# Qualche slides di sommario sullo bYukawa

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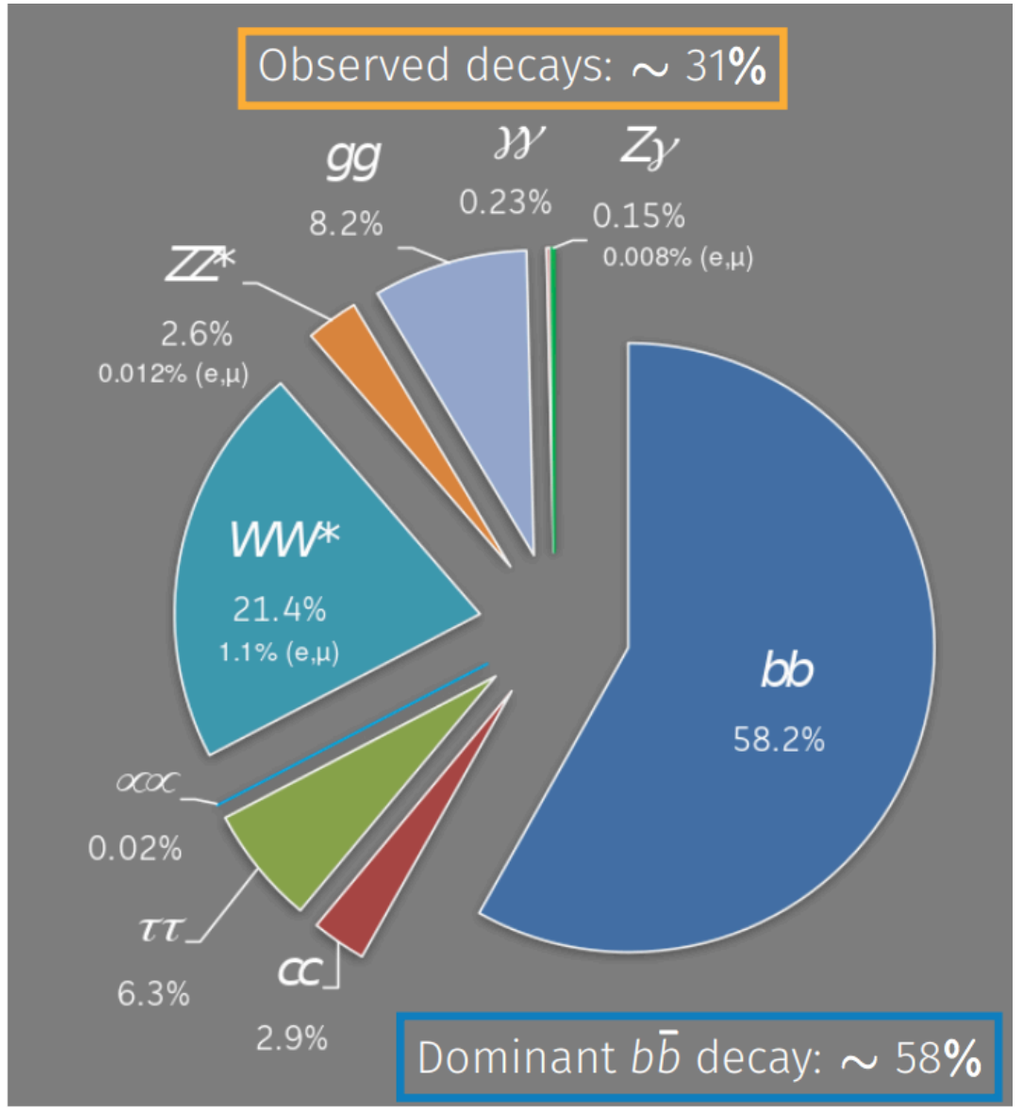
# Higgs Boson decay modes

- Higgs boson branching ratios
- Many decay modes accessible at the LHC
  - Decays to γγ and gg thanks to loops
- 31% of them already observed
- WW, ZZ, γγ, ττ

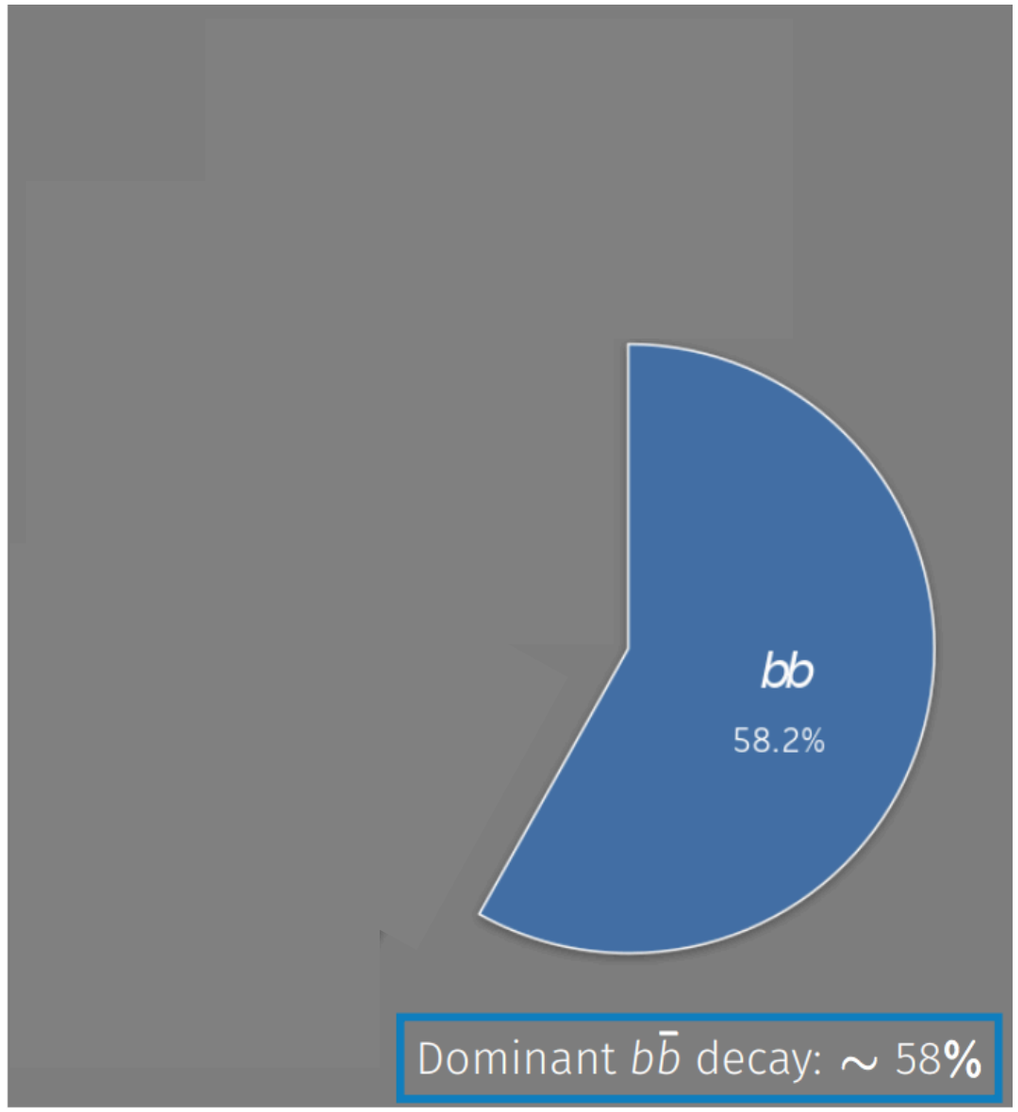


# Higgs Boson decay modes

Why is interesting to observe H->bb?

- To establish the fate of the Higgs boson
  - Expected to be ~58% of the total width
- To control the Higgs Yukawa sector

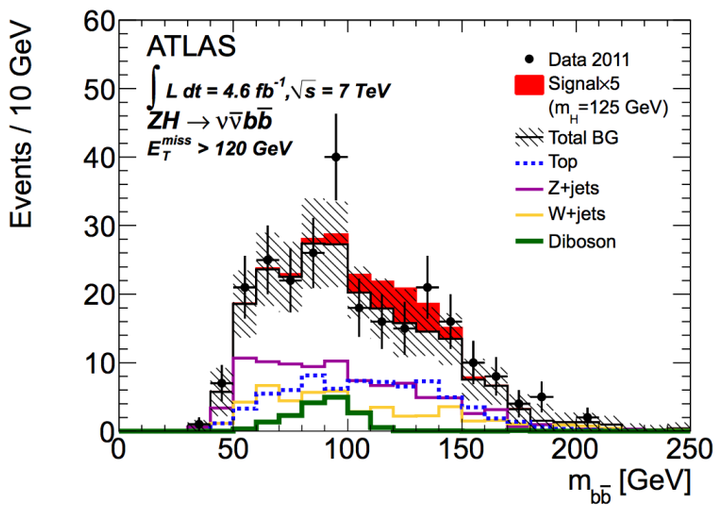
| | down | up |
|---|---|---|
| quark | **bottom** | top |
| lepton | τ | |




- Model dependent estimation of the total width (not directly measurable at the LHC)
  - Only ratio of BR (couplings) are truly model independent at the LHC
  - Absolute coupling measurement requires assumptions on the total width (i.e. no BSM decays)
  - a term accounting for 58% of the total has a dominant effect on all the coupling determination

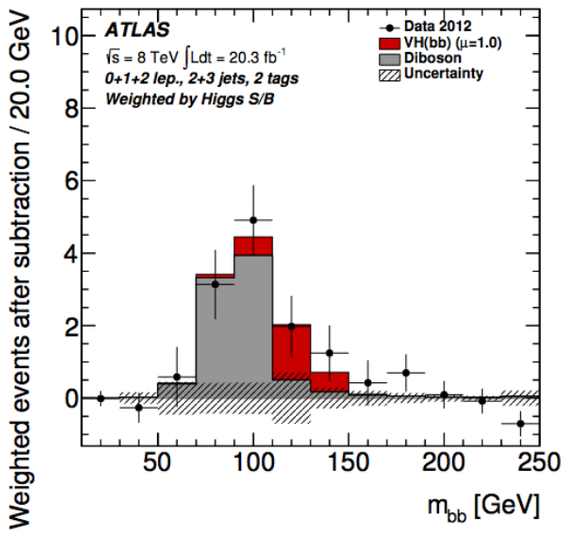
# Pre-summer 2018 (I)

## *Early Run1*



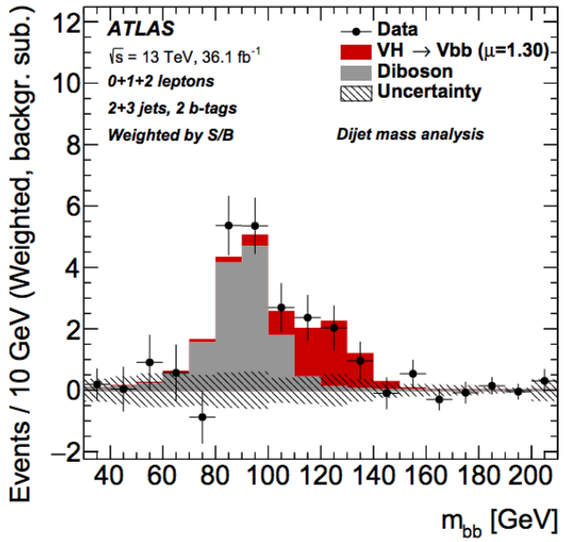

- ATLAS: arXiv:1207.0210
  7TeV data
  Limit ~ 4.5×SM
- CMS: arXiv:1202.4195
  7TeV data
  Limit ~ 6×SM
- Tevatron legacy: arXiv:1207.6436
  2.8σ at 125 GeV (1.5σ exp.)
  3.1σ in full mass range

## *Run1 Legacy*




- ATLAS: arXiv:1409.6212
  1.4σ (2.6σ exp.)
  $\mu^{bb}_{VH} = 0.52 \pm 0.38$
- CMS: arXiv:1310.3687
  2.1σ (2.5σ exp.)
  $\mu^{bb}_{VH} = 0.89 \pm 0.45$
- LHC Combination: arXiv:1606.02266
  2.6σ (3.7σ exp.)
  $\mu^{bb} = 0.70 \pm 0.28$

## *Run2 2015-2017*




- ATLAS: arXiv:1708.03299
  **Evidence** at 3.5σ (3.0σ exp.)
  $\mu^{bb}_{VH} = 1.20 \pm 0.38$
- CMS: arXiv:1709.07497
  **Evidence** at 3.3σ (2.8σ exp.)
  $\mu^{bb}_{VH} = 1.2 \pm 0.40$

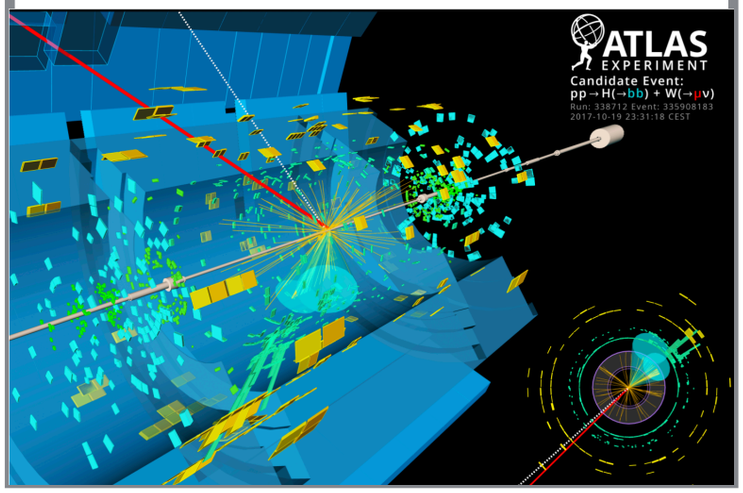
# Pre-summer 2018 (II)

| Analysis | Dataset | Obs. limit | Exp. limit | signal strength | arXiv |
|---|---|---|---|---|---|
| CMS ggF | Run-2 | 5.8 | 3.3 | 2.3±1.7 | 1709.05543 |
| ATLAS VBF | Run-1 | 4.4 | 5.4 | -0.8±2.3 | 1606.02181 |
| CMS VBF | Run-1 | 5.5 | 2.5 | 2.8±1.5 | 1506.01010 |
| ATLAS VBF | Run-2 | 5.9 | 3.0 | 3.0±1.7 | 1807.08639 |
| ATLAS ttH | Run-1 | 3.4 | 2.2 | 1.5±1.1 | 1503.05066 |
| CMS ttH | Run-1 | 4.2 | 3.3 | 1.2±1.6 | 1502.02485 |
| ATLAS ttH | Run-2 | 2.0 | 1.2 | 0.84±0.63 | 1712.08895 |
| CMS ttH | Run-2 | 1.5 | 0.9 | 0.72±0.45 | 1804.03682 |

# 0-,1-,2-lepton channels

## $pp \rightarrow WH$

### $WH \rightarrow l\nu bb$



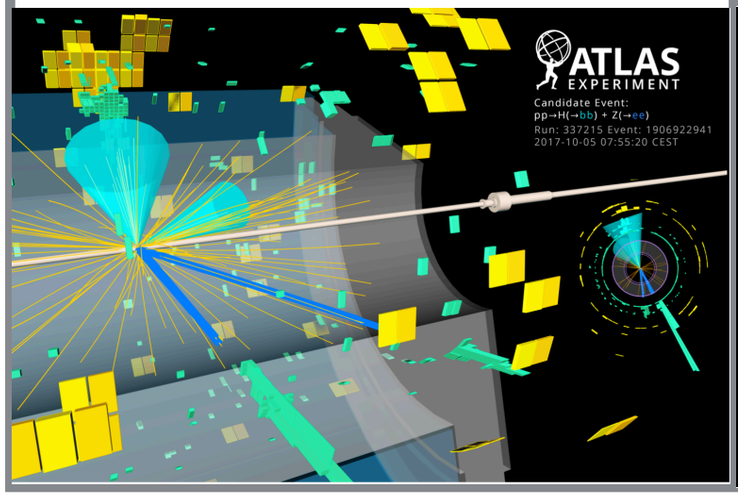

**Trigger**: single ele or MET trigger

$p_T$(W)>150 GeV
well defined isolated e or μ (25-27 GeV)
2,3 jets (45,25 GeV)
2 leading jets b-tagged (70%WP)
multi jet suppressed MET>30 GeV

***W+ Heavy Flavour jets CR:***
$m_{bb}$<75 GeV and $m_{lvb}$>225 GeV

## $pp \rightarrow ZH$

### $ZH \rightarrow llbb$

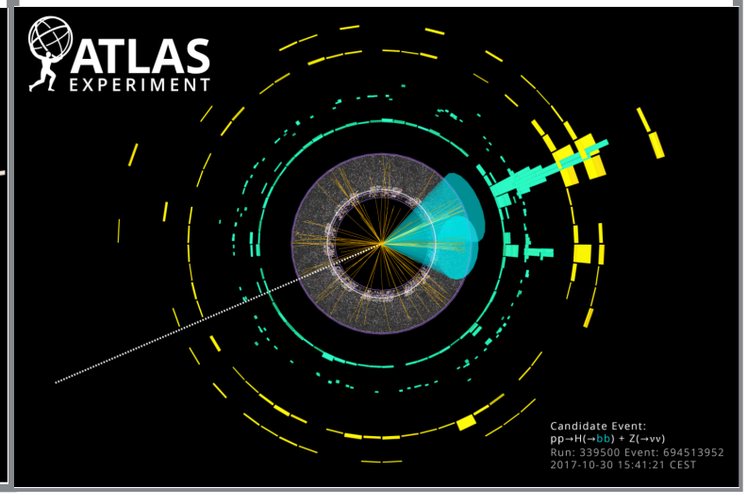



**Trigger**: single lepton trigger

$p_T$(Z)/GeV [75,150] and >150
2e or 2μ (27,7 GeV)
81<$m_{ll}$/GeV<101
2,≥3 jets (45,25 GeV)
2 leading jets b-tagged (70%WP)

***top CR:***
opposite flavour events

### $ZH \rightarrow \nu\nu bb$

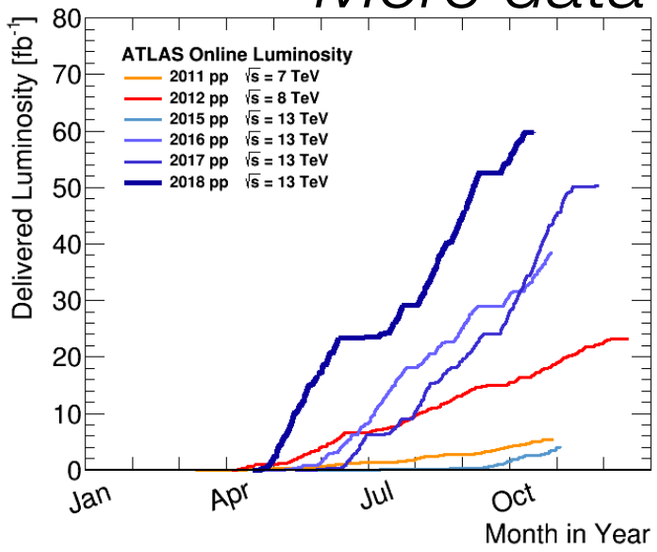



**Trigger**: MET trigger

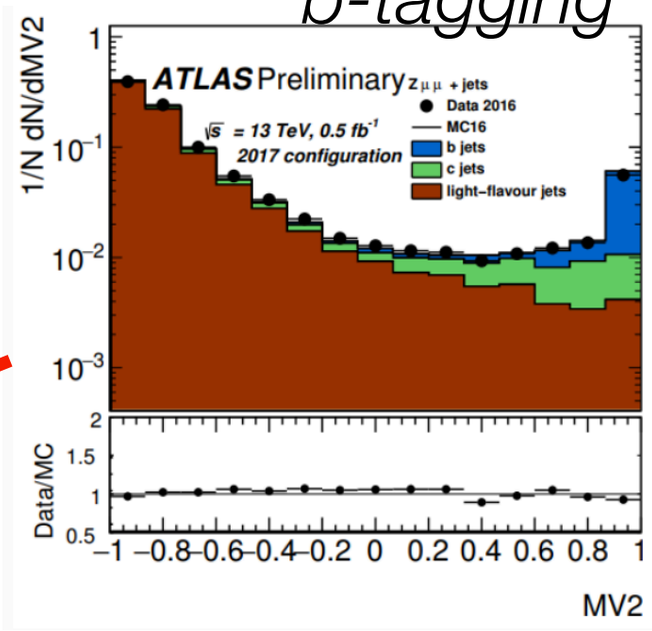
MET=$p_T$(Z)>150 GeV
lepton veto (7 GeV)
2,3 jets (45,25 GeV)
2 leading jets b-tagged (70%WP)
multi jet suppressed by dedicated angular cuts

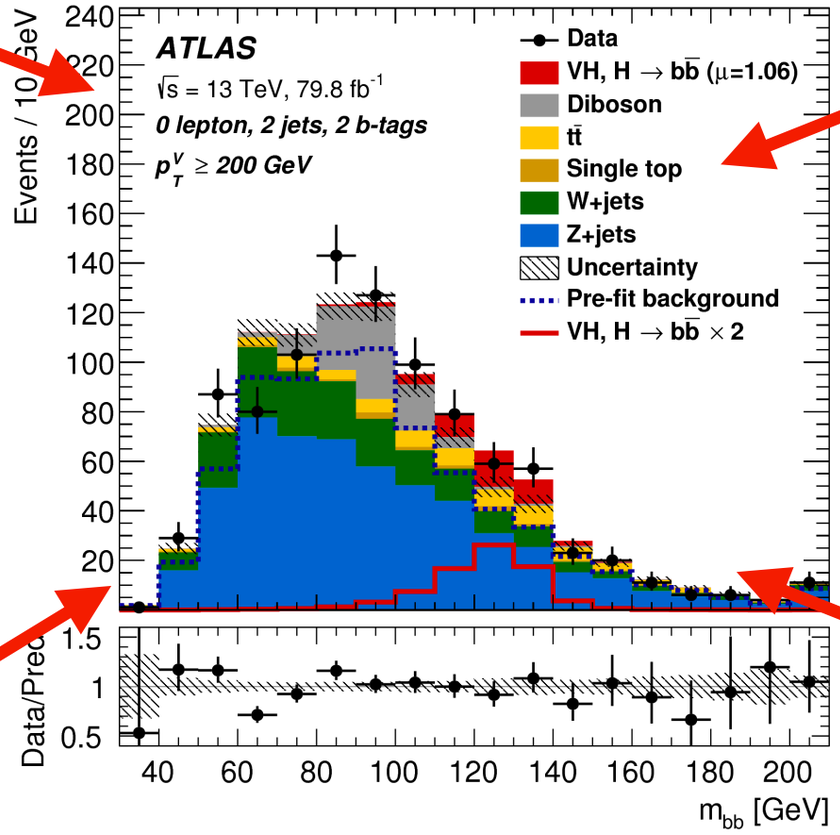
# Ingredients

*More data*

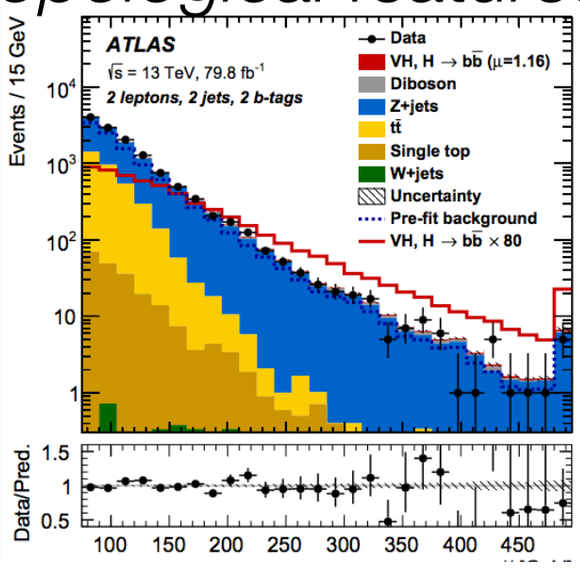



*b-tagging*

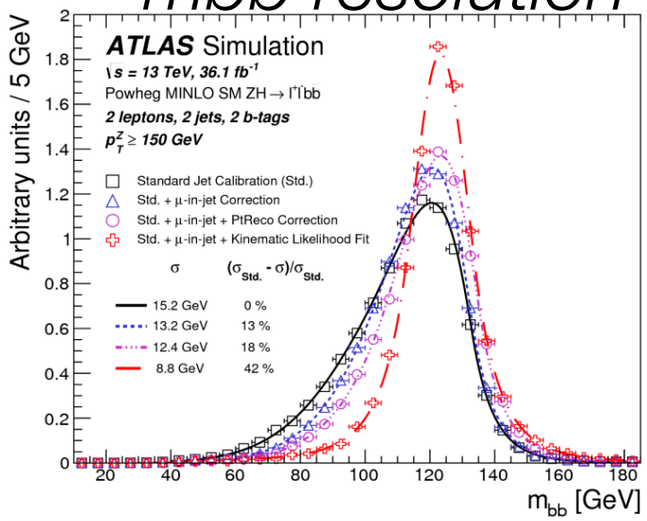


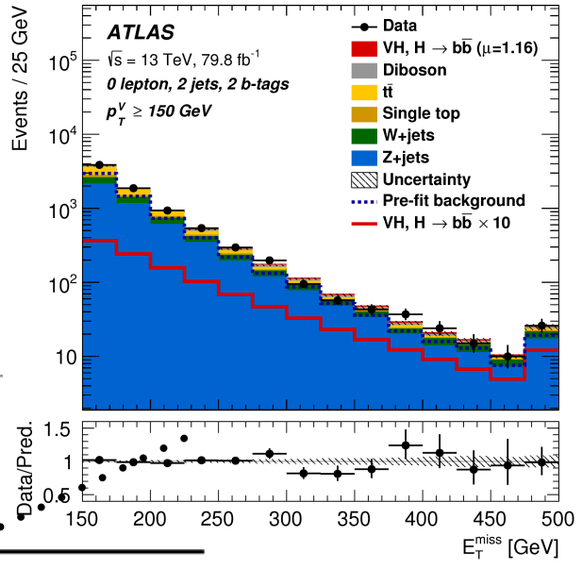

*topological features*

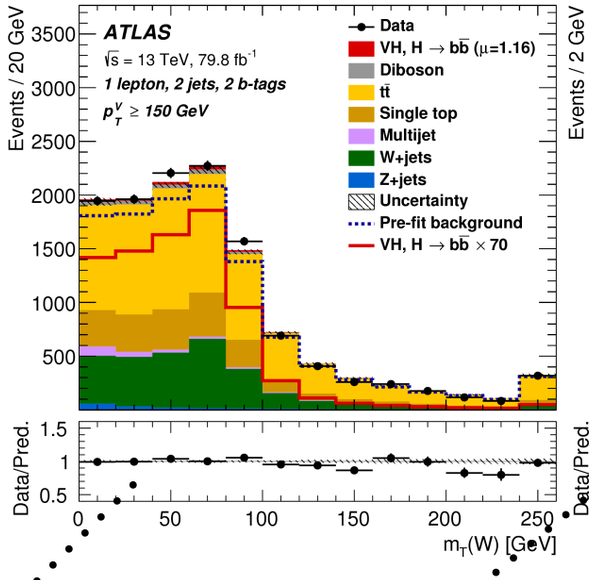


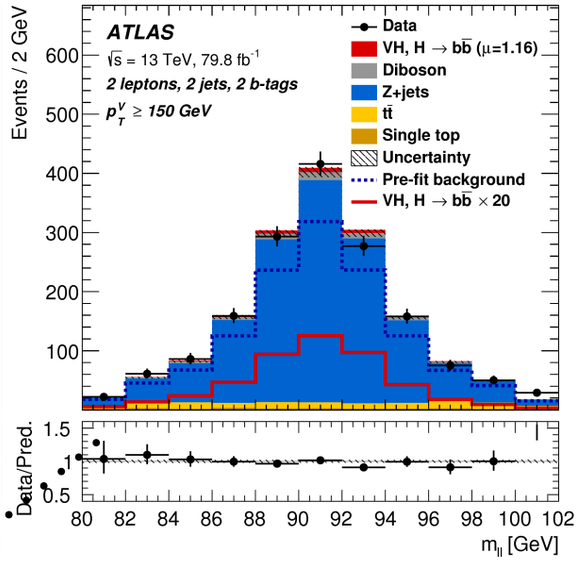

*mbb resolution*



# MVA

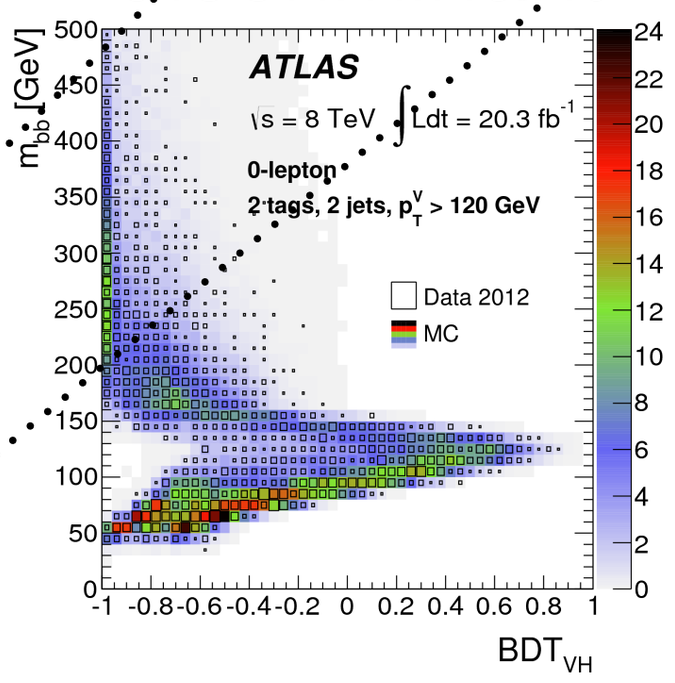


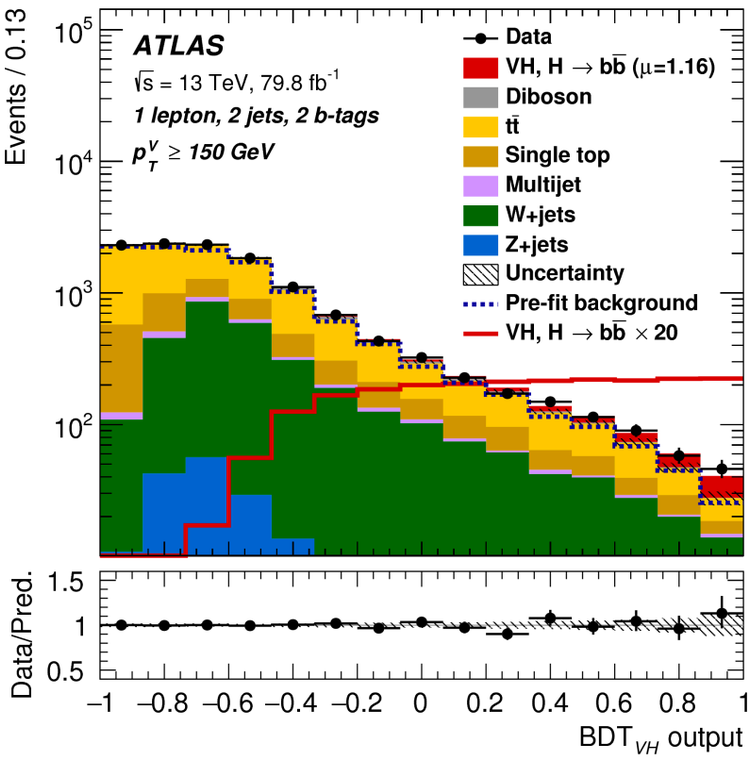




| Variable | 0-lepton | 1-lepton | 2-lepton |
|---|---|---|---|
| $p_{\mathrm{T}}^{V}$ | $\equiv E_{\mathrm{T}}^{\mathrm{miss}}$ | × | × |
| $E_{\mathrm{T}}^{\mathrm{miss}}$ | × | × | |
| $p_{\mathrm{T}}^{b_1}$ | × | × | × |
| $p_{\mathrm{T}}^{b_2}$ | × | × | × |
| $m_{bb}$ | × | × | × |
| $\Delta R(\vec{b_1},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

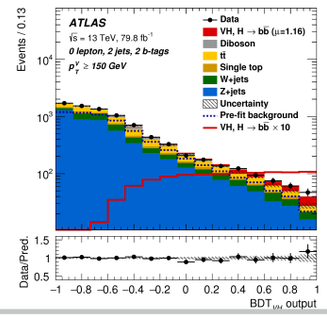
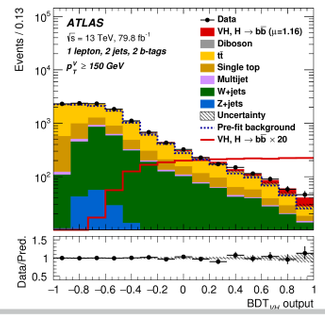
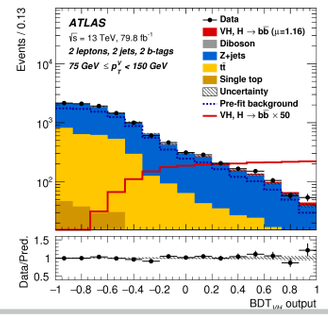
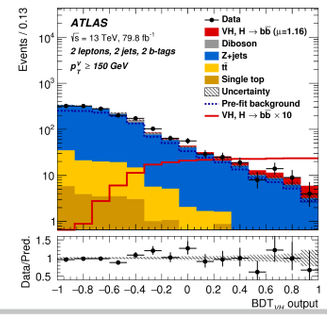
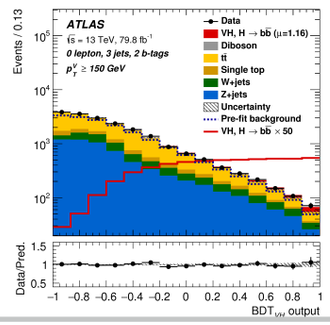
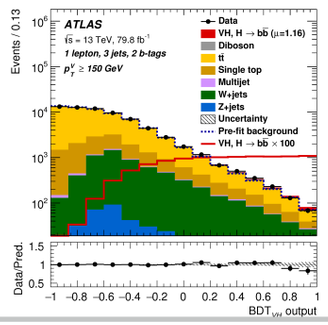
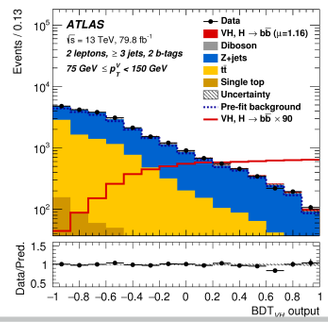
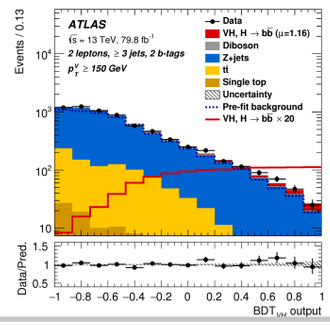
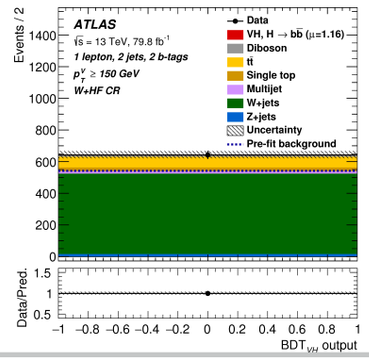
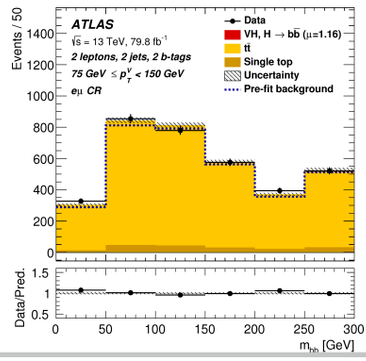
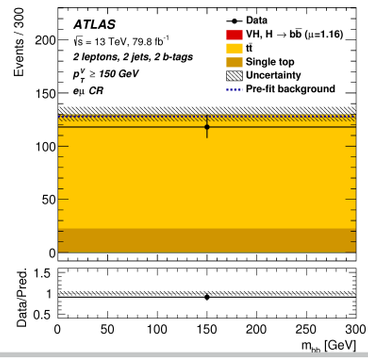
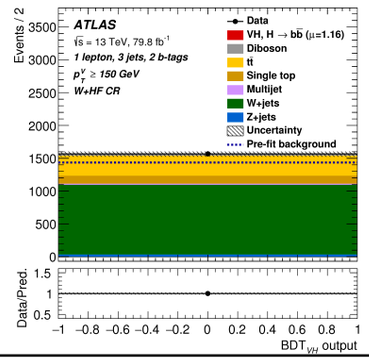
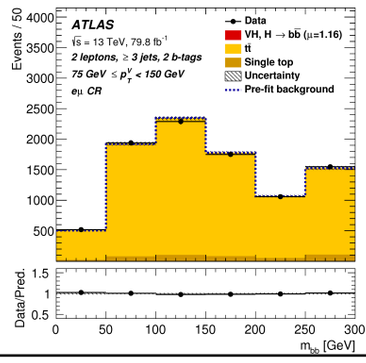
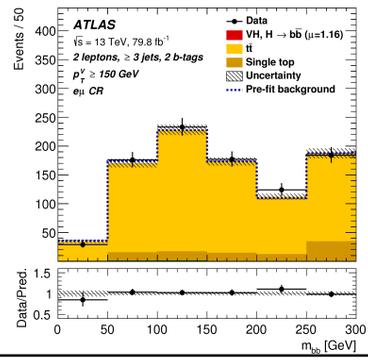
Loose selection and BDT as final discriminant

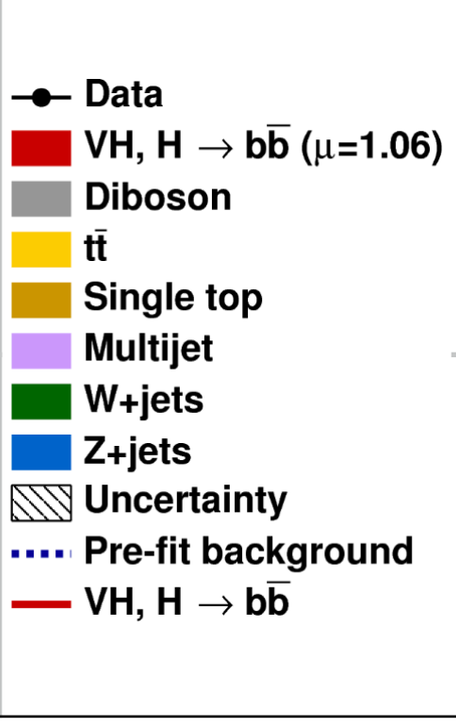



BDT output



# All the regions

| | 0-lepton<br>$p_T(Z)>150$ GeV | 1-lepton<br>$p_T(W)>150$ GeV | 2-lepton<br>$75<p_T(Z)<150$ GeV | 2-lepton<br>$p_T(Z)>150$ GeV |
|---|---|---|---|---|
| SR 2-jets |  |  |  |  |
| SR 3-jets |  |  |  |  |
| CR 2-jets |  |  |  | |
| CR 3-jets |  |  |  | |



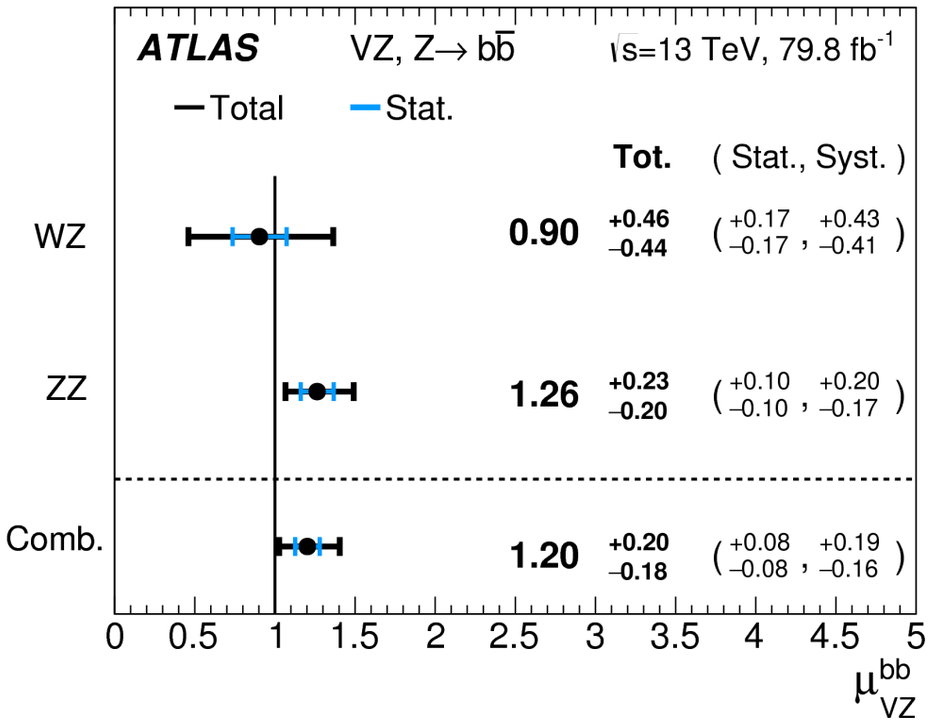
# Systematics

| Source of uncertainty | | $\sigma_\mu$ |
|---|---|---|
| Total | | 0.259 |
| Statistical | | 0.161 |
| Systematic | | 0.203 |
| Experimental uncertainties | | |
| Jets | | 0.035 |
| $E_{\mathrm{T}}^{\mathrm{miss}}$ | | 0.014 |
| Leptons | | 0.009 |
| $b$-tagging | $b$-jets | 0.061 |
| | $c$-jets | 0.042 |
| | light-flavour 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 |
| Multi-jet | | 0.005 |
| MC statistical | | 0.070 |

Analysis dominated by systematic uncertainties

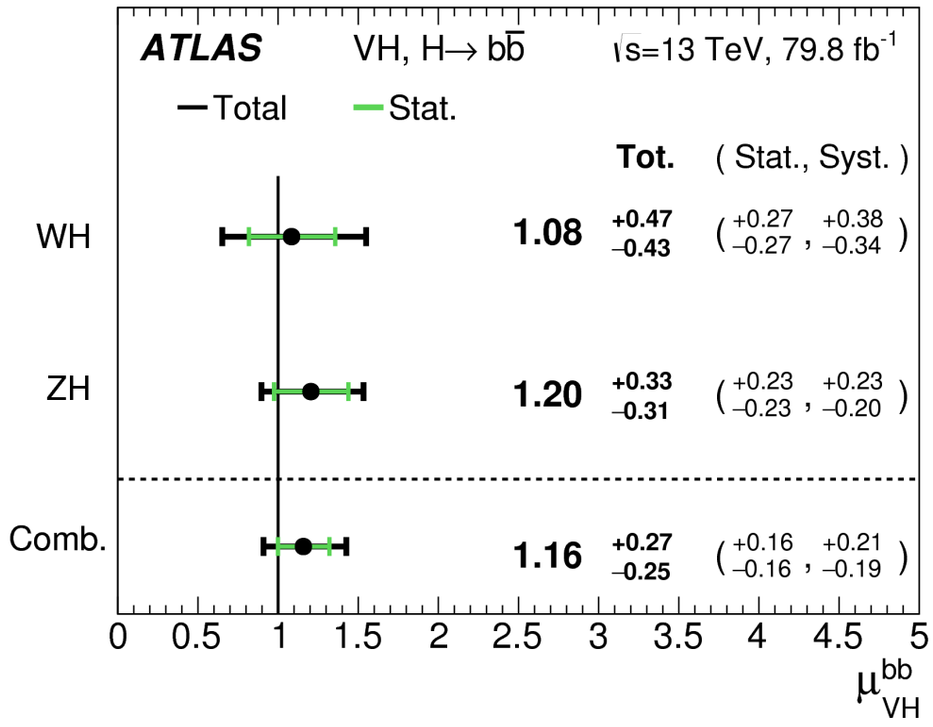
- b-tagging both b and c jet tagging calibration
- Background modelling Z+hf, W+hf, tt
- Mainly shape and extrapolation uncertainties
- Signal modelling little impact on significance
- MC stats

# Results




VZ(bb) Cross Check

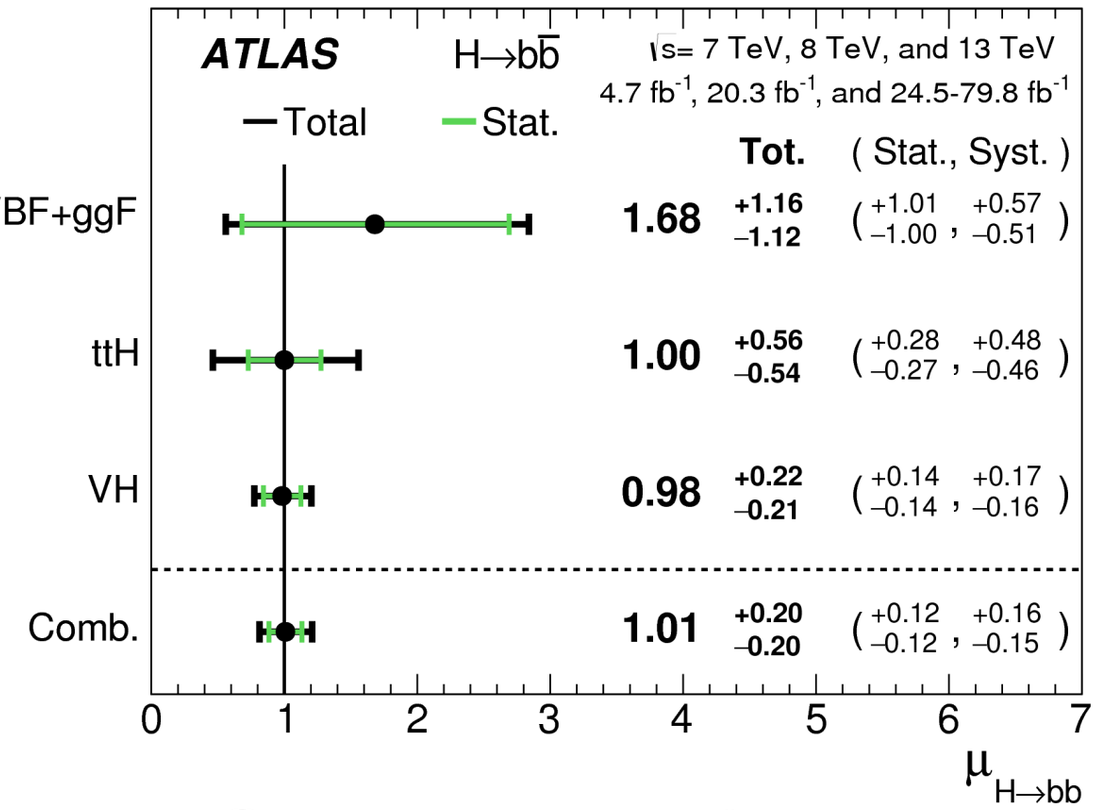
Well under control




Significance of VH(bb)
4.9σ (4.3σ exp.)

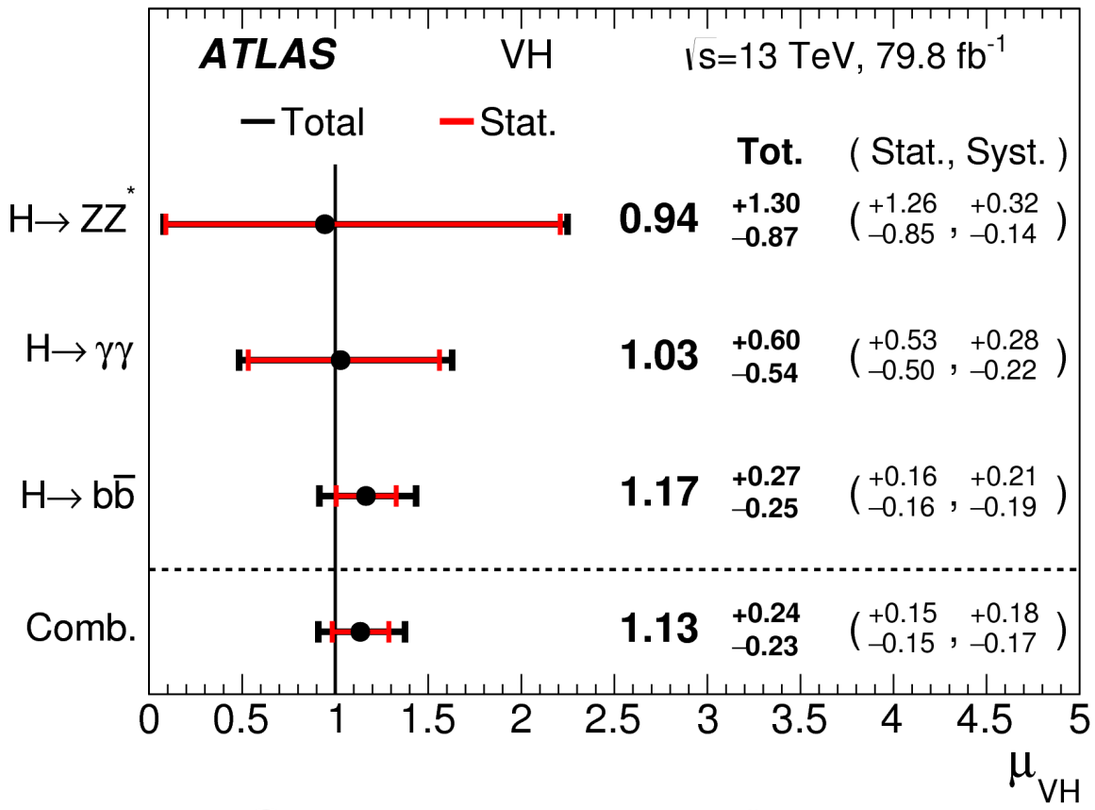
WH: 2.5σ (2.3σ exp.)
ZH: 4.0σ (3.5σ exp.)

# Combinazioni




Observation of Hbb
5.4σ (5.5σ exp.)

VBF 1.5σ
ttH 1.9σ
Compatibility 54%




Observation of VH
5.3σ (4.8σ exp.)

H->4l 1.1σ
H->γγ 1.9σ
Compatibility 96%

# (real) List of ingredients

- MC filters/request
- Derivations
- CxAOD framework
- CP b-tagging
- CP Jets
- Analysis selection
- MVA
- Truth framework
- Modelling studies
- Productions of inputs for the fits
- Fit framework
- Fit studies