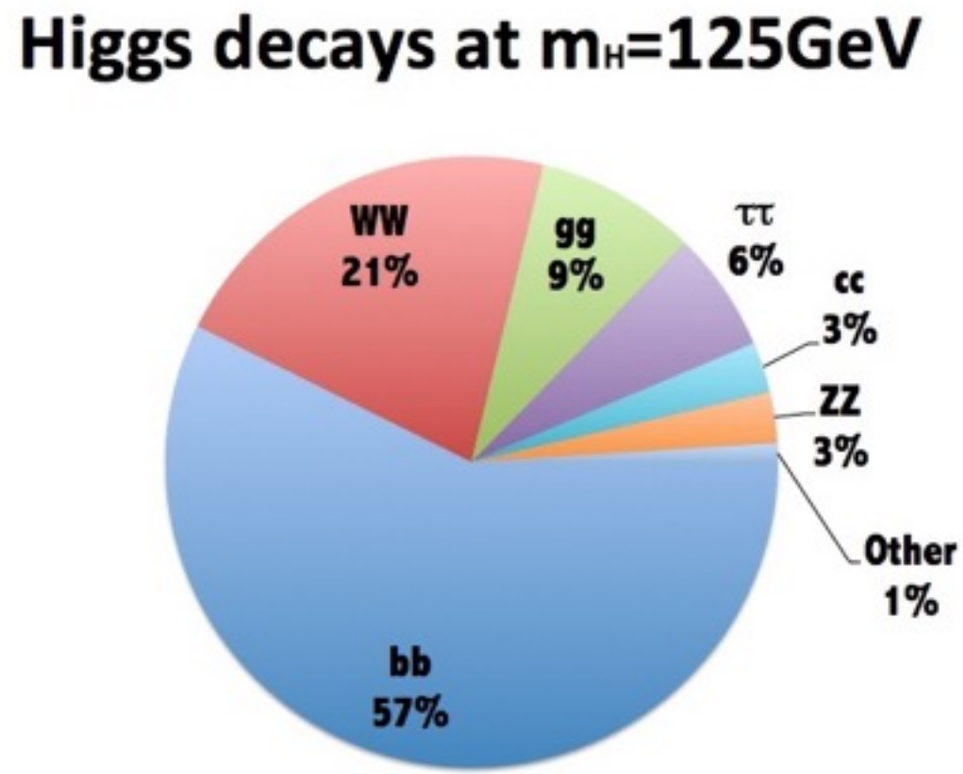
Measurement of SM Higgs boson couplings to bottom and top quarks with the ATLAS detector

Dr. Jose F. Benitez
(University of Iowa, U.S.A.)
on behalf of the ATLAS collaboration

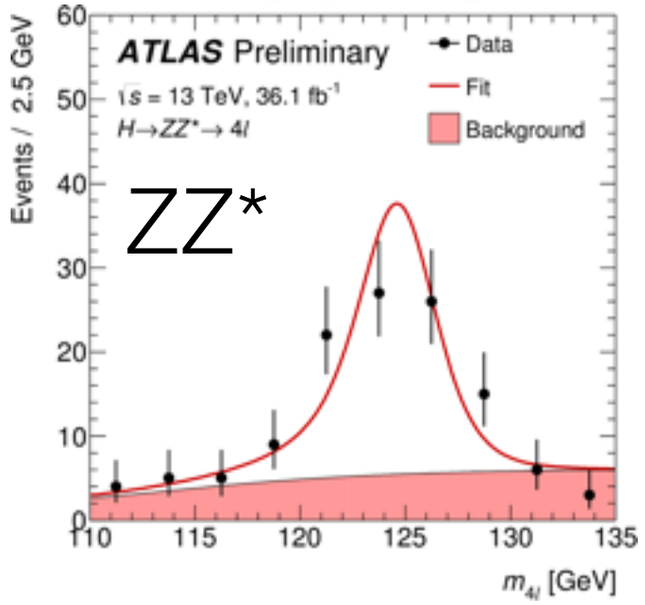
XLVII International Symposium on Multiparticle Dynamics
Tlaxcala, Mexico
September 11-15, 2017

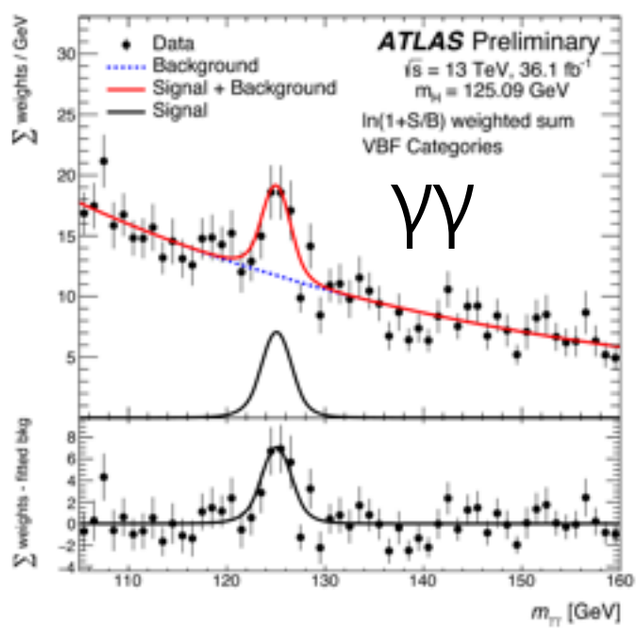
Introduction

- The Higgs boson has been discovered in decays to vector bosons (γγ,ZZ*,WW*).
- **Direct couplings to quarks are not yet observed.**
- The couplings should increase with the mass of the quarks, making the bottom and top couplings the largest.
  - The b-H coupling is measured from VH (V=W,Z) production and H→bb decays
  - The t-H coupling is measured in ttH production combining several decay channels.



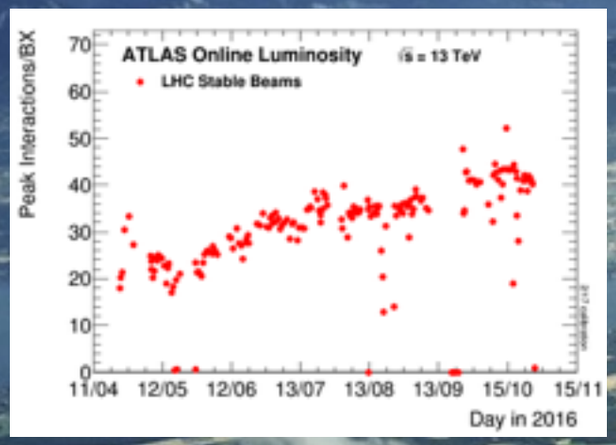
Higgs "golden" channels

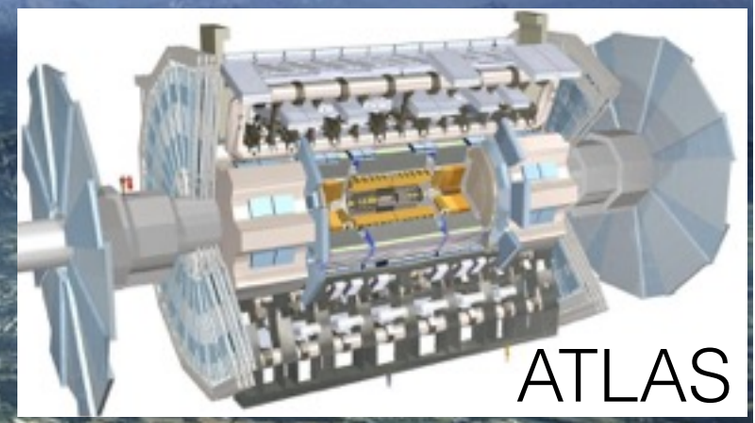


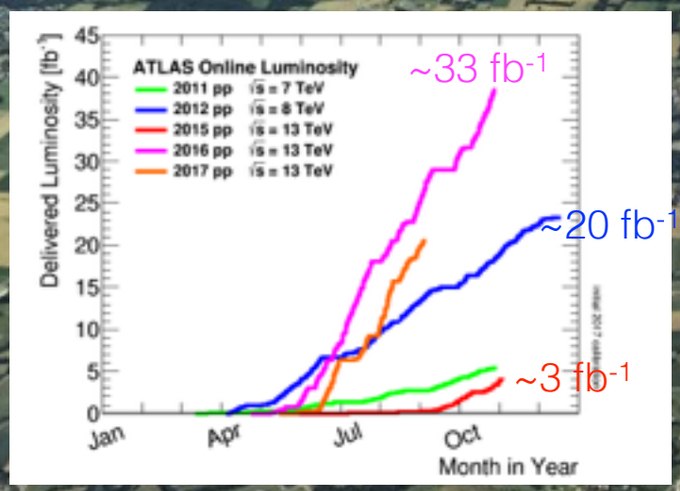


The LHC and ATLAS

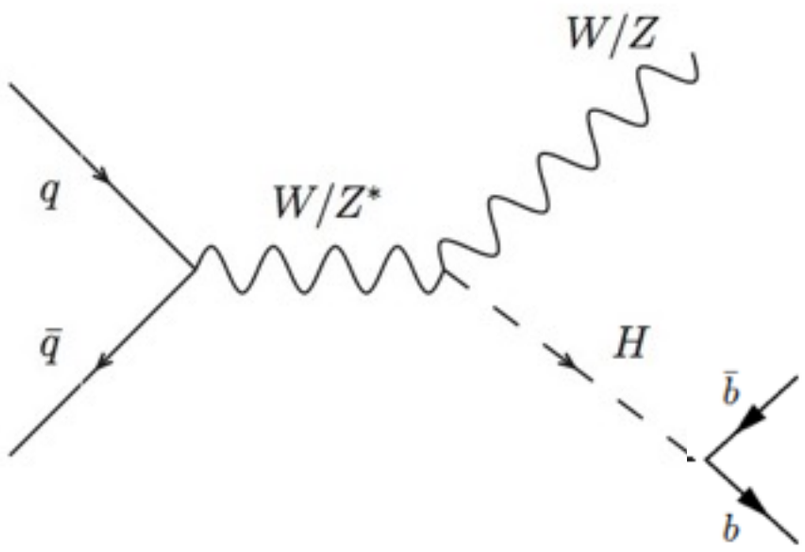
- The LHC Run II started in 2015 with an increased intensity delivering now about 40 proton interactions per bunch crossing. The total delivered luminosity more than doubled the Run I amount.

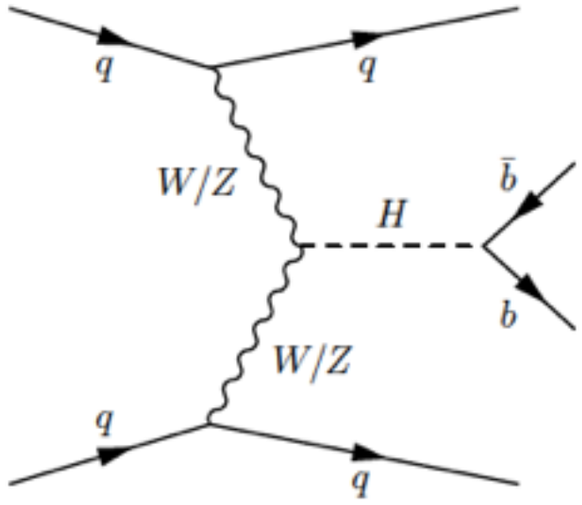


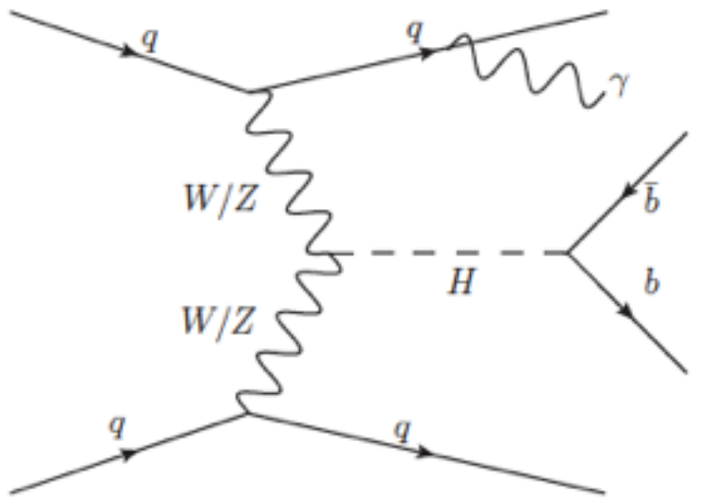




H→bb searches







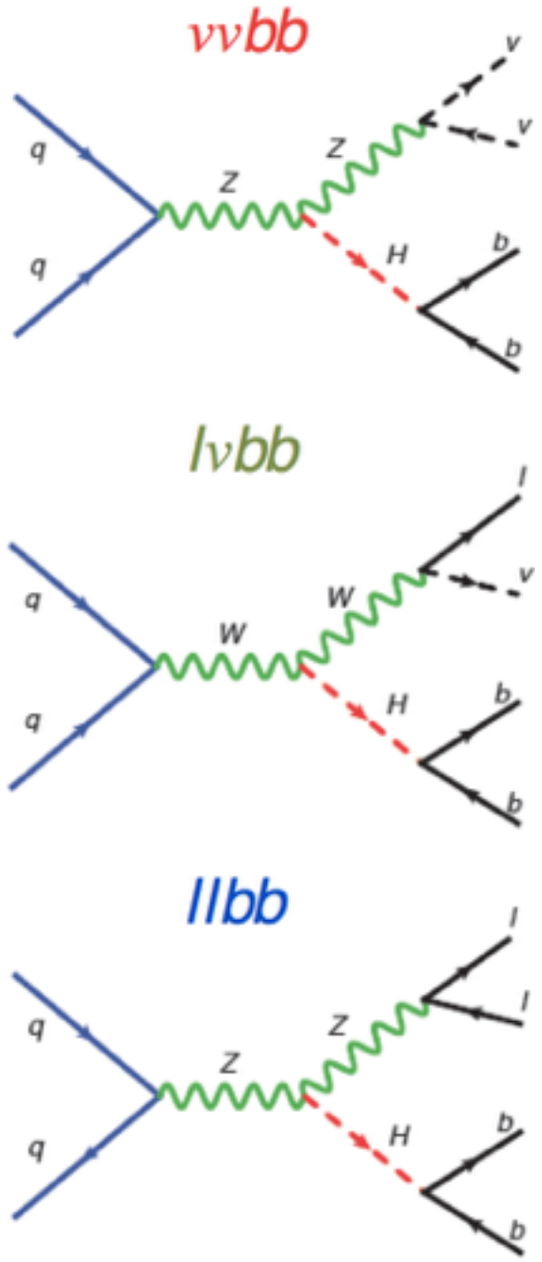
VH(bb) analysis strategy

- This search exploits a clean signature of leptons in the final state: large missing energy ($Z \to \nu\nu$), one isolated lepton ($W \to l\nu$), or two isolated leptons ($Z \to ll$)
- At least two jets with p_T>20 GeV are required in the central region and used for Higgs reconstruction

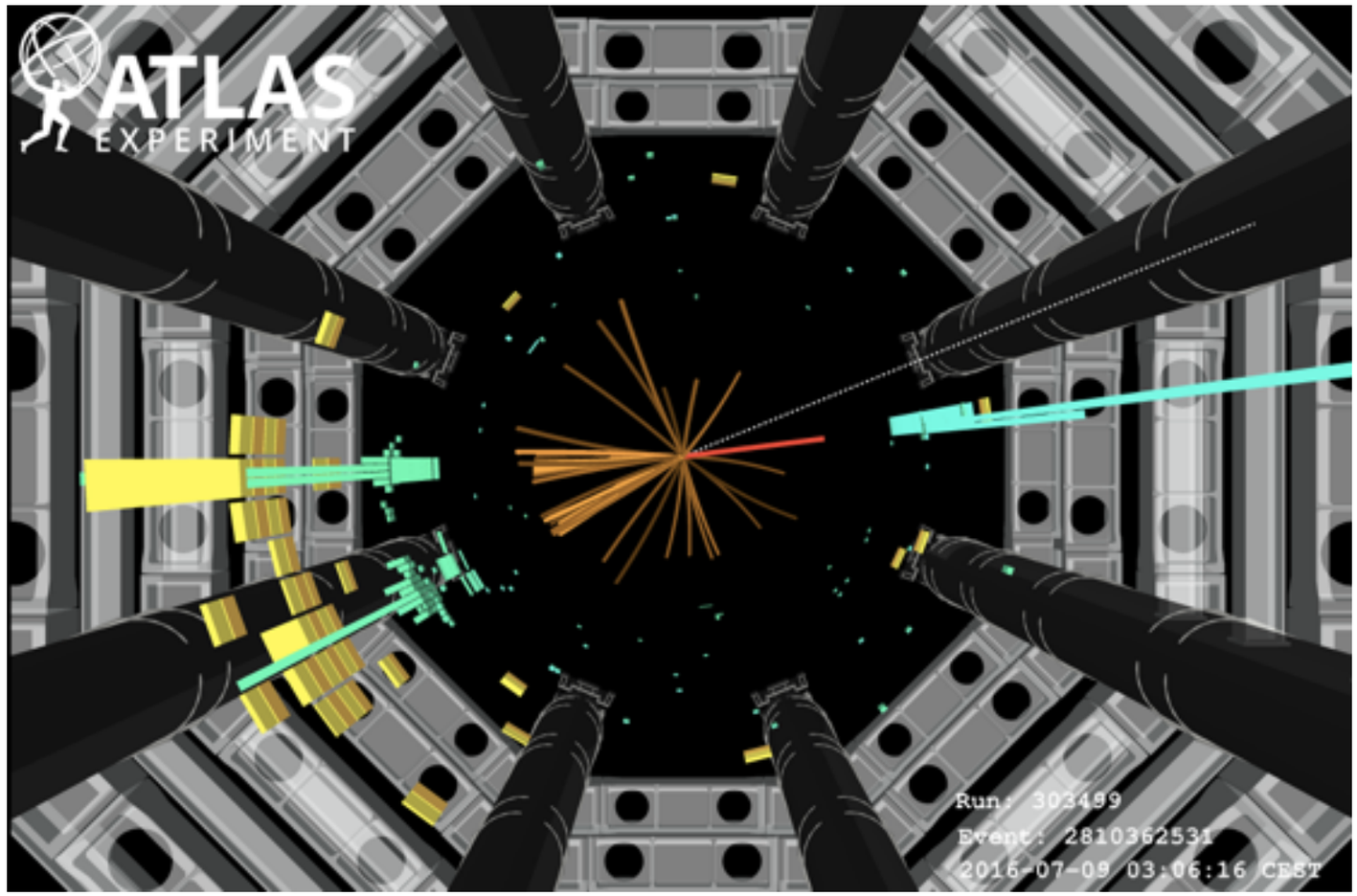
0-lepton channel

1-lepton channel

2-lepton channel



[arXiv:1708:03299]



Event recorded by ATLAS with one isolated electron and two b-tagged jets.

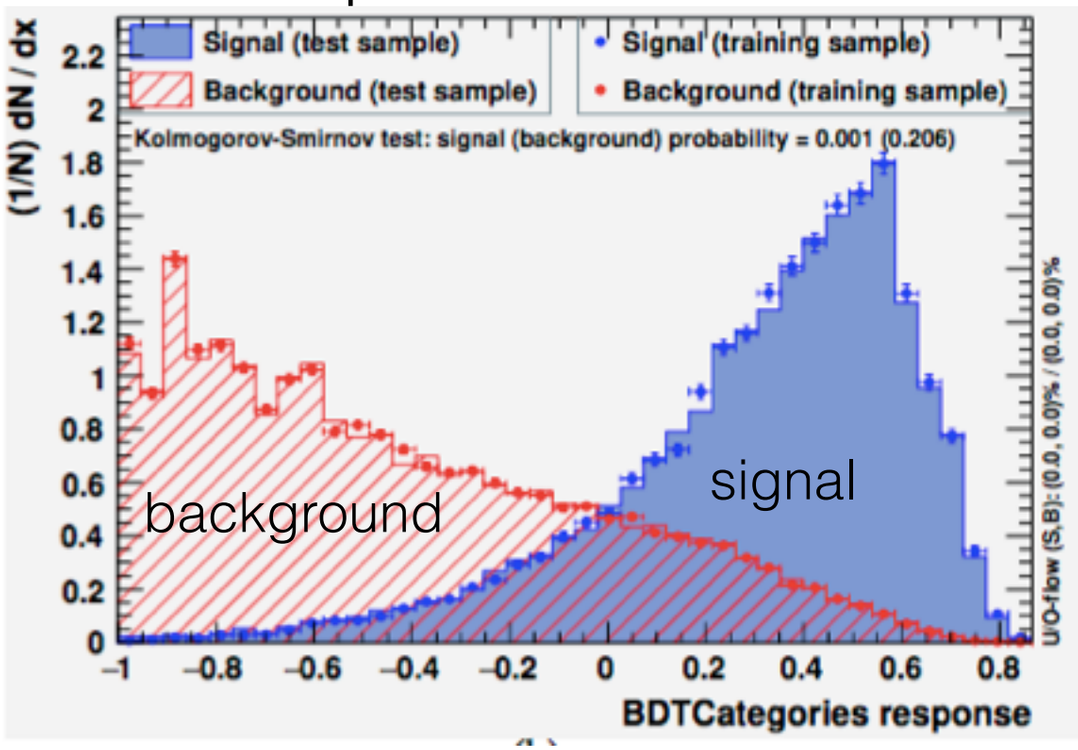
VH(bb) MVA analysis

- A multivariate discriminator (BDT) is trained using several event variables, including m(bb), to score events depending how signal-like they are.

Table 5: Variables used for the multivariate discriminant in each of the categories.

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}	×	×	×
$\Delta R(b_1, b_2)$	×	×	×
$\lvert\Delta\eta(b_1, b_2)\rvert$	×		
$\Delta\phi(V, bb)$	×	×	×
$\lvert\Delta\eta(V, bb)\rvert$			×
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		
$p_{\mathrm{T}}^{\mathrm{jet}_3}$	×	×	×
m_{bbj}	×	×	×

BDT response on simulation

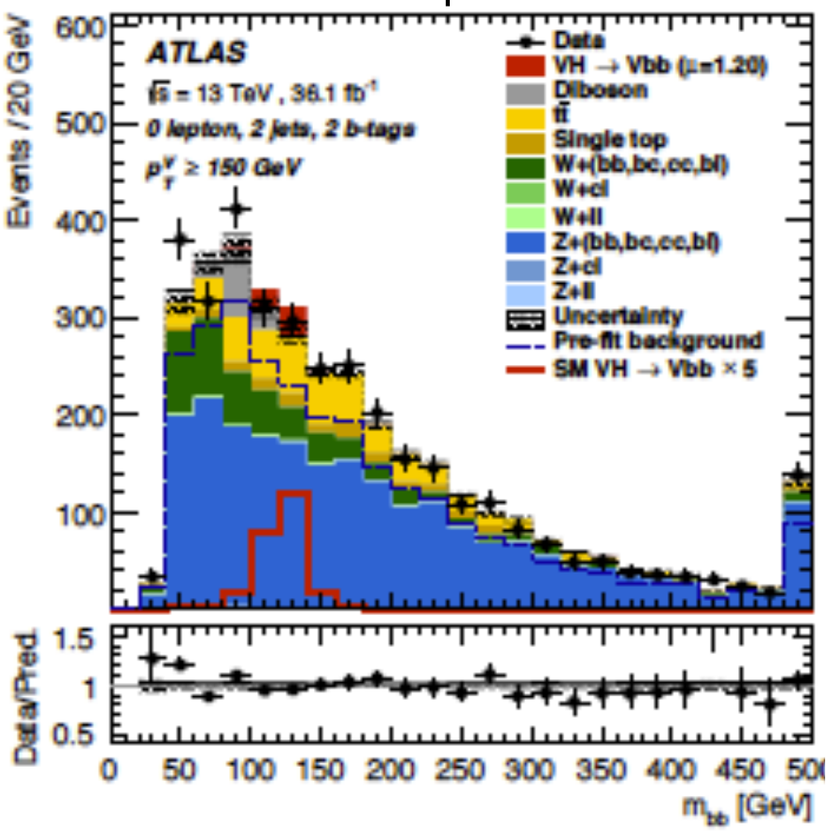


m(bb) distributions

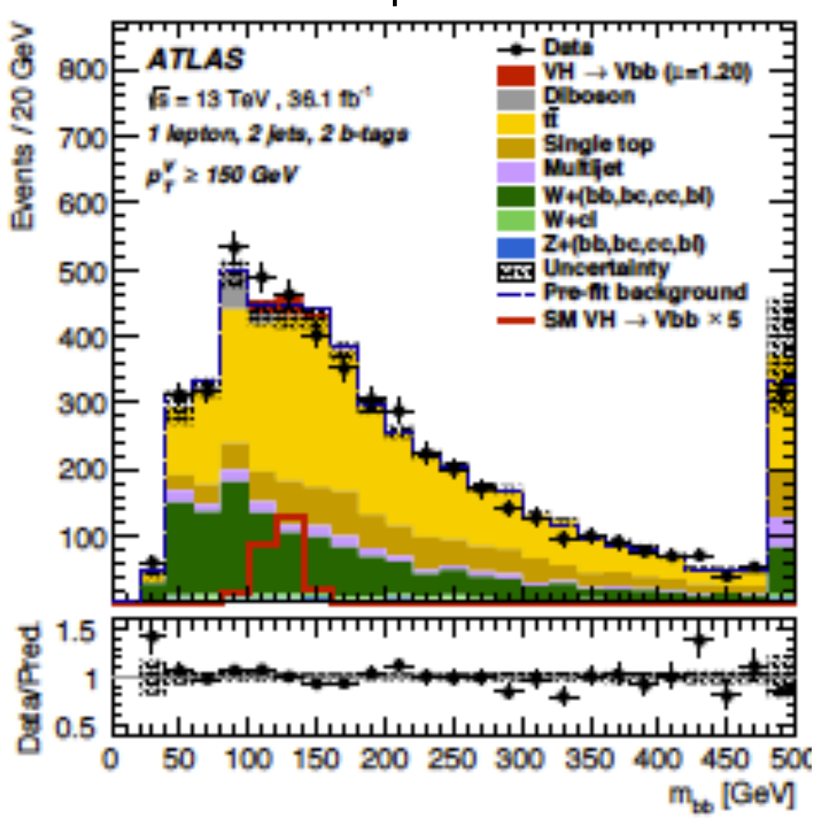
[arXiv:1708:03299]

- The signal contribution is small compared to the background from W/Z + jets and t-t processes.
- The observed data distributions are well modeled by the simulation of the backgrounds.

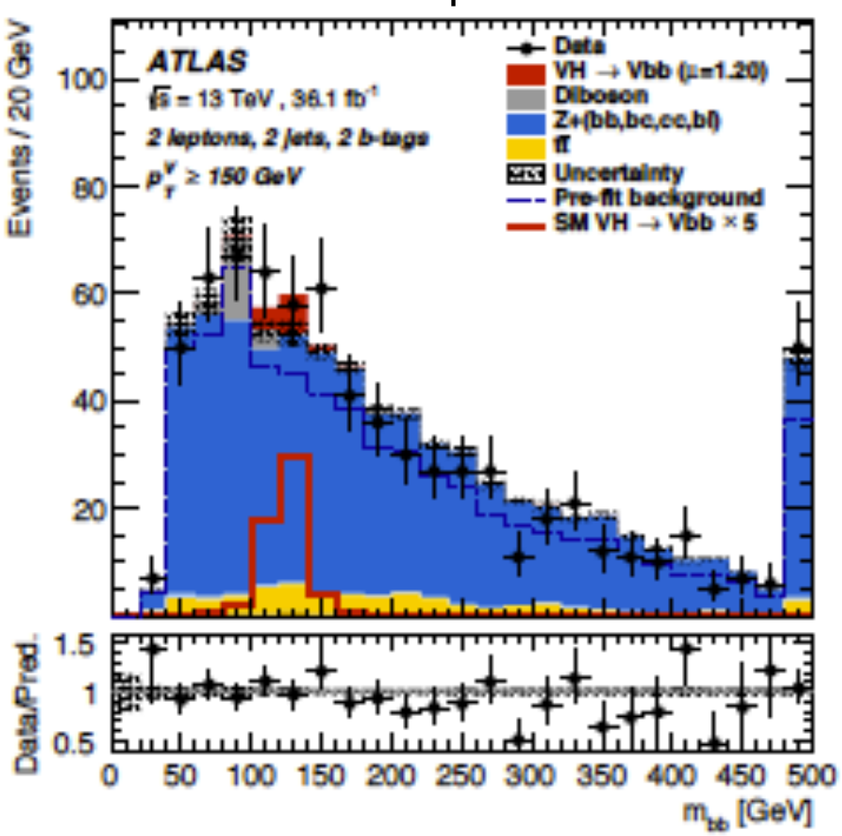
0-lepton



1-lepton



2-lepton

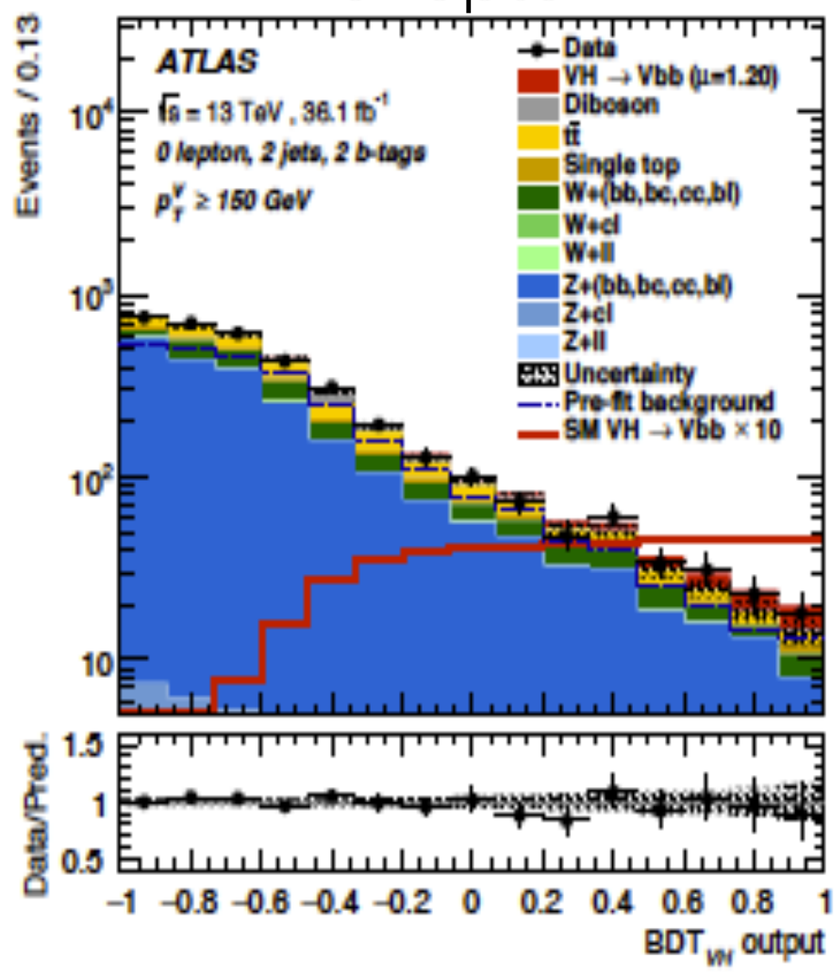


VH(bb) search results

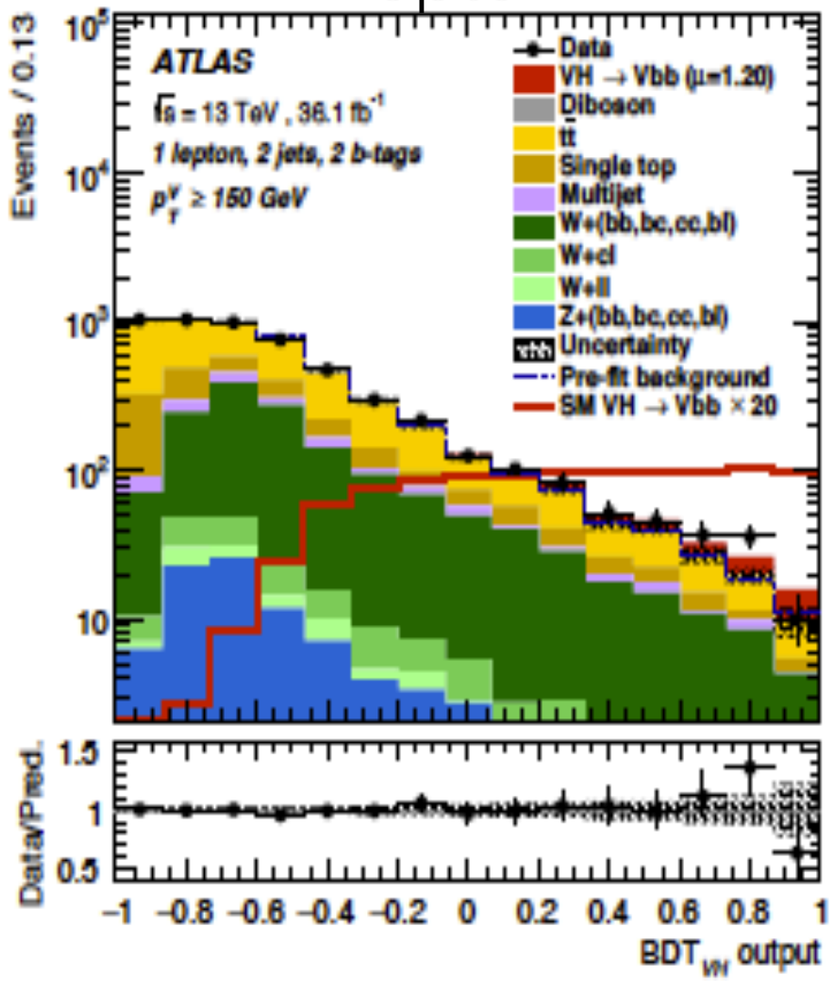
[arXiv:1708:03299]

- A fit including all backgrounds is performed on the BDT distributions. The different colors show the contributions from different backgrounds, mainly W/Z+jets and tt.
- The data is in good agreement with the background plus signal model. A small excess of signal-like events with a strength of μ=1.2 is observed, where μ is the ratio of the observed over the predicted SM rate.

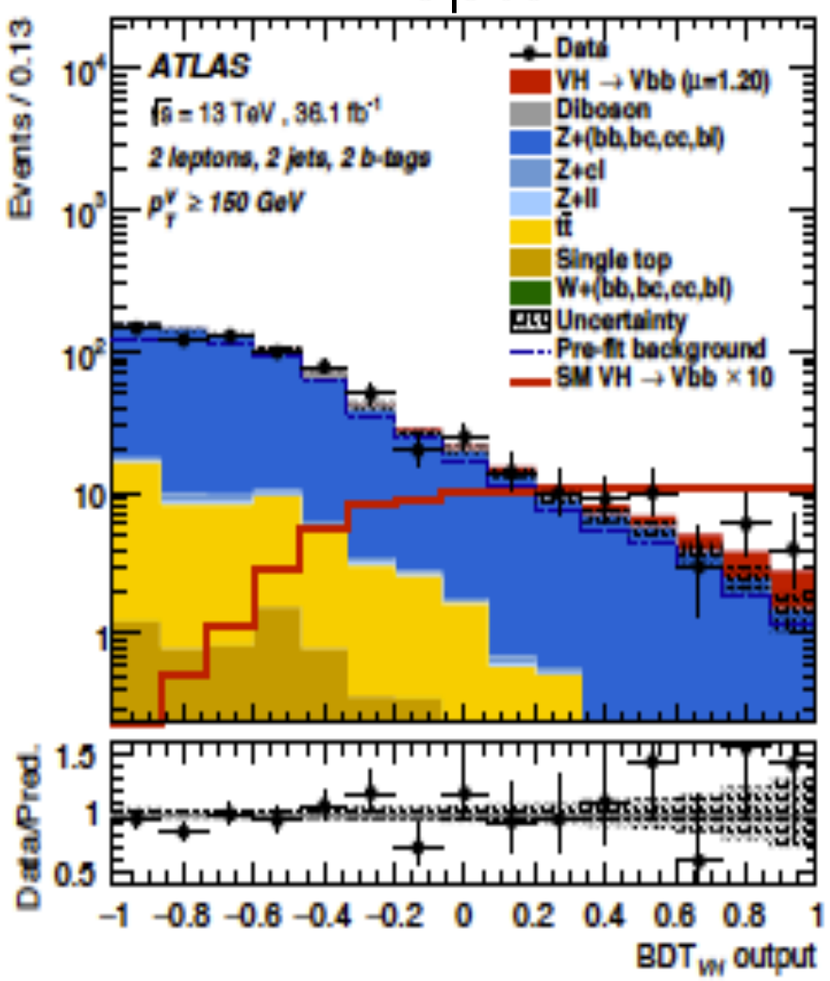
0-lepton



1-lepton



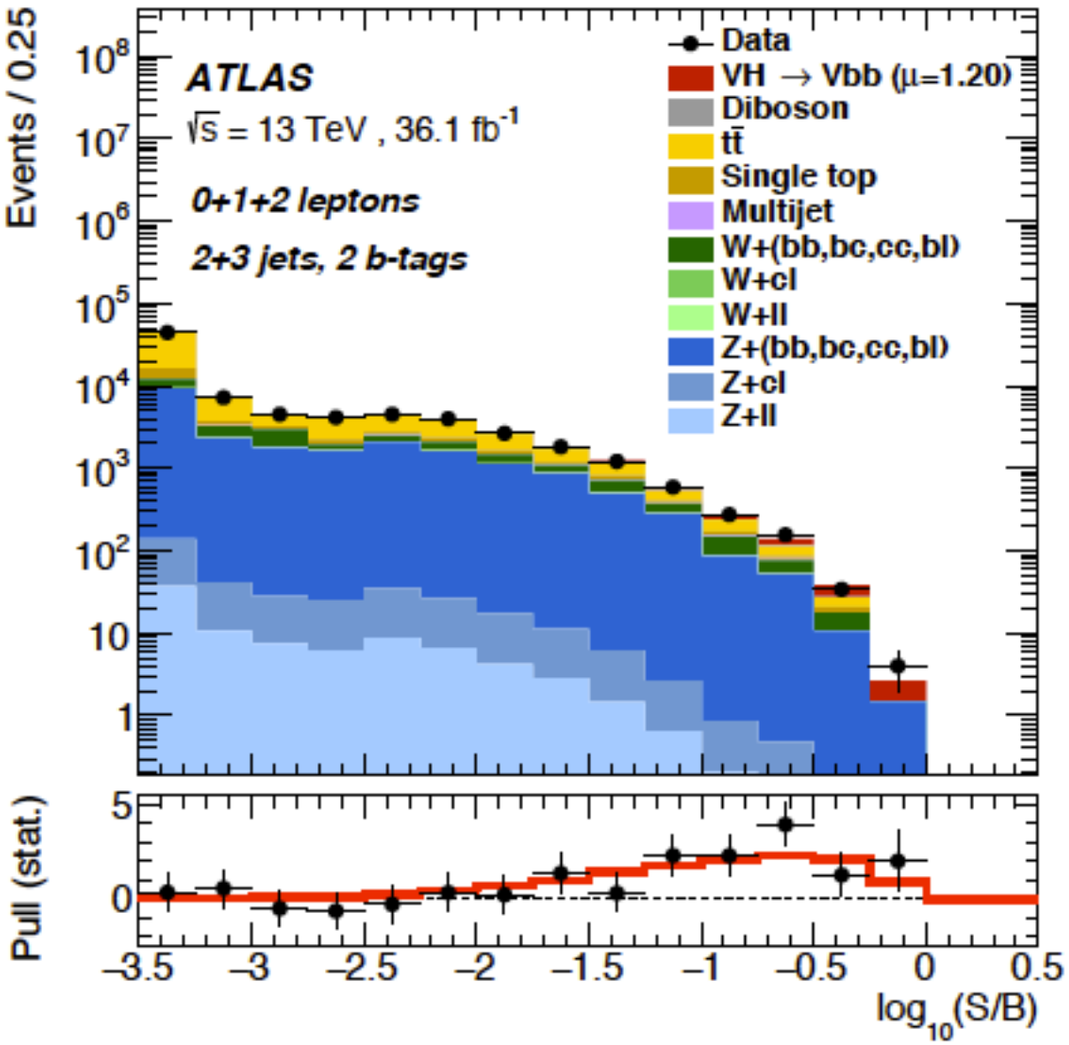
2-lepton

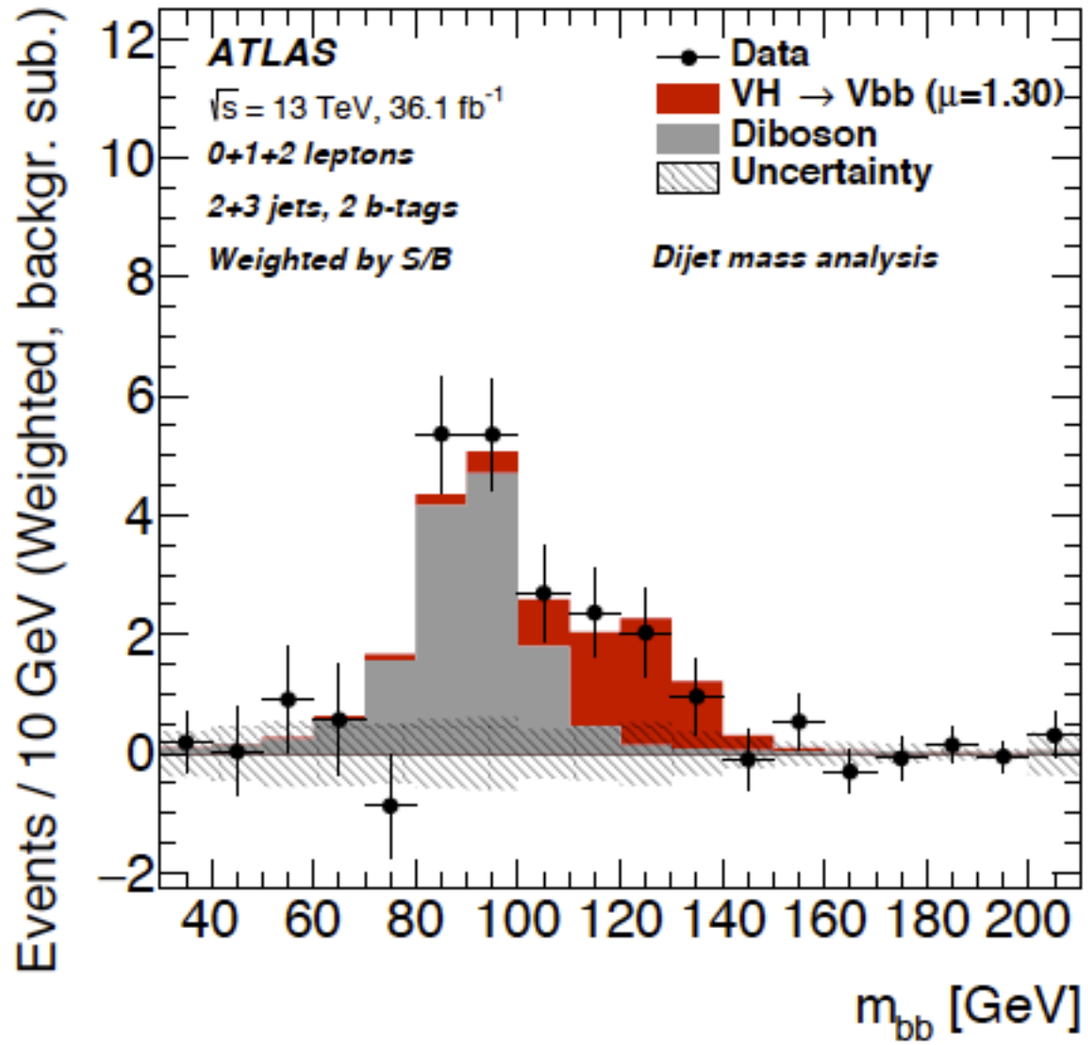


VH(bb) search results

- To better observe the excess of events we combine all regions according to their log(S/B) value (left plot below).
- A cut-based analysis is also perfomed as a cross-check. The m(bb) distribution after subtracting the background is shown in the right plot below.

[arXiv:1708:03299]

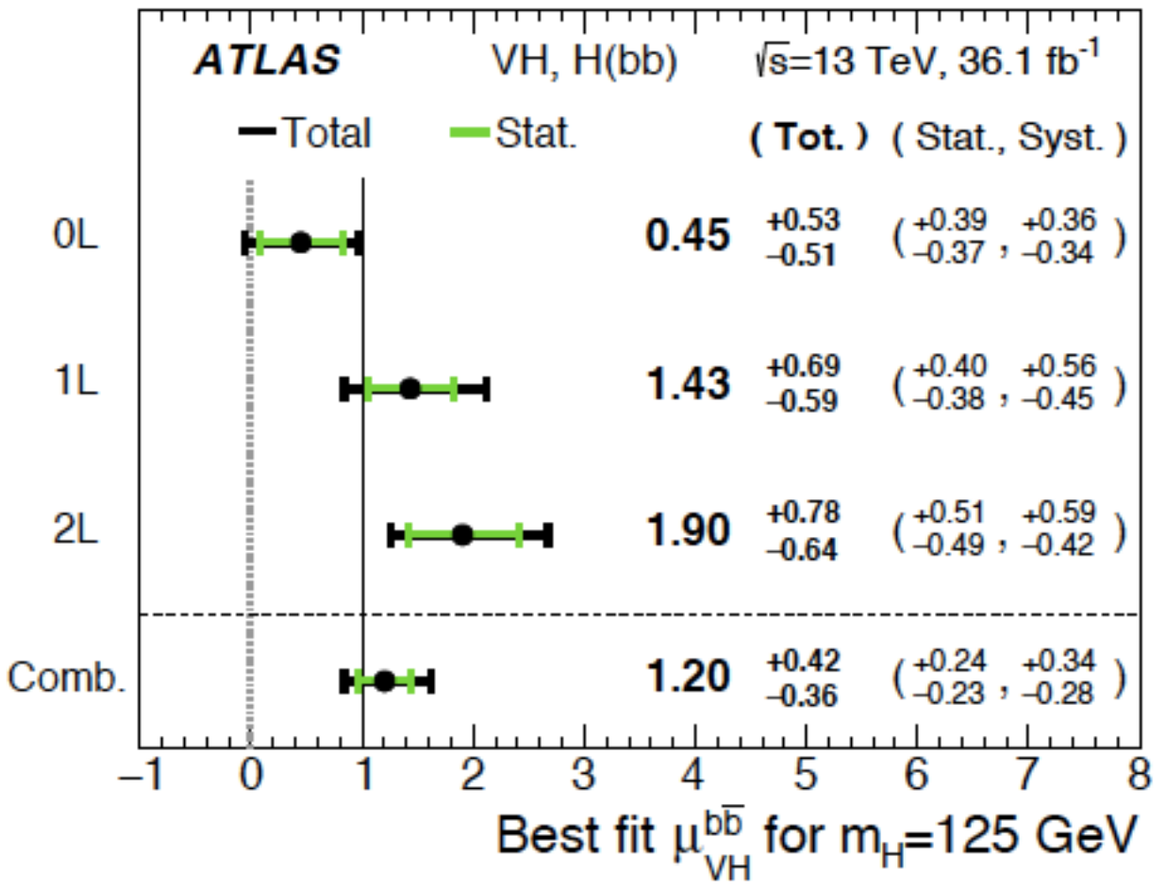




The red distribution is the excess above the background consistent with a Higgs of mass 125 GeV.

VH(bb) signal strength

- Signal strengths in each channel can be determiend from a fit with multiple floating normalization parameters then a combined fit is also performed.
- μ_{VH} is defined as the ratio of the observed signal strength over the expected SM prediction.



The signal strength in all channels and the combination is within the expected value for the SM.

[arXiv:1708:03299]

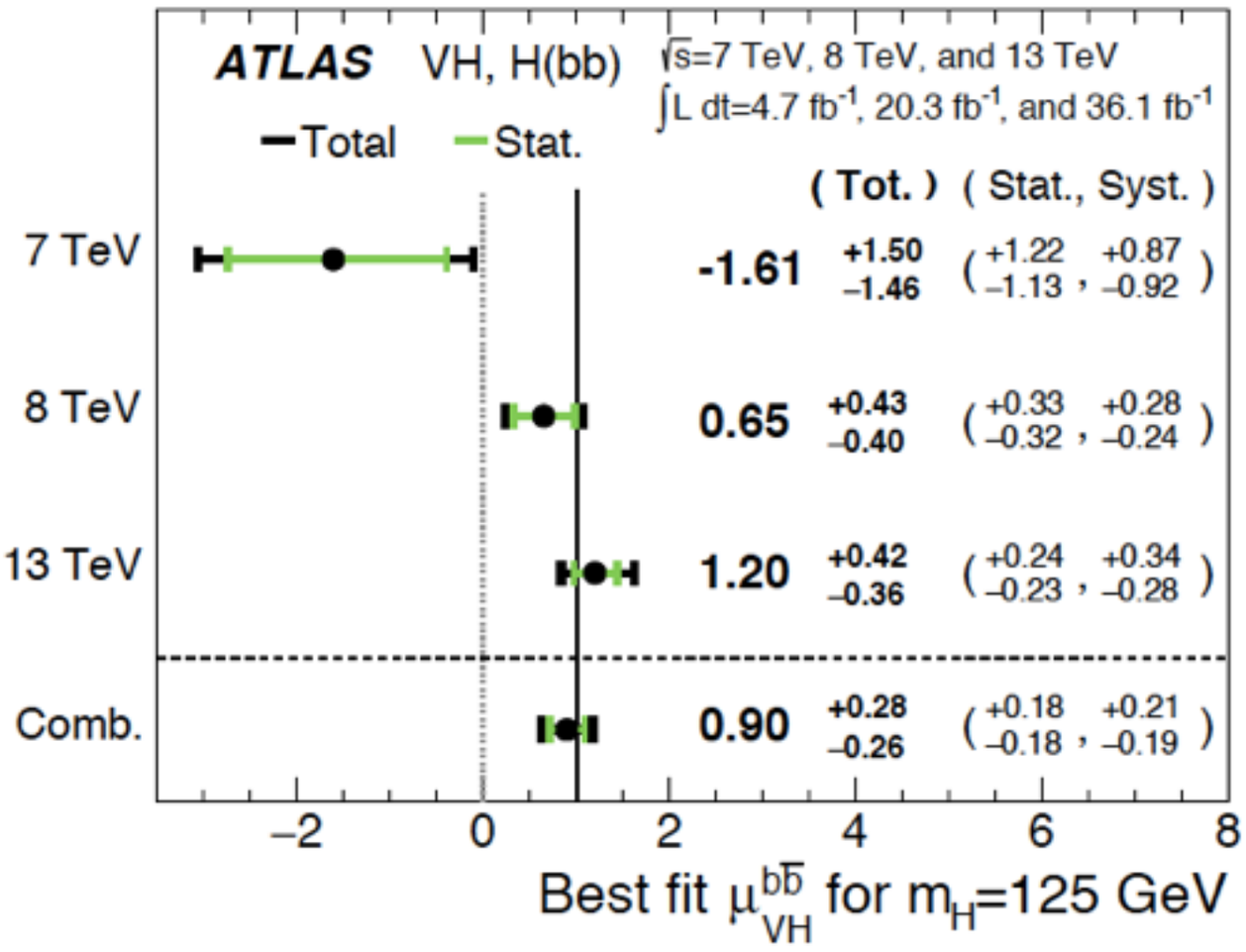
Dataset	p_0		Significance	
	Exp.	Obs.	Exp.	Obs.
0-lepton	4.2%	30%	1.7	0.5
1-lepton	3.5%	1.1%	1.8	2.3
2-lepton	3.1%	0.019%	1.9	3.6
Combined	0.12%	0.019%	3.0	3.5

- The data is compatible with the background-only hypothesis with a probability of only 1.9×10^{-4}. The excess has a **significance of 3.5 sigma**.
- **This is the first evidence at the LHC for the Higgs-quark couplings.**

VH(bb) combination: Run I+Run II

[arXiv:1708:03299]

- The 13 TeV results are combined with previous searches using the 7 and 8 TeV data.

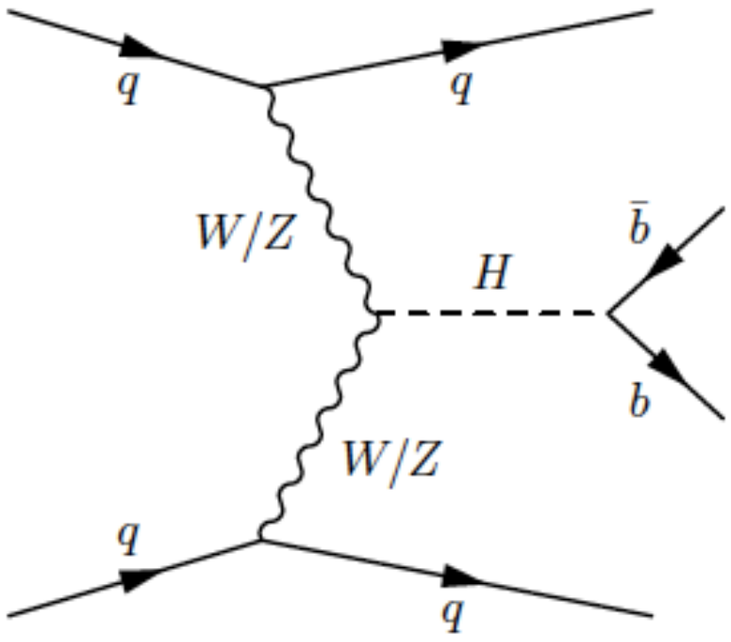


- The different data-sets are compatible with 20% probability.
- The result for the combined signal strength is within the SM expected value.

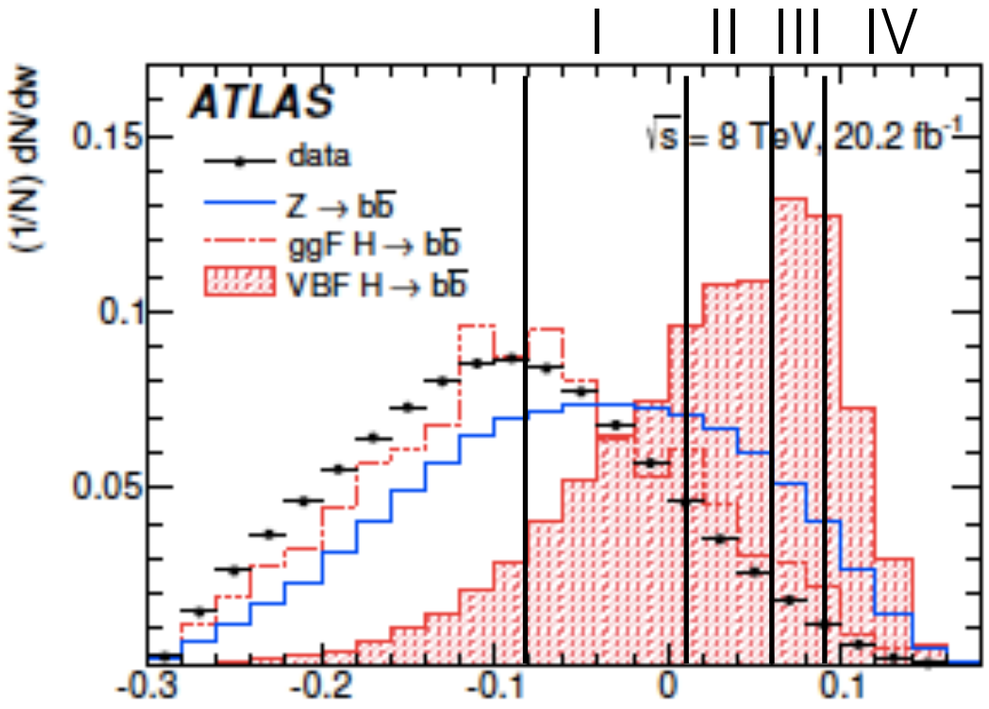
- We observe an **excess with 3.6 sigma**, driven by the new 13 TeV data.

VBF, H→bb

- The search in the VBF production mode requires 4 jets with pT>50 GeV.
- The two forward jets are identified as the VBF jets and the two central jets a the Higgs decay.



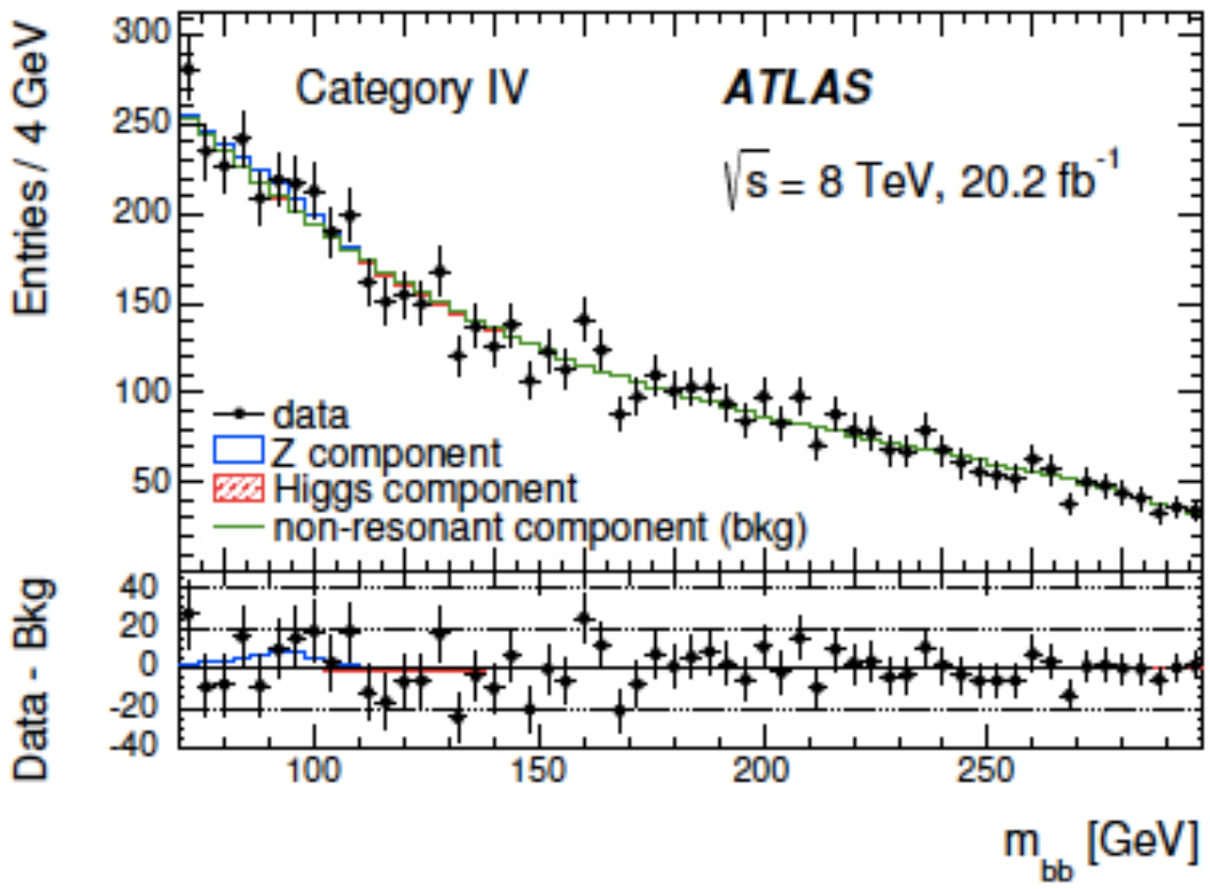
- A multivariate algorithm (BDT) is used to discriminate background using the measured Higgs and VBF candidate jet information.
- Regions in the BDT discriminator are separated based on the signal purity.
- Contribution from ggF process is about 10% in the IV region after full selection.



[JHEP11(2016)112]

VBF, H→bb results

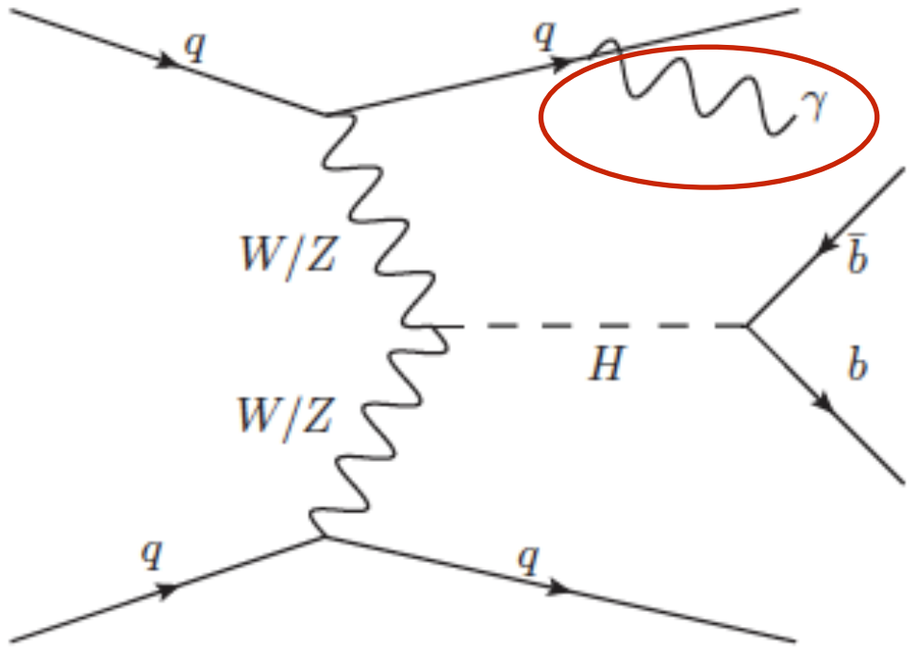
[JHEP11(2016)112]



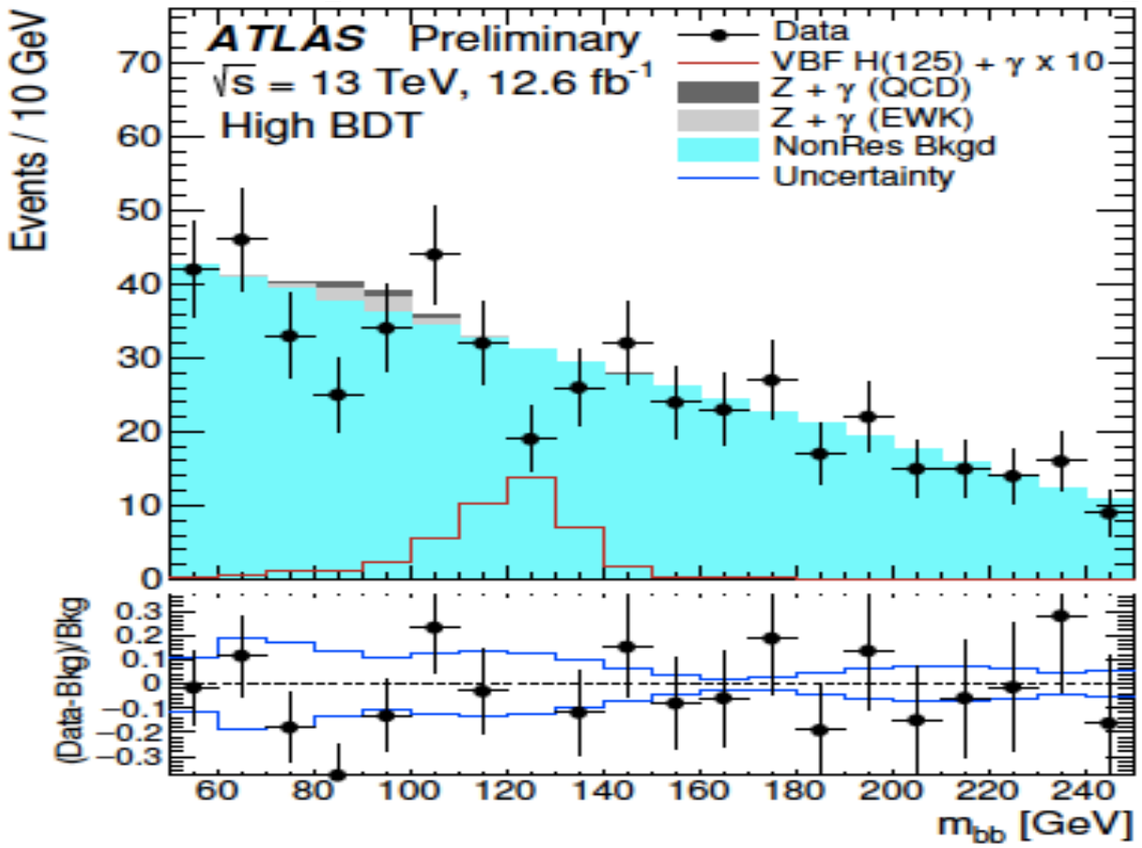
- The data are consistent with background events mainly from QCD multijet processes.
- An **upper limit of 4.4 on the cross section** for this process with respect to the SM cross section is set at 95% CL.

VBF+γ, H→bb results

- A photon with p_T>30 GeV and 4 jets with p_T>40 GeV are required. Two central b-tagged jets are identified as the Higgs.
- The energetic photon enables an efficient trigger and leads to about one order of magnitude reduction in the non-resonant bb production compared to the inclusive VBF production.

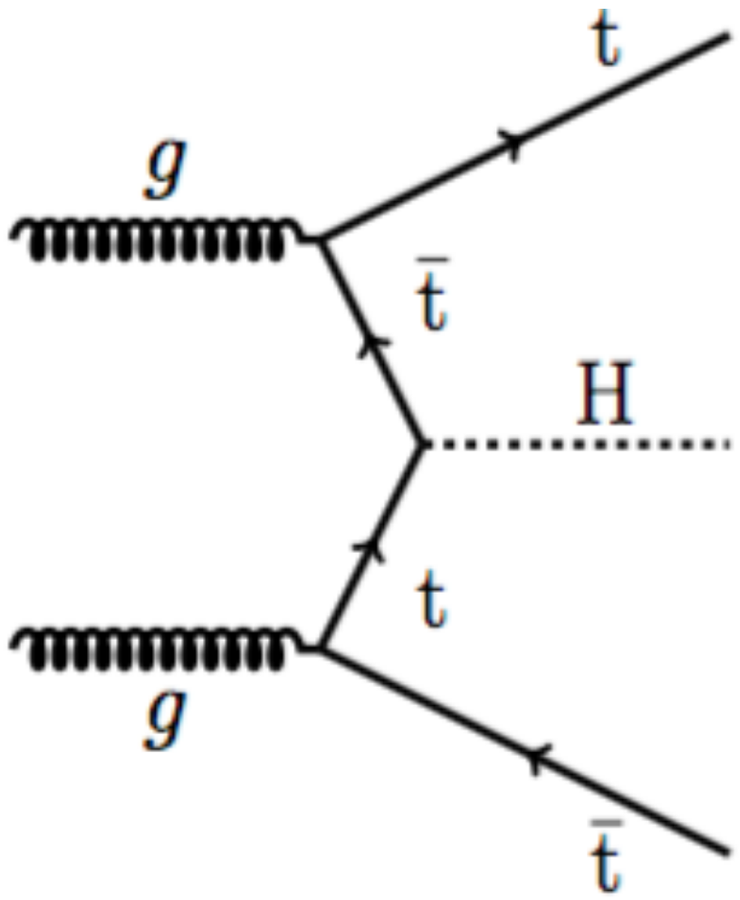


[ATLAS-CONF-2016-063]



- The data are consistent with background-only hypothesis.
- An **upper limit of 4.0** with respect to the SM predicted rate is placed at 95% CL

ttH searches



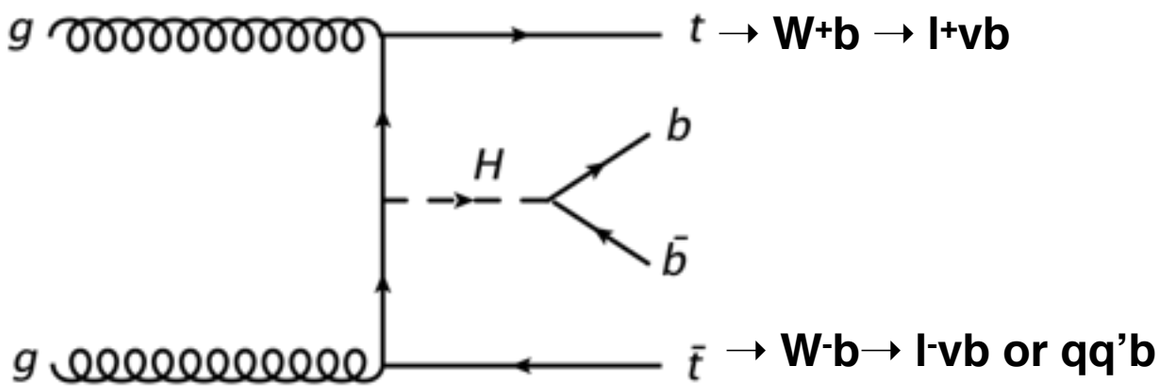
search modes:

- H→bb
- H→γγ
- H→multilepton

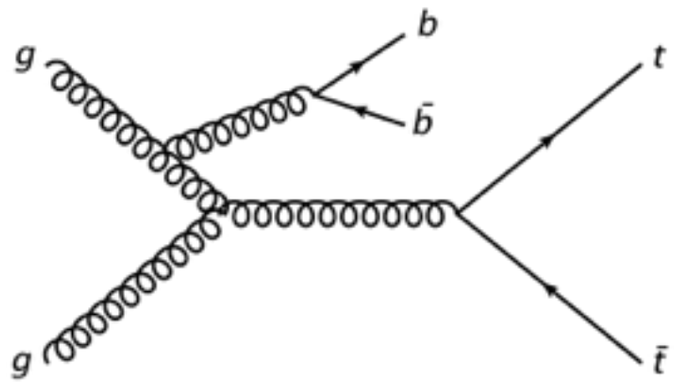
ttH, H→bb

ATLAS-CONF-2016-080

13.2 fb^{-1}



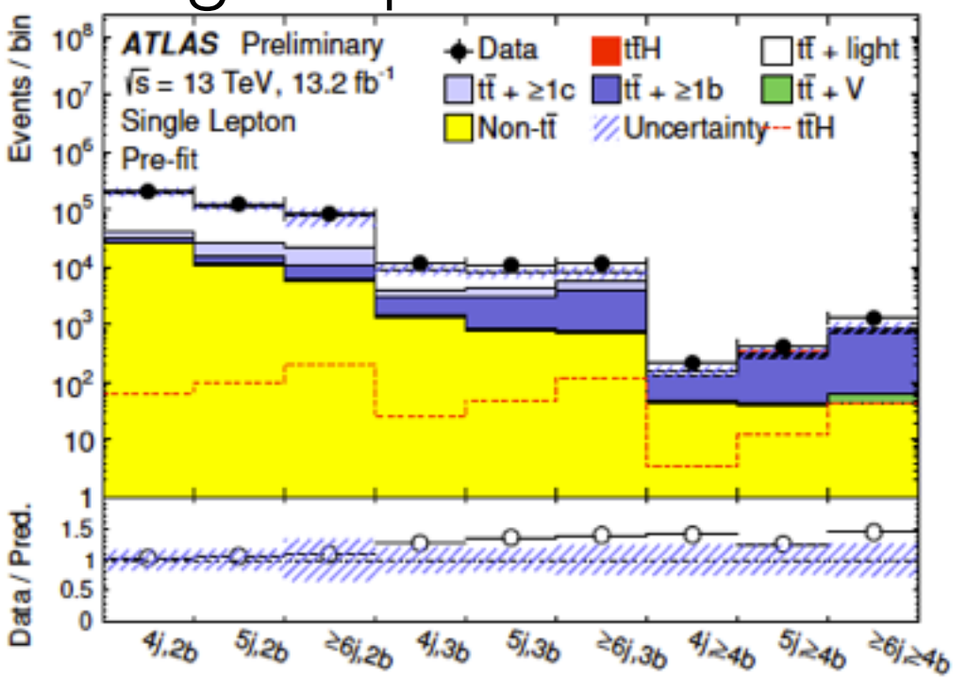
signal



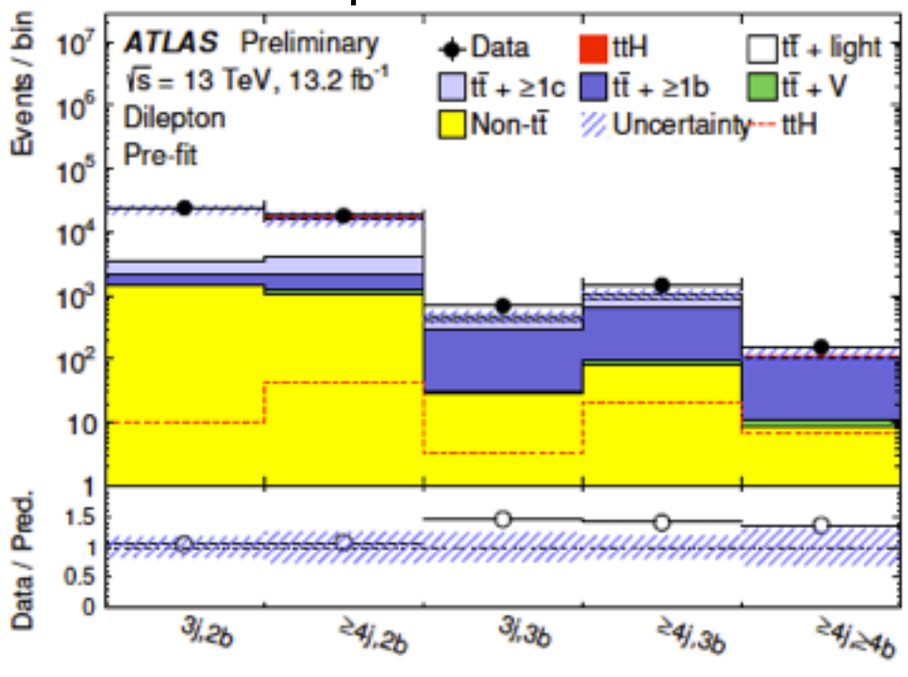
background

- Events with one lepton or two leptons are selected
- Exclusive regions are defined according to the number of leptons, jets, and b-tagged jets
  - # of jets: 4, 5, or >=6 (1-lepton), 3 or >= 4 (dilepton)
  - # of b-jets : 2 , 3 , >=4

single lepton channel



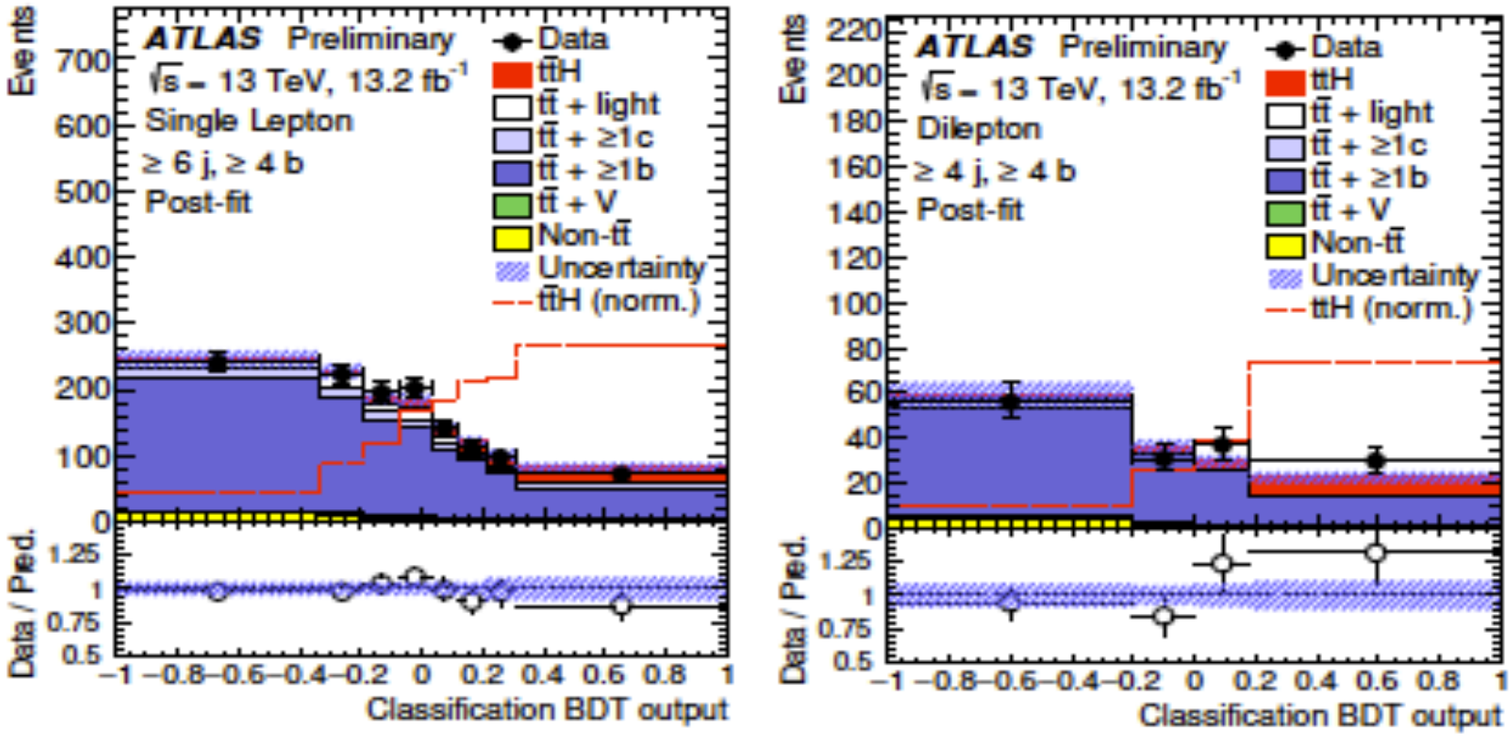
dilepton channel

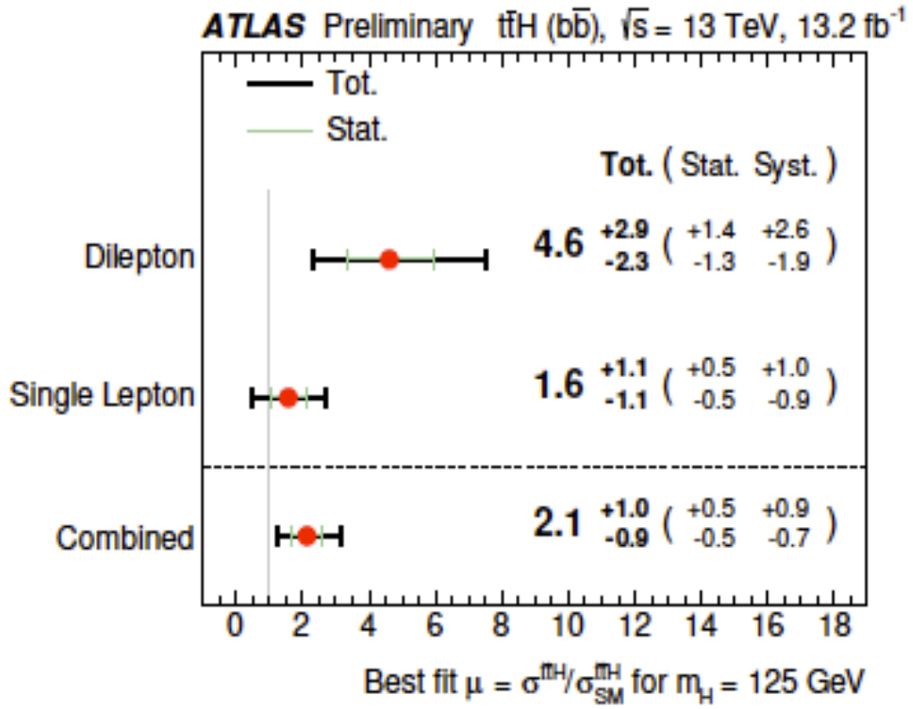


ttH, H→bb results

ATLAS-CONF-2016-080
13.2 fb^{-1}

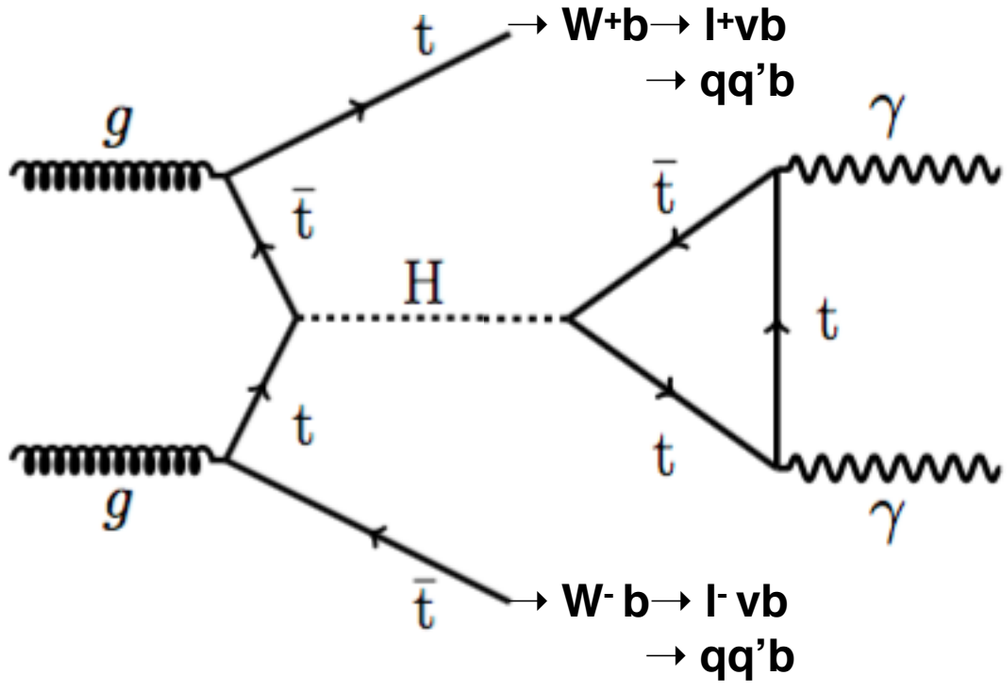
- A two-step multivariate approach uses BDT's
  - to reconstruct ttH event, and
  - to classify each event as signal-like.





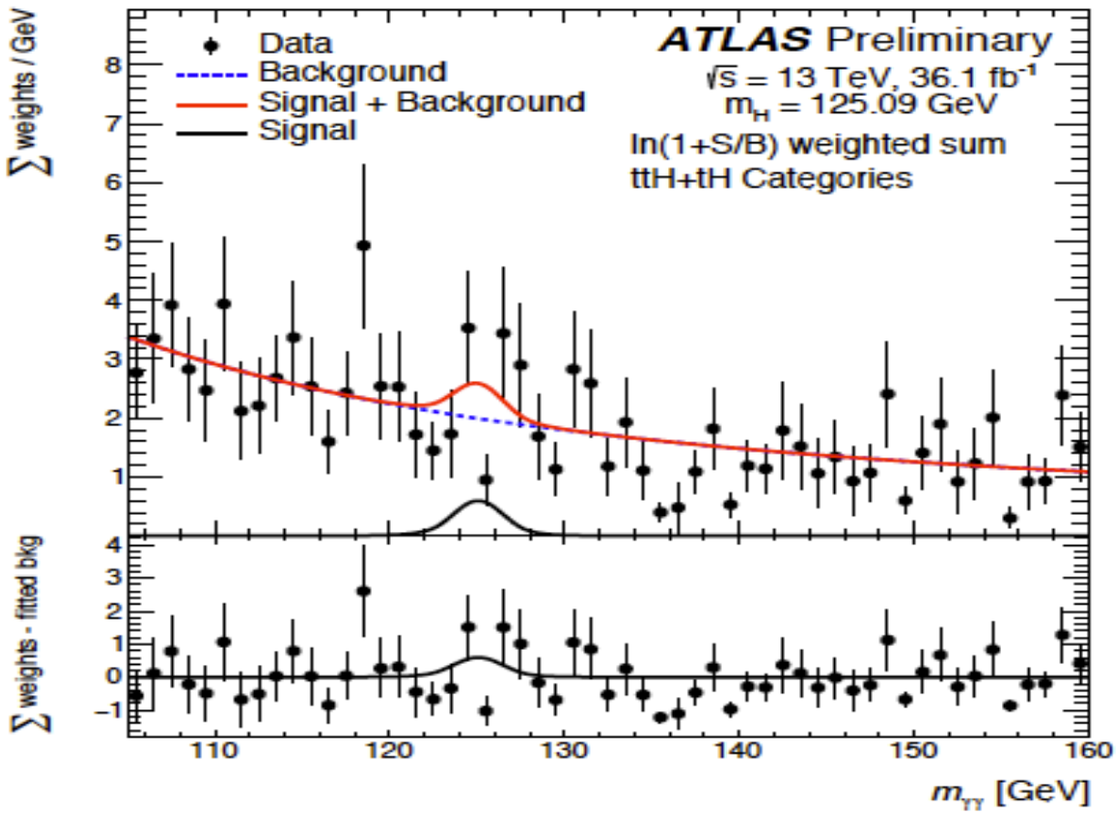
- The observed signal strength
  μ_{ttH} = 2.1 +1.0/-0.9
  is consistent with both background-only and background+signal hypotheses.

ttH, H→γγ

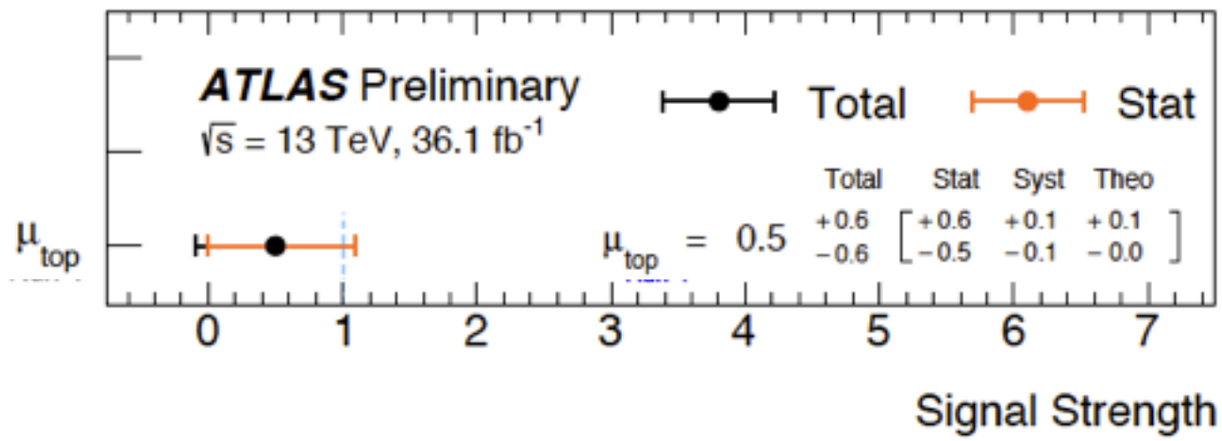


ATLAS-CONF-2017-045
36.1 fb^{-1}

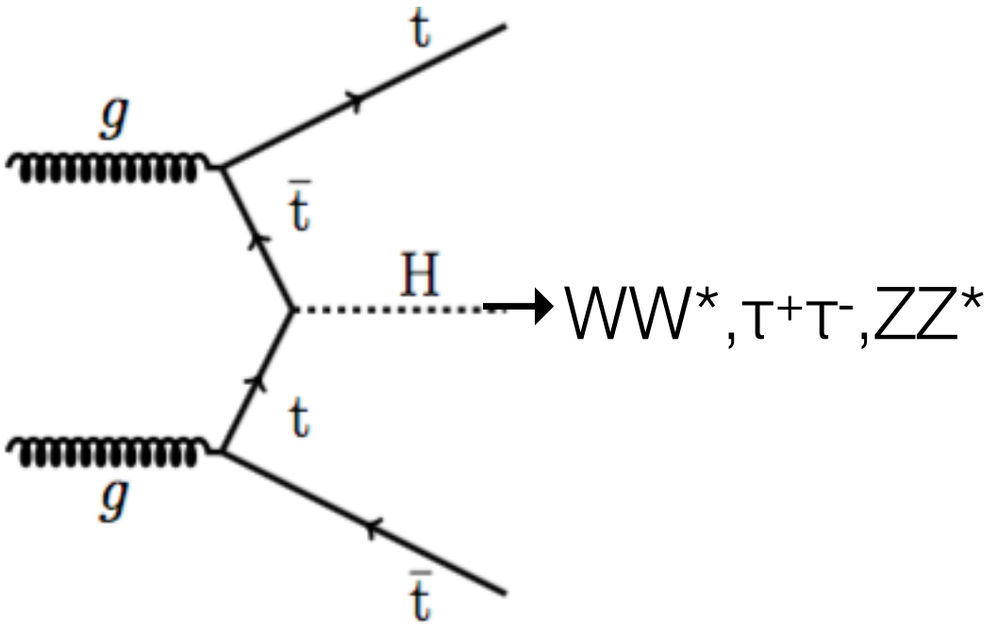
- The search is performed by requiring two isolated photons with $E_T/m_{\gamma\gamma}$>0.35 (0.25) for the leading (sub-leading) photon, driven by the trigger selection.
- Events are categorized into events with **leptons** (>=1 e or μ) or **fully hadronic** (>=3 jets).
- In both cases, at least 1 b-jet is required. Fully hadronic events are further categorized using BDT.



- The observed signal strength is consistent with both a background-only and a background+signal hypothesis
  μ_{ttH} = 0.5 +/-0.6

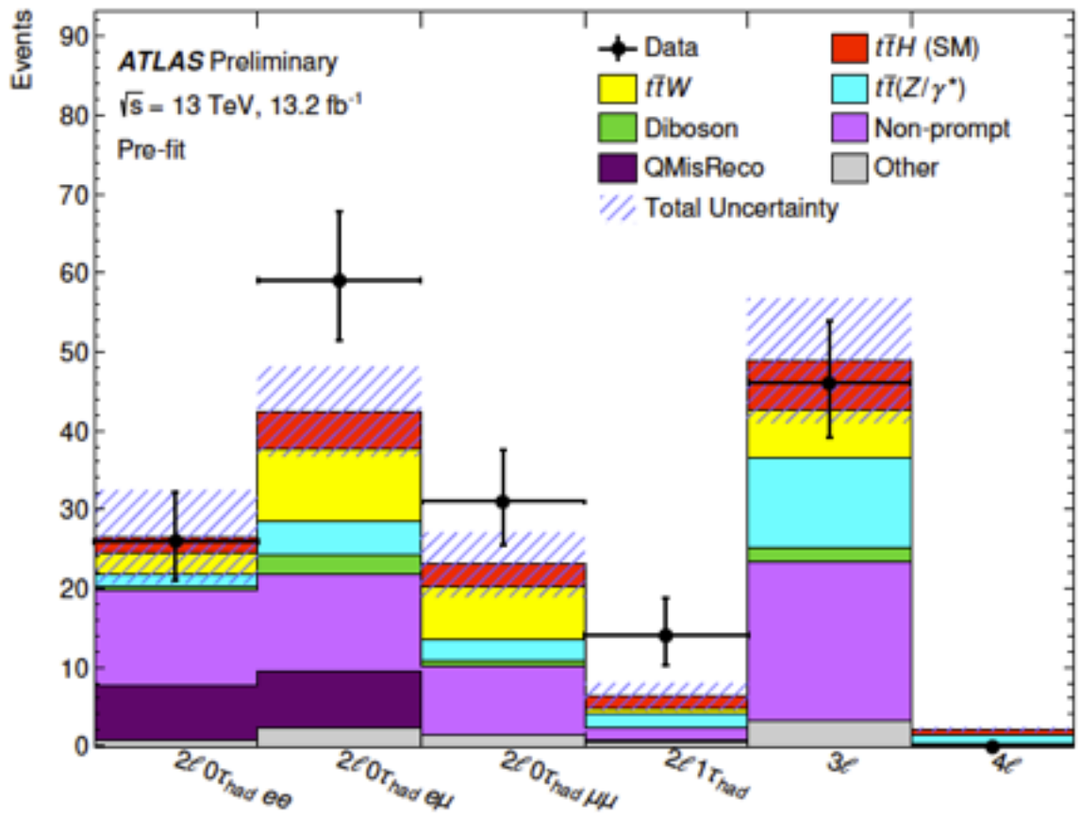


ttH, H→multilepton



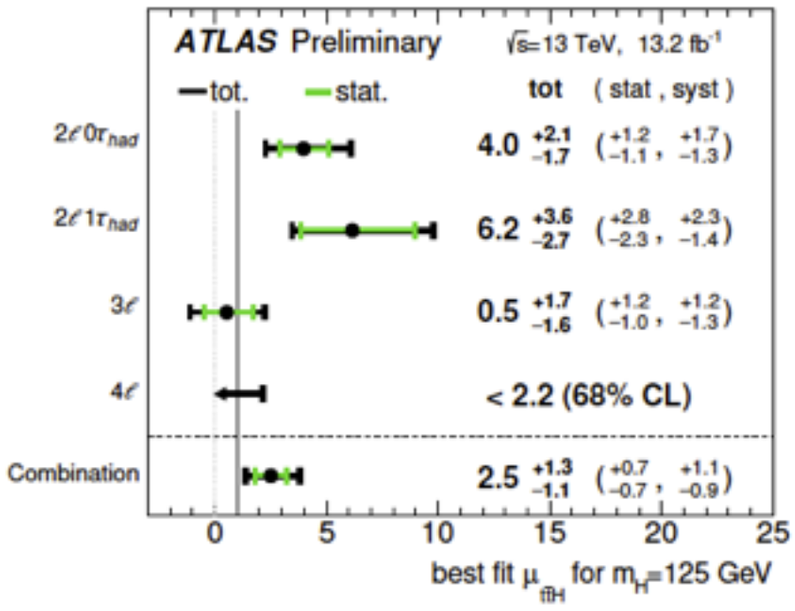
- The search targets the decays of the Higgs boson to W bosons or tau leptons. In addition to the leptons, at least one b-tagged jet is required in the event.
- Most categories are dominated by WW*, except the 2l1τ_{had} where ττ is of same size. The ZZ* channel contributes only a few %.

ATLAS-CONF-2016-058



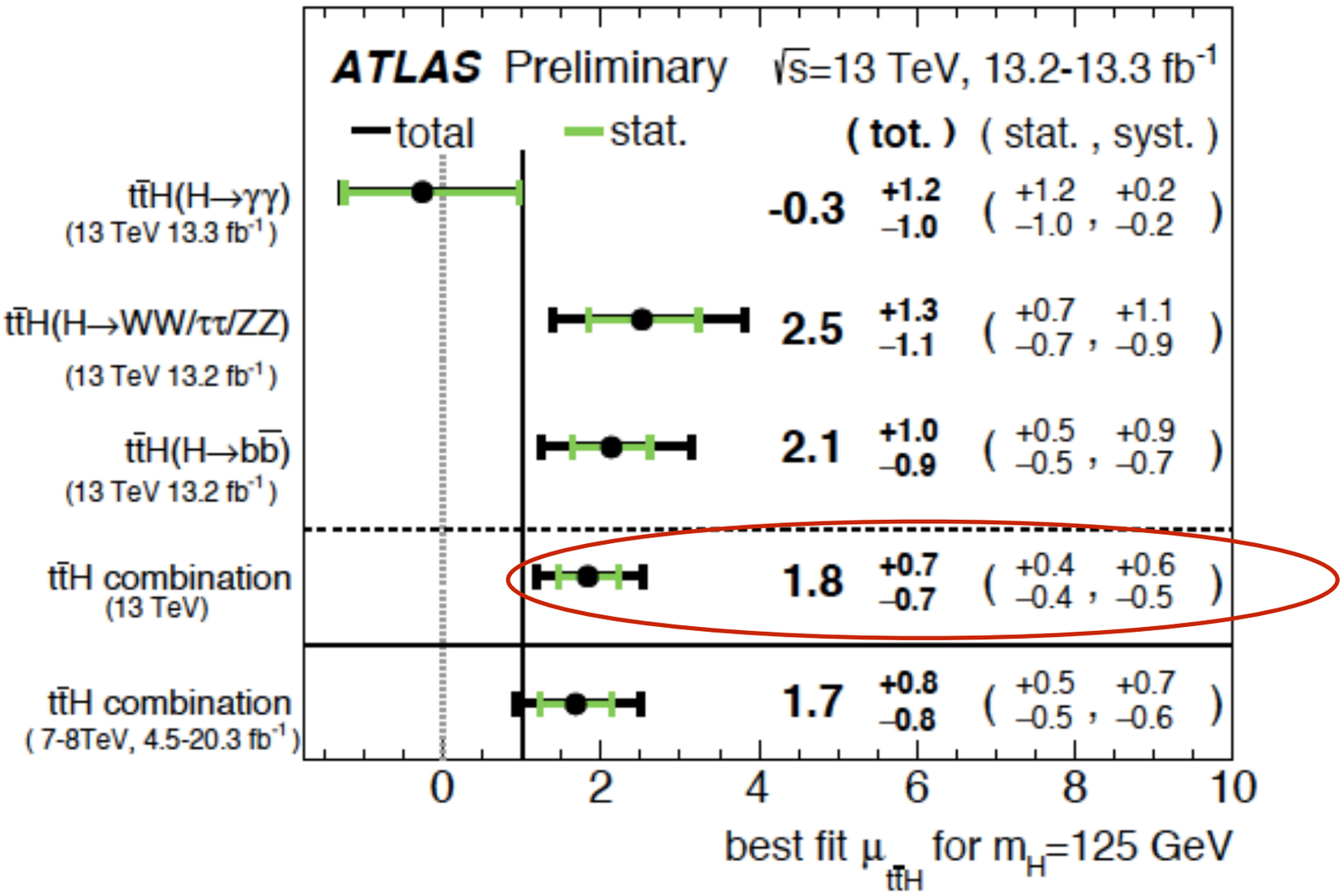
- The best-fit signal strength is consistent with the SM expectation:

μ_{ttH} = 2.5 +1.3/-1.1



ttH combination results

ATLAS-CONF-2016-058
13.2 fb^{-1}

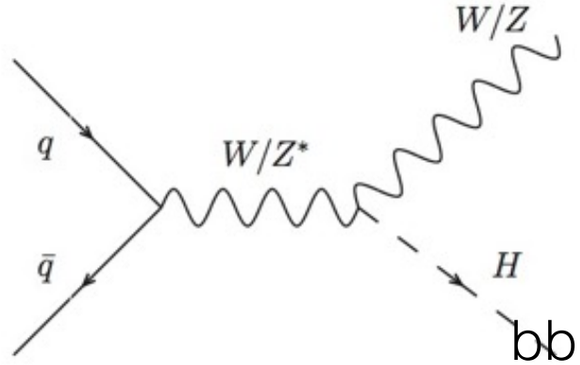


- The combined ttH signal strength is found to be consistent with the SM prediction **μ_{ttH} = 1.8 +/- 0.7** and corresponds to a **significance of 2.8σ** .

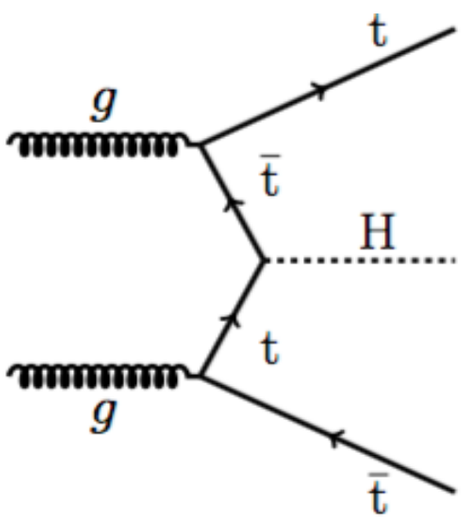
- The current combination uses only ~13 fb^{-1} of 36 fb^{-1} available.

Summary

- The coupling of the Higgs to the quark sector is an important part of the ATLAS program. The couplings to heavy quarks (top and bottom) are the most viable due to their large masses and coupling values.
- We observe for the first time in the LHC evidence for direct decays of H to bb.



- Direct searches for the t-H coupling have been performed using the ttH process and several Higgs decay modes. The sensitivity in this search is close to 3 sigma and will improve after updating to the full data-set.
- Current results are consistent with the SM expectations.
- More precise measurements are expected with new Run II data in the near future and will probe the Higgs-quark sector for possible New Physics.



Thanks.