Vector Boson Scattering and new phenomena at LHC

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ATLAS EXPERIMENT

CMS

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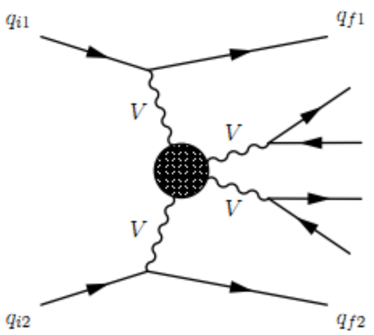
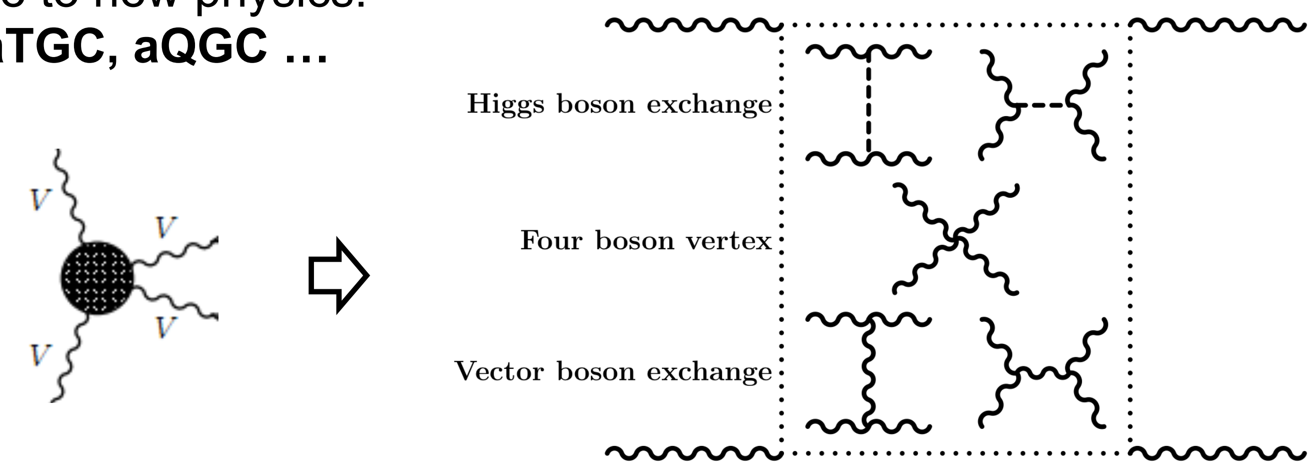
Introduction

- **Vector boson scattering (VBS)** measurements offers an important way to probe **electroweak symmetry breaking**.



- A good probe of the SM in the EW sector. Measure VBS via the corresponding EW productions.

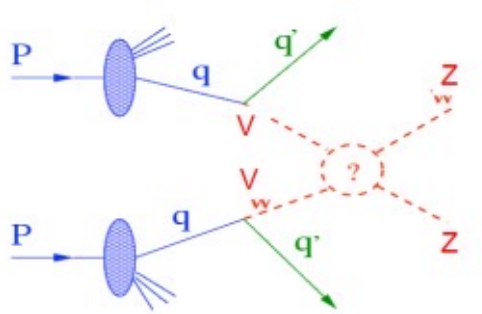
- Sensitive to new physics: **probe aTGC, aQGC …**



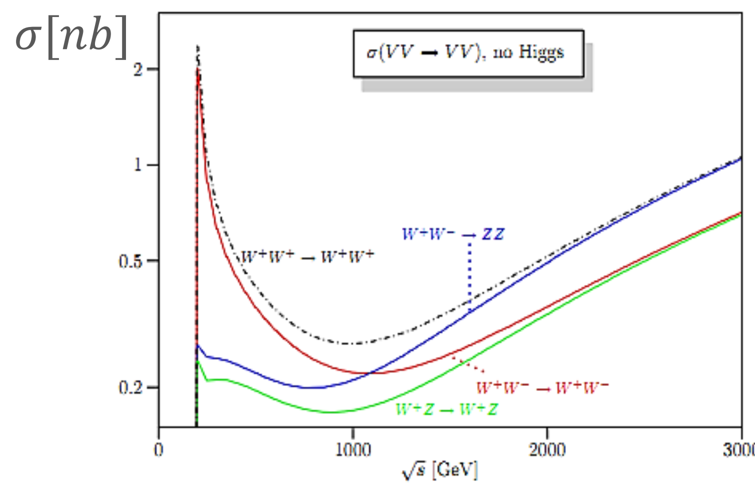
Main interest of VV scattering

- Without Higgs, $W_L^+ W_L^- \rightarrow Z_L Z_L$ would break unitarity.

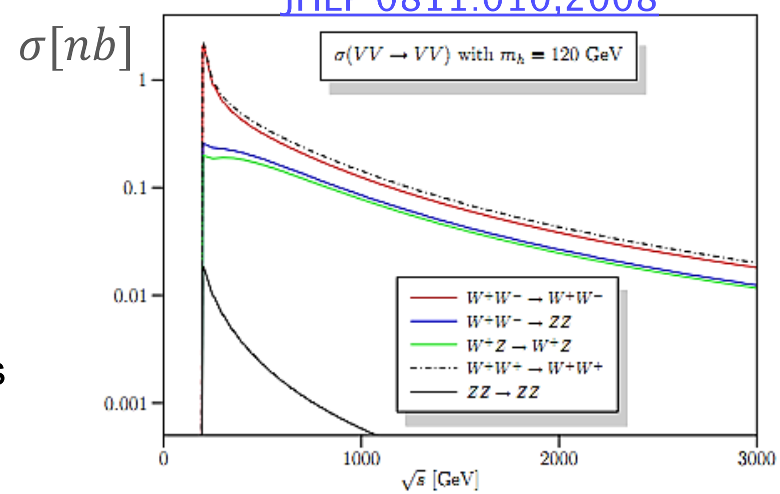
$$\mathcal{M}(W_L^+ W_L^- \rightarrow Z_L Z_L) \sim \frac{s}{m_W^2}$$



- The presence of the Higgs boson prevents the VBS amplitudes from violating unitarity at the TeV scale.
- To understand the nature of EWSB:
  - precise measurements of hVV couplings
  - Measurement of VV→VV cross-sections



JHEP 0811:010,2008



Couplings of gauge bosons

- VBS processes represent a particularly interesting probe of new physics, as they give a unique access to the couplings of gauge bosons.
- Effective field theory:
  - Without committing to a specific model, a convenient instrument for testing experimental data against the presence of BSM effects is that of effective field theories (EFTs).

Wilson coefficients

dimension-8 operators

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \frac{c_i}{\Lambda^2}\mathcal{O}_i + \sum_j \frac{c_j}{\Lambda^4}\mathcal{O}_j + \cdots$$

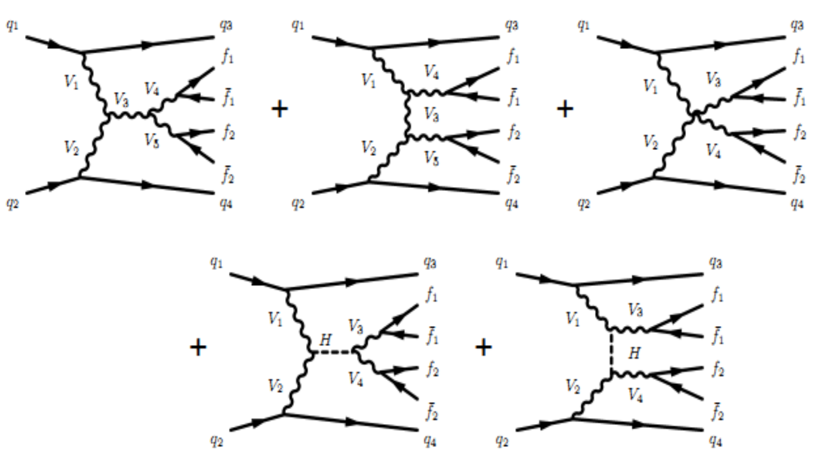
Mass or NP scale

dimension-6 operators

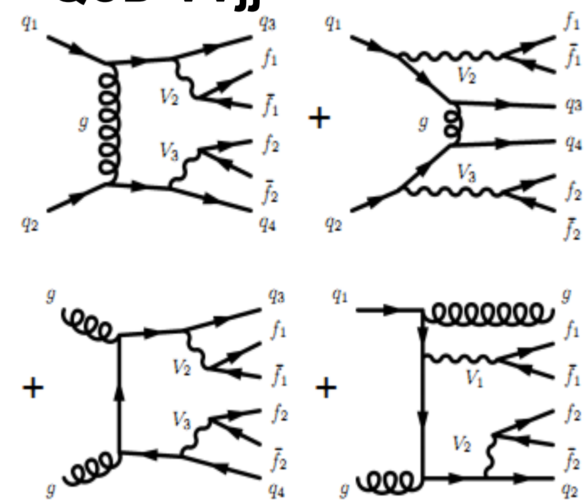
  - Assume experimentally accessible energy $E \ll \Lambda \rightarrow$ low-energy approximation for NP.
  - $c_{i,j}$: dimensionless, parameterize the strength with which the new physics couples to the SM particles.
  - lowest independent aQGC interactions at dimension 8 (dimension 6 also makes aQGC, but also aTGC)

VBS signature

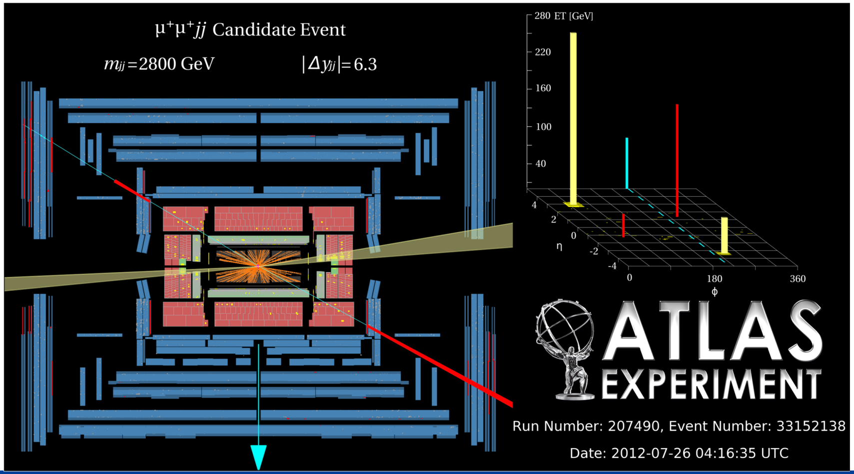
EW-VVjj



QCD-VVjj



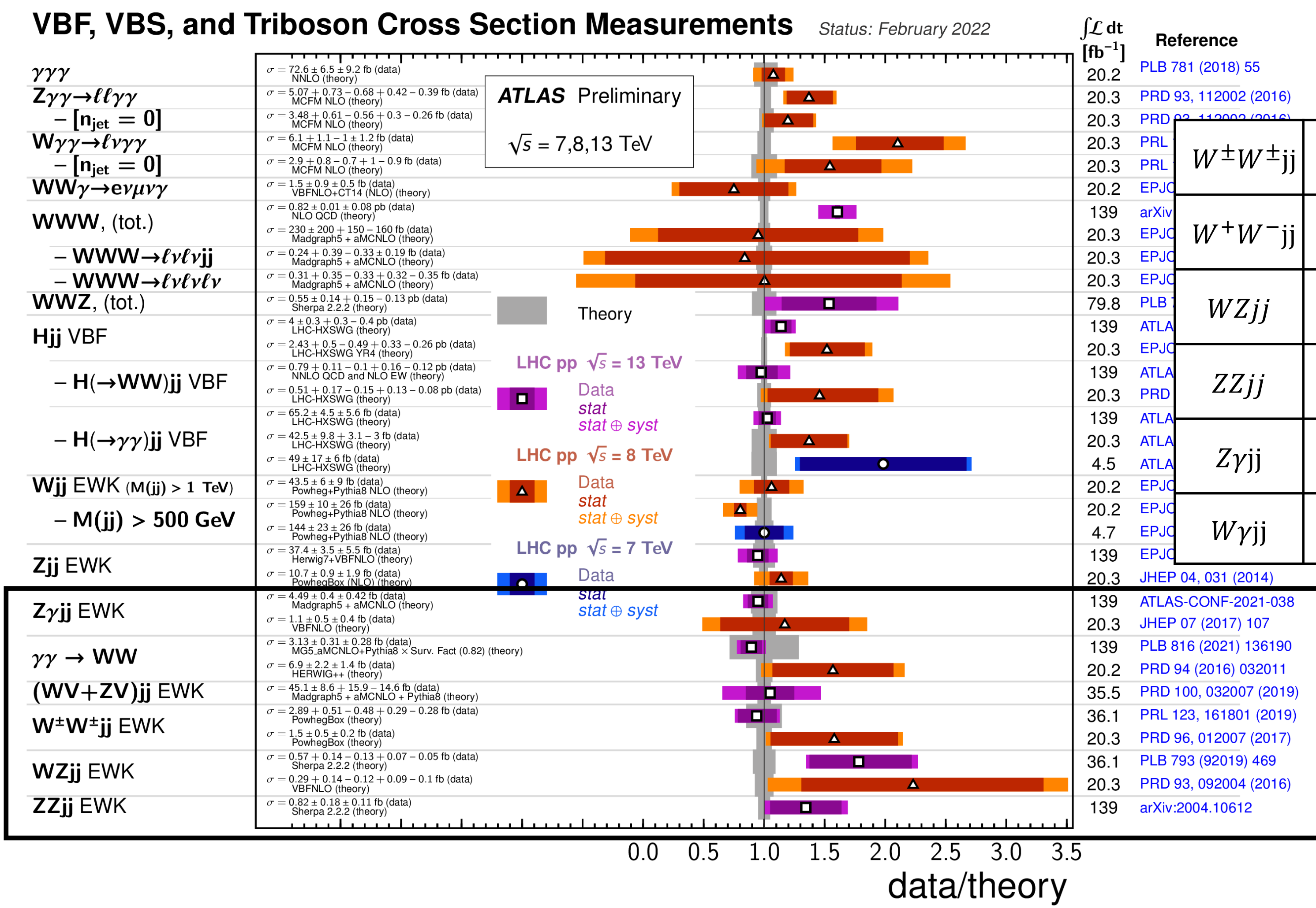
ssWWjj, 8TeV [Phys. Rev. Lett. 113, 141803]



- **VVjj category:**
  - EW-VVjj (including VBS)
  - QCD-VVjj

- **VBS topology:**
  - Two hard forward jets with large m_{jj} and large $\Delta\eta_{jj}$
  - Sensitive variables: $\Delta\eta_{jj}$, m_{jj}, central jet veto, centrality $max\left(\left|\frac{y_i - 0.5(y_{j1}+y_{j2})}{y_{j1}-y_{j2}}\right|\right)$

VBS measurements



CMS

$W^{\pm}W^{\pm}jj$	Phys. Lett. B 809 (2020) 135710
$W^{+}W^{-}jj$	SMP-21-001
$WZjj$	Phys. Lett. B 809 (2020) 135710
$ZZjj$	Phys. Lett. B 812 (2020) 135992
$Z\gamma jj$	PRD 104 (2021) 072001
$W\gamma jj$	PLB 811 (2020) 135988

VBS observations

- VBS observations at the LHC:

13TeV	$W^{\pm}W^{\pm}$jj	$W^{+}W^{-}$jj	$WZjj$	$ZZjj$	$Z\gamma$jj	$W\gamma$jj	$\gamma\gamma \rightarrow WW$
ATLAS	6.5σ	-	5.3σ★	5.5σ★	10σ	-	8.4σ ★
CMS	5.5σ★	5.6σ★	6.8σ	4.0σ	9.4σ★	5.3σ★	-

- 1st observation at LHC: ★ $Z(ll)\gamma$jj CMS $Z(\nu\nu)\gamma$jj ATLAS
- For VBS processes, many channels have been measured and observed at LHC.
- More details of recent observations will show in the next pages.

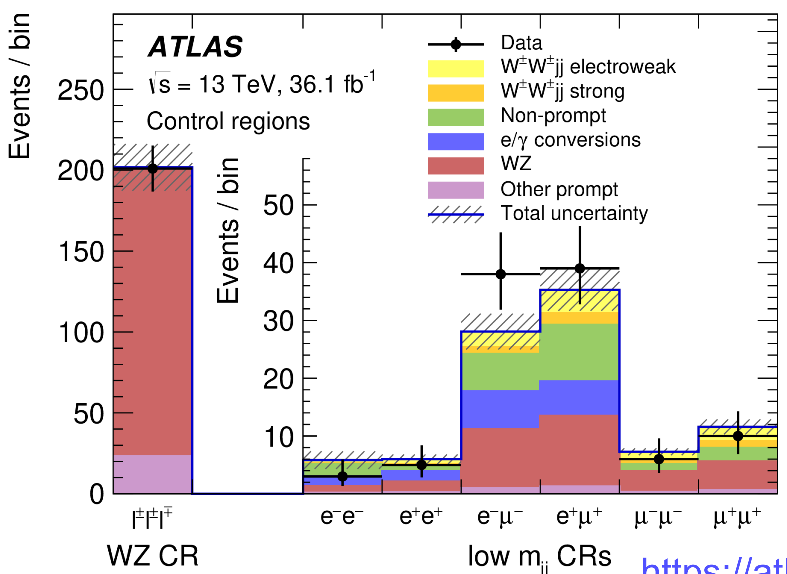
Mainly leptonic decay channels, semi-leptonic decay channels are not included.

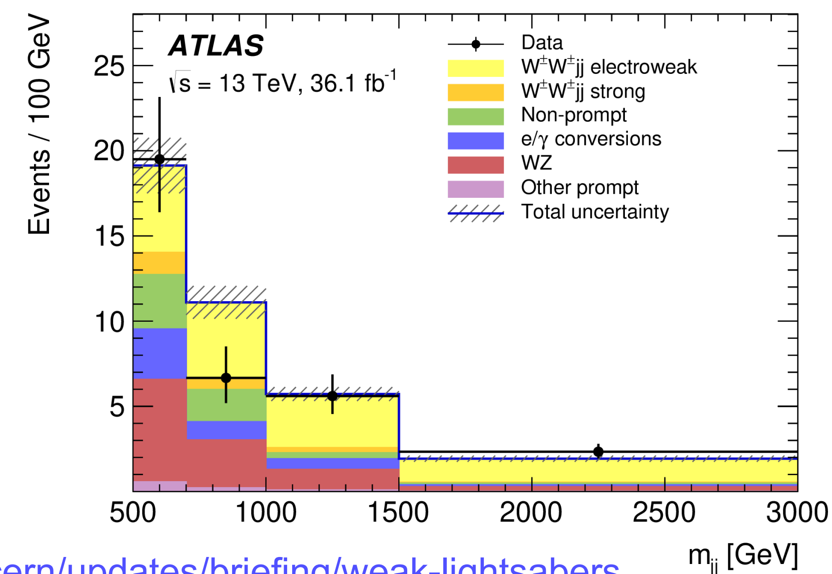
Same-sign WWjj

ATLAS Phys. Rev. Lett. 123 (2019) 161801

- 13TeV, 36.1fb^{-1}
- Dilepton channel
- Significance: 6.5σ(4.4σ)
- Cross-sections:
  - Measured: $\sigma^{fid} = 2.89^{+0.51}_{-0.48}(stat.)^{+0.24}_{-0.22}(exp.syst.)^{+0.14}_{-0.16}(mod\ syst.)^{+0.08}_{-0.06}(lumi)fb$
  - Predicted: $2.01^{+0.33}_{-0.23}fb$ (Sherpa) $3.08^{+0.45}_{-0.46}fb$ (Powheg+Pythia8)

	e^+e^+	e^-e^-	$e^+\mu^+$	$e^-\mu^-$	$\mu^+\mu^+$	$\mu^-\mu^-$	Combined
WZ	1.48 ± 0.32	1.09 ± 0.27	11.6 ± 1.9	7.9 ± 1.4	5.0 ± 0.7	3.4 ± 0.6	30 ± 4
Non-prompt	2.2 ± 1.1	1.2 ± 0.6	5.9 ± 2.5	4.7 ± 1.6	0.56 ± 0.05	0.68 ± 0.13	15 ± 5
e/γ conversions	1.6 ± 0.4	1.6 ± 0.4	6.3 ± 1.6	4.3 ± 1.1	—	—	13.9 ± 2.9
Other prompt	0.16 ± 0.04	0.14 ± 0.04	0.90 ± 0.20	0.63 ± 0.14	0.39 ± 0.09	0.22 ± 0.05	2.4 ± 0.5
$W^\pm W^\pm jj$ strong	0.35 ± 0.13	0.15 ± 0.05	2.9 ± 1.0	1.2 ± 0.4	1.8 ± 0.6	0.76 ± 0.25	7.2 ± 2.3
Expected background	5.8 ± 1.4	4.1 ± 1.1	28 ± 4	18.8 ± 2.6	7.7 ± 0.9	5.1 ± 0.6	69 ± 7
$W^\pm W^\pm jj$ electroweak	5.6 ± 1.0	2.2 ± 0.4	24 ± 5	9.4 ± 1.8	13.4 ± 2.5	5.1 ± 1.0	60 ± 11
Data	10	4	44	28	25	11	122





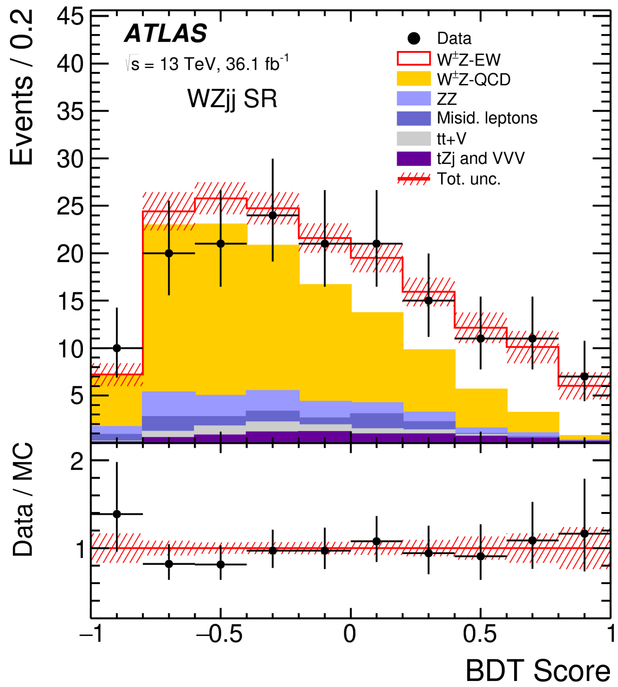
https://atlas.cern/updates/briefing/weak-lightsabers

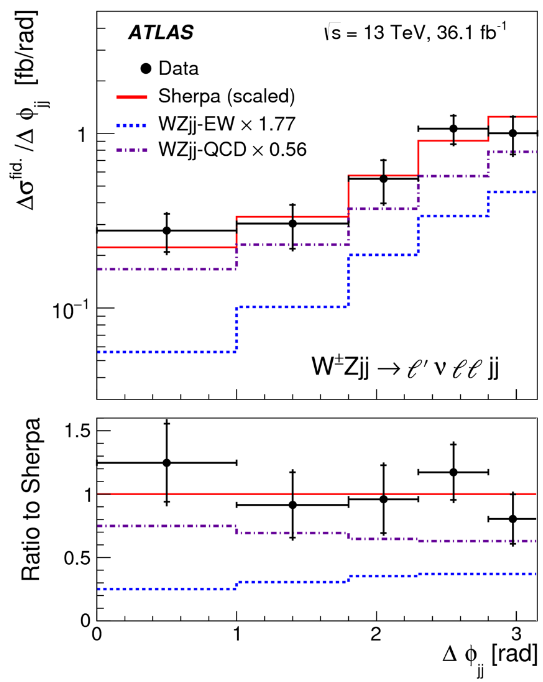
WZjj

ATLAS Phys. Lett. B 793 (2019) 469

- 13TeV, $36.1fb^{-1}$
- WZ decay leptonically
- Significance: $5.3\sigma(3.2\sigma)$
- Best fit results:

$$\mu_{EW} = 1.77^{+0.49}_{-0.43}$$





https://atlas.cern/updates/briefing/weak-lightsabers

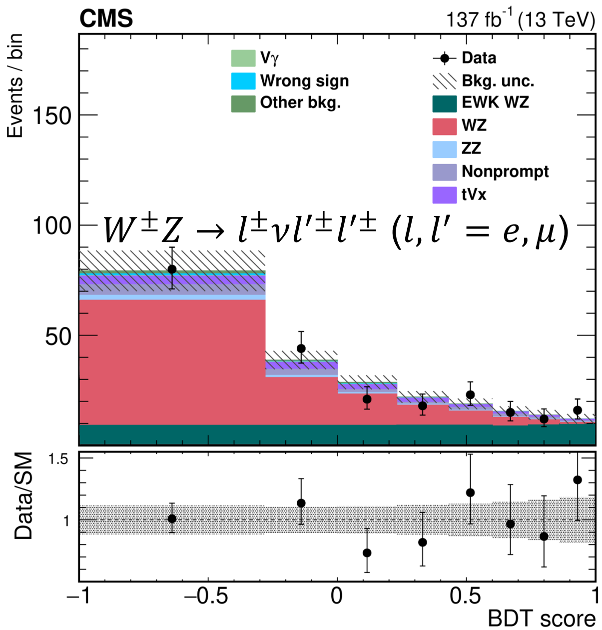
1^{st} differential measurement

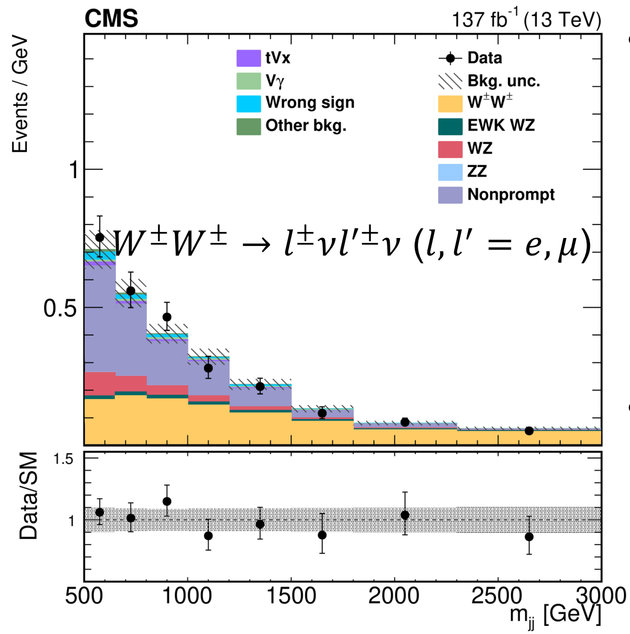
Same-sign WWjj & WZjj

CMS [Phys. Lett. B 809 (2020) 135710]

- 13TeV, 137fb^{-1}
- Leptonically decay
- Significance(WZ): 6.8σ(5.3σ)

	Observed ($W^{\pm}W^{\pm}$) (TeV^{-4})	Expected ($W^{\pm}W^{\pm}$) (TeV^{-4})	Observed (WZ) (TeV^{-4})	Expected (WZ) (TeV^{-4})	Observed (TeV^{-4})	Expected (TeV^{-4})
f_{T0}/Λ^4	[-0.28, 0.31]	[-0.36, 0.39]	[-0.62, 0.65]	[-0.82, 0.85]	[-0.25, 0.28]	[-0.35, 0.37]
f_{T1}/Λ^4	[-0.12, 0.15]	[-0.16, 0.19]	[-0.37, 0.41]	[-0.49, 0.55]	[-0.12, 0.14]	[-0.16, 0.19]
f_{T2}/Λ^4	[-0.38, 0.50]	[-0.50, 0.63]	[-1.0 , 1.3]	[-1.4, 1.7]	[-0.35, 0.48]	[-0.49, 0.63]
f_{M0}/Λ^4	[-3.0, 3.2]	[-3.7, 3.8]	[-5.8, 5.8]	[-7.6, 7.6]	[-2.7, 2.9]	[-3.6, 3.7]
f_{M1}/Λ^4	[-4.7, 4.7]	[-5.4, 5.8]	[-8.2, 8.3]	[-11, 11]	[-4.1, 4.2]	[-5.2, 5.5]
f_{M6}/Λ^4	[-6.0, 6.5]	[-7.5, 7.6]	[-12, 12]	[-15, 15]	[-5.4, 5.8]	[-7.2, 7.3]
f_{M7}/Λ^4	[-6.7, 7.0]	[-8.3, 8.1]	[-10, 10]	[-14, 14]	[-5.7, 6.0]	[-7.8, 7.6]
f_{S0}/Λ^4	[-6.0, 6.4]	[-6.0, 6.2]	[-19, 19]	[-24, 24]	[-5.7, 6.1]	[-5.9, 6.2]
f_{S1}/Λ^4	[-18, 19]	[-18, 19]	[-30, 30]	[-38, 39]	[-16, 17]	[-18, 18]





- Constraints are obtained on the structure of quartic vector boson interactions in the framework of EFT.
- Differential fiducial cross-sections also measured.

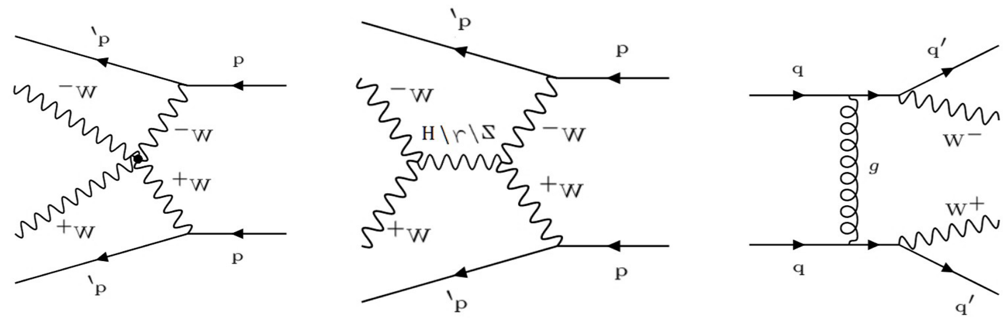
W⁺W⁻jj

CMS SMP-21-001

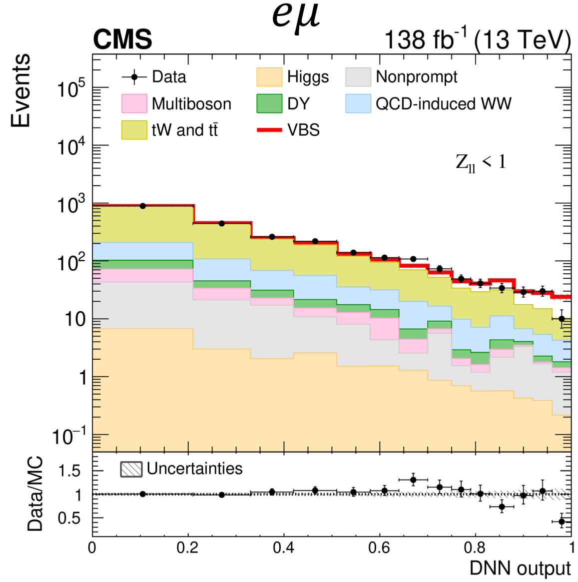
- 13TeV, $138fb^{-1}$
- Two opposite-sign leptons(e or μ)
- Main background: QCD W^+W^-, $t\bar{t}$,DY
- Significance: $5.6\sigma(5.2\sigma)$
- Cross-sections:

$$\sigma_{EW} = 10.2 \pm 2.0fb$$

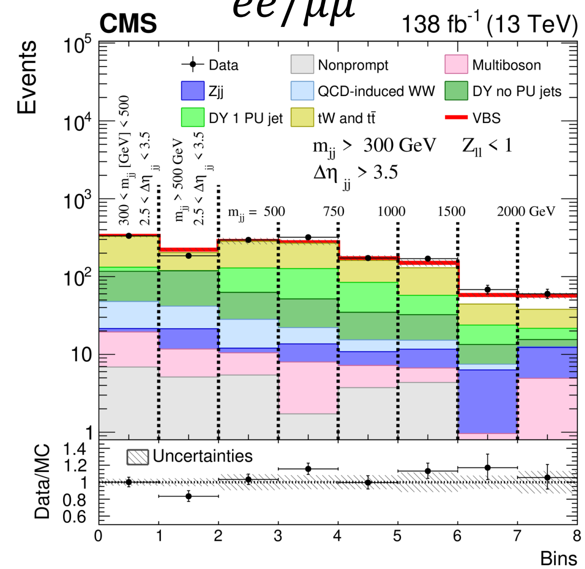
$$\sigma_{EW}^{Pred} = 9.1 \pm 0.6fb$$



$e\mu$



$ee/\mu\mu$

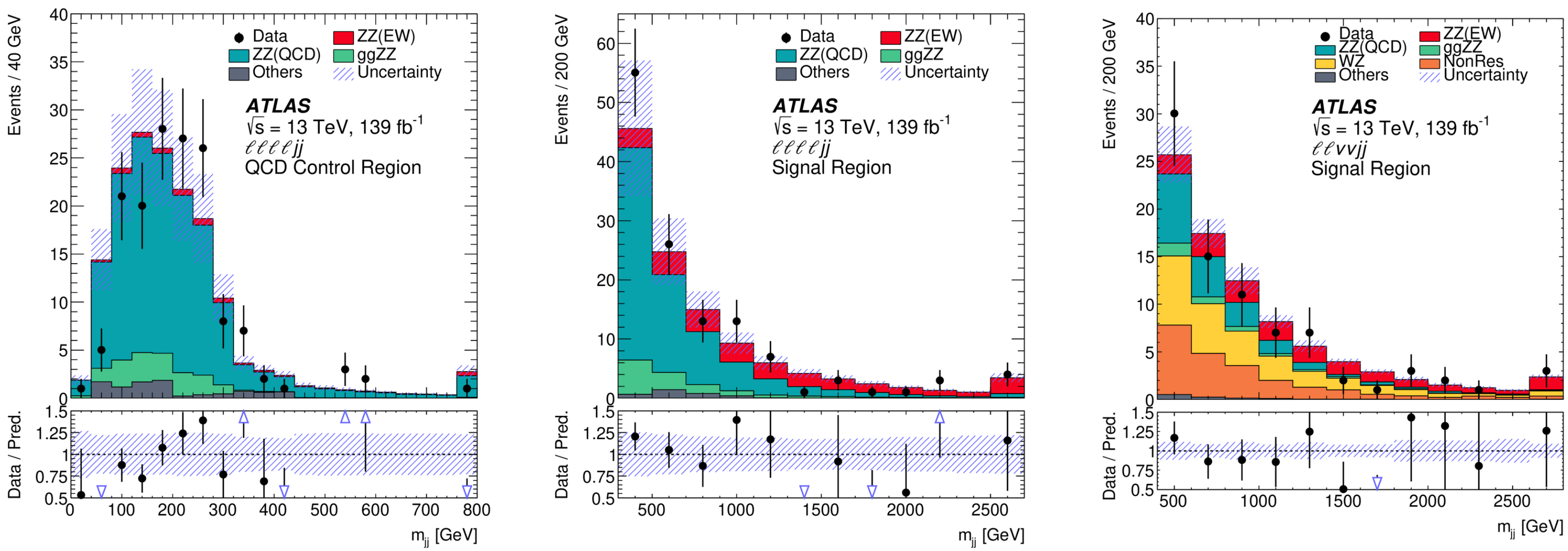


$$Z_{ll} = \frac{1}{2}\left|Z_{l_1} + Z_{l_2}\right|, Z_l = \eta_l - \frac{1}{2}(\eta_{j_1} + \eta_{j_2})$$

ZZjj

ATLAS arXiv:2004.10612

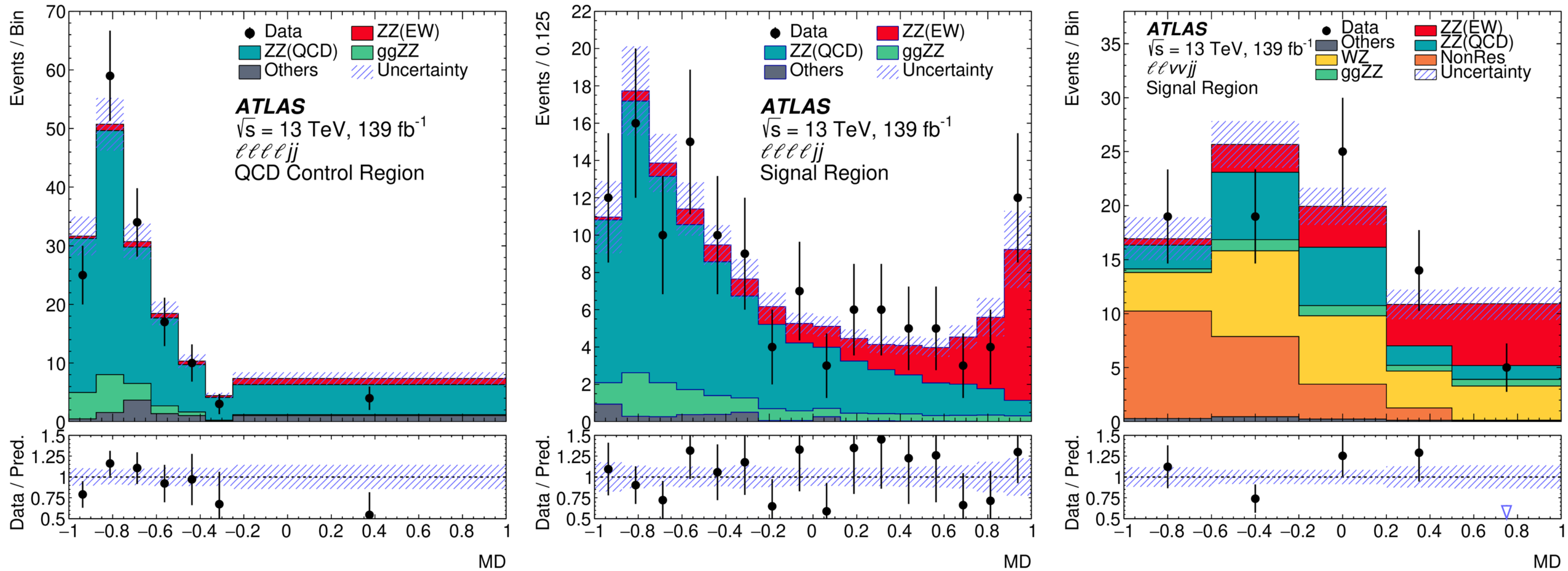
- 13TeV, 139fb^{-1}
- Measure the inclusive ZZjj cross-section (EW + QCD)
- Evidence on EW-ZZjj production
  - Combine $llll jj$ and $ll\nu\nu jj$, fit the multivariate analysis (MVA) output to extract the significance of EW component and signal strength
- Two channels: $llll jj$, $ll\nu\nu jj$
- Backgrounds:
  - $llll jj$: QCD background, fake lepton background, WWZ…
  - $ll\nu\nu jj$: Non-Resonant background, WZ background, Z+jets background, ZZ → $llll$,VVV, ttV, ttVV



ZZjj

ATLAS arXiv:2004.10612

- To extract EW process, a profile likelihood fit is performed on Gradient Boosted Decision Tree (BDTG) response.
- Observed and expected distributions:



- Significance: 5.5σ(4.3σ) $\sigma_{EW-ZZjj} = \mu_{EW} \times \sigma_{SM} = 0.82 \pm 0.21 fb$
- **Nature Physics has accepted the paper and now the team is working on proofing and journal layout quality control.**

https://atlas.cern/updates/briefing/milestone-electroweak-symmetry-breaking

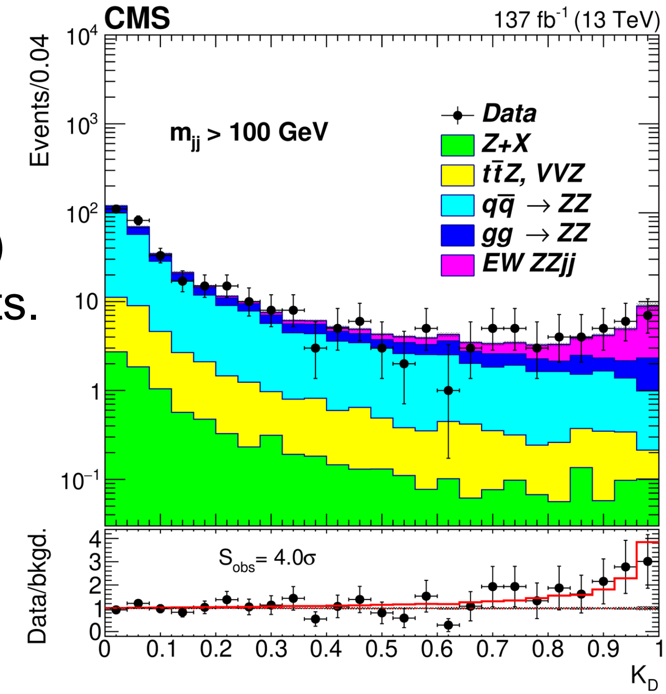
ZZjj

CMS Phys. Lett. B 812 (2020) 135992

- 13TeV, $137 fb^{-1}$
- Channel: $ZZ \to lll'l'$
- Discriminant based on a matrix element likelihood approach (MELA) for EW and EW+QCD measurements.
- Significance: $4.0\sigma(3.5\sigma)$
- Cross-sections:

$$\sigma_{EW} = 0.33^{+0.11}_{-0.10}\,(stat.)^{+0.04}_{-0.03}(syst.)fb$$

$$\sigma^{pred}_{EW} = 0.275 \pm 0.021 fb$$



Coupling	Exp. lower	Exp. upper	Obs. lower	Obs. upper	Unitarity bound
f_{T0}/Λ^4	−0.37	0.35	−0.24	0.22	2.4
f_{T1}/Λ^4	−0.49	0.49	−0.31	0.31	2.6
f_{T2}/Λ^4	−0.98	0.95	−0.63	0.59	2.5
f_{T8}/Λ^4	−0.68	0.68	−0.43	0.43	1.8
f_{T9}/Λ^4	−1.5	1.5	−0.92	0.92	1.8

$Z(ll)\gamma jj$

ATLAS ATLAS-CONF-2021-038

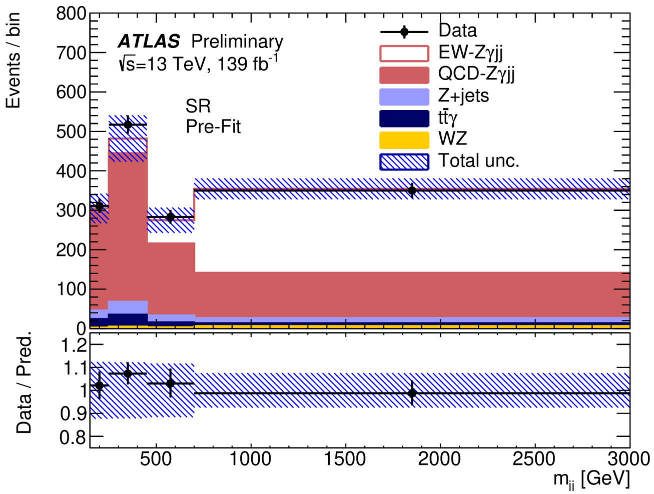
- 13TeV, $139 fb^{-1}$
- Channel: $Z(\rightarrow ee/\mu\mu)\gamma jj$
- EW component is extracted with a maximum likelihood on m_{jj} distribution.
- Simultaneously fit in SR and CR.
- Significance: $10\sigma(11\sigma)$
- Cross-sections:

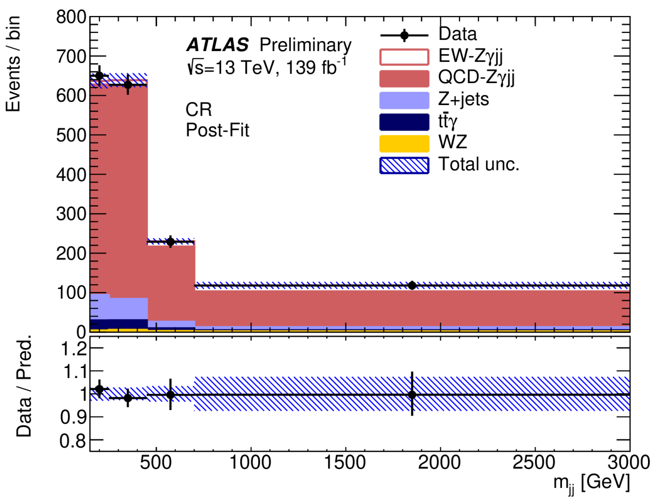
$$\sigma_{EW} = 4.49 \pm 0.40(stat.) \pm 0.42(syst.) fb$$

$$\sigma_{EW}^{pred} = 4.73 \pm 0.01(stat.) \pm 0.15(PDF)^{+0.23}_{-0.22}(scale) fb$$

$$\sigma_{EW+QCD} = 20.6 \pm 0.6(stat.)^{+1.2}_{-1.0}(syst.) fb$$

$$\sigma_{EW}^{pred} = 20.4 \pm 0.1(stat.) \pm 0.2(PDF)^{+2.6}_{-2.0}(scale) fb$$

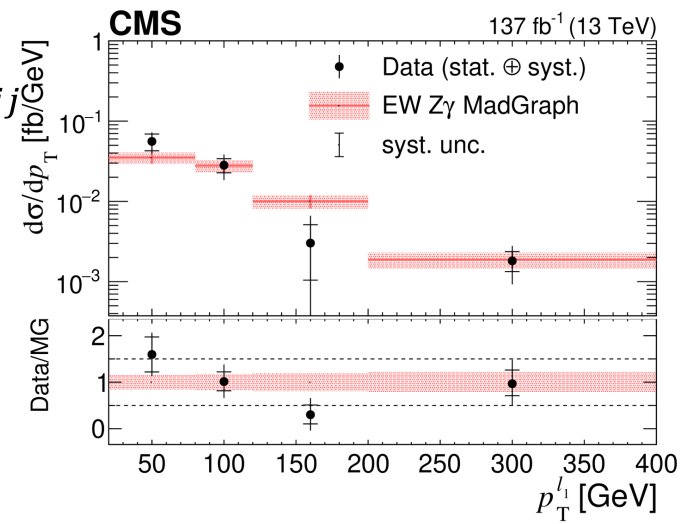


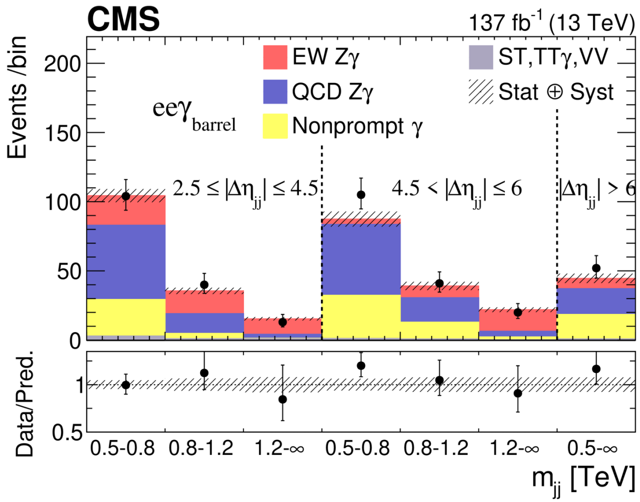


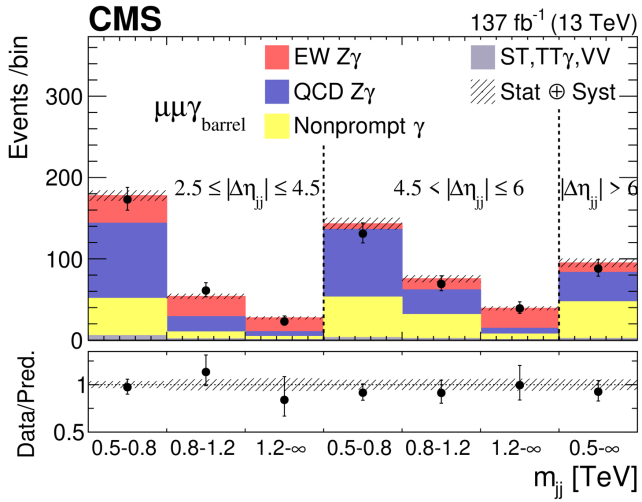
Z(ll)γjj

CMS PRD 104 (2021) 072001

- 13TeV, 137fb^{-1} • Channel: $Z(\to ee/\mu\mu)\gamma jj$
- Simultaneously fit in the SR with 2D m_{jj}- $\Delta\eta_{jj}$ binning and the CR with 1D m_{jj} binning in 4 categories for μ/e and barrel/endcap photon.
- Significance: 9.4σ(8.5σ)
- Exclusion limits on aQGC are derived at 95% CL in terms of the EFT operators M_0 to M_5, M_7, T_0 to T_2, and T_5 to T_9.



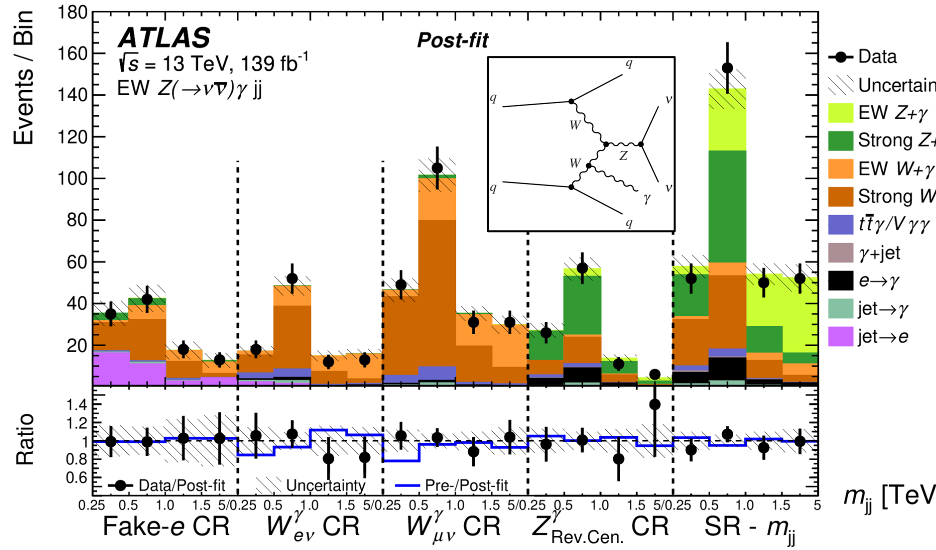


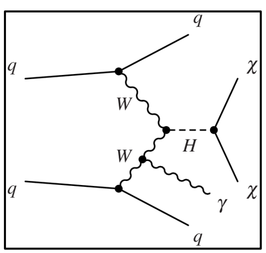


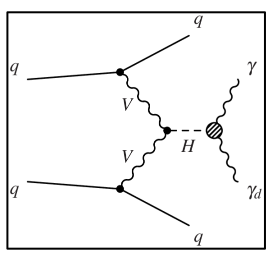
Z(νν)γjj

ATLAS [Eur. Phys. J. C 82 (2022) 105]

- 13TeV, 139fb^{-1}
- Channel: $Z(\rightarrow \nu\nu)\gamma jj$
- Main background: QCD Zγjj, Wγjj($W \rightarrow l\nu$, lepton not reconstructed in detector)
- Significance: 5.2σ(5.1σ)







- Cross-sections:

$$\sigma_{EW} = 1.31 \pm 0.2(stat.) \pm 0.2(syst.)fb$$

1st Observation of EW Zγjj process in neutrino channels

- Similar signatures used to provide strong constraints for:
  - Invisible Higgs decay search: $H(\rightarrow inv.)\gamma jj$
  - Higgs to dark photon: $H(\rightarrow \gamma\gamma_d)jj$

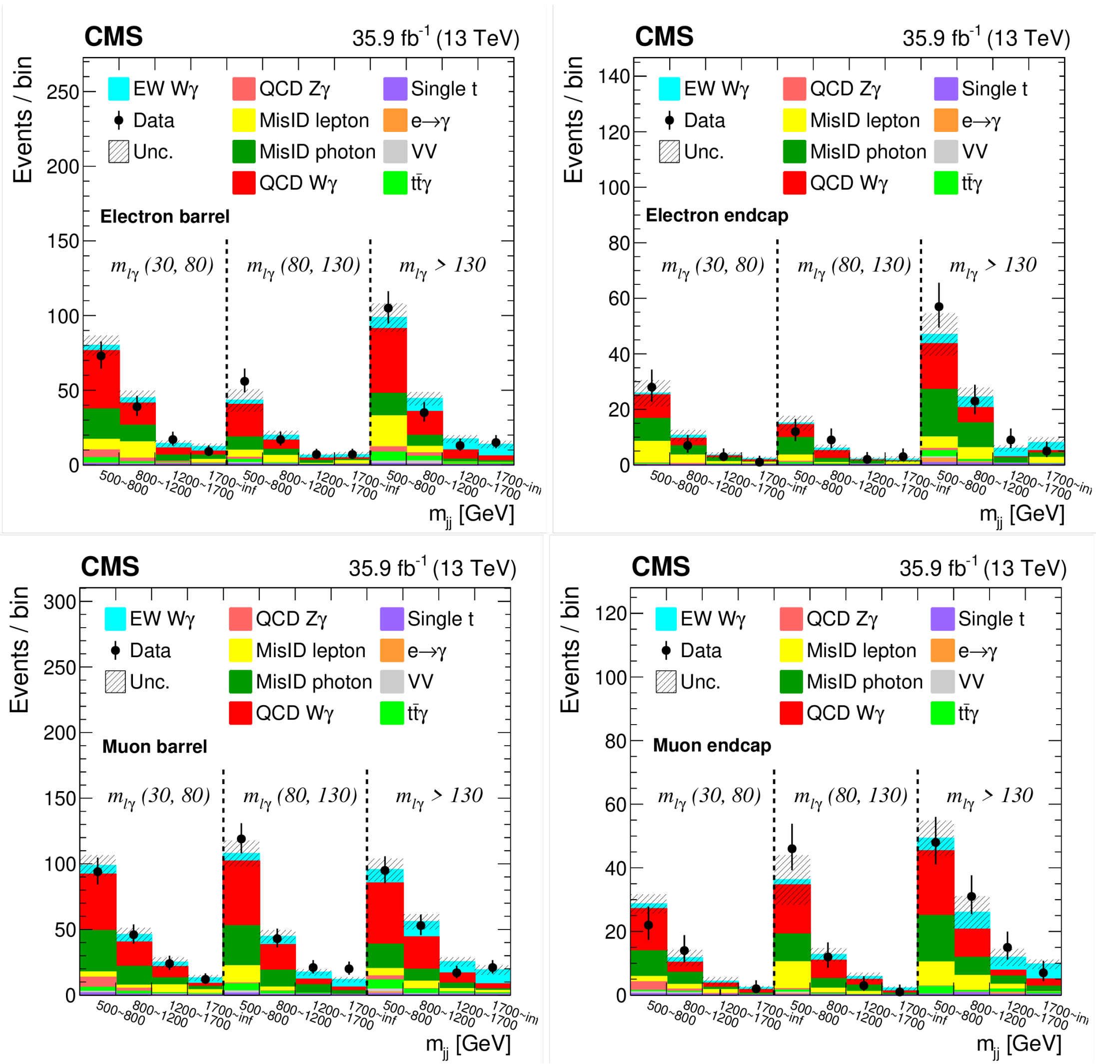
Branching ratio,95%CL →

$0.37(0.34^{+0.15}_{-0.10})$

$0.018(0.017^{+0.007}_{-0.005})$

Wγjj

CMS PLB 811 (2020) 135988



- 13TeV, $35.9fb^{-1}$
- First observation of EW $W\gamma$ production w/ leptonic final states.
- Significance: $5.3\sigma(4.8\sigma)$ combining CMS 13TeV & 8TeV datasets.
- Cross-sections:

$$\sigma_{EW} = 20.4 \pm 4.5fb$$

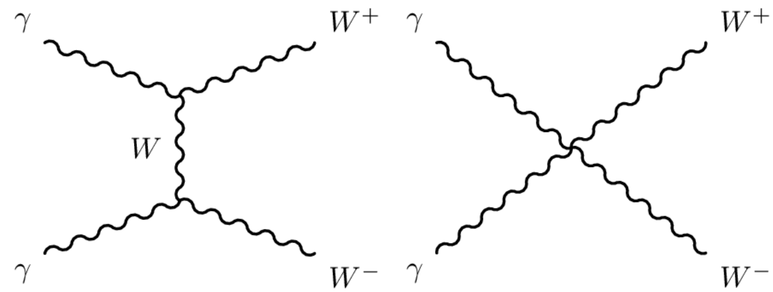
$$\sigma_{EW+QCD} = 108 \pm 16fb$$

- Constraints are placed on aQGC in terms of dimension-8 EFT operators.

$\gamma\gamma \rightarrow WW$

ATLAS Phys. Lett. B 816 (2021) 136190

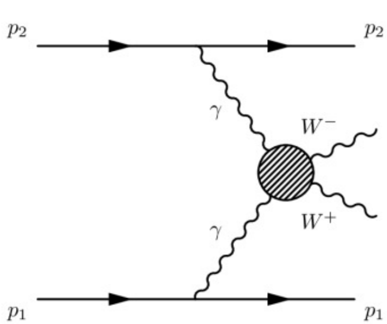
- 13TeV, 139fb^{-1}
- Photon-induced production of W-boson pairs, $WW \rightarrow e^{\pm}\nu\mu^{\pm}\nu$
- $\gamma\gamma \rightarrow WW$:
  - Trilinear and quartic gauge boson interactions.
  - At LO, only involves diagrams with self-couplings of the EW gauge bosons.



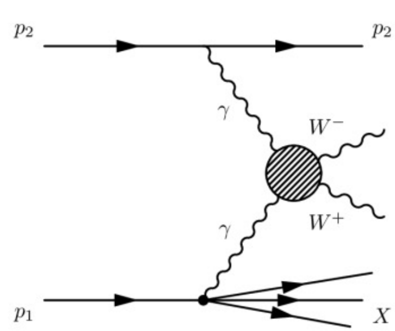
⇨ Directly test the gauge structure of the EW.

Sensitive to aTGC, aQGC.

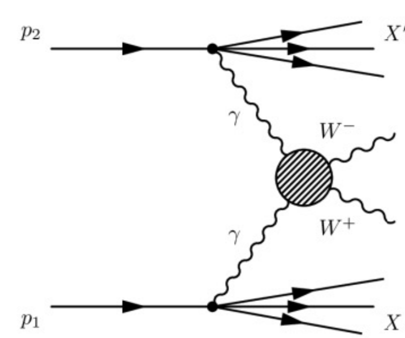
- Signal process: $pp(\gamma\gamma) \rightarrow p^{*}W^{+}W^{-}p^{*}$



elastic



single-dissociative



double-dissociative

$\gamma\gamma \rightarrow WW$

ATLAS [Phys. Lett. B 816 (2021) 136190]

- Signal characteristics:

  $n_{trk} = 0$

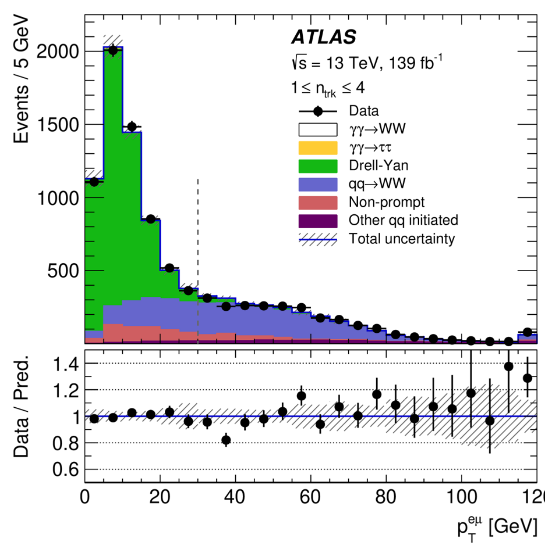
  Quark- and gluon-induced WW or top-quark production

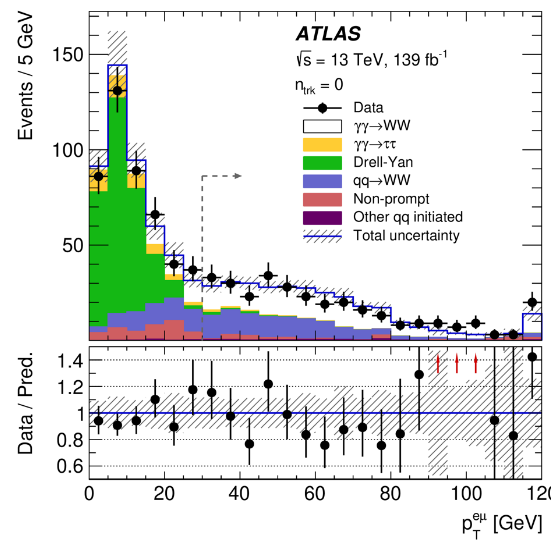
  $e\mu$

  $\gamma\gamma \rightarrow ll$

  $p_T^{e\mu} > 30GeV$

  $\gamma\gamma \rightarrow \tau\tau$





- Significance: $8.4\sigma(6.7\sigma)$
- Cross-sections:
  - measured: $3.13 \pm 0.31(stat.) \pm 0.28(syst.)fb$
  - predicted: $3.5 \pm 1.0fb$

Summary

- VBS observations in ATLAS and CMS:

ssWWjj, osWWjj, WZjj, ZZjj, Zγjj, Wγjj, $\gamma\gamma \rightarrow WW$

EFT interpretation

- More details of CMS $Z\gamma$, Wγ measurements can be found in

Measurement of the electroweak production of Zγ and two jets in proton-proton collisions at sqrt(s) = 13 TeV and constraints on anomalous quartic gauge couplings → **Ying An**

Measurement of electroweak production of Wgamma with two jets in proton-proton collisions at sqrt(s) = 13 TeV from CMS → **Jing Peng**

Backup

EW-VVjj production at 13TeV

$VVjj$	final states	$\sigma(VVjj\text{-EW})$ / fb	$\sigma(VVjj\text{-QCD})$ / fb
$W^\pm W^\pm$	$\ell\nu\ell\nu jj$	4.28 ± 0.01	1.69 ± 0.02
W^+W^-	$\ell\nu\ell\nu jj$	15.57 ± 0.08	35.24 ± 0.13
ZZ	$\ell\ell\nu\nu jj$	0.39 ± 0.01	0.55 ± 0.01
ZV	$\ell\ell jjjj$	0.98 ± 0.07	3.13 ± 0.22
$Z\gamma$	$\ell\ell\gamma jj$	9.24 ± 0.02	71.28 ± 0.33
WZ	$\ell\nu\ell\ell jj$	2.36 ± 0.01	7.19 ± 0.01
ZZ	$\ell\ell\ell\ell jj$	0.12 ± 0.01	0.21 ± 0.01

Philipp Anger's thesis

Production cross-section for EW and QCD VVjj production:

-All results are obtained from SHERPA

-Pre-VBS cuts applied

ssWWjj

ATLAS

Source	Impact [%]
Experimental	
Electrons	0.6
Muons	1.3
Jets and $E_{\mathrm{T}}^{\mathrm{miss}}$	3.2
b-tagging	2.1
Pileup	1.6
Background, statistical	3.2
Background, misid. leptons	3.3
Background, charge misrec.	0.3
Background, other	1.8
Theory modeling	
$W^{\pm}W^{\pm}jj$ electroweak-strong interference	1.0
$W^{\pm}W^{\pm}jj$ electroweak, EW corrections	1.4
$W^{\pm}W^{\pm}jj$ electroweak, shower, scale, PDF & α_s	2.8
$W^{\pm}W^{\pm}jj$ strong	2.9
WZ	3.3
Luminosity	2.4

WZjj

ATLAS

Source	Uncertainty [%]
$WZjj$–EW theory modelling	4.8
$WZjj$–QCD theory modelling	5.2
$WZjj$–EW and $WZjj$–QCD interference	1.9
Jets	6.6
Pile-up	2.2
Electrons	1.4
Muons	0.4
b-tagging	0.1
MC statistics	1.9
Misid. lepton background	0.9
Other backgrounds	0.8
Luminosity	2.1
Total Systematics	10.7

ZZjj

ATLAS

- **Event yields:**

Process	$\ell\ell\ell\ell jj$	$\ell\ell\nu\nu jj$
EW $ZZjj$	20.6 ± 2.5	12.3 ± 0.7
QCD $ZZjj$	77 ± 25	17.2 ± 3.5
QCD $ggZZjj$	13.1 ± 4.4	3.5 ± 1.1
Non-resonant-$\ell\ell$	–	21.4 ± 4.8
WZ	–	22.8 ± 1.1
Others	3.2 ± 2.1	1.2 ± 0.9
Total	114 ± 26	78.4 ± 6.2
Data	127	82

- The definition of fiducial regions are very similar with detector-level selections by using particle-level physics objects.
- Fiducial cross-sections for the inclusive production of the EW and QCD processes are measured separately in individual channels.

$$C = \frac{N_{detector-level}}{N_{FV-truth}} \qquad \sigma = \frac{N_{data} - N_{background}}{\mathcal{L} \times C}$$

***lllljj* C factor**	0.699 ± 0.031
***llvvjj* C factor**	0.216 ± 0.012

- **Cross-sections:**

	Measured fiducial σ [fb]	Predicted fiducial σ [fb]
$\ell\ell\ell\ell jj$	$1.27 \pm 0.12(\text{stat}) \pm 0.02(\text{theo}) \pm 0.07(\text{exp}) \pm 0.01(\text{bkg}) \pm 0.03(\text{lumi})$	$1.14 \pm 0.04(\text{stat}) \pm 0.20(\text{theo})$
$\ell\ell\nu\nu jj$	$1.22 \pm 0.30(\text{stat}) \pm 0.04(\text{theo}) \pm 0.06(\text{exp}) \pm 0.16(\text{bkg}) \pm 0.03(\text{lumi})$	$1.07 \pm 0.01(\text{stat}) \pm 0.12(\text{theo})$

ZZjj

ATLAS

- **Theoretical uncertainties:**

  - PDF, QCD scale, α_s, parton showering (PS).

  - Interference effect between the EW and QCD processes is 6.8%(2.3%) in $llll jj$($llvvjj$) channel. Treat as an extra uncertainty in the EW signal predictions.

  - Generator modelling uncertainty: estimated by comparing Sherpa with MadGraph5 _aMC@NLO 2.6.1 predictions at particle level.

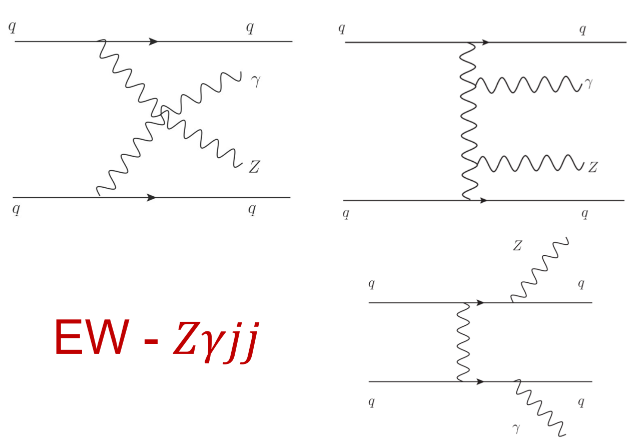
- **Experimental uncertainties:**

  - luminosity: 1.7%.
  - The momentum scale and resolution of leptons and jets, lepton reconstruction and selection efficiencies, trigger selection efficiency, the calculation of the E_T^{miss} soft-term, the pile-up correction, and the b-jet identification efficiency: 5-10%.
  - Jet pile-up uncertainty.

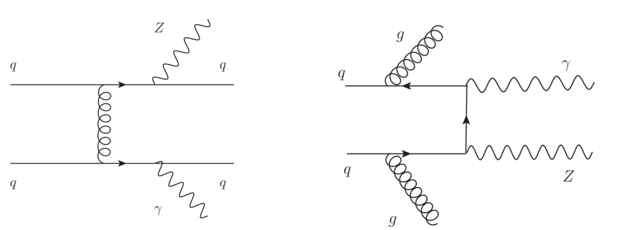
Zγjj

ATLAS ATLAS-CONF-2021-038

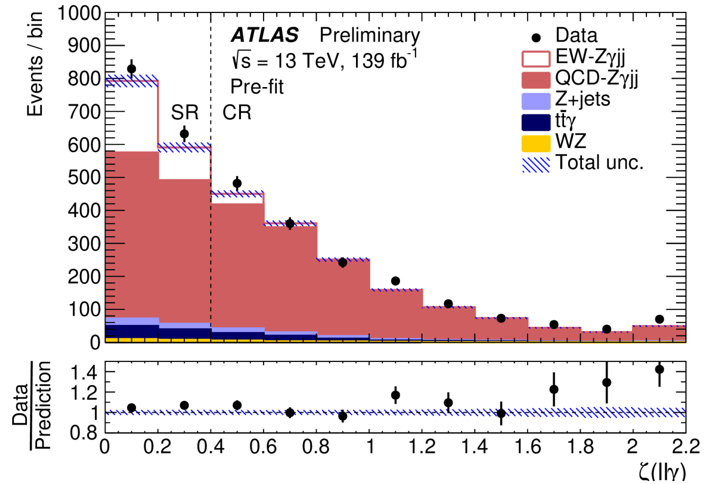
- 13TeV, $139 fb^{-1}$
- Channel: $Z(\rightarrow ee/\mu\mu)\gamma jj$



EW - $Z\gamma jj$



QCD - $Z\gamma jj$



Lepton	$p_T^\ell > 20, 30(\text{leading})$ GeV, $\lvert\eta_\ell\rvert < 2.47$ $N_\ell \geq 2$
Photon	$E_T^\gamma > 25$ GeV, $\lvert\eta_\gamma\rvert < 2.37$ $E_T^{cone20} < 0.07 E_T^\gamma$ $\Delta R(\ell,\gamma) > 0.4$
Jet	$p_T^{jet} > 50$ GeV, $\lvert y_{jet}\rvert < 4.4$ $\lvert\Delta y\rvert > 1.0$ $m_{jj} > 150$ GeV remove jets if $\Delta R(\gamma, j) < 0.4$ or if $\Delta R(\ell, j) < 0.3$
Event	$m_{\ell\ell} > 40$ GeV $m_{\ell\ell} + m_{\ell\ell\gamma} > 182$ GeV $\zeta(\ell\ell\gamma) < 0.4$ $N_{jets}^{gap} = 0$

Fiducial phase space

Zγjj

ATLAS

Source	Size [%]
Electron/photon calibration	± 0.3
Photon	± 0.3
Backgrounds	± 1.0
Electron	± 1.1
Flavour tagging	± 1.1
Muon	± 1.1
MC stat.	± 1.4
Pileup	± 2.6
Jets	± 4.7
QCD-Zγjj modelling	$^{+4.8}_{-4.3}$
EW-Zγjj modelling	$^{+5.7}_{-4.6}$
Data stat.	± 8.8
Total	$^{+13.4}_{-12.6}$

$\gamma\gamma \rightarrow WW$

ATLAS

Source of uncertainty	Impact [% of the fitted cross section]
Experimental	
Track reconstruction	1.1
Electron energy scale and resolution, and efficiency	0.4
Muon momentum scale and resolution, and efficiency	0.5
Misidentified leptons, systematic	1.5
Misidentified leptons, statistical	5.9
Other background, statistical	3.2
Modelling	
Pile-up modelling	1.1
Underlying-event modelling	1.4
Signal modelling	2.1
WW modelling	4.0
Other background modelling	1.7
Luminosity	1.7
Total	8.9