⁻¹ 19.7 fb ⁻¹	[TeV IS 8 TeV 8 TeV
-50 pril 2016		aQ0 Channel WVy Zy Wy	100 GC Limits @95 Limits [-7.7e+01, 8.1e+01] [-7.7e+01, 7.5e+01] [-7.7e+01, 7.4e+01]	150 % C.L. <u>J_{Ldt}</u> 19.3 fb ⁻¹ 19.7 fb ⁻¹ 19.7 fb ⁻¹	[TeV IS 8 TeV 8 TeV 8 TeV 8 TeV
-50		aQ0 Channel WVγ Zγ Wγ ss WW	100 GC Limits @95 [-7.7e+01, 8.1e+01] [-7.7e+01, 7.5e+01] [-7.7e+01, 7.4e+01] [-3.3e+01, 3.2e+01]	150 % C.L. 19.3 fb ⁻¹ 19.7 fb ⁻¹ 19.7 fb ⁻¹ 19.4 fb ⁻¹	TeV 15 8 TeV 8 TeV 8 TeV 8 TeV 8 TeV 8 TeV
-50 pril 2016		aQC Channel WVγ Zγ Wγ ss WW γγ→WW	100 GC Limits @95 [7.7e+01, 8.1e+01] [7.7e+01, 7.5e+01] [7.7e+01, 7.4e+01] [-3.2e+01, 3.2e+01] [-4.2e+00, 4.2e+00]	150 % C.L. 19.3 fb ⁻¹ 19.7 fb ⁻¹ 19.7 fb ⁻¹ 19.4 fb ⁻¹ 24.7 fb ⁻¹	[TeV 8 TeV 8 TeV 8 TeV 8 TeV 7,8 TeV 7,8 TeV
-50 pril 2016		aQ0 WVγ Zγ WY ss WW YY→WW WVY T	100 GC Limits @95 [7.7e+01, 8.1e+01] [7.7e+01, 7.5e+01] [7.7e+01, 7.4e+01] [3.3e+01, 3.2e+01] [4.2e+00, 4.2e+00] [-1.3e+02, 1.2e+02]	150 % C.L. 19.3 fb ⁻¹ 19.7 fb ⁻¹ 19.7 fb ⁻¹ 19.4 fb ⁻¹ 24.7 fb ⁻¹ 19.3 fb ⁻¹	[TeV 8 TeV 8 TeV 8 TeV 8 TeV 7,8 TeV 8 TeV 7,8 TeV 8 TeV
		aQ0 WVγ Zγ Wγ ss WW γγ→WW WVγ Zγ WVγ Zγ Wv	100 GC Limits @95 [-7.7e+01, 8.1e+01] [-7.1e+01, 7.5e+01] [-3.3e+01, 3.2e+01] [-4.2e+00, 4.2e+00] [-1.3e+02, 1.2e+02] [-1.9e+02, 1.8e+02]	150 % C.L. 19.3 fb ⁻¹ 19.7 fb ⁻¹ 19.7 fb ⁻¹ 19.4 fb ⁻¹ 24.7 fb ⁻¹ 19.3 fb ⁻¹ 19.3 fb ⁻¹ 19.3 fb ⁻¹	[TeV 8 TeV 8 TeV 8 TeV 8 TeV 7,8 TeV 8 TeV 8 TeV 8 TeV 8 TeV
		aQ0 Channel WVγ Zγ Wγ SS WW Y7→WW WVγ Zγ Wγ Se WW	100 GC Limits @95 Limits @95 [7.7e+01, 8.1e+01] [-7.7e+01, 7.5e+01] [-7.7e+01, 7.4e+01] [-3.3e+01, 3.2e+01] [-4.2e+00, 4.2e+00] [-1.3e+02, 1.2e+02] [-1.3e+02, 1.3e+02] [-1.2e+02, 1.3e+02] [-1.2e+02, 1.3e+02] [-1.2e+02, 1.3e+02] [-1.2e+02, 1.3e+02]	150 % C.L. 19.3 fb ⁻¹ 19.7 fb ⁻¹ 19.7 fb ⁻¹ 19.7 fb ⁻¹ 19.3 fb ⁻¹ 19.7 fb ⁻¹ 19.7 fb ⁻¹ 19.7 fb ⁻¹ 19.7 fb ⁻¹ 19.7 fb ⁻¹	[TeV 8 TeV 8 TeV
	0 50	aQ0 <u>Channel</u> <u>WVγ</u> Zγ Wγ ss WW <u>Yγ</u> →WW <u>WVγ</u> Zγ WY ss WW <u>Yγ</u> →WW	100 GC Limits @95 Limits @95 [7.7e+01, 8.1e+01] [-7.1e+01, 7.5e+01] [-7.7e+01, 7.4e+01] [-3.3e+01, 7.4e+01] [-4.2e+00, 4.2e+00] [-1.3e+02, 1.2e+02] [-1.2e+02, 1.3e+02] [-4.4e+01, 4.7e+01] [-1.6e+01], 1.6e+01]	150 % C.L. 19.3 fb ⁻¹ 19.7 fb ⁻¹ 19.7 fb ⁻¹ 19.4 fb ⁻¹ 24.7 fb ⁻¹ 19.3 fb ⁻¹ 19.7 fb ⁻¹ 19.7 fb ⁻¹ 19.7 fb ⁻¹ 19.7 fb ⁻¹ 19.4 fb ⁻¹ 24.7 fb ⁻¹	[TeV 8 TeV 8 TeV 7,8 TeV 7,8 TeV
		aQC <u>Channel</u> WVY ZY WY ss WW $\gamma\gamma \rightarrow WW$ ZY WY ss WW $\gamma\gamma \rightarrow WW$ ZY	100 GC Limits @95 Limits @95 [-7.4e01, 8.1e401] [-7.4e01, 7.5e01] [-7.4e01, 7.4e401] [-3.3e401, 3.2e401] [-4.2e400, 4.2e400] [-1.3e402, 1.3e402] [-1.2e402, 1.3e402] [-1.2e402, 1.3e402] [-4.4e401, 4.7e401] [-6.4e401, 1.6e401] [-5.1e402, 5.1e402]	150 % C.L. <u>19.3 (b)</u> ¹ 19.7 (b) ¹ 19.7 (b) ¹ 19.7 (b) ¹ 19.4 (b) ¹ 24.7 (b) ¹ 19.3 (b) ¹ 19.7 (b) ¹ 24.7	[TeV 8 TeV 8 TeV
		aQ0 ^{Channel} ^{WVγ} ^{Zγ} ^{Wγ} ^{SS} WW ^{Yγ→WW} ^{Yγ→WW} ^{Zγ} ^{SS} WW ^{Yγ→WW} ^{Zγ} ^{Yγ→WW}	100 GC Limits @95 Limits @95 [77e+01,8.1e+01] [7.7e+01,7.6e+01] [4.2e+00,4.2e+00] [4.2e+00,4.2e+00] [-1.3e+02,1.2e+02] [-1.3e+02,1.3e+02] [-1.2e+02,1.3e+02] [-1.2e+02,1.3e+02] [-1.6e+01,1.6e+01] [-5.1e+02,5.1e+02] [-5.1e+02,5.1e+02]	150 % C.L. 19.3 b ⁻¹ 19.7 b ⁻¹ 19.7 b ⁻¹ 19.4 b ⁻¹ 24.7 b ⁻¹ 19.7 b ⁻¹ 19.7 b ⁻¹ 19.7 b ⁻¹ 19.7 b ⁻¹ 19.7 b ⁻¹ 19.7 b ⁻¹ 20.3 b ⁻¹	[TeV 8 TeV 8 TeV
		$\begin{array}{c} \text{aQC}\\ \hline \text{Channel}\\ WV\gamma\\ Z\gamma\\ W\gamma\\ \text{ss} WW\\ \gamma\gamma \rightarrow WW\\ WV\gamma\\ Z\gamma\\ W\gamma\\ Ss WW\\ \gamma\gamma \rightarrow WW\\ Z\gamma\\ W\gamma\\ W\gamma\\ Y\gamma \rightarrow WW\\ W\gamma\\ Z\gamma\\ Z\gamma\\ \end{array}$	100 GC Limits @95 	150 % C.L. 19.3 b ⁻¹ 19.7 b ⁻¹ 19.7 b ⁻¹ 19.7 b ⁻¹ 19.3 b ⁻¹ 19.7 b ⁻¹ 19.7 b ⁻¹ 19.7 b ⁻¹ 19.7 b ⁻¹ 19.4 b ⁻¹ 24.7 b ⁻¹ 19.4 b ⁻¹ 20.3 b ⁻¹ 19.7 b ⁻¹	[TeV 8 TeV 8 TeV
		aQC Channel WV γ Z γ W $\gamma \rightarrow$ WV $\gamma \rightarrow$ WV $\gamma \rightarrow$ WV $\gamma \rightarrow$ WV $\gamma \rightarrow$ Z $\gamma \rightarrow$ WV $\gamma \rightarrow$ Z $\gamma \rightarrow$ W $\gamma \rightarrow$ Z $\gamma \rightarrow$ W $\gamma \rightarrow$ N $\gamma \rightarrow$	100 GC Limits @95 Limits (774-01, 814-01) [7,74-01, 78-01] [3,24-01, 78-01] [3,24-01, 78-01] [1,24-02, 78-02] [1,24-02, 78-02] [1,24-02, 78-02] [1,24-02, 78-02] [1,24-02, 78-02] [1,24-02, 78-02] [2,24-02, 25-02] [3,24-01, 314-01] [2,24-02, 25-02] [3,24-01, 314-01] [2,24-02, 25-02] [3,24-01, 314-01] [3,24-01, 314-01] [3,34-01, 314-01] [3,34-01, 314-01] [3,34-01, 314-01] [3,34-01, 314-01] [3,34-01, 314-01]	150 % C.L. 19.3 b ⁻¹ 19.7 b ⁻¹ 19.7 b ⁻¹ 19.4 b ⁻¹ 24.7 b ⁻¹ 19.7 b ⁻¹ 19.7 b ⁻¹ 20.3 b ⁻¹ 20.3 b ⁻¹ 19.7 b ⁻¹ 19.7 b ⁻¹	[TeV 8 TeV 8 TeV
		aQC Channel WV $Z\gamma$ Wy $X\gamma$ SS WW $\gamma\gamma \rightarrow WW$ WV $Z\gamma$ WV $Z\gamma$ WV $Z\gamma$ WY $Z\gamma$ $Z\gamma$ WV $Z\gamma$	100 GGC Limits @95 Limits [7.7e+01, 54e+01] [7.7e+01, 7.4e+01] [7.7e+01, 7.4e+01] [7.7e+0	150 % C.L. 19.3 b ¹ 19.7 b ¹ 19.7 b ¹ 19.7 b ¹ 19.3 b ¹ 19.7 b ¹ 19.7 b ¹ 19.7 b ¹ 19.7 b ¹ 20.3 b ¹ 19.7 b ¹ 20.3 b ¹ 19.7 b ¹	[TeV 8 TeV 8 T
		aQC Channel WV7 Z γ W γ SS WW $\gamma\gamma \rightarrow WW$ V $\gamma = X\gamma$ W $\gamma = X\gamma = WW$ $\gamma \rightarrow WY$ $\gamma \rightarrow WW$ $\gamma \rightarrow WY$ $\gamma \rightarrow WY$	100 GGC Limits @95 Limits [7.7e+01, 8.1e+01] [7.7e+01, 7.5e+01] [4.774+01, 7.5e+01] [4.774+01, 7.5e+01] [4.2e+00, 4.2e+00] [1.3e+02, 1.3e+02] [1.3e+02, 1.3e+02] [4.3e+01, 4.7e+01] [5.1e+02, 5.1e+02] [5.2e+02, 5.1e+02] [5.2e+02, 5.1e+02] [5.2e+02, 5.1e+02] [5.2e+02, 5.1e+02] [5.2e+02, 5.1e+02] [5.2e+02, 5.1e+02] [5.2e+03, 5.1e+01] [5.2e+02, 5.1e+02] [5.2e+03, 5.1e+01] [5.2e+02, 5.1e+02] [5.2e+03, 5.1e+01] [5.2e+03, 5.1e+01][5.2e+03, 5.1e+01] [5.2e+03, 5.2e+03] [5.2e+03, 5.2e+03] [5.2e+03, 5.2e+03] [5.2e+03, 5.2e+03] [5.2e+03, 5.2e+03][5.2e+03] [5.2e+03, 5.2e+03] [5.2e+03, 5.2e+03][5.2e+03] [5.2e+03, 5.2e+03] [5.	150 % C.L. 19.3 b ⁻¹ 19.7 b ⁻¹ 19.7 b ⁻¹ 19.7 b ⁻¹ 19.3 b ⁻¹ 19.3 b ⁻¹ 19.7 b ⁻¹ 19.7 b ⁻¹ 19.7 b ⁻¹ 19.7 b ⁻¹ 20.3 b ⁻¹ 19.7 b ⁻¹	[TeV 8 TeV 8 TeV
$-\frac{1}{-50}$ pril 2016 $\overline{h_{0,0}}/\Lambda^4$ $\overline{h_{0,0}}/\Lambda^4$ $\overline{h_{0,0}}/\Lambda^4$		aQC Channel WVY ZY WY ss WW YY WVY ZY WYY Ss WW YY Ss WW YY WYY Ss WW YY Ss WW YY WY Ss WW YY Ss WY YY Ss WW YY Ss WY YY Ss WY YY Ss WY YY Ss WY YY Ss WY YY YY YY YY YY YY YY YY YY	100 GC Limits @95 Limits (7.7e+01, 5.6+01) (7.7e+01, 7.4e+01) (7.7e+01, 7.4e+01)	150 % C.L. 19.3 b ⁻¹ 19.7 b ⁻¹	[TeV 8 TeV 8 TeV
		aQC Channel $WV\gamma$ $Z\gamma$ $W\gamma$ SS WW $\gamma\gamma \rightarrow WW$ $W\gamma$ $Z\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $W\gamma$ $Z\gamma$ Y $W\gamma$ $Z\gamma$ Y $W\gamma$ $Z\gamma$ Y $W\gamma$ $Z\gamma$ Y $W\gamma$ $Z\gamma$ Y $W\gamma$ $Z\gamma$ Y $W\gamma$ $Z\gamma$ $Z\gamma$ Y $W\gamma$ $Z\gamma$ $Z\gamma$ Y $W\gamma$ $Z\gamma$ Y $W\gamma$ $Z\gamma$ Y $W\gamma$ $Z\gamma$ Y $W\gamma$ $Z\gamma$ Y $W\gamma$ $Z\gamma$ Y $W\gamma$ $Z\gamma$ Y $W\gamma$ $Z\gamma$ Y $W\gamma$ $Z\gamma$ Y $W\gamma$ $Z\gamma$ Y $W\gamma$ $Z\gamma$ Y $W\gamma$ $Z\gamma$ Y $W\gamma$ $Z\gamma$ Y $W\gamma$ $Z\gamma$ Y $W\gamma$ $Z\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $W\gamma$ $Z\gamma$ $Z\gamma$ $W\gamma$ $Z\gamma$ $Z\gamma$ $W\gamma$ $Z\gamma$	100 GGC Limits @95 Limits [7.7e+01, 8.1e+01] [7.7e+01, 7.5e+01] [4.3e+01, 7.5e+01] [4.3e+01, 7.5e+01] [4.3e+02, 7.5e+02] [1.3e+02, 7.5e+02] [1.3e+02, 7.5e+02] [1.3e+02, 7.5e+02] [1.3e+02, 7.5e+02] [2.2e+02, 7.5e+02] [2.2e+02, 7.5e+02] [2.2e+02, 7.5e+02] [2.2e+03, 7.5e+01] [2.2e+02, 7.5e+02] [2.2e+03, 7.5e+01] [2.2e+03, 7.5e+01] [2.2e+	150 % C.L. 19.3 b ⁻¹ 19.7 b ⁻¹ 1	[TeV 8 TeV 8 TeV
$-\frac{1}{-50}$ pril 2016 $\overline{h_{LS}}/\Lambda^4$ $\overline{h_{LS}}/\Lambda^4$ $\overline{h_{LS}}/\Lambda^4$ $\overline{h_{LS}}/\Lambda^4$		aQC Channel WV Z_{γ} wy ss WW $\gamma_{\gamma \rightarrow WW}$ WV Z_{γ} wy Z_{γ} wy Z_{γ} wy Wy Z_{γ} wy Z_{γ} wy wy wy wy wy wy wy wy wy wy	100 GGC Limits @95 Limits (7,74e01,74e01) (7,74e01,74e01) (7,74e01,74e01) (7,74e01,74e01) (7,74e01,74e01) (1,34e01,34e01) (1,34e01,14e02) (1,34e01,14e02) (1,34e02,14e02) (1,34e02,14e02) (1,34e02,14e02) (1,34e02,14e02) (1,34e02,14e02) (2,34e01,34e03) (2,34e01,34e03) (2,34e01,34e03) (2,34e04,34e02) (3,34e03,34e03) (2,34e04,34e02) (3,34e03,34e03) (2,34e04,34e02) (3,34e03,34e03) (2,34e04,34e02) (3,34e03,34e03) (2,34e04,34e03) (3,34e03,34e03,34e03) (3,34e03,34e03,34e03) (3,34e03,34e03,34e03) (3,34e03,34e03,34e03) (3,34e03,34e03,34e03) (3,34e03,34e03,34e03) (3,34e03,34e03,34e03) (3,34e03,34e03,34e03,34e03) (3,34e03,34e03,34e03,34e03,34e03)(3,34e03,34e03,34e03,34e03,34e03)(3,34e03,3	150 % C.L. 19.3 b ⁻¹ 19.7 b ⁻¹ 20.3 b ⁻¹ 20.3 b ⁻¹ 20.3 b ⁻¹ 19.7 b ⁻¹ 19.7 b ⁻¹ 19.7 b ⁻¹ 19.7 b ⁻¹	[TeV 8 TeV 8 T
		aQC Channel WVy $Z\gamma$ wy ss WW $\gamma\gamma \rightarrow WW$ WVy $Z\gamma$ $Y\gamma \rightarrow WW$ $Z\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ $W\gamma$ $Z\gamma$ $W\gamma$ W	100 GGC Limits @95 Limits [7,7e40], 51e40] [7,7e40], 7,5e40] [7,7e40], 7,5e40] [7,7e40], 7,5e40] [7,7e40], 7,5e40] [7,7e40], 7,5e40] [4,2e40], 4,2e400 [1,2e40], 2,2e401 [1,2e40], 2,5e401 [2,2e40], 2,2e401 [2,2e40], 2,2e401 [2,2e40], 2,2e401 [2,2e40], 2,2e401 [4,2e40], 2,4e402 [4,2e40], 2,4e402 [5,3e40], 3,4e402 [4,2e40], 2,4e402 [5,3e40], 3,4e402 [4,2e40], 2,4e402 [5,3e40], 3,4e402 [4,2e40], 2,4e402 [5,3e40], 3,4e402 [4,2e40], 2,4e402 [5,3e40], 3,4e402 [4,2e40], 2,4e402 [5,3e40], 3,4e402 [4,2e40], 3,4e402\\[4,2e40], 3,4e402\\[4,2e	150 % C.L. 19.3 b ⁻¹ 19.7 b ⁻¹ 20.3 b ⁻¹ 20.3 b ⁻¹ 19.7 b ⁻¹	[TeV 8 TeV 8 T
$-\frac{1}{-50}$ pril 2016 $\overline{h_{u,c}}/\Lambda^4$ $\overline{h_{u,c}}/\Lambda^4$ $\overline{h_{u,c}}/\Lambda^4$ $\overline{h_{u,c}}/\Lambda^4$ $\overline{h_{u,c}}/\Lambda^4$		aQC Channel WVγ Zγ Wγ Wγ Wγ Wγ Wγ Wγ Wγ Zγ Zγ Wγγ Wγ	100 GGC Limits @95 Limits (7,74e01,74e01) (7,74e01,74e01) (7,74e01,74e01) (7,74e01,74e01) (7,74e01,74e01) (1,34e01,74e02) (1,34e01,74e02) (1,34e02) (1,34e02	150 % C.L. 19.3 b ⁻¹ 19.7 b ⁻¹ 19.7 b ⁻¹ 19.7 b ⁻¹ 19.4 b ⁻¹ 24.7 b ⁻¹ 19.7 b ⁻¹	[TeV 8 TeV 8 TeV
		aQC Channel WVY SS WW $\gamma \rightarrow WW$ WY $Z\gamma \rightarrow WW$ $\gamma \rightarrow WW$ $Z\gamma \rightarrow WW$ $Z\gamma \rightarrow WW$ $Z\gamma \rightarrow WW$ $Z\gamma \rightarrow WW$ $Z\gamma \rightarrow WW$ $Z\gamma \rightarrow WY$ $W\gamma \rightarrow W\gamma$ $W\gamma \rightarrow W\gamma$ $W\gamma \rightarrow W\gamma$ $W\gamma \rightarrow W\gamma$ $W\gamma \rightarrow W\gamma$ $W\gamma \rightarrow W\gamma$	100 GGC Limits @95 Limits [7,7e40], 7,5e40] [7,7e40], 7,5e40] [7,7e40], 7,5e40] [7,7e40], 7,5e40] [7,7e40], 7,5e40] [7,7e40], 7,5e40] [7,3e40], 7,2e400 [1,3e40], 7,2e400 [1,3e40], 7,2e400 [1,3e40], 7,2e400 [1,3e40], 7,2e400 [2,3e400], 2,5e400 [2,3e400], 2,5e400 [2,3e400], 2,5e400 [2,3e400], 2,5e400 [2,3e400], 2,5e400 [2,3e400], 2,5e400 [3,2e400], 2,5e400 [3,3e400], 2,5e400\\[3,3e400], 2,5e40	$\begin{array}{c} 150\\ \% \ C.L.\\ 19.3 \ b^{-1}\\ 19.7 \ b^{-1}\\ 19.7 \ b^{-1}\\ 19.4 \ b^{-1}\\ 24.7 \ b^{-1}\\ 19.3 \ b^{-1}\\ 19.7 \ b^{-1}\\ 19.7 \ b^{-1}\\ 20.3 \ b^{-1}\\ 20.3 \ b^{-1}\\ 19.7 \ b^{-1}\\ 10.7 \ b^{-1}\\$	[TeV vs 8 TeV 8 TeV
		aQC Channel WVγ Zγ Wγ WVγ Zγ WVγ Zγ WVγ Zγ WVγ Zγ WVγ Zγ WVγ Zγ WVγ Zγ WVγ Xγ WVγ Swww WVγ Swww WVγ Swww WVγ Swww WVγ Swww WVγ Swww WVγ Swww WVγ Swww WVγ Swww WVγ Swww WVγ Swww WVγ Swww WVγ Swww Sww	G00 GC Limits @95 Limits @95 Limits @95 Limits @95 (7.1e+01, 7.5e+01) (7.1e+01, 7.5e+01) (7.1e+01, 7.5e+01) (1.3e+02, 1.2e+02) (1.3e+02, 1.2e+02) (1.3e+02, 1.2e+02) (1.3e+02, 1.3e+02) (1.3e+02,	$\begin{array}{c} 150\\ \text{\% C.L.}\\ \hline \\ 19.7 \text{b}^{-1}\\ 19.7 \text{b}^{-1}\\ 19.7 \text{b}^{-1}\\ 19.7 \text{b}^{-1}\\ 19.7 \text{b}^{-1}\\ 19.7 \text{b}^{-1}\\ 19.7 \text{b}^{-1}\\ 19.7 \text{b}^{-1}\\ 24.7 \text{b}^{-1}\\ 24.7 \text{b}^{-1}\\ 20.3 \text{b}^{-1}\\ 20.3 \text{b}^{-1}\\ 20.3 \text{b}^{-1}\\ 20.3 \text{b}^{-1}\\ 19.7 \text{b}^{-1}\\ 19.7 \text{b}^{-1}\\ 19.7 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 1\\ 19.7 10 1 \\ 19.7 10 1\\ 19.7 10 1 \\ 19.7 10 1 \\ 19.7 10 1 \\ 19.7 10 1 \\ 19.7 10 1 \\ 19.7 10 1 \\ 19.7 10 1 \\ 19.7 10 1 \\ 19.7 10 1 \\ 19.7 10 1 \\ 19.7 10 1 \\ 19.7 10 1 \\ 19.7 10 1 \\ 19.7 10 1 \\ 10 $	[TeV *5 8 TeV 8 TeV

Summary



diboson measurements ...

... and their interpretation







