Observation of *VH* and *H*→*bb* with the ATLAS detector

Faig Ahmadov

JINR Prize Competition for young scientists and specialists

JINR, Dubna

04 December 2018

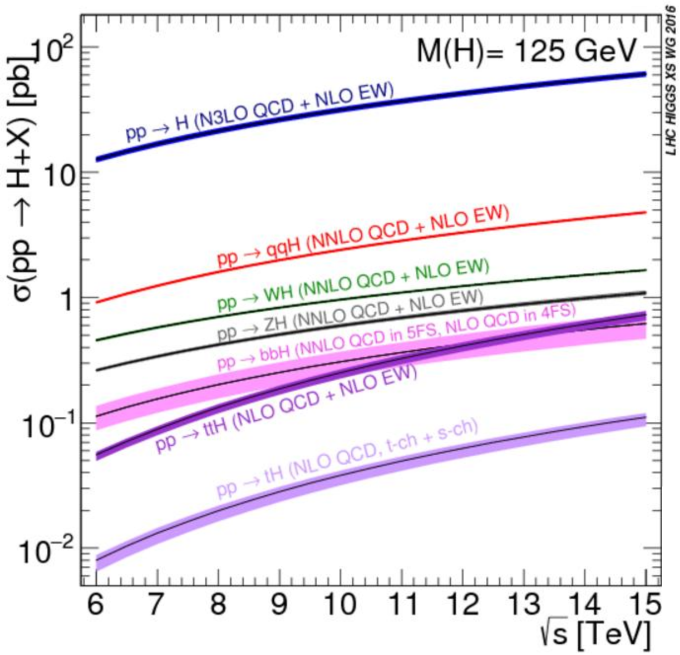
Overview

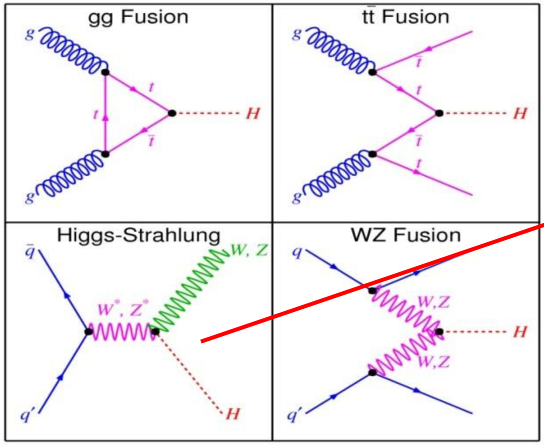
- *Introduction*
- *Object and event selection*
- *Data and simulated samples*
- *Systematic uncertainties*
- *Statistical analysis*
- *Results*
- *Conclusion*

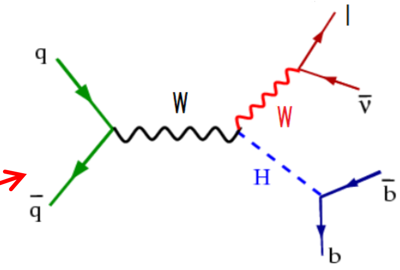
Introduction

- In July 2012, the ATLAS and CMS experiments reported the observation of a new particle with a mass of about 125 GeV and with properties consistent with those expected from the SM Higgs boson.
- Determining the nature of this boson - whether it is indeed the SM Higgs boson - is one of the most important questions in particle physics.
- The ATLAS & CMS measurements have been performed in the bosonic decay modes of the new particle ($H\rightarrow\gamma\gamma$, $H\rightarrow ZZ$, & $H\rightarrow WW$);
- Since then, more precise measurements have strengthened the hypothesis that the new particle is indeed a Higgs boson (observation of the *ggF, VBF, ttH* production and $\gamma\gamma$, ZZ, WW, $\tau\tau$ decay channels);
- Observing the decay into fermions is vital in testing whether the new boson is compatible with a SM Higgs boson.
- In particular, the decay to b-quarks plays an important role since this is the dominant decay mode at this mass ($BR(H\rightarrow bb) \approx 58\%$).
- Therefore an observation in this channel **is crucial** in order to provide a direct constraint on the largest decay mode.

H production & decay channels

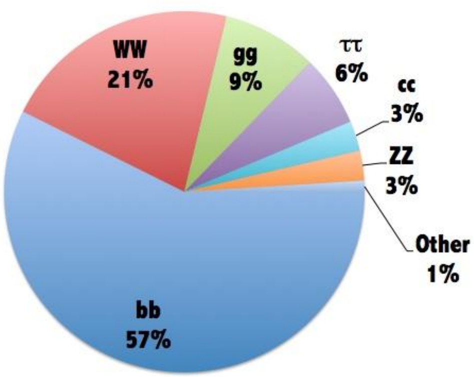






XS(pp->H->bb) ~ 30pb
XS(Bkg->bb) ~ 10^6pb

Higgs decays at m_H=125GeV



V (H→bb); *V=W or Z*

$\sqrt{s}$=13TeV, m_H=125 GeV

BR (H→bb) ~ 58%
BR (W→lν) ~ 33%
BR (Z→ll+νν) ~ 30%
XS (WH+ZH) ~ 2.3 pb

XS(VH-llbb) ~ ***0.4 pb***

XS(Bkg) ~ ***10^3 pb***

The leptonic decays of the vector boson, W or Z can be used for triggering and background reduction purposes.

Object selection

Event preselection: GRL, Vertex, min. 3 tracks, pile-up reweighting, triggers,

Cleaning : MET cleaning, Jet cleaning, …;

Electrons:

Loose: $|\eta|<2.47$, $E_T > 7$GeV , $|d_0|<0.1$mm (for 7TeV data), p_T cone(0.2) <0.04, OR

Signal: Loose + $E_T > 27$GeV, E_T cone (0.3) <0.04.

Muons:

Loose: $|\eta|<2.7$, $E_T > 10$GeV, $|d_0|<0.1$mm & $|z_0|<10$mm , OR (jets electrons)

Signal: Loose + $|\eta|<2.5$, $E_T > 25$GeV , E_T cone (0.3) <0.04.

Jets:

Veto: $p_T > 20$GeV & $|\eta|<2.5$ or $p_T > 30$GeV & $2.5<|\eta|<4.5$, OR with mu and el.

Signal: Veto + $p_T > 20$GeV & $|\eta|<2.5$

b-jets: The MV1 b-tagging algorithm is used to identify jets originating from b-quark fragmentation), MV1 with 70% eff.

MET: The missing transverse momentum E_T^{miss} is reconstructed as the negative vector sum of the momenta of leptons, hadronically decaying τ-leptons and jets, and of a 'soft term' built from additional tracks matched to the primary vertex[

Event selection

Selection	0-lepton	1-lepton: e sub-channel	1-lepton: μ sub-channel	2-lepton
Trigger	E_T^{miss}	Single lepton	E_T^{miss}	Single lepton
Leptons	0 *loose* leptons with $p_T > 7$ GeV	1 *tight* electron $p_T > 27$ GeV	1 *tight* muon $p_T > 25$ GeV	2 *loose* leptons with $p_T > 7$ GeV ≥ 1 lepton with $p_T > 27$ GeV
E_T^{miss}	> 150 GeV	> 30 GeV	–	–
$m_{\ell\ell}$	–	–		81 GeV $< m_{\ell\ell} <$ 101 GeV
Jets	Exactly 2 / Exactly 3 jets			Exactly 2 / ≥ 3 jets
Jet p_T		> 20 GeV for $\lvert\eta\rvert < 2.5$ > 30 GeV for $2.5 < \lvert\eta\rvert < 4.5$		
b-jets		Exactly 2 b-tagged jets		
Leading b-tagged jet p_T		> 45 GeV		
H_T	> 120 GeV (2 jets), >150 GeV (3 jets)	–		–
$\min[\Delta\phi(\vec{E}_T^{miss}, \vec{jets})]$	$> 20°$ (2 jets), $> 30°$ (3 jets)	–		–
$\Delta\phi(\vec{E}_T^{miss}, \vec{bb})$	$> 120°$	–		–
$\Delta\phi(\vec{b}_1, \vec{b}_2)$	$< 140°$	–		–
$\Delta\phi(\vec{E}_T^{miss}, \vec{p}_T^{miss})$	$< 90°$	–		–
p_T^V regions		> 150 GeV		75 GeV $< p_T^V <$ 150 GeV, > 150 GeV
Signal regions	–	$m_{bb} \geq 75$ GeV or $m_{top} \leq 225$ GeV		Same-flavour leptons Opposite-sign charges ($\mu\mu$ sub-channel)
Control regions	–	$m_{bb} < 75$ GeV and $m_{top} > 225$ GeV		Different-flavour leptons Opposite-sign charges

Additional cuts for Dijet-mass analysis

Selection	Channel: 0-lepton	Channel: 1-lepton	Channel: 2-lepton
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
$\Delta R(\vec{b}_1, \vec{b}_2)$	<3.0	<1.8	<1.2

Data and simulated samples

- Data: $\sqrt{s}$=*13TeV*, *79.8±1.6 fb^{-1}* (2015 – 2017).
- The generators used for the simulation of the signal and background processes:

Process	ME generator	ME PDF	PS and Hadronisation	UE model tune	Cross-section order
Signal, mass set to 125 GeV and $b\bar{b}$ branching fraction to 58%					
$qq \to WH \to \ell\nu b\bar{b}$	Powheg-Box v2 [76] + GoSam [79] + MiNLO [80,81]	NNPDF3.0NLO$^{(\star)}$ [77]	Pythia 8.212 [68]	AZNLO [78]	NNLO(QCD)+ NLO(EW) [82–88]
$qq \to ZH \to \nu\nu b\bar{b}/\ell\ell b\bar{b}$	Powheg-Box v2 + GoSam + MiNLO	NNPDF3.0NLO$^{(\star)}$	Pythia 8.212	AZNLO	NNLO(QCD)$^{(\dagger)}$+ NLO(EW)
$gg \to ZH \to \nu\nu b\bar{b}/\ell\ell b\bar{b}$	Powheg-Box v2	NNPDF3.0NLO$^{(\star)}$	Pythia 8.212	AZNLO	NLO+ NLL [89–93]
Top quark, mass set to 172.5 GeV					
$t\bar{t}$	Powheg-Box v2 [94]	NNPDF3.0NLO	Pythia 8.230	A14 [95]	NNLO+NNLL [96]
s-channel	Powheg-Box v2 [97]	NNPDF3.0NLO	Pythia 8.230	A14	NLO [98]
t-channel	Powheg-Box v2 [97]	NNPDF3.0NLO	Pythia 8.230	A14	NLO [99]
Wt	Powheg-Box v2 [100]	NNPDF3.0NLO	Pythia 8.230	A14	Approximate NNLO [101]
Vector boson + jets					
$W \to \ell\nu$	Sherpa 2.2.1 [71, 102, 103]	NNPDF3.0NNLO	Sherpa 2.2.1 [104, 105]	Default	NNLO [106]
$Z/\gamma^* \to \ell\ell$	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					
$qq \to WW$	Sherpa 2.2.1	NNPDF3.0NNLO	Sherpa 2.2.1	Default	NLO
$qq \to WZ$	Sherpa 2.2.1	NNPDF3.0NNLO	Sherpa 2.2.1	Default	NLO
$qq \to ZZ$	Sherpa 2.2.1	NNPDF3.0NNLO	Sherpa 2.2.1	Default	NLO
$gg \to VV$	Sherpa 2.2.2	NNPDF3.0NNLO	Sherpa 2.2.2	Default	NLO

Systematic 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)
$H \to b\bar{b}$ branching fraction	1.7%
Acceptance from scale variations	2.5 – 8.8%
Acceptance from PS/UE variations for 2 or more jets	2.9 – 6.2% (depending on lepton channel)
Acceptance from PS/UE variations for 3 jets	1.8 – 11%
Acceptance from PDF+α_S variations	0.5 – 1.3%
m_{bb}, p_T^V, from scale variations	S
m_{bb}, p_T^V, from PS/UE variations	S
m_{bb}, p_T^V, from PDF+α_S variations	S
p_T^V from NLO EW correction	S

ZZ	
Normalisation	20%
0-to-2 lepton ratio	6%
Acceptance from scale variations	10 – 18%
Acceptance from PS/UE variations for 2 or more jets	6%
Acceptance from PS/UE variations for 3 jets	7% (0-lepton), 3% (2-lepton)
m_{bb}, p_T^V, from scale variations	S (correlated with WZ uncertainties)
m_{bb}, p_T^V, from PS/UE variations	S (correlated with WZ uncertainties)
m_{bb}, from matrix-element variations	S (correlated with WZ uncertainties)
WZ	
Normalisation	26%
0-to-1 lepton ratio	11%
Acceptance from scale variations	13 – 21%
Acceptance from PS/UE variations for 2 or more jets	4%
Acceptance from PS/UE variations for 3 jets	11%
m_{bb}, p_T^V, from scale variations	S (correlated with ZZ uncertainties)
m_{bb}, p_T^V, from PS/UE variations	S (correlated with ZZ uncertainties)
m_{bb}, from matrix-element variations	S (correlated with ZZ uncertainties)
WW	
Normalisation	25%

Z + jets	
$Z + ll$ normalisation	18%
$Z + cl$ normalisation	23%
Z + HF 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%
m_{bb}, p_T^V	S
W + jets	
$W + ll$ normalisation	32%
$W + cl$ normalisation	37%
W + HF 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)
m_{bb}, p_T^V	S
$t\bar{t}$ (all are uncorrelated 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%
m_{bb}, p_T^V	S
Single top-quark	
Cross-section	4.6% (s-channel), 4.4% (t-channel), 6.2% (Wt)
Acceptance 2-jet	17% (t-channel), 55% ($Wt(bb)$), 24% (Wt(other))
Acceptance 3-jet	20% (t-channel), 51% ($Wt(bb)$), 21% (Wt(other))
m_{bb}, p_T^V	S (t-channel, $Wt(bb)$, Wt(other))
Multi-jet (1-lepton)	
Normalisation	60 – 100% (2-jet), 90 – 140% (3-jet)
BDT template	S

Statistical analysis

Multivariate analysis

Variable	0-lepton	1-lepton	2-lepton
p_{T}^{V}	$\equiv E_{\mathrm{T}}^{\mathrm{miss}}$	$\times$	$\times$
$E_{\mathrm{T}}^{\mathrm{miss}}$	$\times$	$\times$	
$p_{\mathrm{T}}^{b_1}$	$\times$	$\times$	$\times$
$p_{\mathrm{T}}^{b_2}$	$\times$	$\times$	$\times$
m_{bb}	$\times$	$\times$	$\times$
$\Delta R(\vec{b_1}, \vec{b_2})$	$\times$	$\times$	$\times$
$\lvert\Delta\eta(\vec{b_1}, \vec{b_2})\rvert$	$\times$		
$\Delta\phi(\vec{V}, \vec{bb})$	$\times$	$\times$	$\times$
$\lvert\Delta\eta(\vec{V}, \vec{bb})\rvert$			$\times$
m_{eff}	$\times$		
$\min[\Delta\phi(\vec{\ell}, \vec{b})]$		$\times$	
m_{T}^{W}		$\times$	
$m_{\ell\ell}$			$\times$
$E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{S_{\mathrm{T}}}$			$\times$
m_{top}		$\times$	
$\lvert\Delta Y(\vec{V}, \vec{bb})\rvert$		$\times$	
		Only in 3-jet events	
$p_{\mathrm{T}}^{\mathrm{jet}_3}$	$\times$	$\times$	$\times$
m_{bbj}	$\times$	$\times$	$\times$

Process	$\sigma \times \mathcal{B}$ [fb]	Acceptance [%]		
		0-lepton	1-lepton	2-lepton
$qq \to ZH \to \ell\ell b\bar{b}$	29.9	<0.1	0.1	6.0
$gg \to ZH \to \ell\ell b\bar{b}$	4.8	<0.1	0.2	13.5
$qq \to WH \to \ell\nu b\bar{b}$	269.0	0.2	1.0	–
$qq \to ZH \to \nu\nu b\bar{b}$	89.1	1.9	–	–
$gg \to ZH \to \nu\nu b\bar{b}$	14.3	3.5	–	–

Process	Normalisation factor
$t\bar{t}$ 0- and 1-lepton	0.98 ± 0.08
$t\bar{t}$ 2-lepton 2-jet	1.06 ± 0.09
$t\bar{t}$ 2-lepton 3-jet	0.95 ± 0.06
W + HF 2-jet	1.19 ± 0.12
W + HF 3-jet	1.05 ± 0.12
Z + HF 2-jet	1.37 ± 0.11
Z + HF 3-jet	1.09 ± 0.09

Dijet-mass analysis

- The number of signal regions is increased to fourteen as a consequence of splitting the event regions with $p_T^V > 150\ GeV$ in two ($150 - 200\ GeV$ and $> 200\ GeV$);
- The $W + HF$ CRs are merged into the corresponding SR;
- $|\Delta R(j1,j2)| \leq 1.8\ (150 \leq p_T^V < 200\ GeV)$,

  $|\Delta R(j1,j2)| \leq 1.2\ (200\ GeV < p_T^V)$;

  $m_T^W < 120\ GeV$ (1-lepton),

  $E_T^{miss} / \sqrt{S_T} < \sqrt{3.5\ GeV}$ (2-lepton).

Diboson analysis

- A measurement of the signal strength of the *ZZ* and *WZ* processes is conducted to validate the main multivariate analysis;
- The method differs from the global likelihood fit only by the use of the BDT_{VZ} output distributions as inputs, instead of BDT_{VH};
- The parameter of interest, μ_{VZ}, is the signal strength of the combined *WZ* and *ZZ* diboson processes;
- The SM Higgs boson is included as a background process normalised to the predicted SM cross-section with an uncertainty of 50%, which conservatively encompasses the previous measurement and uncertainty.

Combinations

✓ The results of the statistical analysis of the *13 TeV* data are combined with those from the data recorded at *7 TeV* and *8 TeV* (Run 1) to improve the precision of the measurement.

✓ A second combination is performed with the results of the searches for the *H→bb* decay in the *ttH* and *VBF+ggH* production modes carried out with the Run 1 and Run 2 data.

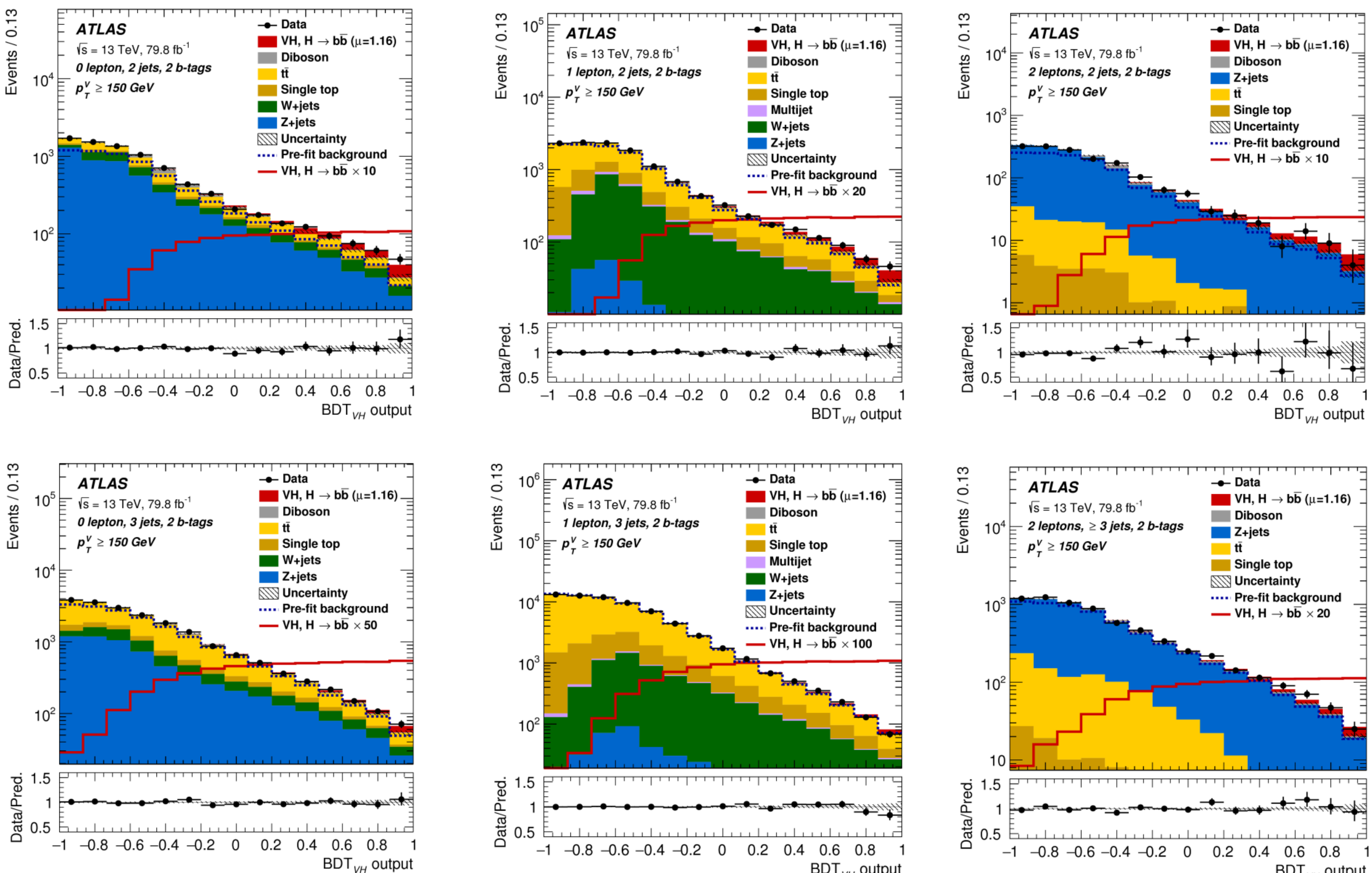
✓ A third combination is also performed combining the Run 2 *VH, H→bb* result with other results in the *VH* production mode, but for the case of the Higgs boson decaying into two photons or via ZZ^* into four leptons.

Results of the SM Higgs boson search at $\sqrt{s}$ = 13 TeV

BDT_{VH} *output* post-fit distributions

2-jet

3-jet



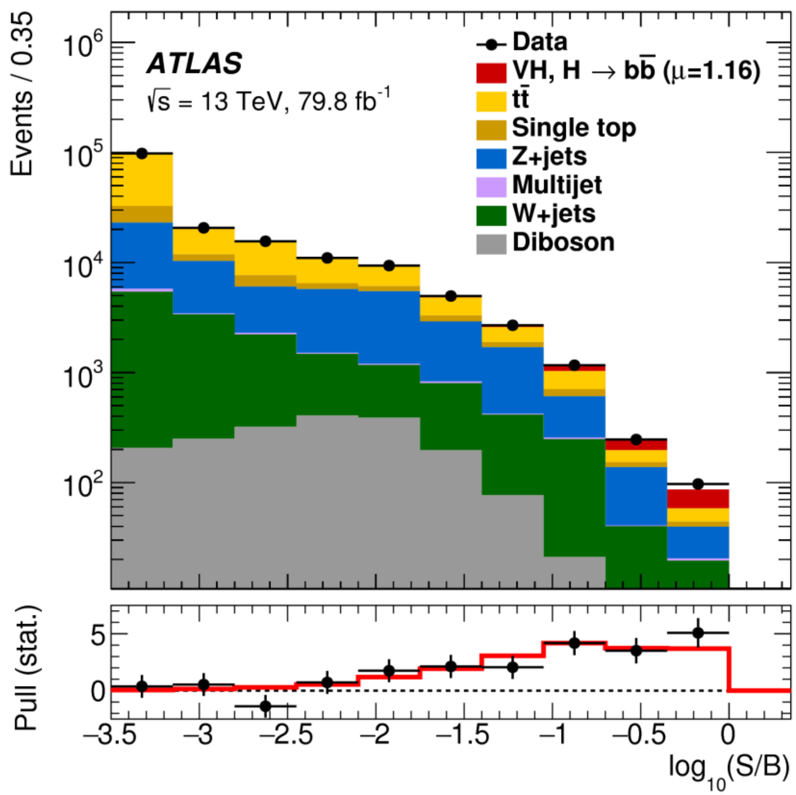
0-lepton 1-lepton 2-lepton

Yields & signal strengths (μ)

	0-lepton		1-lepton		2-lepton			
	$p_T^V > 150\,GeV$, 2-b-tag		$p_T^V > 150\,GeV$, 2-b-tag		$75\,GeV < p_T^V < 150\,GeV$, 2-$b$-tag		$p_T^V > 150\,GeV$, 2-b-tag	
Process	2-jet	3-jet	2-jet	3-jet	2-jet	≥3-jet	2-jet	≥3-jet
$Z + ll$	17 ± 11	27 ± 18	2 ± 1	3 ± 2	14 ± 9	49 ± 32	4 ± 3	30 ± 19
$Z + cl$	45 ± 18	76 ± 30	3 ± 1	7 ± 3	43 ± 17	170 ± 67	12 ± 5	88 ± 35
Z + HF	4770 ± 140	5940 ± 300	180 ± 9	348 ± 21	7400 ± 120	14160 ± 220	1421 ± 34	5370 ± 100
$W + ll$	20 ± 13	32 ± 22	31 ± 23	65 ± 48	< 1	< 1	< 1	< 1
$W + cl$	43 ± 20	83 ± 38	139 ± 67	250 ± 120	< 1	< 1	< 1	< 1
W + HF	1000 ± 87	1990 ± 200	2660 ± 270	5400 ± 670	2 ± 0	13 ± 2	1 ± 0	4 ± 1
Single top quark	368 ± 53	1410 ± 210	2080 ± 290	9400 ± 1400	188 ± 89	440 ± 200	23 ± 7	93 ± 26
$t\bar{t}$	1333 ± 82	9150 ± 400	6600 ± 320	50200 ± 1400	3170 ± 100	8880 ± 220	104 ± 6	839 ± 40
Diboson	254 ± 49	318 ± 90	178 ± 47	330 ± 110	152 ± 32	355 ± 68	52 ± 11	196 ± 35
Multi-jet e sub-ch.	–	–	100 ± 100	41 ± 35	–	–	–	–
Multi-jet μ sub-ch.	–	–	138 ± 92	260 ± 270	–	–	–	–
Total bkg.	7850 ± 90	19020 ± 140	12110 ± 120	66230 ± 270	10960 ± 100	24070 ± 150	1620 ± 30	6620 ± 80
Signal (post-fit)	128 ± 28	128 ± 29	131 ± 30	125 ± 30	51 ± 11	86 ± 22	28 ± 6	67 ± 17
Data	8003	19143	12242	66348	11014	24197	1626	6686

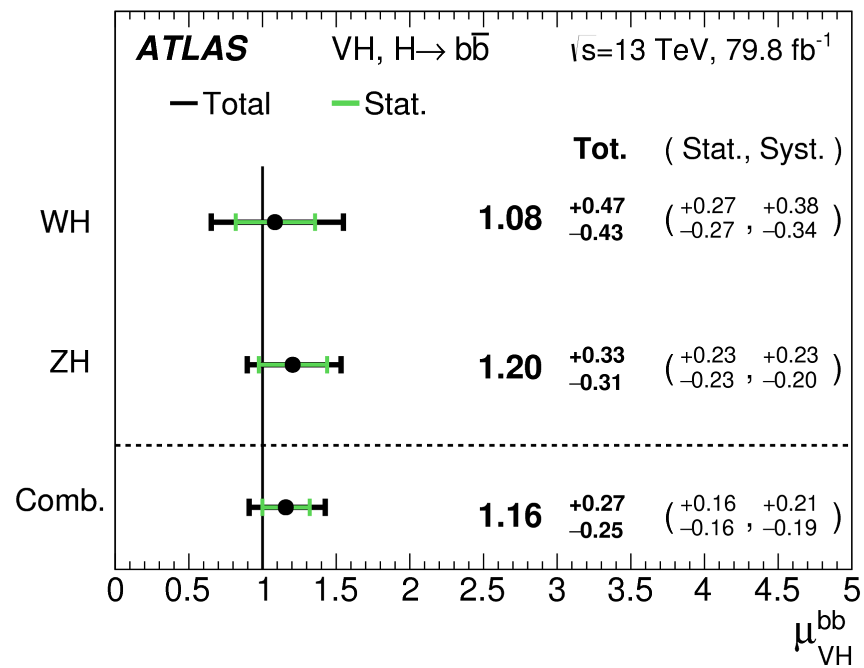
Signal strength	Signal strength	p_0		Significance	
		Exp.	Obs.	Exp.	Obs.
0-lepton	$1.04^{+0.34}_{-0.32}$	$9.5 \cdot 10^{-4}$	$5.1 \cdot 10^{-4}$	3.1	3.3
1-lepton	$1.09^{+0.46}_{-0.42}$	$8.7 \cdot 10^{-3}$	$4.9 \cdot 10^{-3}$	2.4	2.6
2-lepton	$1.38^{+0.46}_{-0.42}$	$4.0 \cdot 10^{-3}$	$3.3 \cdot 10^{-4}$	2.6	3.4
$VH,\ H \to b\bar{b}$ combination	$1.16^{+0.27}_{-0.25}$	$7.3 \cdot 10^{-6}$	$5.3 \cdot 10^{-7}$	4.3	4.9

Yields & μ



Event yields as a function of log10(S/B) for data, background and a Higgs boson signal with mH=125 GeV.

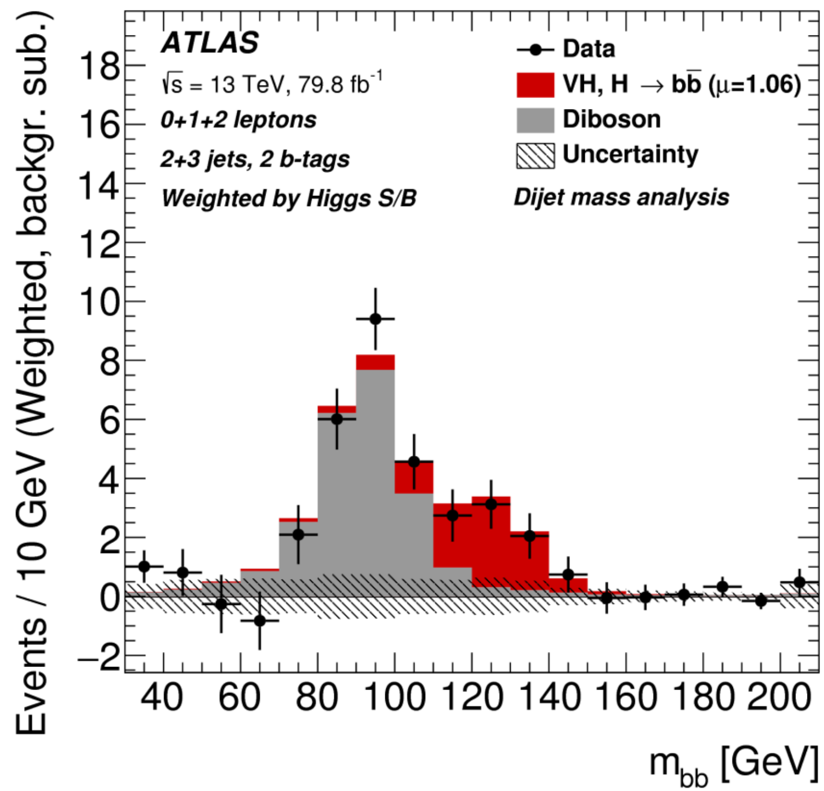
The fitted values of the Higgs boson signal strength μ_{VHbb} for m_H=125 GeV for the WH and ZH processes and their combination.



Results of the dijet-mass analysis

The distribution of m_{bb} in data after subtraction of all backgrounds except for the *WZ* and *ZZ* diboson processes.

The expected contribution of the associated *WH* and *ZH* production of a SM Higgs boson with $m_H = 125\ GeV$ is shown scaled by the measured signal strength ($\mu = 1.06$).

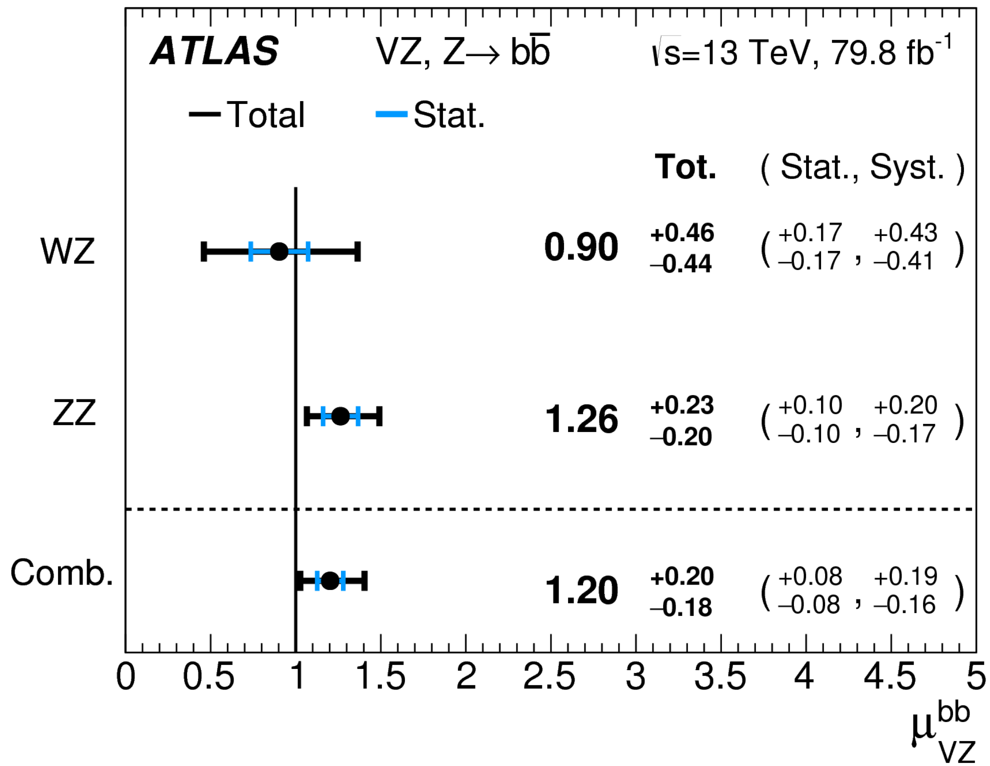


The fitted value of the signal strength is

$$\mu_{VHbb}=1.06\pm0.20(stat.)^{+0.30}_{-0.26}(syst.),$$

in good agreement with the result of the multivariate analysis.

Results of the diboson analysis

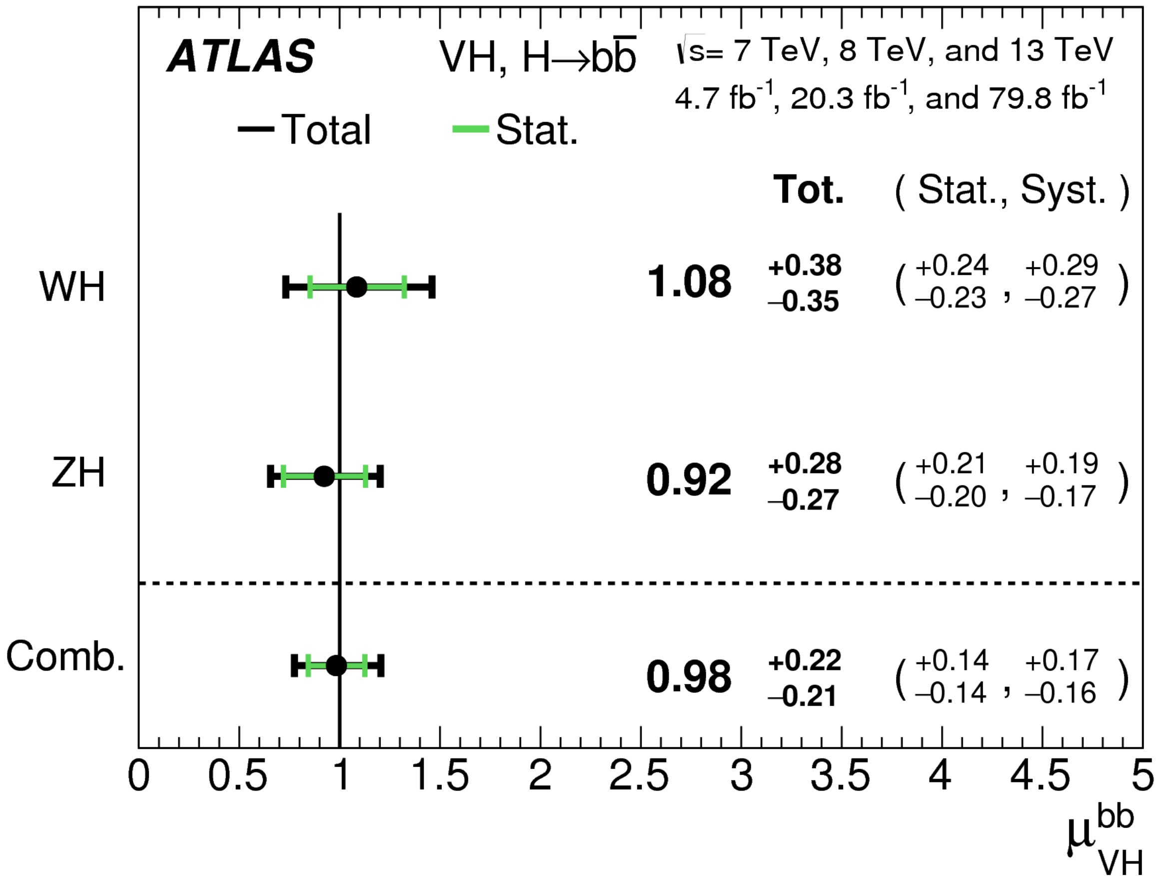


A value of signal strength

$$\mu_{VZbb}=1.20\pm0.08(stat.)^{+0.19}_{-0.16}(syst.),$$

in good agreement with the Standard Model prediction.

Results of combinations

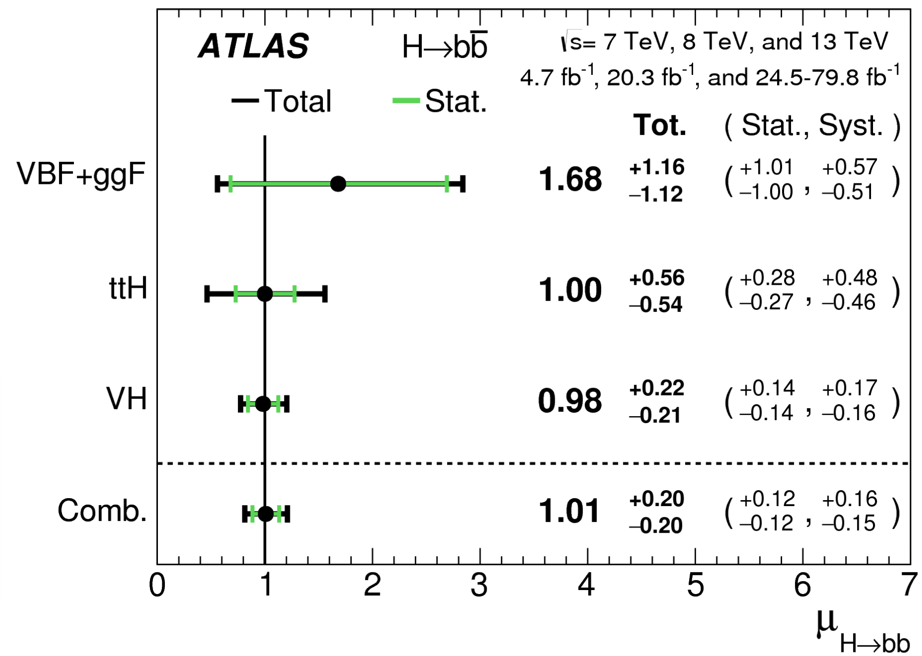


The fitted values of the Higgs boson signal strength for m_H=125 GeV, using the 7 TeV, 8 TeV and 13 TeV data.

Observation of $H \rightarrow bb$ decays

Channel	Significance	
	Exp.	Obs.
VBF+ggF	0.9	1.5
$t\bar{t}H$	1.9	1.9
VH	5.1	4.9
$H \rightarrow b\bar{b}$ combination	5.5	5.4

The fitted values of the Higgs boson signal strength $\mu_{H\rightarrow bb}$ for m_H=125 GeV separately for the VH, ttH and VBF+ggF analyses along with their combination, using the 7 TeV, 8 TeV and 13 TeV data.



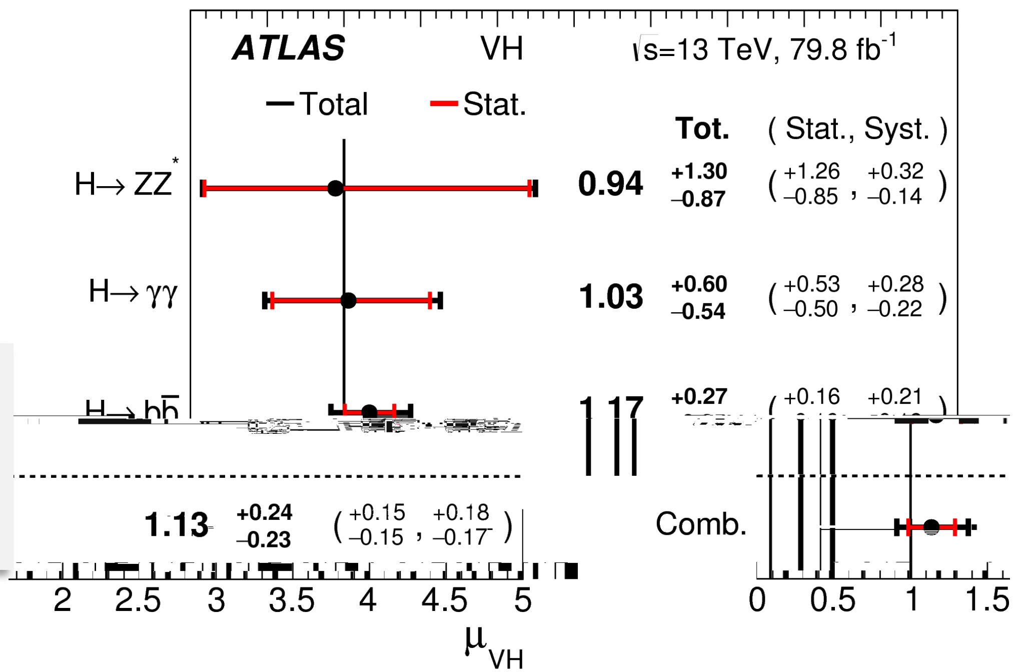
Expected and observed significance values (in standard deviations) for the H→bb channels fitted independently and their combination using the 7 TeV, 8 TeV and 13 TeV data.

Observation of VH production

Channel	Significance	
	Exp.	Obs.
$H \to ZZ^* \to 4\ell$	1.1	1.1
$H \to \gamma\gamma$	1.9	1.9
$H \to b\bar{b}$	4.3	4.9
VH combined	4.8	5.3

Expected and observed significance values (in standard deviations) for the VH production channels from the combined fit, using 13 TeV data.

The fitted values of the Higgs boson signal strength μ_{VH} for m_H=125 GeV separately for the $H \to bb$, $H \to \gamma\gamma$ and $H \to ZZ^* \to 4\ell$ decay modes, along with their combination.



Conclusion I

- ✓ For the data corresponding to an integrated luminosity of *79.8* fb^{-1} collected at a centre-of-mass energy of $\sqrt{s} = 13$ *TeV*, an excess over the expected background is observed, with a significance of **4.9 standard deviations** compared with an expectation of **4.3**.

- ✓ The measured signal strength relative to the SM prediction for $m_H = 125$ *GeV* is found to be

$$\mu_{VHbb} = \mathbf{1.16} \pm 0.16(stat.)^{+0.21}_{-0.19}(syst.).$$

- ✓ This result is combined with previous results based on all the Run 1 data collected at centre-of-mass energies of *7 TeV* and *8 TeV*.

- ✓ An excess over the expected SM background is observed, with a significance of **4.9 standard deviations** compared with an expectation of **5.1**.

- ✓ The measured signal strength relative to the SM expectation is found to be

$$\mu_{VHbb} = \mathbf{0.98} \pm 0.14(stat.)^{+0.17}_{-0.16}(syst.).$$

Conclusion II

- ✓ Combined the results for the SM Higgs boson decaying into a ***bb*** pair in the *VH, ttH* and *VBF+ggF* production modes at *√s= 7 TeV, 8 TeV* and *13 TeV*.

- ✓ An excess over the expected SM background is observed, with a significance of **5.4σ** compared with an expectation of **5.5σ**, providing an observation of the $H \to bb$ decay mode and the measured signal strength relative to the SM expectation is

$$\mu_{H\to bb}=\mathbf{1.01}\pm 0.12(stat.)^{+0.16}_{-0.15}(syst.),$$

  consistent with the value of the Yukawa coupling to bottom quarks in the SM.

- ✓ In addition, the Run 2 *VH, H→bb* result is further combined with the results of other Run2 searches for the Higgs boson decaying into either *4l* or *γγ* in the ***VH*** production mode.

- ✓ The result is an observed significance of **5.3σ**, to be compared with an expectation of **4.8σ** and the measured signal strength relative to the SM expectation is

$$\mu_{VH}=\mathbf{1.13}\pm 0.15(stat.)^{+0.18}_{-0.17}(syst.).$$

- ✓ **This provides a direct observation of the Higgs boson being produced in association with a vector boson.**

CERN press release

ATLAS observes elusive Higgs boson decay to a pair of bottom quarks
"ATLAS is proud to announce the observation of this important and challenging Higgs boson decay. While the result is certainly a confirmation of the Standard Model, it is equally a triumph for our analysis teams. "

Long-sought decay of Higgs boson observed
"This observation is a milestone in the exploration of the Higgs boson. It shows that the ATLAS and CMS experiments have achieved deep understanding of their data and a control of backgrounds that surpasses expectations. ATLAS has now observed all couplings of the Higgs boson to the heavy quarks and leptons of the third generation as well as all major production modes."

Karl Jakobs, spokesperson of the ATLAS collaboration.

Links

CERN Press release:
Long-sought decay of Higgs boson observed

ATLAS press release:
ATLAS observes elusive Higgs boson decay to a pair of bottom quarks

Газета Дубна ЕЖЕНЕДЕЛЬНИК ОИЯИ :
О «неуловимом» распаде бозона Хиггса

ATLAS paper:
Observation of *H→bb* decays and *VH* production with the ATLAS detector
Phys. Lett. B 786 (2018) 59

Thank You!