Electroweak Physics (di-boson) measurements with the ATLAS detector





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Physics motivation

- Di-boson processes
 - important tests of the Electroweak (EW)
 Sector of the Standard Model (SM) at high energy regimes
 - sensitivity to new heavy particles
 - irreducible background to Higgs measurements
- Anomalous Triple/Quartic Gauge Couplings (aTGC/aQGC)
 - self-couplings fundamental predictions of the SM
 - probe for new physics through deviations of measured cross sections from predictions









Di-boson production at the LHC

- Measurement of di-boson processes involving combinations of W, Z and γ
 - * W/Z γ , ZZ, WZ, W[±]W[∓], W[±]W[±]
- Measured mainly through their leptonic final states
 - Relatively low backgrounds
 - Low branching ratios
 - $BR(W \rightarrow \ell v) = 0.108, BR(Z \rightarrow \ell \ell) = 0.03366$
- Small cross sections O(1-100pb)
- Gluon contribution up to ~10%
 depending on the channel



Signatures

Leptons and photons

★ High-p_T isolated electrons/muons and photons

Z bosons

Invariant mass in windows around the Z pole

W bosons

- * Large missing E
 - Calculated from jets, leptons and calorimetric clusters
- * Transverse mass selection

- Leptons and photons** High-p*
- Z bosons
 - Invariant mass in windows around the Z pole

W bosons

- * Large missing E
 - Calculated from jets, leptons and calorimetric clusters
- * Transverse mass selection



- Leptons and photons** High-p*
- Z bosons
 - Invariant mass in windows around the Z pole

W bosons

- * Large missing E_T to account for the neutrino
 - Calculated from jets, leptons and calorimetric clusters
- Transverse mass selection



Run 166466 Event 26227945 Time 2010-10-07 22:16:39 UTC

 μ^+

example of high-pT isolated leptons and missing ET

WZ→evµµ Candidate

MET

μ

Backgrounds

Estimated with data driven methods

- V + jets characteristics:
 - High-pT leptons from boson decays
 - Leptons from heavy flavor decays
 - Jets misidentified as leptons/photons
 - Particles outside the detector acceptance

ttbar and single top characteristics:

- Prompt isolated leptons from W decays
- Large missing ET





Estimated from MC

- Di-boson processes
 - Background to each other

How do we measure cross sections?

- *"Cut and Count"* analysis: *observed events*
- Background estimation
- Measurement of fiducial cross section
 - In a phase space defined by the detector's acceptance and our selection requirements

$$\sigma_{tot} = \underbrace{N_{obs} - N_{bkg}}_{A \cup C \cup BR \cup \int \mathcal{L}dt}$$

$$A = \frac{N_{MC,gen}^{fid}}{N_{MC,gen}^{tot}} \qquad C = \frac{N_{MC,reco}^{Selected}}{N_{MC,gen}^{fid}}$$

 $N_{obs} = N_{sig} + N_{bkg}$ N_{bkg} $N_{sig} = \mathcal{L} \cdot \sigma^{fid} \cdot C$ $\sigma_{fid} = \frac{N_{obs} - N_{bkg}}{C \int \mathcal{L}dt}$

- Extrapolate to total phase space
- Optionally provide differential cross sections in fiducial volumes
- Distributions "unfolded" from detector effects

acceptance correction for kinematic and geometric selection criteria

correction for detector effects

$Z\gamma/W\gamma$ production

Phys. Rev. D 87, 112003 (2013)

- Measured final states
 - * $\ell^{\pm}\nu\gamma$, ℓ^{\pm} ℓ^{\mp} γ , $\nu\nu\gamma$ (l:e, μ)
- Backgrounds
- * W/ γ +jets for the $\ell^{\pm} v \gamma$
- * Z+jets for the $\ell^{\pm} \ell^{\mp} \gamma$
- ***** Z/γ+jets, W→ev for the ννγ
- Dominant systematic uncertainties
- Photon ID, jet/EM energy scale and resolution and background normalization



data driven estimate

Event selection

- ✓ isolated high-p_T lepton, isolated high-p_T photon and E_T^{miss} + Z-veto $ℓ^{\pm}νγ$
- ✓ isolated high-p_T leptons with M_{ℓℓ} > 40 GeV and isolated high-p_T photon $ℓ^{\pm}ℓ^{\mp}γ$
- Isolated high-ET photon and ET^{miss} ννγ
- * $\Delta R(\ell, \gamma) > 0.7$ to suppress FSR
- ★ jet-veto p_T > 30 GeV for exclusive measurements



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$Z\gamma/W\gamma$ production

- Inclusive Wγ measurement above NLO theoretical prediction (MCFM) by 1-2σ
- Worse discrepancy at high $E_{T^{\gamma}}$ and jet multiplicity

Fair agreement for Zy

2



	Measurement [pb]	Theory (MCFM) [pb]	
Wγ→ℓvγ	2.77±0.03(stat)±0.33(syst)±0.14(lumi)	1.96±0.17	
Ζγ→ℓℓγ	1.31±0.02(stat)±0.11(syst)±0.05(lumi)	1.18±0.05	
Ζγ→ννγ	0.133±0.013(stat)±0.020(syst)±0.005(lumi)	0.156±0.012	1

$Z\gamma/W\gamma$ production

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New NNLO QCD corrections have sizable effect;

provide better agreement with the measurement

- \ast Corrections for Wy: ~ 19% 26%
- * Corrections for Z γ : ~ 8% 18%
- arXiv: 1504.01330v1 [hep-ph]
 arXiv: 1407.1618v1 [hep-ph]
 Phys. Lett. B731 (2014) 204



	LO [pb]	NLO [pb]	NNLO [pb]	Measurement [pb]
σΖγ→ℓℓγ	0.8149+8.0%-9.3%	1.222+4.2%-5.3%	1.320+1.3%-2.3%	1.31±0.02(stat)±0.11(syst)±0.05(lumi)
σ₩γ→ℓνγ	0.8726+6.8%-8.1%	2.058±6.8%	2.453±4.1%	2.77±0.03(stat)±0.33(syst)±0.14(lumi)

ZZ production

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

Measured final states

*
$$\ell^{\pm}\ell^{\mp}\ell^{\pm}\ell^{\mp}$$
 (l:e, μ) and $\ell^{\pm}\ell^{\mp}vv$ (7 JeV only)

- Backgrounds
- * W/Z+jets, Top, WW, WZ
- Estimated with data-driven methods

Event selection

 ✓ 4 (or 2) isolated high-p⊤ leptons
 ✓ (4ℓ): enhanced muon acceptance lηl<2.7 and electron acceptance lηl < 3.16
 ✓ (2ℓ2v): axial-E⊤^{miss*} > 75 GeV to suppress

Z+jets background

*the projection of the E_T^{miss} along the direction opposite to the $Z \rightarrow \ell \ell$ candidate in the transverse plane



ZZ production



\sqrt{S}	$\int {\cal L} { m dt} ~ [{ m fb}^{-1}]$	Measurement [pb]	Theory (MCFM) [pb]
7 TeV	4.6	6.7±0.7(stat) ^{+0.4} -0.3(syst)±0.3(lumi)	5.89 +0.22-0.18
8 TeV	20.3	7.1 ^{+0.5} -0.4(stat)±0.3(syst)±0.2(lumi)	7.2 ^{+0.3} -0.2

W[±]Z production

- Measured final states
- * ℓ^{\pm} v $\ell^{\pm}\ell^{\mp}$ (l:e, μ)
- Backgrounds
- * Z+jets (~15%), Top (~4%) (data driven)
- * ZZ (~5%) and W/Z + γ (~3%) (MC estimate)

Event selection

✓ 3 isolated high-p⊤ leptons and E⊤^{miss}
 ✓ tight Z-mass window IM_{ℓℓ}-M_{PDG}I < 10 GeV
 ✓ tight isolation and identification criteria on the W-lepton



W[±]Z production

- Compatible with SM expectation from MCFM
- Systematic uncertainties dominate at 8 TeV measurement
- Data-driven background estimate
- Reconstruction efficiencies
- Luminosity



\sqrt{S}	$\int {\cal L} { m dt} ~ [{ m fb}^{-1}]$	Measurement [pb]	Theory (MCFM) [pb]
7 TeV	4.6	19.0 ^{+1.4} -1.3(stat) ^{+0.9} -0.9(syst) ^{+0.4} -0.4(lumi)	17.6 ^{+1.1} -1.0
8 TeV	13	20.3 ^{+0.8} -0.7(stat) ^{+1.2} -1.1(syst) ^{+0.7} -0.6(lumi)	20.3±0.8

$W^{\pm}W^{\mp}$ production

- Measured final states
- * $l^{\pm} v l^{\mp} v$ (l:e, μ) in 0-jet bin
- Backgrounds
 - * Top (~15%), Drell-Yan (~5%),
 W+jets (~5%) (data driven)
 - various di-bosons (MC estimate)

Event selection

- \blacksquare 2 isolated high-p_T leptons and E_T^{miss}
- In hard jet-veto to reject ttbar and single top events
- ✓ Z-veto $Im_Z m_{\ell\ell}I > 15 GeV$ to suppress Drell-Yan background in same flavor channels



W[±]W[∓] production

Phys.Rev.D 87, 112001 (2013), ATLAS-CONF-2014-033



- Measured cross section higher than SM prediction (CT10 NLO pdf) by $\sim 2.1\sigma$
- NNLO corrections: Enhancement of cross section by ~10% (*arXiv:1408:5243*)
- NNLL resummation of large logs: Enhancement of cross section can partially explain the excess (arXiv: 1407:4537, arXiv: 1407:4481)

\sqrt{S}	$\int {\cal L} { m dt} ~ [{ m fb}^{-1}]$	Measurement [pb]	Theory (MCFM) [pb]	
7 TeV	4.6	51.9±2.0(stat)±3.9(syst)±2.0(lumi)	44.7 ^{+2.1} -1.9	
8 TeV	20.3	71.4±1.2(stat) ^{+5.0} -4.4(syst) ^{+2.2} -2.1(lumi)	58.7 ^{+3.0} -2.7	19

W[±]W[∓]/W[±]Z production in semileptonic final state JHEP01(2015)049

* l±vjj (l:e,μ)

to suppress multijet bkg

Measured final states

Event Selection

✓ single lepton triggers

 \blacksquare isolated high-p_T lepton,

*E*_T^{miss} and two jets

- ✓ m_T(W) > 40 GeV
- $extsf{w} \Delta \eta(i_1,i_2) < 1.5$ to increase signal-to-bkg ratio $extsf{w} 25 \text{ GeV} < m_{ii} < 250 \text{ GeV}$

Background composition

- W/Z+jets (89%), multijet (~5%) data driven estimate
- top (~4%) MC estimate

	Electron channel	Muon channel
Total Background	~126000	~132500
Data	127650	134846



W[±]W[∓]/W[±]Z production in semileptonic final state JHEP01(2015)049

■ fiducial cross section measurement and extrapolation to the total phase space imes simultaneous maximum likelihood fit to m_{ii}



dominant systematics

W/Z+jets rateJet energy resolution

	Measurement [pb]	Theory (MC@NLO) [pb]	signal significance
σ^{tot}	68±7(stat)±19(syst)	61.1±2.2	3.40

W[±]W[±]+2jets production

- Measured final states
- * $\ell^{\pm}\nu\ell^{\pm}\nu+ii$ (l:e, μ)
- Backgrounds
- * WZ+ 2 jets, Wγ+ 2 jets MC estimate
- ttbar, single Z production through charge misidentification - data driven estimate



More details on talk by K. Bachas First evidence of VV→ VV scattering



dominant systematics

- Jet energy scale
- ✓ WZ+jets normalization

Anomalous gauge boson couplings

- Self interactions of gauge bosons are predicted by the SM (non-abelian nature of the EWK)
- Anomalous couplings can manifest themselves with increased cross sections and modification of kinematic distributions
- Effective Lagrangians approach to parametrize the anomalous couplings as deviations from SM (SM+higher order operators)



Summary of aTGC Limits

			Oct 2014		
WW	8	ATLAS Limits CMS Prel. Limits D0 Limit LEP Limit		Ζ	ATLAS Limits CMS Prel. Limits DO Limit LEP Limit
A10	Ψγ	-0.410 - 0.460 4.6 fb ⁻¹	$\Delta \kappa_{7}$	W	
Δκ _γ		-0.380 - 0.290 5.0 fb ⁻¹			V -0.090 - 0.105 4.6 m V -0.043 - 0.033 5.0 fb ⁻¹
	WW	-0.210 - 0.220 4.9 fb ⁻¹		⊢•⊣ Ľ	EP Combination $-0.074 - 0.051 \ 0.7 \ \text{fb}^{-1}$
	WV	-0.210 - 0.220 4.6 fb ⁻¹	2	⊢ W	/W -0.062 - 0.059 4.6 fb ⁻¹
	WV	-0.110 - 0.140 5.0 fb ⁻¹	λ _Z	<u>н</u> W	/W -0.048 - 0.048 4.9 fb ⁻¹
	D0 Comb	Dination -0.158 - 0.255 8.6 fb ⁻¹		⊢- W	/Z -0.046 - 0.047 4.6 fb ⁻¹
	LEP Com	nbination -0.099 - 0.066 0.7 fb ⁻¹			
2	μ Wγ	-0.065 - 0.061 4.6 fb ⁻¹			$-0.038 - 0.030 5.0 \text{ fb}^{-1}$
λ_{γ}	μ	-0.050 - 0.037 5.0 fb ⁻¹			EP Combination -0.059 - 0.017 0.7 fb ⁻¹
	WW WW	-0.048 - 0.048 4.9 fb ⁻¹	Δα ^Z	— — W	/W -0.039 - 0.052 4.6 fb ⁻¹
	H WV	-0.039 - 0.040 4.6 fb ⁻¹	<u>∆</u> 9 ₁	⊢ W	/W -0.095 - 0.095 4.9 fb ⁻¹
	⊢ WV	-0.038 - 0.030 5.0 fb ⁻¹		⊢ – – W	/Z -0.057 - 0.093 4.6 fb ⁻¹
	⊢⊶ D0 Comb	oination -0.036 - 0.044 8.6 fb ⁻¹			$-0.055 - 0.071 4.6 \text{ fb}^{-1}$
	LEP Com	nbination -0.059 - 0.017 0.7 fb ⁻¹			=P Combination -0.054 - 0.064 8.6 lb
-0.5	0 0.5	1 1.5 TCC Limita @059/ C L	-0.5	0 0.5	1 1.5 aTCC Limita $\bigcirc 05\%$ C L
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Nov 2013					
					ATLAS Limits
		ATLAS Limits		7 vv	ATLAS Limits CMS Prel. Limits CDF Limit
χZΖ	, ZZZ	ATLAS Limits H	ZγZ,	Ζγγ	ATLAS Limits HI
γZZ	ZZZ	ATLAS Limits CMS Prel. Limits	ΖγΖ,	Zyy	ATLAS Limits CMS Prel. Limits CDF Limit γ -0.015 - 0.016 4.6 fb ⁻¹
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γZZ f ^γ ₄	ZZZ ZZ ZZ ZZ ZZ ZZ ZZ ZZ	-0.015 - 0.015 4.6 fb ⁻¹ -0.004 - 0.004 19.6 fb ⁻¹	ΖγΖ, h ₃ ^γ		ATLAS Limits CMS Prel. Limits CDF Limit γ -0.015 - 0.016 4.6 fb ⁻¹ γ -0.003 - 0.003 5.0 fb ⁻¹ γ -0.004 - 0.004 19.5 fb ⁻¹
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$\frac{\mathbf{v}^{\mathbf{z}}}{\mathbf{f}_{4}^{\mathbf{z}}}$	$\begin{array}{c} \mathbf{Z}\mathbf{Z}\mathbf{Z}\mathbf{Z} \\ \mathbf{Z}\mathbf{Z}\mathbf{Z} \\ \mathbf{Z}\mathbf{Z} \\ \mathbf{Z}\mathbf{Z} \\ \mathbf{Z} \\ $	ATLAS Limits CMS Prel. Limits -0.015 - 0.015 4.6 fb ⁻¹ -0.004 - 0.004 19.6 fb ⁻¹ -0.004 - 0.003 5.1, 19.6 fb ⁻¹ -0.013 - 0.013 4.6 fb ⁻¹ 0.004 - 0.004 40.0 fb ⁻¹	ΖγΖ, h ^γ ₃		ATLAS Limits CMS Prel. Limits CDF Limit Imits Y -0.015 - 0.016 4.6 fb ⁻¹ Y -0.003 - 0.003 5.0 fb ⁻¹ Y -0.004 - 0.004 19.5 fb ⁻¹ Y -0.022 - 0.020 5.1 fb ⁻¹ Y -0.013 - 0.014 4.6 fb ⁻¹
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$\begin{array}{c} \mathbf{x}\mathbf{Z}\mathbf{Z}\\ \mathbf{f}_{4}^{\gamma}\\ \mathbf{f}_{4}^{Z}\\ \mathbf{f}_{5}^{\gamma} \end{array}$	$\begin{array}{c c} zzz \\ zzz \\ \hline zz \\ z$	$\begin{array}{c} \text{ATLAS Limits} \\ \text{CMS Prel. Limits} \\ \hline \\ -0.015 - 0.015 \ 4.6 \ \text{fb}^{-1} \\ -0.004 - 0.004 \ 19.6 \ \text{fb}^{-1} \\ -0.004 - 0.003 \ 5.1, \ 19.6 \ \text{fb}^{-1} \\ -0.013 - 0.013 \ 4.6 \ \text{fb}^{-1} \\ -0.004 - 0.004 \ 19.6 \ \text{fb}^{-1} \\ -0.003 - 0.003 \ 5.1, \ 19.6 \ \text{fb}^{-1} \\ -0.016 - 0.015 \ 4.6 \ \text{fb}^{-1} \\ -0.005 - 0.005 \ 19.6 \ \text{fb}^{-1} \\ -0.004 - 0.004 \ 19.6 \ \text{fb}^{-1} \\ -0.005 - 0.005 \ 19.6 \ \text{fb}^{-1} \\ -0.004 - 0.004 \ 19.6 \ \text{fb}^{-1} \\ -0.005 - 0.005 \ 19.6 \ \text{fb}^{-1} \\ -0.004 - 0.004 \ 19.6 \ \text{fb}^{-1} \\ -0.005 - 0.005 \ 10.005$	ΖγΖ, h ₃ ^γ h ₃ ² h ₃ ^γ	$\begin{array}{c} z_{yy} \\ \vdots \\ $	ATLAS Limits CMS Prel. Limits CDF Limit Y -0.015 - 0.016 4.6 fb ⁻¹ Y -0.003 - 0.003 5.0 fb ⁻¹ Y -0.004 - 0.004 19.5 fb ⁻¹ Y -0.013 - 0.014 4.6 fb ⁻¹ Y -0.013 - 0.014 4.6 fb ⁻¹ Y -0.003 - 0.003 5.0 fb ⁻¹ Y -0.013 - 0.014 4.6 fb ⁻¹ Y -0.003 - 0.003 5.0 fb ⁻¹ Y -0.003 - 0.003 5.0 fb ⁻¹ Y -0.003 - 0.004 19.5 fb ⁻¹ Y -0.020 - 0.021 5.1 fb ⁻¹ Y -0.009 - 0.009 4.6 fb ⁻¹
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$\begin{cases} \mathbf{y} \mathbf{Z} \mathbf{Z} \\ \mathbf{f}_{4}^{\gamma} \\ \mathbf{f}_{5}^{Z} \\ \mathbf{f}_{5}^{Z} \\ \mathbf{f}_{5}^{Z} \\ \mathbf{f}_{5}^{Z} \end{cases}$	$\begin{array}{c c} zzz \\ zzz \\ zz \\ zz \\ zz \\ zz \\ zz \\ $	$\begin{array}{c} \text{ATLAS Limits} \\ \text{CMS Prel. Limits} \\ \hline \\ -0.015 - 0.015 & 4.6 \text{ fb}^{-1} \\ -0.004 - 0.004 & 19.6 \text{ fb}^{-1} \\ -0.004 - 0.003 & 5.1, 19.6 \text{ fb}^{-1} \\ -0.013 - 0.013 & 4.6 \text{ fb}^{-1} \\ -0.004 - 0.004 & 19.6 \text{ fb}^{-1} \\ -0.003 - 0.003 & 5.1, 19.6 \text{ fb}^{-1} \\ -0.016 - 0.015 & 4.6 \text{ fb}^{-1} \\ -0.005 - 0.005 & 19.6 \text{ fb}^{-1} \\ -0.013 - 0.013 & 4.6 \text{ fb}^{-1} \\ -0.013 - 0.013 & 4.6 \text{ fb}^{-1} \\ -0.005 - 0.005 & 19.6 \text{ fb}^{-1} \\ -0.005 - 0.005 & 19.6 \text{ fb}^{-1} \end{array}$	$ \begin{array}{c} Z_{3}Z_{4} \\ h_{3}^{\gamma} \\ h_{3}^{Z} \\ h_{4}^{\chi}x100 \\ h_{4}^{Z}x100 \end{array} $	$\begin{array}{c c} z_{yy} \\ \hline \\ z_{yy} \\ \hline \\ 1 \\ \hline \\ 1 \\ \hline \\ 1 \\ \hline \\ 1 \\ \hline \\ 2^{\prime} \\ \hline \\ 1 \\ \hline 1 \\ 1 \\$	ATLAS Limits CMS Prel. Limits CDF Limit Imits CDF Limit Y $-0.015 - 0.016$ 4.6 fb^{-1} Y $-0.003 - 0.003$ 5.0 fb^{-1} Y $-0.004 - 0.004$ 19.5 fb^{-1} Y $-0.022 - 0.020$ 5.1 fb^{-1} Y $-0.013 - 0.014$ 4.6 fb^{-1} Y $-0.003 - 0.003$ 5.0 fb^{-1} Y $-0.003 - 0.003$ 5.0 fb^{-1} Y $-0.003 - 0.004$ 19.5 fb^{-1} Y $-0.009 - 0.009$ 4.6 fb^{-1} Y $-0.004 - 0.004$ 5.0 fb^{-1} Y $-0.004 - 0.004$ 5.0 fb^{-1} Y $-0.009 - 0.009$ 4.6 fb^{-1}
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$\begin{cases} \gamma \\ f_4^{\gamma} \\ f_5^{\gamma} $	$\begin{array}{c c} \mathbf{Z}\mathbf{Z}\mathbf{Z}\mathbf{Z} \\ \mathbf{Z}\mathbf{Z}\mathbf{Z} \\ \mathbf{Z}\mathbf{Z}\mathbf{Z} \\ \mathbf{Z}\mathbf{Z} \\ \mathbf{Z}\mathbf{Z} \\ \mathbf{Z}\mathbf{Z} \\ \mathbf{Z} \\ $	ATLAS Limits CMS Prel. Limits $-0.015 - 0.015 + 4.6 \text{ fb}^{-1}$ $-0.004 - 0.004 + 19.6 \text{ fb}^{-1}$ $-0.004 - 0.003 + 5.1, 19.6 \text{ fb}^{-1}$ $-0.013 - 0.013 + 4.6 \text{ fb}^{-1}$ $-0.004 - 0.004 + 19.6 \text{ fb}^{-1}$ $-0.003 - 0.003 + 5.1, 19.6 \text{ fb}^{-1}$ $-0.005 - 0.005 + 19.6 \text{ fb}^{-1}$ $-0.004 - 0.004 + 5.1, 19.6 \text{ fb}^{-1}$ $-0.005 - 0.005 + 19.6 \text{ fb}^{-1}$ $-0.005 - 0.005 + 19.6 \text{ fb}^{-1}$ $-0.004 - 0.003 + 5.1, 19.6 \text{ fb}^{-1}$ $-0.004 - 0.003 + 5.1, 19.6 \text{ fb}^{-1}$ $-0.004 - 0.003 + 19.6 \text{ fb}^{-1}$	ΖγΖ, h ₃ ^γ h ₃ ² h ₄ ^χ x100 h ₄ ^χ x100	$\begin{array}{c c} z_{yy} \\ z_{yy} \\ \vdots \\ $	ATLAS Limits CMS Prel. Limits CDF Limit Y $-0.015 - 0.016 + 4.6 \text{ fb}^{-1}$ Y $-0.003 - 0.003 + 5.0 \text{ fb}^{-1}$ Y $-0.004 - 0.004 + 19.5 \text{ fb}^{-1}$ Y $-0.022 - 0.020 + 5.1 \text{ fb}^{-1}$ Y $-0.013 - 0.014 + 4.6 \text{ fb}^{-1}$ Y $-0.003 - 0.003 + 5.0 \text{ fb}^{-1}$ Y $-0.003 - 0.003 + 5.0 \text{ fb}^{-1}$ Y $-0.003 - 0.004 + 19.5 \text{ fb}^{-1}$ Y $-0.009 - 0.009 + 4.6 \text{ fb}^{-1}$ Y $-0.004 - 0.004 + 5.0 \text{ fb}^{-1}$ Y $-0.009 - 0.009 + 4.6 \text{ fb}^{-1}$ Y $-0.009 - 0.009 + 4.6 \text{ fb}^{-1}$ Y $-0.001 - 0.001 + 5.0 \text{ fb}^{-1}$ Y $-0.003 - 0.003 + 19.5 \text{ fb}^{-1}$
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First limits on aQGC

More details on talk by K. Bachas

Measurement of VBS allows limit setting on anomalous quartic couplings



Conclusions

- Very good understanding of the physics processes with high precisions
- Excellent performance of the ATLAS detector
 - Di-boson measurements of fiducial, total and differential cross sections with 7 and 8 TeV
 - Exclusion limits on aTGC, no deviations from the SM, expected sensitivity will increase at higher centre-ofmass energies
 - Evidence of the same sign WW+2 jets EW production
 (3.6σ significance)
 - First limits on aQGC through VBS
- Looking forward for Run-2 and beyond for more precise measurements and probes for new physics!

back up

MC simulation

- Wγ/Zγ
 - Ivγ: Alpgen+Herwig(PS)+Jimmy(UE)
 - II\u03c7, vv\u03c7: Sherpa
 - Z(II):Pythia, ttbar:Powheg, WW,Top:MC@NLO
 - ZZ

- Powheg+Pythia and gg2ZZ
- Z/W+jets, Z/Wγ: Alpgen
- * ttbar: MC@NLO, single Top: AcerMC(MC@NLO)
- * WZ (WW): Herwig(Powheg), Z/Wγ Madgraph
- WZ
 - MC@NLO+Herwig+Jimmy(7TeV), Powheg(8TeV)
 - Z/W+jets, DY: Alpgen, WW: MC@NLO, ZZ: Powheg
 - * multijet: PythiaB, ttbar: MC@NLO, W/Z+γ, ttbar+W/Z: Madgraph
- WW
 - MC@NLO+Herwig+Jimmy and gg2WW(7TeV), Powheg+Pythia(8TeV)
 - Z/W/γ+jets, DY, Wγ: Alpgen, WZ/ZZ: Herwig(7TeV), Powheg(8TeV)
 - ttbar: MC@NLO, single Top: AcerMC
- WV semileptonic
 - diboson:MC@NLO+Herwig+Jimmy
 - W/Z+jets: Alpgen+Herwig+Jimmy
 - ttbar:MC@NLO+Herwig+Jimmy, single Top:MC@NLO
 - * ZZ:Herwig, Wγ: Madgraph

- ssWW+2jets
 - * Sherpa
 - WZ/γ+jets, ZZ+jets: Sherpa
 - ttbar+W/Z:Madgraph
 - Wγ:Alpgen

parameter	observed limit	expected limit
a4	-0.139, 0.157	-0.104, 0.116
a5	-0.229, 0.244	-0.180, 0.199

	Measurement [fb]	Theory [fb] (PowhegPythia8)	signal significance
Inclusive	2.1±0.5(stat)±0.3(syst)	1.96±0.17	4.5
EW-only	1.3±0.4(stat)±0.2(syst)	1.18±0.05	3.6

aTGC parameters

Vertex	Parameters	channel
WWY	λ	WW, WY
WWZ	λz	WW, WZ
ZZγ	h	Zγ
Ζγγ	h	Zγ
ΖγΖ	f ₄	ZZ
ZZZ	f ₄	ZZ