

Vector Boson Scattering, Triple Gauge-Boson Production, and Limits on Anomalous Quartic Gauge-Boson Couplings with the ATLAS Detector

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On behalf of the ATLAS Collaboration

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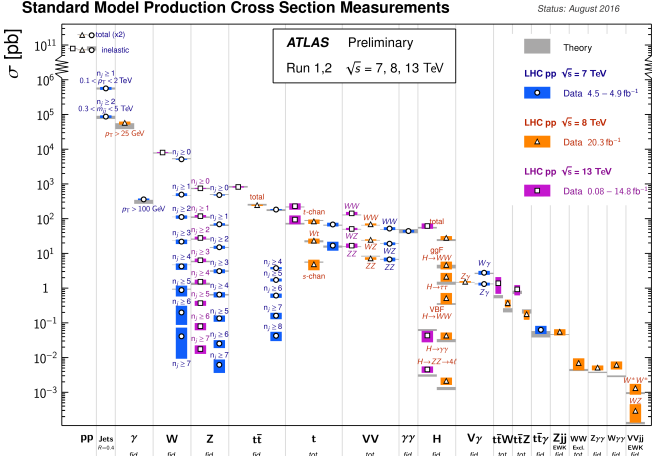
Chicago

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Introduction

- In the absence of a SM Higgs boson, the amplitudes of longitudinally polarized vector boson scattering (VBS) processes increase with \sqrt{s} , begin to violate unitarity at TeV scale.
- Crucial to experimentally verify that the Higgs regulates the cross section precisely.
- $SU(2) \times U(1)$ non-Abelian structure of the electroweak sector predicts the gauge-boson self-couplings.
 - SM quartic gauge-boson couplings (QGC): $WWWW, WWZZ, WWZ\gamma, WW\gamma\gamma$.
 - New physics could manifest itself as anomalous QGC (aQGC), expressed by higher-dimensional operators supplementing the SM Lagrangian.

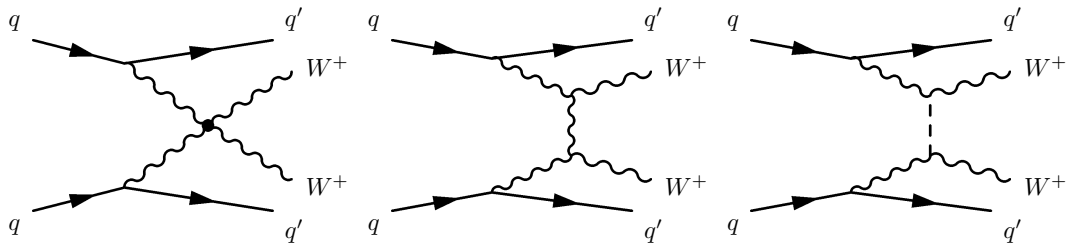
- VBS and tri-boson are main processes to probe the QGC at LHC.
- Rare processes, cross sections typically $\ll 1$ pb.



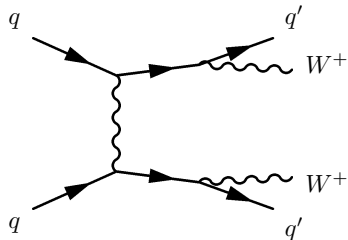
- $W^\pm W^\pm (\rightarrow \ell^\pm \nu \ell^\pm \nu) jj$ at 8 TeV: [Phys. Rev. Lett. 113, 141803](#), published in October 2014.
- Updated $W^\pm W^\pm (\rightarrow \ell^\pm \nu \ell^\pm \nu) jj$ at 8 TeV: preliminary results in July 2016.
- $WZ (\rightarrow \ell \nu \ell \ell) jj$ at 8 TeV: [Phys. Rev. D 93, 092004](#), published in May 2016.
- $WW/WZ (\rightarrow \ell \nu jj) jj$ at 8 TeV: preliminary results in July 2016.
- Exclusive $\gamma\gamma \rightarrow W^+ W^- (\rightarrow e^\pm \mu^\mp)$ at 8 TeV: [arXiv:1607.03745](#), submitted in July 2016.
- $W (\rightarrow \ell \nu) \gamma\gamma$ at 8 TeV: [Phys. Rev. Lett. 115, 031802](#), published in July 2015.
- $Z (\rightarrow ee/\mu\mu/\nu\nu) \gamma\gamma$ at 8 TeV: [Phys. Rev. D 93, 112002](#), published in June 2016.
- $W^\pm W^\pm W^\mp (\rightarrow \ell^\pm \nu \ell^\pm \nu \ell^\mp \nu / \ell^\pm \nu \ell^\pm \nu jj)$ at 8 TeV: preliminary results in July 2016, presented for the first time.

$W^\pm W^\pm (\rightarrow \ell^\pm \nu \ell^\pm \nu) jj$ at 8 TeV I

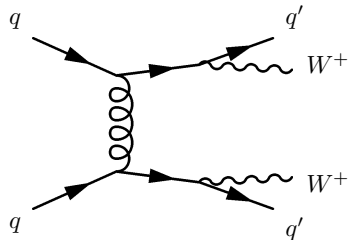
- [Phys. Rev. Lett. 113, 141803](#), published in October 2014.
- Electroweak (α_{EW}^4 at LO) VBS:



- Electroweak (α_{EW}^4 at LO) non-VBS:

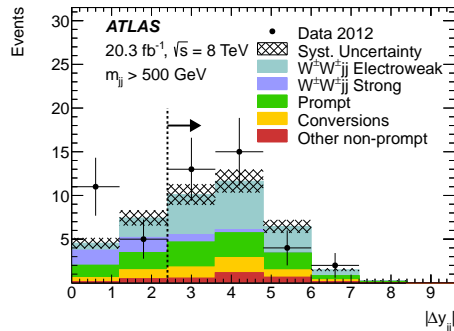
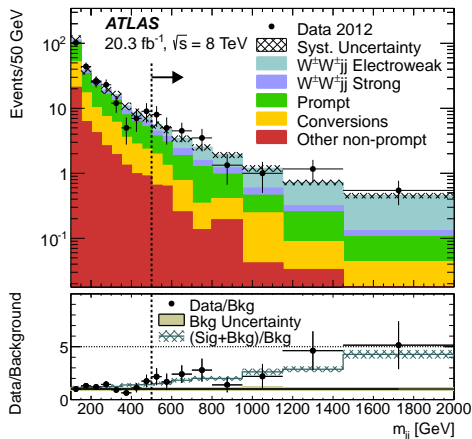


- Strong ($\alpha_S^2 \alpha_{EW}^2$ at LO):



- $W^\pm W^\pm jj$ is ideal for studying VBS due to the relatively low contribution from strong production:
 - With some basic cuts ($p_T^\ell > 5$ GeV, $m_{\ell\ell} > 4$ GeV, $p_T^j > 10$ GeV), the electroweak/strong is $\sim 1/1$ for $W^\pm W^\pm jj$, $\sim 1/30$ for $W^\pm W^\mp jj$ and similar scale for other $VVjj$ processes.
- Analysis aims:
 - Measure the strong + electroweak production; isolate and measure the electroweak production.
 - Use the measurement of electroweak-only production to study the aQGCs from $WWWW$ vertex.
- Signal regions:
 - “Inclusive” region to measure strong + electroweak production: $m_{jj} > 500$ GeV.
 - “VBS” region to measure electroweak-only production: $m_{jj} > 500$ GeV and $|\Delta y_{jj}| > 2.4$.

$W^\pm W^\pm (\rightarrow \ell^\pm \nu \ell^\pm \nu) jj$ at 8 TeV III

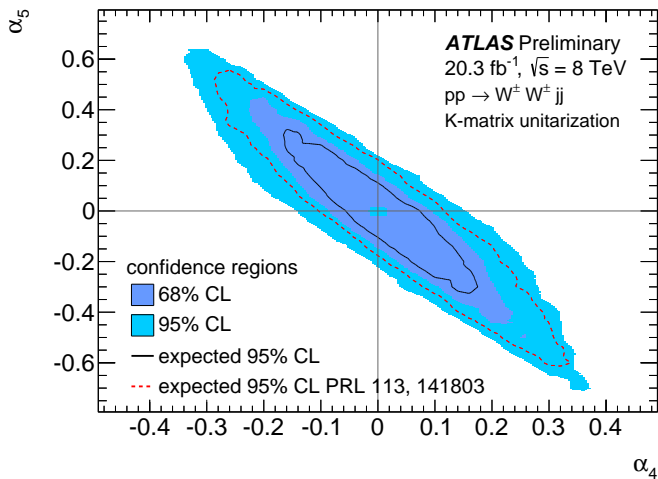


- The significance of strong + electroweak production in inclusive region is 4.5 (3.4) σ for observed (expected).
- Measured $\sigma_{\text{strong+electroweak}}^{\text{fid}} = 2.1 \pm 0.5(\text{stat}) \pm 0.3(\text{syst})$ fb.
- Predicted $\sigma_{\text{strong+electroweak}}^{\text{fid}} = 1.52 \pm 0.11$ fb (NLO in α_s).

- The significance of electroweak-only production in VBS region is 3.6 (2.8) σ for observed (expected).
- Measured $\sigma_{\text{electroweak}}^{\text{fid}} = 1.3 \pm 0.4(\text{stat}) \pm 0.2(\text{syst})$ fb.
- Predicted $\sigma_{\text{electroweak}}^{\text{fid}} = 0.95 \pm 0.06$ fb (NLO in α_s ; including the interference with strong production).

Updated $W^\pm W^\pm(\rightarrow \ell^\pm \nu \ell^\pm \nu)jj$ at 8 TeV

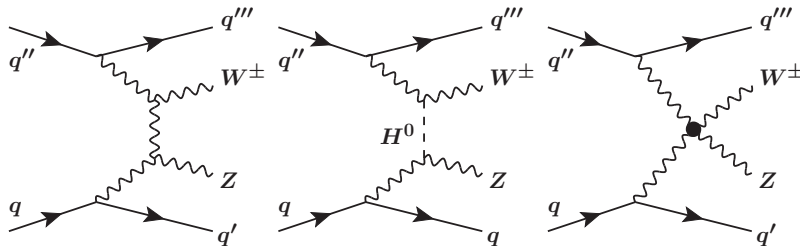
- Preliminary results in July 2016.
- In the $W^\pm W^\pm(\rightarrow \ell^\pm \nu \ell^\pm \nu)jj$ at 8 TeV paper [Phys. Rev. Lett. 113, 141803](#), the measurement in VBS region is used to study the aQGCs from $WWWW$ vertex.
- ATLAS has updated this analysis, mainly explored various discriminating variables to improve the sensitivity to aQGCs, and extended the description of the whole analysis.
- By applying WW trasverse mass > 400 GeV on top of the VBS region, the aQGCs limits are improved by $\sim 35\%$.



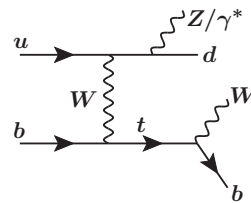
$WZ(\rightarrow \nu\ell\ell)jj$ at 8 TeV I

- [Phys. Rev. D 93, 092004](#), published in May 2016.

- Electroweak VBS:



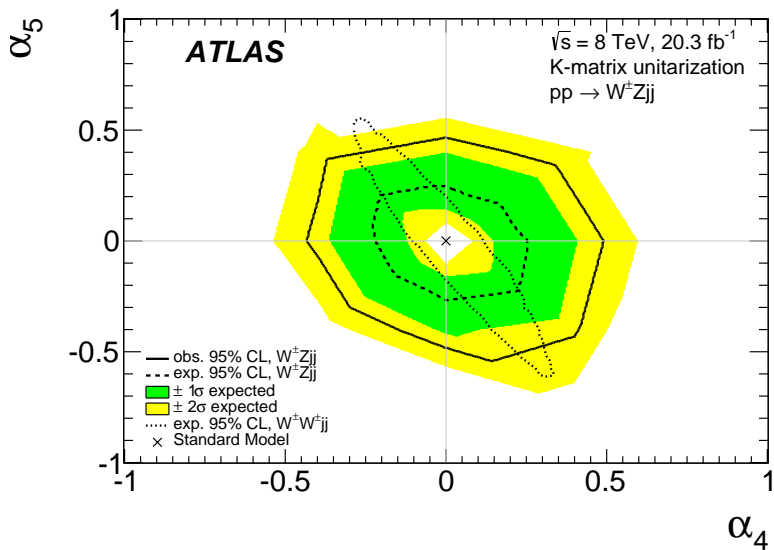
- Electroweak tZj :



- Given the low significance of electroweak $WZjj$ signal, upper limit is derived.
- The measured electroweak $WZjj$ production is $0.29^{+0.14}_{-0.12}(\text{stat})^{+0.09}_{-0.10}(\text{sys})$ fb; SM prediction is 0.13 ± 0.01 fb at NLO.

95% CL upper limit on $\sigma_{W^\pm Z jj\text{-EW}\rightarrow \ell' \nu \ell \ell}^{\text{fid.}}$ [fb]		
	VBS only	VBS + tZj
VBS phase space		
Observed	0.63	0.67
Expected	0.45	0.49
$\pm 1\sigma$ Expected	[0.28; 0.62]	[0.33; 0.67]
$\pm 2\sigma$ Expected	[0.08; 0.80]	[0.19; 0.84]
aQGC phase space		
Observed	0.25	0.25
Expected	0.13	0.13
$\pm 1\sigma$ Expected	[0.08; 0.20]	[0.08; 0.20]
$\pm 2\sigma$ Expected	[0.04; 0.28]	[0.06; 0.28]

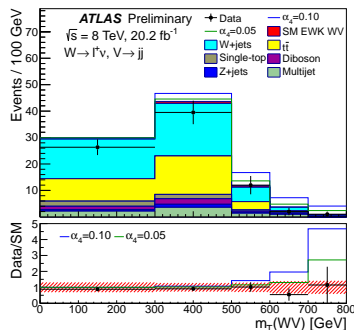
- Constrains are derived on the aQGCs from the $WWZZ$ vertex.



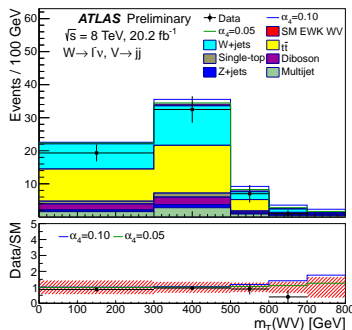
- Preliminary results in July 2016.
- Less sensitivity to the SM signal compared to the fully leptonic final states, due to the larger background.
- Better sensitivity to aQGCs, benefit from larger branching fraction and one less neutrino.
- Focus on the search for aQGCs.
- $V \rightarrow jj$ reconstructed as either two jets or one merged jet:
 - “Resolved” selection ($V \rightarrow jj$ reconstructed as two jets):
 - Four small-radius (0.4) jets.
 - “Merged” selection ($V \rightarrow jj$ reconstructed as one merged jet, i.e. $V \rightarrow J$):
 - Two small-radius (0.4) jets.
 - One large-radius (1.2) jet; jet substructure consistent with the two-body decay.
- The “resolved” region is further categorized by $W \rightarrow \ell^+\nu$ and $W \rightarrow \ell^-\nu$.

WW/WZ($\rightarrow \ell\nu jj$)jj at 8 TeV II

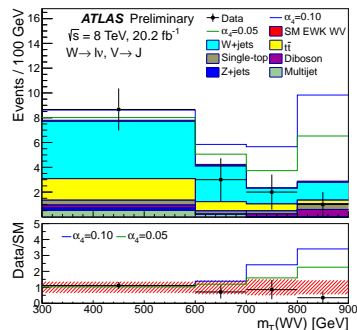
- The transverse mass of WV is used to search for the aQGCs.
- The “merged” region significantly improves the aQGC sensitivity, as indicated in the plots.



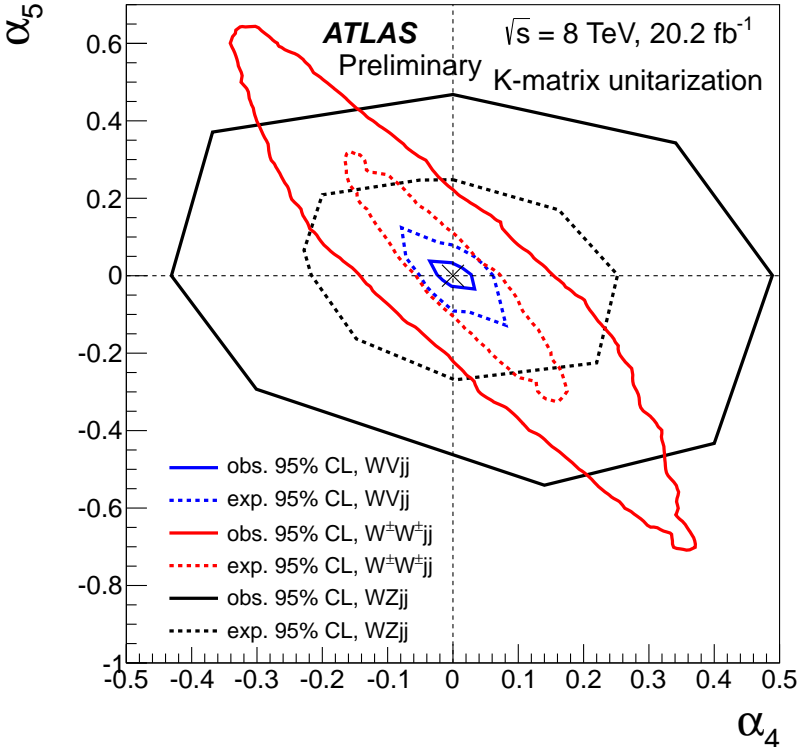
$W \rightarrow \ell^+ \nu, V \rightarrow jj$
“Resolved” region



$W \rightarrow \ell^- \nu, V \rightarrow jj$
“Resolved” region



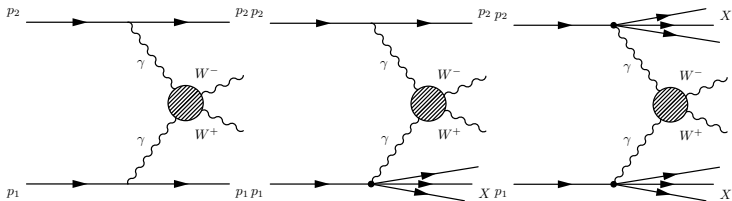
$W \rightarrow \ell \nu, V \rightarrow J$
“Merged” region



Exclusive $\gamma\gamma \rightarrow W^+W^- (\rightarrow e^\pm\mu^\mp)$ at 8 TeV I

- [arXiv:1607.03745](https://arxiv.org/abs/1607.03745), submitted in July 2016.

- Measure the production cross section and probe the aQGCs from $WW\gamma\gamma$ vertex.

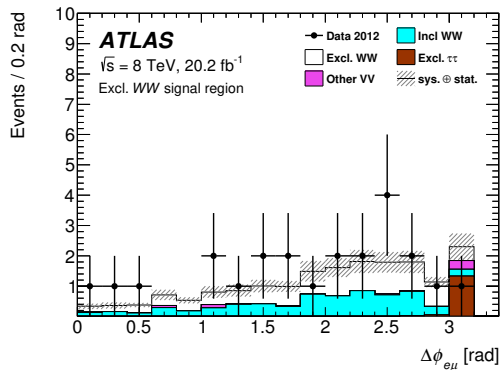
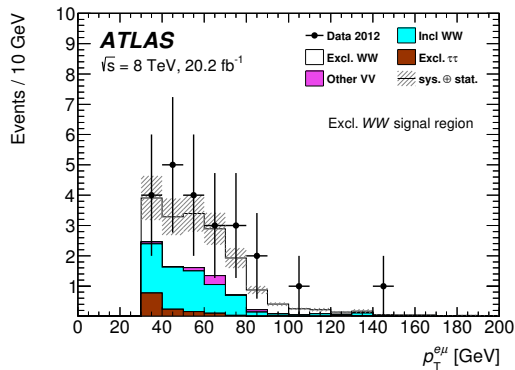


- Basic selections:

- Two opposite-sign leptons with $p_T > 25, 20$ GeV, $|\eta_e| < 2.47$ excluding $[1.37, 1.52]$, $|\eta_\mu| < 2.5$
- $m_{e\mu} > 20$ GeV, $p_T^{e\mu} > 30$ GeV.
- No additional charged particle tracks near the two leptons.
- To probe the aQGCs: additional $p_T^{e\mu} > 120$ GeV requirement.

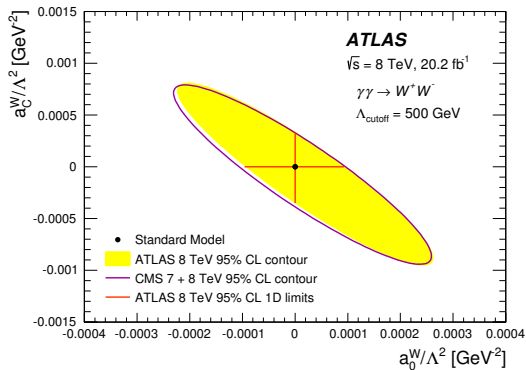
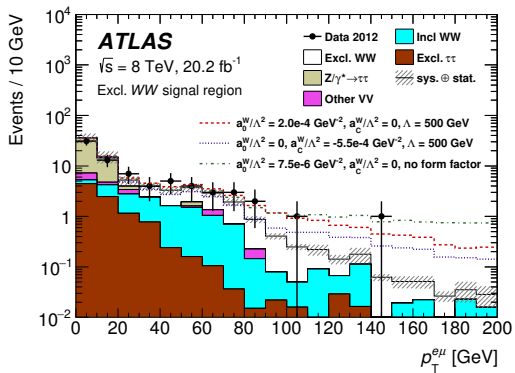
	Expected Signal	Data	Total Bkg	Incl W^+W^-	Excl. $\tau\tau$	Other-VV	Other Bkg	SM/Data	ϵA (Signal)
Preselection	22.6 ± 1.9	99424	97877	11443	21.4	1385	85029	0.98	0.254
$p_T^{e\mu} > 30$ GeV	17.6 ± 1.5	63329	63023	8072	4.30	896.3	54051	1.00	0.198
Δz_0^{iso} requirement	9.3 ± 1.2	23	8.3 ± 2.6	6.6 ± 2.5	1.4 ± 0.3	0.3 ± 0.2	-	0.77	0.105 ± 0.012
aQGC signal region									
$p_T^{e\mu} > 120$ GeV	0.37 ± 0.04	1	0.37 ± 0.13	0.32 ± 0.12	0.05 ± 0.03	0	-	0.74	0.0042 ± 0.0005

Exclusive $\gamma\gamma \rightarrow W^+W^- (\rightarrow e^\pm\mu^\mp)$ at 8 TeV II



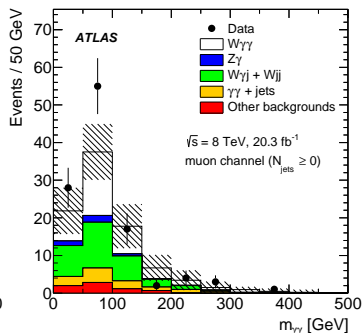
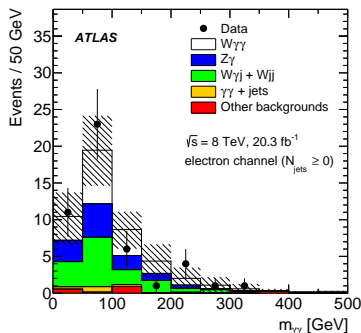
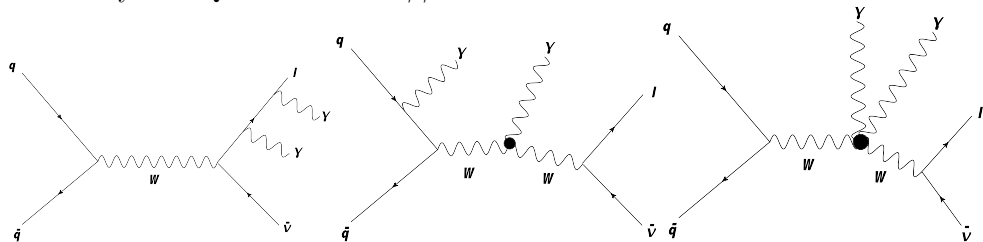
- The observed signal significance is 3.0σ .
- $\sigma_{\gamma\gamma \rightarrow W^+W^- \rightarrow e^\pm\mu^\mp}^{\text{Measured}} = 6.9 \pm 2.2(\text{stat.}) \pm 1.4(\text{sys.}) \text{ fb.}$
- $\sigma_{\gamma\gamma \rightarrow W^+W^- \rightarrow e^\pm\mu^\mp}^{\text{Predicted}} = 4.4 \pm 0.3 \text{ fb.}$

Exclusive $\gamma\gamma \rightarrow W^+W^- (\rightarrow e^\pm\mu^\mp)$ at 8 TeV III



$W(\rightarrow l\nu)\gamma\gamma$ at 8 TeV I

- [Phys. Rev. Lett. 115, 031802](#), published in July 2015.
- Analysis aims:
 - Measure the production cross sections in the inclusive ($N_{jets} \geq 0$) and exclusive ($N_{jets} = 0$) regions.
 - Study the aQGCs from $WW\gamma\gamma$ vertex.



- The observed signal significance in the inclusive case is larger than 3σ .
- The dominant systematic uncertainty arises from the data-driven estimate of $W\gamma j + Wjj$ background, which is 14% (23%) for inclusive (exclusive) case.

	σ^{fid} [fb]	σ^{MCFM} [fb]
Inclusive ($N_{\text{jet}} \geq 0$)		
$\mu\nu\gamma\gamma$	$7.1^{+1.3}_{-1.2}$ (stat.) ± 1.5 (syst.) ± 0.2 (lumi.)	2.90 ± 0.16
$e\nu\gamma\gamma$	$4.3^{+1.8}_{-1.6}$ (stat.) ± 1.9 (syst.) ± 0.2 (lumi.)	
$\ell\nu\gamma\gamma$	$6.1^{+1.1}_{-1.0}$ (stat.) ± 1.2 (syst.) ± 0.2 (lumi.)	
Exclusive ($N_{\text{jet}} = 0$)		
$\mu\nu\gamma\gamma$	3.5 ± 0.9 (stat.) $^{+1.1}_{-1.0}$ (syst.) ± 0.1 (lumi.)	1.88 ± 0.20
$e\nu\gamma\gamma$	$1.9^{+1.4}_{-1.1}$ (stat.) $^{+1.1}_{-1.2}$ (syst.) ± 0.1 (lumi.)	
$\ell\nu\gamma\gamma$	$2.9^{+0.8}_{-0.7}$ (stat.) $^{+1.0}_{-0.9}$ (syst.) ± 0.1 (lumi.)	

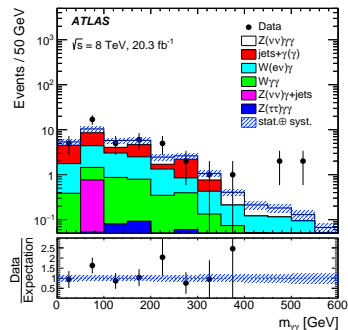
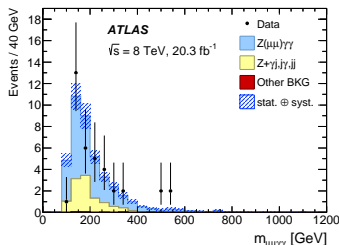
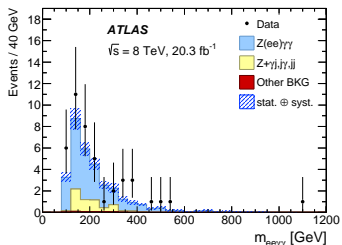
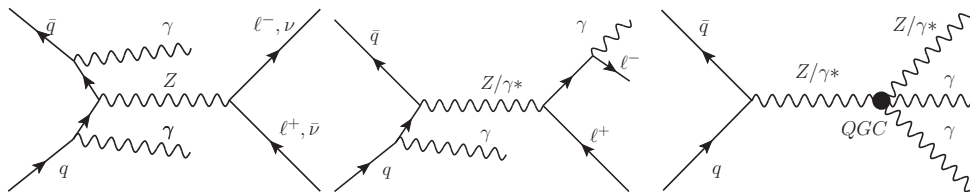
- The measured cross section is higher by 1.9σ in the inclusive case.

- The measurement in the exclusive case with additional requirement of $m_{\gamma\gamma} > 300$ GeV is used to study the aQGCs.

		Observed [TeV ⁻⁴]	Expected [TeV ⁻⁴]
$n = 0$	f_{T0}/Λ^4	$[-0.9, 0.9] \times 10^2$	$[-1.2, 1.2] \times 10^2$
	f_{M2}/Λ^4	$[-0.8, 0.8] \times 10^4$	$[-1.1, 1.1] \times 10^4$
	f_{M3}/Λ^4	$[-1.5, 1.4] \times 10^4$	$[-1.9, 1.8] \times 10^4$
$n = 1$	f_{T0}/Λ^4	$[-7.6, 7.3] \times 10^2$	$[-9.6, 9.5] \times 10^2$
	f_{M2}/Λ^4	$[-4.4, 4.6] \times 10^4$	$[-5.7, 5.9] \times 10^4$
	f_{M3}/Λ^4	$[-8.9, 8.0] \times 10^4$	$[-11.0, 10.0] \times 10^4$
$n = 2$	f_{T0}/Λ^4	$[-2.7, 2.6] \times 10^3$	$[-3.5, 3.4] \times 10^3$
	f_{M2}/Λ^4	$[-1.3, 1.3] \times 10^5$	$[-1.6, 1.7] \times 10^5$
	f_{M3}/Λ^4	$[-2.9, 2.5] \times 10^5$	$[-3.7, 3.3] \times 10^5$

$Z(\rightarrow ee/\mu\mu/\nu\nu)\gamma\gamma$ at 8 TeV I

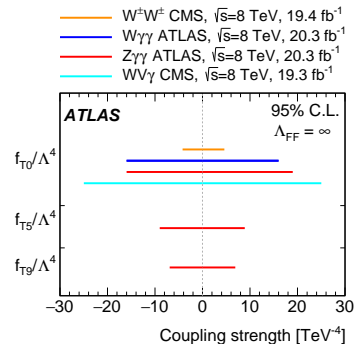
- [Phys. Rev. D 93, 112002](#), published in June 2016.
- Analysis aims:
 - Measure the production cross sections in the inclusive ($N_{jets} \geq 0$) and exclusive ($N_{jets} = 0$) regions.
 - Study the aQGCs from $Z\gamma\gamma$ and $ZZ\gamma\gamma$ vertices, which vanish in the SM at tree level.



$Z(\rightarrow ee/\mu\mu/\nu\nu)\gamma\gamma$ at 8 TeV II

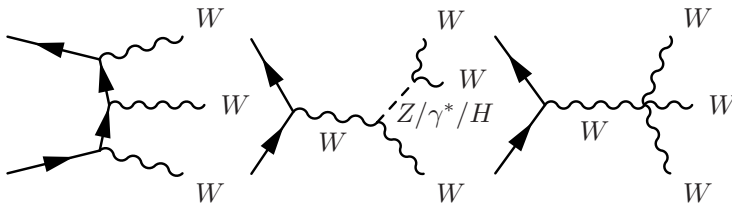
Channel	Measurement [fb]	MCFM Prediction [fb]
$N_{\text{jets}} \geq 0$		
$e^+e^-\gamma\gamma$	$6.2^{+1.2}_{-1.1}(\text{stat.}) \pm 0.4(\text{syst.}) \pm 0.1(\text{lumi.})$	$3.70^{+0.21}_{-0.11}$
$\mu^+\mu^-\gamma\gamma$	$3.83^{+0.95}_{-0.85}(\text{stat.})^{+0.48}_{-0.47}(\text{syst.}) \pm 0.07(\text{lumi.})$	
$\ell^+\ell^-\gamma\gamma$	$5.07^{+0.73}_{-0.68}(\text{stat.})^{+0.41}_{-0.38}(\text{syst.}) \pm 0.10(\text{lumi.})$	
$\nu\bar{\nu}\gamma\gamma$	$2.5^{+1.0}_{-0.9}(\text{stat.}) \pm 1.1(\text{syst.}) \pm 0.1(\text{lumi.})$	$0.737^{+0.039}_{-0.032}$
$N_{\text{jets}} = 0$		
$e^+e^-\gamma\gamma$	$4.6^{+1.0}_{-0.9}(\text{stat.})^{+0.4}_{-0.3}(\text{syst.}) \pm 0.1(\text{lumi.})$	$2.91^{+0.23}_{-0.12}$
$\mu^+\mu^-\gamma\gamma$	$2.38^{+0.77}_{-0.67}(\text{stat.})^{+0.33}_{-0.32}(\text{syst.})^{+0.05}_{-0.04}(\text{lumi.})$	
$\ell^+\ell^-\gamma\gamma$	$3.48^{+0.61}_{-0.56}(\text{stat.})^{+0.29}_{-0.25}(\text{syst.}) \pm 0.07(\text{lumi.})$	
$\nu\bar{\nu}\gamma\gamma$	$1.18^{+0.52}_{-0.44}(\text{stat.})^{+0.48}_{-0.49}(\text{syst.}) \pm 0.02(\text{lumi.})$	$0.395^{+0.049}_{-0.037}$

- The observed significance of $\ell\ell\gamma\gamma$ is 6.3 (6.0) σ for inclusive (exclusive) case.
- The measured cross sections and the MCFM (NLO) predictions are compatible within 1.7 (0.9) σ for inclusive (exclusive) $\ell\ell\gamma\gamma$ channel, and within 1.2 σ in the $\nu\nu\gamma\gamma$ channel.



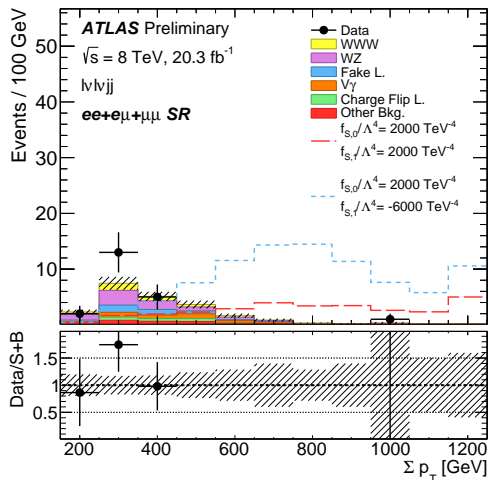
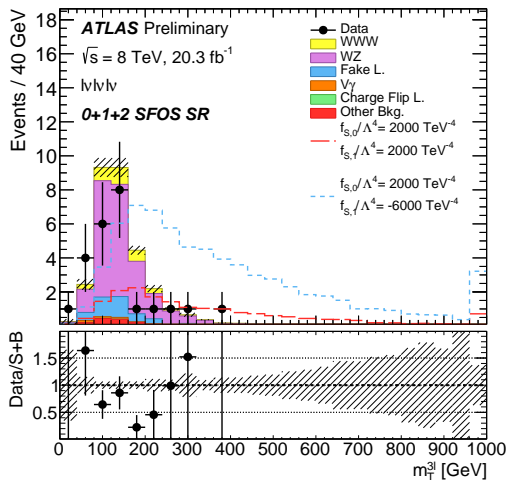
- The measurement in the exclusive channels with additional requirement of $m_{\gamma\gamma} > 200$ ($\ell\ell\gamma\gamma$) and 300 ($\nu\nu\gamma\gamma$) GeV is used to study the aQGCs.
- Sensitivity dominated by the $\nu\nu\gamma\gamma$ channel.

- Preliminary results in July 2016, presented for the first time.
- Measurements of $W^\pm W^\pm W^\mp$ production and study the aQGCs from $WWWW$ vertex.

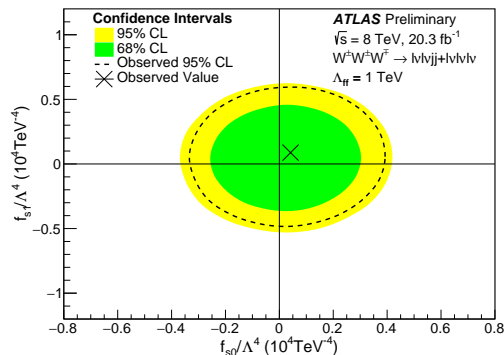
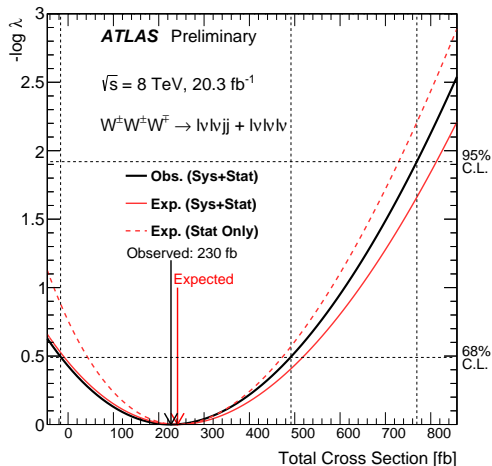


- $W^\pm W^\pm W^\mp \rightarrow \ell^\pm \nu \ell^\pm \nu \ell^\mp \nu$:
 - Clean, low branching fraction.
 - Categorized by the number of same-flavor opposite-sign (SFOS) pairs.
 - 0 SFOS: $e^\pm e^\pm \mu^\mp$ and $\mu^\pm \mu^\pm e^\mp$; 1 SFOS: $e^\pm \mu^\pm e^\mp$ and $e^\pm \mu^\pm \mu^\mp$; 2 SFOS: $e^\pm e^\pm e^\mp$ and $\mu^\pm \mu^\pm \mu^\mp$
- $W^\pm W^\pm W^\mp \rightarrow \ell^\pm \nu \ell^\pm \nu jj$:
 - Less clean, higher branching fraction.
 - Categorized as $e^\pm e^\pm jj$, $\mu^\pm \mu^\pm jj$, and $e^\pm \mu^\pm jj$.

$W^\pm W^\pm W^\mp (\rightarrow \ell^\pm \nu \ell^\pm \nu \ell^\mp \nu / \ell^\pm \nu \ell^\pm \nu jj)$ at 8 TeV II



$W^\pm W^\pm W^\mp (\rightarrow l^\pm \nu l^\pm \nu l^\mp \nu / l^\pm \nu l^\pm \nu jj)$ at 8 TeV III

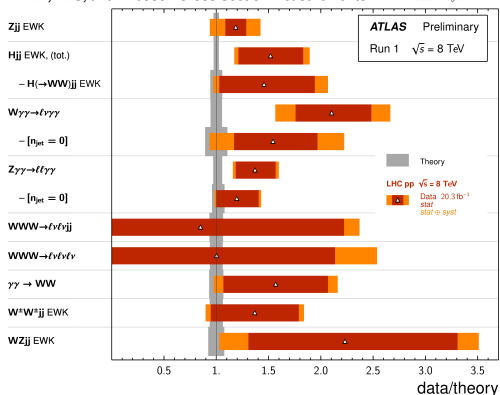


- Given the low significance of the signal, upper limit on the production cross section is also derived.

- The VBS and tri-boson processes have been studied in ATLAS, several observe $> 3\sigma$ signal significance.
 - $W^\pm W^\pm (\rightarrow \ell^\pm \nu \ell^\pm \nu) jj$ (3.6σ).
 - Exclusive $\gamma\gamma \rightarrow W^+ W^- (\rightarrow e^\pm \mu^\mp)$ (3.0σ).
 - $W (\rightarrow \ell\nu)\gamma\gamma$ ($> 3\sigma$).
 - $Z (\rightarrow \ell\ell)\gamma\gamma$ (6.3σ).
 - So far low signal significance for $WZ (\rightarrow \ell\nu\ell\ell)jj$, $WW/WZ (\rightarrow \ell\nu jj)jj$, $Z (\rightarrow \nu\nu)\gamma\gamma$, and $W^\pm W^\pm W^\mp (\rightarrow \ell^\pm \nu \ell^\pm \nu \ell^\mp \nu / \ell^\pm \nu \ell^\pm \nu jj)$.
- No significant deviations from SM are observed. Constraints are placed on aQGCs.
 - Although the signal significance is low, $WW/WZ (\rightarrow \ell\nu jj)jj$ and $Z (\rightarrow \nu\nu)\gamma\gamma$ give more stringent limits than the fully leptonic decay channels.
- More 8 TeV results to be finalized.
- Most of the 8 TeV analyses are statistically limited, look forward to Run-2 results.

VBF, VBS, and Triboson Cross Section Measurements

Status: August 2016



Backup

- Basic selections:

- Two same-sign leptons with $p_T > 25$ GeV, $|\eta_e| < 2.47$ excluding $[1.37, 1.52]$, $|\eta_\mu| < 2.5$, $m_{\ell\ell} > 20$ GeV, $|m_{ee} - m_Z| > 10$ GeV.
- Two jets with $p_T > 30$ GeV, $|\eta| < 4.5$; $E_T^{miss} > 40$ GeV.

Exclusive $\gamma\gamma \rightarrow W^+W^- (\rightarrow e^\pm\mu^\mp)$ at 8 TeV

Coupling	Λ_{cutoff}	Observed allowed range [GeV^{-4}]	Expected allowed range [GeV^{-4}]
$f_{M,0}/\Lambda^4$	500 GeV	$[-3.7 \times 10^{-9}, 3.6 \times 10^{-9}]$	$[-3.5 \times 10^{-9}, 3.4 \times 10^{-9}]$
$f_{M,1}/\Lambda^4$	500 GeV	$[-13 \times 10^{-9}, 14 \times 10^{-9}]$	$[-12 \times 10^{-9}, 13 \times 10^{-9}]$
$f_{M,0}/\Lambda^4$	∞	$[-6.6 \times 10^{-11}, 6.6 \times 10^{-11}]$	$[-5.8 \times 10^{-11}, 6.2 \times 10^{-11}]$
$f_{M,1}/\Lambda^4$	∞	$[-24 \times 10^{-11}, 25 \times 10^{-11}]$	$[-23 \times 10^{-11}, 23 \times 10^{-11}]$

Coupling	Λ_{cutoff}	Observed allowed range [GeV^{-2}]	Expected allowed range [GeV^{-2}]
a_0^W/Λ^2	500 GeV	$[-0.96 \times 10^{-4}, 0.93 \times 10^{-4}]$	$[-0.90 \times 10^{-4}, 0.87 \times 10^{-4}]$
a_C^W/Λ^2	500 GeV	$[-3.5 \times 10^{-4}, 3.3 \times 10^{-4}]$	$[-3.3 \times 10^{-4}, 3.1 \times 10^{-4}]$
a_0^W/Λ^2	∞	$[-1.7 \times 10^{-6}, 1.7 \times 10^{-6}]$	$[-1.5 \times 10^{-6}, 1.6 \times 10^{-6}]$
a_C^W/Λ^2	∞	$[-6.4 \times 10^{-6}, 6.3 \times 10^{-6}]$	$[-5.9 \times 10^{-6}, 5.8 \times 10^{-6}]$

- Basic selections:

- One lepton with $p_T > 20$ GeV, $|\eta_e| < 2.47$ excluding $[1.37, 1.52]$, $|\eta_\mu| < 2.4$.
- Two photons with $E_T > 20$ GeV, $|\eta| < 2.37$ excluding $[1.37, 1.52]$, $\Delta R(\ell, \gamma) > 0.7$.
- $E_T^{miss} > 25$ GeV; W trasverse mass > 40 GeV.

- Basic selections for $Z(\rightarrow ee/\mu\mu)\gamma\gamma$:
 - Two opposite-sign leptons with $p_T > 25$ GeV, $|\eta_e| < 2.47$, $|\eta_\mu| < 2.4$, $m_{\ell\ell} > 40$ GeV.
 - Two photons with $E_T > 15$ GeV, $|\eta| < 2.37$ excluding $[1.37, 1.52]$, $\Delta R(\ell, \gamma) > 0.4$.
- Basic selections for $Z(\rightarrow \nu\nu)\gamma\gamma$:
 - $E_T^{miss} > 110$ GeV; $\gamma\gamma$ system and \vec{p}_T^{miss} back-to-back: $\Delta\phi(\vec{p}_T^{miss}, \gamma\gamma) > 5\pi/6$.

$Z(\rightarrow ee/\mu\mu/\nu\nu)\gamma\gamma$ at 8 TeV

n	Λ_{FF} [TeV]	Limits 95% C.L.	Observed [TeV ⁻⁴]	Expected [TeV ⁻⁴]
0	∞	f_{T9}/Λ^4	$[-0.74, 0.74] \times 10^4$	$[-0.58, 0.59] \times 10^4$
		f_{T5}/Λ^4	$[-0.69, 0.68] \times 10^3$	$[-0.52, 0.52] \times 10^3$
		f_{T0}/Λ^4	$[-0.86, 1.03] \times 10^2$	$[-0.65, 0.82] \times 10^2$
		f_{M2}/Λ^4	$[-1.6, 1.6] \times 10^4$	$[-1.2, 1.2] \times 10^4$
		f_{M3}/Λ^4	$[-2.9, 2.7] \times 10^4$	$[-2.2, 2.2] \times 10^4$
2	0.4	f_{T9}/Λ^4	$[-0.89, 0.86] \times 10^6$	$[-0.71, 0.68] \times 10^6$
	0.6	f_{T5}/Λ^4	$[-2.3, 2.2] \times 10^4$	$[-1.8, 1.8] \times 10^4$
	0.7	f_{T0}/Λ^4	$[-2.3, 2.1] \times 10^3$	$[-1.9, 1.6] \times 10^3$
	5.5	f_{M2}/Λ^4	$[-1.8, 1.9] \times 10^4$	$[-1.4, 1.5] \times 10^4$
	5.0	f_{M3}/Λ^4	$[-3.4, 3.3] \times 10^4$	$[-2.6, 2.6] \times 10^4$