Evidence for the $H \rightarrow b\bar{b}$ decay with the ATLAS detector

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on behalf of the ATLAS Collaboration

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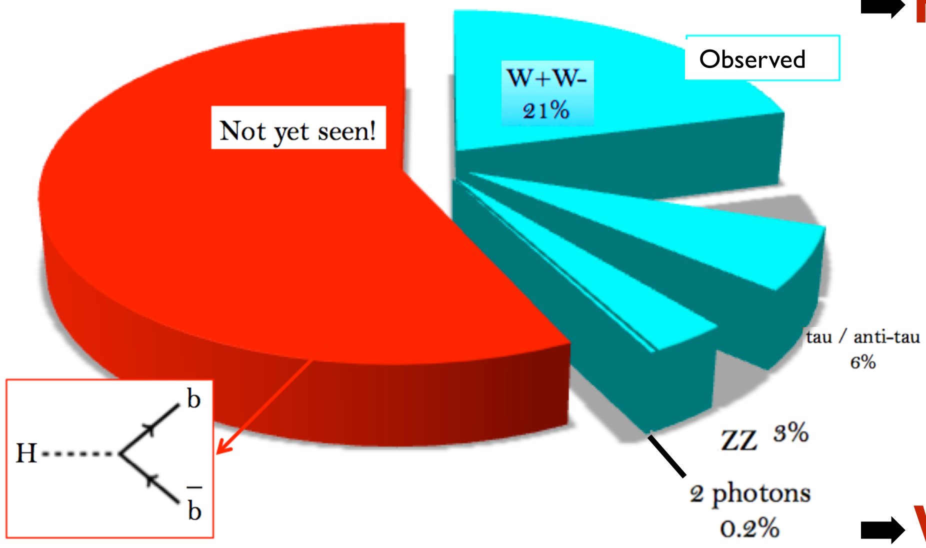
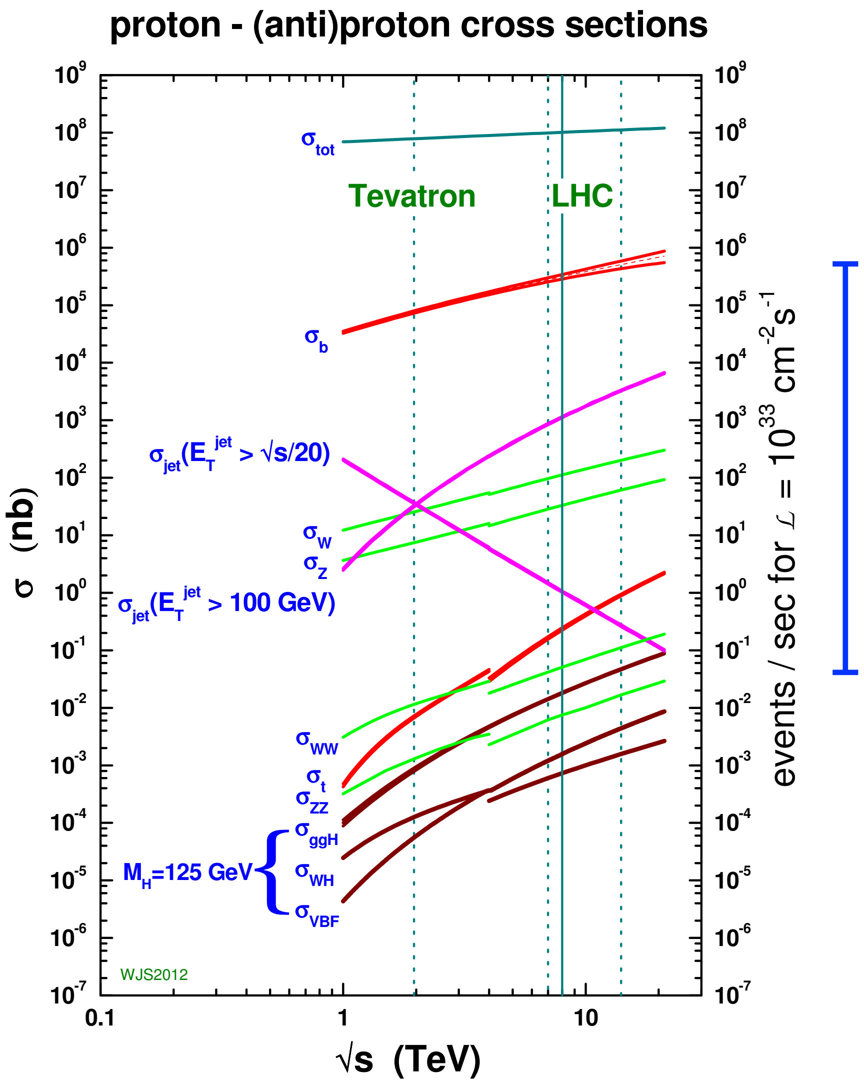
Motivation for VH, H → $b\bar{b}$ and Previous results



- ➡ **H → $b\bar{b}$ an important missing piece of the "Higgs puzzle":**
  - ➡ **Provides direct probe of coupling to quarks**
  - ➡ **Drives the uncertainty on the total decay width, and thus on measurement of absolute couplings**
  - ➡ **The more Higgs boson decays we see, the less "space" remains available for "undetected/invisible" decays**
- ➡ **VH leptonic signatures → suppression of multi-jet bkg / trigger**



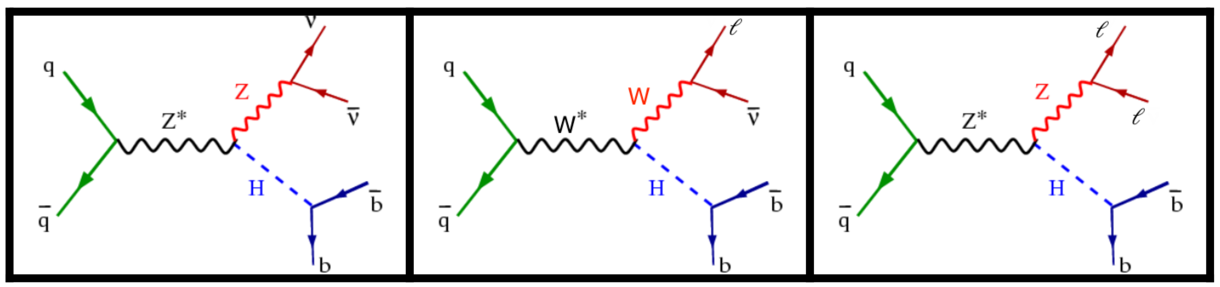
previous VHbb at Higgs mass = 125 GeV	Signal strength**	Significance (expected)	Significance (observed)
CDF+DØ combination [1] 9.7 fb-1 @ $\sqrt{s}$ = 1.96TeV	$1.9^{+0.8}_{-0.7}$	1.5σ	2.8σ (3.1σ global)
ATLAS Run-I [2] 4.7/20.3 fb-1 @ $\sqrt{s}$ = 7/8TeV	$0.52^{+0.40}_{-0.37}$	2.6σ	1.4σ
CMS Run-I [3] 5.1/19.7 fb-1 @ $\sqrt{s}$ = 7/8TeV	$0.89^{+0.47}_{-0.44}$	2.5σ	2.1σ
ATLAS+CMS Run-I* [4]	$0.70^{+0.29}_{-0.27}$	3.7σ	2.6σ

*with sub-leading contribution from ttH, H → bb

$$**\mu = \frac{\sigma \times \mathrm{BR}}{(\sigma \times \mathrm{BR})_{\mathrm{SM}}}$$

[1] Phys. Rev. Lett. **109** (2012) 071804
[2] JHEP01(2015)069
[3] Eur.Phys.J. C75(5), 212 (2015) + twiki
[4] JHEP08(2016)045

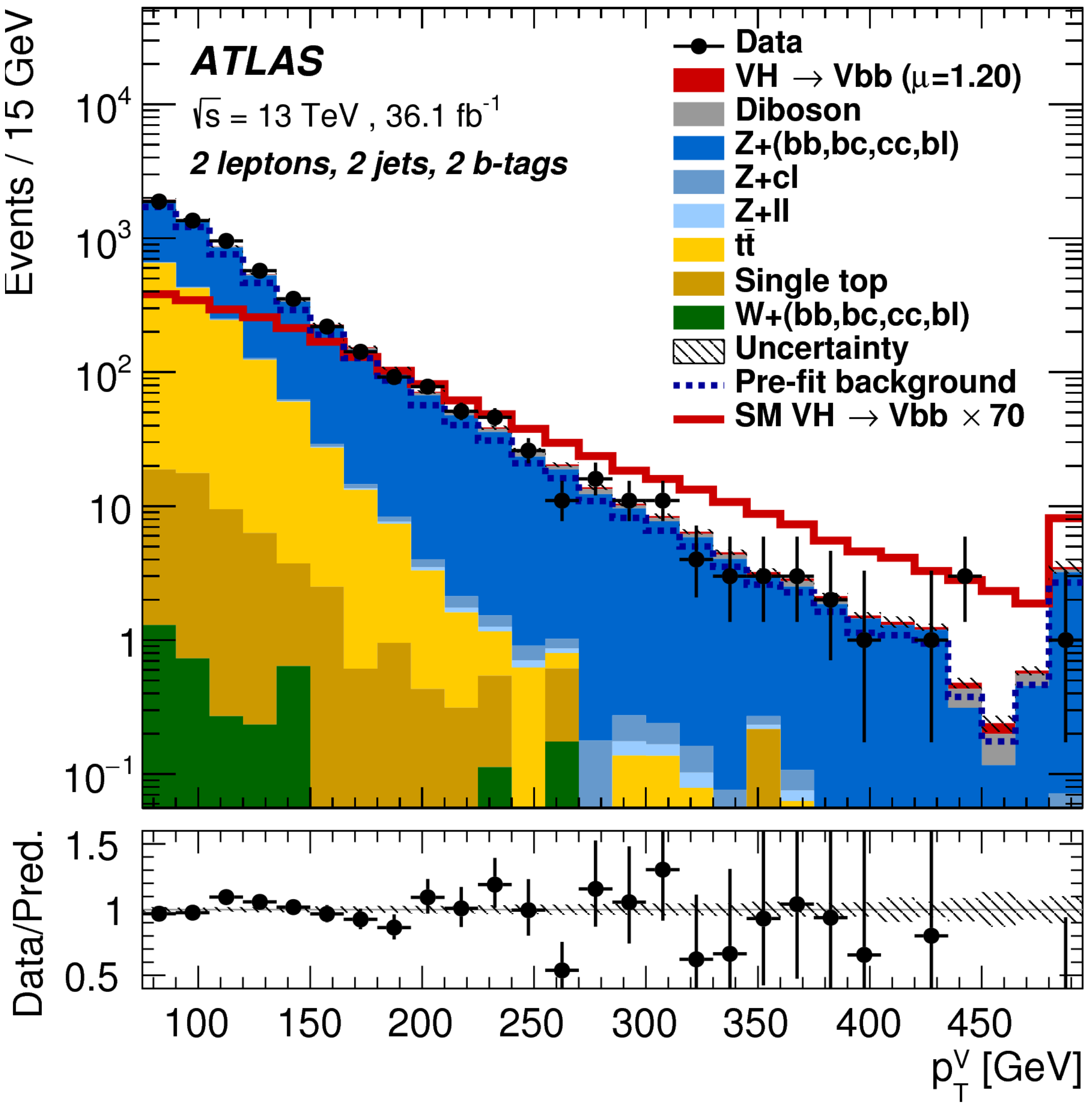
How to make a use of the leptonic signatures?



Performed with the pp collisions data at $\sqrt{s}$ = 13TeV, collected in 2015 and 2016, corresponding to an integrated luminosity of 36.1 fb^{-1}. [JHEP 12 (2017) 024]

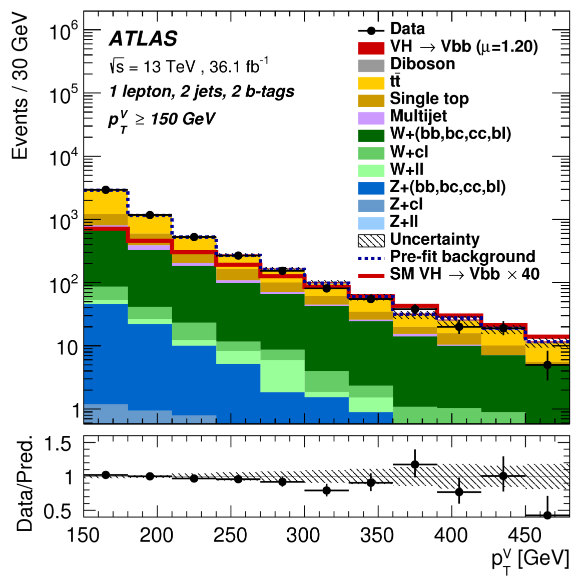
VH, H → $b\bar{b}$ selection

- ➡ 0 / 1 / 2 lepton (e or μ)
- ➡ Trigger based on single lepton and MET (MET also used for W→$\mu\nu$)
- ➡ 2 b-tagged jets with (> 45, > 20) GeV
- ➡ Exactly 2 or 3 jets (0, 1-lepton), 2 or ≥ 3 jets (2-lepton)
- ➡ Requiring high $p_T(V)$ → improving S/B ratio
- ➡ Exploited in event categorisation:
  - ➡ 75 < $p_T(V)$ ≤ 150 GeV (2-lepton)
  - ➡ $p_T(V)$ > 150 (all channels)

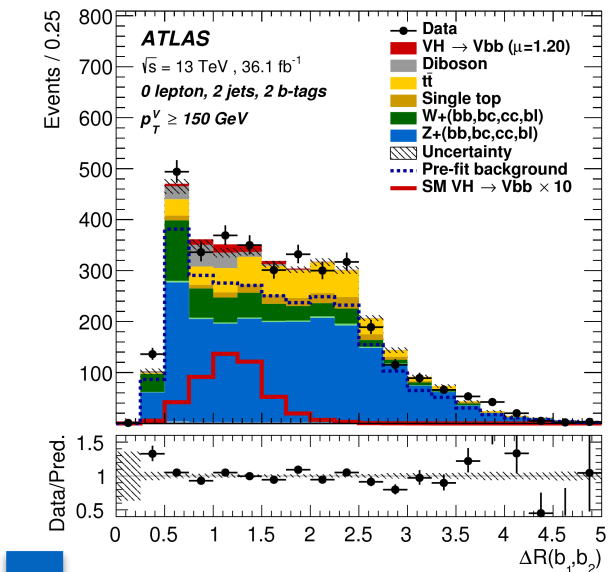


Multivariate analysis

$p_T(V)$



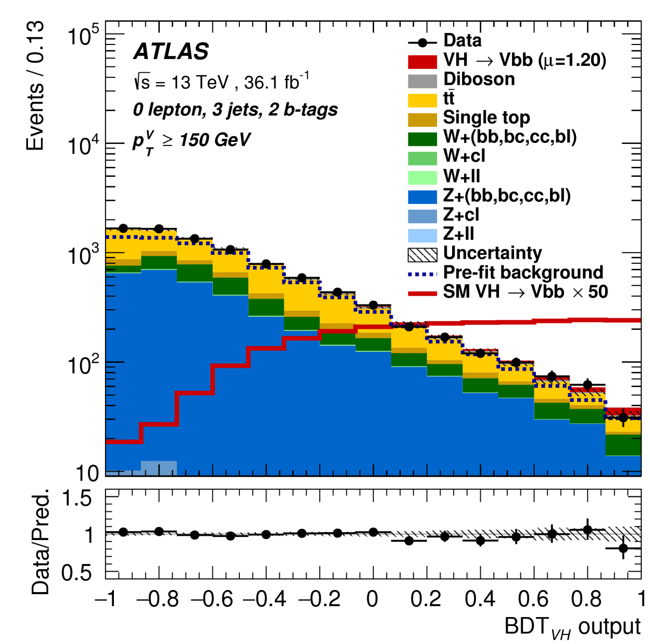
$\Delta R(b_1,b_2)$



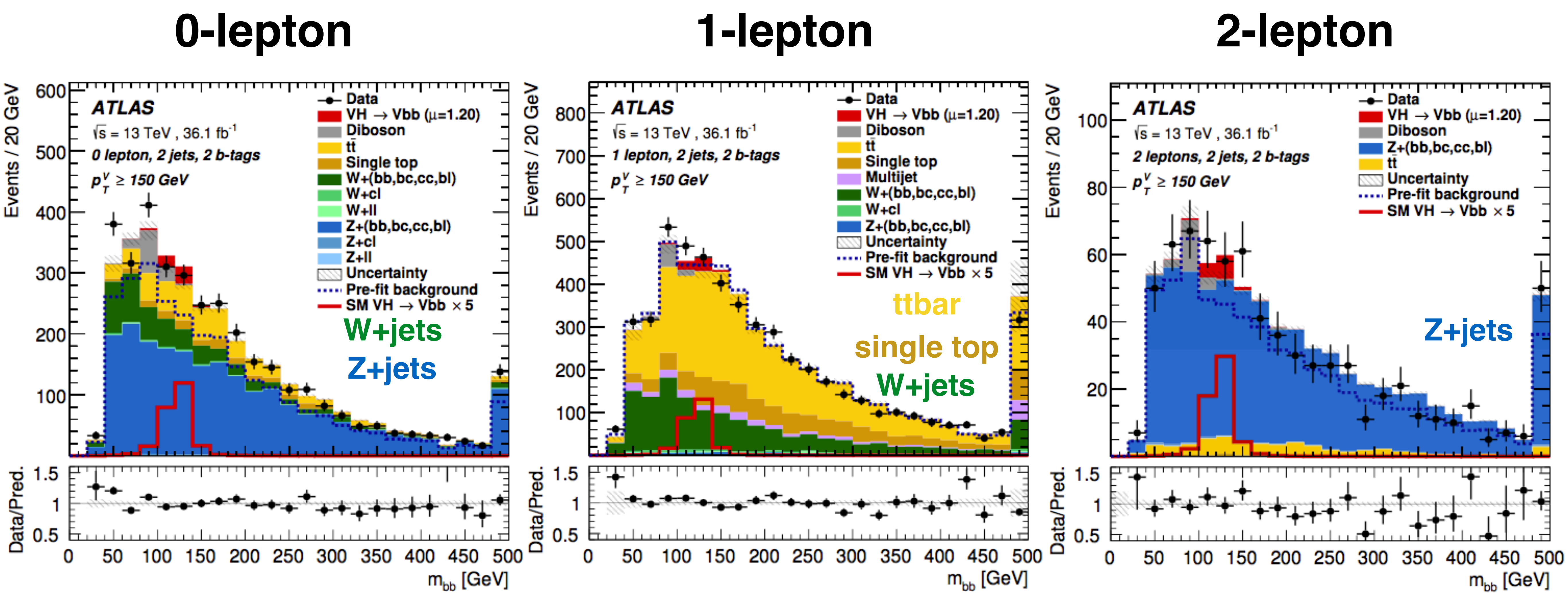
- ➡ One BDT per channel and analysis region
- ➡ Two versions of the BDTs
  - ➡ Same inputs
  - ➡ Separate VH(→ $b\bar{b}$) from backgrounds, denoted as BDT_{VH}
  - ➡ Separate VZ(→ $b\bar{b}$) from backgrounds, denoted as BDT_{VZ}

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

- ➡ A fit to a multivariate discriminant (BDT) is performed to separate signal from background
  - ➡ MVA analysis: VH(→ $b\bar{b}$) fit on BDT_{VH}
  - ➡ Validation: VZ(→ $b\bar{b}$) fit on BDT_{VZ}
  - ➡ Cross check: VH(→ $b\bar{b}$) fit on m_{bb}
- ➡ A likelihood fit is applied across channels and multiple analysis regions to extract the signal strength $\mu = \frac{\sigma \times BR}{(\sigma \times BR)_{SM}}$ and the normalisations of the main backgrounds
- ➡ Shapes and relative normalisations across regions parametrised by nuisance parameters (NPs), constrained within allowed systematic uncertainties (priors)



Backgrounds



➡ Distribution of best discriminating variable m_{bb}

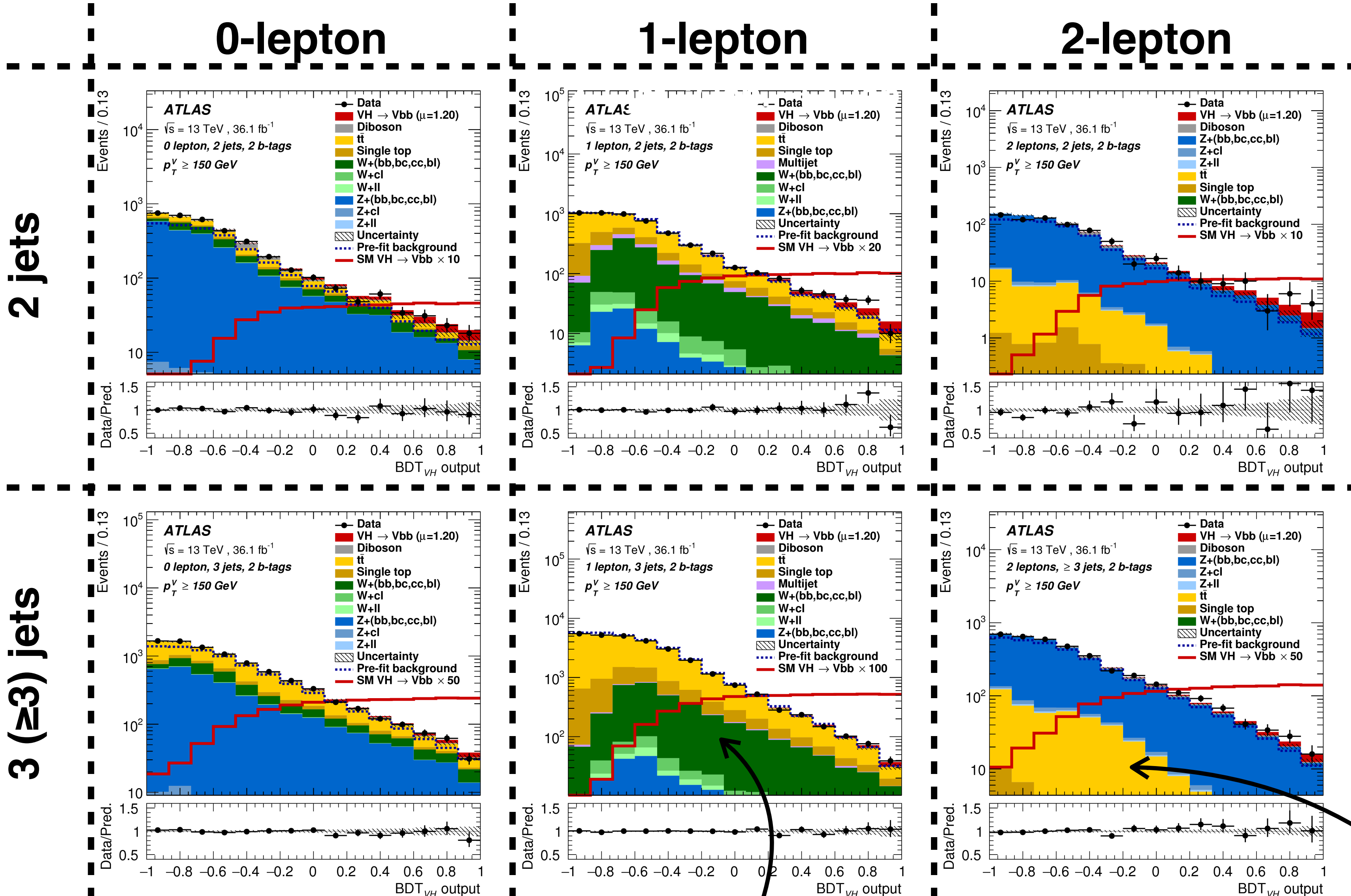
➡ Non-resonant backgrounds from W+jets, Z+jets, ttbar and single top

➡ W+jets / Z+jets is mainly suppressed by b-jet requirement (except W/Z+bb)

➡ ttbar is mainly suppressed by the requirement on jet multiplicity

➡ Resonant VZ, $Z\rightarrow b\bar{b}$ backgrounds, used to validate the analysis procedure

Background estimation strategy



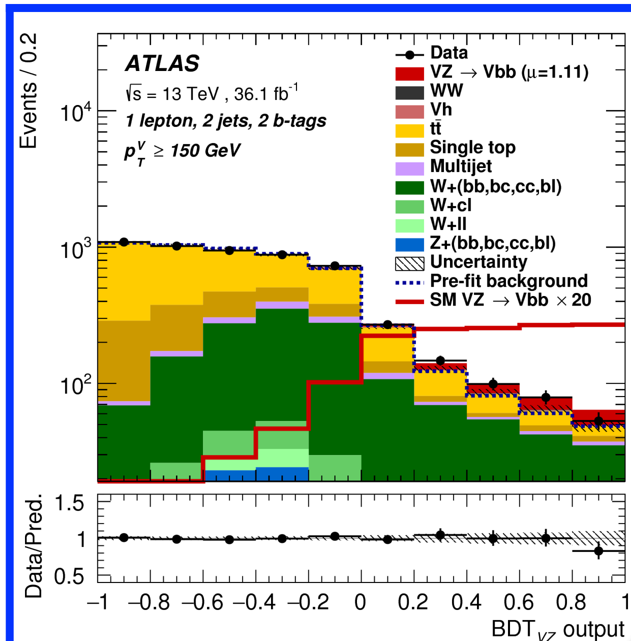
- ➡ **Z+jets**: **Constrained in 2-lepton, extrapolated to 0-lepton**
- ➡ **W+jets**: **Constrained in 1-lepton with a dedicated control region, extrapolated to 0-lepton**
- ➡ **ttbar**:
  - ➡ **In 0-lepton and 1-lepton: constrained together**
  - ➡ **In 2-lepton: constrained in a dedicated control region**

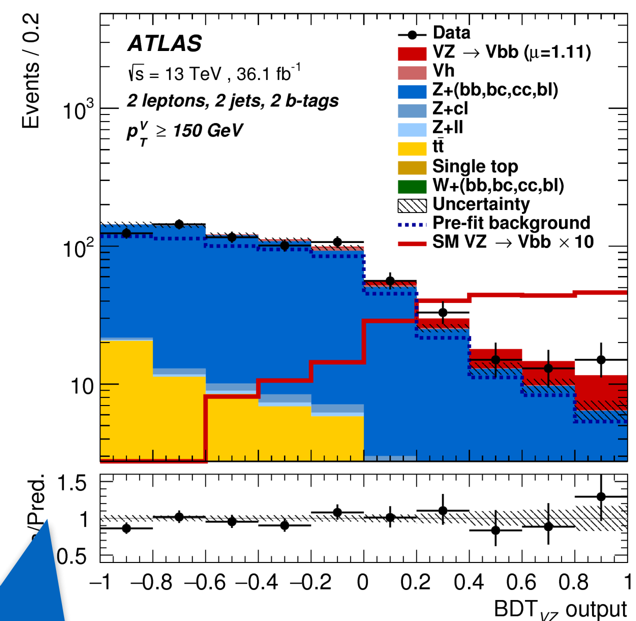
- ➡ **1-lepton W+jets control region**:
  - ➡ **m_{bb} < 75 GeV and *m_{top} > 225 GeV**
  - ➡ **~ 75-80 % purity**
- ➡ **2-lepton ttbar control region**:
  - ➡ **Require eμ**
  - ➡ **> 99 % purity**

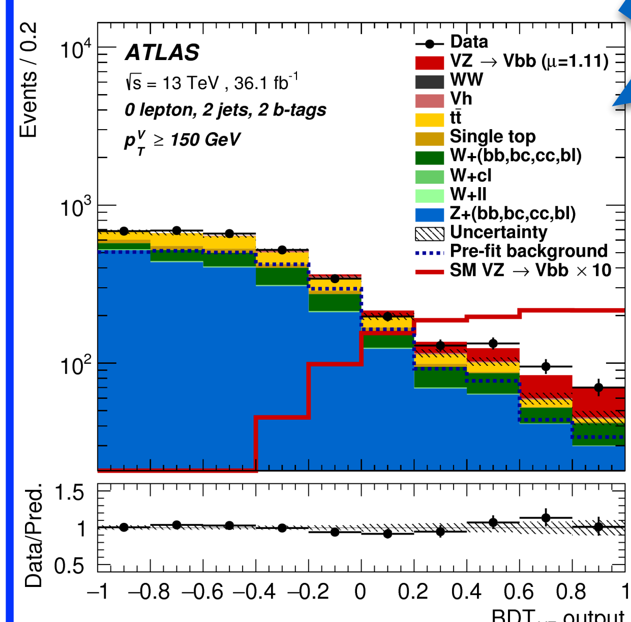
*** Reconstructed top quark mass**

Validation with VZ production

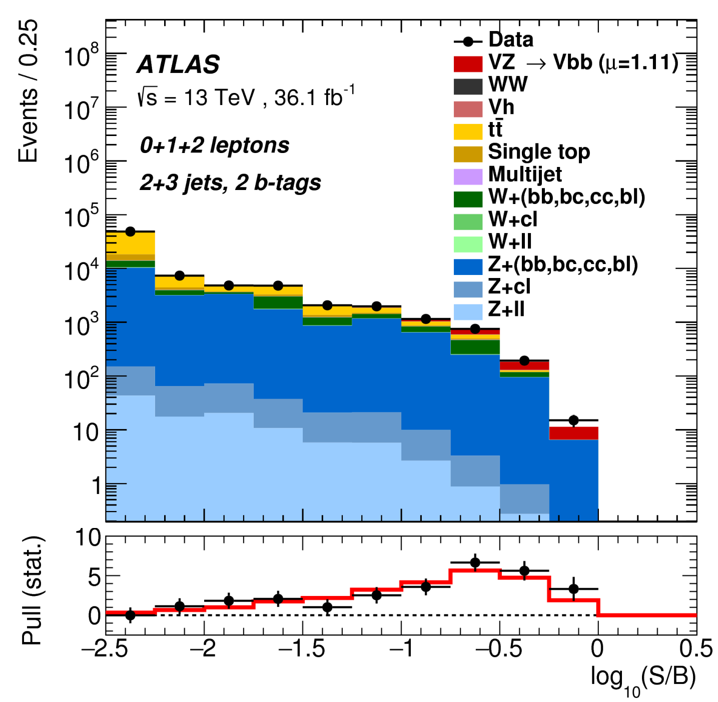
VZ, Z → $b\bar{b}$ as signal, fit on BDT$_{VZ}$

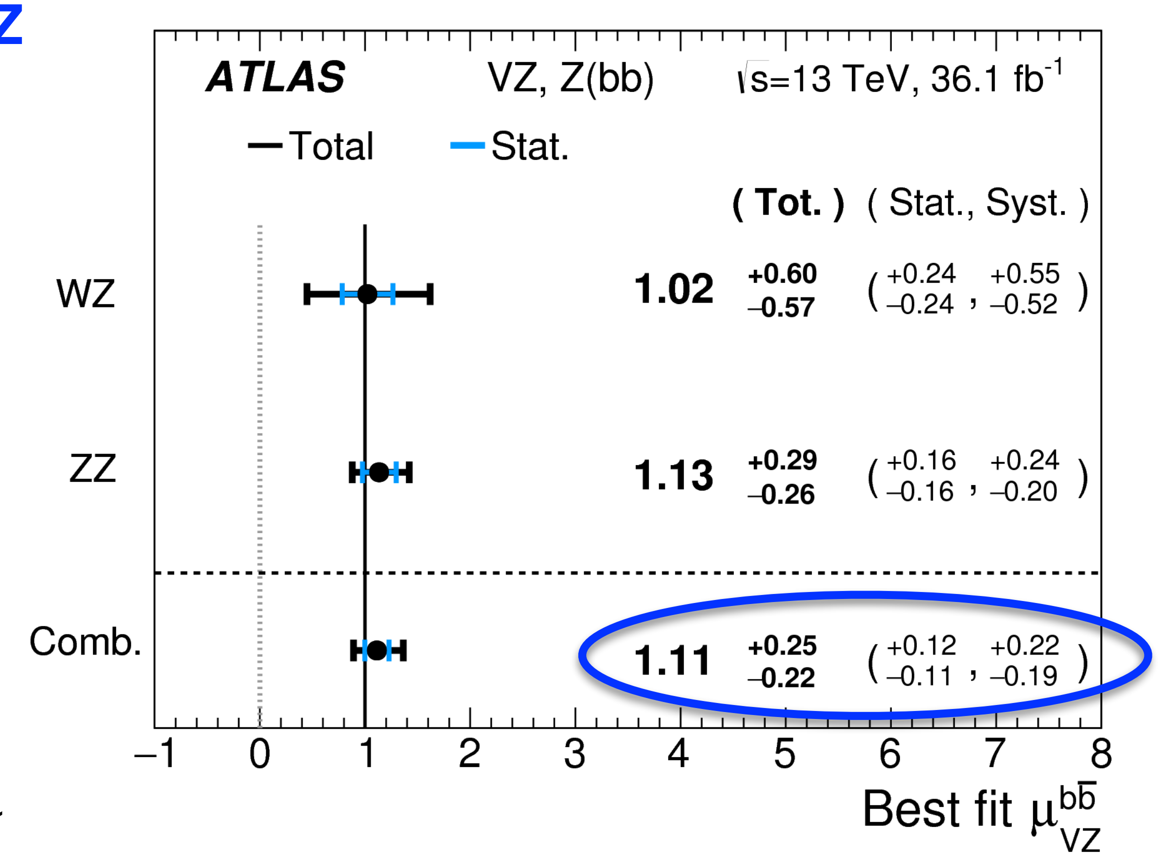






36.1 fb^{-1} of Run-2 data

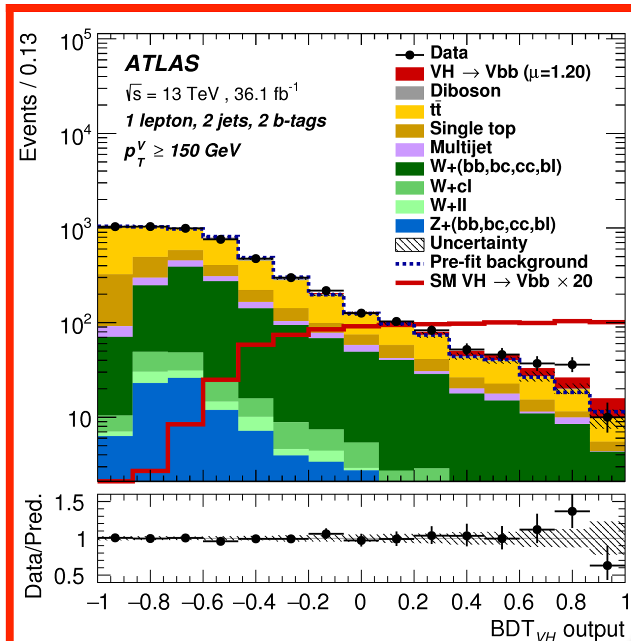


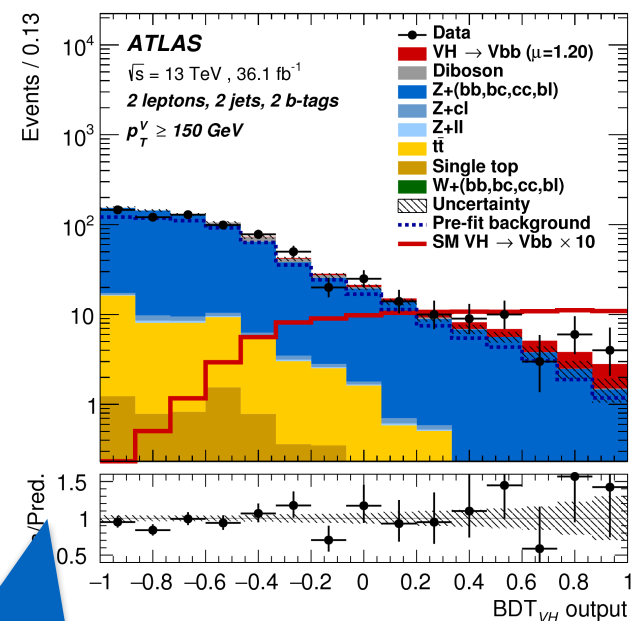


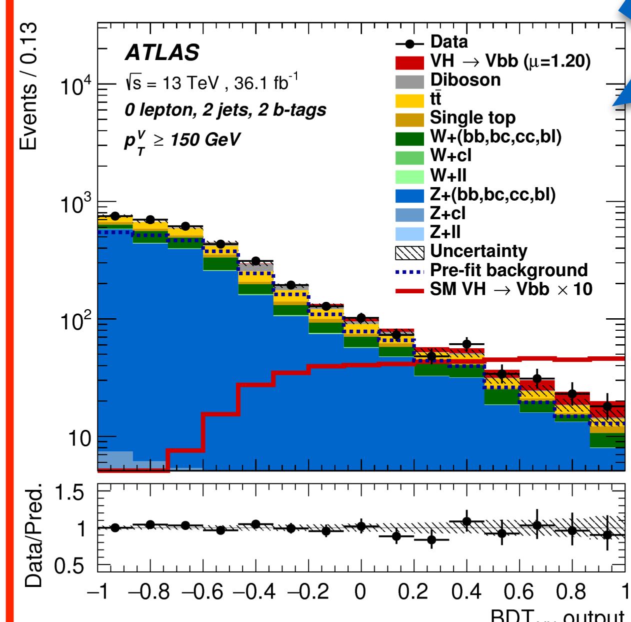
- ➡ **5.3σ expected significance**
- ➡ **5.8σ observation of VZ, Z → $b\bar{b}$**
- ➡ **Compatible with SM expectation within 1σ**
- ➡ **Validates BDT analysis**

MVA analysis fit

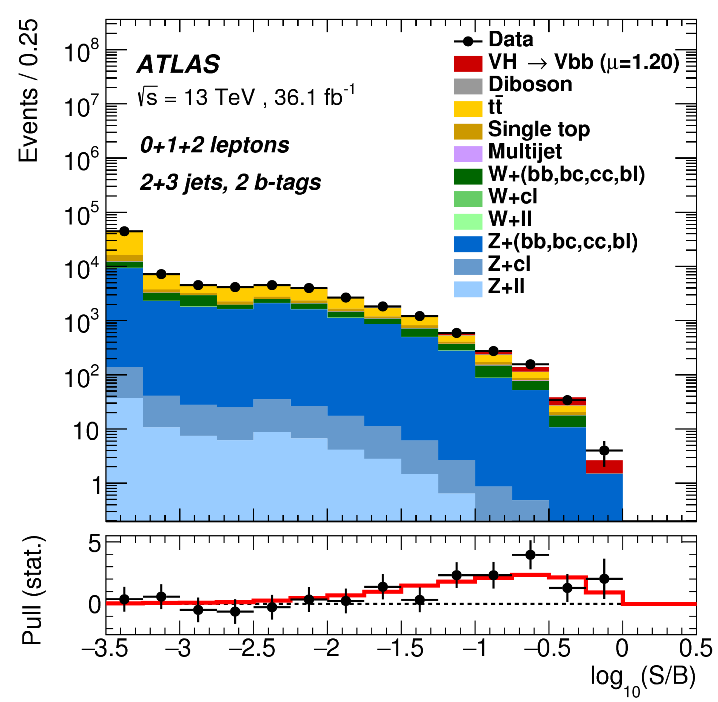
VH, H → $b\bar{b}$ as signal, fit on BDT_{VH}

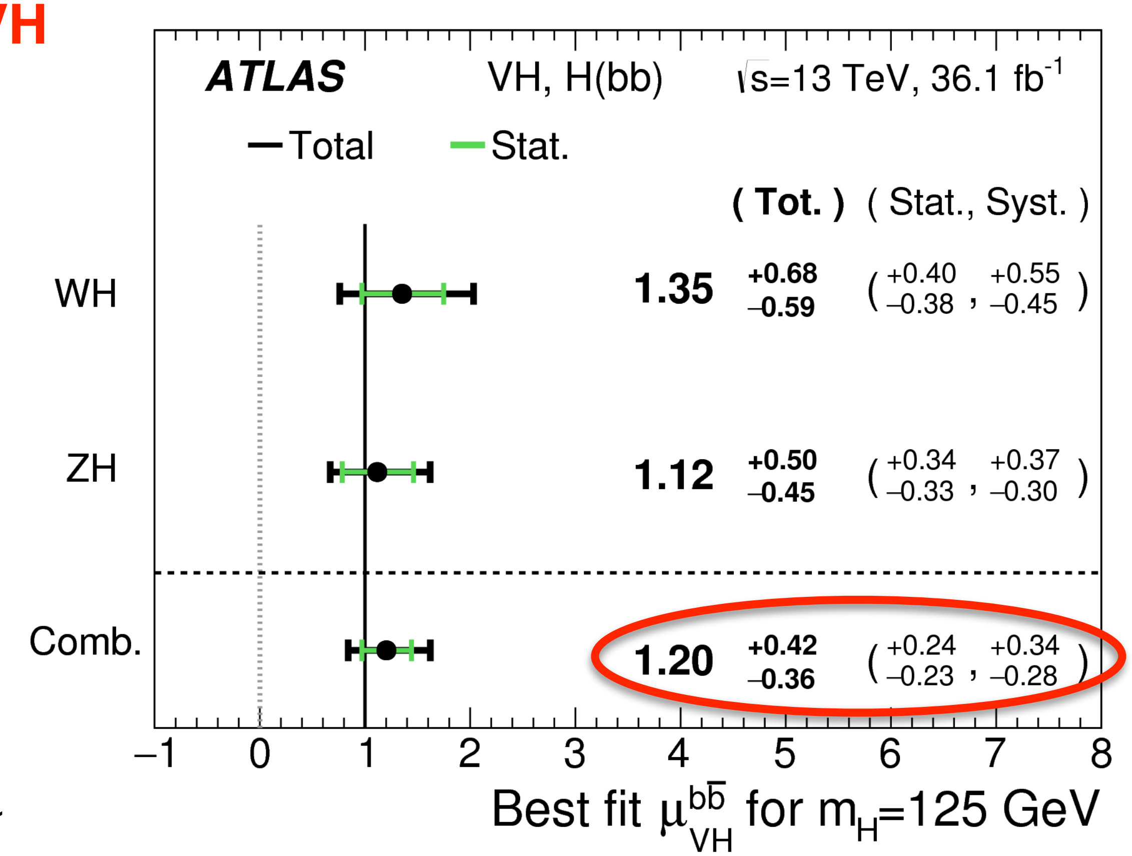






36.1 fb^{-1} of Run-2 data





- ➡ **3.0σ expected significance**
- ➡ **3.5σ observed significance**
- ➡ **Evidence for VH, H → $b\bar{b}$**
- ➡ **Compatible with SM expectation within 1σ**

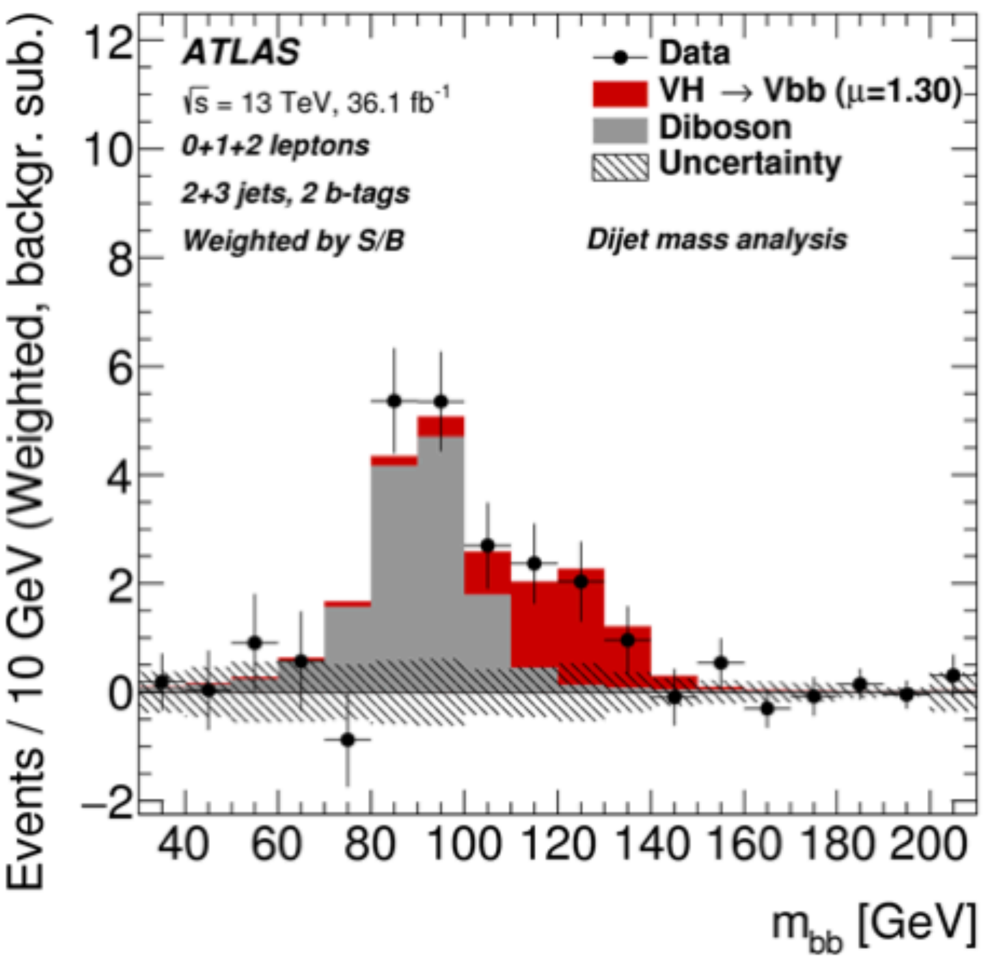
Impact of systematics in MVA analysis

Source of uncertainty		σ_μ
Total		0.39
Statistical		0.24
Systematic		0.31
Experimental uncertainties		
Jets		0.03
$E_{\mathrm{T}}^{\mathrm{miss}}$		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

- ➡ **Systematic uncertainties are dominant**
- ➡ **Main systematic uncertainties:**
  - ➡ **Signal modelling (dominated by extrapolation uncertainty from high pT(V) to inclusive phase space, and presently by parton shower/underlying events systematics)**
    - ➡ **Signal uncertainty doesn't affect the significance**
  - ➡ **Background modeling (similar contribution from all the backgrounds, with a statistical component from floating normalisations)**
  - ➡ **B-tagging calibration uncertainty**
  - ➡ **Limited size of Monte Carlo samples (despite generator slicing/filtering)**

Cross check fit: dijet mass analysis

36.1 fb^{-1} of Run-2 data



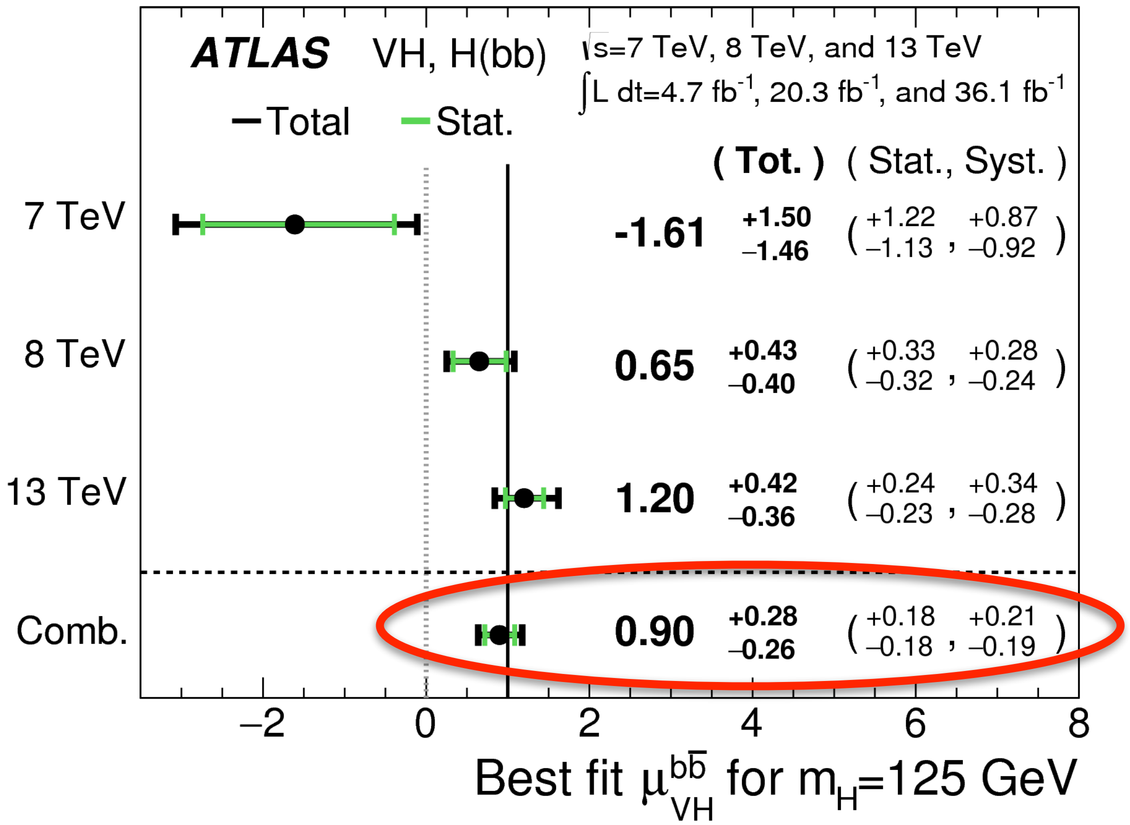
All analysis regions combined, weighted by their S/B, with all backgrounds except VZ subtracted.

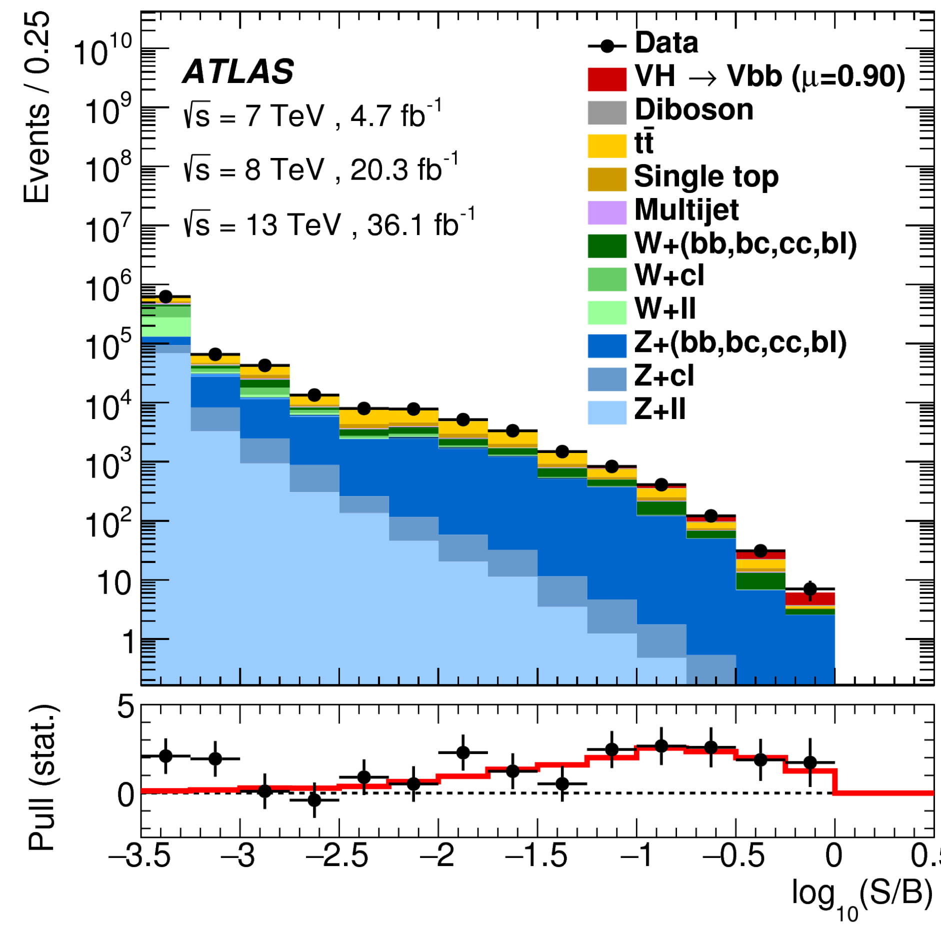
- **A fit to m_{bb} observable is applied**
- **An additional $p_T(V)$ category at 200 GeV**
  - **Additional cut on $\Delta R(b_1,b_2)$, getting tighter with increasing $p_T(V)$**
- **Important validation of MVA analysis**
- **Higgs boson signal strength:**

$$\mu = 1.30^{+0.28}_{-0.27}(\text{stat.})^{+0.37}_{-0.29}(\text{syst})$$

- **2.8σ expected significance**
- **3.5σ observed significance**
- **Consistent result with MVA analysis → solid results**

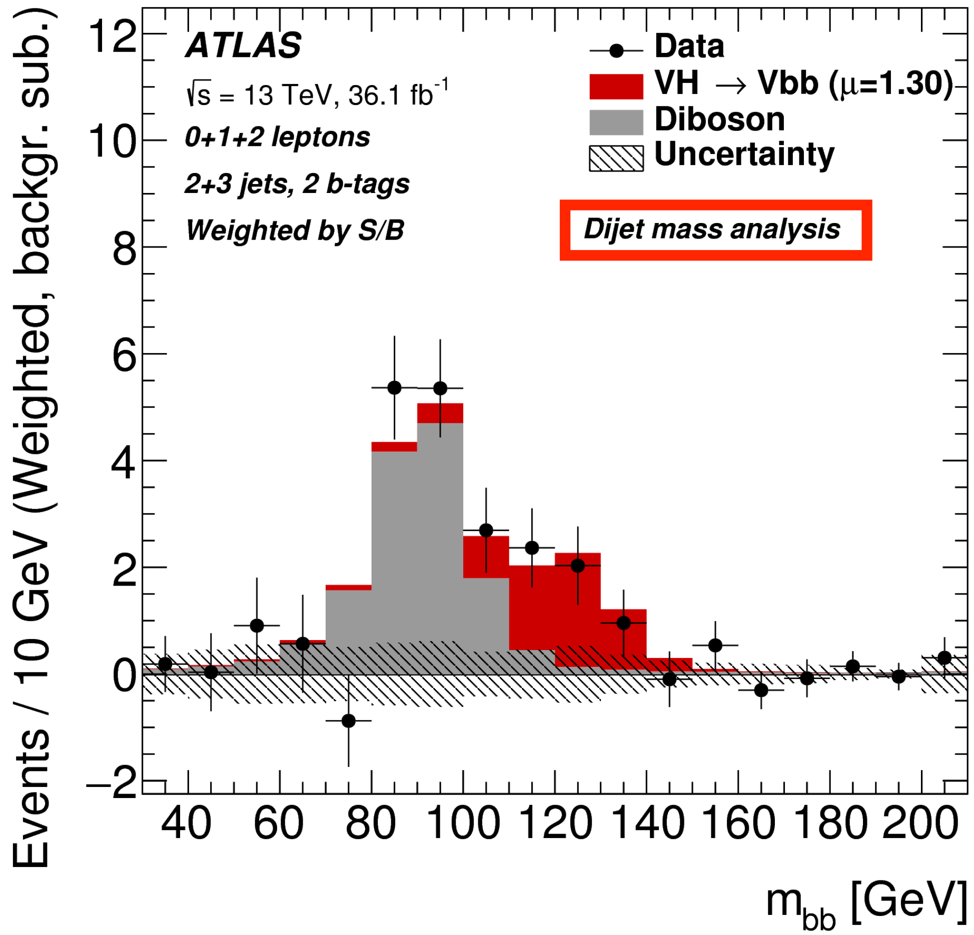
Combination with Run1

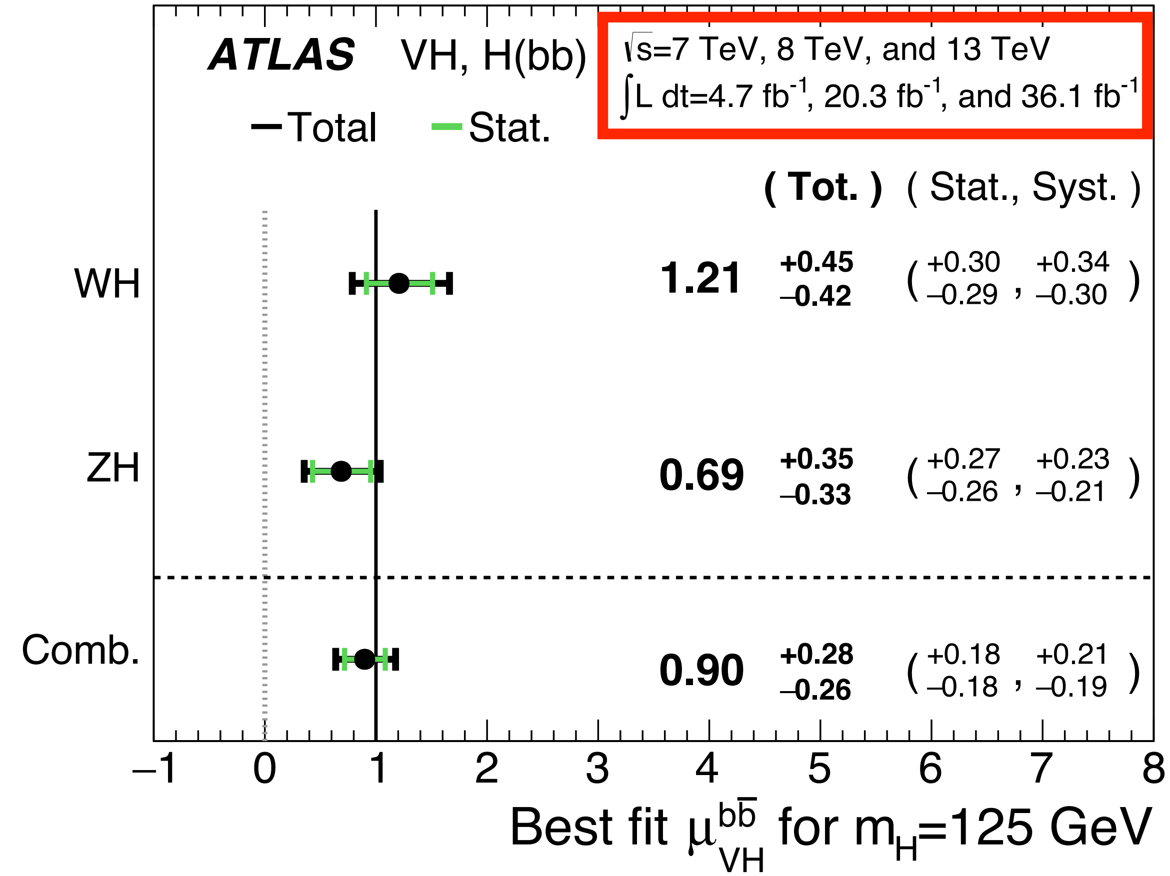




- **Run-2 MVA VH, H → $b\bar{b}$ analysis is combined with the corresponding Run-1 analysis**
  - **4.0σ expected significance**
  - **3.6σ observed significance**
  - **Fitted signal strength compatible with SM within 0.4σ**

Conclusions

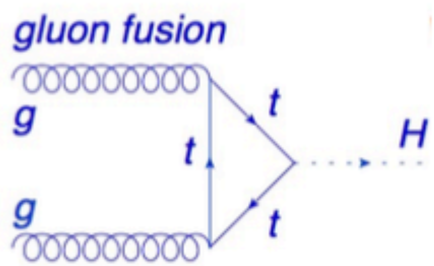
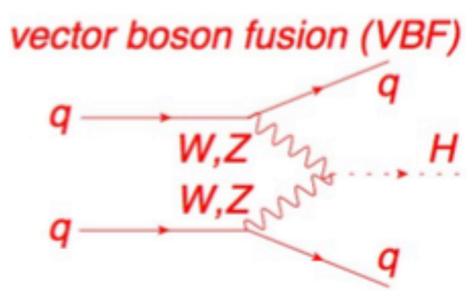
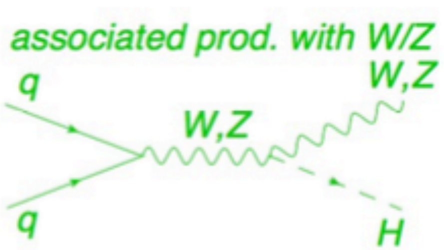
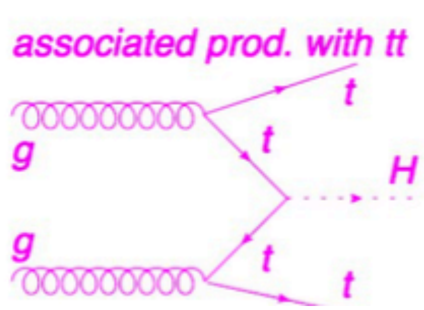




- ➡ **3.6σ evidence (4.0σ expected) has been obtained for VH (→ $b\bar{b}$)**
- ➡ **Within the present ~25-30% uncertainty on μ, the result compatible with Standard Model (SM) prediction**
- ➡ **Assuming the SM production rate, results consistent with the Yukawa coupling to b-quarks in the SM**
- ➡ **More than 3 times data in full Run2, this is definitely only the first step of a wonderful journey**

Backup

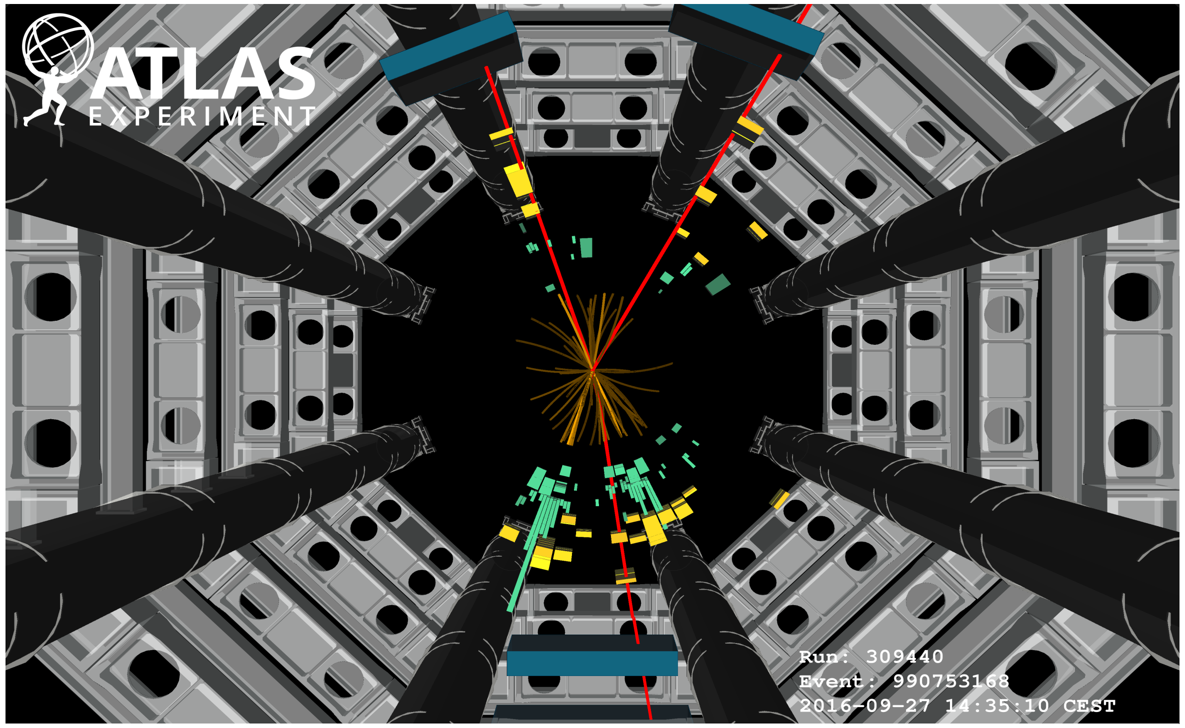
Let's have a look at the production mode

Production mode	Primary signature	
	Just $H \to bb$	• Huge multi-jet background • Triggering possible at high $p_T(H)$, but S/B expected to be ~ O(0.1%) • Jet substructure analysis by CMS ($p_T(H)$>450 GeV)
	2 VBF jets (+ γ)	• Large multi-jet background • Still a fully hadronic final state: trigger and background modeling is challenging • Additional γ helps (~similar sensitivity, higher S/B)
	W, Z	• Exploit leptonic signatures for trigger, and suppression of multi-jet background. • *Main search channel for $H \to bb$ at the LHC!*
	top+anti-top	• Leptonic signatures for trigger, but challenging due to combinatorics and tt+bb backgrounds • But gives access also to top quark coupling!

Details in the event selection

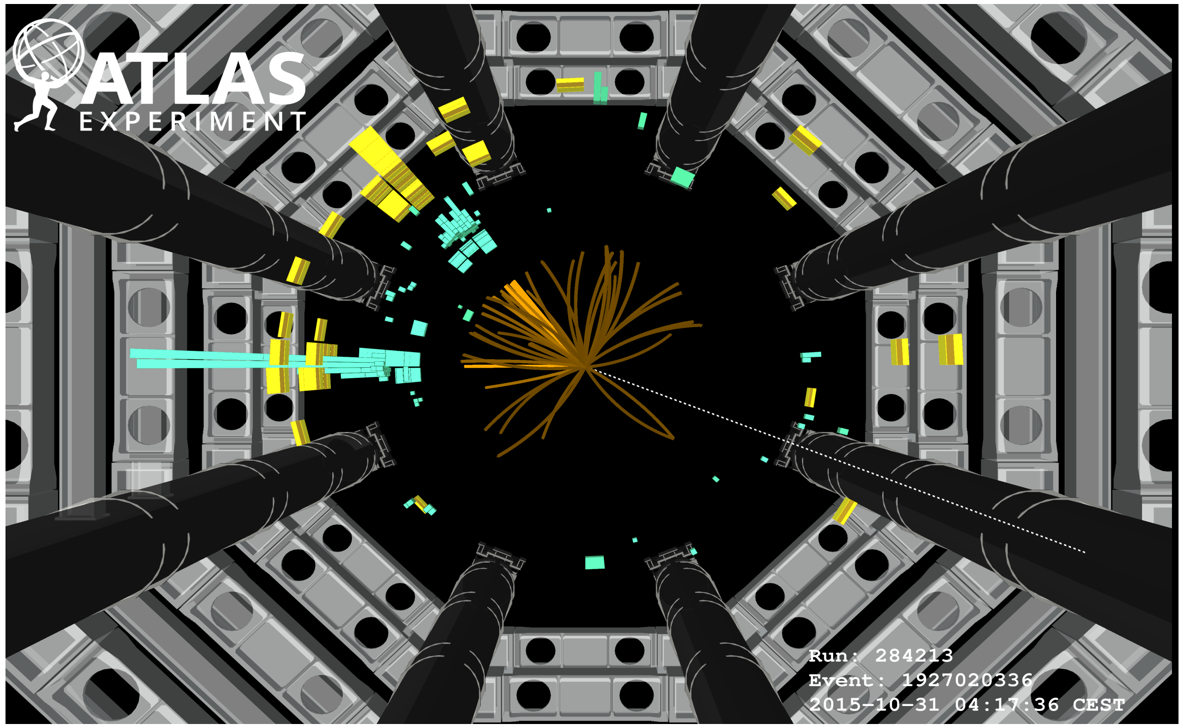
Selection	0-lepton	1-lepton		2-lepton
		e sub-channel	μ sub-channel	
Trigger	$E_{\mathrm{T}}^{\mathrm{miss}}$	Single lepton	$E_{\mathrm{T}}^{\mathrm{miss}}$	Single lepton
Leptons	0 loose leptons with $p_{\mathrm{T}} > 7$ GeV	1 tight electron $p_{\mathrm{T}} > 27$ GeV	1 medium muon $p_{\mathrm{T}} > 25$ GeV	2 loose leptons with $p_{\mathrm{T}} > 7$ GeV ≥ 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
Jet p_{T}	> 20 GeV			
b-jets	Exactly 2 b-tagged jets			
Leading b-tagged jet p_{T}	> 45 GeV			
H_{T}	> 120 (2 jets), >150 GeV (3 jets)	–		–
$\min[\Delta\phi(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, \vec{\mathrm{jets}})]$	$> 20°$ (2 jets), $> 30°$ (3 jets)	–		–
$\Delta\phi(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, \vec{bb})$	$> 120°$	–		–
$\Delta\phi(\vec{b}_1, \vec{b}_2)$	$< 140°$	–		–
$\Delta\phi(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, \vec{E}_{\mathrm{T,trk}}^{\mathrm{miss}})$	$< 90°$	–		–
p_{T}^{V} regions	> 150 GeV			(75, 150] GeV, > 150 GeV
Signal regions	✓	$m_{bb} \geq 75$ GeV or $m_{\mathrm{top}} \leq 225$ GeV		Same-flavour leptons Opposite-sign charge ($\mu\mu$ sub-channel)
Control regions	–	$m_{bb} < 75$ GeV and $m_{\mathrm{top}} > 225$ GeV		Different-flavour leptons

Event display

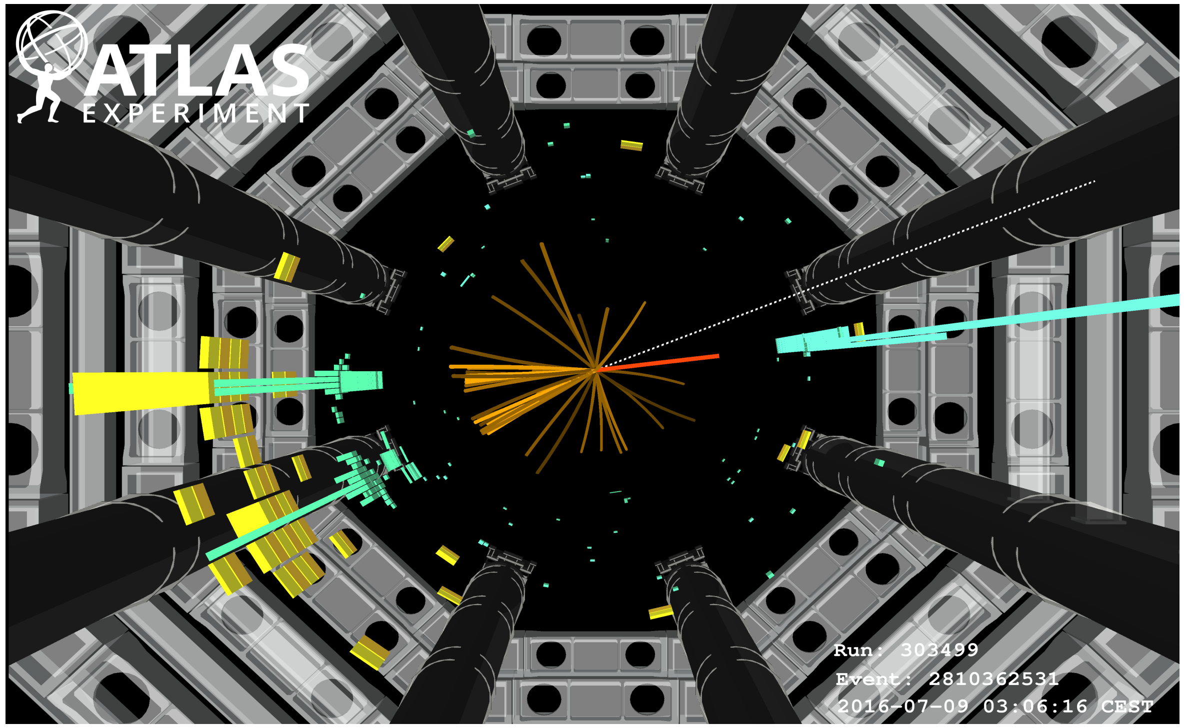


2-lepton $N_{sig,exp}=102$

0-lepton $N_{sig,exp}=98$

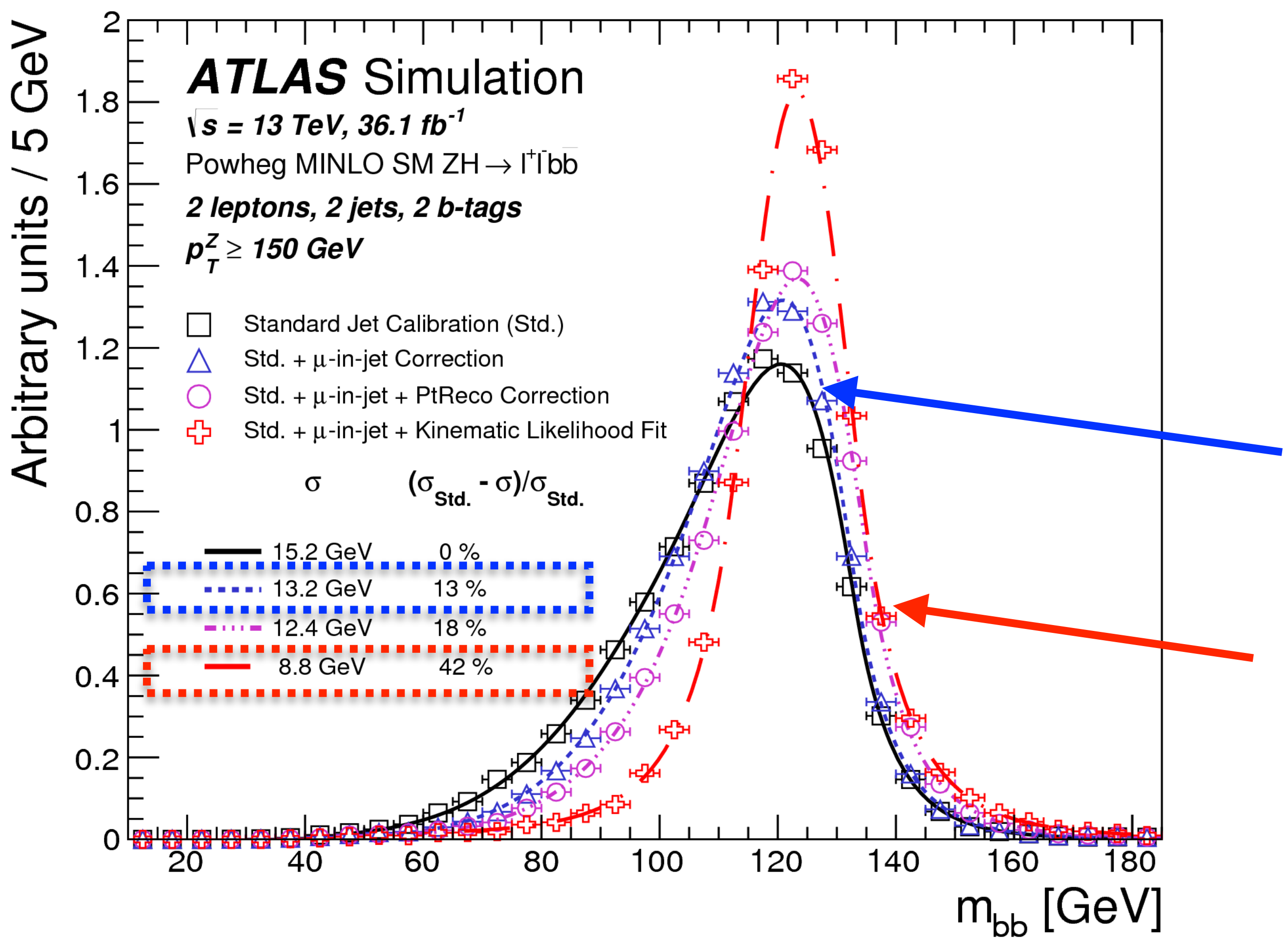


1-lepton $N_{sig,exp}=97$



Higgs mass reconstruction

mBB

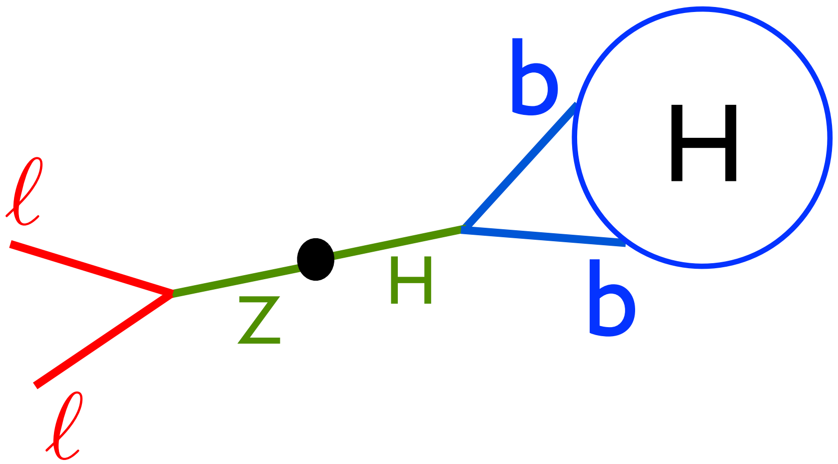


Sharpening signal mass peak directly improves sensitivity

Two most important corrections:

- ➡ ***μ*-in-jet corrections: if available, add muon to jet momentum (+13%)**
- ➡ **For 2-lepton channel (≤ 3jets), use full kinematic likelihood fit, exploiting constraint**

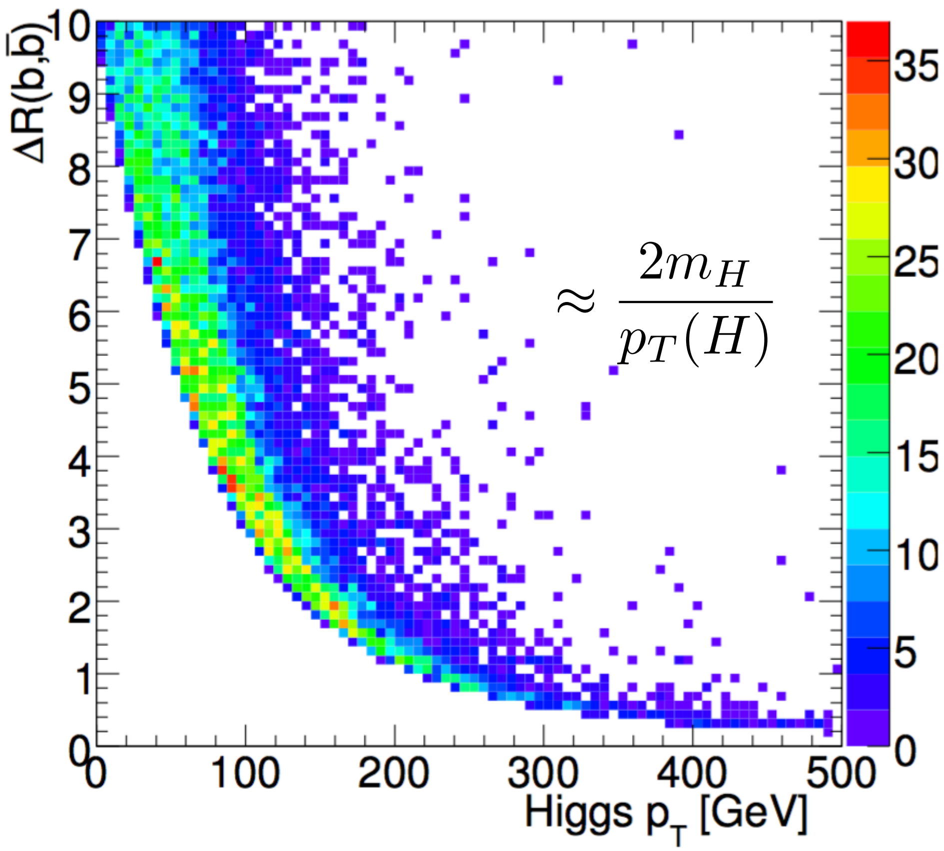
$$\vec{p}_{T,b\bar{b}} = \sum_{\ell} \vec{p}_{T,\ell}$$



(+20%)

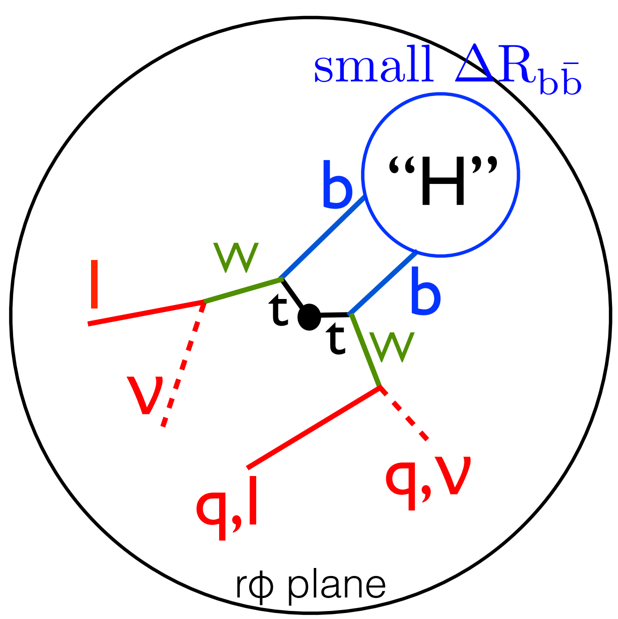
OK, S/B is what we care about!

dRBB

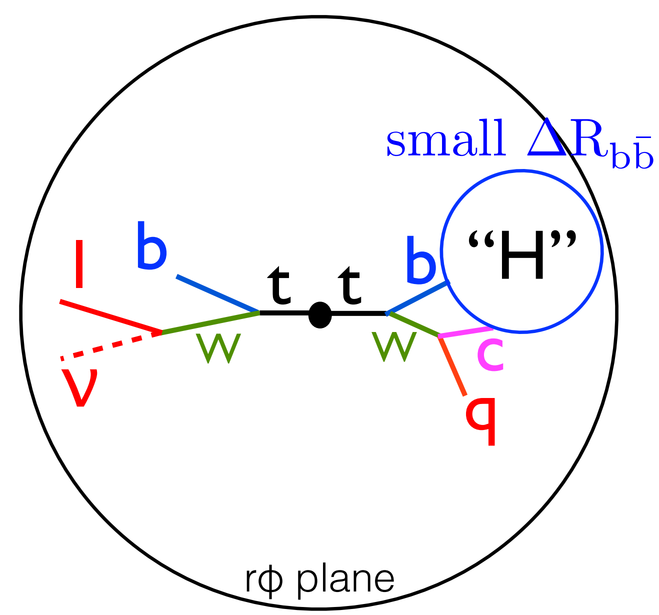


- ➡ **$H \rightarrow b\bar{b}$ is a simple 2-body decay**
- ➡ **For high $p_T(H)$, can require**
  - ➡ **low $\Delta R(bb)$**
- ➡ **With almost no loss in signal efficiency**

ttbar background



low p_T(V/H)



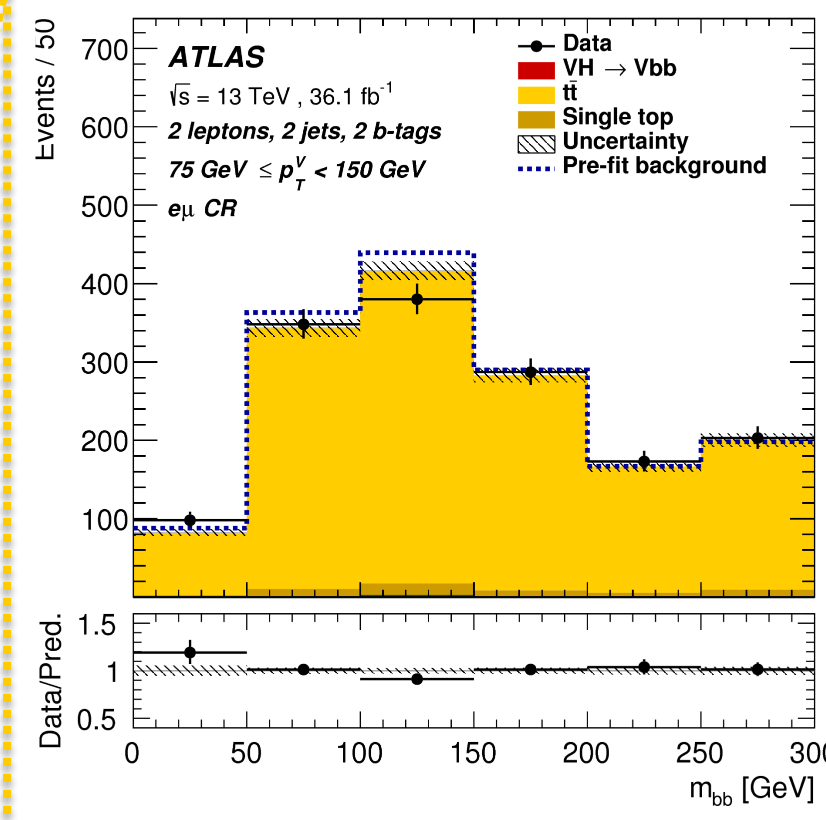
high p_T(V/H)

- ➡ **Backgrounds (esp. ttbar) significantly suppressed by these requirements!**
- ➡ **First realised in the context of jet substructure [PRL 100:242001, 2008, Butterworth et al., ATL-PHYS-PUB-2009-088]**

Control regions

➡ **Dedicated control regions (CRs) are defined to better isolate specific background**

Control region	W+HF	ttbar
Channel	1-lepton	2-lepton
Selection	$m_{b\bar{b}} < 75$ GeV $m_{top} > 225$ GeV	Same as signal, but require e+μ final state
Analysis regions	2- / 3- jets	2- / ≥3- jets low / high-$p_T(V)$
Purity	~75-80%	>99%
Fit observable	Yield only	m_{bb}



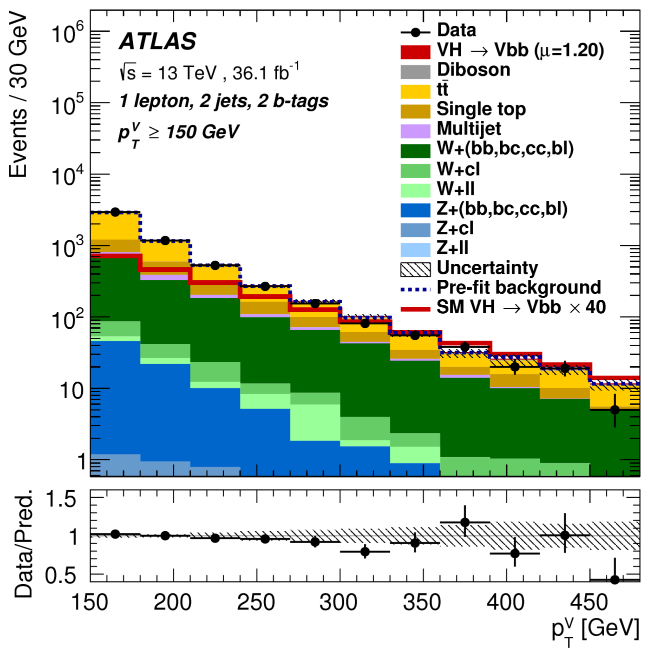
m_{bb} distribution in CR used to constrain systematics on m_{bb} shape

➡ **Due to the very different regions of phase space probed, the ttbar background model in the 2-lepton channel is decorrelated from the 0- and 1-lepton channels**

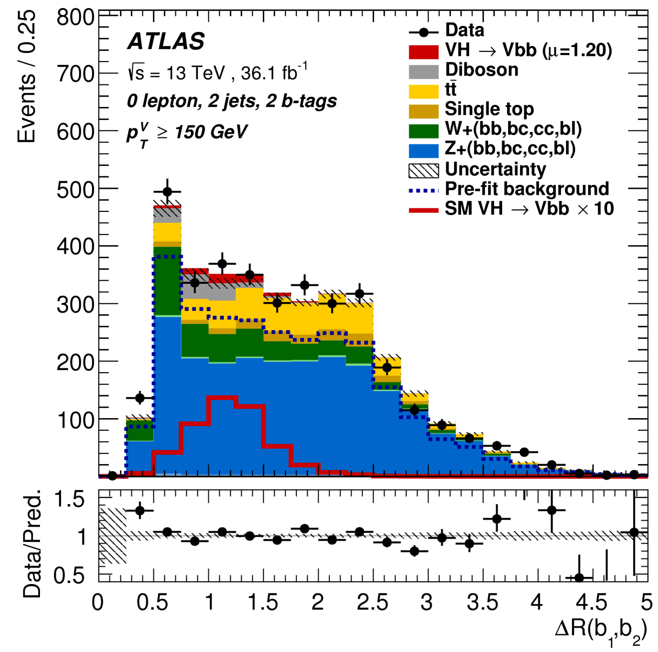
➡ **In total 8 signal regions and 6 control regions**

Multi Variate Analysis techniques

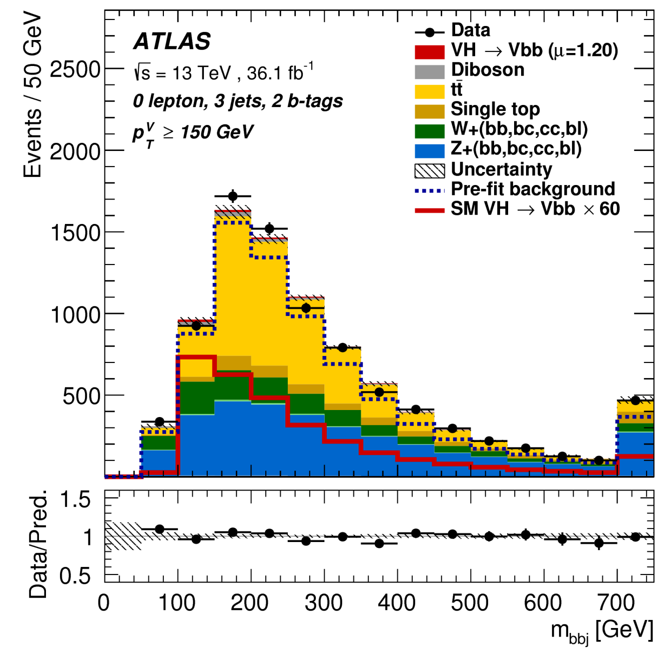
Separate signal and background



$p_T(V)$

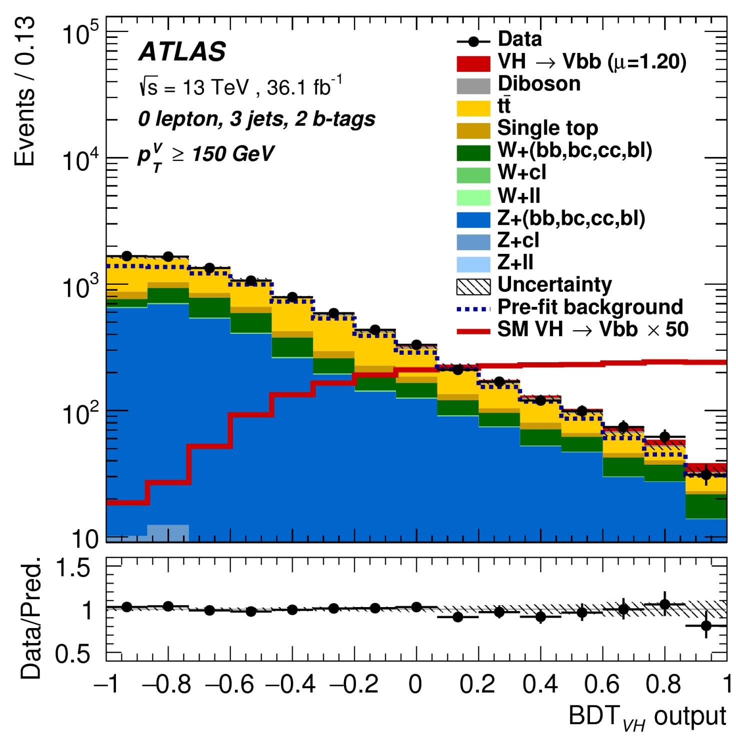


$\Delta R(b_1, b_2)$



m_{bbj}

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

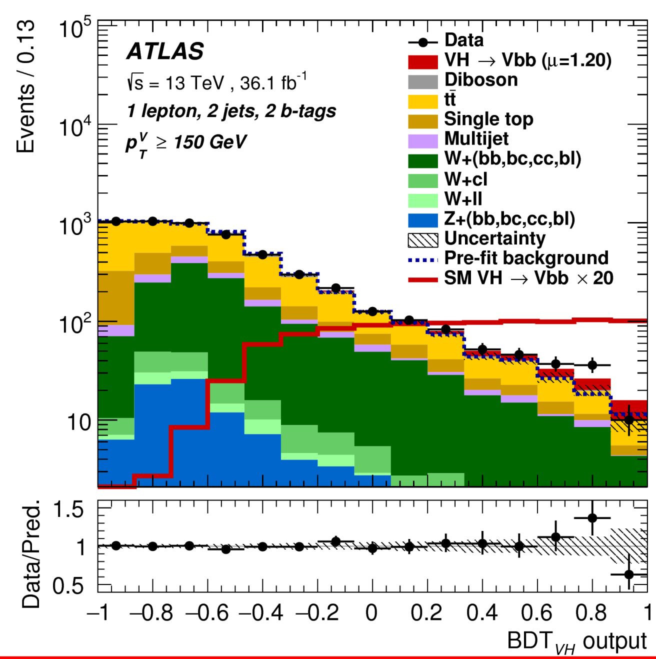


- ➡ **Use Multi Variate Analysis (BDT) to combine all observables into a single final discriminant**
- ➡ **One BDT per channel and analysis region**

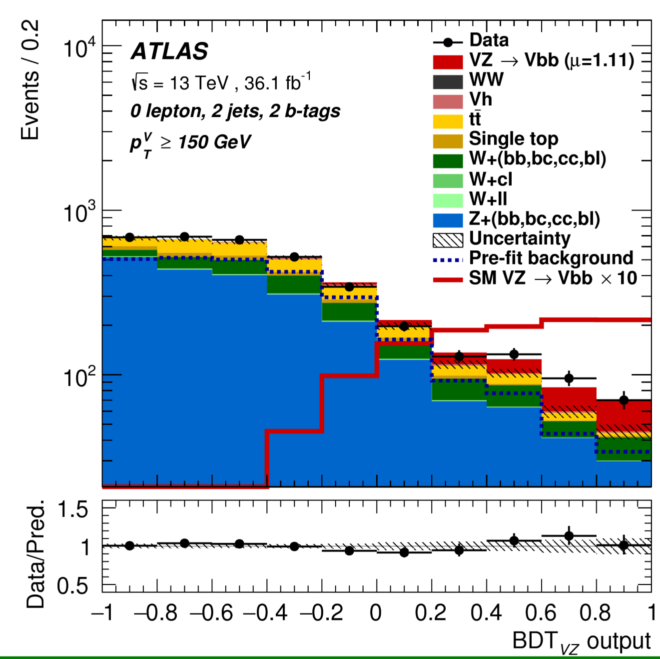
Fit and validation strategy

- ➡ **A likelihood fit is applied across channels and multiple analysis regions to extract the signal strength** $\mu = \frac{\sigma \times \mathrm{BR}}{(\sigma \times \mathrm{BR})_{\mathrm{SM}}}$ **and the normalisations of the main backgrounds**
- ➡ **Shapes and relative normalisations across regions parametrized by nuisance parameters (NPs), constrained within allowed systematic uncertainties (priors)**
- ➡ **A nominal analysis (main observable: BDTVH output), two validation analyses (main observable: BDTVZ output and mbb).**

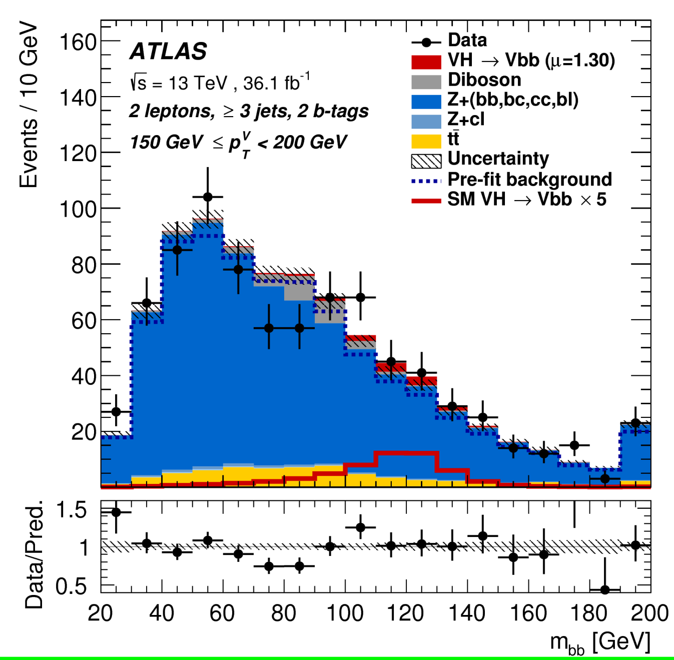
$\mathrm{BDT}_{(VH,\, H\to bb)}$



$\mathrm{BDT}_{(VZ,\, Z\to bb)}$



m_{bb}



Systematic 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%
m_{bb}, p_T^V	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)
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), 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 – 400% (3-jet)
BDT template	S

Summary of the systematic uncertainties in the background modelling for

- ➡ **Z + jets**
- ➡ **W + jets**
- ➡ **ttbar**
- ➡ **single top quark**
- ➡ **multi-jet production.**

Systematic uncertainties

ZZ	
Normalisation	20%
0-to-2 lepton ratio	6%
Acceptance from scale variations (var.)	10 – 18% (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.	13 – 21% (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	11%
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%

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 – 14% (depending on lepton channel)
Acceptance from PS/UE var. for 3 jets	13%
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

Summary of the systematic uncertainties in the background modelling for

- ➡ **diboson**
- ➡ **Signal**

post fit scale factor

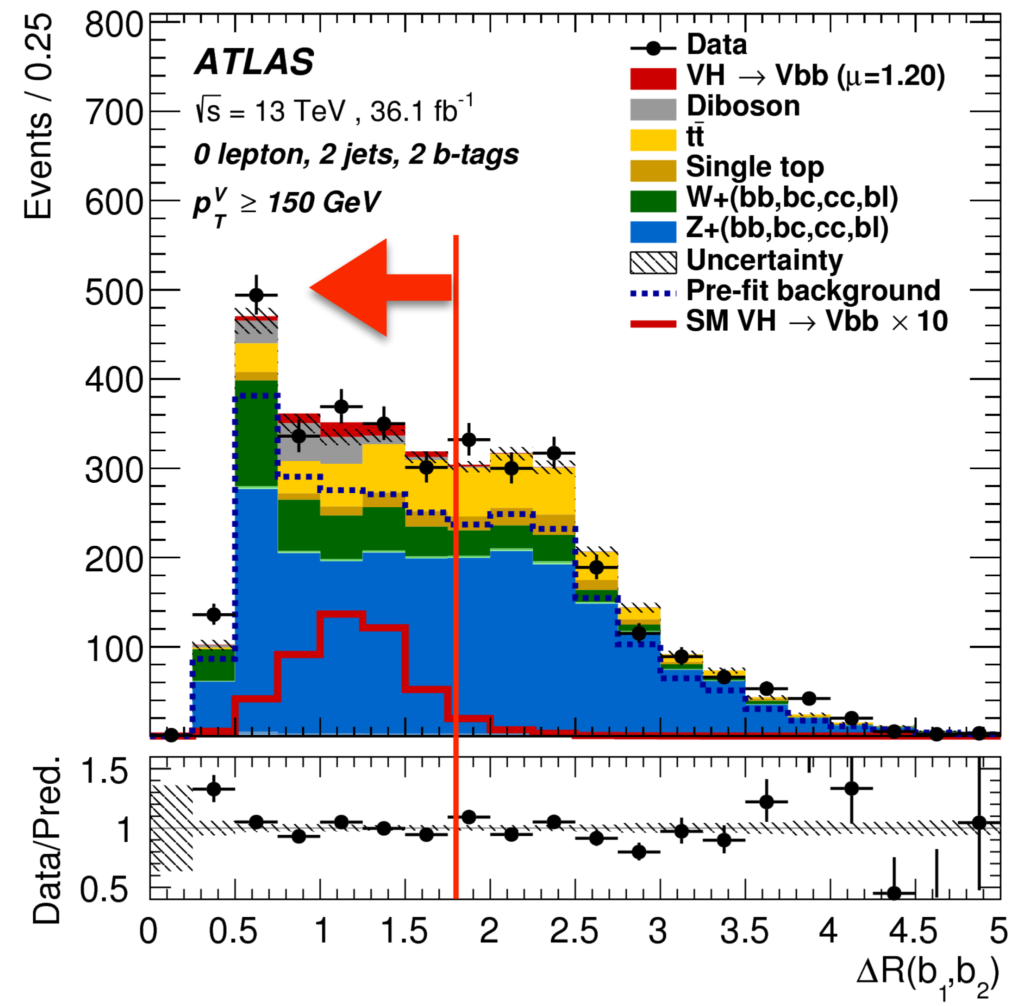
Process	Normalisation factor
$t\bar{t}$ 0- and 1-lepton	0.90 ± 0.08
$t\bar{t}$ 2-lepton 2-jet	0.97 ± 0.09
$t\bar{t}$ 2-lepton 3-jet	1.04 ± 0.06
$W + \mathrm{HF}$ 2-jet	1.22 ± 0.14
$W + \mathrm{HF}$ 3-jet	1.27 ± 0.14
$Z + \mathrm{HF}$ 2-jet	1.30 ± 0.10
$Z + \mathrm{HF}$ 3-jet	1.22 ± 0.09

Factors applied to the nominal normalisations of the ttbar, W+HF and Z+HF backgrounds, as obtained from the global fit to the 13 TeV data for the nominal multivariate analysis, used to extract the Higgs boson signal. The errors include the statistical and systematic

Cross Check fit: m_{bb}

Channel			
Selection	0-lepton	1-lepton	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



- ➡ To fully exploit the **High PT**, the di-jet mass analysis includes (on top of MVA analysis):
    - ➡ An additional category for events with $p_T(V) > 200$ GeV
    - ➡ Topological requirements that require smaller $\Delta R(b_1,b_2)$ for the increasing $p_T(V)$

Regions used in likelihood fit for the dijet-mass analysis

Channel	SR/CR	Categories					
		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}†	Yield*	m_{bb}†

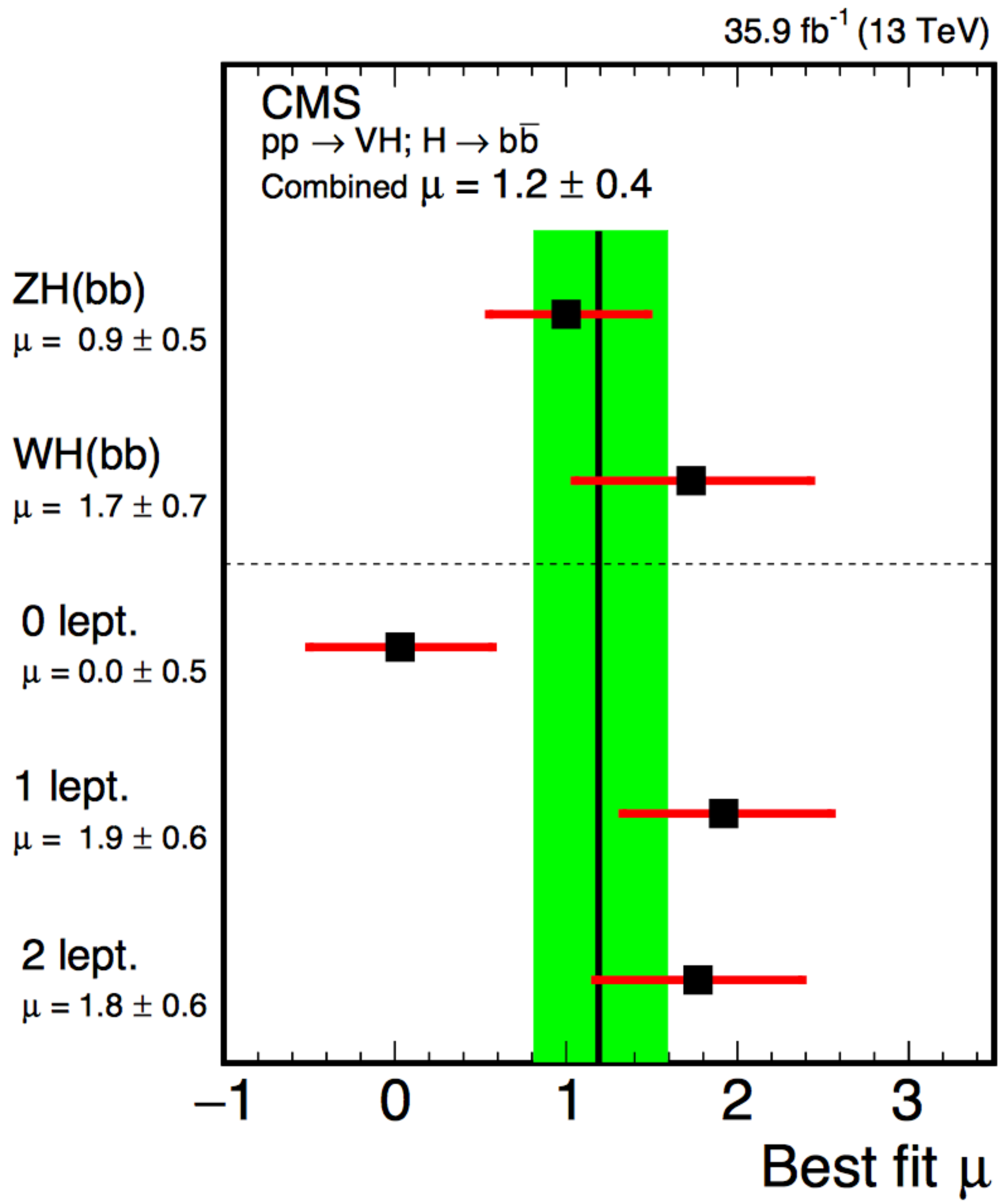
merged

CMS v.s. ATLAS

- Analysis also performed by the other sister. [CMS]

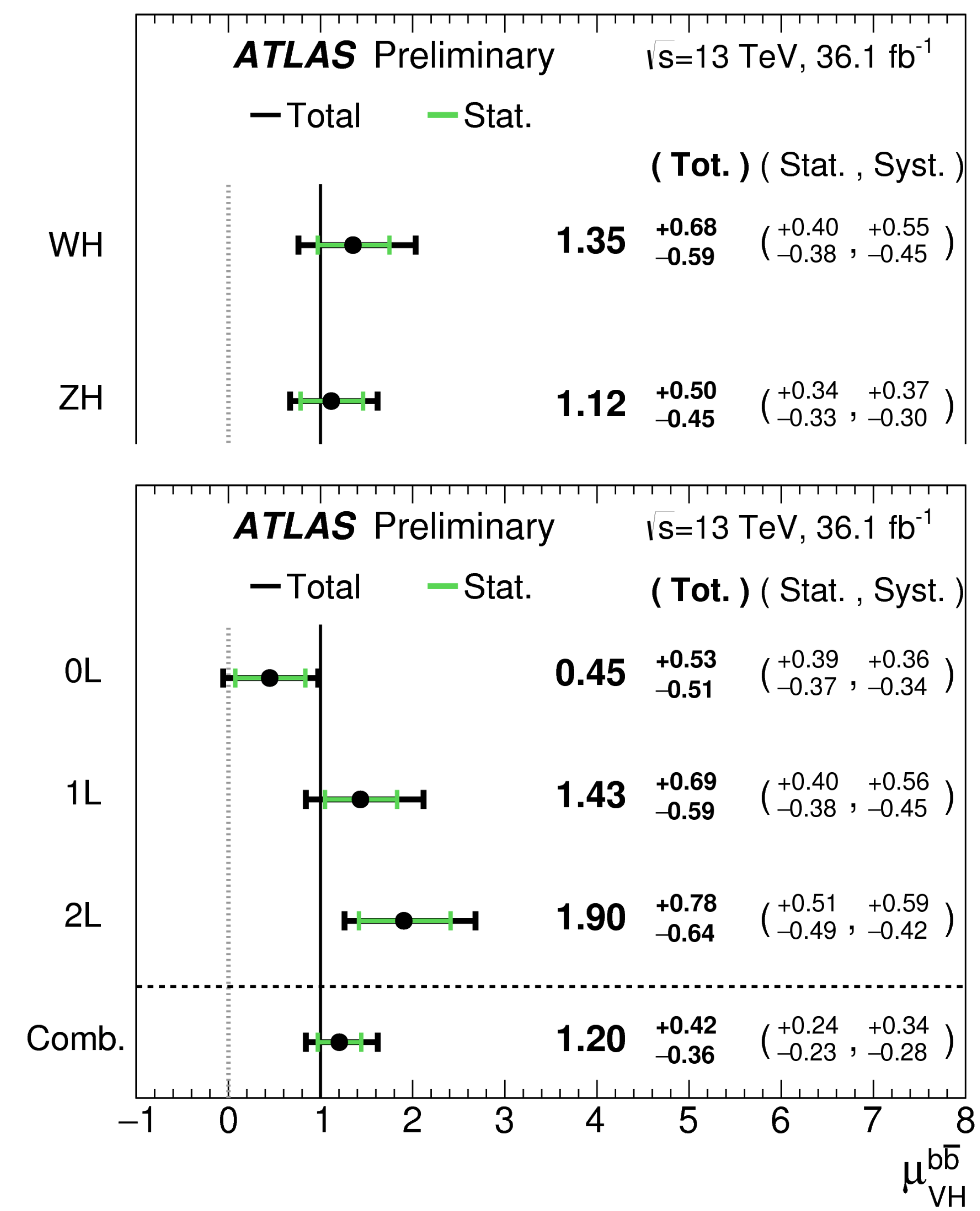
CMS

mu(VHbb) $1.19^{+0.21}_{-0.20}(\text{stat})^{+0.34}_{-0.32}(\text{syst})$



ATLAS

$1.20^{+0.24}_{-0.23}(\text{stat})^{+0.34}_{-0.28}(\text{syst})$



CMS v.s. ATLAS

- A close eye on the systematic uncertainties and significances.

CMS

	Source	Type	Individual contribution to the μ uncertainty (%)	Effect of removal to the μ uncertainty (%)
1	Scale factors ($t\bar{t}$, V+jets)	norm.	9.4	3.5
2	Size of simulated samples	shape	8.1	3.1
	Simulated samples' modeling	shape	4.1	2.9
3	b tagging efficiency	shape	7.9	1.8
	Jet energy scale	shape	4.2	1.8
5	Signal cross sections	norm.	5.3	1.1
	Cross section uncertainties (single-top, VV)	norm.	4.7	1.1
4	Jet energy resolution	shape	5.6	0.9
	b tagging mistag rate	shape	4.6	0.9
	Integrated luminosity	norm.	2.2	0.9
	Unclustered energy	shape	1.3	0.2
	Lepton efficiency and trigger	norm.	1.9	0.1

ATLAS

	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
4	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		
1	Signal		0.17
3	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
2	MC statistical		0.13

CMS

Channels	Significance expected	Significance observed
0-lepton	1.5	0.0
1-lepton	1.5	3.2
2-lepton	1.8	3.1
Combined	2.8	3.3

ATLAS

Dataset	p_0 Exp.	p_0 Obs.	Significance Exp.	Significance 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