Measurement of Triboson Production and aQGCs with the ATLAS detector

Multi-Boson Interactions 2019

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Outline

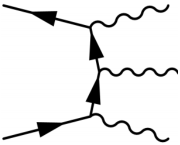
- Introduction to Standard Model triboson processes
- ATLAS triboson measurements and limits on anomalous quartic gauge couplings (aQGCs)
- Evidence for the production of three massive vector bosons
- Prospects

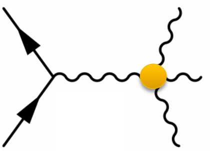
Why Triboson Measurements at the LHC?

- Triboson measurements: stringent tests of SM predictions in the EW sector
  - High luminosity and centre-of-mass energy allow **unprecedented sensitivity**

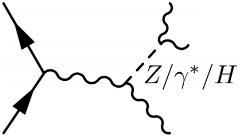
- Sensitivity to BSM via **anomalous gauge couplings** and **narrow resonances**
  - aQGC: fully neutral couplings forbidden within the SM at tree-level
  - Triboson BSM resonances: new era to be explored at the LHC
  - **Connecting EW to the Higgs sector**: accessible via $VH(\rightarrow VV)$, where $V = W/Z$

- Non-negligible source of **irreducible background** for Higgs/BSM/SM searches and measurements





QGC



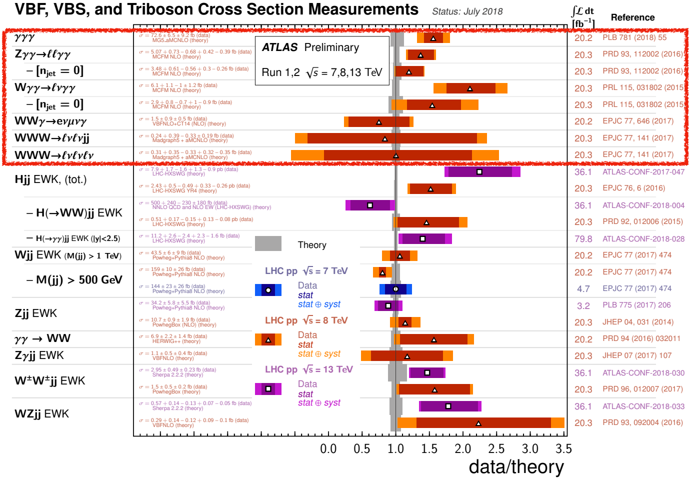
VH

Triboson Production at the LHC

- $\gamma\gamma\gamma$: test of perturbative QCD with γ in final state (**Phys. Lett. B781 (2018) 55**)
  - Measured σ yields $1.6 \times \sigma_{\mathrm{SM}}$, significant ($> 2\sigma$) **discrepancy**
- ***V*** $\gamma\gamma$: first triboson **observation** in ***Z*** $\gamma\gamma$ and **limits on** $ZZ\gamma/Z\gamma\gamma$ **couplings** (**Phys. Rev. D93 (2016) 112002**)
  - **Evidence** for ***W*** $\gamma\gamma$ (**JHEP 10 (2017) 072** & **Phys. Rev. Lett. 115 (2015) 031802**)
- ***WV*** γ: first attempt by CMS (**Phys. Rev. D90 (2014) 032008**) in the semileptonic final states
  - Observed limit 3.4 times larger than SM prediction and **no evidence for anomalous** ***WW*** $\gamma\gamma$ **and** ***WWZ*** γ **couplings**

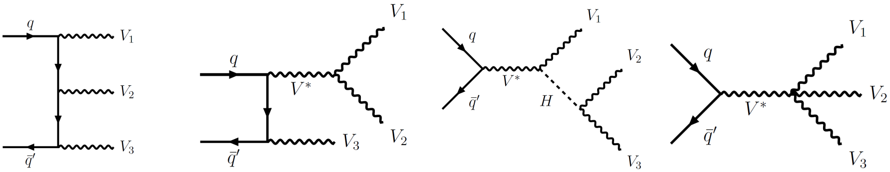
Triboson Production with ATLAS Detector

- Triboson processes, apart from pure $\gamma(Z)\gamma\gamma$, among the **least precisely measured!**
- Most triboson measurements still dominated by statistical uncertainties
  - **Hot prospects with increasing luminosity**
- ***WWW*** needs improvement, ***WWZ***, ***WZZ*** and ***ZZZ*** never attempted before



Production of *WVV* at the LHC

- Goal: search for the production of ***WVV*** ($V = W/Z$) in *pp* collisions
- Production of *WVV* is sensitive to both triple (**TGC**) and quartic gauge couplings (**QGC**)
- Off-shell production via *VH* treated as part of the signal definition
- Possibility to probe anomalous quartic gauge couplings (aQGCs)
  - Limits on aQGC are not evaluated for this paper, focus on cross-section measurement



- NLO corrections: QCD $\sim 100\%$ and EW $\sim 1 - 10\%^{(\star)}$
  - NLO QCD corrections are mandatory
  - NLO EW corrections small as compared to actual sensitivity, rise in boosted regime

($\star$) **JHEP 06 (2008) 082**, **JHEP 12 (2013) 096**, **JHEP 07 (2018) 076**

Overview of *WWW* and *WVZ* Analyses

- Focused on the search for the production of ***WWW***, ***WWZ*** and ***WZZ***
  - *ZZZ* has smaller cross section$\times$branching ratio $\rightarrow$ not yet sensitive

- Looking into two-, three- and four-light-lepton ($\ell = e, \mu$) final states
  - ***WWW***: semileptonic (**2ℓSS**) and fully leptonic channels (**3ℓ**)
  - ***WVZ***: semileptonic and fully leptonic channels (**3ℓ** and **4ℓ**)

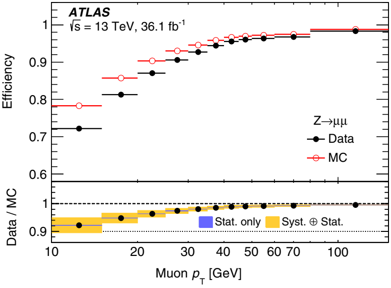
- Shape analysis to enhance sensitivity to signal processes
  - Constrain normalisation of relevant irreducible background processes

- ***WWW* cut-based, *WVZ* MVA-based**
  - *WWW*: accurate estimation of reducible backgrounds
  - *WVZ*: phase space split according to kinematic properties and MVA discriminants developed
  - **Complementarity** ensured by vetoing (requiring) a $Z \rightarrow \ell^+\ell^-$ candidate in *WWW* (*WVZ*)

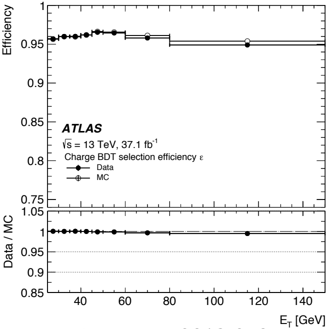
- **Combined profile likelihood fit** of discriminating shapes, single bins and a dedicated control region (CR)

Lepton Reconstruction & Selection

- More stringent definition of leptons in the *WWW* analysis, affected by a larger contamination from mis-reconstructed and non-prompt leptons
- In order to suppress reducible backgrounds all leptons in *WWW* and some of them (see later) in *WVZ* are required to fulfil:
  - **Nonprompt lepton** BDT requirement: reject leptons originating from heavy-flavour decays combining *b*-tagging related observables
  - **Charge-flip tagger** BDT requirement: reject electrons with misidentified electric charge



Phys. Rev. D 97 (2018) 072003



CERN-EP-2018-273

WWW - Event Selection

- Main analysis strategy: avoid (SF)OS leptons in 2ℓSS (3ℓ)
- $\boldsymbol{WWW \to \ell\nu\ell\nu qq}$: two same-sign leptons ($\ell^{\pm}\ell'^{\pm}$), missing transverse momentum ($E_{\mathrm{T}}^{\mathrm{miss}}$) and two jets with an invariant mass close to 80 GeV
  - At least 2 jets with *b*-jet veto
  - Specific $\Delta\eta_{jj}$ and m_{jj} cuts to reduce $W^{\pm}W^{\pm}$ contamination
  - Split phase space according to lepton flavour ($\boldsymbol{ee}$, $\boldsymbol{e\mu}$, $\boldsymbol{\mu e}$, $\boldsymbol{\mu\mu}$)
- $\boldsymbol{WWW \to \ell\nu\ell\nu\ell\nu}$: three leptons and $E_{\mathrm{T}}^{\mathrm{miss}}$
  - 0 SFOS requirement suppresses majority of backgrounds
  - *b*-jet veto is additionally applied to suppress $t\bar{t}$ events

	$WWW \to \ell\nu\ell\nu qq$	$WWW \to \ell\nu\ell\nu\ell\nu$
Lepton	Two leptons with $p_{\mathrm{T}} > 27(20)$ GeV and one same-sign lepton pair	Three leptons with $p_{\mathrm{T}} > 27(20, 20)$ GeV and no same-flavour opposite-sign lepton pairs
$m_{\ell\ell}$	$40 < m_{\ell\ell} < 400$ GeV	–
Jets	At least two jets with $p_{\mathrm{T}} > 30(20)$ GeV and $\lvert\eta\rvert < 2.5$	–
m_{jj}	$m_{jj} < 300$ GeV	–
$\Delta\eta_{jj}$	$\lvert\Delta\eta_{jj}\rvert < 1.5$	–
$E_{\mathrm{T}}^{\mathrm{miss}}$	$E_{\mathrm{T}}^{\mathrm{miss}} > 55$ GeV (only for *ee*)	–
Z boson veto	$m_{ee} < 80$ GeV or $m_{ee} > 100$ GeV (only for *ee* and μee)	
Lepton veto	No additional lepton with $p_{\mathrm{T}} > 7$ GeV and $\lvert\eta\rvert < 2.5$	
b-jet veto	No *b*-jets with $p_{\mathrm{T}} > 25$ GeV and $\lvert\eta\rvert < 2.5$	

Suppress *Z* decays

Suppress $W^{\pm}W^{\pm}$

Suppress most 3ℓ backgrounds

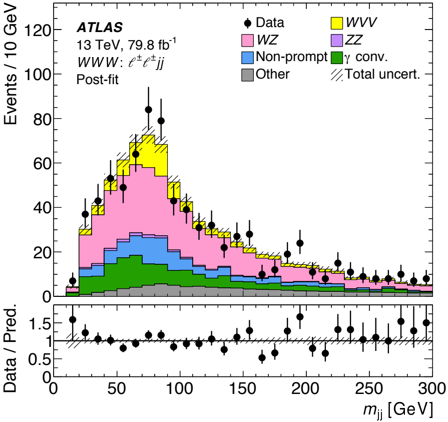
WWW - Background Composition

- Few SM processes can mimic these final states
- A large fraction of background processes is due to mis-reconstructed or mis-identified physics objects

WZ
Largest background

V+γ
A photon is reconstructed as an electron

Non-prompt
Mostly $t\bar{t}$ and W+j

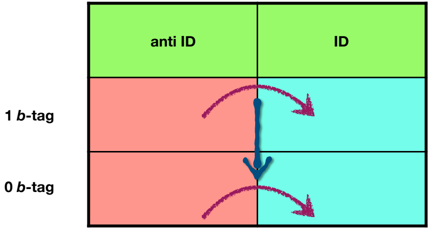


- $t\bar{t}$ dominates non-prompt sources in channels with μ
- Non-isolated anti-ID electrons and muons used to estimate the non-prompt background
- Non-prompt rates from regions similar to the 2ℓSS and 3ℓ SRs: the only difference is requiring exactly 1 *b*-tagged jet
- The non-prompt rate is determined by simultaneously fitting the following formula across all channels

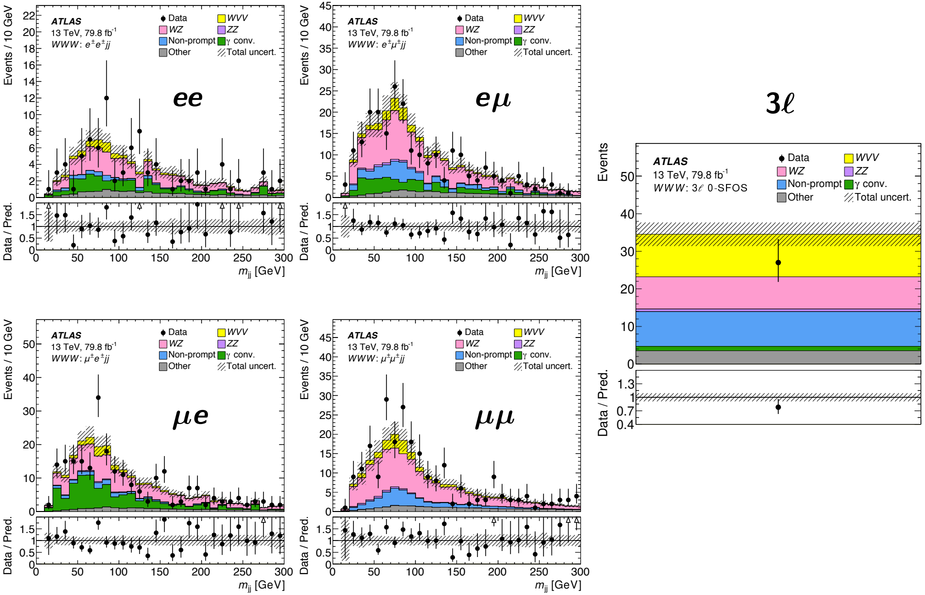
$$N_{\text{anti ID, ID, (ID)}} = Data_{\text{anti ID, ID, (ID)}} - \sum_i BG^i_{\text{anti ID, ID, (ID)}}$$

$$N_{\text{ID, ID, (ID)}} = Data_{\text{ID, ID, (ID)}} - \sum_i BG^i_{\text{ID, ID, (ID)}}$$

$$\text{Rate}_{\text{non-prompt}} = \frac{N_{\text{ID, ID, (ID)}}}{N_{\text{anti ID, ID, (ID)}}}$$



WWW - Pre-Fit Inputs



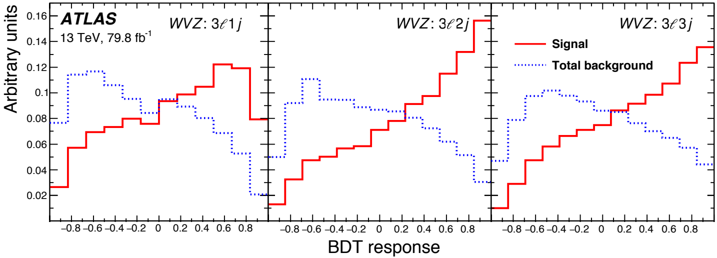
WVZ - Event Selection

- $Z \to \ell^+\ell^-$ candidate required: naturally orthogonal to *WWW* analysis
- Common selection
- $\boldsymbol{WVZ \to \ell\nu qq\ell\ell}$
  - At least one reconstructed jet
  - Scalar sum of lepton and jet p_{T} (H_{T}) above 200 GeV → suppress most of Z + jets
  - Phase space split according to number of jets: 1 (**3ℓ1j**), 2 (**3ℓ2j**) and ⩾ 3 (**3ℓ3j**)
- $\boldsymbol{WWZ \to \ell\nu\ell\nu\ell\ell}$ and $\boldsymbol{WZZ \to qq\ell\ell\ell\ell}$
  - 3rd and 4th p_{T} leading ℓ fulfilling Nonprompt and charge-flip reqs → suppress Z + jets
  - Categorising events according to whether the no-$Z \to \ell^+\ell^-$ lepton pair is same flavour (SF) or different flavour (**4ℓ DF**)
  - SF region further split into on-shell (**4ℓ on-shell SF**) and off-shell (**4ℓ off-shell SF**)

	$WVZ \to \ell\nu qq\ell\ell$	$WVZ \to \ell\nu\ell\nu\ell\ell/qq\ell\ell\ell\ell$
Z boson	At least one OS lepton pair with $\lvert m_{\ell\ell} - m_Z\rvert < 10$ GeV	
Low mass resonance veto	$m_{\ell\ell} > 12$ GeV for any OS lepton pair	
b-jet veto	No b-jets with $p_{\mathrm{T}} > 25$ GeV and $\lvert\eta\rvert < 2.5$	
Leptons	One additional nominal lepton	One additional OS lepton pair; third and fourth lepton nominal
H_{T}	$H_{\mathrm{T}} > 200$ GeV	–

- Prompt processes dominate background sources in WVZ channels
- WZ and ZZ dominate 3ℓ and 4ℓ channels, respectively
  - Train a Boosted Decision Tree (BDT) in each of the six regions
  - Combine background- and signal-like regions in a fully shape analysis
- Built several variables to separate $WVZ \to \ell\nu qq\ell\ell$ from $WZ + j$
  - Invariant masses for combinations of $W \to \ell\nu$, $V \to jj$ and $Z \to \ell\ell$ candidates
- Most discriminating variables in $3\ell1j$, $3\ell2j$ and $3\ell3j$:
  - total invariant mass of the system (leptons, jet and $E_{\mathrm{T}}^{\mathrm{miss}}$)
  - di-jet invariant mass
  - invariant mass of best $W \to jj$ candidate

$3\ell1j$ **$3\ell2j$** **$3\ell3j$**



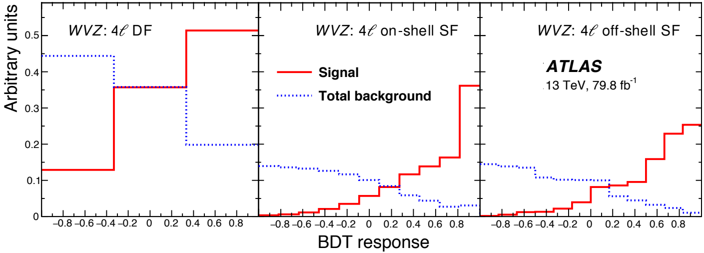
Strategy:

- 4ℓ DF region rich in *WVZ*, very sensitive to signal
- Half of $WWZ \to 4\ell$ and most of $WZZ \to 4\ell qq'$ expected in SF region
  - Dominated by *ZZ*, main 4ℓ background, this region allows constraint on its normalisation
- SF split in 4ℓ on-shell SF and 4ℓ off-shell SF to gain in sensitivity
  - Based on whether the invariant mass of the no-$Z \to \ell^+\ell^-$ lepton pair is within 10 GeV of the Z

Top-ranked MVA input variables in DF, on-shell SF and off-shell SF regions:

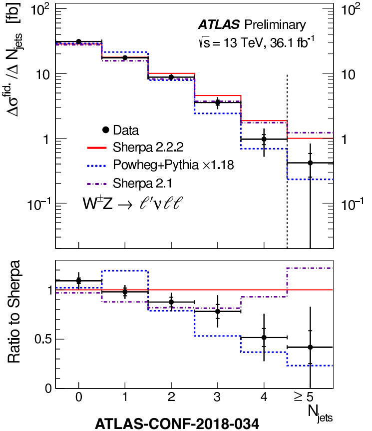
- no-$Z \to \ell^+\ell^-$ lepton pair invariant mass
- multiplicity of reconstructed jets
- E_T^{miss}

4ℓ DF **4ℓ on-shell SF** **4ℓ off-shell SF**



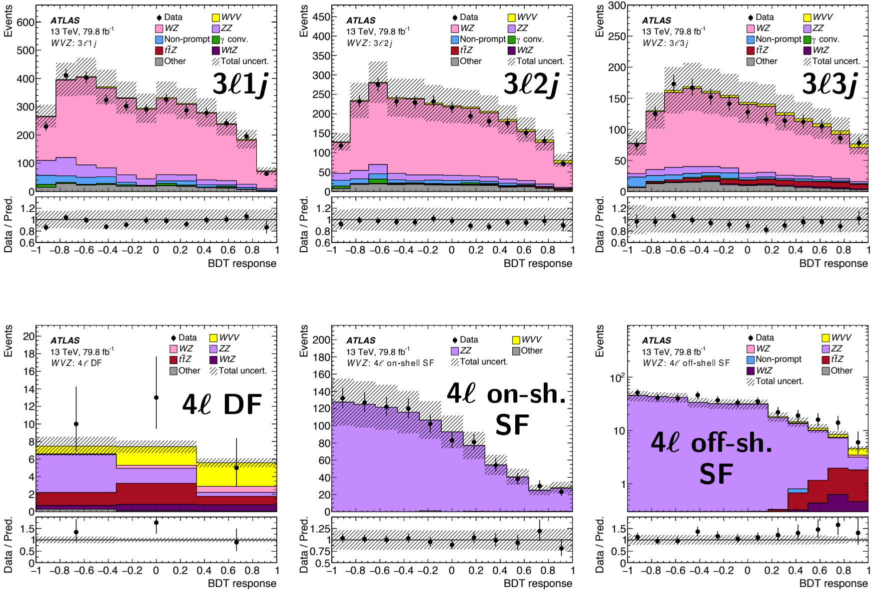
WVZ - NJet-based Reweighting

- Nice modelling of all relevant kinematic observables in 3ℓ and 4ℓ regions, but... jet multiplicity
  - Trend already observed by latest *WZ* (**ATLAS-CONF-2018-034**) and *ZZ* (**Phys. Rev. D97 (2018) 032005**) measurements
- Assumption: the poor description of the distributions is mainly due to *WZ* and *ZZ*, as they are dominating by far the regions at issue
- Two principles are underlying the reweighting procedure:
  - it is **shape-only**: *WZ* (*ZZ*) overall normalisation is unchanged with respect to the Sherpa prediction in 3ℓ (4ℓ);
  - it is **combined** in the two channels (*ZZ* contamination in the 3ℓ channel is non-negligible).
- A scale factor is extracted in each of the jet-multiplicity bins (0-1, 2, $\geqslant$ 3 jets)
- Significant improvement in the description of jet-related kinematical properties and no degradation in the modelling of observables related to leptons



ATLAS-CONF-2018-034

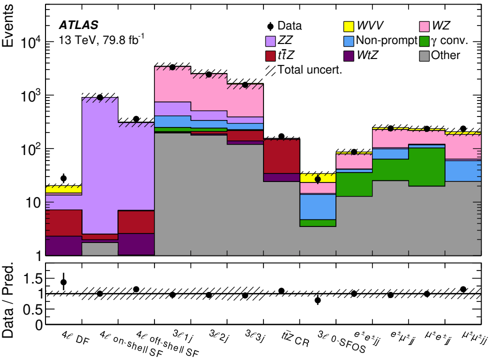
WVZ - Pre-Fit Inputs



WVV Combination - Overview and Fit Model

- Define one common signal strength μ_{WVV} for *WWW* and *WVZ* processes
- Inputs to the *WVV* combined fit
  - **2ℓSS**: m_{jj} distribution in each region (4×30 bins)
  - **3ℓ**: 1 bin from the *WWW* region, 12 + 13 + 13 bins from the *WVZ* regions and 1 bin from a dedicated $t\bar{t}Z$ CR ($\geqslant$ 4 jets & $\geqslant$ 2 *b*-tagged)
  - **4ℓ**: $3 + 12 + 11 = 26$ bins
  - $\rightarrow$ grand total of **186 bins** entering the **combined fit**
- Correlated systematics
  - experimental uncertainties
  - irreducible background (theory)
- Uncorrelated systematics
  - reducible background: data-driven in *WWW*, pure simulation in *WVZ*

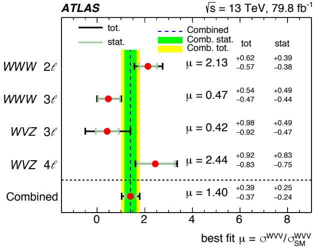
Pre-fit summary

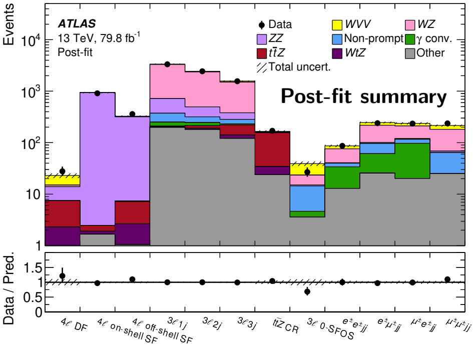


WVV Combination - Fit Results

- Expected: $\mu_{WVV}^{\text{Asimov}} = 1^{+0.36}_{-0.34} = 1^{+0.24}_{-0.24}\,(\text{stat.})\ ^{+0.27}_{-0.24}\,(\text{syst.})$
- Observed: $\mu_{WVV}^{\text{Data}} = 1.40^{+0.39}_{-0.37} = 1.40^{+0.25}_{-0.24}\,(\text{stat.})\ ^{+0.30}_{-0.27}\,(\text{syst.})$
- Exclusion of background-only hypothesis: **evidence**
  - *WVV* (expected and observed)
  - $WWW \to 2\ell$ and $WVZ \to 4\ell$ (observed)

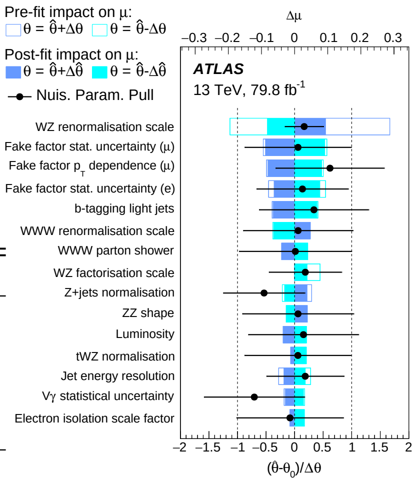
Decay channel	Significance Observed	Significance Expected
WWW combined	3.2σ	2.4σ
$WWW \to \ell\nu\ell\nu qq$	4.0σ	1.7σ
$WWW \to \ell\nu\ell\nu\ell\nu$	1.0σ	2.0σ
WVZ combined	3.2σ	2.0σ
$WVZ \to \ell\nu qq\ell\ell$	0.5σ	1.0σ
$WVZ \to \ell\nu\ell\nu\ell\ell/qq\ell\ell\ell\ell$	3.5σ	1.8σ
WVV combined	4.1σ	3.1σ



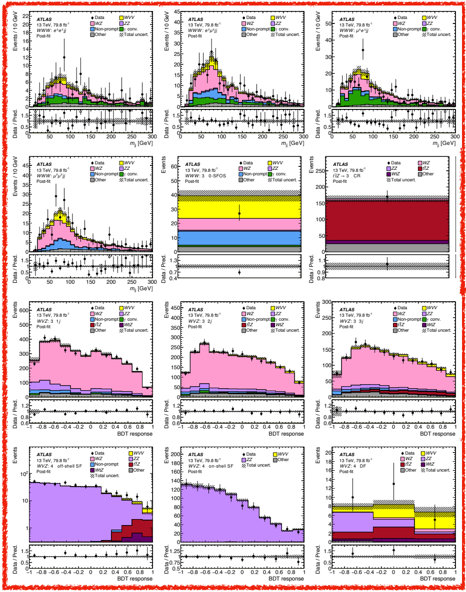


- Constraints and pulls compatible with *WWW* and *WVZ* standalone fits
- Largest impact from data-driven estimation and theory uncertainties

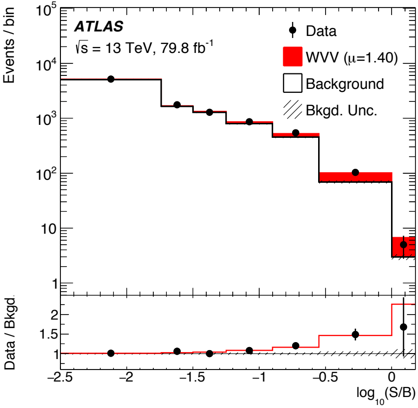
Uncertainty source	$\Delta\mu_{WVV}$	
Data-driven	+0.14	−0.14
Theory	+0.15	−0.13
Instrumental	+0.12	−0.09
MC stat. uncertainty	+0.06	−0.04
Generators	+0.04	−0.03
Total systematic uncertainty	+0.30	−0.27



WVV Combination - Post-Fit Plots

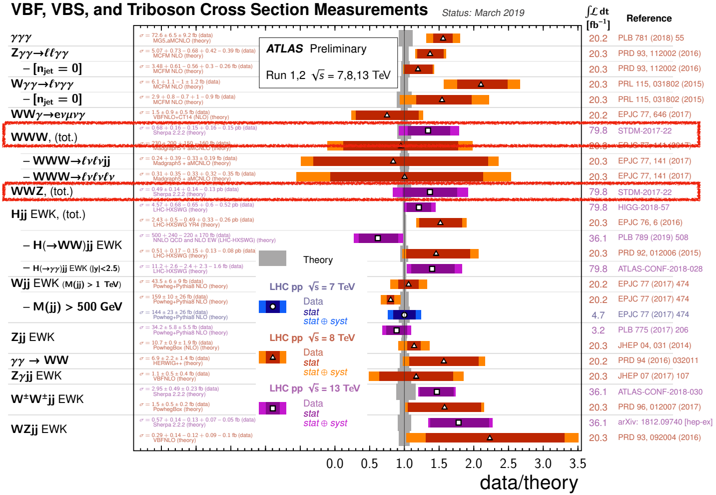


Sort bins according to S/B and merge bins



Extraction of Cross Sections

- Extract: σ_{WWW} and σ_{WWZ}
  - Limited sensitivity to WZZ → fixed to SM prediction
- Results: $\sigma_{WWW} = 0.65^{+0.23}_{-0.21}$ pb and $\sigma_{WWZ} = 0.55^{+0.21}_{-0.19}$ pb



Summary

- Expected evidence combining four WVV channels:
  - $WWW \to 3\ell$: 2.0σ
  - $WVZ \to 4\ell$: 1.8σ
  - $WWW \to 2\ell$: 1.7σ
  - $WVZ \to 3\ell$: 1.0σ
  - ➡ $\boldsymbol{WVV}$ **:** $\boldsymbol{3.1\sigma}$
- Best-fit $\mu_{WVV} = 1.40^{+0.25}_{-0.24}$ (stat.) $^{+0.30}_{-0.27}$ (syst.)
  - Observed significance above 3σ in WVV($\boldsymbol{4.1\sigma}$), $WWW \to 2\ell$ and $WVZ \to 4\ell$
- Cross-section measurement
  - $\sigma_{WWW} = 0.65^{+0.23}_{-0.21}$ pb
  - $\sigma_{WWZ} = 0.55^{+0.21}_{-0.19}$ pb
- **Evidence for the Standard Model production of three massive vector bosons**
- Road to 5σ: improvements in data-driven estimation and VV theory uncertainties

BACKUP

Loose muons

- Medium (loose) ID in *WWW* (*WVZ*)
- Gradient (FixedCutLoose) isolation in *WWW* (*WVZ*)
- $|\eta| < 2.5$
- $p_{\mathrm{T}} > 20(15)$ GeV in *WWW* (*WVZ*)
- $|z_0 \sin\theta| < 0.5$ mm
- $d_0/\sigma_{d_0} < 3$

Loose electrons

- Tight (loose) ID in *WWW* (*WVZ*)
- FixedCutLoose isolation
- $|\eta| < 2.47$
- crack region: $|\eta| < 1.37$ or $|\eta| > 1.52$
- $p_{\mathrm{T}} > 20(15)$ GeV in *WWW* (*WVZ*)
- $|z_0 \sin\theta| < 0.5$ mm
- $d_0/\sigma_{d_0} < 5$

Jets

- AntiKt4TopoEM collection
- $p_{\mathrm{T}} > 25$ GeV and JVT cut
- $|\eta| < 2.5$

Triggers

- Lowest ATLAS unprescaled single-lepton triggers

Overlap removal

Keep	Remove	Cone size (ΔR) or track
electron	electron (lower p_{T})	shared track
electron	CT muon	shared track
muon	electron	shared track
electron	jet	0.2
jet	electron	0.4
muon	jet	0.2
jet	muon	0.4

All Lepton Definitions

Lepton defintion	Quality	Minimum p_{T}	Isolation	Maximum $\|d_0\|/\sigma_{d_0}$	Maximum $\|z_0 \sin\theta\|$	n.p.l. BDT	ch.mis. BDT
Nominal e	Tight	15 GeV	Fix (Loose)	5	0.5 mm	yes	yes
Nominal μ WWW	Medium		Gradient	3			–
Nominal μ WVZ	Loose		FixCutLoose	3			–
Loose e	Loose	15 GeV	no	5	0.5 mm	no	no
Loose μ				3			–
Veto e	Loose	7 GeV	no	no	no	no	no
Veto μ	Loose and $\|\eta\| < 2.7$						–
Fake e	Medium not Tight	15 GeV	no	5	0.5 mm	no	no
Fake μ	Not nominal WWW			10			–
Photon-like e	Defined as for nominal, but no hit in first pixel layer					no	no

Logical OR of five single-lepton triggers per data period

Trigger	2015	2016	2017
HLT_e24_lhmedium_L1EM20VH	×		
HLT_e60_lhmedium	×		
HLT_e120_lhloose	×		
HLT_mu20_iloose_L1MU15	×		
HLT_mu50	×	×	×
HLT_mu26_ivarmedium		×	×
HLT_e26_lhtight_nod0_ivarloose		×	×
HLT_e60_lhmedium_nod0		×	×
HLT_e140_lhloose_nod0		×	×

WWW

WWW - Non-Prompt Lepton Estimation

- In channels with μ the non-prompt background, dominated by $t\bar{t}$, is the second largest background
- Usage of non-isolated anti-ID electron and muon definitions to estimate the non-prompt background
- Non-prompt rates from regions similar to the 2ℓSS and 3ℓ SRs: the only difference is requiring exactly 1 b-tagged jet
- The non-prompt rate is determined by simultaneously fitting the following formula across all channels

$$N_{\text{anti ID, ID, (ID)}} = Data_{\text{anti ID, ID, (ID)}} - \sum_i BG^i_{\text{anti ID, ID, (ID)}}$$

$$N_{\text{ID, ID, (ID)}} = Data_{\text{ID, ID, (ID)}} - \sum_i BG^i_{\text{ID, ID, (ID)}}$$

$$\text{Rate}_{\text{non-prompt}} = \frac{N_{\text{ID, ID, (ID)}}}{N_{\text{anti ID, ID, (ID)}}}$$

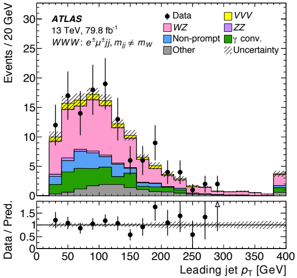
- Closure test shows that ID lepton shapes are well modelled by anti-ID leptons

BTag CR 3l
We require exactly 3 leptons
Lepton Pt 27,20,20
0 Same Flavor Opposite Sign Lepton Pairs
Exactly 1 B-tagged Jet

BTag CR 2l
Exactly 2 same-sign leptons
Lepton Pt > 20 (27) Jet Pt > 20 (30)
40 GeV<Mll<400 GeV | Mll - 90 | > 10 GeV (ee Only)
Mjj <300 GeV |DEtaJJ| <1.5
MET > 55 GeV (ee Only)

- The $V+\gamma$ (mostly $V=W$) background is an important background in the 2ℓSS channels with electrons
- Poor MC available statistics and modelling: data-driven estimation, similar to non-prompt background one
- Perform estimation in a region where a Z peak with 3 leptons is reconstructed: $Z(\rightarrow\mu\mu)+\gamma$
- "Photon-like electron": no hit found in the innermost layer of the pixel detector, and the Nonprompt lepton and charge-flip tagger BDT requirements are not applied
- Use photon-like (instead of anti-ID) electrons to define an orthogonal region of data enriched in $\gamma\rightarrow e$
- Well-behaved data-driven estimations of non-prompt and fake leptons

Zgamma Region
We require exactly 3 leptons
Lepton Pt 27,20,20
1 SFOS (**μμe**)
80 GeV < Mlll < 100 GeV
N-bjets == 0



WVZ

3ℓ MVA Inputs

Input Variable	3ℓ-1j	3ℓ-2j	3ℓ-3j
$m_{3\ell}$	5	4	5
$m_{\ell_0\ell_1}$	7	9	
$m_{\ell_0\ell_2}$	8	8	
$m_{\ell_1\ell_2}$	10	10	
leading jet p_{T}	12	14	
$p_{\mathrm{T}}^{\ell_0}$	3	3	
$p_{\mathrm{T}}^{\ell_1}$	6	5	8
$p_{\mathrm{T}}^{\ell_2}$	9	12	9
$E_{\mathrm{T}}^{\mathrm{miss}}$		6	11
$\Sigma p_{\mathrm{T}}(\ell)$	2	2	4
$\Sigma p_{\mathrm{T}}(j)$			2
H_{T}	4	7	
total lepton charge	13	15	12
invariant mass of all leptons, jets and $E_{\mathrm{T}}^{\mathrm{miss}}$	1		7
invariant mass of the best $Z \to \ell\ell$ and leading jet	11		
sub-leading jet p_{T}		11	3
m_{jj} for the two leading p_{T} jets		1	
$m_{\mathrm{T}}^{W\to\ell\nu}$		13	
number of reconstructed jets			10
$m_{jj}^{\mathrm{best}\ W}$			1
smallest m_{jj}			6

Input Variable	DF	on-shell SF	off-shell SF
number of reconstructed jets	6	4	6
$m_{4\ell}$	3	6	4
$E_{\mathrm{T}}^{\mathrm{miss}}$	4	1	1
$H_{\mathrm{T}}^{\mathrm{lep}}$	1		
$H_{\mathrm{T}}^{\mathrm{had}}$	5		
$m_{\ell\ell}^{\text{second best pair}}$	2	3	2
$m_{\ell\ell}^{\text{best } Z}$		5	5
H_{T}		2	3

WVV

Stability of the Combined fit

Performed *WVV* combined fit with four alternative configurations:

- without applying the jet-multiplicity based reweighting in *WVZ*
- treating the diboson scale uncertainties uncorrelated across regions
- letting diboson background free to float (instead of 20% prior)
- treating signal theory uncertainties (Sherpa's renormalisation and factorisation scales) correlated between the *WVZ* and *WWW* processes

All results are compatible with the nominal configuration; e.g.:

- diboson floating: $\mu_{WVV} = 1.40^{+0.39}_{-0.37}$ and $\mu_{WZ} = 0.96 \pm 0.05$, $\mu_{ZZ} = 1.02 \pm 0.05$
- signal scales correlated: $1.39^{+0.39}_{-0.37}$ (vs. nominal: $1.40^{+0.39}_{-0.37}$)