Measurements of cross-sections in Higgs boson decays to two W bosons with the ATLAS detector

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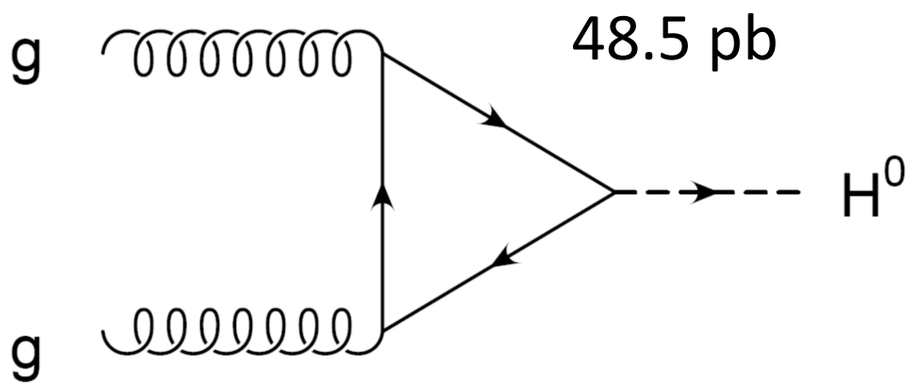
EPS-HEP2019

Higgs →WW* production

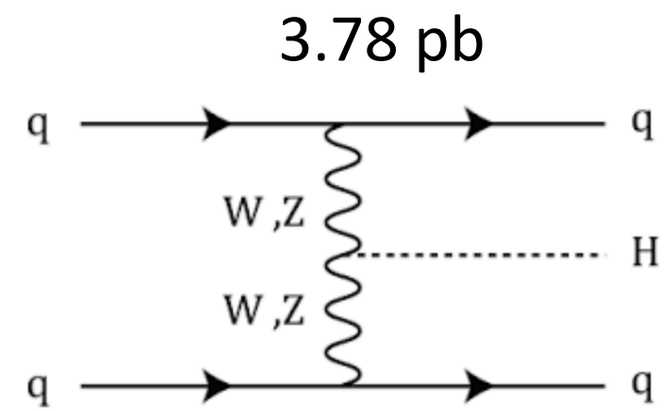
This talk will concentrate on the ggF, VBF and VH production modes, followed by the decays H→WW*

Gluon-fusion: ggF



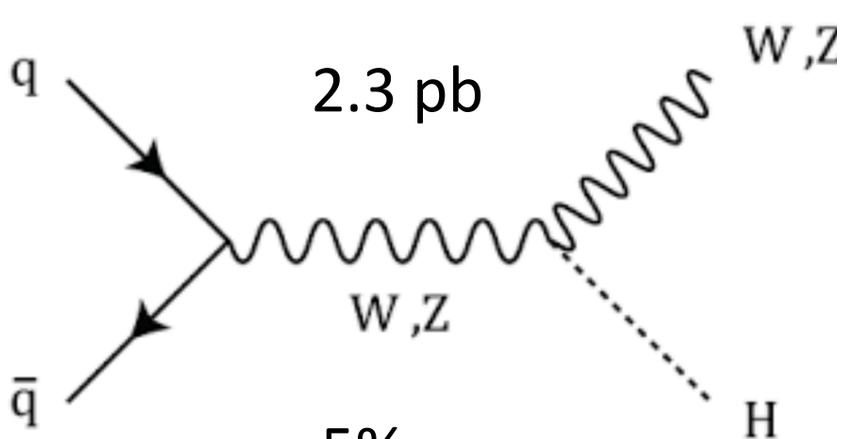
~ 87%

Vector boson fusion: VBF



~7%

Associated production VH



5%
(3%WH, 2% ZH)

ggF is the dominant production process
VBF and VH production modes, are cleaner:

- VBF is characterized by 2 jets with large $\Delta\eta_{jj}$ and m_{jj}
- VH by additional leptons, jets or larger MET

Higgs $\longrightarrow$WW* decay

	BR(%)
bb	57
WW	22
$\tau\tau$	6.2
ZZ	2.8
$\gamma\gamma$	0.23
Zγ	0.15

The H->WW*$\rightarrow$lvlv decay accounts for 1.5% of the overall final states

- is more abundant than the h$\rightarrow$ZZ$\rightarrow$4l or h$\rightarrow\gamma\gamma$
- is cleaner than h$\rightarrow$bb which is affected by large backgrounds

Characterized by

- the presence of 2 leptons with small opening angle
- requiring different flavor leptons helps reducing further the backgrounds
- the presence of 2 neutrinos that prevent a full reconstruction of the Higgs mass, contrary to the ZZ and $\gamma\gamma$ final states

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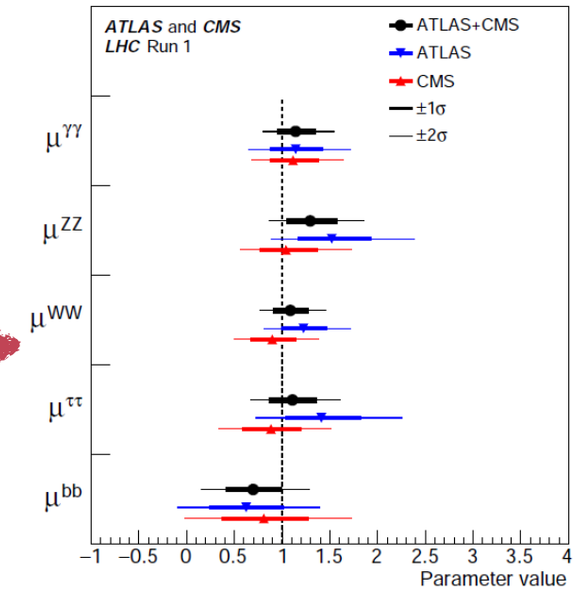
ggF and VBF analysis

Selection close to the run I analysis. The ggf run I analysis gave most precise signal strength among all Higgs channels.



Analysis at 13 TeV on 36.1 fb^{-1} (2015+2016):

- 1 e +1 μ opposite sign (p_T>22/15 GeV)
- MET

ggF selection: 0, 1 jet required (p_{Tj}>30 GeV)
VBF selection at least 2 jets (p_{Tj}>30 GeV)

3 Signal Regions further split by leading lepton flavor, m_{ll}, and subleading lepton p_T

The VBF analysis additionally uses BDT to disentangle signal and bkgs

BDT

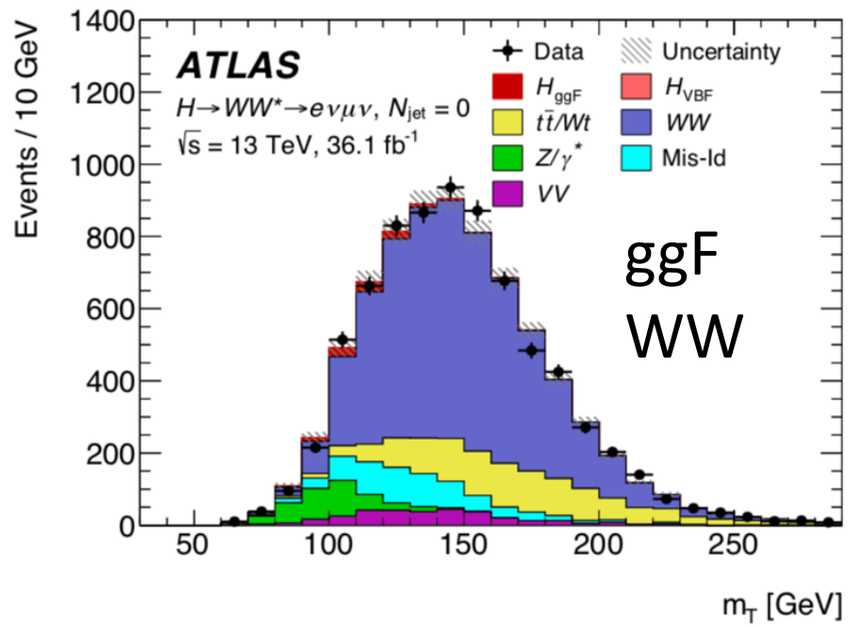
$$m_{jj},\ \Delta y_{jj},\ m_{\ell\ell},\ \Delta\phi_{\ell\ell},\ m_{\mathrm{T}},\ \sum_{\ell} C_{\ell},\ \sum_{\ell,j} m_{\ell j},\ p_{\mathrm{T}}^{\mathrm{tot}}$$

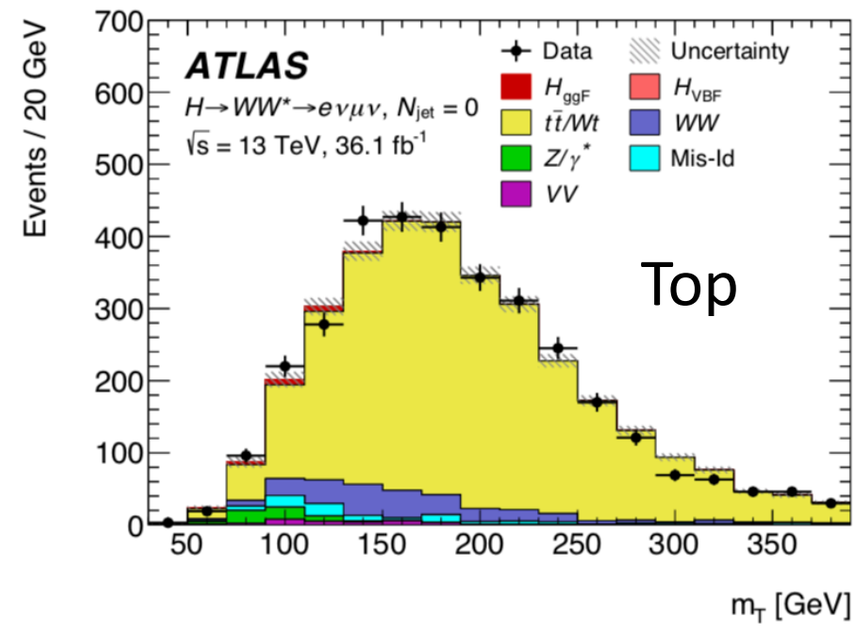
Main Backgrounds Rejection	ggF		VBF
	0j	1j	
tt	b-jet veto (PTj>20 GeV)	b-jet veto (PTj>20 GeV)	b-jet veto CJV+OLV
WW	low m_{ll}, $\Delta\varphi_{ll}$	low m_{ll}, $\Delta\varphi_{ll}$	CJV+OLV
Z/γ* (DY)	low $\Delta\varphi_{ll}$	$m_{\tau\tau}$<m_Z-25 GeV	$m_{\tau\tau}$<m_Z-25 GeV

Central Jet Veto (CJV)
leptons inside rapidity gap of jets: Outside Lep. Veto (OLV)

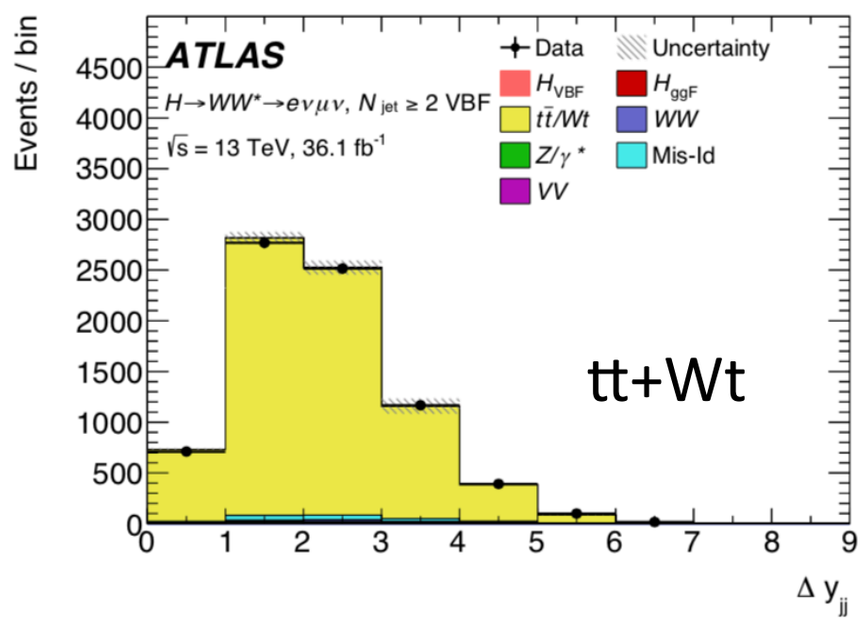
ggF and VBF backgrounds

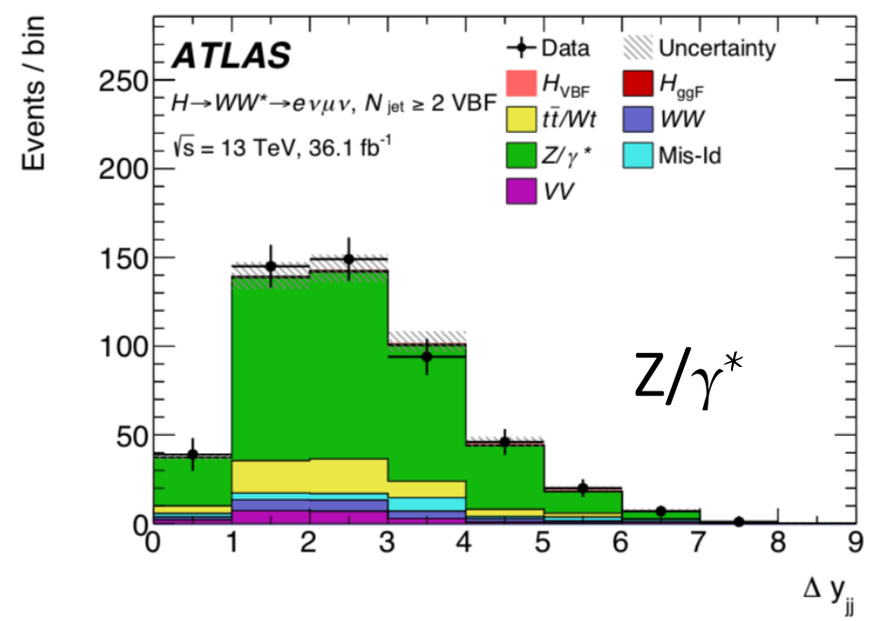
The normalization of the main backgrounds is constrained via Control Regions: tt+Wt, WW and Z/γ* : Good Data and MC agreement.





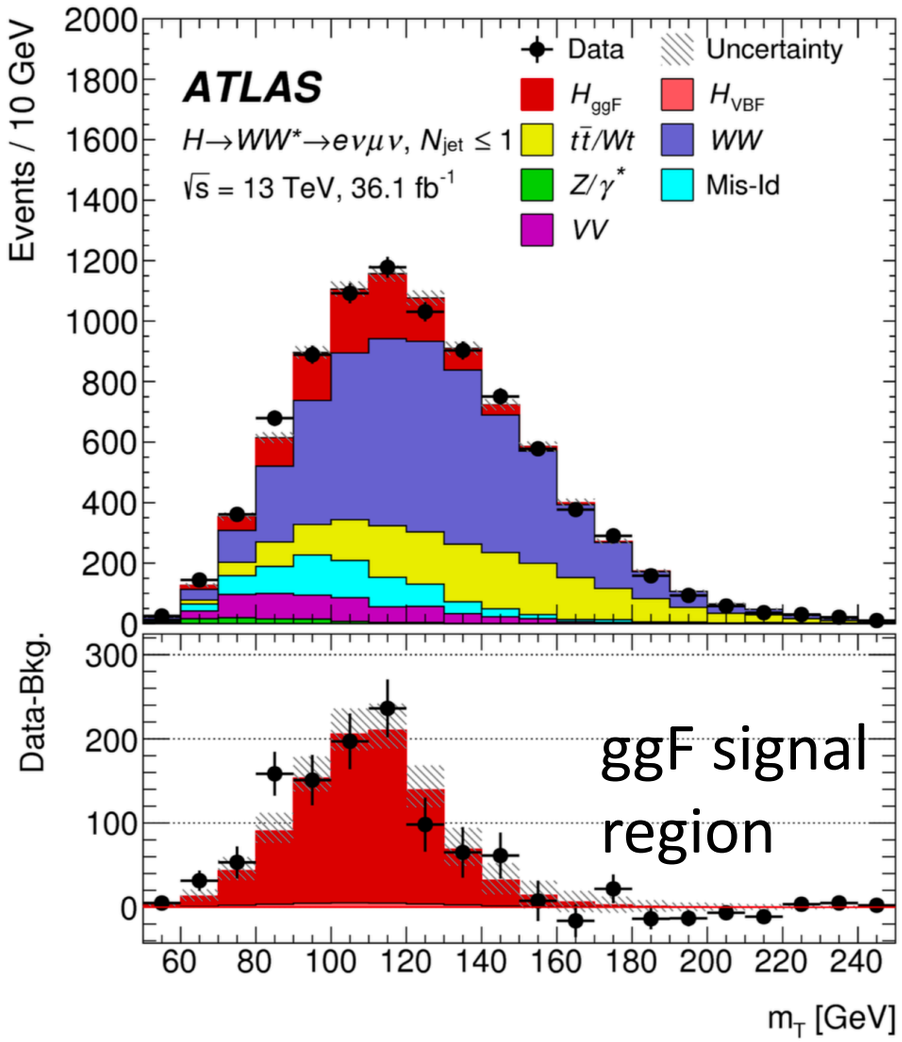
post-fit



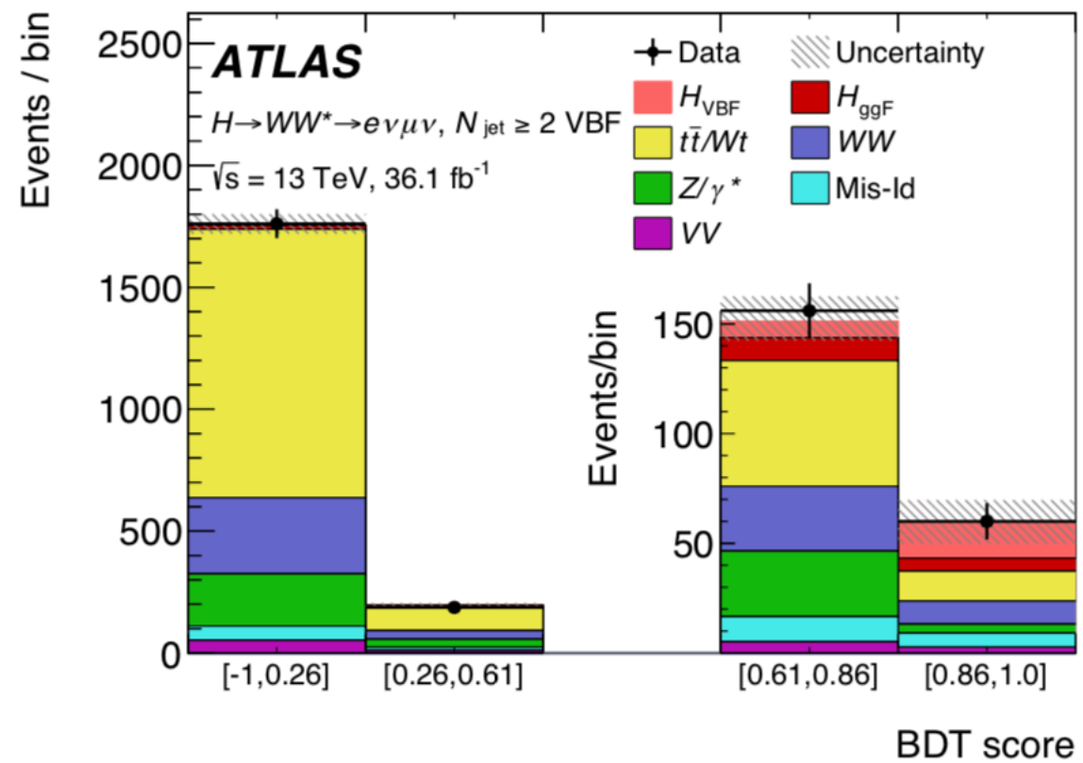


W+jets and multi jet events (fake lepton bkgs) are estimated from data, selecting events with 1 lepton passing ID and the second failing it, but passing a looser ID. Extrapolating the yield to the SR with two fully identified leptons

ggF and VBF signal Post-fit



VBF BDT score in SR



Process	$N_{jet} = 0$ ggF	$N_{jet} = 1$ ggF	$N_{jet} \geq 2$ VBF Inclusive	$N_{jet} \geq 2$ VBF BDT: [0.86, 1.0]
H_{ggF}	639 ± 110	285 ± 51	42 ± 16	6 ± 3
H_{VBF}	7 ± 1	31 ± 2	28 ± 16	16 ± 6
WW	3016 ± 203	1053 ± 206	400 ± 60	11 ± 2
VV	333 ± 38	208 ± 32	70 ± 12	3 ± 1
$t\bar{t}/Wt$	588 ± 130	1397 ± 179	1270 ± 80	14 ± 2
Mis-Id	447 ± 77	234 ± 49	90 ± 30	6 ± 2
Z/γ^*	27 ± 11	76 ± 24	280 ± 40	4 ± 1
Total	5067 ± 80	3296 ± 61	2170 ± 50	60 ± 10
Observed	5089	3264	2164	60

Simultaneous fit of the SRs & CRs:

- M_{TH} for ggF
- BDT output for VBF.

Uncertainties

Source	$\Delta\sigma_{\mathrm{ggF}} \cdot \mathcal{B}_{H\to WW^*}$ [%]	$\Delta\sigma_{\mathrm{VBF}} \cdot \mathcal{B}_{H\to WW^*}$ [%]
Data statistics	10	46
CR statistics	7	9
MC statistics	6	21
Theoretical uncertainties	10	19
ggF signal	5	13
VBF signal	<1	4
WW	6	12
Top-quark	5	5
Experimental uncertainties	8	9
b-tagging	4	6
Modelling of pile-up	5	2
Jet	2	2
Lepton	3	<1
Misidentified leptons	6	9
Luminosity	3	3
TOTAL	18	57

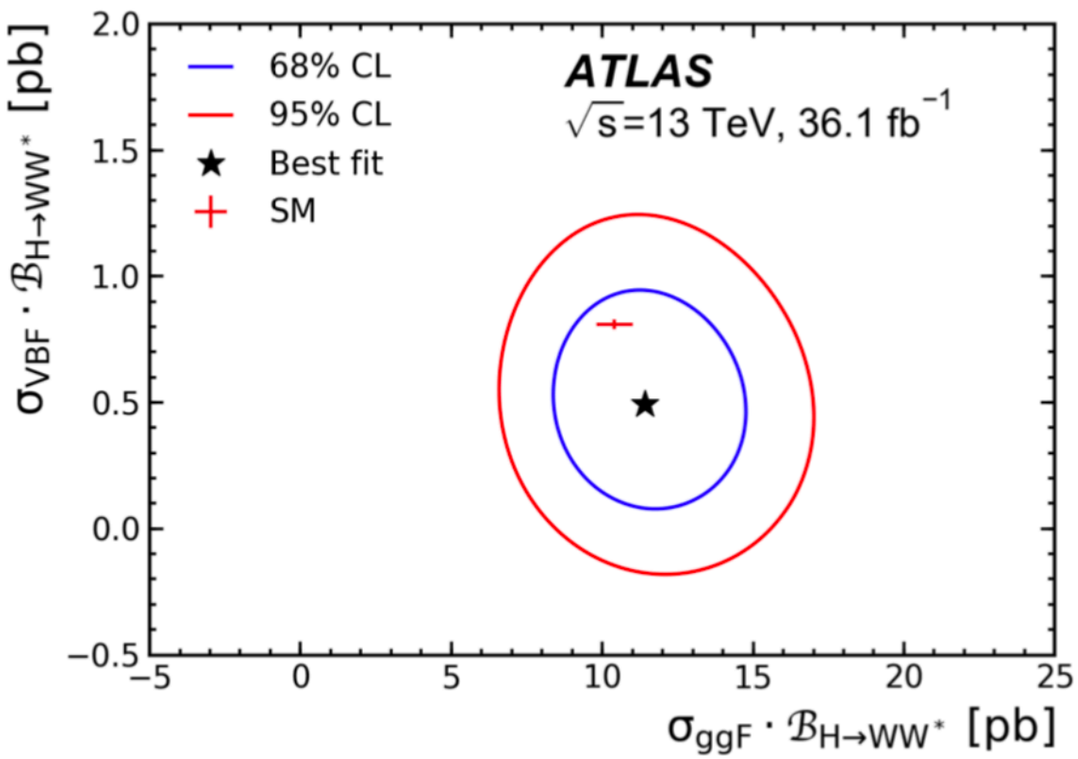
ggF is systematics dominated: 30% better than in run I

- Main experimental systematics: b-tag and jet energy scale, misidentified leptons.
- Main theoretical uncertainties:

1) ggF: uncertainty on gg→WW and qq→WW bkg ratio (gg→WW x-section limited NLO accuracy)

2) VBF: matching and UEPS & modeling of qq→WW and QCD scale uncertainty of ggF contamination

Results



Significances:
6.3 (5.2) σ for ggF
1.9 (2.7) σ for VBF

SM expectations agree within 1 σ

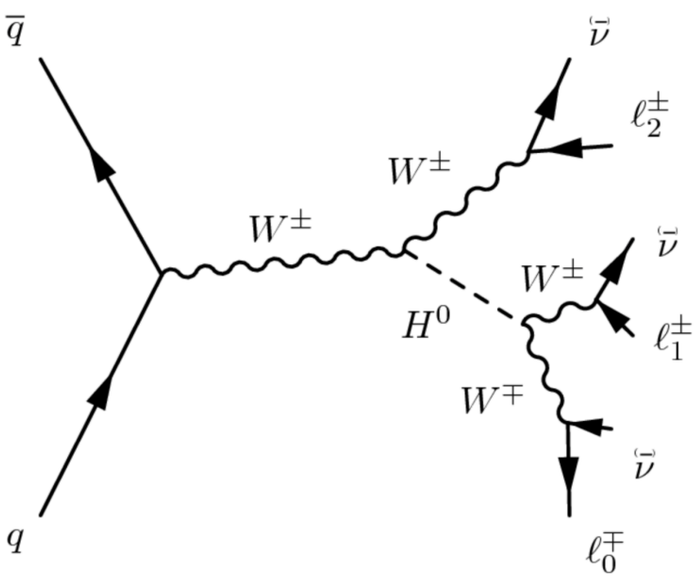
	Measurements	Predictions
$\sigma_{\mathrm{ggF}} \cdot \mathcal{B}_{H\to WW^*}$	$= 11.4^{+1.2}_{-1.1}(\text{stat.})^{+1.2}_{-1.1}(\text{theo syst.})^{+1.4}_{-1.3}(\text{exp syst.})\ \text{pb} = 11.4^{+2.2}_{-2.1}\ \text{pb}$	10.4 ± 0.6 pb
$\sigma_{\mathrm{VBF}} \cdot \mathcal{B}_{H\to WW^*}$	$= 0.50^{+0.24}_{-0.22}(\text{stat.}) \pm 0.10(\text{theo syst.})^{+0.12}_{-0.13}(\text{exp syst.})\ \text{pb} = 0.50^{+0.29}_{-0.28}\ \text{pb}.$	0.81 ± 0.02 pb

$$\mu_{\mathrm{ggF}} = 1.10^{+0.10}_{-0.09}(\text{stat.})^{+0.13}_{-0.11}(\text{theo syst.})^{+0.14}_{-0.13}(\text{exp syst.}) = 1.10^{+0.21}_{-0.20}$$
$$\mu_{\mathrm{VBF}} = 0.62^{+0.29}_{-0.27}(\text{stat.})^{+0.12}_{-0.13}(\text{theo syst.}) \pm 0.15(\text{exp syst.}) = 0.62^{+0.36}_{-0.35}.$$

VH (H→WW*)

arXiv:1903.10052 Submitted to Phys. Lett. B

Analysis at 13 TeV on 36.1 fb^{-1} (2015+2016)

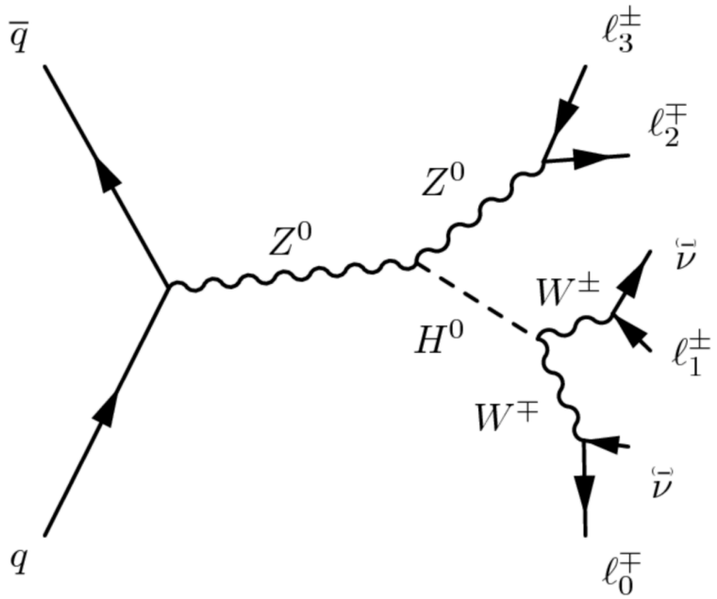


WH main selection cuts, 2 categories:

- 3 leptons (e/μ) total charge±1 (p_T>15 GeV): 2 categories depending on the number of Same Flavor Opposite Sign (SFOS) lepton pairs.

Z dominated SFOS ≥ 1	Z depleted SFOS = 0
≤ 1 jets	-
0 b-jets	0 b-jets

- BDT against main bkgs: diboson & top quark ($t\bar{t}V$ or $t\bar{t}$)
- CR for WZ/Wγ* norm and top CR for misidentified leptons
- Data Driven method for Z+jets/Zγ



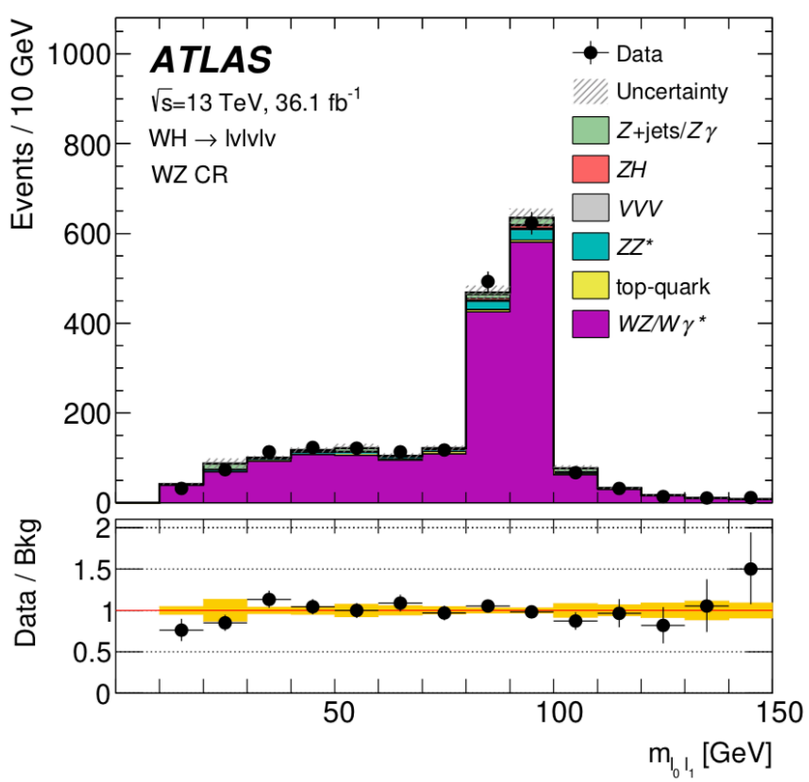
ZH main selection cuts:

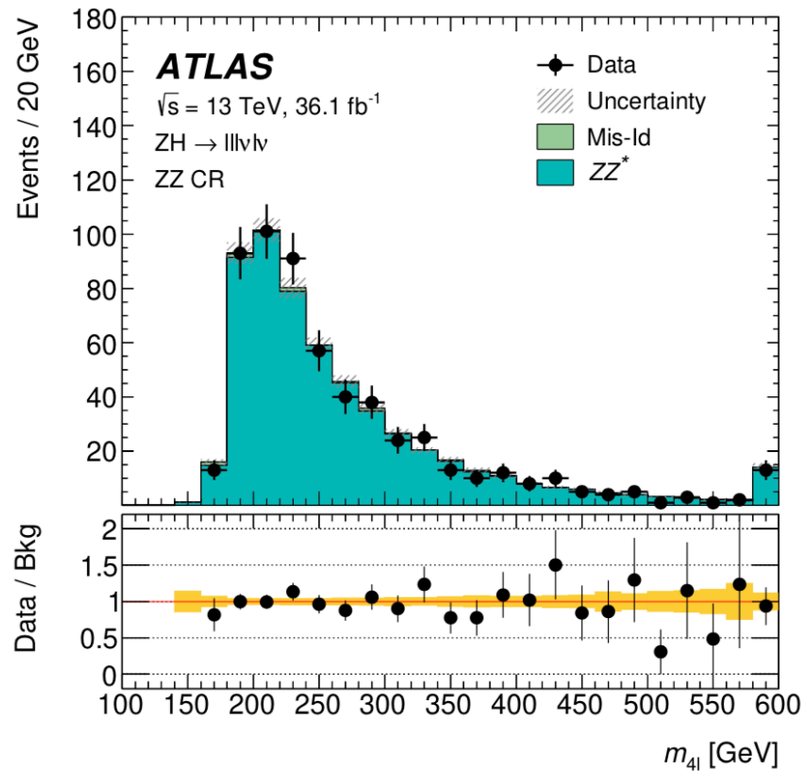
- 4 leptons (e/μ) total charge 0 (p_T>10 GeV)

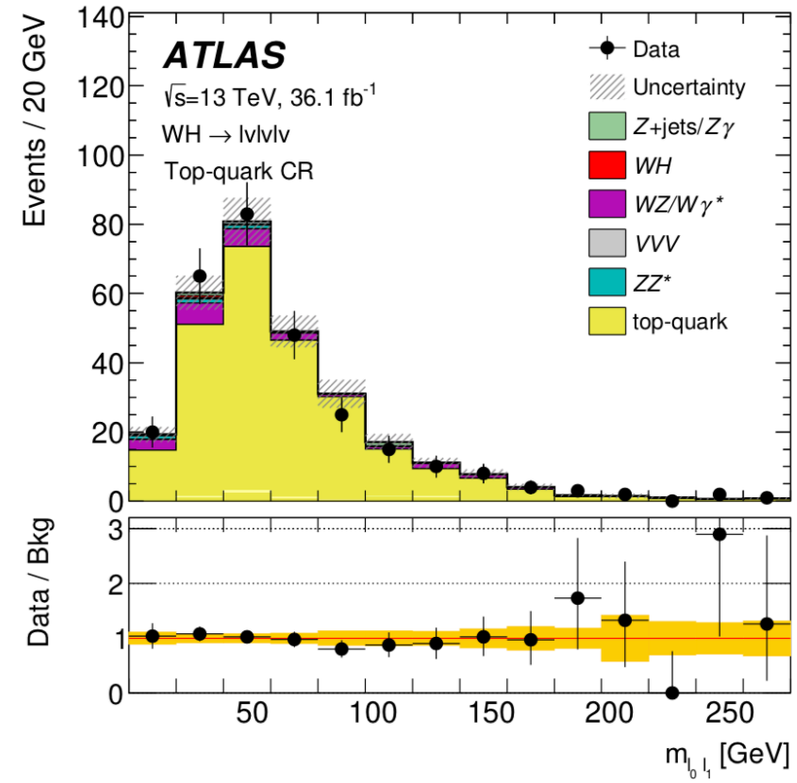
1-SFOS	2-SFOS categories
≤2 jets	≤1 jets
0 b-jet	0 b-jet

Main bkgs: ZZ*(normalisation from CR for 2SFOS SR),
$t\bar{t}Z$ suppressed with b-tag veto and jet multiplicity
Data Driven method for Z+jets/Zγ

Control regions and event yields



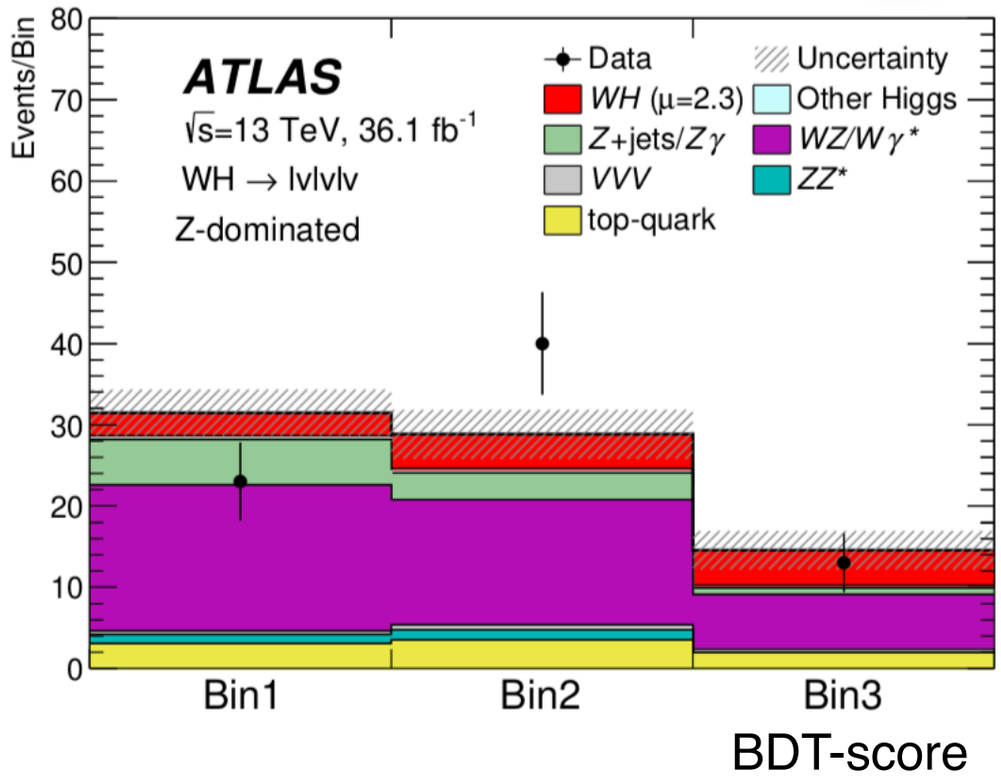


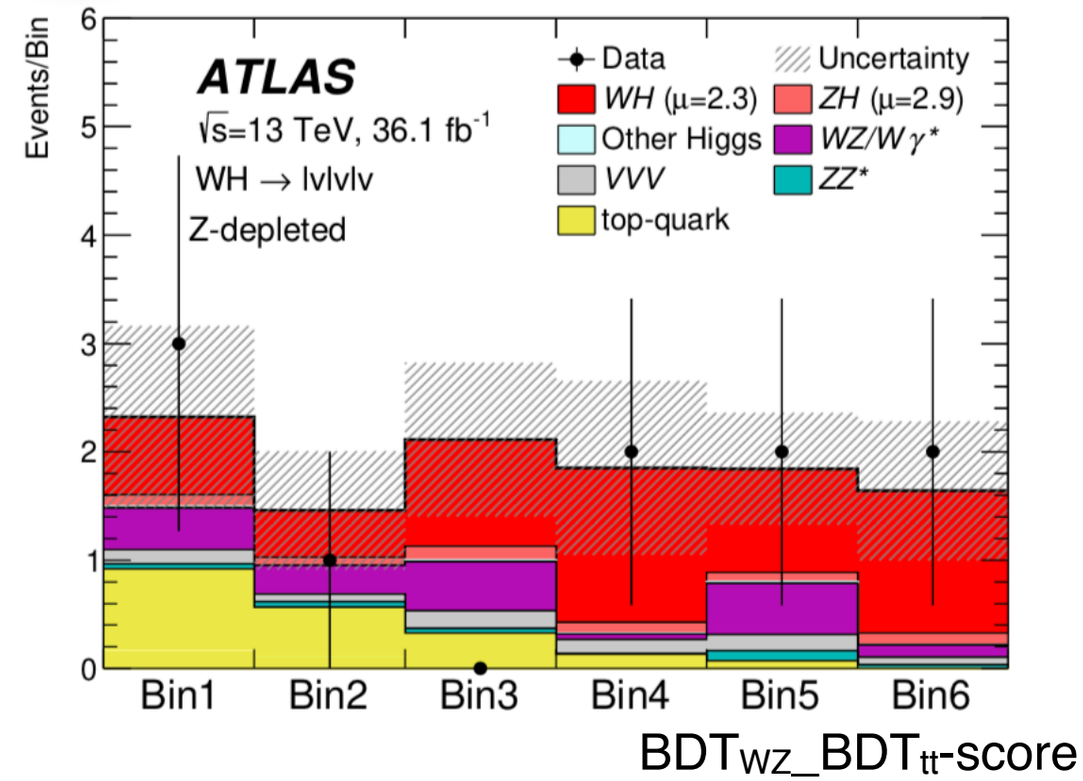


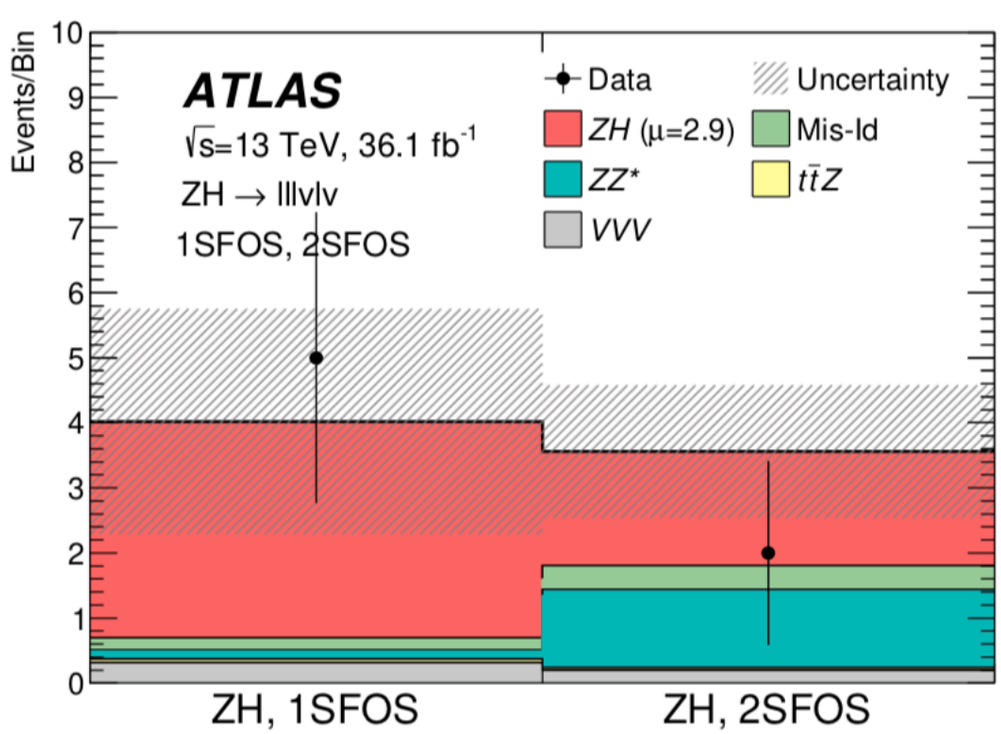
yields in SR

Process	WH		ZH	
	Z-dominated	Z-depleted	1-SFOS	2-SFOS
WH	11 ± 6	5.8 ± 2.8	—	
ZH	1.1 ± 0.6	0.61 ± 0.34	3.3 ± 1.7	1.8 ± 0.9
Total background	62 ± 5	4.7 ± 1.0	0.65 ± 0.17	1.8 ± 0.3
Observed	76	10	5	2

Signal regions







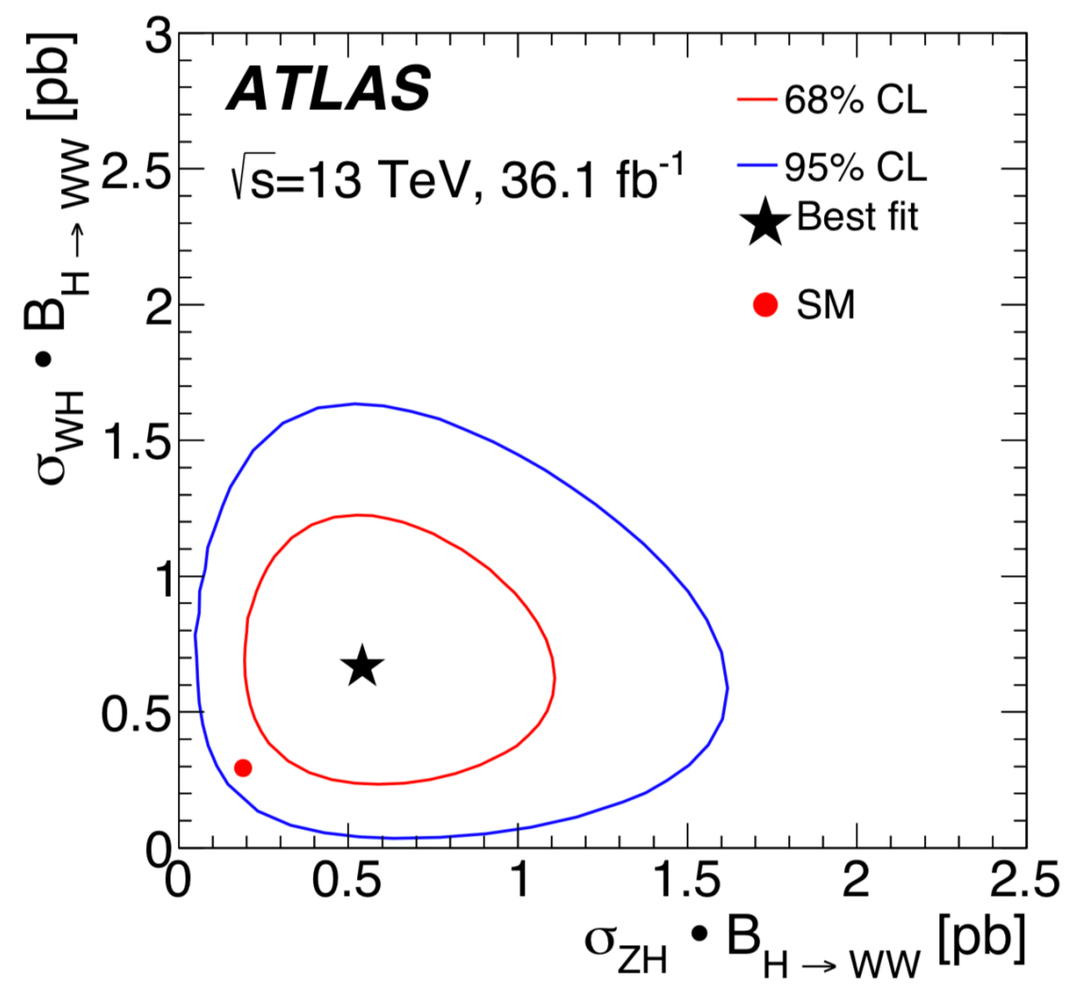
Significances

	Observed	Expected
WH	2.6	1.3
ZH	2.8	1.2
Combined	4.1	1.9

Signal strength and cross-sections

	signal strength	combined
WH	$2.3^{+1.1}_{-0.9}(\text{stat.})^{+0.41}_{-0.33}(\text{theo syst.})^{+0.49}_{-0.36}(\text{exp syst.})$	$2.5^{+0.8}_{-0.7}(\text{stat.})^{+0.37}_{-0.26}(\text{theo syst.})^{+0.30}_{-0.23}(\text{exp syst.})$
ZH	$2.9^{+1.7}_{-1.3}(\text{stat.})^{+0.66}_{-0.27}(\text{theo syst.})^{+0.54}_{-0.28}(\text{exp syst.})$	

	x-section (pb)
WH	$0.67^{+0.31}_{-0.27}(\text{stat.})^{+0.11}_{-0.09}(\text{theo syst.})^{+0.14}_{-0.11}(\text{exp syst.})$
ZH	$0.54^{+0.31}_{-0.24}(\text{stat.})^{+0.11}_{-0.05}(\text{theo syst.})^{+0.10}_{-0.05}(\text{exp syst.})$

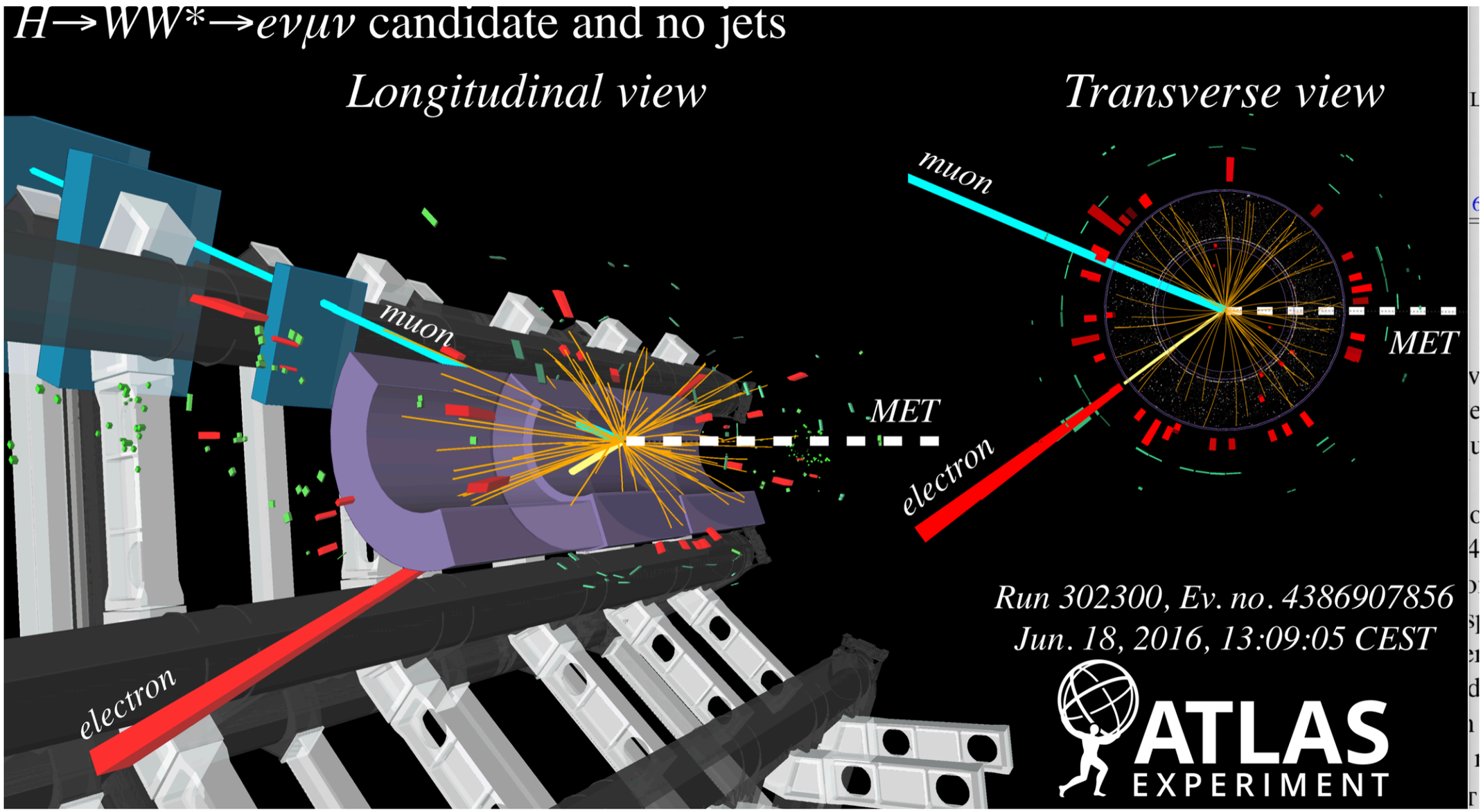


Statistically dominated!

- Main Theoretical syst
  - WZ+top-quark bkgs ⟶ WH
  - ZH signal ⟶ ZH
- Main Exp syst:
  - misidentified leptons

Conclusions

Let me conclude showing you one of these beautiful events the study of which has still a lot to tell, in particular in terms of Higgs properties Effective Field theories and to search deviations from the SM, as we are now entering an exciting precision era, during which we have a unique possibility to unravel NewPhysics



back-up

ggF+VBF SR selection

Category	$N_{\text{jet},(p_T>30\text{ GeV})} = 0$ ggF	$N_{\text{jet},(p_T>30\text{ GeV})} = 1$ ggF	$N_{\text{jet},(p_T>30\text{ GeV})} \geq 2$ VBF
Preselection	Two isolated, different-flavour leptons ($\ell = e, \mu$) with opposite charge $p_T^{\text{lead}} > 22$ GeV , $p_T^{\text{sublead}} > 15$ GeV $m_{\ell\ell} > 10$ GeV $p_T^{\text{miss}} > 20$ GeV		
Background rejection	$\Delta\phi(\ell\ell, E_T^{\text{miss}}) > \pi/2$ $p_T^{\ell\ell} > 30$ GeV	$N_{b\text{-jet},(p_T>20\text{ GeV})} = 0$ $\max\left(m_T^{\ell}\right) > 50$ GeV $m_{\tau\tau} < m_Z - 25$ GeV	
$H \to WW^* \to e\nu\mu\nu$ topology	$m_{\ell\ell} < 55$ GeV $\Delta\phi_{\ell\ell} < 1.8$		central jet veto outside lepton veto
Discriminant variable BDT input variables	m_T		BDT $m_{jj}, \Delta y_{jj}, m_{\ell\ell}, \Delta\phi_{\ell\ell}, m_T, \sum_\ell C_\ell, \sum_{\ell,j} m_{\ell j}, p_T^{\text{tot}}$

$$m_T = \sqrt{\left(E_T^{\ell\ell} + E_T^{\text{miss}}\right)^2 - \left|\mathbf{p}_T^{\ell\ell} + \boldsymbol{E}_T^{\text{miss}}\right|^2} \text{ where } E_T^{\ell\ell} = \sqrt{|\mathbf{p}_T^{\ell\ell}|^2 + m_{\ell\ell}^2}$$

ggF+VBF CR selection

CR	$N_{\text{jet},(p_T>30\text{ GeV})} = 0$ ggF	$N_{\text{jet},(p_T>30\text{ GeV})} = 1$ ggF	$N_{\text{jet},(p_T>30\text{ GeV})} \geq 2$ VBF
WW	$55 < m_{\ell\ell} < 110$ GeV $\Delta\phi_{\ell\ell} < 2.6$	$m_{\ell\ell} > 80$ GeV $\lvert m_{\tau\tau} - m_Z \rvert > 25$ GeV	
	$N_{b\text{-jet},(p_T>20\text{ GeV})} = 0$		
		$\max\left(m_T^{\ell}\right) > 50$ GeV	
$t\bar{t}/Wt$	$N_{b\text{-jet},(20\text{ GeV}<p_T<30\text{ GeV})} > 0$ $\Delta\phi(\ell\ell, E_T^{\text{miss}}) > \pi/2$ $p_T^{\ell\ell} > 30$ GeV $\Delta\phi_{\ell\ell} < 2.8$	$N_{b\text{-jet},(p_T>30\text{ GeV})} = 1$ $N_{b\text{-jet},(20\text{ GeV}<p_T<30\text{ GeV})} = 0$ $\max\left(m_T^{\ell}\right) > 50$ GeV	$N_{b\text{-jet},(p_T>20\text{ GeV})} = 1$ central jet veto
		$m_{\tau\tau} < m_Z - 25$ GeV	
			outside lepton veto
Z/γ^*	$N_{b\text{-jet},(p_T>20\text{ GeV})} = 0$ $m_{\ell\ell} < 80$ GeV		
	no p_T^{miss} requirement		central jet veto
		$\max\left(m_T^{\ell}\right) > 50$ GeV	outside lepton veto
	$\Delta\phi_{\ell\ell} > 2.8$	$m_{\tau\tau} > m_Z - 25$ GeV	$\lvert m_{\tau\tau} - m_Z \rvert \leq 25$ GeV

Table 4: Post-fit normalisation factors which scale the corresponding estimated yields in the signal region; the dash indicates where MC-based normalisation is used. The errors include the statistical and systematic uncertainties.

Category	WW	$t\bar{t}/Wt$	Z/γ^*
$N_{\text{jet},(p_T>30\text{ GeV})} = 0$ ggF	1.06 ± 0.09	0.99 ± 0.17	0.84 ± 0.04
$N_{\text{jet},(p_T>30\text{ GeV})} = 1$ ggF	0.97 ± 0.17	0.98 ± 0.08	0.90 ± 0.12
$N_{\text{jet},(p_T>30\text{ GeV})} \geq 2$ VBF	–	1.01 ± 0.01	0.93 ± 0.07

ggF+VBF MC samples

Process	Matrix element (alternative)	PDF set	UEPS model (alternative model)	Prediction order for total cross-section
ggF H	Powheg-Box v2 NNLOPS [8, 10, 16] (MG5_aMC@NLO [47, 48])	PDF4LHC15 NNLO [9]	Pythia 8 [14] (Herwig 7 [49])	N^3LO QCD + NLO EW [24–28]
VBF H	Powheg-Box v2	PDF4LHC15 NLO	Pythia 8 (Herwig 7)	NNLO QCD + NLO EW [24, 29–31]
VH	Powheg-Box v2 [50]	PDF4LHC15 NLO	Pythia 8	NNLO QCD + NLO EW[51–53]
$qq \to WW$	Sherpa 2.2.2 [32, 33] (Powheg-Box v2, MG5_aMC@NLO)	NNPDF3.0NNLO [34]	Sherpa 2.2.2 [35, 36] (Herwig++ [49])	NLO [37]
$gg \to WW$	Sherpa 2.1.1 [37]	CT10 [54]	Sherpa 2.1	NLO [38]
$WZ/V\gamma^*/ZZ$	Sherpa 2.1	CT10	Sherpa 2.1	NLO [37]
$V\gamma$	Sherpa 2.2.2 (MG5_aMC@NLO)	NNPDF3.0NNLO	Sherpa 2.2.2 (CSS variation [35, 55])	NLO [37]
$t\bar{t}$	Powheg-Box v2 [56] (Sherpa 2.2.1)	NNPDF3.0NLO	Pythia 8 (Herwig 7)	NNLO+NNLL [57]
Wt	Powheg-Box v1 [58] (MG5_aMC@NLO)	CT10 [54]	Pythia 6.428 [59] (Herwig++)	NLO [58]
Z/γ^*	Sherpa 2.2.1	NNPDF3.0NNLO	Sherpa 2.2.1	NNLO [60, 61]

- ggF signal: generated at NNLO in QCD with Powheg-box v2 NNLOPS. The transverse momentum spectrum was found to be compatible with the resumed NNLO+NNLL HRes2.3 calculation.
  - ggF x-section calculation is done at N3LO QCD and NLO EW
- VBF simulated at NLO in QCD with Powheg-box v2.
  - VBF the QCD &EW NLO cross-sections are corrected with approximate NNLO QCD corrections.

W+jet + multi-jet fakes

Estimated from data, selecting events with one lepton passing Identification (ID) and the second failing it, but passing a looser identification (anti-ID).

The number of events in the signal region is obtained by using extrapolation factors binnec in pT and eta.

The extrapolation factor model the ratio between ID leptons and anti-ID leptons.

The extrapolation factors are obtained from Z+jet.

A sample composition correction factor is also added, which is obtained from the MC ratio among W+jets and Z+jets.

For the VBF the multi-jet background is also evaluated (negligible for other regions)

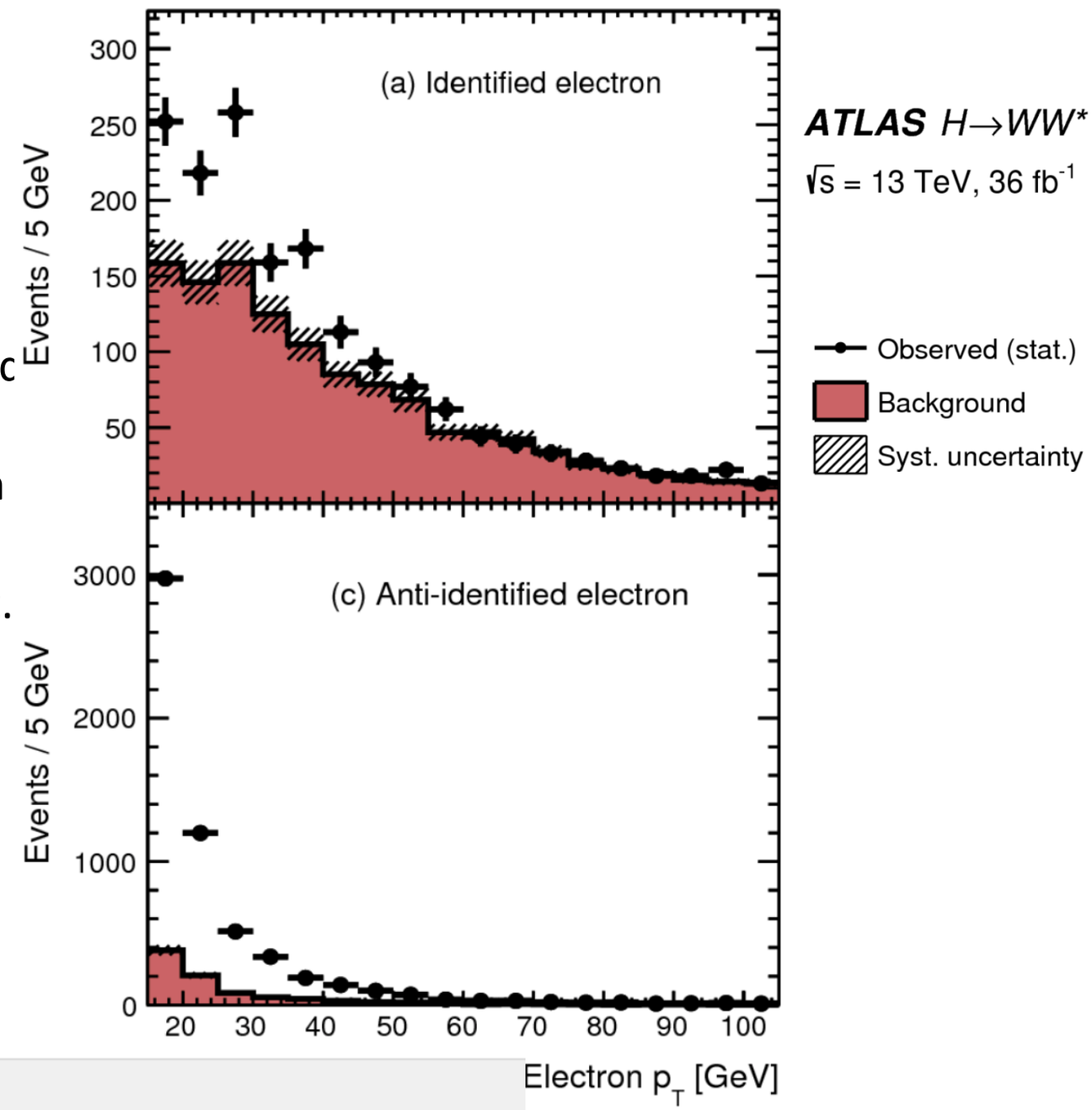
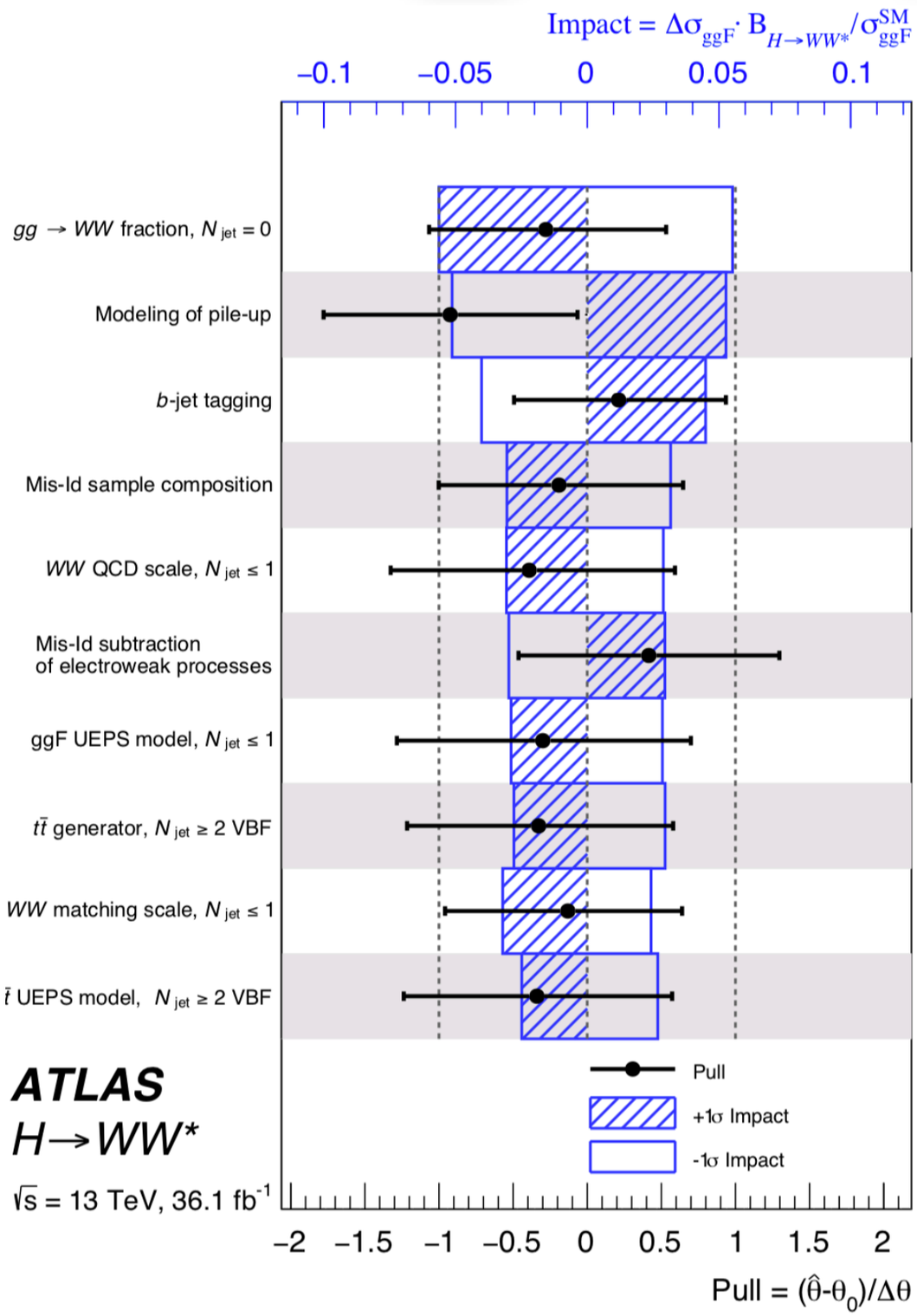
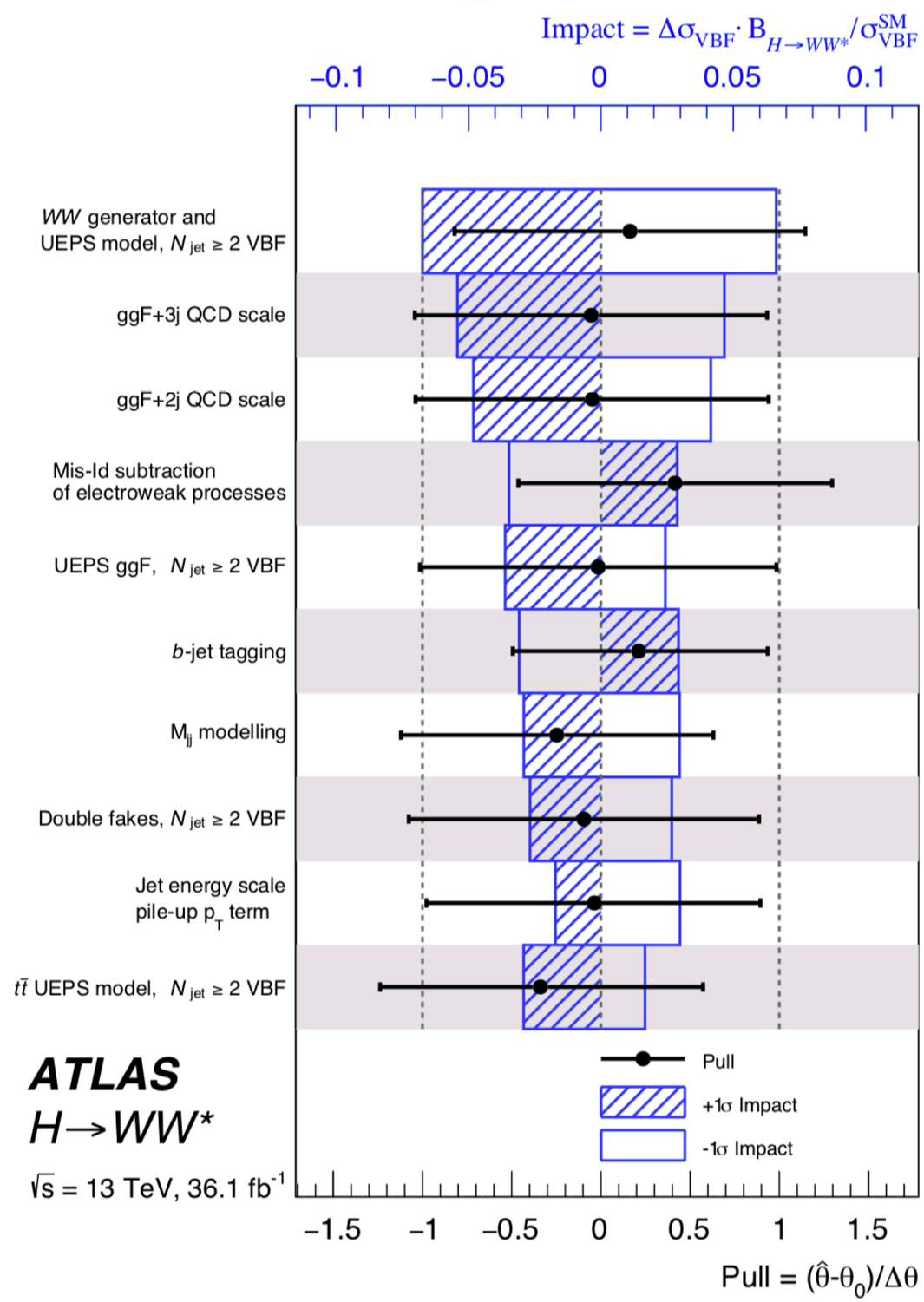


Figure 1:
Distributions of p_T in the Z+jets control sample used to determine the extrapolation factors for misidentified leptons: (a) identified electron, (b) identified muon, (c) anti-identified electron, and (d) anti-identified muon. The black points represent the data sample (Observed); the histograms are the background MC estimates (Background) of the sum of electroweak processes other than the associated production of a Z boson and jets. The systematic band on the background prediction includes the MC statistic error and the uncertainties of the electroweak processes.

ggF & VBF systematics impact





VH selection

	WH		ZH	
Preselection	3 isolated leptons ($p_T > 15$ GeV) total lepton charge ± 1		4 isolated leptons ($p_T > 10$ GeV) total lepton charge 0	
Category	Z-dominated	Z-depleted	2-SFOS	1-SFOS
Number of SFOS	2 or 1	0	2	1
Number of jets	≤ 1	—	≤ 1	≤ 2
Number of b-jets	0	0	0	0
E_T^{miss} [GeV]	> 30	—	> 45	—
$p_T^{4\ell}$ [GeV]	—	—	> 45	—
$m_{\ell\ell}$ [GeV]	> 12 (min. SFOS)	—	> 10	> 10
$\lvert m_{\ell\ell} - m_Z \rvert$ [GeV]	> 25 (SFOS)	—	< 10 ($m_{\ell_2\ell_3}$)	< 10 ($m_{\ell_2\ell_3}$)
$m_{\ell_0\ell_1}$ [GeV]	—	—	< 55	< 60
$\Delta\phi^{boost}_{\ell_0\ell_1}$	—	—	< 2.3	< 1.9
$m_{\tau\tau}$ [GeV]	—	—	—	< 50
$\Delta\phi_{\ell_0\ell_1, E_T^{miss}}$ [rad]	—	—	—	> 0.4
$m_{4\ell}$ [GeV]	—	—	> 140	—
BDT	$BDT_{Zdom} > 0.3$	$BDT_{t\bar{t}} > 0.2$ & $BDT_{WZ} > 0.15$	—	—

- Z veto is used in the Z dominated WH region
- b-tag efficiency point 85%, 33 rejection factor light jets, 3 for c
- l0,l1 are originating from Higgs decay
- in the ZH 1SFOS leptons the ZZ* bkg contributes through Z->tautau, therefore a cut on mtautau<50 is set
- a cut on m4l>140 GeV is used to make selection orthogonal to H->ZZ

VH CRs

Channel (Category)	WH (Z-dominated and Z-depleted)		ZH (2-SFOS)
CR	WZ	Top-quark	ZZ
Number of leptons	3	3	4
Total lepton charge	± 1	± 1	0
Number of SFOS	2 or 1	≤ 2	2
Number of jets	≤ 1	≥ 1	≤ 1
Number of b-jets	0	$\geq$ **1**	0
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 50	> 50 (2 or 1 SFOS)	—
$\lvert m_{\ell\ell} - m_Z \rvert$ [GeV]	$<$ **25**	> 25 (2 or 1 SFOS)	< 10 ($m_{\ell_2\ell_3}$)
$m_{\ell_0\ell_1}$ [GeV]	—	—	$>$ **55**
$m_{\ell\ell}$ (min. SFOS) [GeV]	> 12	> 12 (2 or 1 SFOS)	—
Normalisation factors	0.99±0.05	0.97±0.08	1.13±0.06

- The contributions from Z+jets/Zgamma are estimated both for WH and ZH with a data driven technique: 1 lepton fails ID (looser ID) and the other passes. Extrapolation factors are used to extrapolate to SR, which are obtained from the data in a Z+jet enriched phase space

VH samples

Process	Generator (alternative)	UEPS model (alternative)	Prediction order for total cross section
$q\bar{q} \to WH$	Powheg-Box v2 MiNLO	Pythia8 (Herwig 7)	NNLO QCD + NLO EW [16–18]
$q\bar{q} \to ZH$	Powheg-Box v2 MiNLO	Pythia8 (Herwig 7)	NNLO QCD + NLO EW [16–18]
$gg \to ZH$	Powheg-Box v2	Pythia8 (Herwig 7)	NLO + NLL [19]
ggF H	Powheg-Box v2 NNLOPS	Pythia8	NNNLO QCD + NLO EW [20]
VBF H	Powheg-Box v2	Pythia8	NNLO QCD + NLO EW [21]
$t\bar{t}$	Powheg-Box v2 (Sherpa 2.2.1)	Pythia8 (Herwig 7) (Sherpa 2.2.1)	NNLO+NNLL [22]
Wt	Powheg-Box v1	Pythia6	NLO [23]
$t\bar{t}W/Z$	MG5_aMC@LO	Pythia8	NLO [24, 25]
tZ	MG5_aMC@LO	Pythia6	LO [26]
$q\bar{q}/qg \to \ell\nu\ell\ell$	Sherpa 2.2.2 (Powheg-Box v2)	Sherpa 2.2.2 (Herwig++)	NLO [27]
$q\bar{q}/qg \to \ell\ell\ell\ell$	Sherpa 2.1/2.2.2 (Powheg-Box v2)	Sherpa 2.1/2.2.2 (Herwig++)	NLO [27]
$gg \to \ell\ell\ell\ell$	Sherpa 2.1.1	Sherpa 2.1.1	NLO [28]
VVV	Sherpa 2.2.2 (MG5_aMC@NLO)	Sherpa 2.2.2 (Pythia8)	NLO [29]

VH CR definitions

Channel (Category)	WH (Z-dominated and Z-depleted)		ZH (2-SFOS)
CR	WZ	Top-quark	ZZ
Number of leptons	3	3	4
Total lepton charge	± 1	± 1	0
Number of SFOS	2 or 1	≤ 2	2
Number of jets	≤ 1	≥ 1	≤ 1
Number of b-jets	0	$\geq$ **1**	0
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 50	> 50 (2 or 1 SFOS)	—
$\lvert m_{\ell\ell} - m_Z \rvert$ [GeV]	$<$ **25**	> 25 (2 or 1 SFOS)	< 10 ($m_{\ell_2\ell_3}$)
$m_{\ell_0\ell_1}$ [GeV]	—	—	$>$ **55**
$m_{\ell\ell}$ (min. SFOS) [GeV]	> 12	> 12 (2 or 1 SFOS)	—
Normalisation factors	0.99±0.05	0.97±0.08	1.13±0.06

VH systematics

Source	$\Delta\sigma_{WH} \cdot \mathcal{B}_{H\to WW^*}$ [%]
Data statistics in SR	43
Data statistics in CR	6
Theoretical uncertainties	16
$WZ/W\gamma^*$(*)	12
Top-quark(*)	8
WH signal(*)	4
ZZ^*	2
Experimental uncertainties	12
Impact parameter mismodelling	8
Misidentified leptons	8
b-tagging	1
MC statistics	9
Luminosity	3
TOTAL	49

Source	$\Delta\sigma_{ZH} \cdot \mathcal{B}_{H\to WW^*}$ [%]
Data statistics in SR	50
Data statistics in CR	< 1
Theoretical uncertainties	15
ZH signal	14
Top-quark	1
$WZ/W\gamma^*$	< 1
ZZ^*	< 1
Experimental uncertainties	7
Misidentified leptons	3
b-tagging	1
MC statistics	11
Luminosity	2
TOTAL	54

- The ttbar scale uncertainty is dominating in the WH theory systematics:
  Scale and Radiation variations using 1 Powheg + Pythia 8 generated with variable shower radiation (A14 var3c eigentune), modified factorization and renormalization scale (x2 and x0.5) and the NLO radiation (hdamp = 1.5mtop and 3mtop)

- the WZ modeling in WH theory systematics: sherpa versus powheg box v2