# Towards the observation of H→bb: Search for VH, H→bb decays with 80 $fb^{-1}$ of 13 TeV ATLAS data


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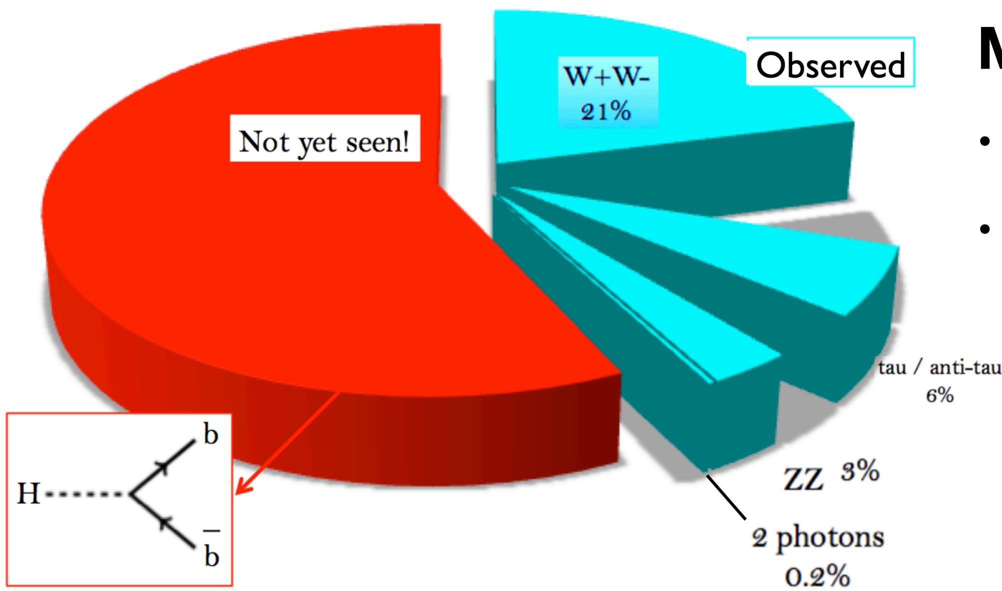
On behalf of the ATLAS Collaboration



Higgs Hunting - Paris
23rd July 2018


ATLAS EXPERIMENT

# Introduction

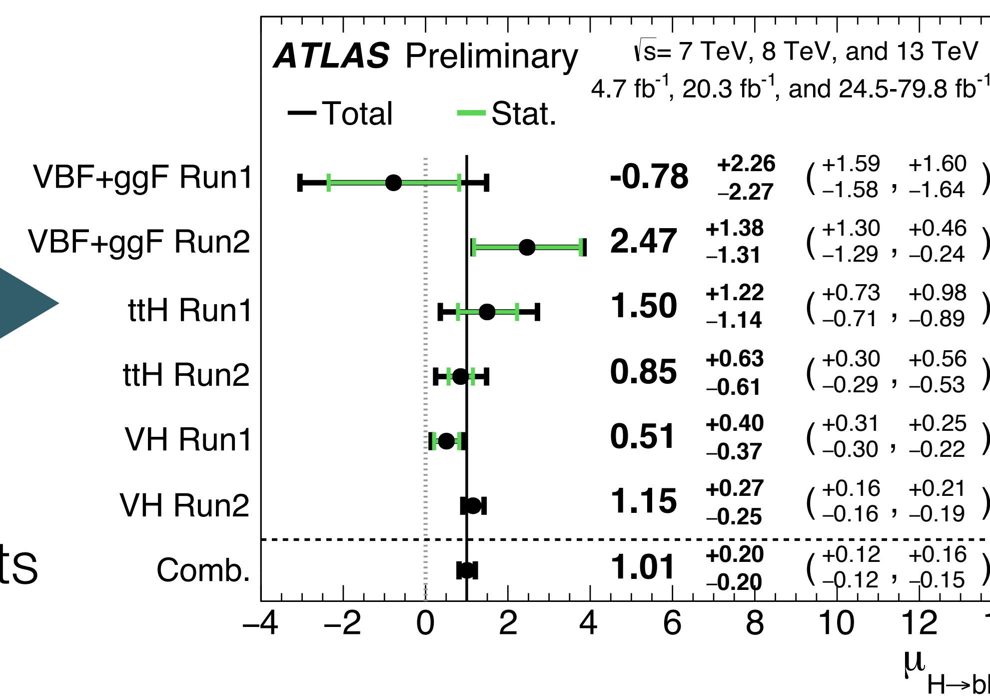



## Motivation: Why H→bb ?

- Direct measure of the **Yukawa coupling** to down type quarks
- **Highest Branching Ratio (58%) in SM**:
  - Fill the gap left for possible new physics
  - Reduce uncertainties on Higgs width and couplings

## Summary:

- Very nice results presented in Laurent's talk today:
  - **VH observation!**
  - **H→bb observation!**
- ***VH, H→bb is leading the sensitivity*** in these two results



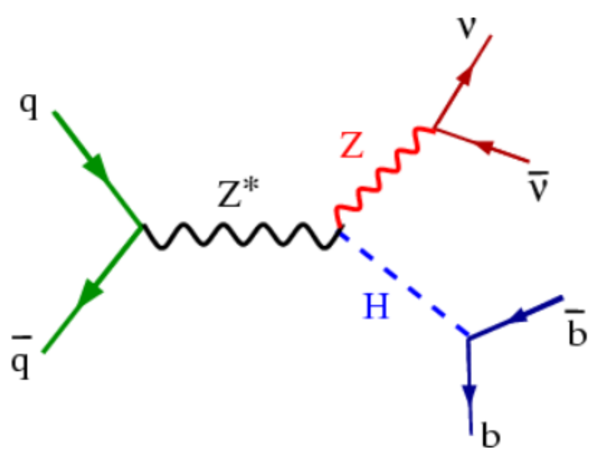

## This talk: focus on Run2 VH, H→bb measurement

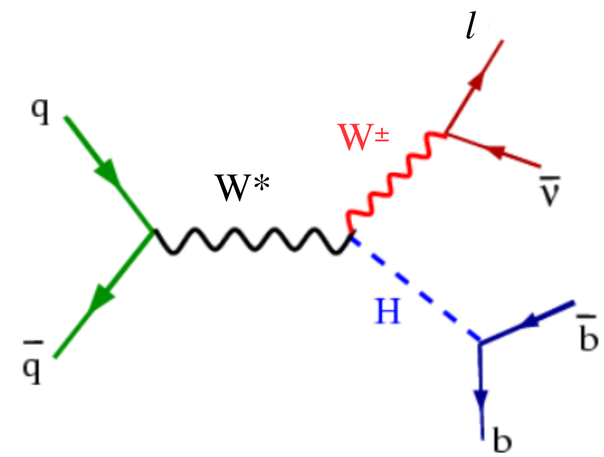
- Analysis strategy + Signal&Bkg modeling
- Results @ 80 fb$^{-1}$
- ***di-jet mass*** analysis and ***VZ, Z→bb*** crosschecks

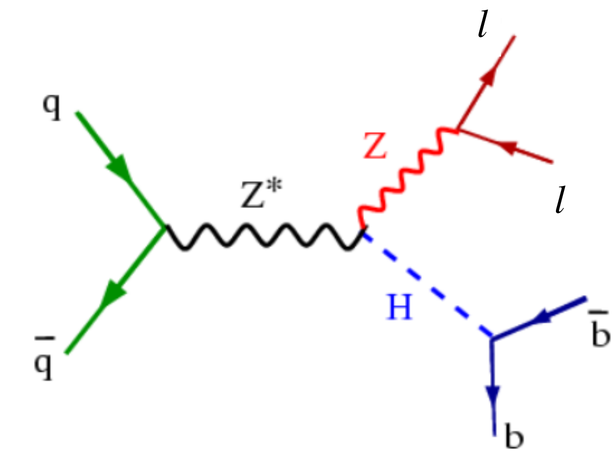
| Channel | Significance Exp. | Significance Obs. |
|---|---|---|
| VBF+ggF | 0.9 | 1.5 |
| $t\bar{t}H$ | 1.9 | 1.9 |
| $VH$ | 5.1 | 4.9 |
| $H \to bb$ Combination | 5.5 | 5.4 |

# Event Selection

- ***Exploit leptonic signatures*** for trigger, and suppression of multi-jet background.
- ***3 channels*** (0, 1, 2 charged leptons)
- ***Exactly 2 b-tagged jets (70% eff. WP).*** Consider only 2-jet and 3-jet events (in 2-lepton ≥ 3-jets).




***0-lepton:***

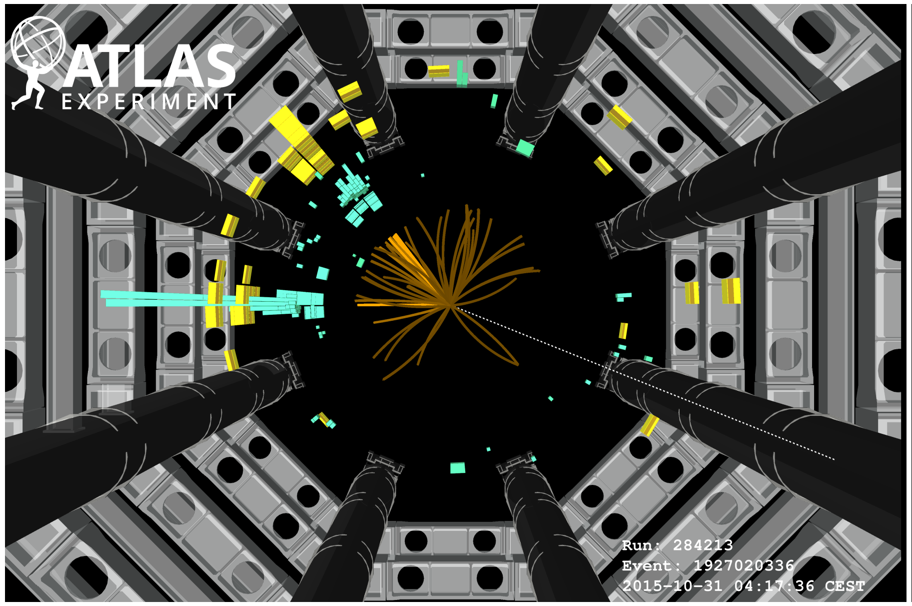
- *Mainly Z→νν but also W→lnu*
- *$p_T^V$ = MET. $p_T^V$ > 150 GeV*

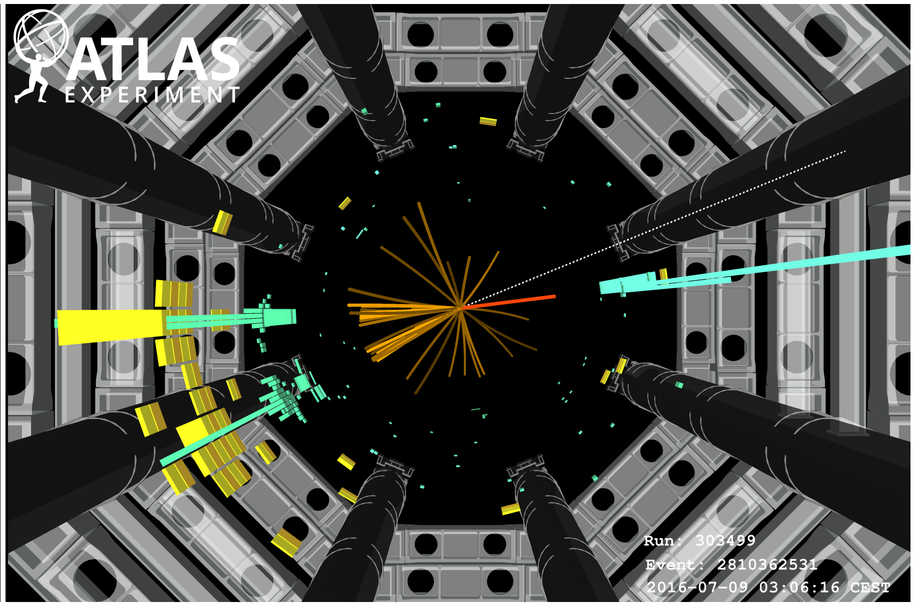
***1-lepton (l=e,mu):***

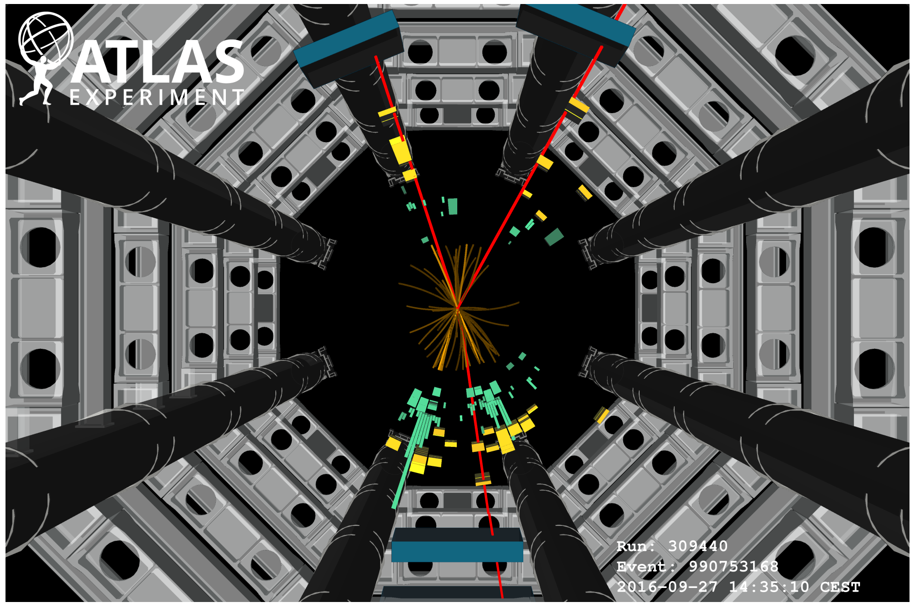
- *Mainly W→lν but also Z→ll*
- *$p_T^V = p_T(l,MET)$. $p_T^V$ > 150 GeV*

***2-lepton (l=e,mu):***

- *Same flavor, mainly Z→ll*
- *$p_T^V = p_T(ll)$ [75,150] GeV, > 150 GeV*



# Signal and Background Modeling

***Use of NLO generators for all samples***

- Very different background composition in the three channels:

**0-lepton**

**Diboson: Sherpa**

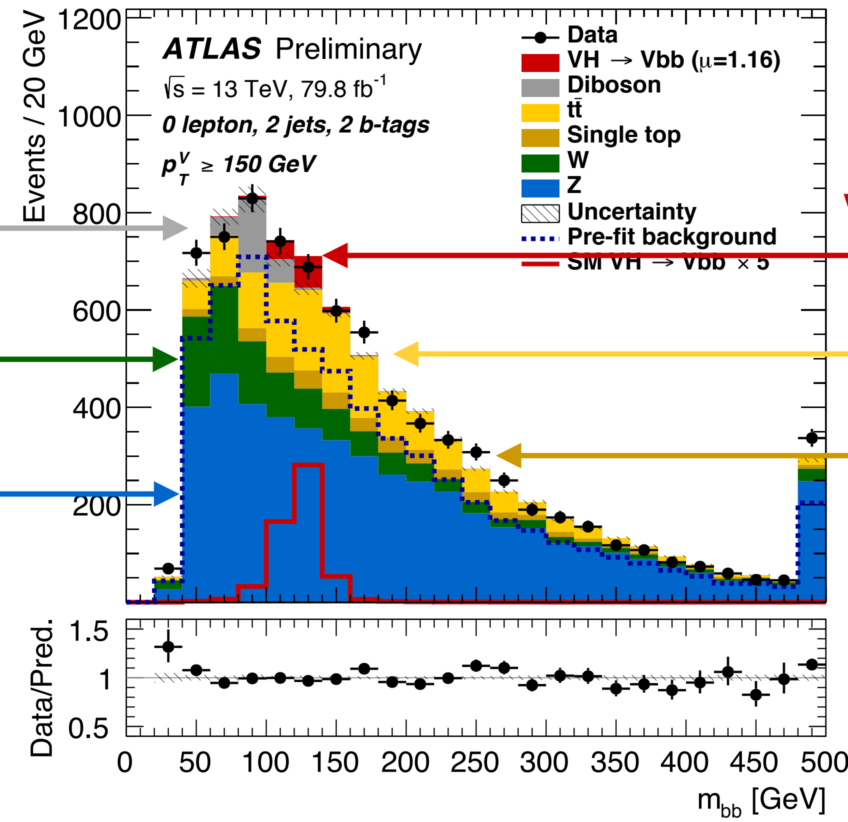
**W+jet: Sherpa**

**Z+jet: Sherpa**

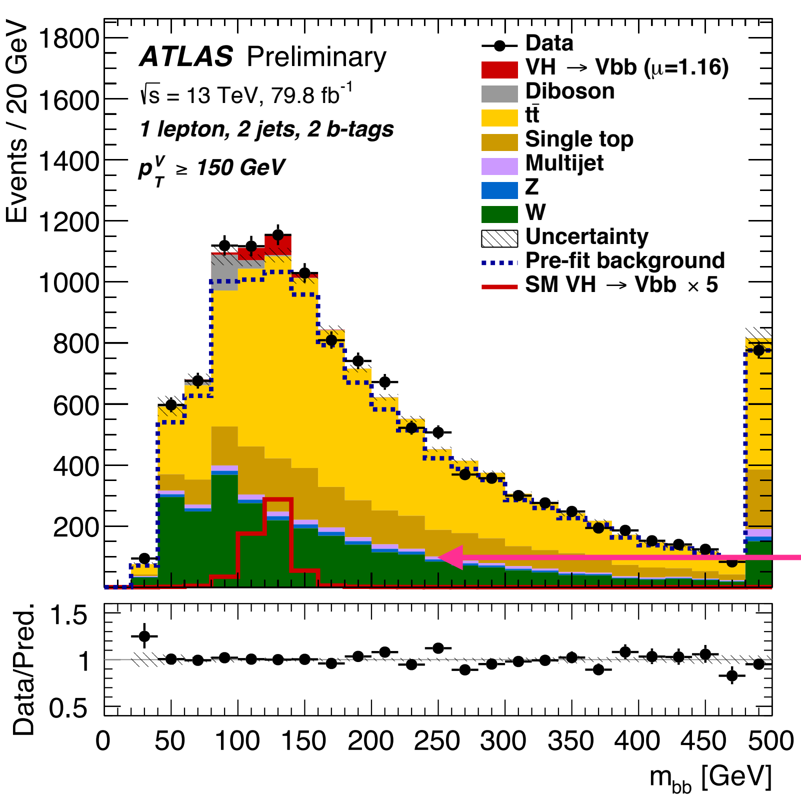
**VH: Powheg+Pythia8**

**ttbar: Powheg+Pythia8**

**Singletop: Powheg+Pythia8**



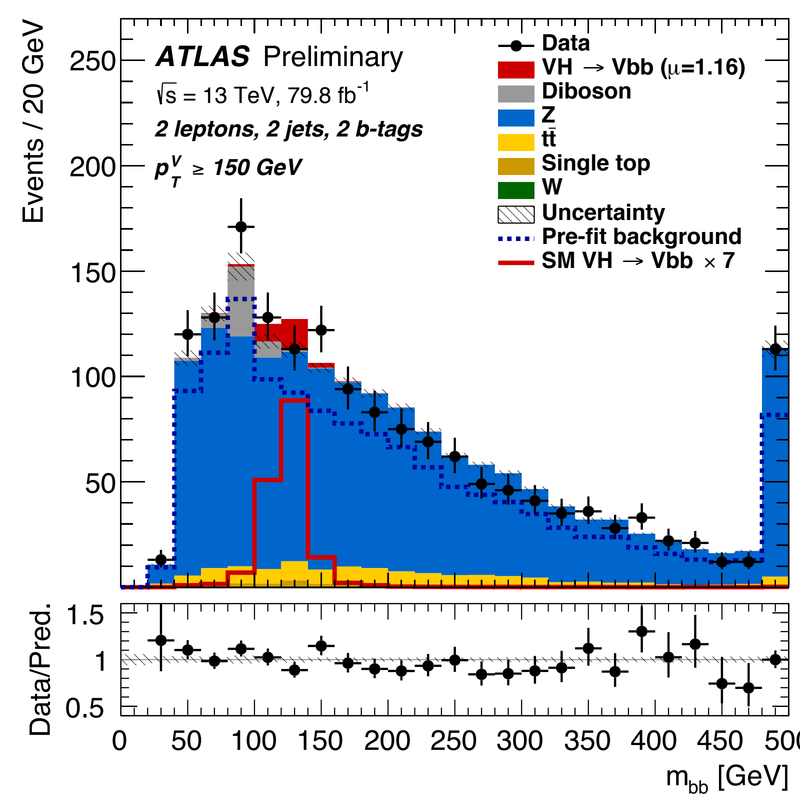

**1-lepton**




**Multijet background**

data-driven estimation (template method)

**2-lepton**




ATLAS-CONF-2018-036

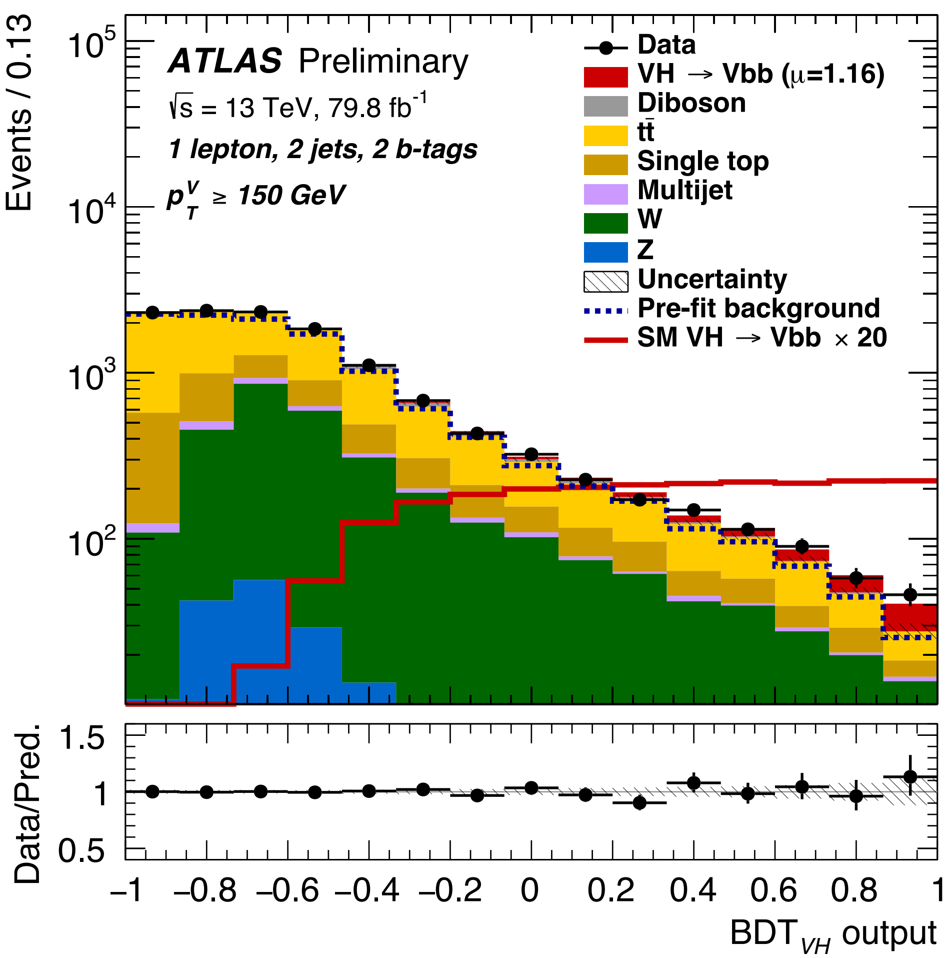
# Multivariate Analysis

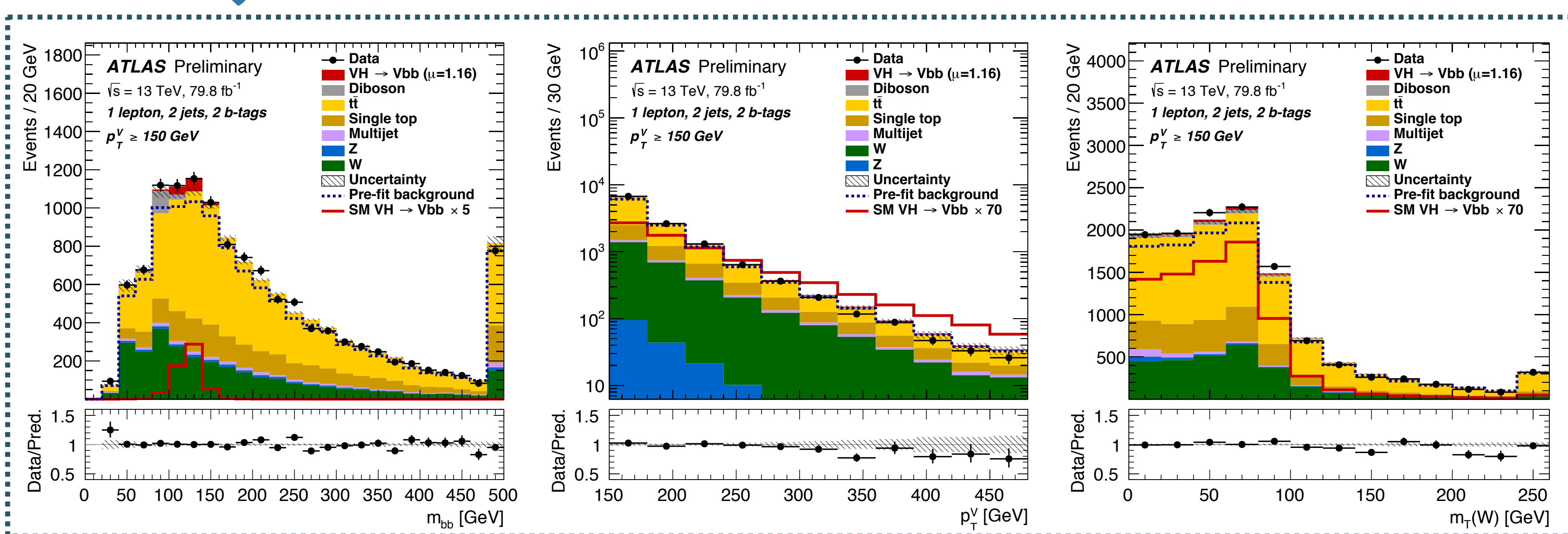
**$m_{bb}$ is the most discriminating variable for VHbb signal:**

- Construct Boosted Decision Tree (BDT) of ***several variables*** to have better discrimination.
- ***$m_{bb}$, $\Delta R_{bb}$ and $p_T^V$ are in order the most important variables.*** full table in backup
- ***Separate trainings for each channel and jet category.***

***Table:*** *variables used in BDT training*

| Variable | 0-lepton | 1-lepton | 2-lepton |
|---|---|---|---|
| $m_{jj}$ | ✓ | ✓ | ✓ |
| $\Delta R(jet_1, jet_2)$ | ✓ | ✓ | ✓ |
| $p_T^{\text{jet1}}$ | ✓ | ✓ | ✓ |
| $p_T^{\text{jet2}}$ | ✓ | ✓ | ✓ |
| $p_T^V$ | ✓ | ✓ | ✓ |
| $\Delta\phi(V,H)$ | ✓ | ✓ | ✓ |
| $\|\Delta\eta(jet_1, jet_2)\|$ | ✓ | | |
| $M_{eff}(M_{eff3})$ | ✓ | | |
| $E_T^{\text{miss}}$ | $\equiv p_T^V$ | ✓ | |
| $\min(\Delta\phi(\ell, jet))$ | | ✓ | |
| $m_T^W$ | | ✓ | |
| $\Delta Y(W,H)$ | | ✓ | |
| $m_{\text{top}}$ | | ✓ | |
| $E_T^{\text{miss}}$ significance | | | ✓ |
| $\Delta\eta(V,H)$ | | | ✓ |
| $m_{\ell\ell}$ | | | ✓ |
| Only in 3 Jet Events | | | |
| $p_T^{\text{jet}_3}$ | ✓ | ✓ | ✓ |
| $m_{jjj}$ | ✓ | ✓ | ✓ |




$m_{bb}$ $p_T^V$ $m_T^W$

# Signal extraction method

**Binned maximum likelihood fit to extract signal strength and normalization of main backgrounds:**

- Fit the final BDT output for each SR
- **8 Signal Regions (SR):** (0,1,2-lepton high $p_T^V$ + low $p_T^V$ in 2-lepton) × 2/3jet event
- **2 W+HF CRs in 1-lepton:** (high $p_T^V$) × 2/3jet event
- **4 top eμ CRs in 2-lepton:** (high $p_T^V$ + low $p_T^V$) × 2/3jet event

| Control Region | W+HF | ttbar |
|---|---|---|
| Channel | 1-lepton | 2-lepton |
| Definition of the region | $m_{top^*}$ >225GeV && $m_{bb}$ <75GeV | Require e$\mu$ final state |
| Purity | 75% | 99% |
| Fit observable | Yield only | $m_{bb}$ |
| Purpose | Extract W+HF norm in 0+1 lep | Constrain $m_{bb}$ shape systematics in 2-lep |

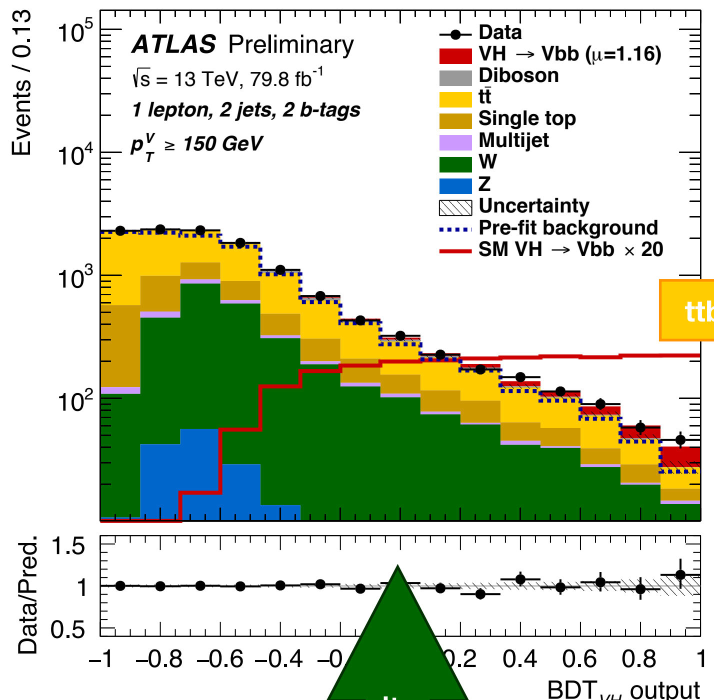
- Systematic uncertainties on **shapes** and **relative normalizations** are parametrized by **nuisance parameters (NPs)**, constrained with priors (mostly from generator comparison).

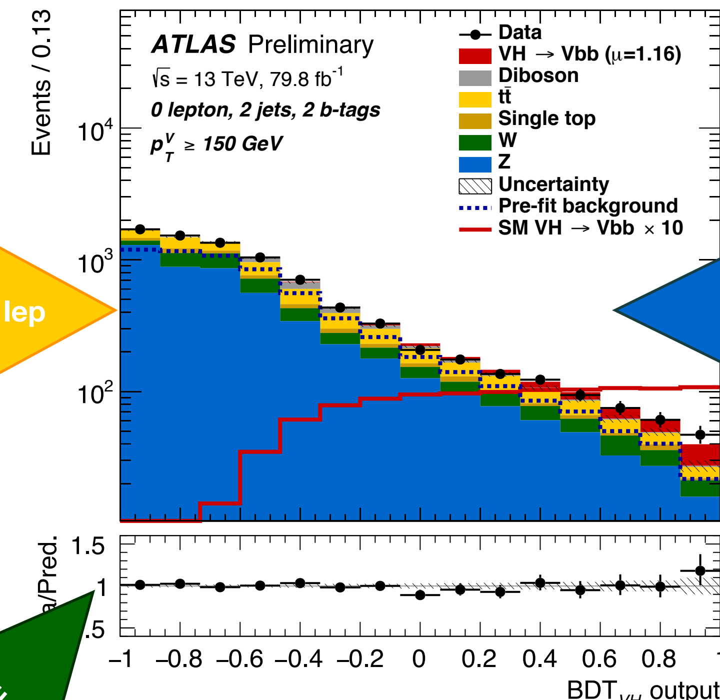
*$m_{top}$ = ($jet_b$ + lepton + $\nu_{tlv}$).M()

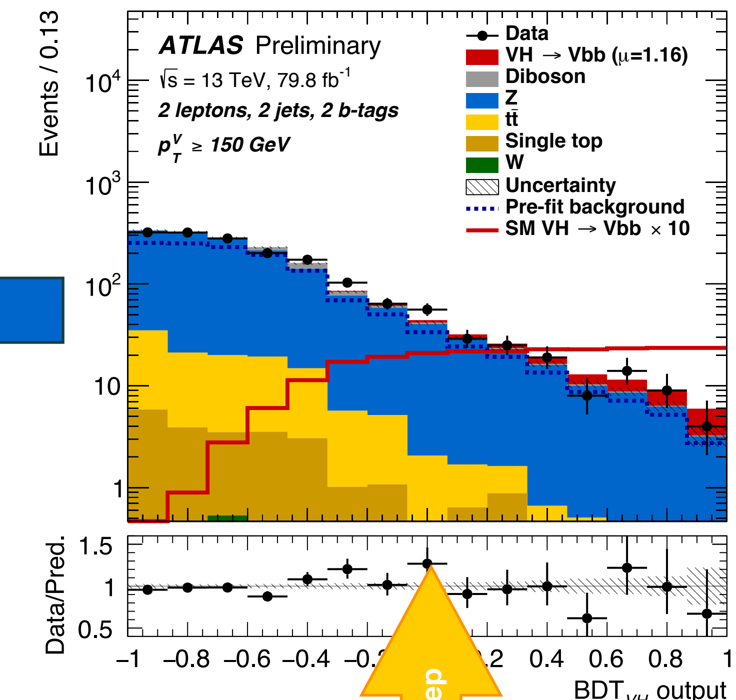
# The fit model: floating normalizations

| | 1-lep | 0-lep | 2-lep |
|---|---|---|---|

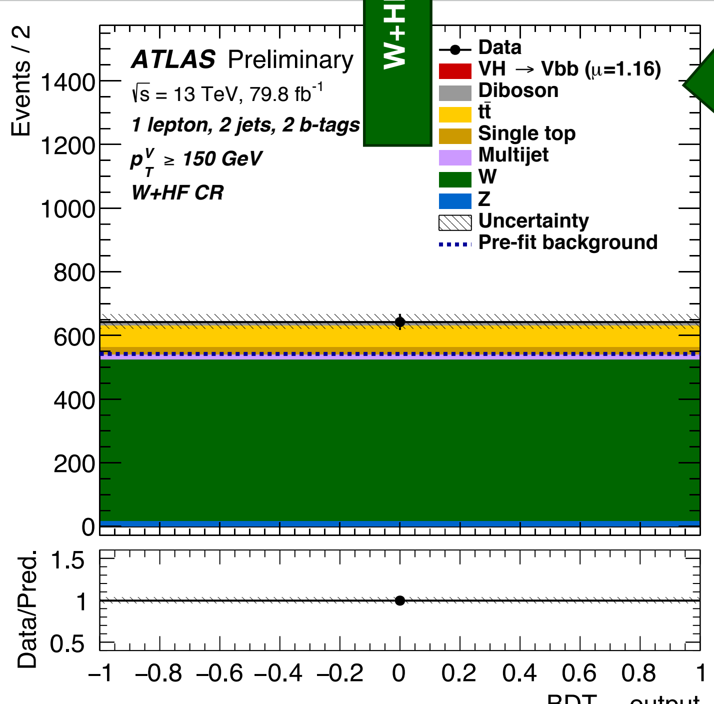
**SR**



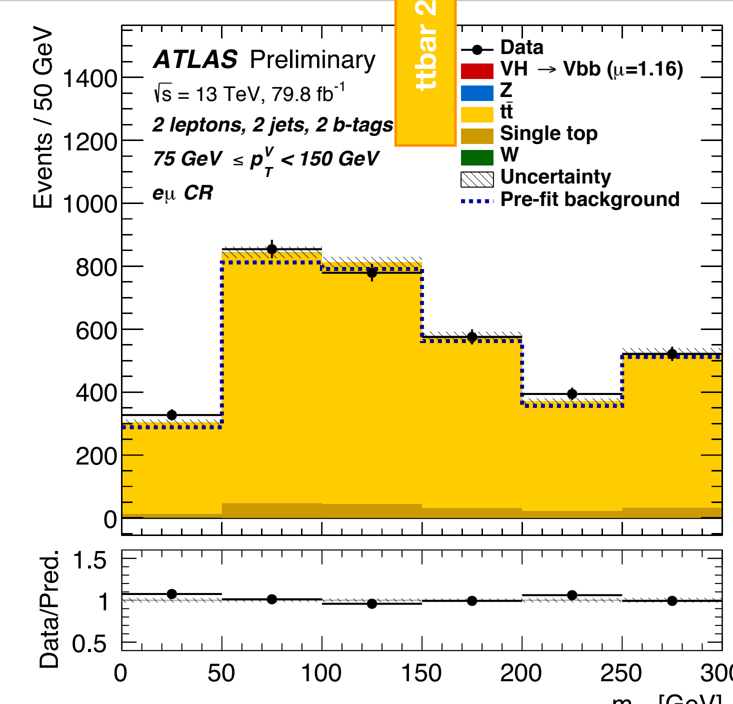



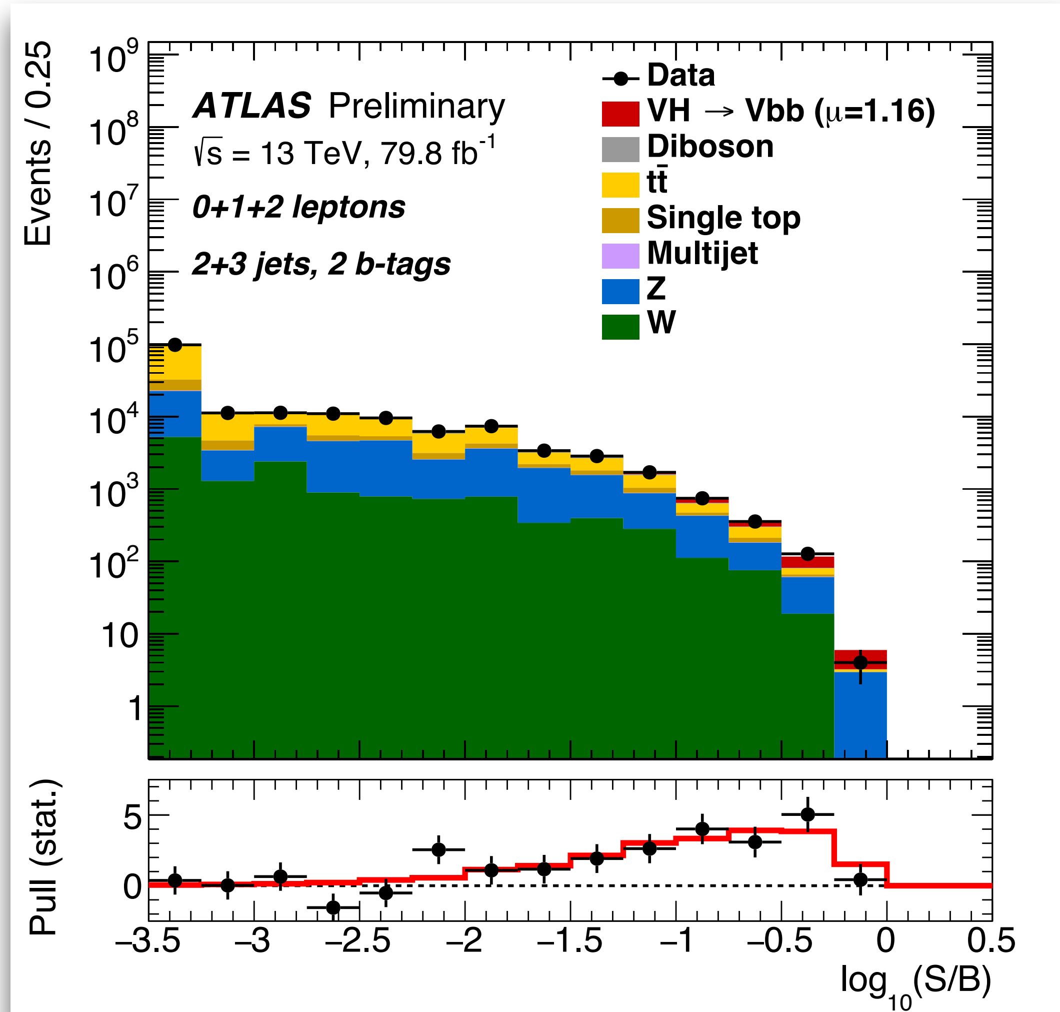

**CR**




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



# VH, H→bb fit results @ 80 fb$^{-1}$



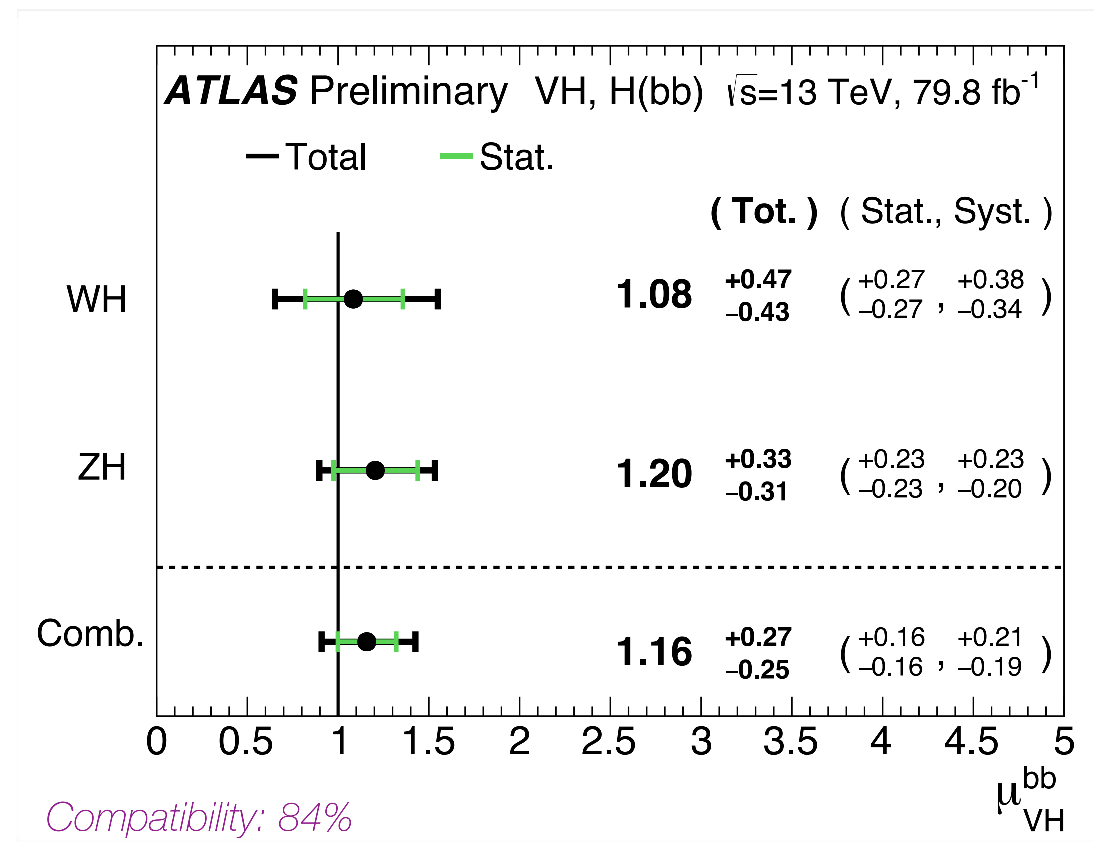

**4.9σ (4.3σ exp.)**

$$\mu^{bb}_{VH} = 1.16^{+0.27}_{-0.25}$$

## *Run 2 results (2015+2016+2017):*

| Signal strength parameter | Signal strength | Significance Exp. | Significance Obs. |
|---|---|---|---|
| 0-lepton | $1.04^{+0.34}_{-0.32}$ | 3.1 | 3.3 |
| 1-lepton | $1.09^{+0.46}_{-0.42}$ | 2.4 | 2.6 |
| 2-lepton | $1.38^{+0.46}_{-0.42}$ | 2.6 | 3.4 |
| $VH,\ H \rightarrow b\bar{b}$ combination | $1.16^{+0.27}_{-0.25}$ | 4.3 | 4.9 |

*Single channel: Combined fit with 3 signal strength




*VH and WH: Combined fit with 2 signal strength

# Systematic uncertainties

EPS17: HIGG-2016-29

| Source of uncertainty | | $\sigma_\mu$ |
|---|---|---|
| Total | | 0.259 |
| Statistical | | 0.161 |
| Systematic | | 0.203 |
| Experimental uncertainties | | |
| Jets | | 0.035 |
| $E_T^{miss}$ | | 0.014 |
| Leptons | | 0.009 |
| $b$-tagging | $b$-jets | 0.061 |
| | $c$-jets | 0.042 |
| | light jets | 0.009 |
| | extrapolation | 0.008 |
| Pile-up | | 0.007 |
| Luminosity | | 0.023 |
| Theoretical and modelling uncertainties | | |
| Signal | | 0.094 |
| Floating normalisations | | 0.035 |
| $Z$ + jets | | 0.055 |
| $W$ + jets | | 0.060 |
| $t\bar{t}$ | | 0.050 |
| Single top quark | | 0.028 |
| Diboson | | 0.054 |
| Multijet | | 0.005 |
| MC statistical | | 0.070 |

***Great effort to reduce the main systematic uncertainties.***

| | EPS17 (36 fb-1) | ICHEP 18 (80 fb-1) |
|---|---|---|
| Total | 0.39 | 0.26 |
| Stat | 0.24 | 0.16 |
| Syst | 0.31 | 0.20 |

***b-tagging dominant experimental uncertainty***

*This has a limited effect on the significance, but it is **important for Xsection measurements**.*

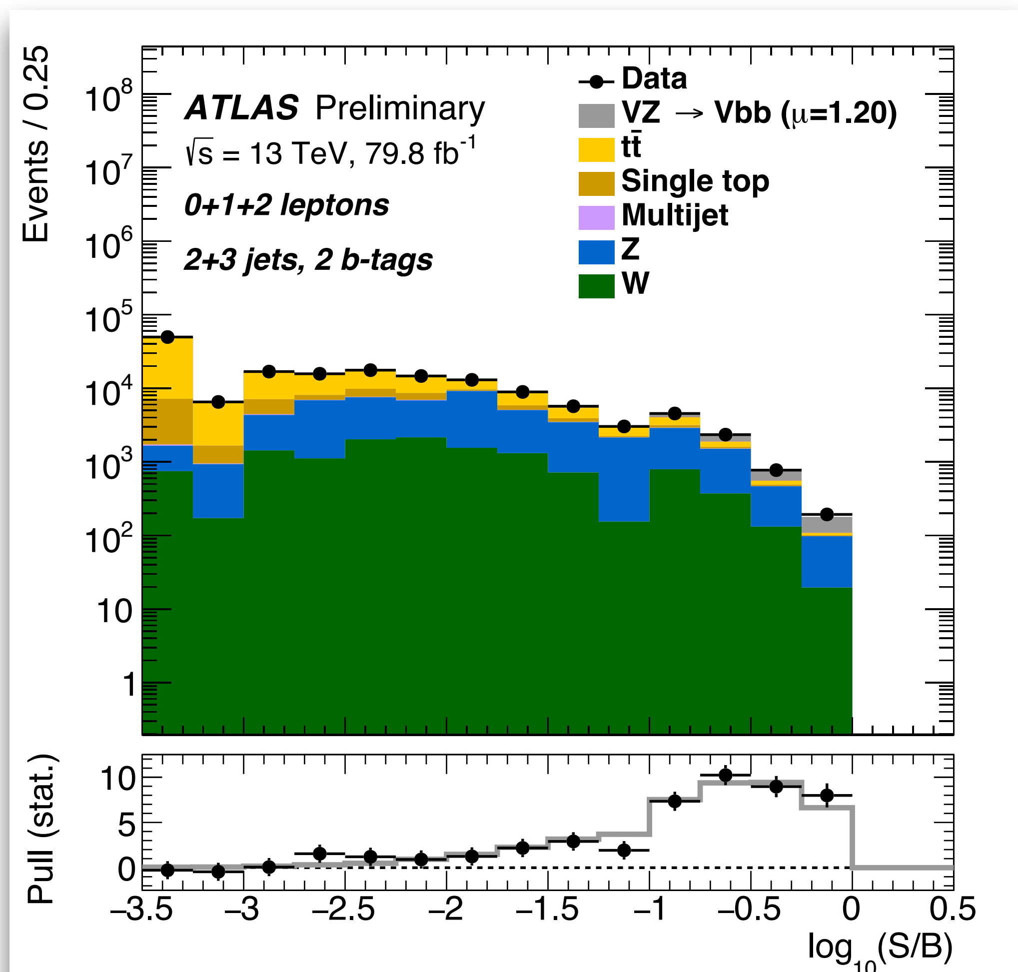
***modeling uncertainties (shapes and norm)***
*compare different generators at truth level*

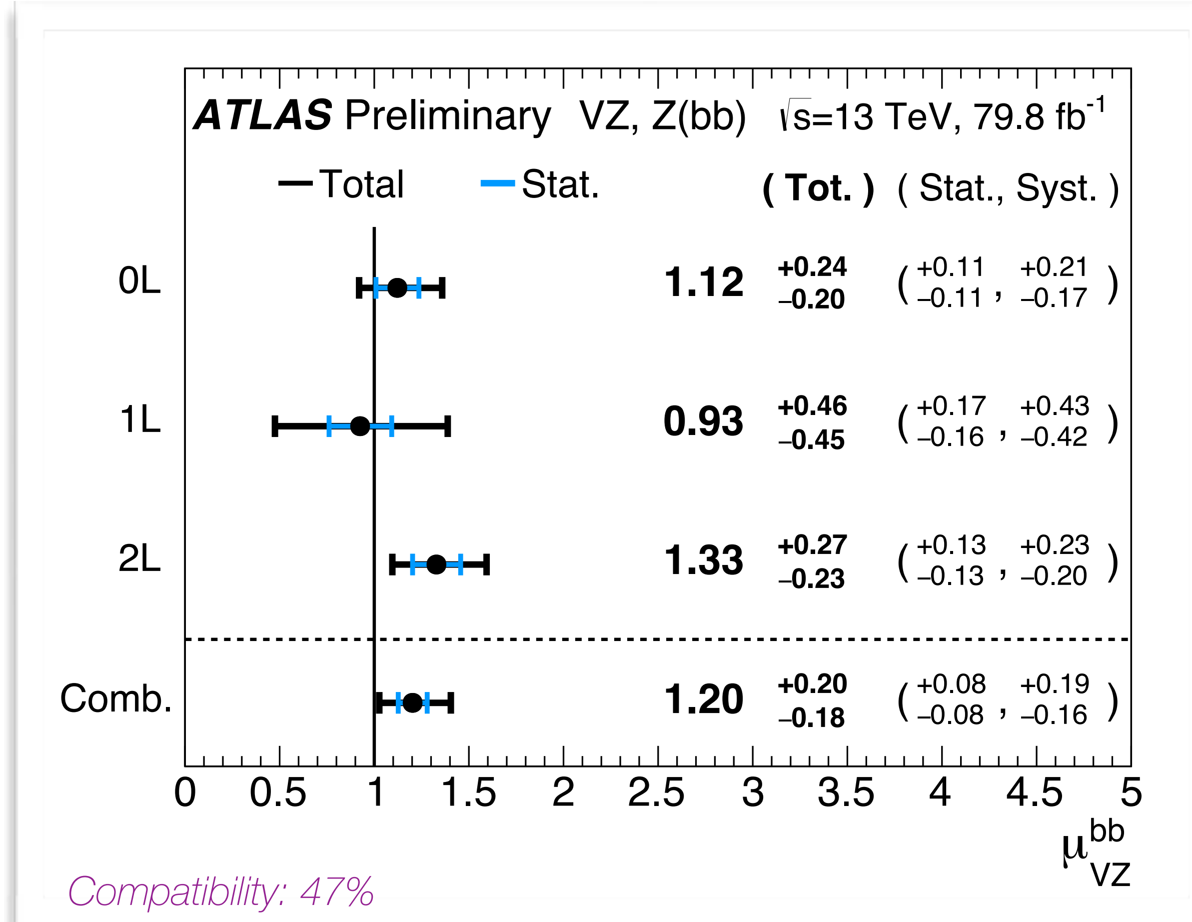
***Can limit BDT sensitivity and induce fit instabilities***

# Validation: the VZ, Z→bb analysis @ 80 fb-1

**Validate the BDT analysis:**

- Same selection as VH
- Retrain the BDT (same hyper-param.) using:
  - Same backgrounds (+VH)
  - ***VZ, Z→bb as signal***
- Repeat the fit on BDT_VZ to extract VZ, Z→bb $\boldsymbol{\mu}$.




Fit to diboson VZ, Z → bb (≫**5σ**):

$$\mu^{bb}_{VZ} = 1.20^{+0.20}_{-0.18}$$

*Signal strength compatible with SM as expected.*

***analysis procedure is validated!***

# Crosscheck: di-jet mass analysis

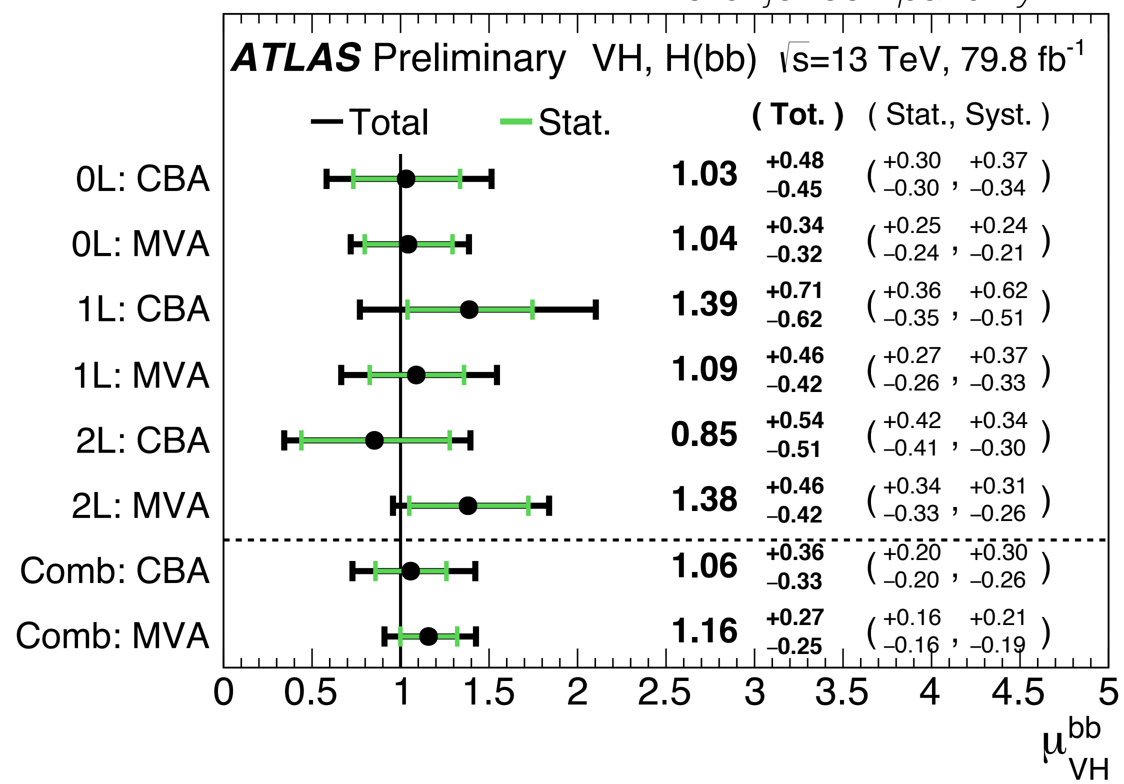
**Analysis strategy:**

- Fit the *m(bb)* ***spectrum*** of the ***two jets system***.
- More regions: split in ***more $p_T^V$ bins***.
- ***Add extra cuts*** to suppress V+jets and ttbar.

| | 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 |

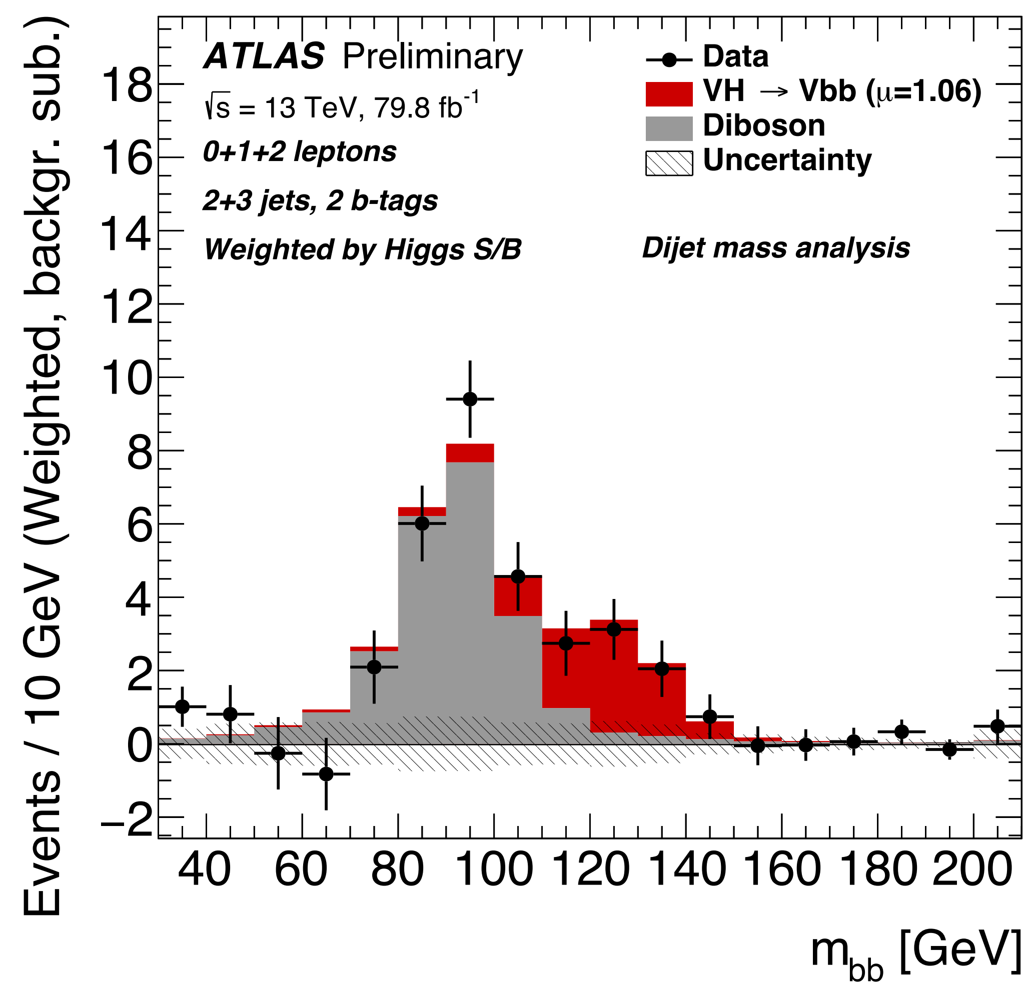
*MVA & di-jet compatibility:*




**3.6σ (3.5σ exp.)**

$$\mu_{VH}^{bb} = 1.06^{+0.36}_{-0.33}$$

*The di-jet analysis is 27% (19% for exp.) less sensitive than the MVA analysis.*



# Conclusions & Run1+Run2 Combination

**Run2 VH, H→bb:**

- MVA analysis: apply fit on BDT discriminant (14 regions in the fit: 8 SRs + 6 CRs)
- **Signal strength compatible with SM expectation:**

$$\mu_{VH}^{bb} = 1.16^{+0.27}_{-0.25}$$ **4.9σ (4.3σ exp.)**

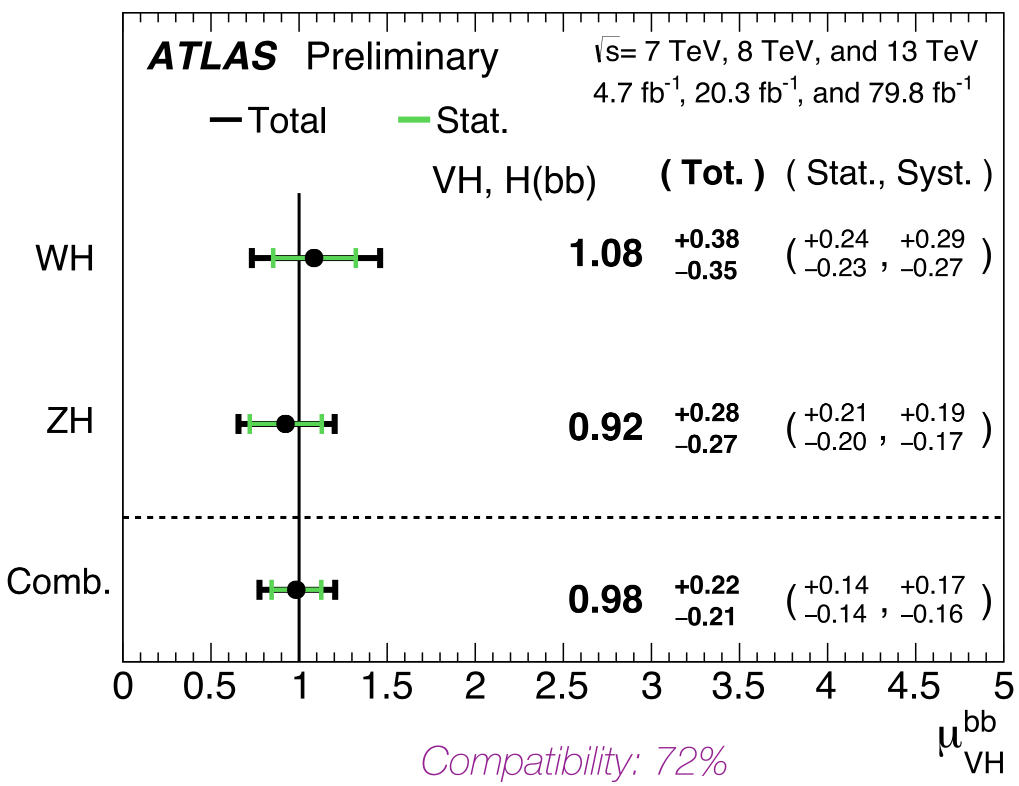
- Successful **validation with VZ, Z→bb** analysis
- **Independent crosscheck** with di-jet analysis compatible with MVA: $\mu_{VH}^{bb} = 1.06^{+0.36}_{-0.33}$ **[3.6σ obs.]**
- **Combination with Run1 results (20.3+4.7 fb$^{-1}$):**

***VH, H→bb***
***Run1+Run2 combination:***

*fit results @ 20.3 fb$^{-1}$+4.7 fb$^{-1}$+79.8 fb$^{-1}$*

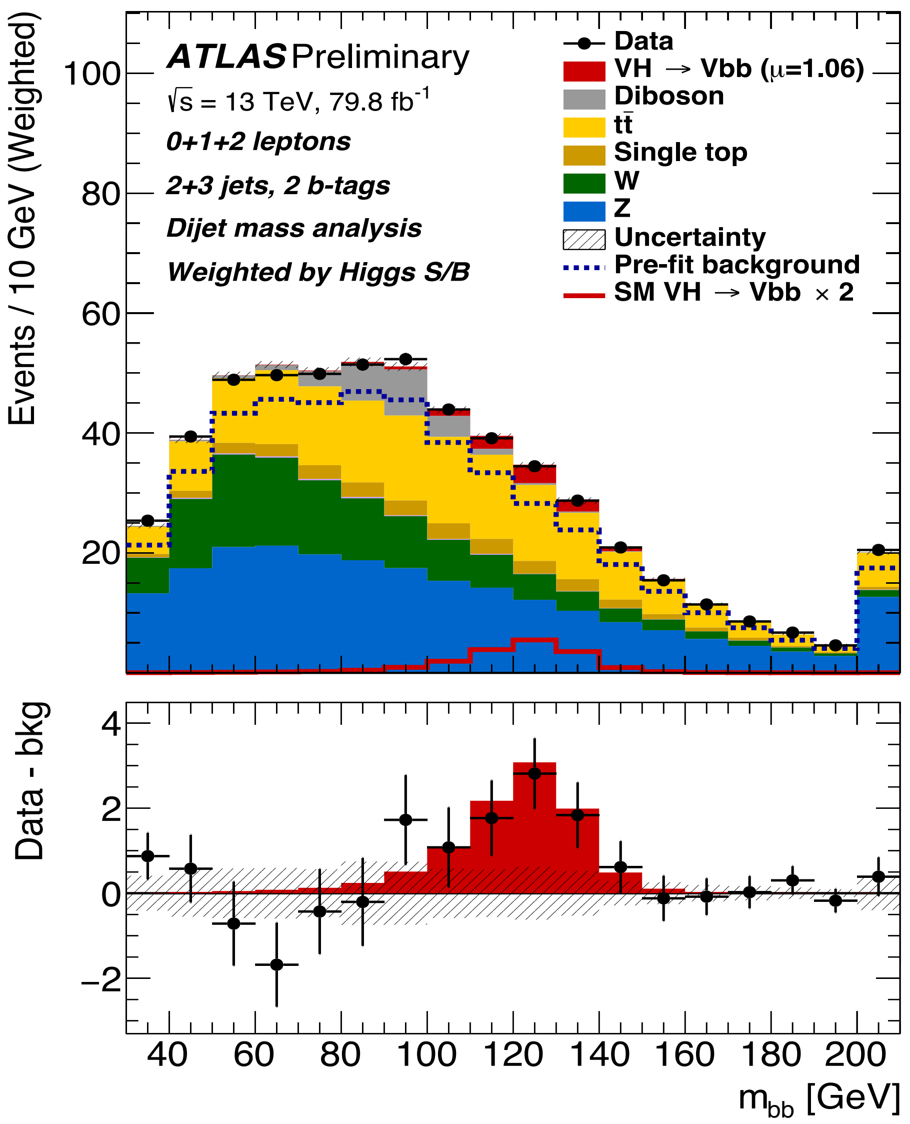
$$\mu_{VH}^{bb} = 0.98^{+0.22}_{-0.21}$$

**4.9σ (5.1σ exp.)**



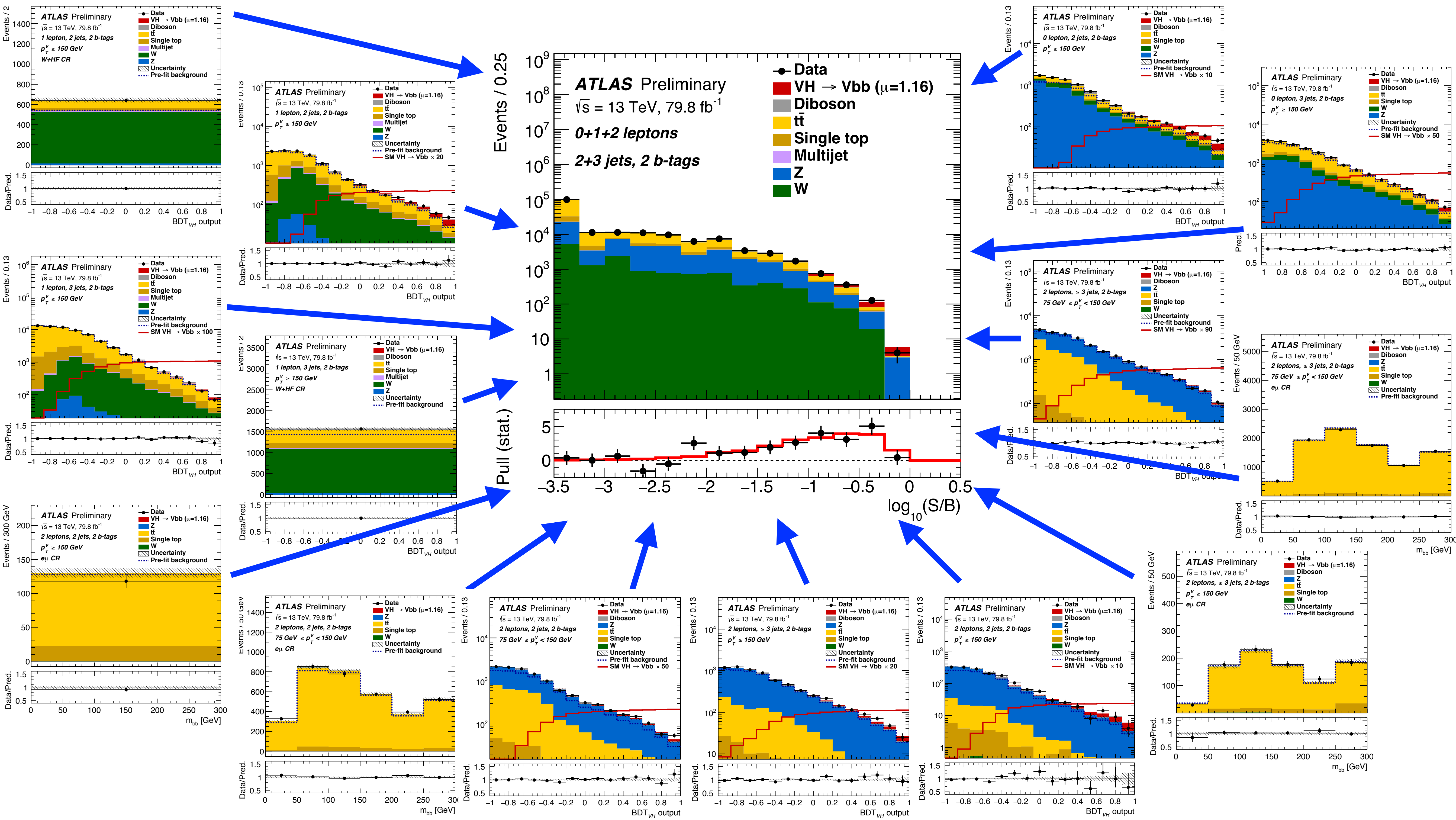

*Compatibility: 72%*

# Backup



ATLAS Preliminary
√s = 13 TeV, 79.8 fb-1
0+1+2 leptons
2+3 jets, 2 b-tags
Dijet mass analysis
Weighted by Higgs S/B
Data
VH → Vbb (μ=1.06)
Diboson
tt̄
Single top
W
Z
Uncertainty
Pre-fit background
SM VH → Vbb × 2
Events / 10 GeV (Weighted)
Data - bkg
m_bb [GeV]

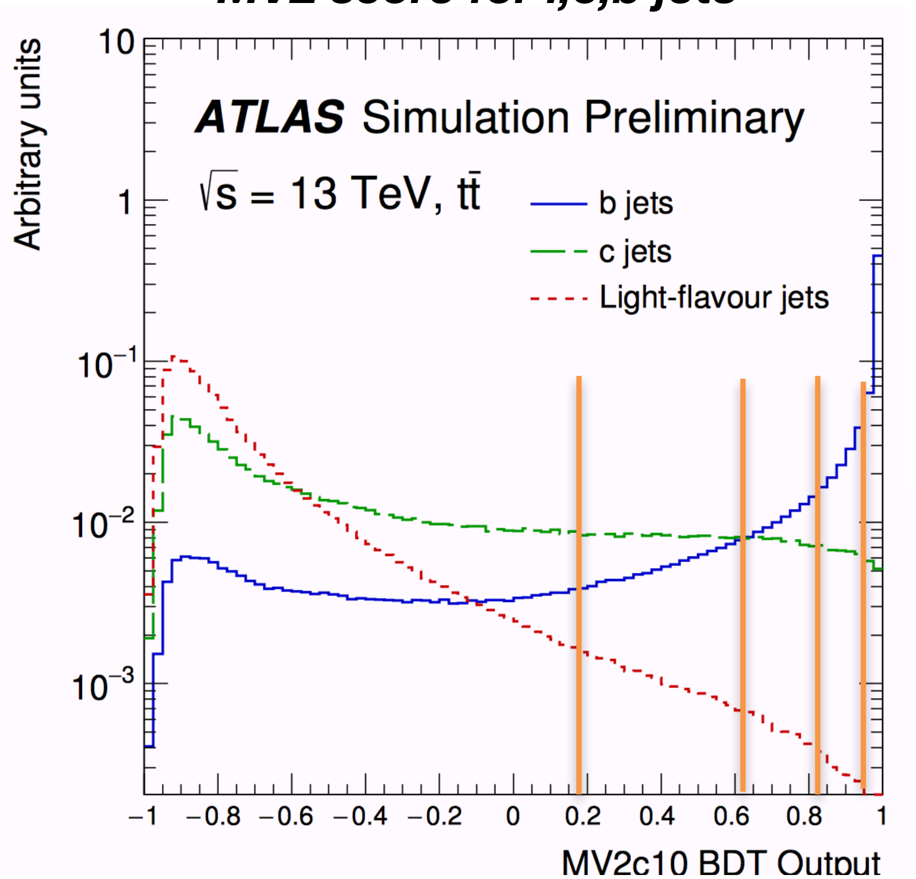
# Full picture of the simultaneous fit:

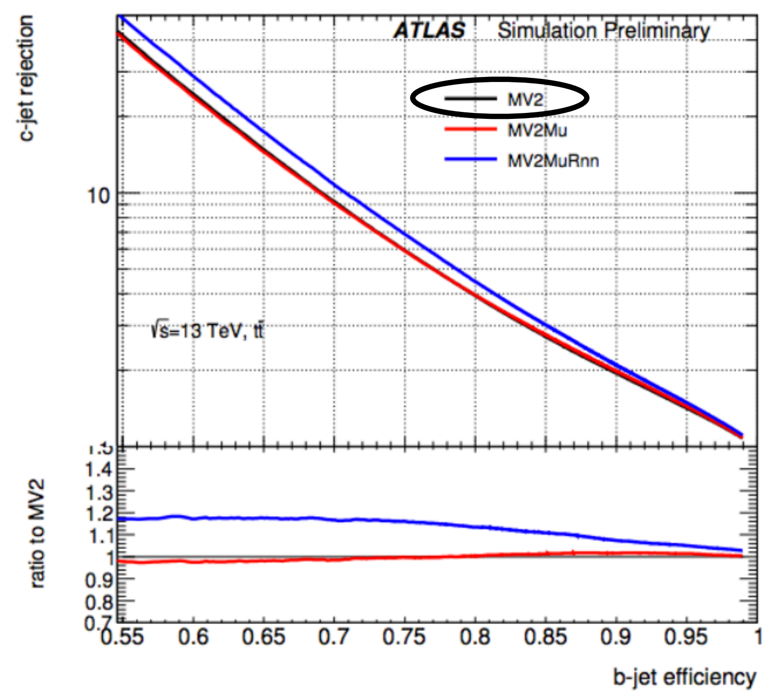


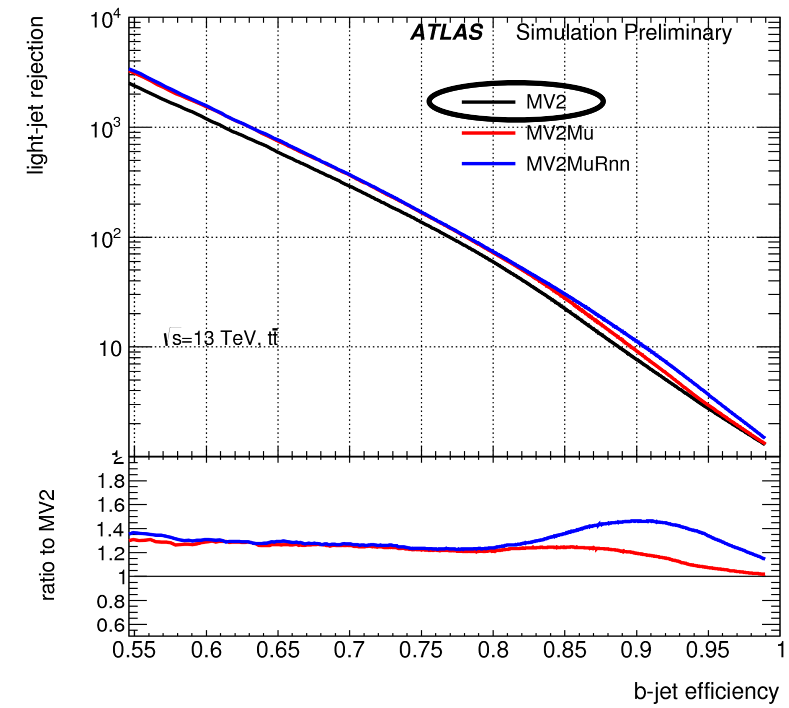
# BTagging in ATLAS

ATL-PHYS-PUB-2017-013

***MV2 score for l,c,b jets***

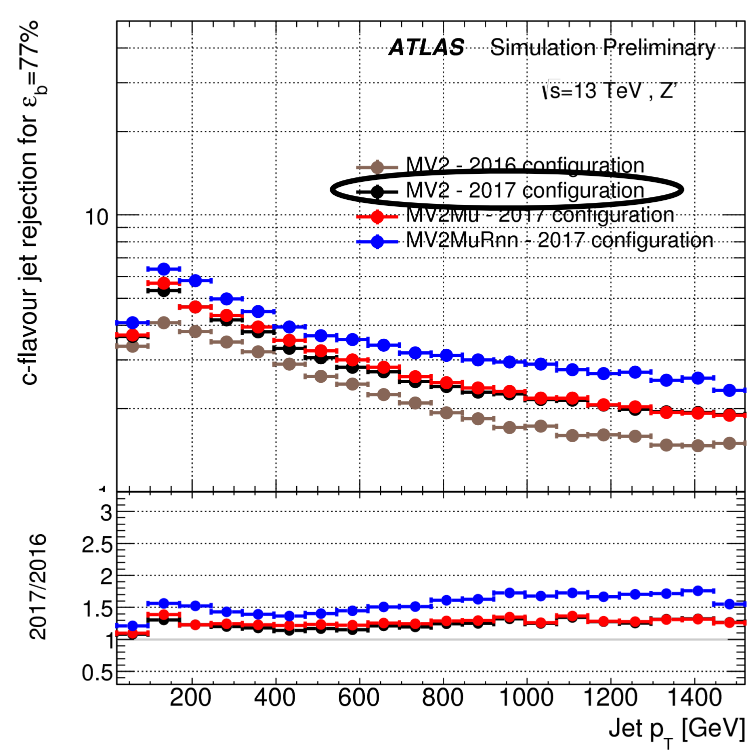


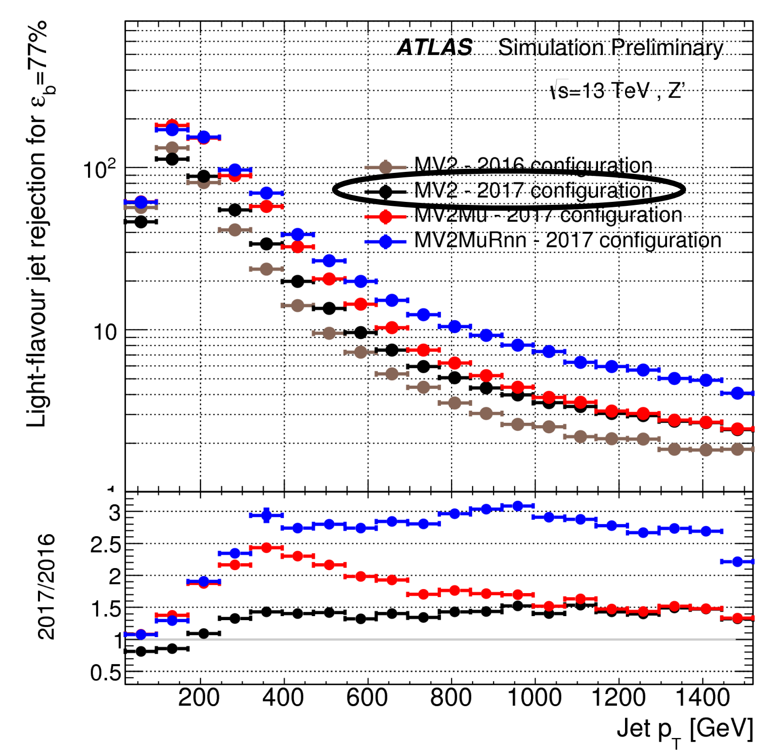




***C-jet rejection***

***Light-jet rejection***



# Event Selection

***Table:*** *same event selection as EPS 2017*

| Selection | 0-lepton | 1-lepton | | 2-lepton |
|---|---|---|---|---|
| | | $e$ sub-channel | $\mu$ 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 *tight* muon $p_{\mathrm{T}} > 25$ GeV | 2 *loose* leptons with $p_{\mathrm{T}} > 7$ GeV $\geq 1$ 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 / Exactly 3 jets | | | Exactly 2 / $\geq 3$ jets |
| Jet $p_{\mathrm{T}}$ | $> 20$ GeV for $\lvert\eta\rvert < 2.5$ and $> 30$ GeV for $2.5 < \lvert\eta\rvert < 4.5$ | | | |
| $b$-jets | Exactly 2 $b$-tagged jets | | | |
| Leading $b$-tagged jet $p_{\mathrm{T}}$ | $> 45$ GeV | | | |
| $H_{\mathrm{T}}$ | $> 120$ (2 jets), $>150$ GeV (3 jets) | – | | – |
| $\min[\Delta\phi(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, \vec{\mathrm{jets}})]$ | $> 20^\circ$ (2 jets), $> 30^\circ$ (3 jets) | – | | – |
| $\Delta\phi(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, \vec{bb})$ | $> 120^\circ$ | – | | – |
| $\Delta\phi(\vec{b}_1, \vec{b}_2)$ | $< 140^\circ$ | – | | – |
| $\Delta\phi(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, \vec{E}_{\mathrm{T,trk}}^{\mathrm{miss}})$ | $< 90^\circ$ | – | | – |
| $p_{\mathrm{T}}^{V}$ regions | $> 150$ GeV | | | 75 GeV $< p_{\mathrm{T}}^{V} <$ 150 GeV, $> 150$ GeV |
| Signal regions | – | $m_{bb} \geq 75$ GeV or $m_{\mathrm{top}} \leq 225$ GeV | | Same-flavour leptons Opposite-sign charges ($\mu\mu$ sub-channel) |
| Control regions | – | $m_{bb} < 75$ GeV and $m_{\mathrm{top}} > 225$ GeV | | Different-flavour leptons Opposite-sign charges |

# Generators:

| Process | ME generator | ME PDF | PS and Hadronisation | UE model tune | Cross-section order ace2.5cm |
|---|---|---|---|---|---|
| Signal, mass set to 125 GeV and $bb$ branching fraction to 58% | | | | | |
| $qq \to WH$ $\to \ell\nu b\bar{b}$ | Powheg-Box v2 [55] + GoSam [58] + MiNLO [59,60] | NNPDF3.0NLO$^{(\star)}$ [56] | Pythia8.212 [47] | AZNLO [57] | NNLO(QCD)+ NLO(EW) [61,62,63,64,65,66,67] |
| $qq \to ZH$ $\to \nu\nu b\bar{b}/\ell\ell b\bar{b}$ | Powheg-Box v2 + GoSam + MiNLO | NNPDF3.0NLO$^{(\star)}$ | Pythia8.212 | 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$^{(\star)}$ | Pythia8.212 | AZNLO | NLO+ NLL [68,69,70,71,72] |
| Top quark, mass set to 172.5 GeV | | | | | |
| $t\bar{t}$ | Powheg-Box v2 [73] | NNPDF3.0NLO | Pythia8.230 | A14 [74] | NNLO+NNLL [75] |
| $s$-channel | Powheg-Box v2 [76] | NNPDF3.0NLO | Pythia8.230 | A14 | NLO [77] |
| $t$-channel | Powheg-Box v2 [76] | NNPDF3.0NLO | Pythia8.230 | A14 | NLO [78] |
| $Wt$ | Powheg-Box v2 [79] | NNPDF3.0NLO | Pythia8.230 | A14 | Approximate NNLO [80] |
| Vector boson + jets | | | | | |
| $W \to \ell\nu$ | Sherpa 2.2.1 [50,81,82] | NNPDF3.0NNLO | Sherpa 2.2.1 [83,84] | Default | NNLO [85] |
| $Z/\gamma^* \to \ell\ell$ | 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:

**Main sources of systematics:**

- Experimental systematics:
  - B-tagging
  - jet energy calibration
- Modeling of simulated background:
  - Normalization and shape mismodels in MC.
  - Obtained from comparison at truth level between different generators
- Higgs theory related uncertainties:
  - Xsection and BR uncertainties
  - follow the recommendations of the LHC Higgs Cross Section working group

**Signal systs:**

| 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 ratio | 1.7 % |
| Acceptance from scale variations (var.) | 2.5 – 8.8% |
| Acceptance from PS/UE var. for 2 or more jets | 2.9 – 6.2% (depending on lepton channel) |
| Acceptance from PS/UE var. for 3 jets | 1.8 – 11% |
| Acceptance from PDF+$\alpha_S$ 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+$\alpha_S$ var. | S |
| $p_T^V$ from NLO EW correction | S |

**Background systs:**

| $Z$ + 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% ($Wt \to bb$), 24% ($Wt \to oth$) |
| Acceptance 3-jet | 20% ($t$-channel), 51% ($Wt \to bb$), 21% ($Wt \to oth$) |
| $m_{bb}$, $p_T^V$ | S ($t$-channel, $Wt \to bb$, $Wt \to oth$) |
| **Multi-jet (1-lepton)** | |
| Normalisation | 60 – 100% (2-jet), 90 – 140% (3-jet) |
| BDT template | S |

S = shape only syst

PS/UE = parton shower/ underlying event.

# Diboson Systematic uncertainties:

**Extra systematics uncertainties for Diboson Validation analysis only:**

| | |
|---|---|
| $ZZ$ | |
| Normalisation | 20% |
| 0-to-2 lepton ratio | 6% |
| Acceptance from scale variations (var.) | 10 – 18% |
| Acceptance from PS/UE var. for 2 or more jets | 6% |
| Acceptance from PS/UE var. for 3 jets | 7% (0-lepton), 3% (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% |
| Acceptance from PS/UE var. for 2 or more jets | 4% |
| 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% |

# BDT variables

***Table:*** *from internal note*

| Variable | Name | 0-lepton | 1-lepton | 2-lepton |
|---|---|---|---|---|
| $m_{jj}$ | mBB | ✓ | ✓ | ✓ |
| $\Delta R(jet_1, jet_2)$ | dRBB | ✓ | ✓ | ✓ |
| $p_T^{\mathrm{jet1}}$ | pTB1 | ✓ | ✓ | ✓ |
| $p_T^{\mathrm{jet2}}$ | pTB2 | ✓ | ✓ | ✓ |
| $p_T^V$ | pTV | ✓ | ✓ | ✓ |
| $\Delta\phi(V,H)$ | dPhiVBB | ✓ | ✓ | ✓ |
| $\|\Delta\eta(jet_1, jet_2)\|$ | dEtaBB | ✓ | | |
| $M_{eff}(M_{eff3})$ | HT | ✓ | | |
| $E_{\mathrm{T}}^{\mathrm{miss}}$ | MET | $\equiv p_T^V$ | ✓ | |
| $\min(\Delta\phi(\ell, jet))$ | dPhiLBmin | | ✓ | |
| $m_{\mathrm{T}}^W$ | mTW | | ✓ | |
| $\Delta Y(W,H)$ | dYWH | | ✓ | |
| $m_{\mathrm{top}}$ | mTop | | ✓ | |
| $E_{\mathrm{T}}^{\mathrm{miss}}$ significance | METSig | | | ✓ |
| $\Delta\eta(V,H)$ | dEtaVBB | | | ✓ |
| $m_{\ell\ell}$ | mLL | | | ✓ |
| | Only in 3 Jet Events | | | |
| $p_T^{\mathrm{jet}_3}$ | pTJ3 | ✓ | ✓ | ✓ |
| $m_{jjj}$ | mBBJ | ✓ | ✓ | ✓ |

# Ranking plot