H(bb) at ATLAS

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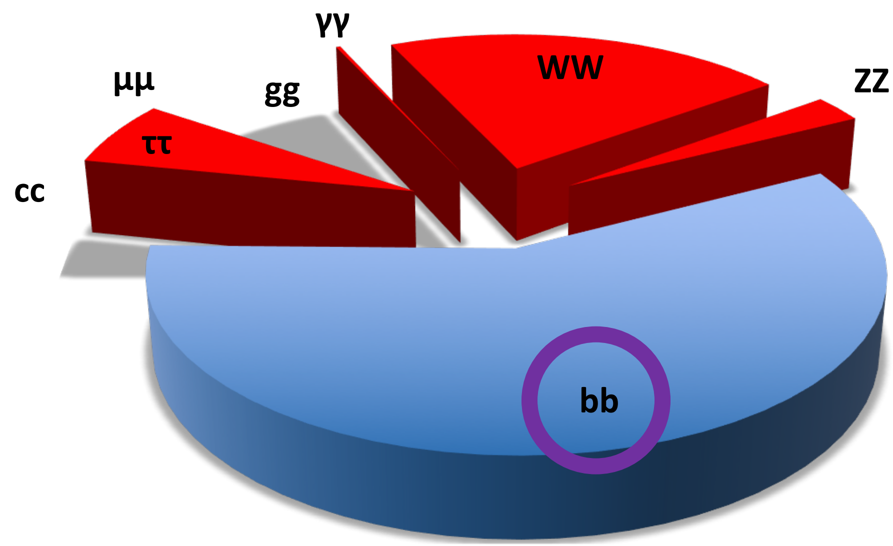
On behalf of the ATLAS Collaboration

H(bb)

Channel	Number of Events for 36.1 fb^{-1} m_H = 125 GeV
ggH, H(bb)	~920k
VBF H, H(bb) ATLAS-CONF-2016-063	~78k
VH, H(bb) (V=W, Z) ATLAS-CONF-2017-041	~47k
ttH, H(bb) ATLAS-CONF-2016-080	~11k

Observed decays ~31%



Dominant decay ~58%

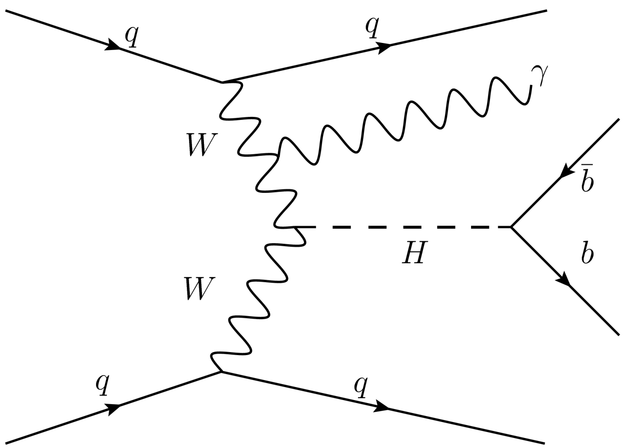
See K. Liu's dedicated talk on ttH, H(bb)

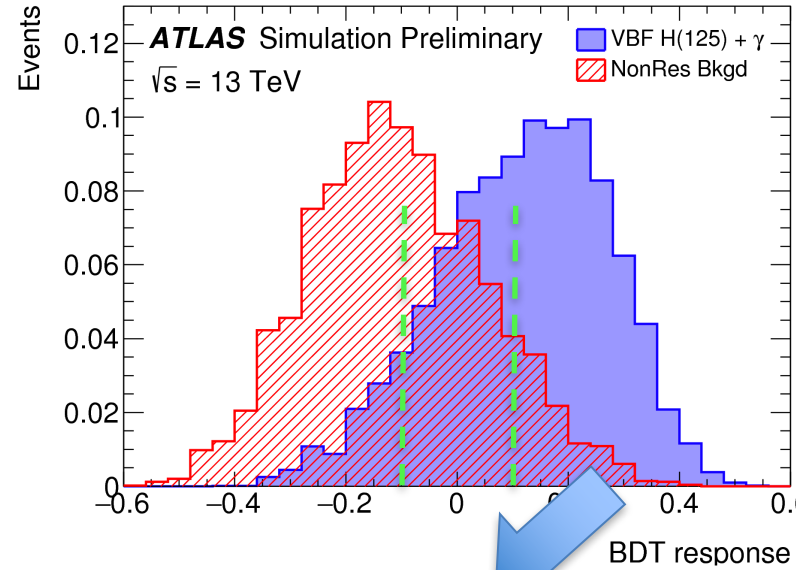
Only focusing on Run-2 results

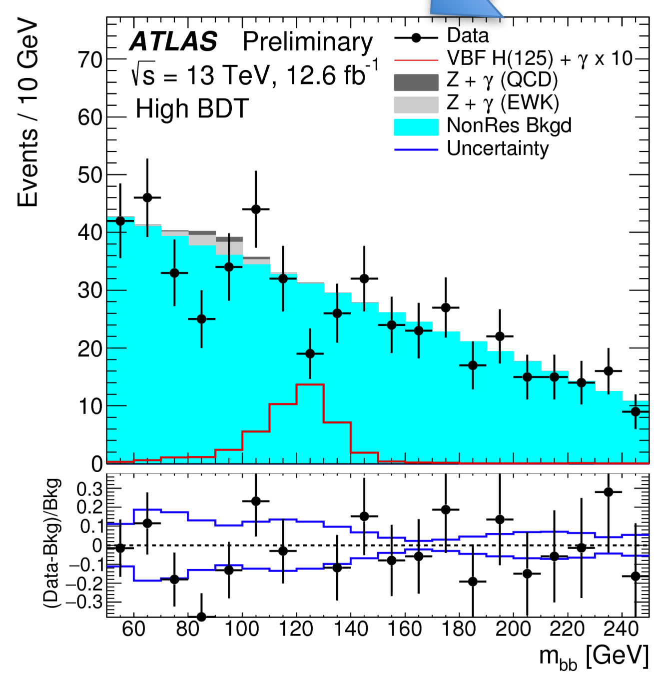
VBF H(bb)+γ

13 TeV, 12.6 fb^{-1}

- Search for H(bb) with a high p_T γ (p_T > 25 GeV)
  - ➢ Extra handle for trigger and to suppress multi-jet background







- Boosted Decision Trees (BDT) used to define 3 analysis regions
  - ➢ Z(bb)+γ as cross-check
  - ➢ Fit dijet invariant mass (m_{bb}) in 3 BDT regions

VBF H(bb)+γ Results

Result	$H(\to b\bar{b}) + \gamma jj$	$Z(\to b\bar{b}) + \gamma jj$
Expected significance	0.4	1.3
Expected p-value	0.4	0.1
Observed p-value	0.9	0.4
Expected limit	$6.0\ ^{+2.3}_{-1.7}$	$1.8\ ^{+0.7}_{-0.5}$
Observed limit	4.0	2.0
Observed signal strength μ	$-3.9\ ^{+2.8}_{-2.7}$	$0.3\ \pm 0.8$

- Limiting factors
  - Statistics in background fit
  - Signal modelling uncertainties

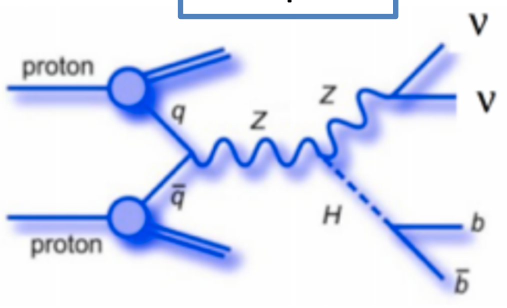
Uncertainty source	Uncertainty $\Delta\mu$
Non-resonant background uncertainty in medium-BDT region	0.22
Non-resonant background uncertainty in high-BDT region	0.21
Non-resonant background uncertainty in low-BDT region	0.17
Parton shower uncertainty on $H + \gamma$ acceptance	0.16
QCD scale uncertainty on $H + \gamma$ cross section	0.13
Jet energy uncertainty from calibration across η	0.10
Jet energy uncertainty from flavour composition in calibration	0.09
Integrated luminosity uncertainty	0.08

VH, H(bb)

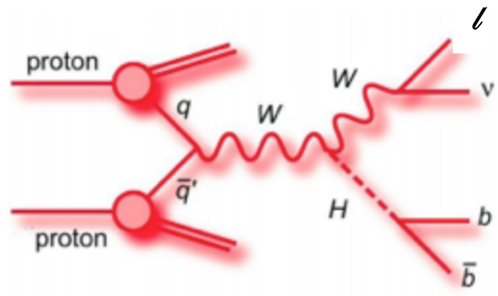
13 TeV, 36.1 fb^{-1}

- Full 2015+16 VH(bb) analysis
  - 2 and 3-jet, high p_T^V regions

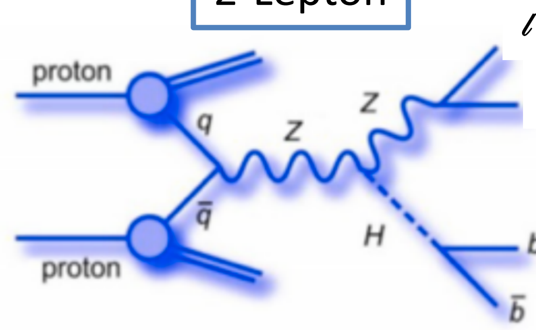
0-Lepton



1-Lepton



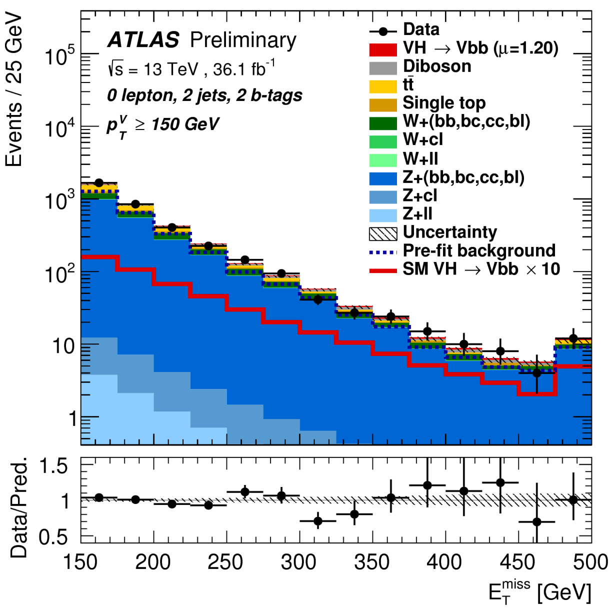
2-Lepton

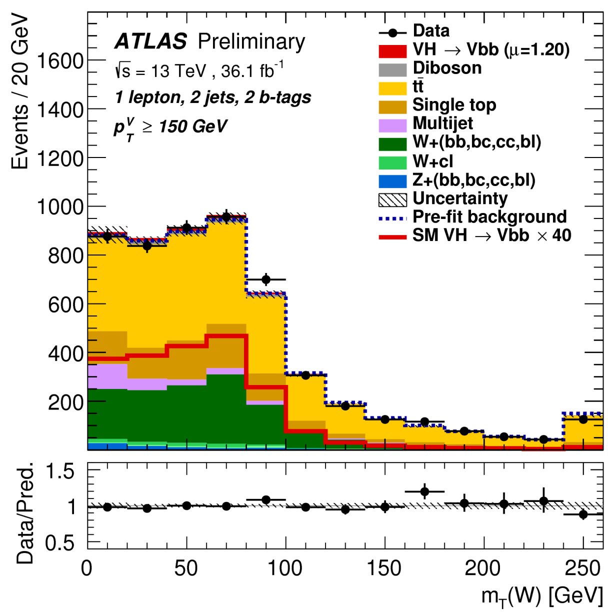


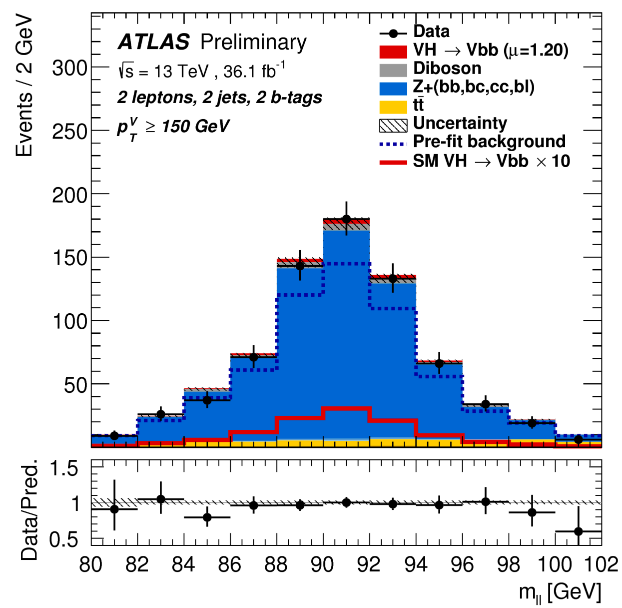
Z+hf, W+hf, ttbar

W+hf, ttbar, single-top

Z+hf, ttbar

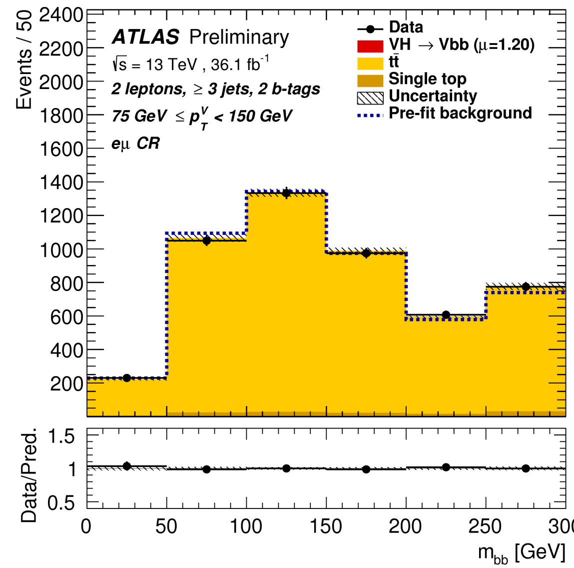






VH, H(bb) Analysis

- Three versions of the analysis
  - ➢ **Nominal:** BDT VH, H(bb)
  - ➢ BDT VZ, Z(bb)
  - ➢ Cut-based m_{bb} VH, H(bb)



- Simultaneous fit to discriminating variable in all analysis regions
  - ➢ Normalisation of $t\bar{t}$ and Z/W+hf freely floating
  - ➢ Uncertainties on overall and relative normalisation between regions
  - ➢ Shape uncertainties on all non-negligible backgrounds

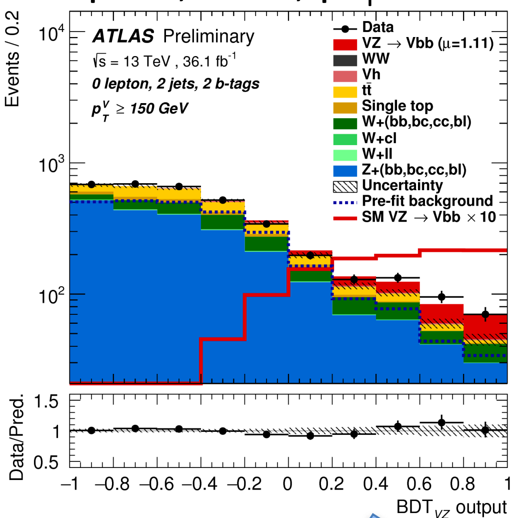
New $t\bar{t}$ and W+hf control regions (see A. Bell's talk)

Channel	SR/CR	Categories: 2 b-tagged jets, 75 GeV $< p_T^V <$ 150 GeV, 2 jets	75 GeV $< p_T^V <$ 150 GeV, 3 jets	$p_T^V >$ 150 GeV, 2 jets	$p_T^V >$ 150 GeV, 3 jets
0-lepton	SR	-	-	BDT	BDT
1-lepton	SR	-	-	BDT	BDT
2-lepton	SR	BDT	BDT	BDT	BDT
1-lepton	W+HF CR	-	-	Yield	Yield
2-lepton	$e\mu$ CR	m_{bb}	m_{bb}	Yield	m_{bb}

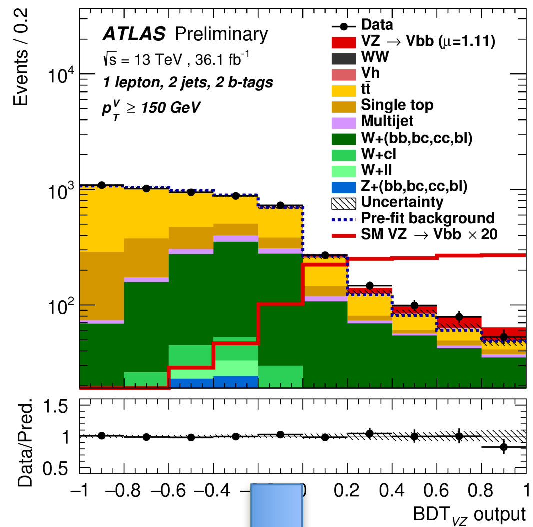
Nominal:
8 Signal Regions
6 Control Regions

VZ, Z(bb) Cross-check

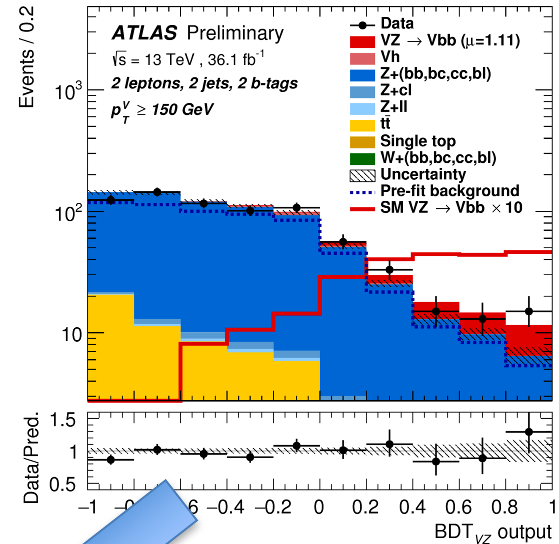
0-Lepton, 2-Jet, p^V_T> 150 GeV

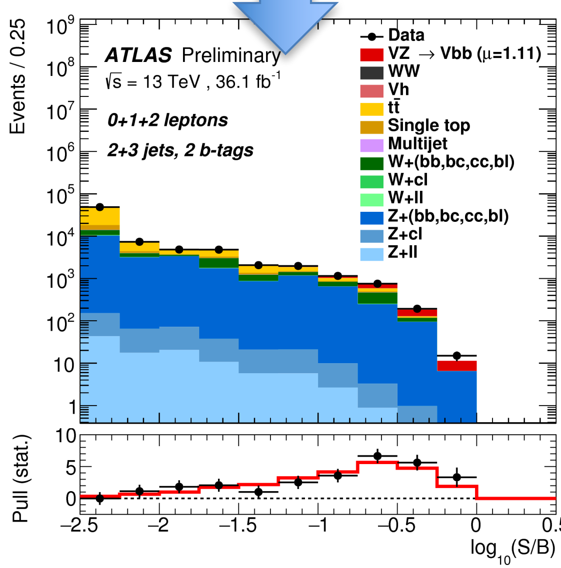


1-Lepton, 2-Jet, p^V_T> 150 GeV

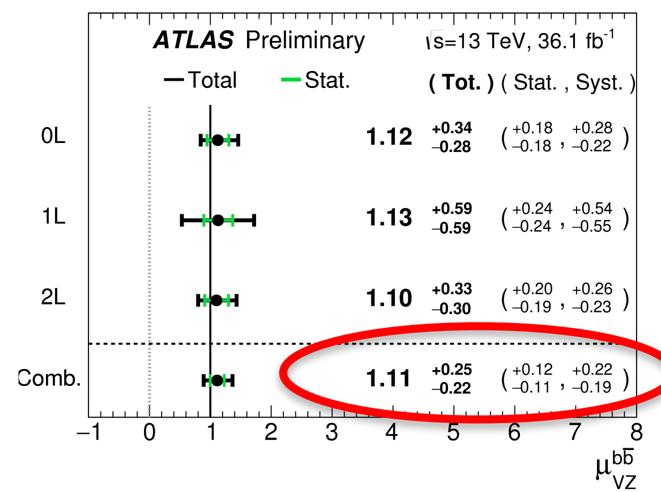


2-Lepton, 2-Jet, p^V_T> 150 GeV





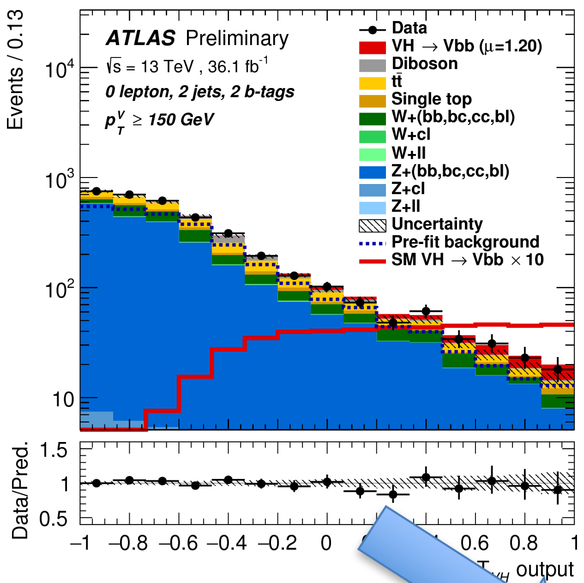
Diboson
WZ, Z(bb)
ZZ, Z(bb)



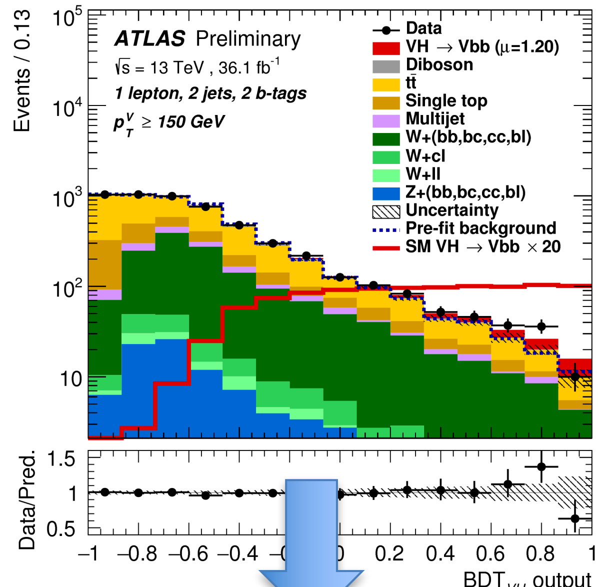
Significance:
Observed 5.8σ
Expected 5.3σ

VH, H(bb) BDT

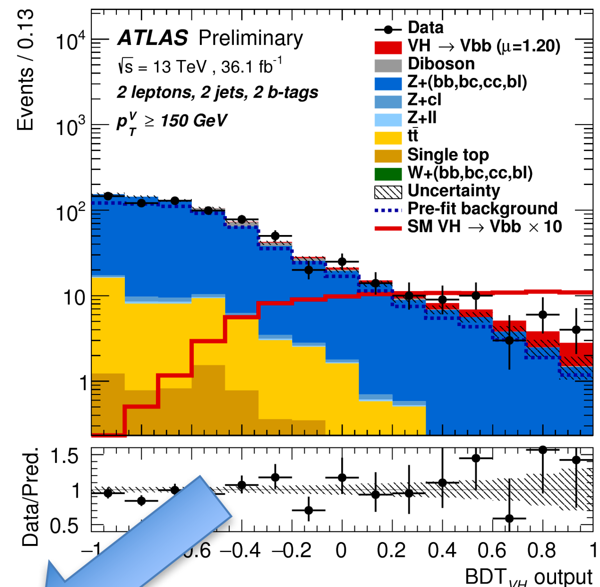
0-Lepton, 2-Jet, $p^V_T > 150$ GeV

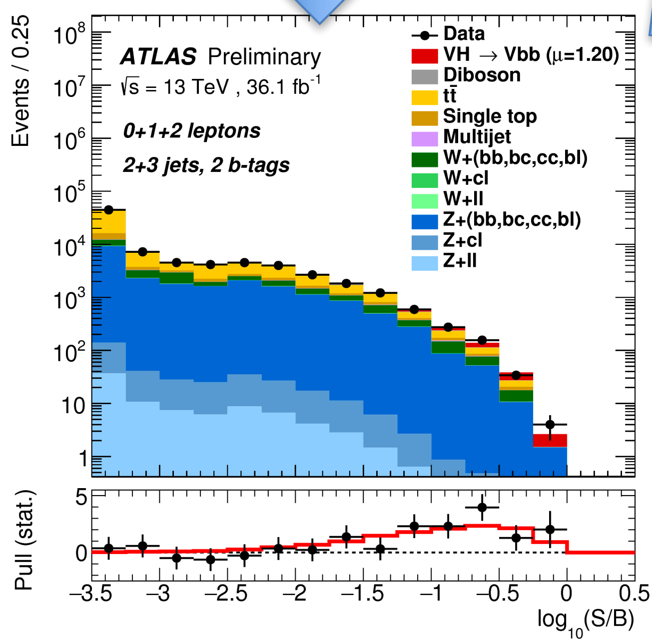


1-Lepton, 2-Jet, $p^V_T > 150$ GeV



2-Lepton, 2-Jet, $p^V_T > 150$ GeV

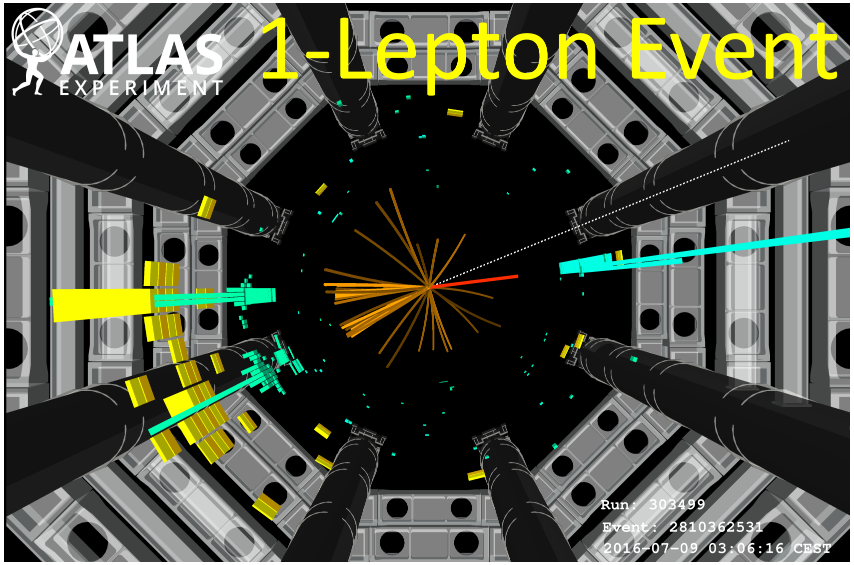




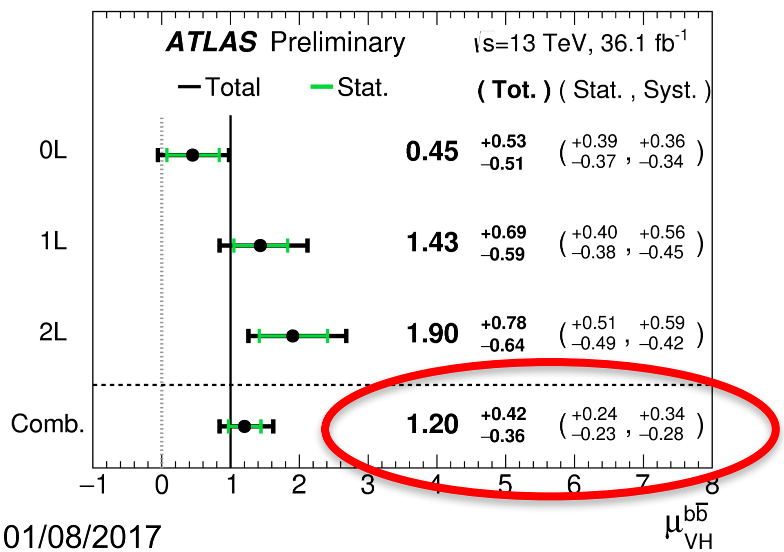
VH Signal
WH, H(bb)
ZH, H(bb)

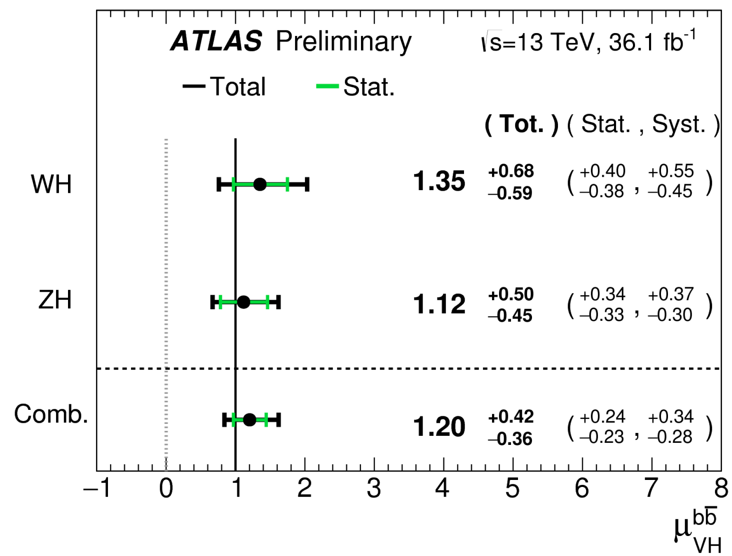
VH, H(bb) Result

- 36.1 fb^{-1} VH, H(bb) result



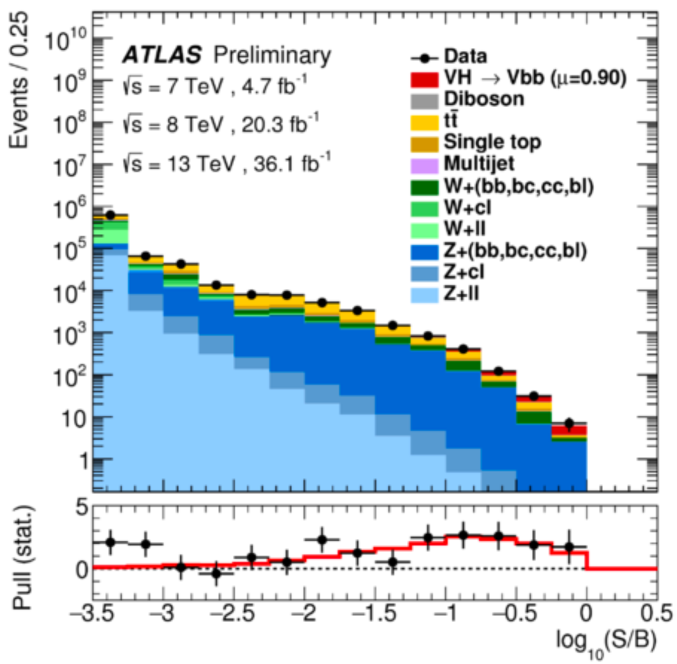
Significance:
Observed 3.5σ
Expected 3.0σ

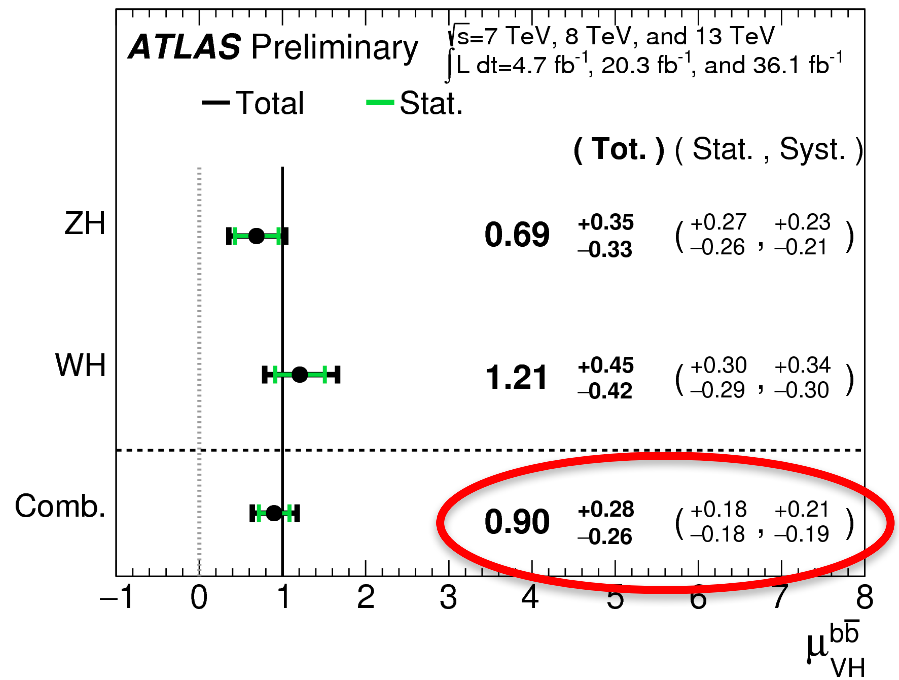




VH, H(bb) Run 1+2 Combination

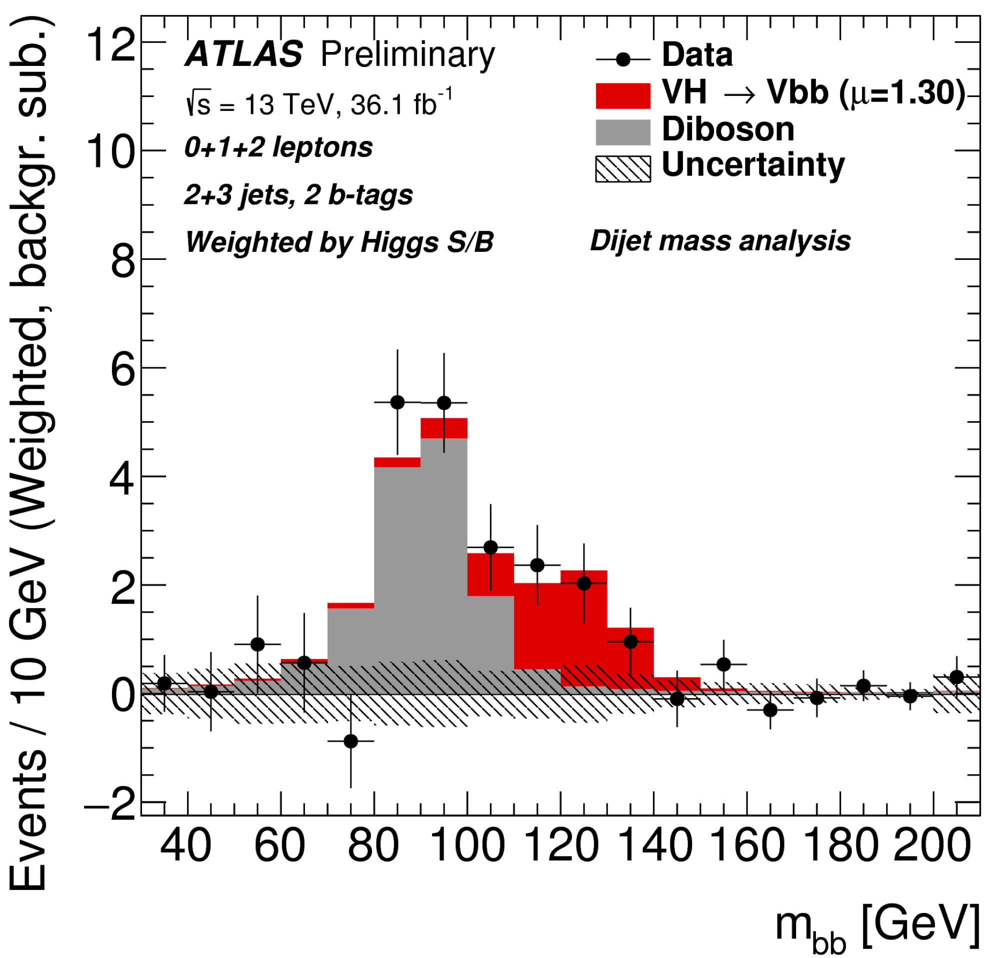
- Combine with 4.7 fb^{-1} and 20.3 fb^{-1} Run 1 result





Significance:
Observed 3.6σ
Expected 4.0σ

VH, H(bb) m_{bb} Result



Selection	0-lepton	1-lepton	2-lepton
	Channel		
m_T^W	-	< 120 GeV	-
$E_T^{miss}/\sqrt{S_T}$	-	-	$< 3.5\sqrt{\text{GeV}}$

	p_T^V regions		
p_T^V	[75, 150] GeV (2-lepton only)	[150, 200] GeV	[200, ∞] GeV
$\Delta R(b_1, b_2)$	<3.0	<1.8	<1.2

14 Signal Regions
4 Control Regions

Significance:
3.5σ observed
2.8σ expected

Signal strength: $\mu=1.30^{+046}_{-0.40}$ (tot.) $^{+0.28}_{-0.27}$ (stat.) $^{+0.37}_{-0.29}$ (syst.)

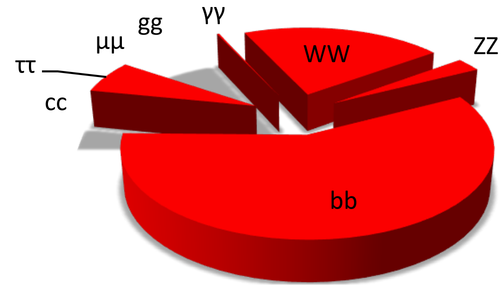
VH, H(bb) Considerations

Source of uncertainty		σ_μ
Total		0.39
Statistical		0.24
Systematic		0.31
Experimental uncertainties		
Jets		0.03
E_T^{miss}		0.03
Leptons		0.01
b-tagging	b-jets	0.09
	c-jets	0.04
	light jets	0.04
	extrapolation	0.01
Pile-up		0.01
Luminosity		0.04
Theoretical and modelling uncertainties		
Signal		0.17
Floating normalisations		0.07
Z+jets		0.07
W+jets		0.07
$t\bar{t}$		0.07
Single top-quark		0.08
Diboson		0.02
Multijet		0.02
MC statistical		0.13

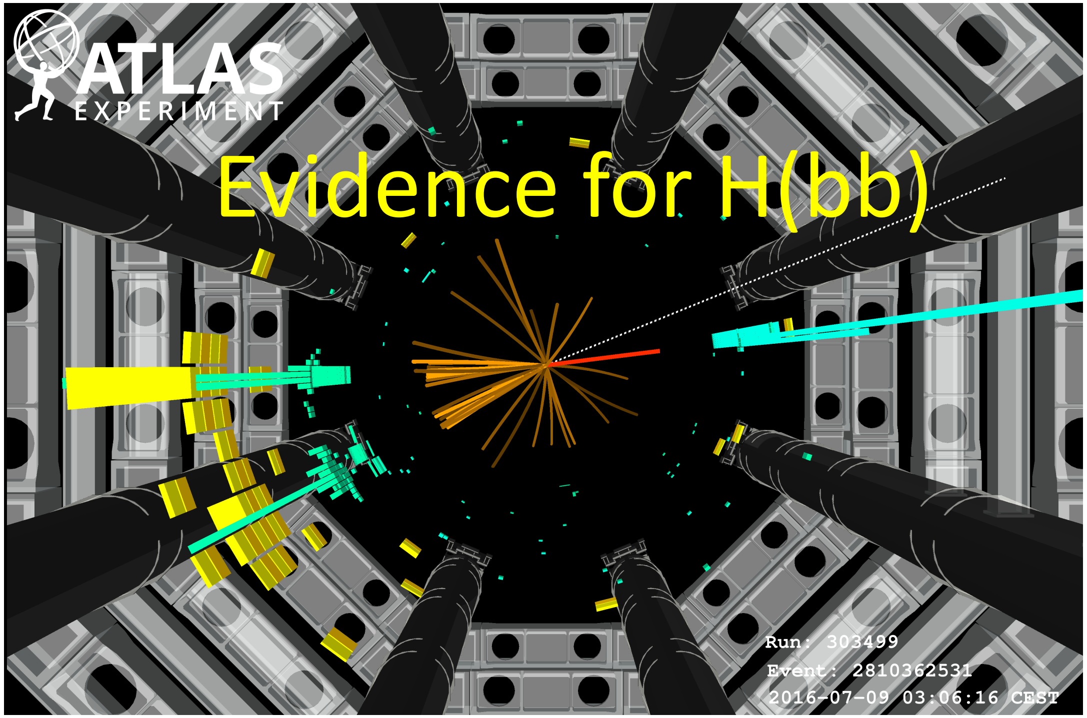
Limiting factors
- Signal modelling
- Monte Carlo statistics
- Flavour tagging
- Background modelling

Summary

- Run 2 H(bb) searches conducted in VH, VBF and ttH production channels
  - ➢ Full set of results on 2015+16 dataset in progress
- **Evidence for H->bb in VH production channel**
  - ➢ **Heralds a new era of H(bb) measurements**
- Challenges
  - ➢ VH, H(bb) channel systematically limited
  - ➢ VBF H, H(bb) still statistically limited



Evidence (or better) for ~88%



Backup Slides

VH, Simulated Samples

Process	ME generator	ME PDF	PS and Hadronization	UE model tune	Cross-section order	ace2.5cm
Signal						
$qq \to WH \to \ell\nu bb$	Powheg-Box v2 + GoSam + MiNLO	NNPDF3.0NLO$^{(\star)}$	Pythia8.212	AZNLO	NNLO(QCD)+ NLO(EW)	
$qq \to ZH \to \nu\nu bb/\ell\ell bb$	Powheg-Box v2 + GoSam + MiNLO	NNPDF3.0NLO$^{(\star)}$	Pythia8.212	AZNLO	NNLO(QCD)$^{(\dagger)}$+ NLO(EW)	
$gg \to ZH \to \nu\nu bb/\ell\ell bb$	Powheg-Box v2	NNPDF3.0NLO$^{(\star)}$	Pythia8.212	AZNLO	NLO(QCD)+ NLL(QCD)	
Top-quark						
$t\bar{t}$	Powheg-Box v2	NNPDF3.0NLO	Pythia8.212	A14	NNLO+NNLL	
t-channel	Powheg-Box v1	CT10f4	Pythia6.428	P2012	NLO	
s-channel	Powheg-Box v2	CT10	Pythia6.428	P2012	NLO	
Wt	Powheg-Box v2	CT10	Pythia6.428	P2012	NLO	
Vector boson + jets						
$W \to \ell\nu$	Sherpa 2.2.1	NNPDF3.0NNLO	Sherpa 2.2.1	Default	NNLO	
$Z/\gamma* \to \ell\ell$	Sherpa 2.2.1	NNPDF3.0NNLO	Sherpa 2.2.1	Default	NNLO	
$Z \to \nu\nu$	Sherpa 2.2.1	NNPDF3.0NNLO	Sherpa 2.2.1	Default	NNLO	
Diboson						
WW	Sherpa 2.1.1	CT10	Sherpa 2.1.1	Default	NLO	
WZ	Sherpa 2.2.1	NNPDF3.0NNLO	Sherpa 2.2.1	Default	NLO	
ZZ	Sherpa 2.2.1	NNPDF3.0NNLO	Sherpa 2.2.1	Default	NLO	

VH, Event Selection

Selection	0-lepton	1-lepton		2-lepton
		e sub-channel	μ sub-channel	
Trigger	$E_{\mathrm{T}}^{\mathrm{miss}}$	Single lepton	$E_{\mathrm{T}}^{\mathrm{miss}}$	Single lepton
Leptons	0 loose lepton	1 tight electron $p_{\mathrm{T}} > 27$ GeV	1 medium muon $p_{\mathrm{T}} > 25$ GeV	2 loose leptons ≥ 1 lepton with $p_{\mathrm{T}} > 27$ GeV
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 150 GeV	> 30 GeV		-
$m_{\ell\ell}$	-	-		81 GeV $< m_{\ell\ell} <$ 101 GeV
Jets	Exactly 2 or 3 jets			Exactly 2 or ≥ 3 jets
b-jets	exactly 2 b-tagged jets			
Leading b-tagged jet p_{T}	> 45 GeV			
H_{T}	> 120 (2 jets), >150 GeV (3 jets)	-		-
$\min\Delta\phi(E_{\mathrm{T}}^{\mathrm{miss}}, \mathrm{jet})$	$> 20°$ (2 jets), $> 30°$ (3 jets)	-		-
$\Delta\phi(E_{\mathrm{T}}^{\mathrm{miss}}, bb)$	$> 120°$	-		-
$\Delta\phi(b_1, b_2)$	$< 140°$	-		-
$\Delta\phi(E_{\mathrm{T}}^{\mathrm{miss}}, E_{\mathrm{T,trk}}^{\mathrm{miss}})$	$< 90°$	-		-
p_{T}^{V} regions	> 150 GeV			[75, 150] GeV, > 150 GeV
Signal Region	✓	$m_{bb} \geq 75$ GeV or $m_{\mathrm{top}} \leq 225$ GeV		Same flavour leptons opposite-sign charge ($\mu\mu$ sub-channel)
Control Region	-	$m_{bb} < 75$ GeV and $m_{\mathrm{top}} > 225$ GeV		Different flavour leptons

VH, Signal Acceptance

$m_H = 125$ GeV at $\sqrt{s} = 13$ TeV				
Process	Cross-section × BR [fb]	Acceptance [%]		
		0-lepton	1-lepton	2-lepton
$qq \to (Z \to \ell\ell)(H \to b\bar{b})$	29.9	< 0.1	< 0.1	7.0
$gg \to (Z \to \ell\ell)(H \to b\bar{b})$	4.8	< 0.1	< 0.1	15.7
$qq \to (W \to \ell\nu)(H \to b\bar{b})$	269.0	0.2	1.0	–
$qq \to (Z \to \nu\nu)(H \to b\bar{b})$	89.1	1.9	–	–
$gg \to (Z \to \nu\nu)(H \to b\bar{b})$	14.3	3.5	–	–

VH, BDT Input Variables

Variable	0-lepton	1-lepton	2-lepton
p_T^V		$\times$	$\times$
E_T^{miss}	$\times$	$\times$	$\times$
$p_T^{b_1}$	$\times$	$\times$	$\times$
$p_T^{b_2}$	$\times$	$\times$	$\times$
m_{bb}	$\times$	$\times$	$\times$
$\Delta R(b_1, b_2)$	$\times$	$\times$	$\times$
$\|\Delta\eta(b_1, b_2)\|$	$\times$		
$\Delta\phi(V, bb)$	$\times$	$\times$	$\times$
$\|\Delta\eta(V, bb)\|$			$\times$
m_{eff}	$\times$		
$\min[\Delta\phi(\ell, b)]$		$\times$	
m_T^W		$\times$	
$m_{\ell\ell}$			$\times$
m_{top}		$\times$	
$\|\Delta Y(V, bb)\|$		$\times$	
	Only in 3-jet events		
$p_T^{jet_3}$	$\times$	$\times$	$\times$
m_{bbj}	$\times$	$\times$	$\times$

VH, Background Uncertainties

Z+jets	
$Z + ll$ normalisation	18%
$Z + cl$ normalisation	23%
$Z + bb$ normalisation	Floating (2-jet, 3-jet)
$Z + bc$-to-$Z + bb$ ratio	30-40%
$Z + cc$-to-$Z + bb$ ratio	13-15%
$Z + bl$-to-$Z + bb$ ratio	20-25%
0-to-2 lepton ratio	7%
p_T^V, m_{bb}	S
W+jets	
$W + ll$ normalisation	32%
$W + cl$ normalisation	37%
$W + bb$ normalisation	Floating (2-jet, 3-jet)
$W + bl$-to-$W + bb$ ratio	26% (0-lepton) and 23% (1-lepton)
$W + bc$-to-$W + bb$ ratio	15% (0-lepton) and 30% (1-lepton)
$W + cc$-to-$W + bb$ ratio	10% (0-lepton) and 30% (1-lepton)
0-to-1 lepton ratio	5%
W+HF CR to SR ratio	10% (1-lepton)
p_T^V, m_{bb}	S
$t\bar{t}$ (all are decorrelated between the 0+1 and 2-lepton channels)	
$t\bar{t}$ normalisation	Floating (0+1 lepton, 2-lepton 2-jet, 2-lepton 3-jet)
0-to-1 lepton ratio	8%
2-to-3-jet ratio	9% (0+1-lepton only)
W+HF CR to SR ratio	25%
p_T^V, m_{bb}	S
Single top-quark	
Cross-section	4.6% (s-channel), 4.4% (t-channel), 6.2% (Wt)
Acceptance 2-jet	17% (t-channel), 35% (Wt)
Acceptance 3-jet	20% (t-channel), 41% (Wt)
m_{bb}, p_T^V	S (t-channel, Wt)
Multi-jet (1-lepton)	
Normalisation	60-100% (2-jet), 100-500%(3-jet)
BDT template	S

VH, Diboson Uncertainties

	ZZ
Normalisation	20%
0-to-2 lepton ratio	6%
Acceptance from scale variations (var.)	10.3% - 18.2% (Stewart-Tackmann jet binning method)
Acceptance from PS/UE var. for 2 or more jets	5.6% (0-lepton), 5.8% (2-lepton)
Acceptance from PS/UE var. for 3 jets	7.3% (0-lepton), 3.1% (2-lepton)
m_{bb}, p_{T}^{V}, from scale var.	S (correlated with WZ uncertainties)
m_{bb}, p_{T}^{V}, from PS/UE var.	S (correlated with WZ uncertainties)
m_{bb}, from matrix element var.	S (correlated with WZ uncertainties)
	WZ
Normalisation	26%
0-to-1 lepton ratio	11%
Acceptance from scale var.	12.7% - 21.2% (Stewart-Tackmann jet binning method)
Acceptance from PS/UE var. for 2 or more jets	3.9%
Acceptance from PS/UE var. for 3 jets	10.8%
m_{bb}, p_{T}^{V}, from scale var.	S (correlated with ZZ uncertainties)
m_{bb}, p_{T}^{V}, from PS/UE var.	S (correlated with ZZ uncertainties)
m_{bb}, from matrix element var.	S (correlated with ZZ uncertainties)
	WW
Normalisation	25%

VH, Signal Uncertainties

	Signal
Cross-section (scale)	0.7% (qq), 27% (gg)
Cross-section (PDF)	1.9% ($qq \to WH$), 1.6% ($qq \to ZH$), 5% (gg)
Branching ratio	1.7 %
Acceptance from scale variations (var.)	2.5% – 8.8% (Stewart-Tackmann jet binning method)
Acceptance from PS/UE var. for 2 or more jets	10.0% – 13.9% (depending on lepton channel)
Acceptance from PS/UE var. for 3 jets	12.9%–13.4% (depending on lepton channel)
Acceptance from PDF+α_s var.	0.5%–1.3%
m_{bb}, p_{T}^{V}, from scale var.	S
m_{bb}, p_{T}^{V}, from PS/UE var.	S
m_{bb}, p_{T}^{V}, from PDF+α_s var.	S
p_{T}^{V} from NLO EW correction	S

VH, Background Normalisation

Process	Normalisation factor
$t\bar{t}$ 0- and 1-lepton	0.90 ± 0.08
$t\bar{t}$ 2-lepton 2-jet	0.97 ± 0.09
$t\bar{t}$ 2-lepton 3-jet	1.04 ± 0.06
W + HF 2-jet	1.22 ± 0.14
W + HF 3-jet	1.27 ± 0.14
Z + HF 2-jet	1.30 ± 0.10
Z + HF 3-jet	1.22 ± 0.09

VH, Cut-based Regions

Channel	SR/CR	Categories					
		2 b-tagged jets					
		75 GeV< p_T^V <150 GeV		150 GeV< p_T^V <200 GeV		p_T^V > 200 GeV	
		2 jets	3 jets	2 jets	3 jets	2 jets	3 jets
0 lepton	SR	-	-	m_{bb}	m_{bb}	m_{bb}	m_{bb}
1 lepton	SR plus W+HF CR	-	-	m_{bb}	m_{bb}	m_{bb}	m_{bb}
2 lepton	SR	m_{bb}	m_{bb}	m_{bb}	m_{bb}	m_{bb}	m_{bb}
2 lepton	$e\mu$ CR	m_{bb}	m_{bb}	Yield*	$m_{bb}{}^{\dagger}$	Yield*	$m_{bb}{}^{\dagger}$

VH, Cut flow

Signal regions	0-lepton		1-lepton		2-lepton			
	$p_T^V > 150$ GeV, 2-tag		$p_T^V > 150$ GeV, 2-tag		75 GeV $< p_T^V <$ 150 GeV, 2-tag		$p_T^V > 150$ GeV, 2-tag	
Sample	2-jet	3-jet	2-jet	3-jet	2-jet	≥3-jet	2-jet	≥3-jet
$Z + ll$	9.0 ± 5.1	15.5 ± 8.1	< 1	–	9.2 ± 5.4	35 ± 19	1.9 ± 1.1	16.4 ± 9.3
$Z + cl$	21.4 ± 7.7	42 ± 14	2.2 ± 0.1	4.2 ± 0.1	25.3 ± 9.5	105 ± 39	5.3 ± 1.9	46 ± 17
Z+HF	2198 ± 84	3270 ± 170	86.5 ± 6.1	186 ± 13	3449 ± 79	8270 ± 150	651 ± 20	3052 ± 66
$W + ll$	9.8 ± 5.6	17.9 ± 9.9	22 ± 10	47 ± 22	< 1	< 1	< 1	< 1
$W + cl$	19.9 ± 8.8	41 ± 18	70 ± 27	138 ± 53	< 1	< 1	< 1	< 1
W+HF	460 ± 51	1120 ± 120	1280 ± 160	3140 ± 420	3.0 ± 0.4	5.9 ± 0.7	< 1	2.2 ± 0.2
Single top-quark	145 ± 22	536 ± 98	830 ± 120	3700 ± 670	53 ± 16	134 ± 46	5.9 ± 1.9	30 ± 10
$t\bar{t}$	463 ± 42	3390 ± 200	2650 ± 170	20640 ± 680	1453 ± 46	4904 ± 91	49.6 ± 2.9	430 ± 22
Diboson	116 ± 26	119 ± 36	79 ± 23	135 ± 47	73 ± 19	149 ± 32	24.4 ± 6.2	87 ± 19
Multi-jet e sub-ch.	–	–	102 ± 66	27 ± 68	–	–	–	–
Multi-jet μ sub-ch.	–	–	133 ± 99	90 ± 130	–	–	–	–
Total bkg.	3443 ± 57	8560 ± 91	5255 ± 80	28110 ± 170	5065 ± 66	13600 ± 110	738 ± 19	3664 ± 56
Signal (fit)	58 ± 17	60 ± 19	63 ± 19	65 ± 21	25.6 ± 7.8	46 ± 15	13.6 ± 4.1	35 ± 11
Data	3520	8634	5307	28168	5113	13640	724	3708

VH, Composition High S/B

Process	Bin 11	Bin 12	Bin 13	Bin 14
Data	274	156	34	4
Signal (fit)	32.4	25.0	11.1	1.1
Total Background	238.3	113.7	27.3	1.5
$Z + ll$	0.2	0.1	< 0.1	< 0.1
$Z + cl$	0.7	0.4	< 0.1	< 0.1
Z+HF	86.1	51.3	10.5	1.5
$W + ll$	0.20	0.1	< 0.1	–
$W + cl$	1.6	0.2	< 0.1	–
W+HF	58.9	24.5	6.9	–
Single top-quark	19.2	7.6	2.9	–
$t\bar{t}$	61.3	25.7	6.2	–
Diboson	4.7	1.7	0.4	< 0.1
Multi-jet e sub-ch.	0.1	–	–	–
Multi-jet μ sub-ch.	5.2	2.0	< 0.1	–

VH, Detailed Results

Dataset	p_0		Significance	
	Exp.	Obs.	Exp.	Obs.
0-lepton	4.2%	30%	1.7	0.5
1-lepton	3.5%	1.1%	1.8	2.3
2-lepton	3.1%	0.019%	1.9	3.6
Combined	0.12%	0.019%	3.0	3.5

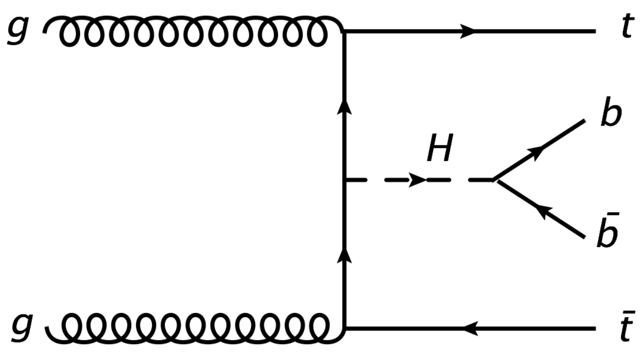
VH, Composition Control Regions

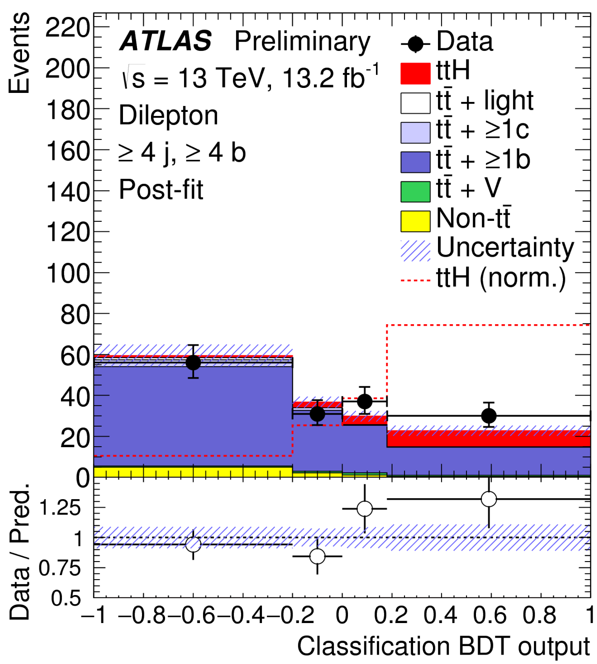
Control regions	1-lepton		2-lepton			
	$p_T^V > 150$ GeV, 2-tag		75 GeV $< p_T^V <$ 150 GeV, 2-tag		$p_T^V > 150$ GeV, 2-tag	
Sample	2-jet	3-jet	2-jet	≥3-jet	2-jet	≥3-jet
$Z + ll$	< 1	< 1	< 1	< 1	< 1	< 1
$Z + cl$	–	< 1	< 1	< 1	< 1	< 1
Z+HF	6.6 ± 0.7	19.3 ± 1.4	2.1 ± 0.2	2.8 ± 0.2	< 1	1.2 ± 0.1
$W + ll$	1.1 ± 0.1	2.9 ± 0.1	–	–	–	–
$W + cl$	2.6 ± 1.1	8.7 ± 3.7	–	–	–	–
W+HF	234 ± 21	594 ± 45	3.0 ± 0.3	2.7 ± 0.3	< 1	< 1
Single top-quark	10.3 ± 2.8	40 ± 14	50 ± 15	127 ± 45	5.8 ± 1.8	27.9 ± 9.8
$t\bar{t}$	24.8 ± 7.8	107 ± 29	1437 ± 41	4852 ± 85	48.8 ± 3.8	431 ± 21
Diboson	5.6 ± 1.9	12.1 ± 4.2	–	< 1	–	–
Multi-jet e sub-ch.	8.2 ± 5.3	2.2 ± 5.6	–	–	–	–
Multi-jet μ sub-ch.	6.8 ± 5.1	3.7 ± 5.4	–	–	–	–
Total bkg.	300 ± 16	791 ± 27	1492 ± 37	4985 ± 68	55.2 ± 3.9	461 ± 19
Signal (fit)	< 1	1.2 ± 0.4	< 1	< 1	< 1	< 1
Data	302	790	1489	4967	50	470

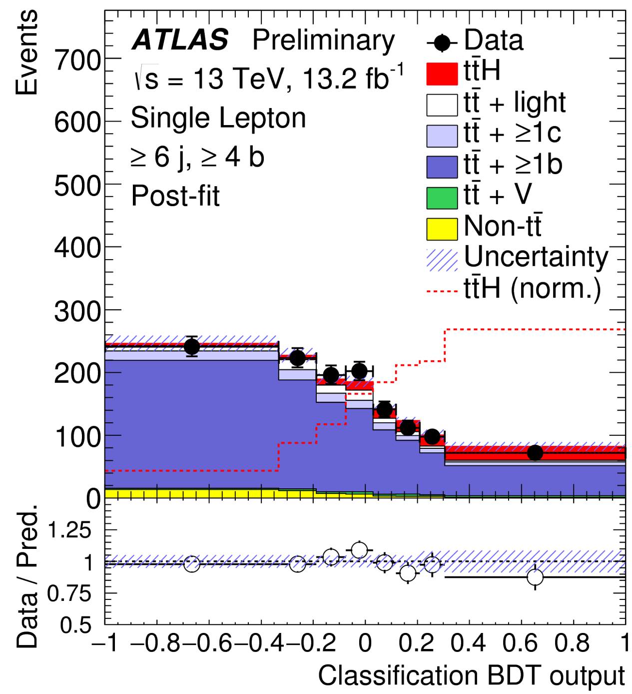
ttH, H(bb)

13 TeV, 13.2 fb^{-1}

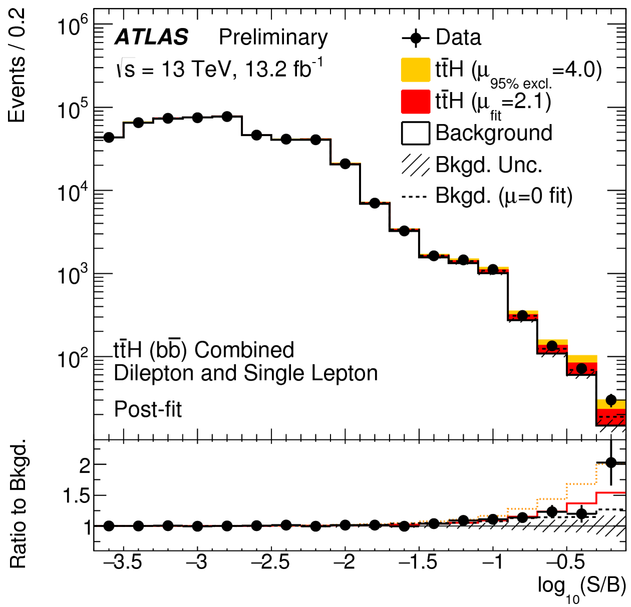
- Search in both single and di-lepton channels
  - Categorise according to jet and b-tag multiplicity
  - Reconstruction multivariate analysis (MVA) matches jets to partons
  - Classification MVA discriminates signal from background

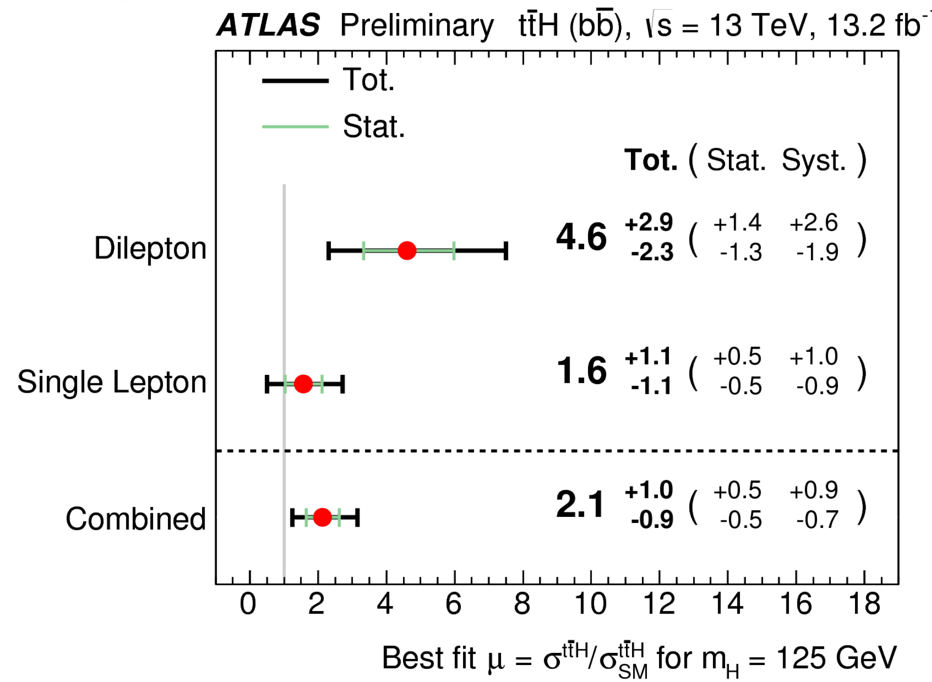






ttH, H(bb) Results





Reached Run 1 sensitivity

Uncertainty source	$\Delta\mu$	
$t\bar{t}+\geq 1b$ modelling	+0.53	−0.53
Jet flavour tagging	+0.26	−0.26
$t\bar{t}H$ modelling	+0.32	−0.20
Background model statistics	+0.25	−0.25
$t\bar{t}+\geq 1c$ modelling	+0.24	−0.23
Jet energy scale and resolution	+0.19	−0.19
$t\bar{t}$+light modelling	+0.19	−0.18
Other background modelling	+0.18	−0.18
Jet-vertex association, pileup modelling	+0.12	−0.12
Luminosity	+0.12	−0.12
$t\bar{t}Z$ modelling	+0.06	−0.06
Light lepton (e,μ) ID, isolation, trigger	+0.05	−0.05
Total systematic uncertainty	+0.90	−0.75
$t\bar{t}+\geq 1b$ normalisation	+0.34	−0.34
$t\bar{t}+\geq 1c$ normalisation	+0.14	−0.14
Statistical uncertainty	+0.49	−0.49
Total uncertainty	+1.02	−0.89

Limiting factors:

- Modelling of $t\bar{t}$ +heavy flavour (hf)
- Flavour tagging
- Monte Carlo statistics
- Signal modelling