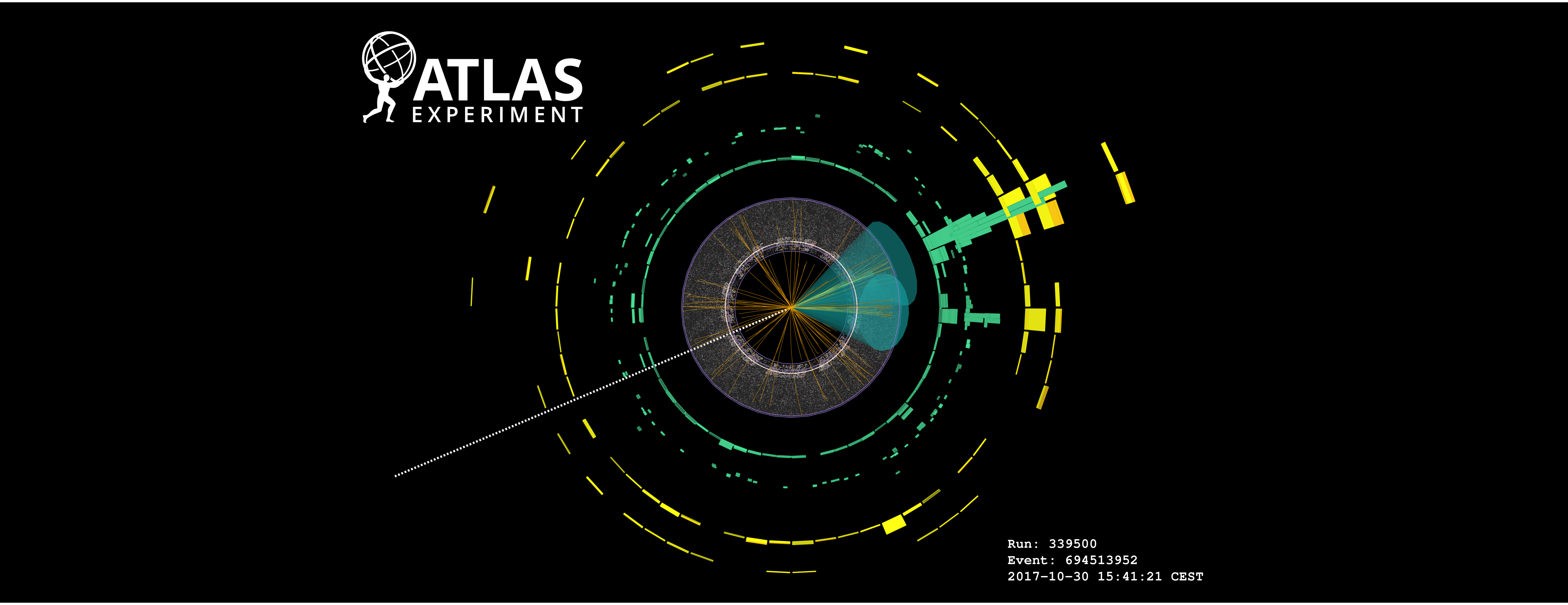
Observation of H→bb decays in the VH production mode and first differential measurement with the ATLAS detector



IOP HEPP

8th-10th April 2019
Imperial College London

Luca Ambroz - University of Oxford

Outline

- Observation of $H \rightarrow bb$ decays with the ATLAS detector

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- Measurement of the $VH \rightarrow bb$ production as a function of the vector-boson transfer momentum with the ATLAS detector

  ATLAS-CONF-2018-053

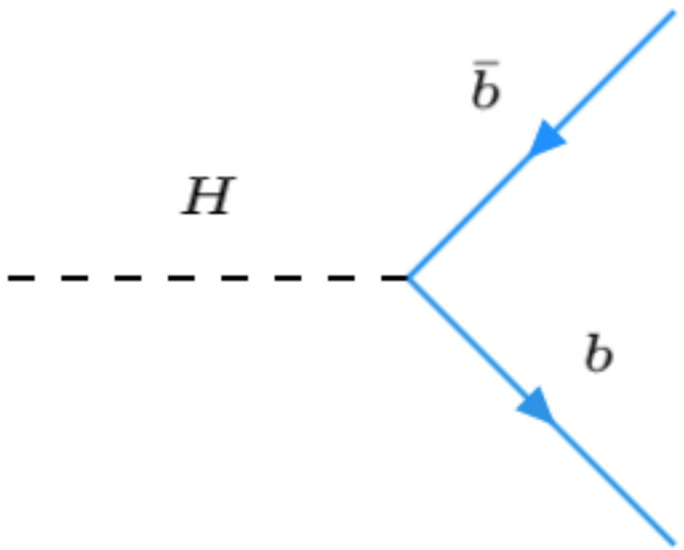
UK involvement

- Queen Mary University of London
- Royal Halloway University of London
- University College London (UCL)
- University of Birmingham
- University of Glasgow
- University of Liverpool
- University of Manchester
- University of Oxford

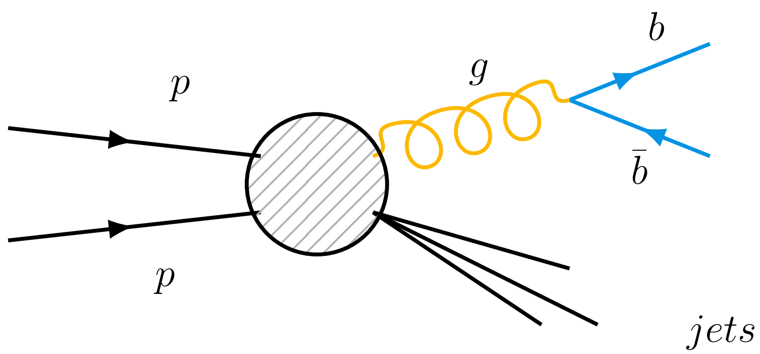
Observation of H→bb decays with the ATLAS detector

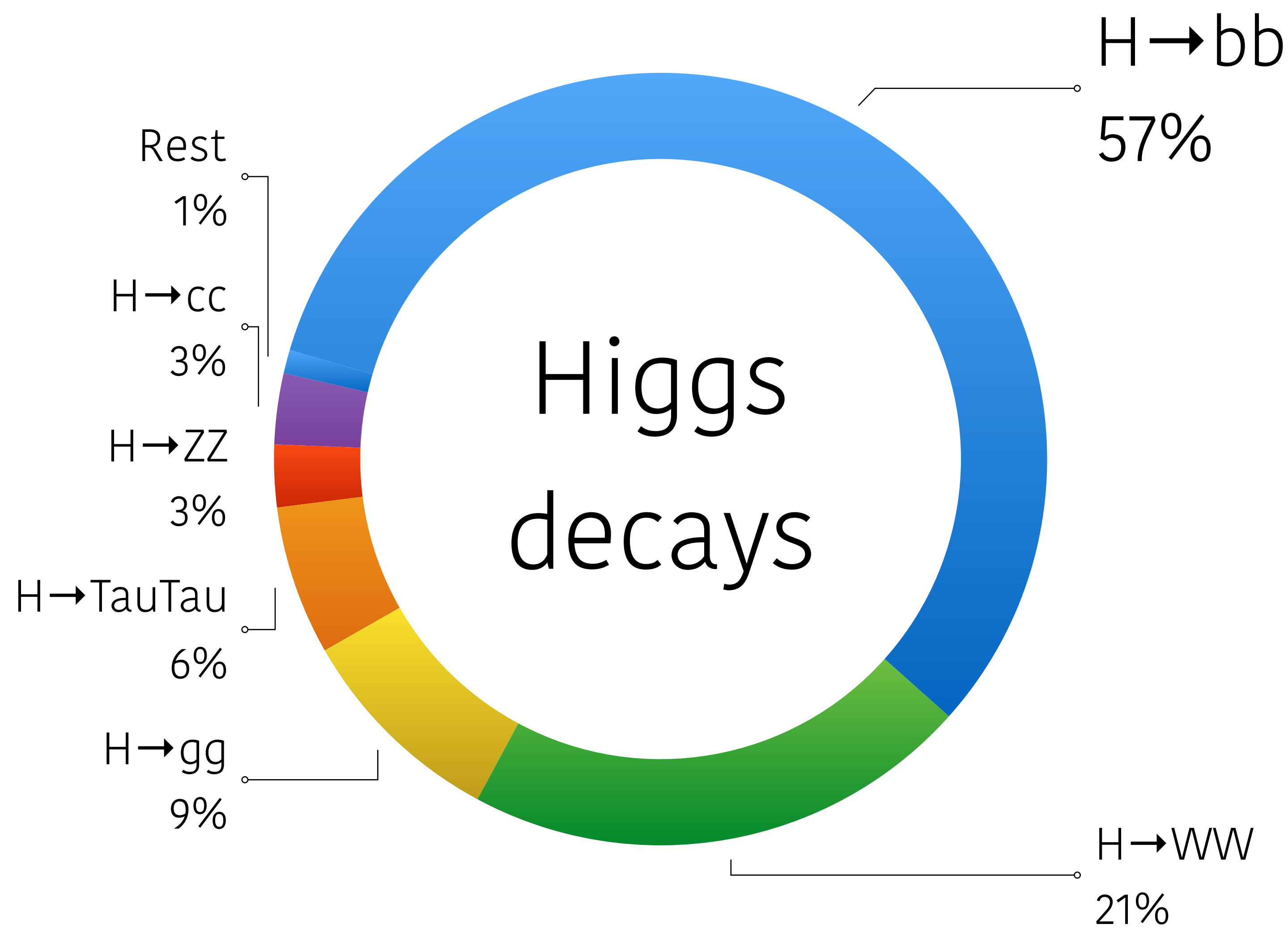
H→bb

- ***Motivations***:
  - *largest Branching Ratio;*
  - *driving uncertainty for the total Higgs boson width;*
  - *measurement of the Yukawa Coupling to down type quarks.*

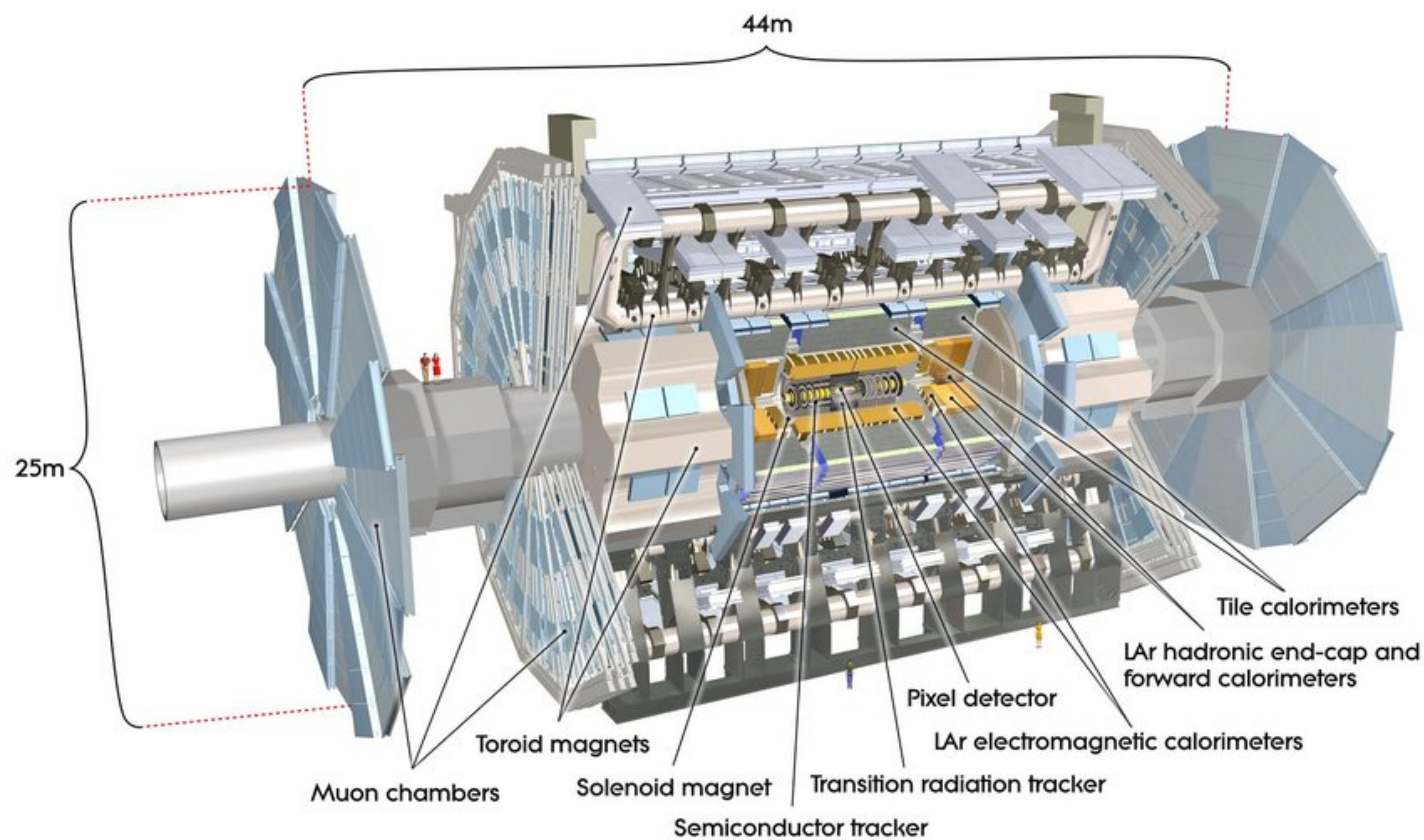


- ***Main challenge***:
  - *large QCD background.*





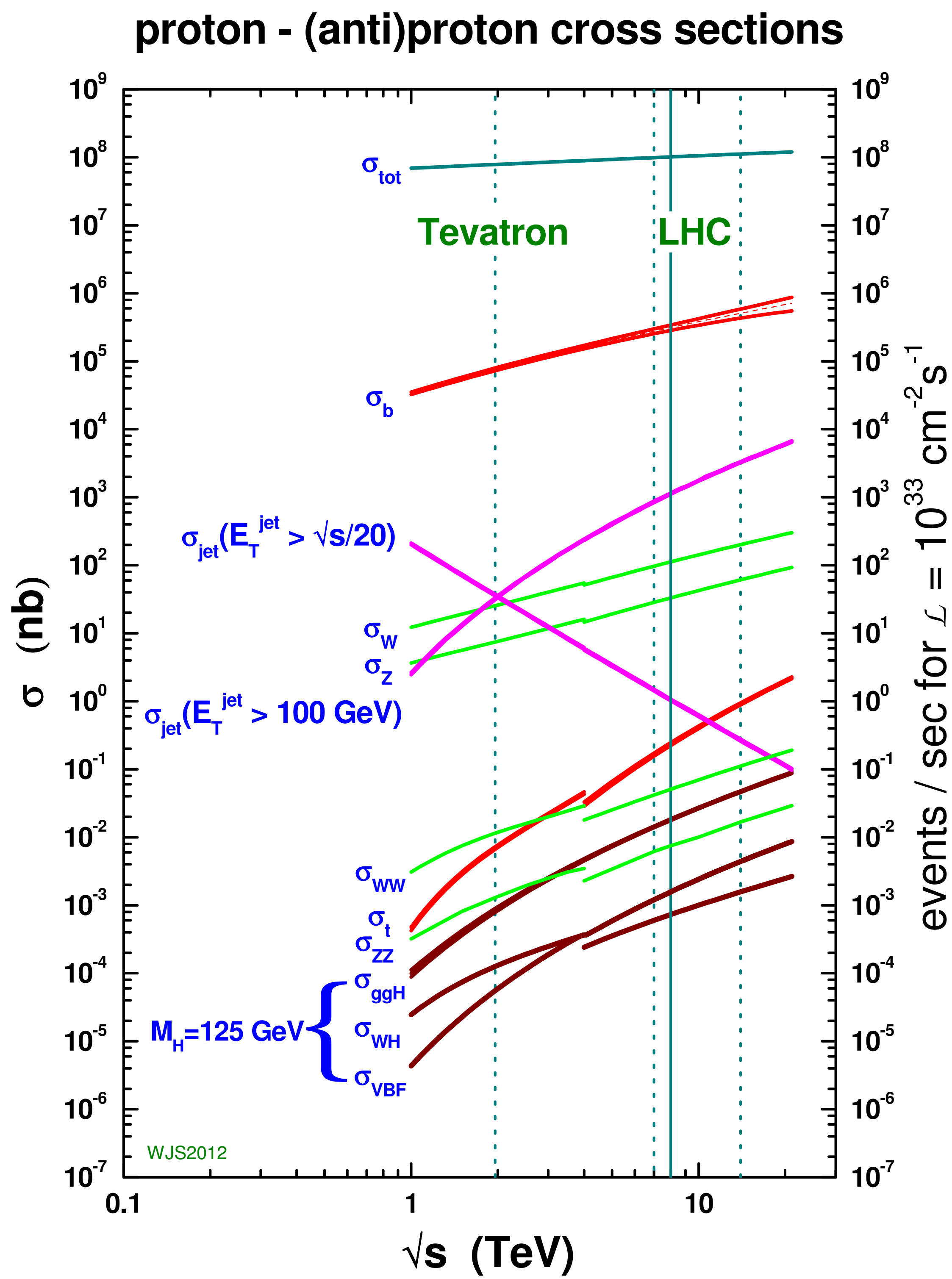
ATLAS detector



Few key ingredients for searching for H→bb:

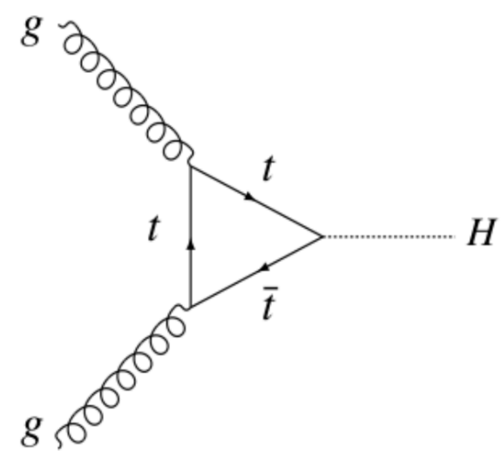
- high **b-tagging efficiency** from the tracker;
- good **energy resolution** from the calorimeters.

Higgs production at the LHC



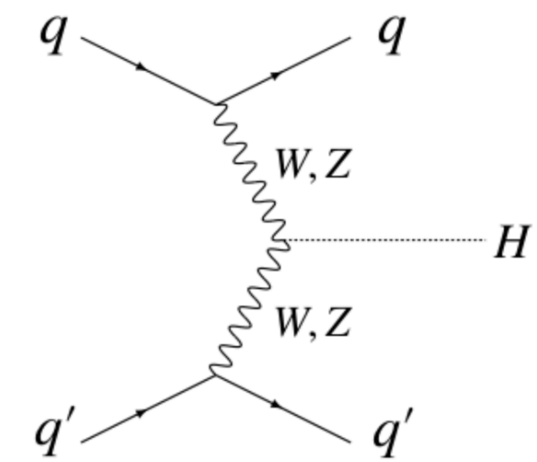
Source: W.J. Stirling

Gluon fusion (88%)



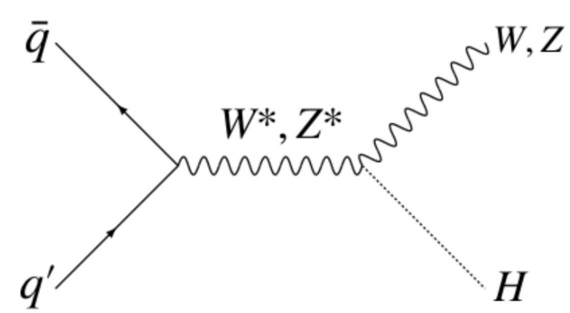
Only for the boosted regime.

Vector boson fusion (7%)



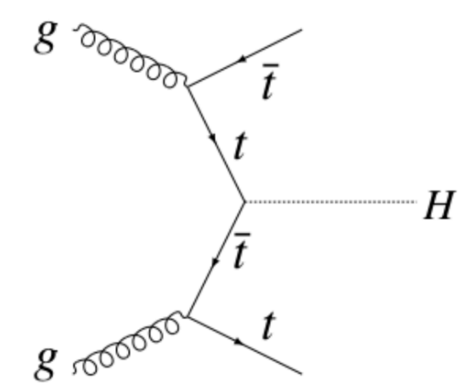
Searched with an associated γ.

Associate production with a vector boson (3%)



Most sensitive production H→bb.

Associate production with a top pair (1%)

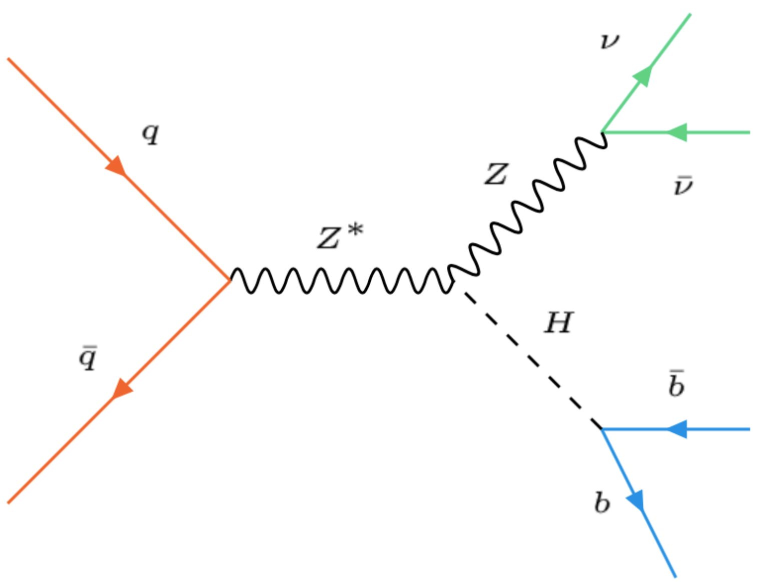


Small cross-section.

Search for VH→bb

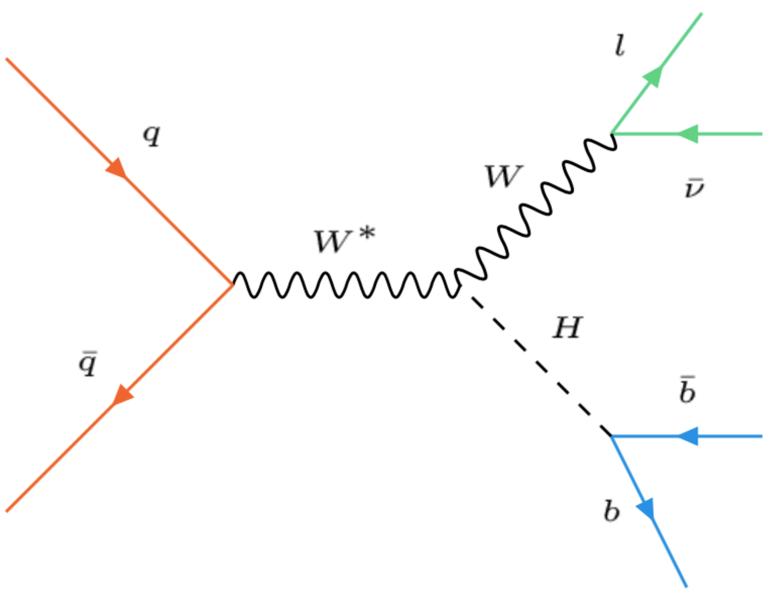
- 2 b-jets per event.
- *0 or 1 more additional jet (in the 2-lepton channel also 2 or more).*
- *3 decay channels according to the number of charged leptons (0, 1, 2).*

0-Lepton



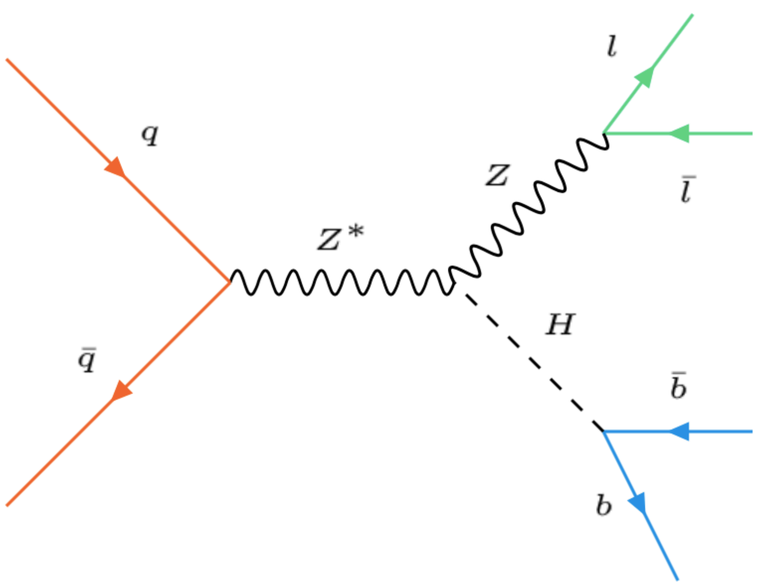
- Target: mainly Z→νν but also W→lν
- E_T^{miss} trigger
- Lepton veto
- Reconstructed E_T^{miss} > 150 GeV.

1-Lepton



- Target: mainly W→lν
- Lepton or E_T^{miss} trigger
- p_T^{Lep}> 25 (27) GeV for μ (e)
- p_T^{W}> 150 GeV

2-Lepton



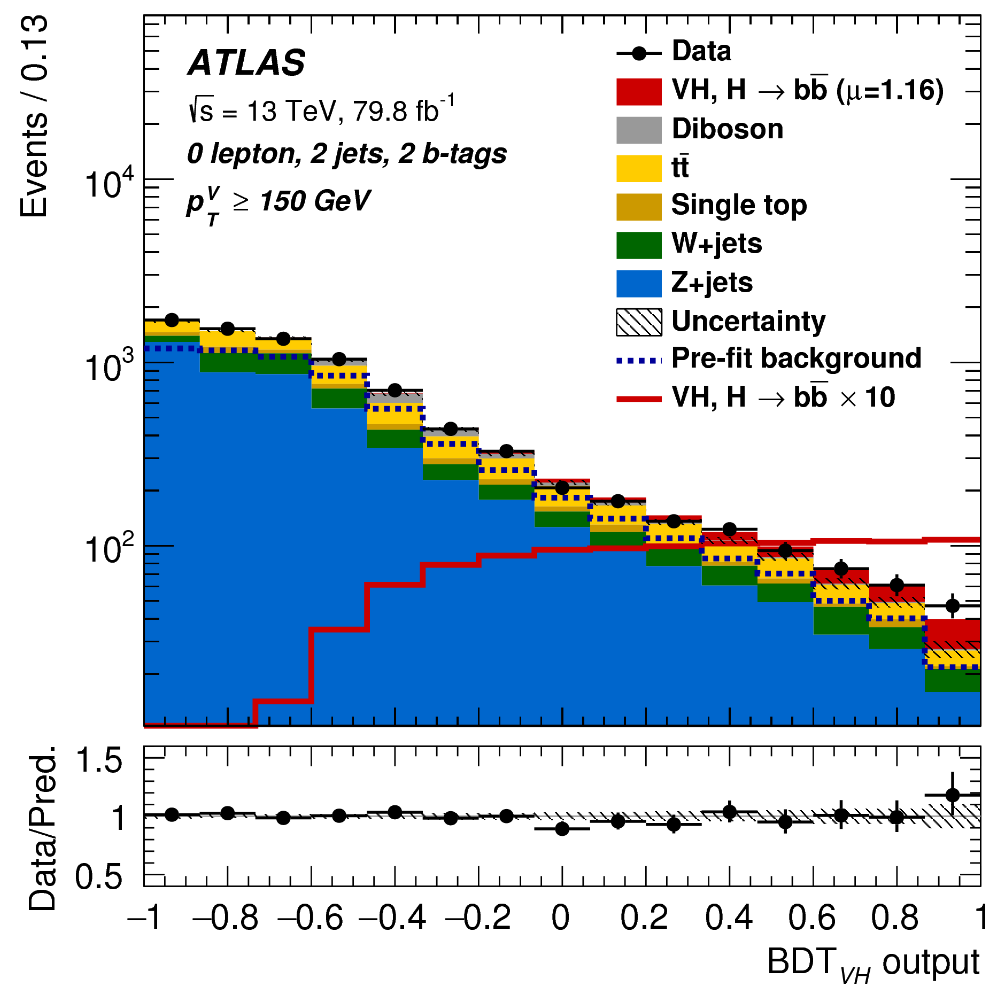
- Target: mainly Z→ll
- Single lepton triggers
- 2 lep same flav opposite charge
- p_T^{Z}> 150 GeV

Multivariate analysis

Several discriminating variables (m_{bb}, dR_{bb}, p_T^V) to discriminate between signal and background:

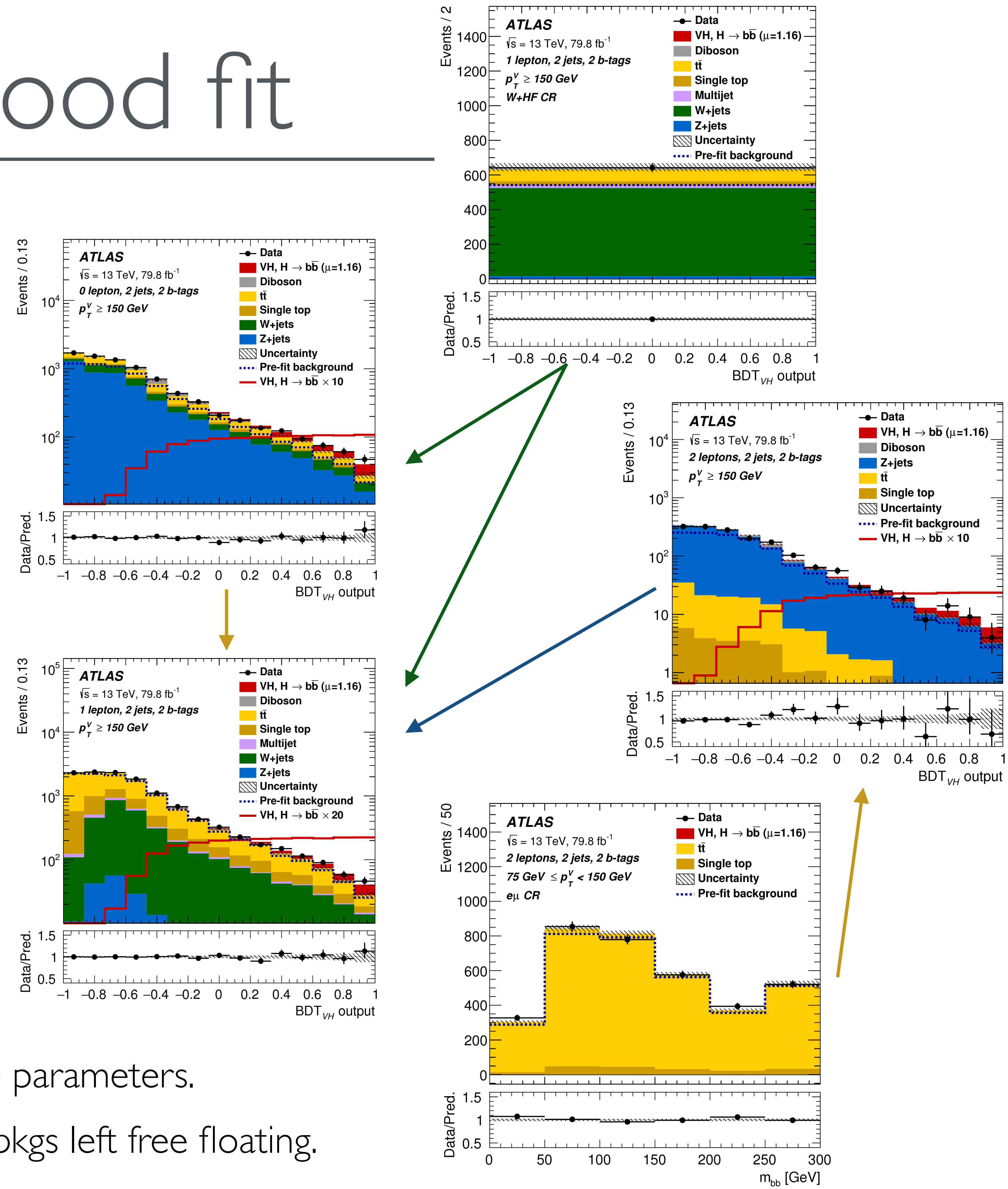
1. construct a BDT to improve sensitivity;
2. perform separate training for each signal region;
3. transform BDT output to optimise signal sensitivity;
4. use a binned maximum likelihood fit to extract the signal strength (μ).

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



Profile likelihood fit

- Simultaneous fit of 14 analysis regions:
  - 8 signal regions across the three lepton channels.
  - 4 top control regions.
  - 2 W + Heavy Flavours control regions.
  - In 0 lepton channel Z + Heavy Flavours estimated from the 2 lepton channel.



- Systematics described by nuisance parameters.
- Normalisation of signal and main bkgs left free floating.

VH→bb results

- Measured signal strength (μ) for VH→bb with 80fb^{-1} of data:

$$\mu_{VH}^{b\bar{b}} = \frac{\sigma_{obs}}{\sigma_{SM}} = 1.16^{+0.27}_{-0.25}$$

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- Observed significance 4.9σ (expected 4.3σ).

- Contributions for the individual lepton channels:

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

Systematic uncertainties

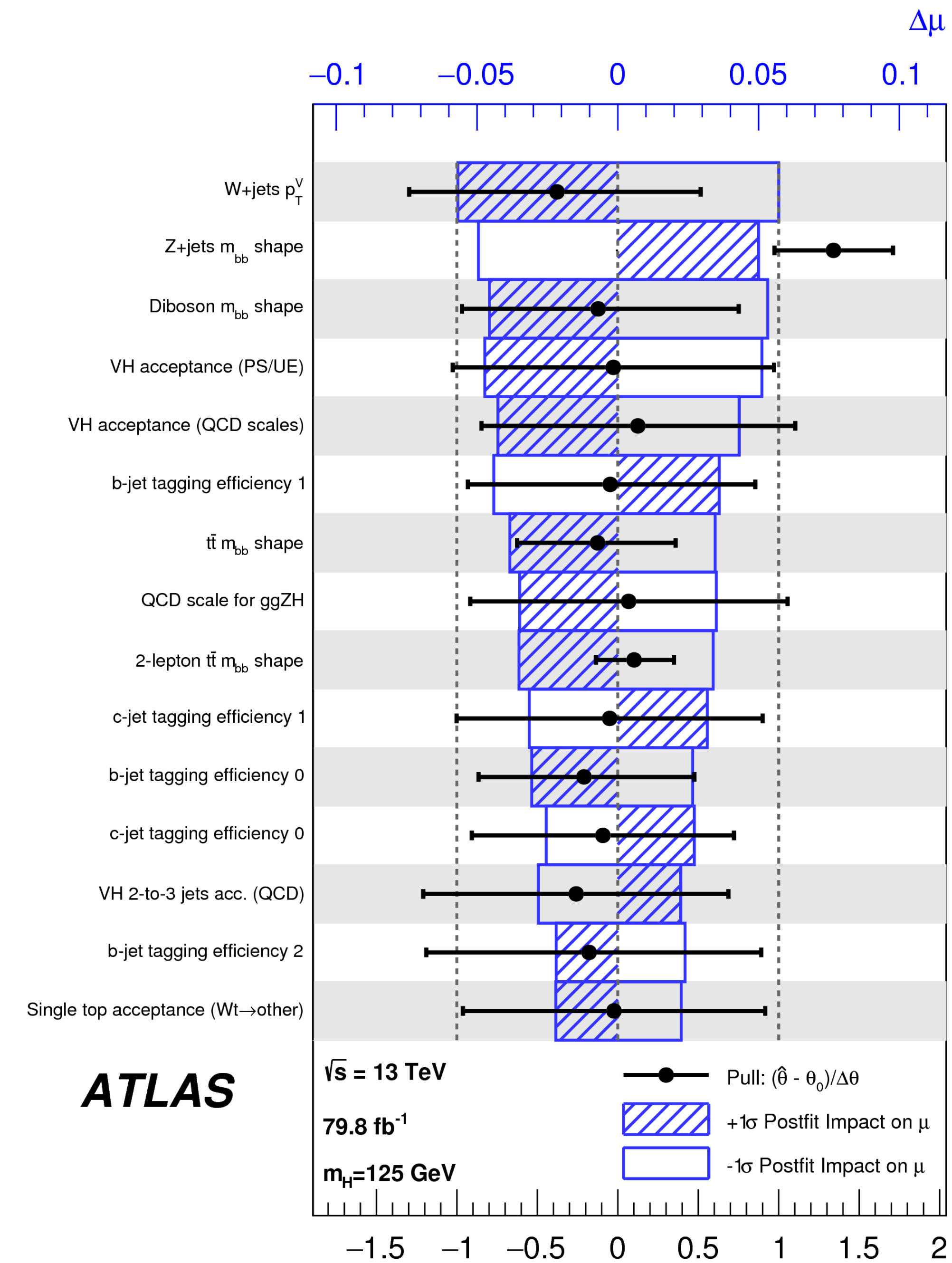
Flavour-tagging calibrations

Signal and Background modelling

Limited MC statistics

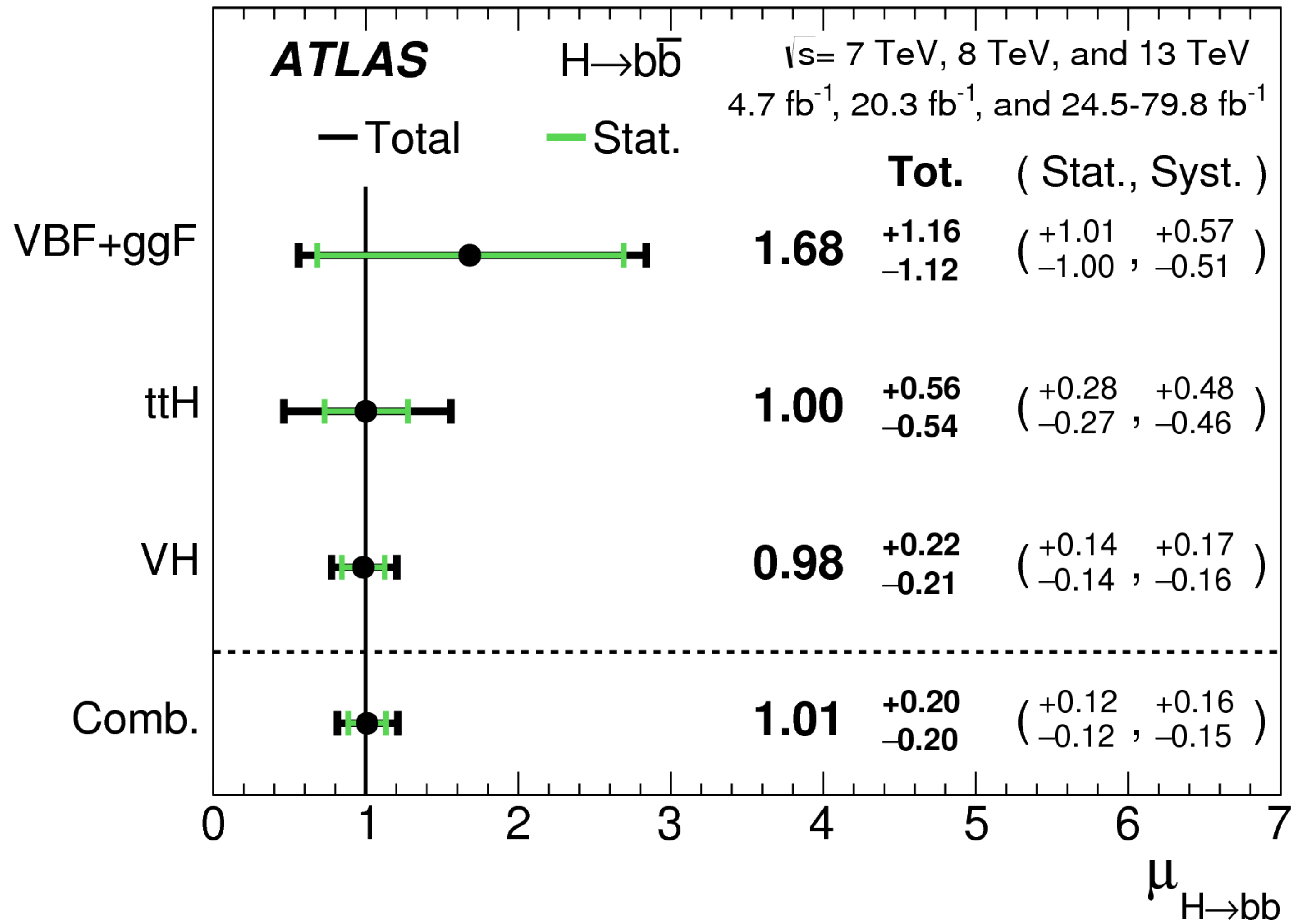
Source of uncertainty		σ_μ
Total		0.259
Statistical		0.161
Systematic		0.203
Experimental uncertainties		
Jets		0.035
$E_{\mathrm{T}}^{\mathrm{miss}}$		0.014
Leptons		0.009
b-tagging	b-jets	0.061
	c-jets	0.042
	light-flavour jets	0.009
	extrapolation	0.008
Pile-up		0.007
Luminosity		0.023
Theoretical 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 limited by **systematic uncertainties**



H→bb combination

- The VH, VBF and ttH analysis of Run-1 and Run-2 have beed combined:

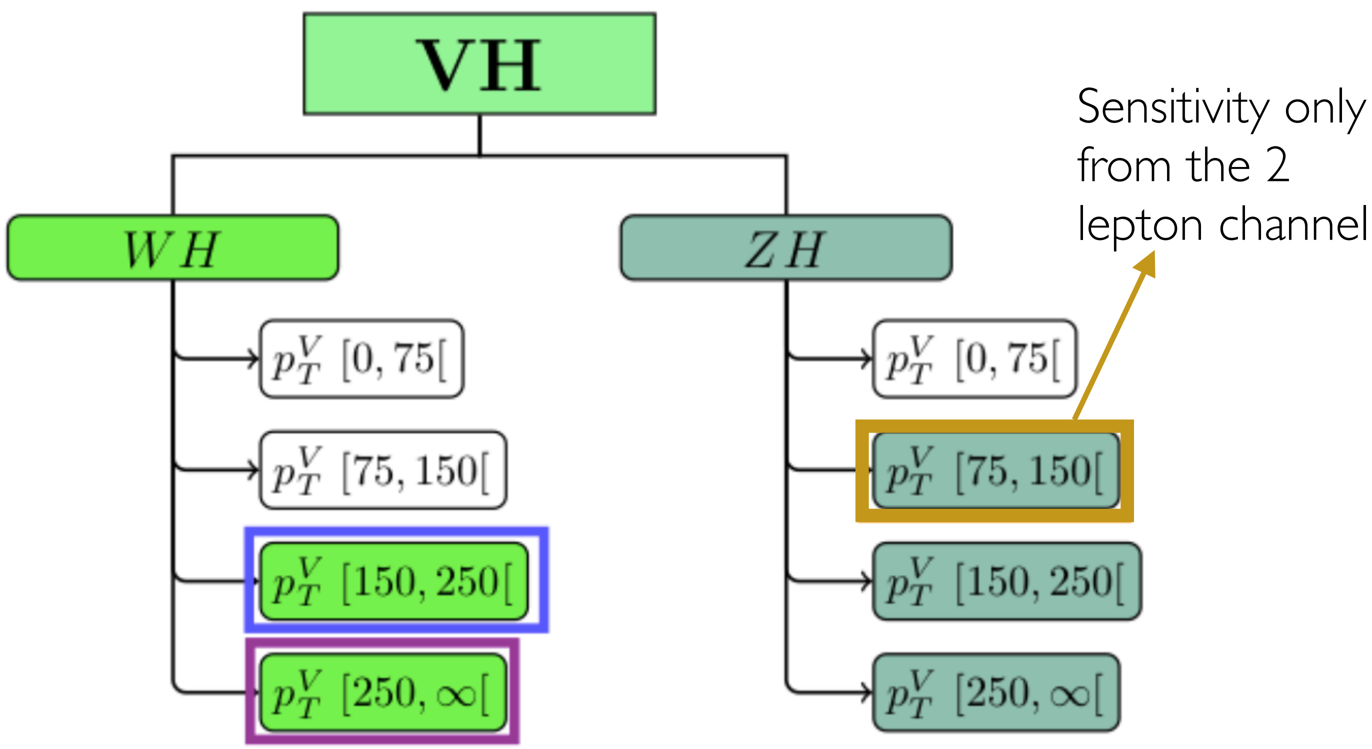


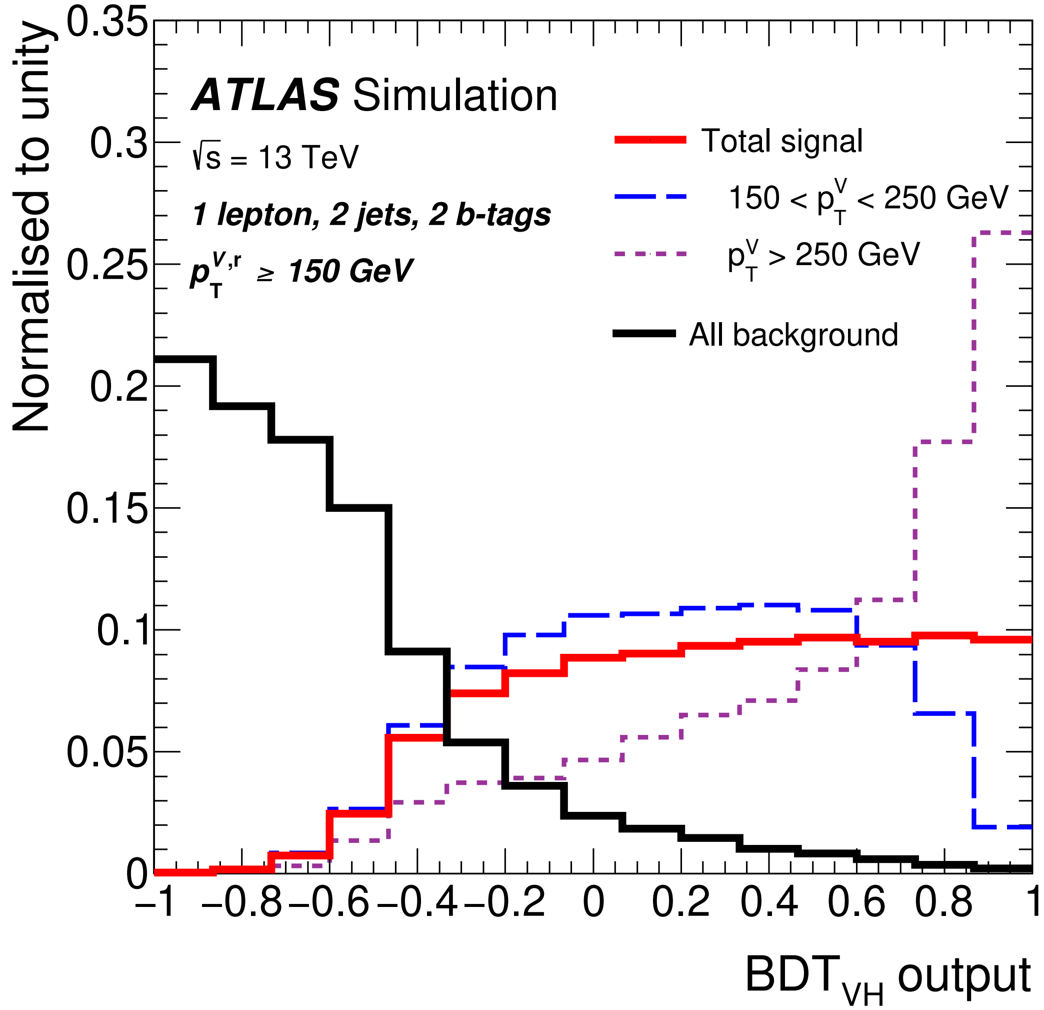
- The result is the **observation** of H→bb decays at 5.4σ (5.5σ expected).

Measurement of the VH→bb production as a function of the vector-boson transfer momentum

VH→bb differential measurement

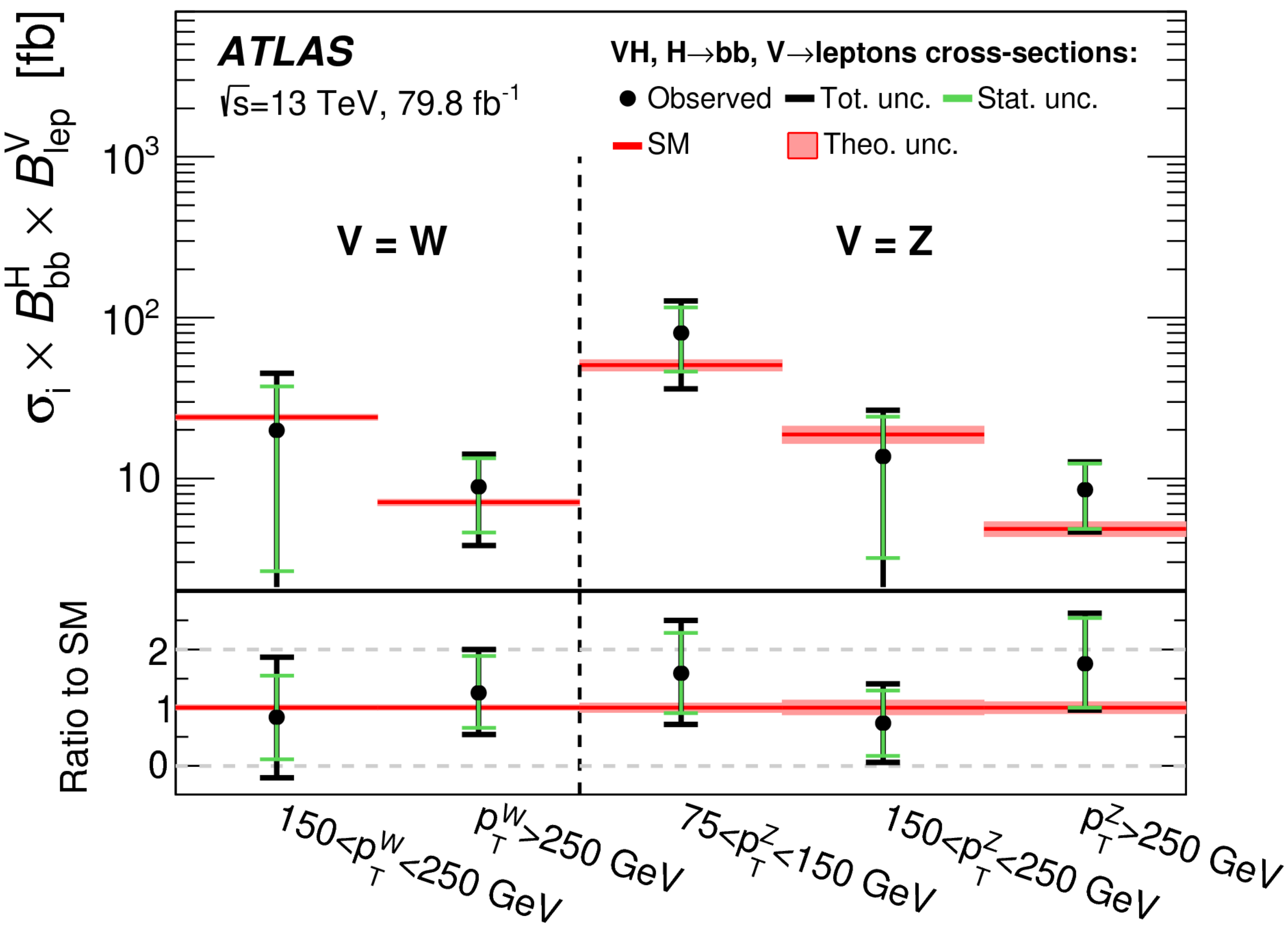
- Definition of five **fiducial differential cross section regions** (STXS framework) according to p_T of the W/Z boson:





- Analysis strategy kept the same as the "observation analysis" (event selection, MVA training..)
- New assessment of signal systematics.
- p_T^V regions potentially sensitive to **BSM** physics.

Measured cross-sections



Results compatible with the Standard Model

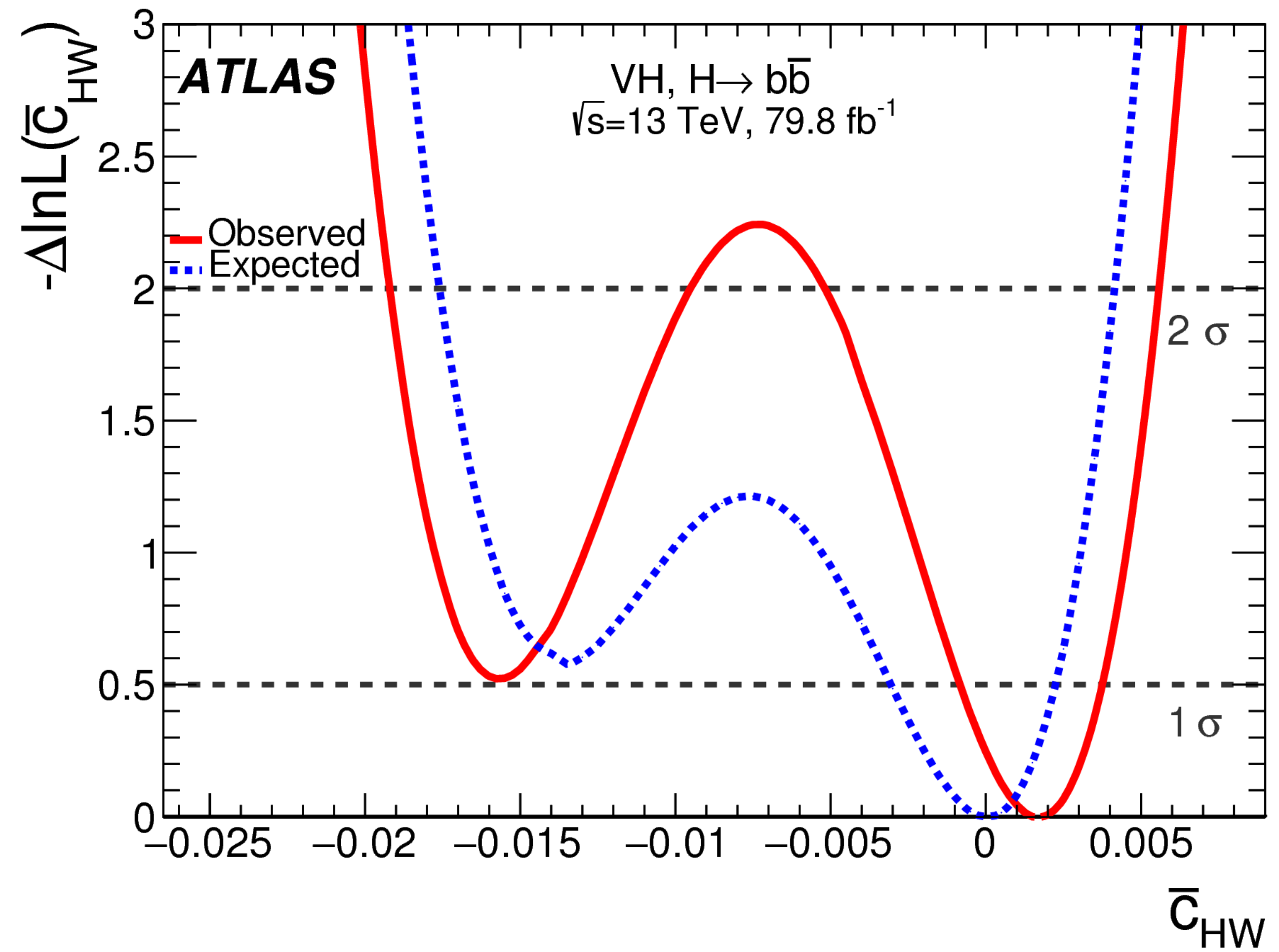
Effective Field Theories

- The SM Lagrangian can be expanded with and Effective Field Theory parametrisation:

$$\mathcal{L}_{EFT} = \mathcal{L}_{SM} + \sum_i c_i^{(6)} \mathcal{O}_i^{(6)} / \Lambda^2$$

- The cross-sections measured are particularly sensitive to these new **coefficients**.

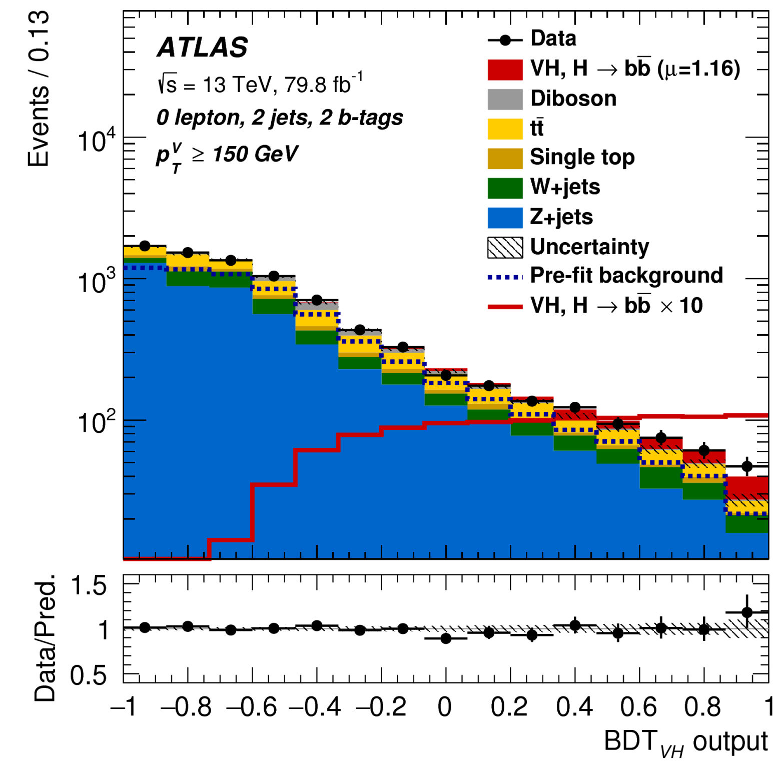
- 1-D fits of the coefficients for the effective Lagrangian have been performed.



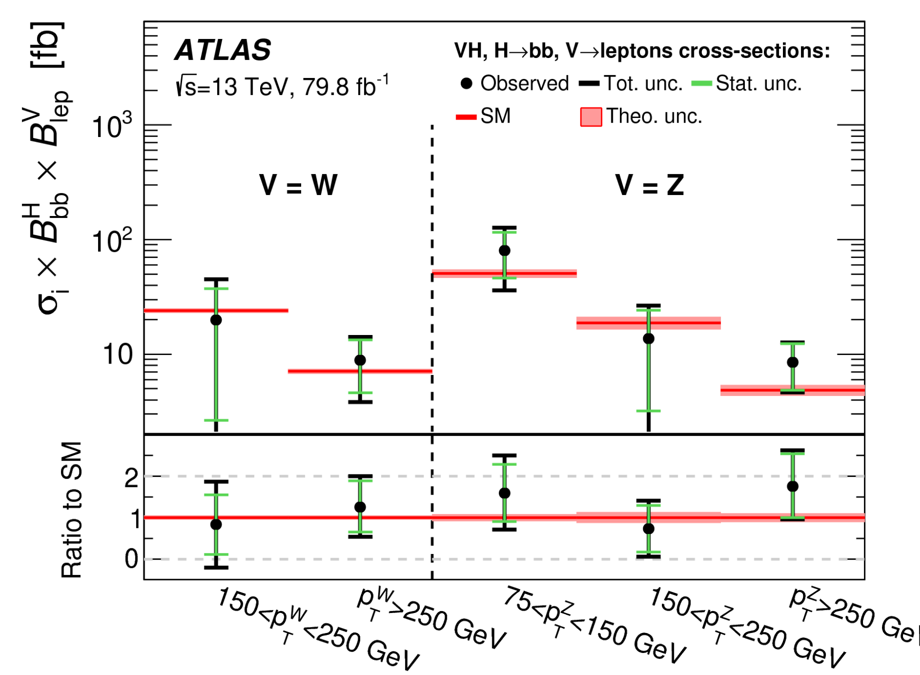
Conclusions

- H→bb decays at 5.4σ (5.5σ expected) have been **observed** with the ATLAS detector:

$$\mu_{VH}^{b\bar{b}} = \frac{\sigma_{obs}}{\sigma_{SM}} = 1.16^{+0.27}_{-0.25}$$



- VH→bb **cross-section measurements** have been performed.



- All the measurements are consistent with the Standard Model.