Higgs results with direct top and b-Yukawas with ATLAS

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Outline

- Direct measurement of Higgs-bottom Yukawa coupling

  - VH, VBF H->bb and ttH(H → bb)

- Direct measurement of Higgs-Top Yukawa coupling

  - ttH(bb)

  - ttH (multi-lepton), including H → W$^+$W$^-$, H → $\tau\tau$, H → ZZ

  - ttH($\gamma\gamma$)

Higgs-bottom Yukawa coupling

- H→bb has the largest predicted branching ratio (~58%)

  - Test of Yukawa coupling between b-quarks and Higgs boson

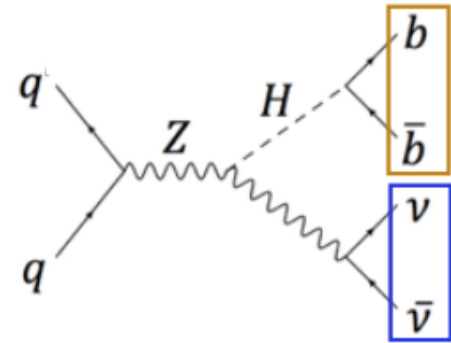- ATLAS+CMS Results in Run 1: observed significance 2.6σ (expected 3.7σ)
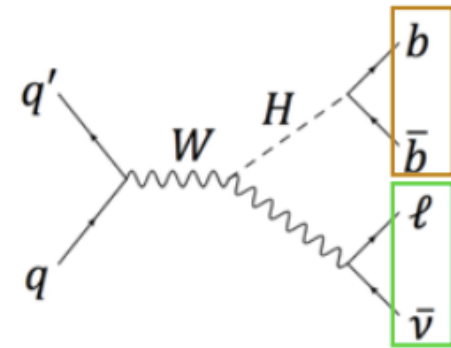
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VH(bb) only

$$\mu_{bb}^{CMS+ATLAS}=0.70^{+0.29}_{-0.27}$$
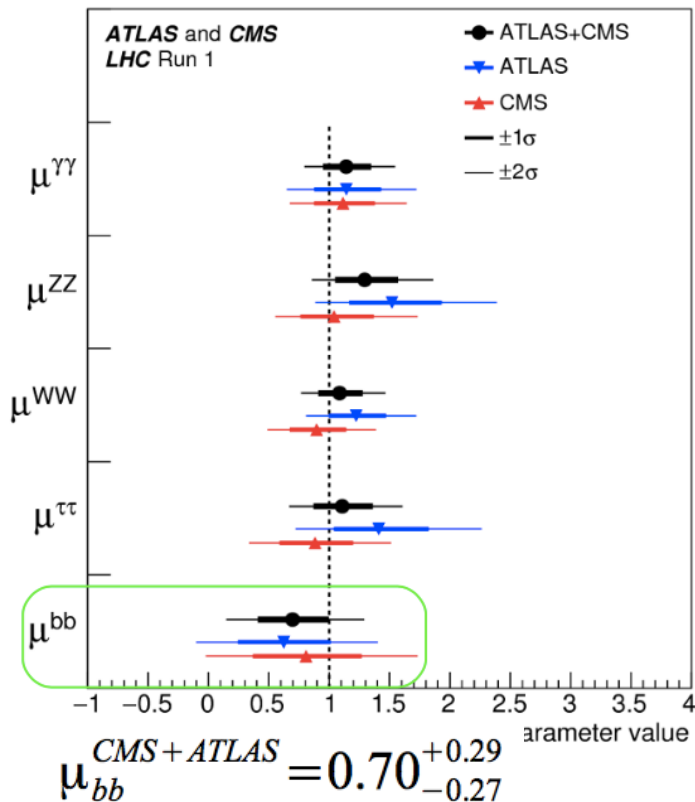
channels with a first Run-2 result

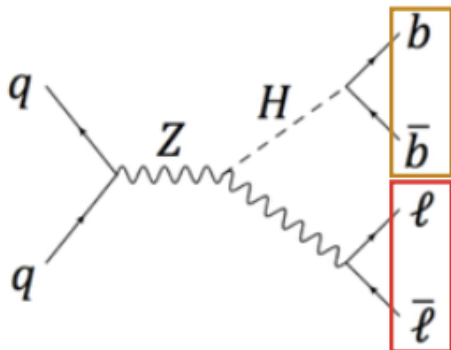| channel	Reference	Integrated Lumiosity
VH(bb̄)	ATLAS-CONF-2016-091	13.2 fb^{-1} (13TeV)
VBF H(bb)γ	ATLAS-CONF-2016-063	12.5 fb^{-1} (13TeV)

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VH(bb) searches : 3 channels

➤ 0-lepton:

$E_T^{miss} > 150$ GeV

➤ 1-lepton:

e/μ, $p_T > 25$ GeV

Tight isolation

Missing E_T

$p_T^V > 150$ GeV

➤ 2-leptons:

Isolated ee, μμ

$p_T^1 > 25$ GeV, $p_T^2 > 7$ GeV

No missing E_T,

$m_{\ell\ell}$ compatible with m_Z.

➤ Two jets

anti-kT with R=0.4

$P_T^{j1} > 45$ GeV

$p_T^{j2} > 20$ GeV

➤ Improved b-tagging with respect to Run 1:

Eff: 70%, light jet rejection: 380, charm rejection: 12

➤ Analysis categories:

	0 lepton	1 lepton	2 leptons
2 jets	$p_V^T > 150$GeV	$p_V^T > 150$GeV	$p_V^T < 150$GeV
			$p_V^T > 150$GeV
3 jets	$p_V^T > 150$GeV	$p_V^T > 150$GeV	$p_V^T < 150$GeV
			$p_V^T > 150$GeV

Major Background in VH(bb) searches

- Z+bjets dominates in 0, 2 lepton channels

- Top quark and W+jets in 1 lepton channel

- Multi-jet background

  - negligible in 0/2 lepton channels after anti-QCD cuts
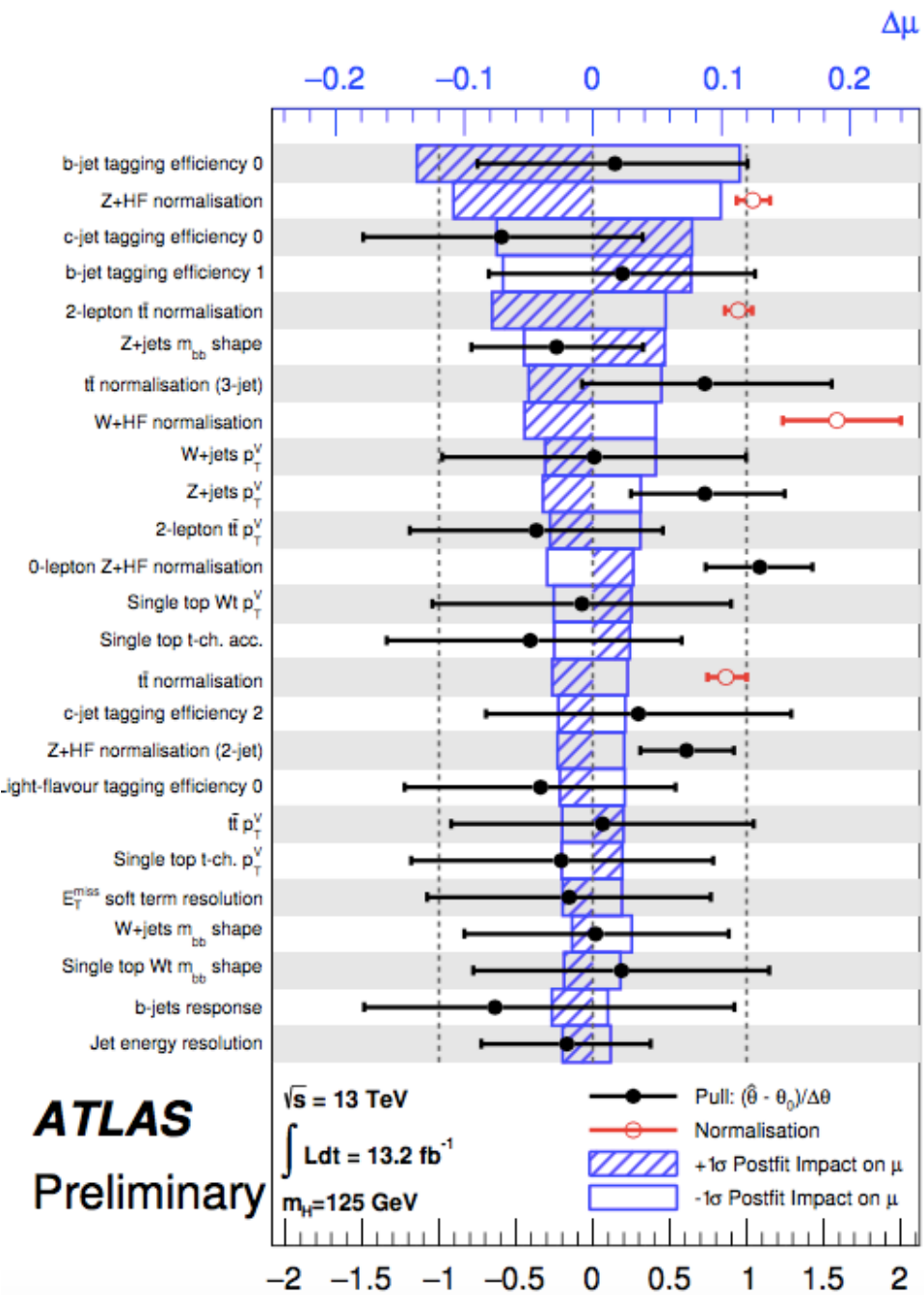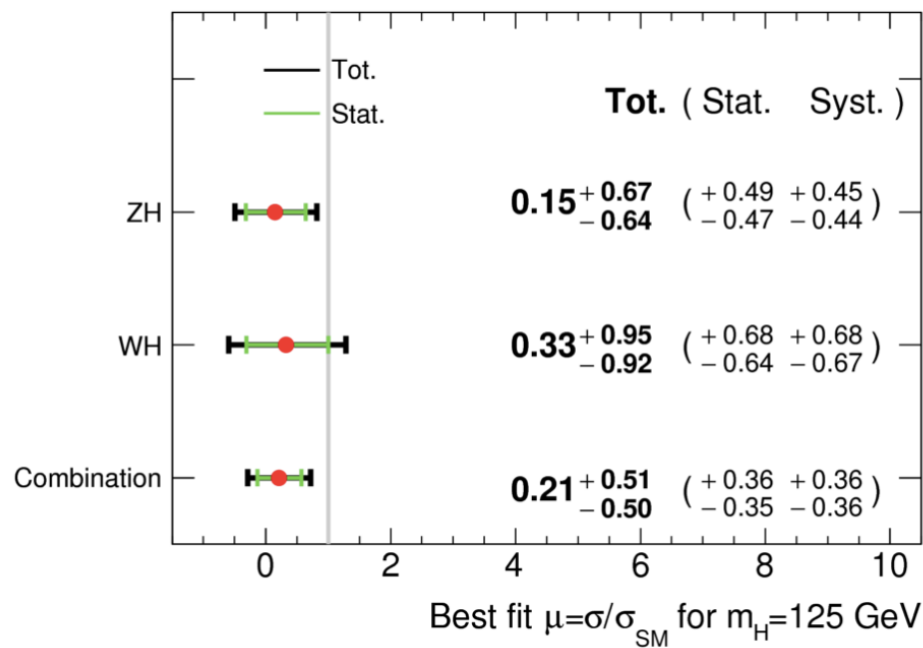
  - Data-driven estimate in 1 lepton channel

0 Lepton   1 Lepton   2 Lepton
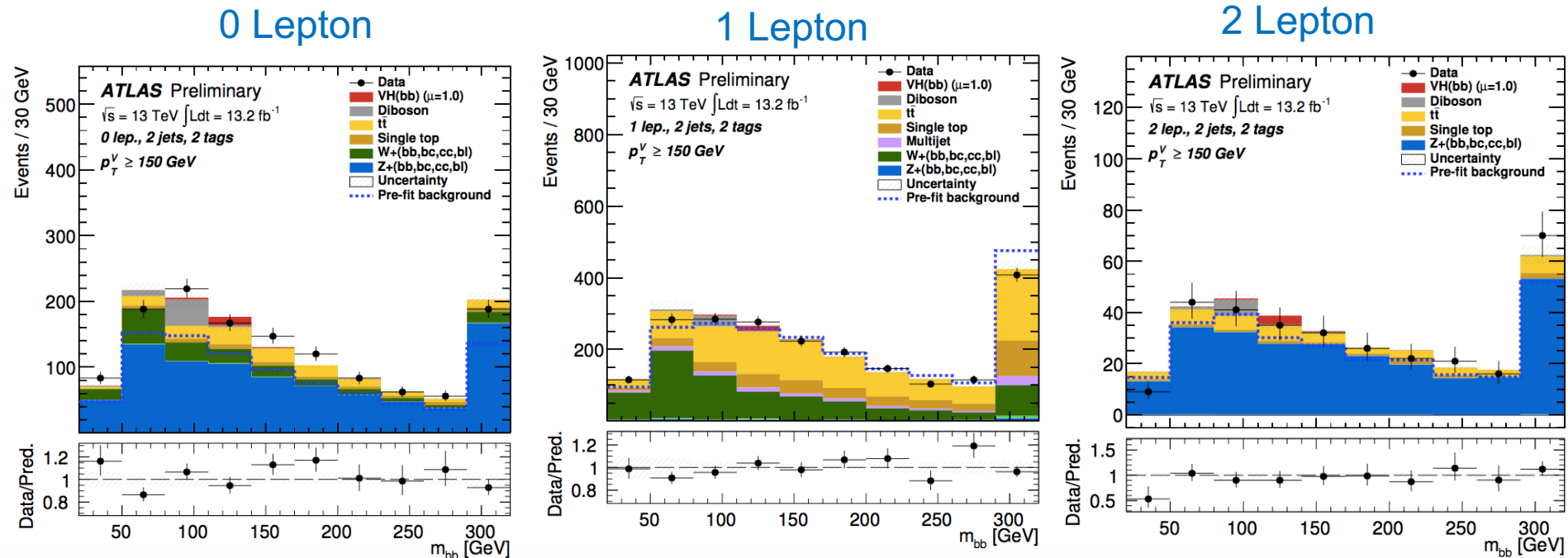
VH(bb) searches : results

Combined signal strength with 13.2 fb^{-1} at √s= 13 TeV

$$\mu_{VH,\,H\to bb} = 0.21^{+0.51}_{-0.50}$$

- Systematic and statistical uncertainties of the same size
- Dominant systematics from b-tagging and
- background normalization modelling (W+jets, Z+jets, top)

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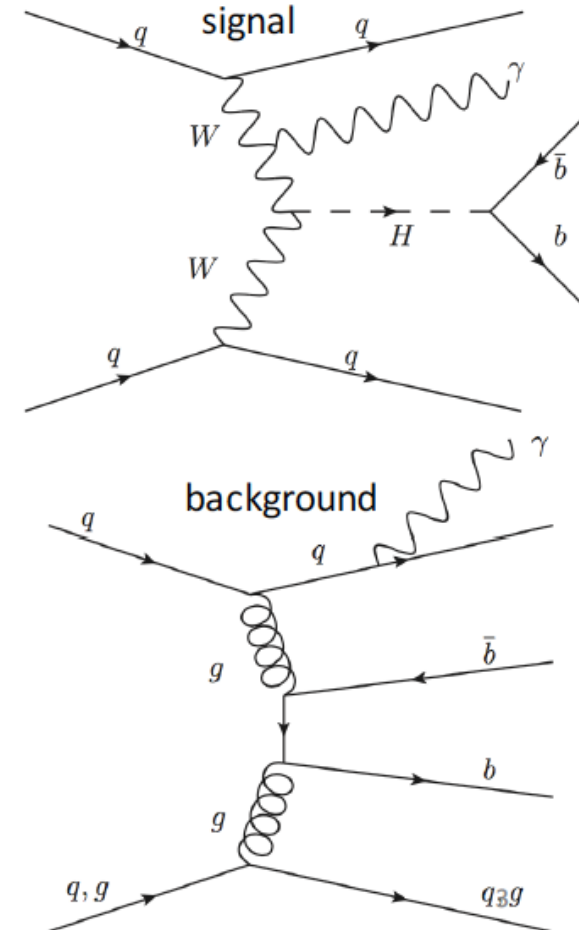# VBF H(bb)γ

- Search for H->bb in VBF events containing a central photon

- Advantages of requiring a photon
  - extra handle for trigger
  - suppresses QCD background
  - Special VBF production
  - Sensitive to WWH VBF production
  - not sensitive to ZZH VBF

- Existing results for inclusive VBF (H->bb)
  - ATLAS in Run 1
    - observed (expected) upper limit : 4.4 (5.4) x SM
  - CMS in Run 1
    - observed (expected) significance : 2.2 (0.8) x SM
    - observed (expected) upper limit : 5.5 (2.5) x SM
  - CMS in Run 2 (2015 data)
    - observed (expected) upper limit: 3.0 (5.0) x SM

VBF H(bb)γ : event selection

ATLAS-CONF-2016-063

- Trigger:
  - L1 trigger: single photon (pT > 25 GeV)
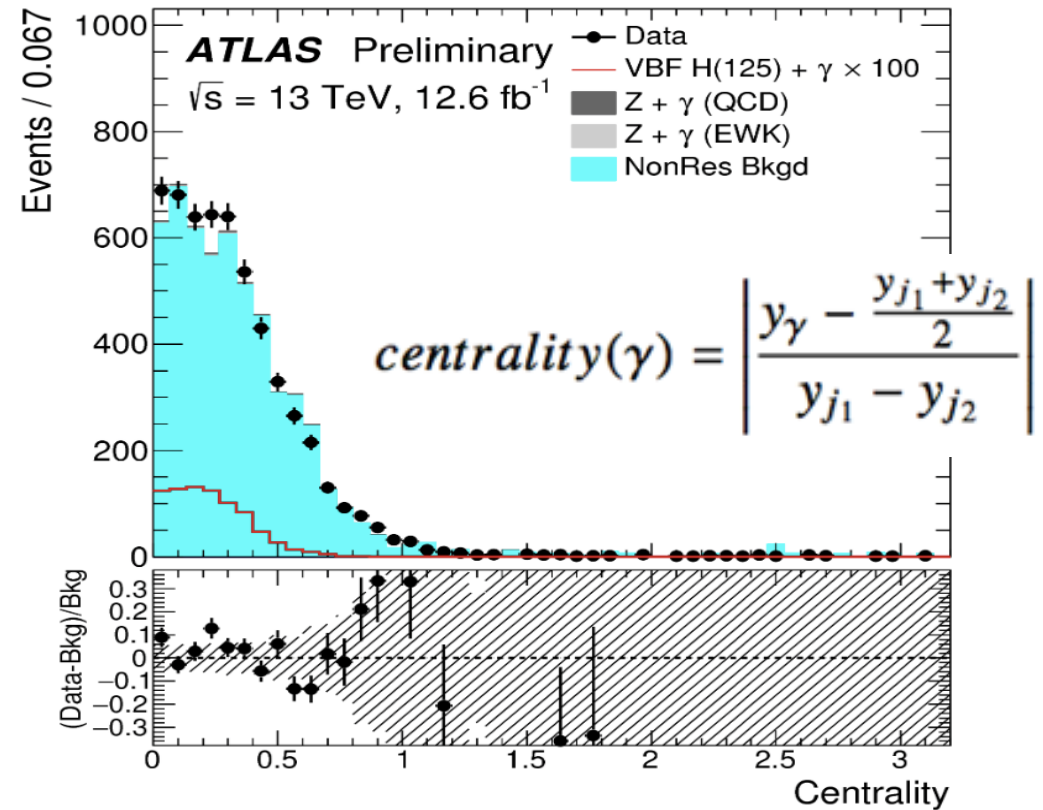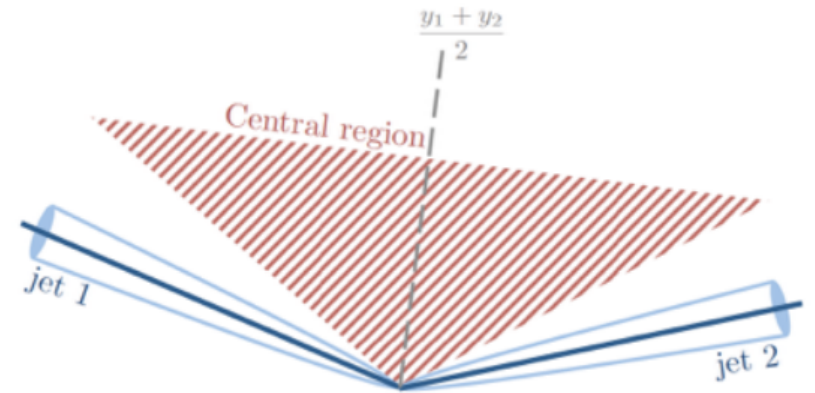 - High level trigger: 4 jets pT > 35 GeV, mjj> 700 GeV

- Offline Selection:
  - Tight ID photon, pT > 30 GeV
  - 4 jets with pT> 40 GeV
  - 2 central($|\eta|$<2.5) b-tagged jets
  - pT(bb)>80GeV
  - mjj> 800 GeV

- BDT discriminant

$$\Delta R(jet, \gamma), m_{jj}, \Delta \eta_{jj}, H_T^{soft}, jet\ width, \gamma\ centrality, p_T^{balance}$$

- Define 3 regions with different S/B

- Fit m$_{bb}$ in 3 regions

$$centrality_y(\gamma) = \left| \frac{y_\gamma - \frac{y_{j_1}+y_{j_2}}{2}}{y_{j_1} - y_{j_2}} \right|$$

ATLAS Preliminary
$\sqrt{s}$ = 13 TeV, 12.6 fb^{-1}

- Data
- VBF H(125) + $\gamma \times 100$
- Z + γ (QCD)
- Z + γ (EWK)
- NonRes Bkgd

Events / 0.067
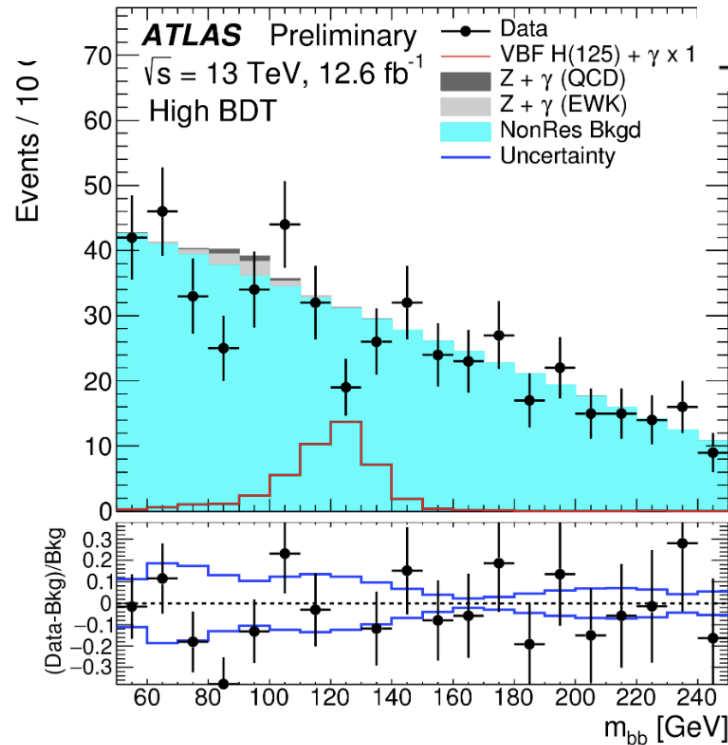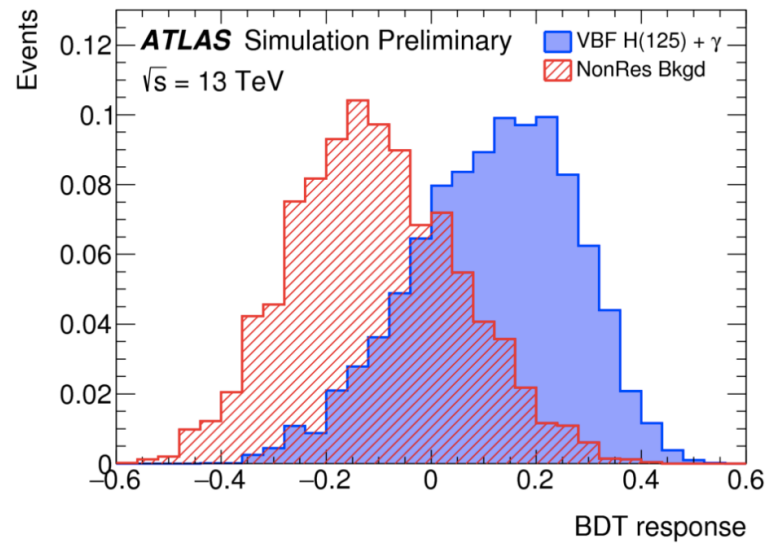
(Data-Bkg)/Bkg

Centrality

VBF H(bb)γ: signal extraction

- Non-resonant background (γ+jets) estimated with 2nd order polynomial fit.

- Simultaneous fit on three signal regions
  - Low/medium/high BDT regions

BDT output

High BDT score region

Result	$H(\to b\bar{b}) + \gamma jj$	$Z(\to b\bar{b}) + \gamma jj$
Expected significance	0.4	1.3
Expected p-value	0.4	0.1
Observed p-value	0.9	0.4
Expected limit	$6.0\ {}^{+2.3}_{-1.7}$	$1.8\ {}^{+0.7}_{-0.5}$
Observed limit	4.0	2.0
Observed signal strength μ	$-3.9\ {}^{+2.8}_{-2.7}$	$0.3\ \pm 0.8$

VBF H (bb) γ production cross section limit

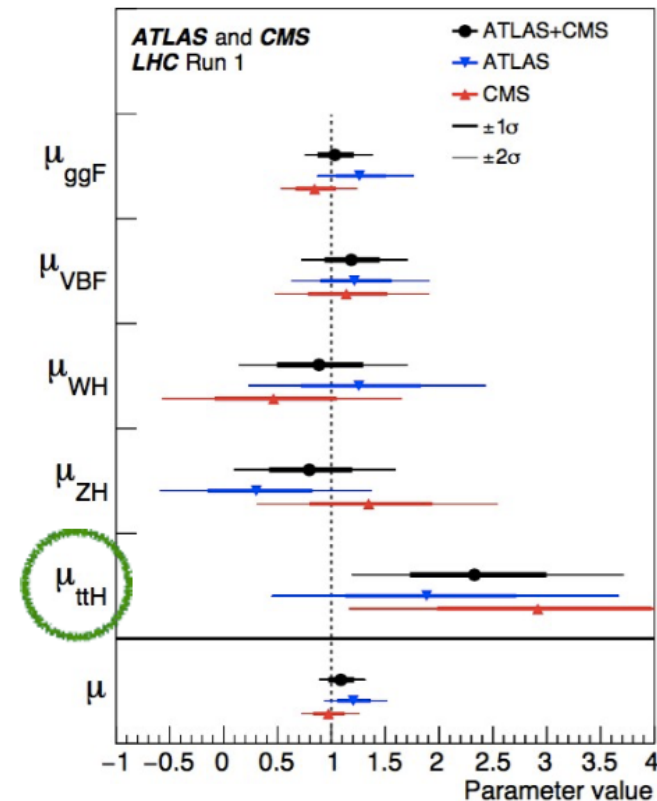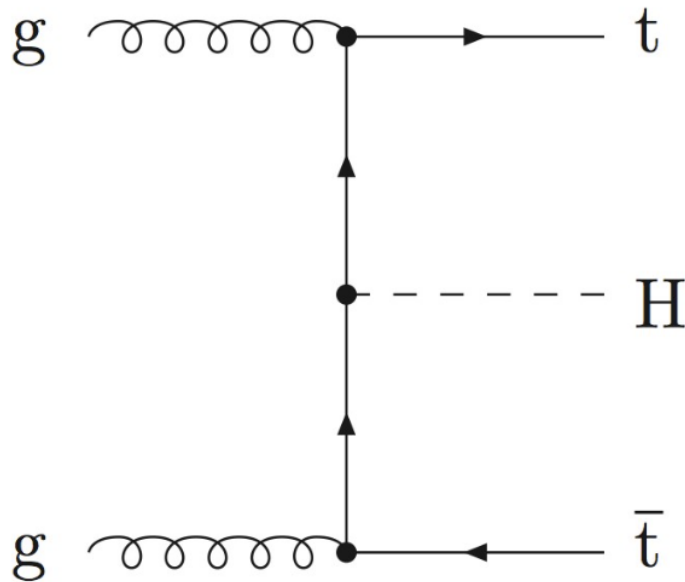➤ Expected 95% CL limit:

$$6.0^{+2.3}_{-1.7}$$

➤ Observed 95% CL limit:

$$4 \times (\sigma \times BR)^{SM}$$
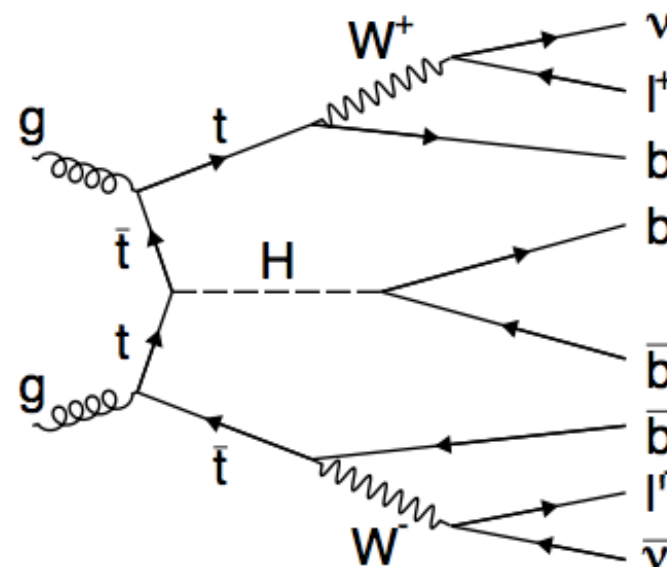
Higgs-top Yukawa coupling
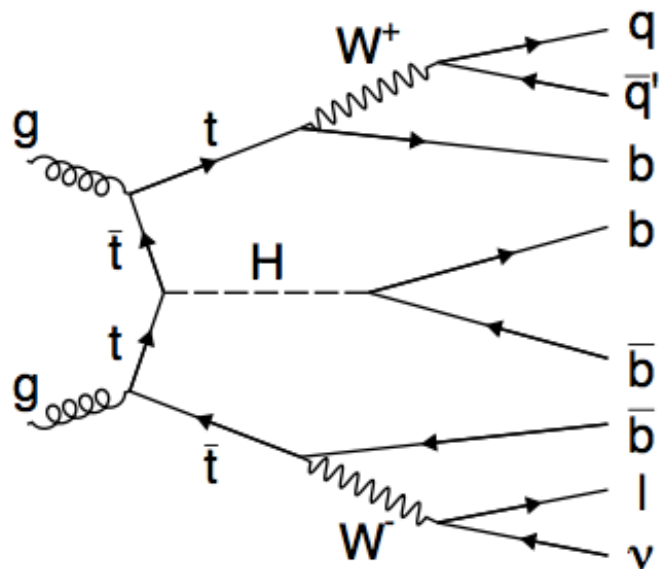
- Direct measurement of Higgs-Top coupling via ttH production.
- ttH signal strength (μ_{ttH}) measured in LHC Run 1
  - 4.4 sigma observed significance (ATLAS+CMS run1 combination)
  - 2.0 sigma expected significance

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ttH(bb)
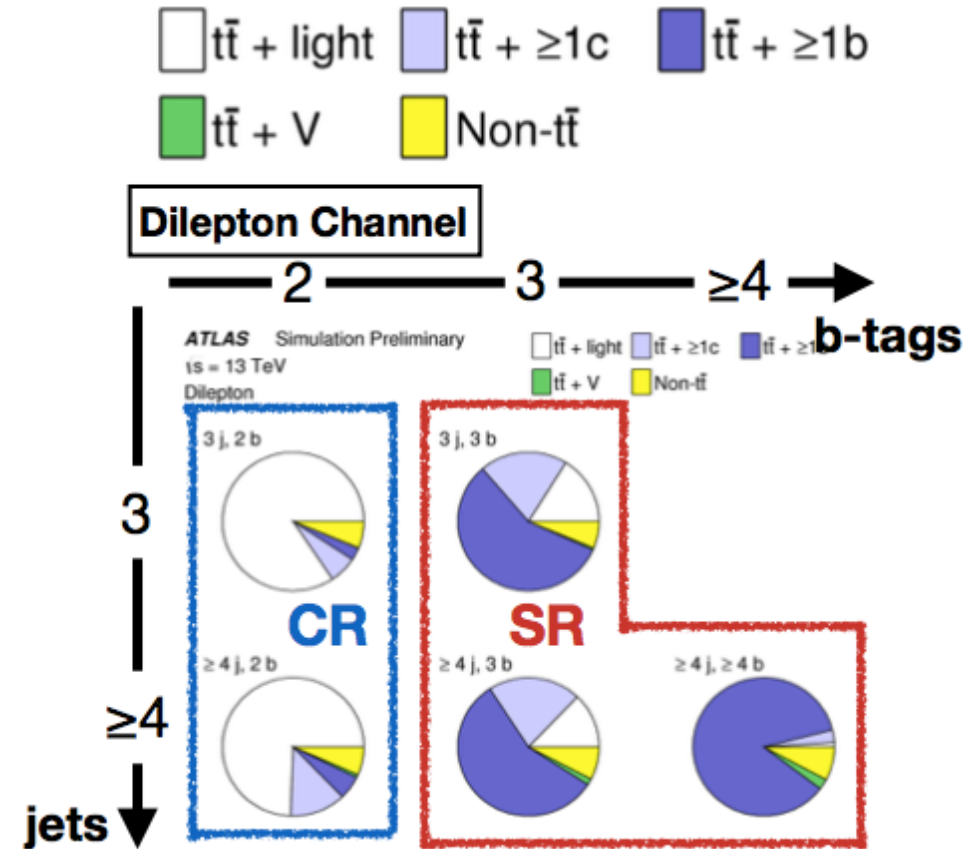
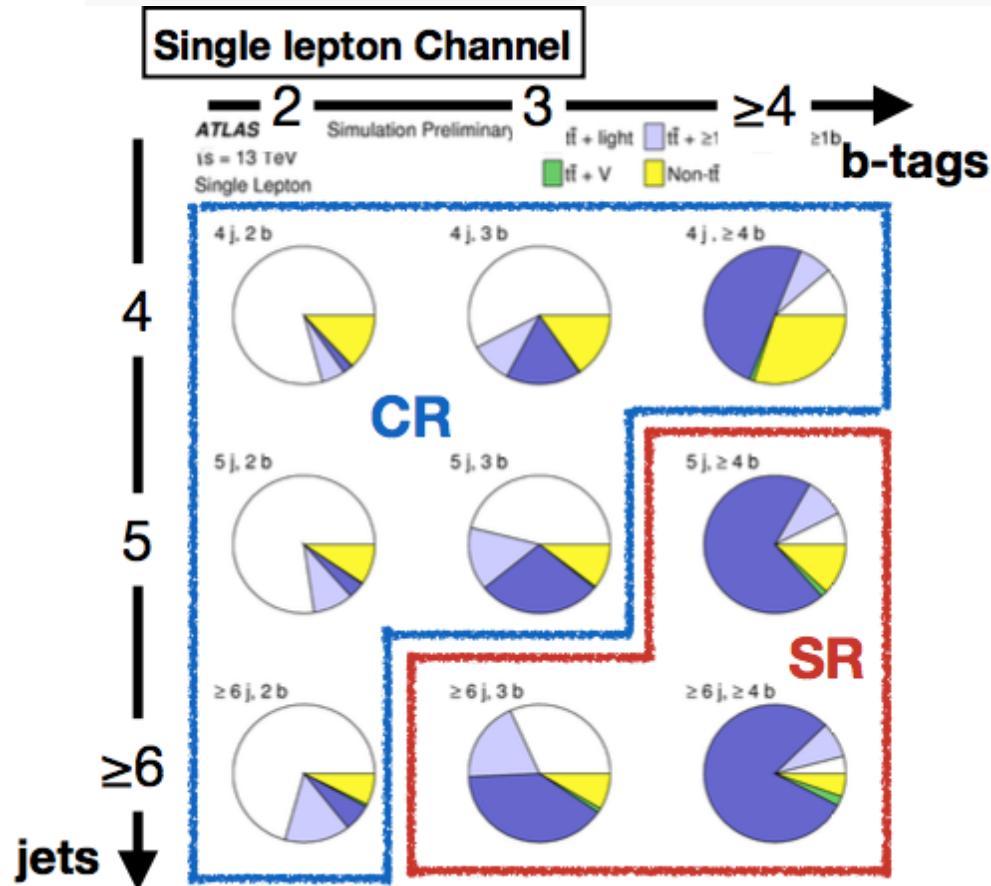**Single Lepton Channel**
- 1 light lepton (e,μ)
- At least 4 jets
- At least 2 b-tagged jets

Dilepton Channel
- 2 opposite charge light leptons (e,μ)
- At least 3 jets
- At least 2 b-tagged jets
- Z mass veto
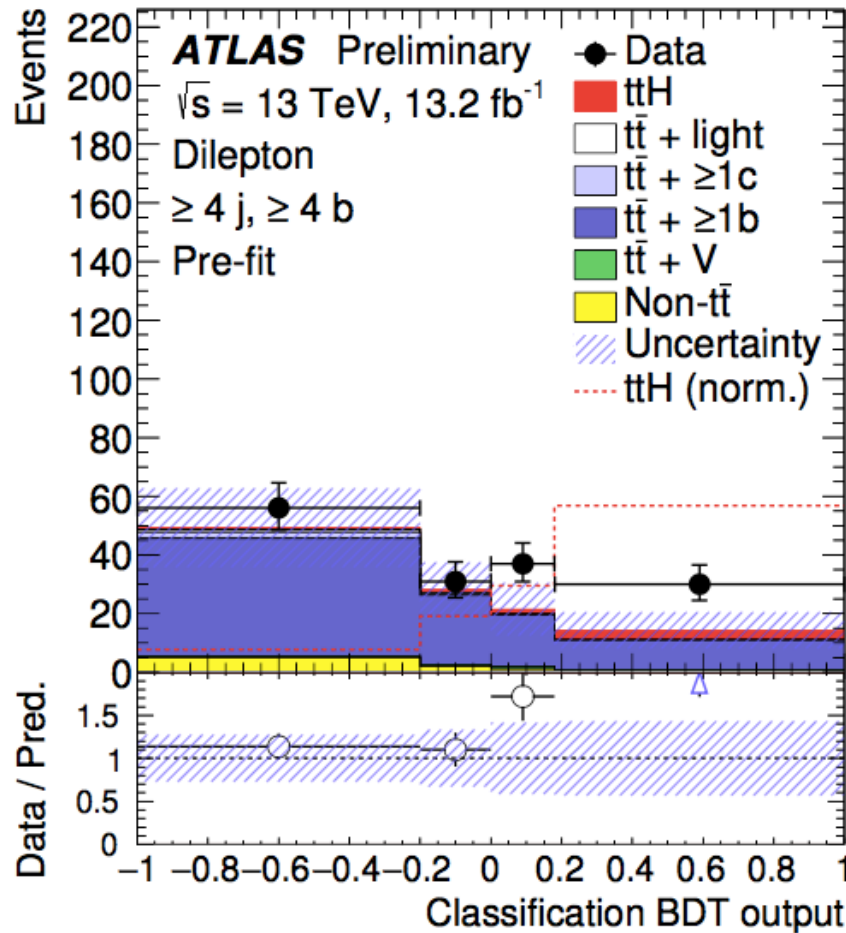
ttH(bb)

Signal Region (SR) : Enriched in signal.

Control Region (CR) : Use to constraint backgrounds.

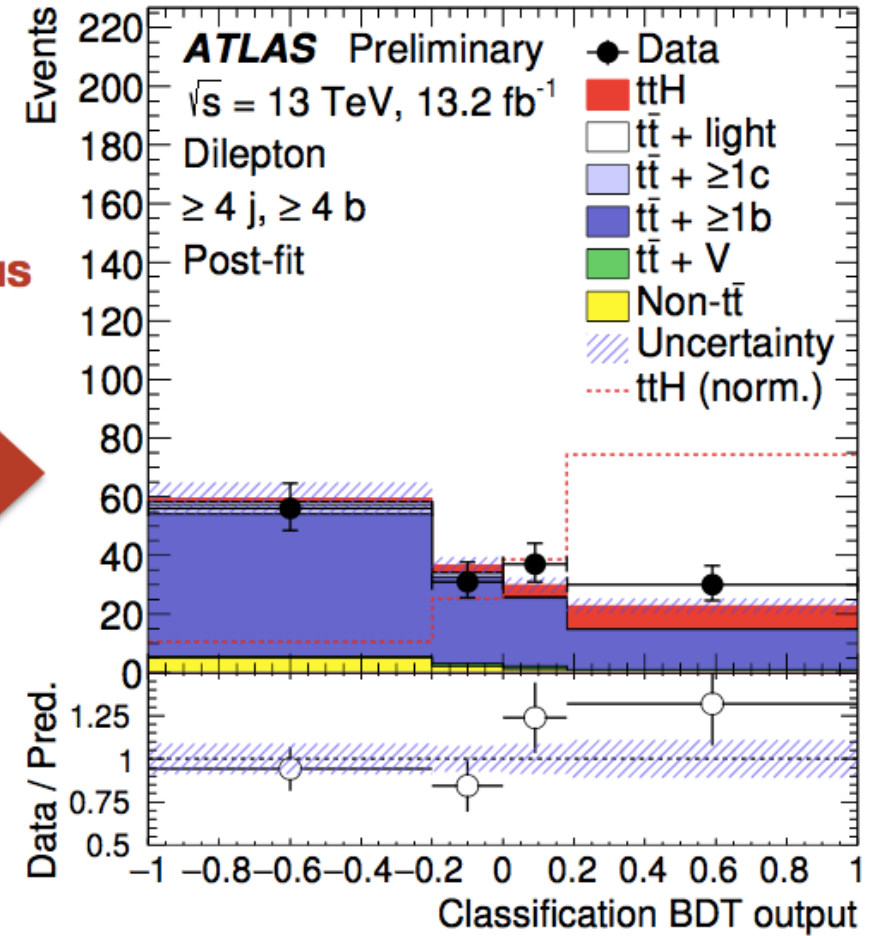tt + ≥1 bjet, tt + ≥1 cjet, and tt + light jets are the dominant backgrounds

ttH(bb)

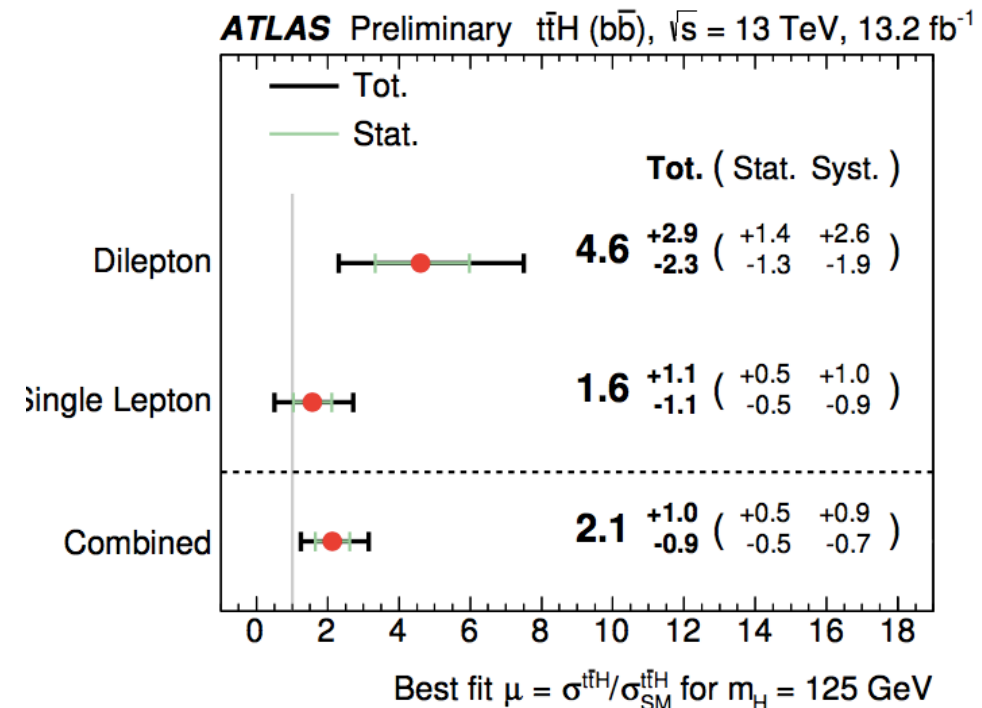- In SR, "Classification BDT" is used to extract signal in
- Simultaneous fit to all region

ttH(bb)

- Summary of signal strength measurements
- Major systematics: tt+X modelling, jet flavor tagging

Uncertainty source	$\Delta\mu$	
$t\bar{t}+ \geq 1b$ modelling	+0.53	−0.53
Jet flavour tagging	+0.26	−0.26
$t\bar{t}H$ modelling	+0.32	−0.20
Background model statistics	+0.25	−0.25
$t\bar{t}+ \geq 1c$ modelling	+0.24	−0.23
Jet energy scale and resolution	+0.19	−0.19
$t\bar{t}+$light modelling	+0.19	−0.18
Other background modelling	+0.18	−0.18
Jet-vertex association, pileup modelling	+0.12	−0.12
Luminosity	+0.12	−0.12
$t\bar{t}Z$ modelling	+0.06	−0.06
Light lepton (e, μ) ID, isolation, trigger	+0.05	−0.05
Total systematic uncertainty	+0.90	−0.75
$t\bar{t}+ \geq 1b$ normalisation	+0.34	−0.34
$t\bar{t}+ \geq 1c$ normalisation	+0.14	−0.14
Statistical uncertainty	+0.49	−0.49
Total uncertainty	+1.02	−0.89

ATLAS Preliminary $t\bar{t}H$ (b$\bar{b}$), $\sqrt{s}$ = 13 TeV, 13.2 fb^{-1}

	Tot. (Stat. Syst.)
Dilepton	4.6 $^{+2.9}_{-2.3}$ ($^{+1.4}_{-1.3}$ $^{+2.6}_{-1.9}$)
Single Lepton	1.6 $^{+1.1}_{-1.1}$ ($^{+0.5}_{-0.5}$ $^{+1.0}_{-0.9}$)
Combined	2.1 $^{+1.0}_{-0.9}$ ($^{+0.5}_{-0.5}$ $^{+0.9}_{-0.7}$)

Best fit $\mu = \sigma^{t\bar{t}H}/\sigma^{t\bar{t}H}_{SM}$ for m_H = 125 GeV

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ttH (multi-leptons) analysis: event selection and background

Higgs decay mode	Branching ratio [%]
H → bb	58.1
H → WW	21.5
H → ττ	6.3
H → ZZ	2.6
H → γγ	0.23

t̄tH(multileptons) channel has many possible final states → focus on those with clean signature and low backgrounds.

t̄tH(multileptons) Feynman diagram
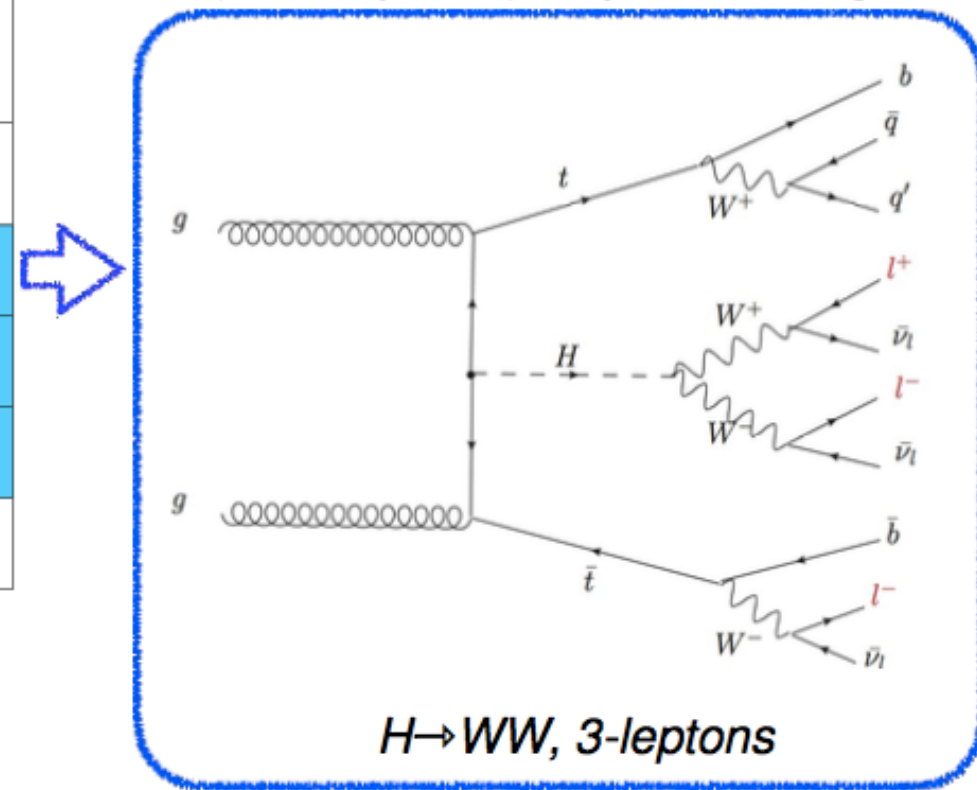
H→WW, 3-leptons
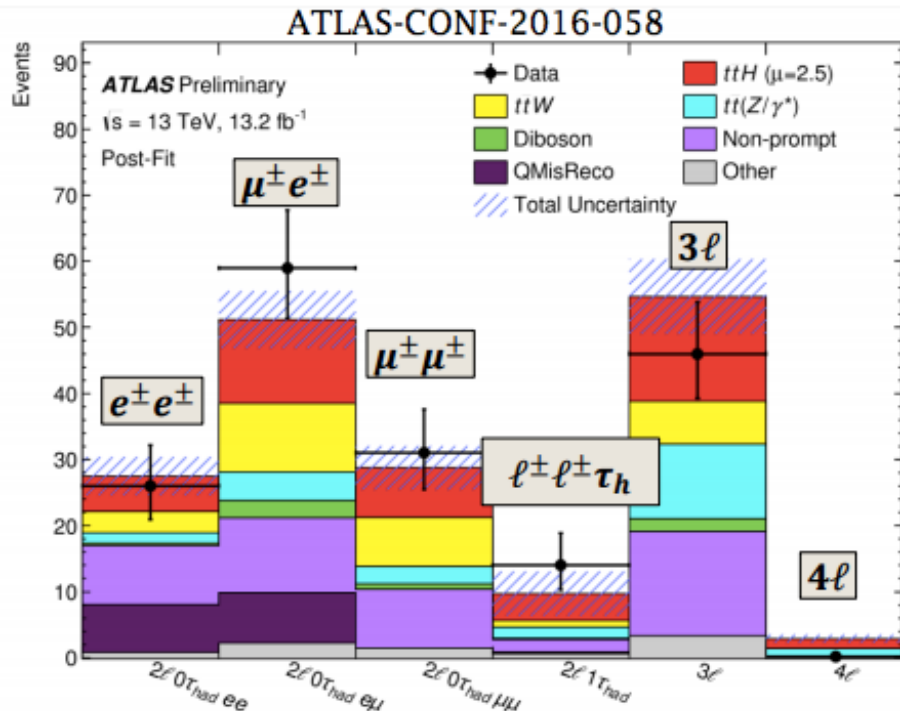
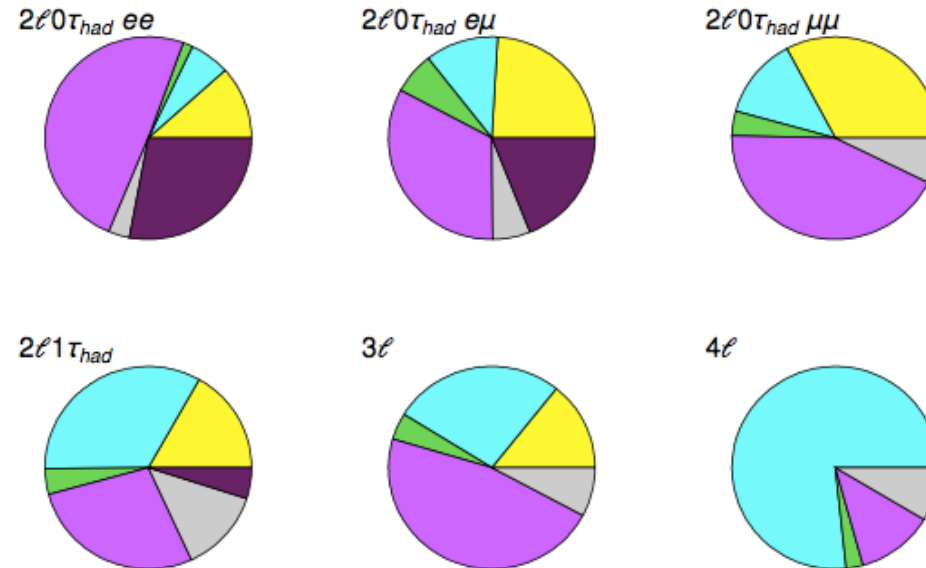# ttH (multi-leptons) analysis: event selection and background

- two same charge light leptons + no $\tau_{had} \rightarrow 2l \, 0\tau_{had}$

➤ (at least 5 jets and at least 1 bjet)

- two same charge light leptons + one $\tau_{had} \rightarrow 2l \, 1\tau_{had}$

➤ (at least 4 jets and at least 1 bjet)

- three light leptons $\rightarrow 3l$ (≥ 4jets, ≥ 1bjet, or 3jets, ≥ 2bjets)

- four light leptons $\rightarrow 4l$ (≥ 2jets, ≥ 1bjet)

Cut and count analysis in 6 categories

ttH (multi-leptons) analysis: Results

- Systematic uncertainty is dominated by
  - non-prompt background estimates in the $2l\,0\tau_{had}$, $2l\,1\tau_{had}$, and $3l$ channels.
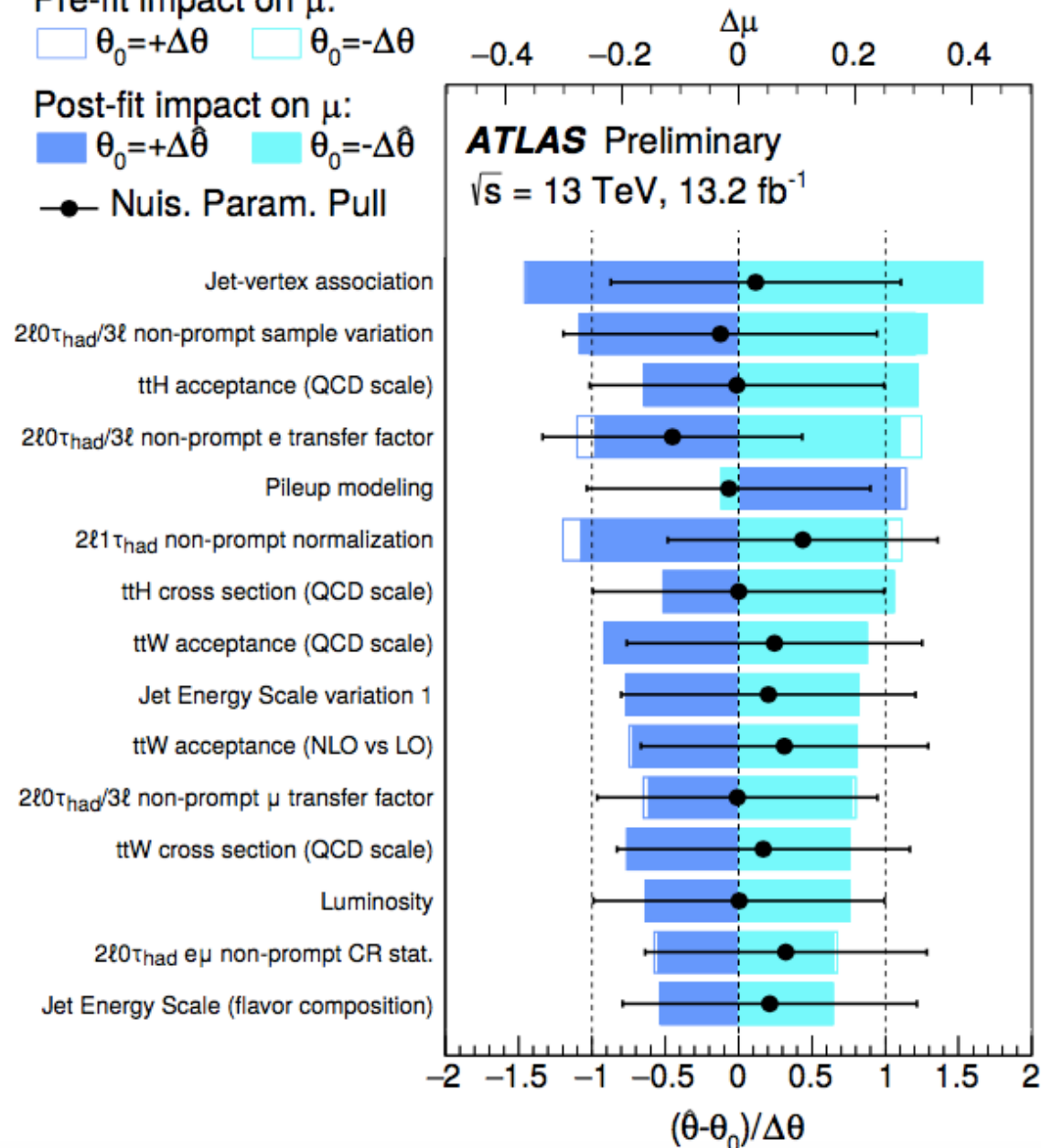 - ttV modelling , pileup modelling

ttH analyses: combination
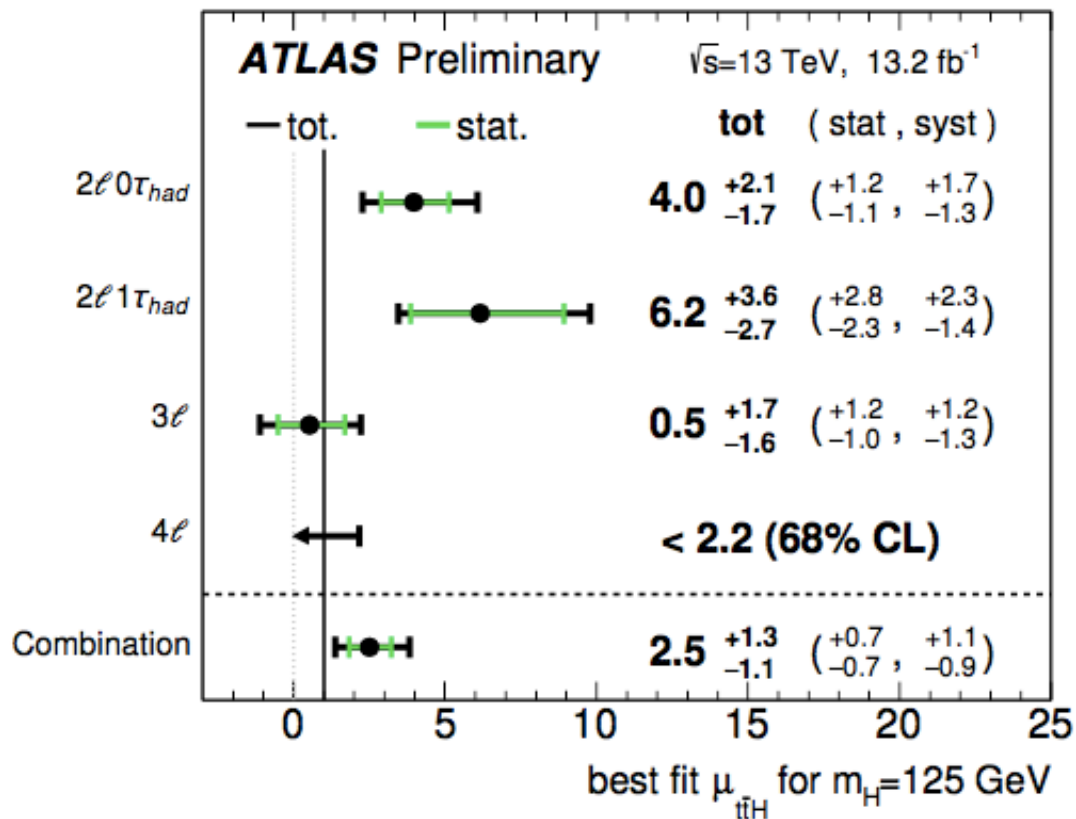
- Summary of the ttH signal strength measurements
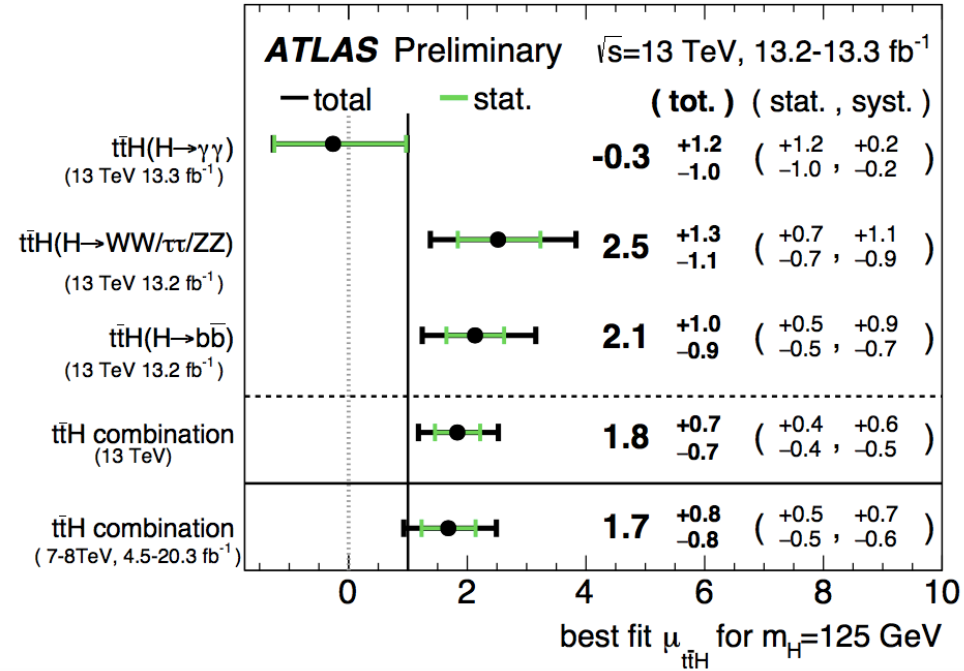
- Expected and observed significance

Channel	Significance	
	Observed [σ]	Expected [σ]
$t\bar{t}H, H \to \gamma\gamma$	-0.2	0.9
$t\bar{t}H, H \to (WW, \tau\tau, ZZ)$	2.2	1.0
$t\bar{t}H, H \to b\bar{b}$	2.4	1.2
$t\bar{t}H$ combination	2.8	1.8

Summary

- The search for the Higgs decays to b-quarks in ATLAS
  - Using part of 2015-2016 data (~13fb^{-1})
  - VH(bb) : Expected (observed) significance: 1.92 (0.42)
  - VBF H(bb)γ: first ATLAS result (ever)
    Expected (observed) 95% CL limit: 6 (4) times the SM expectation

- A search for ttH production process has been performed in three channels
  - Using part of 2015-2016 data (~13fb^{-1})
  - ttH (bb), ttH (multileptons), and ttH (γγ)
  - The best fit value of the ttH signal strength is 1.8 ± 0.7.
  - Observed significance: 2.8 sigma (1.8 expected from SM).

- The results with full 2015-2016 dataset are coming soon.

- Stay Tuned!

ttH (multi-lepton) systematics

Uncertainty Source	$\Delta\mu$	
Non-prompt leptons and charge misreconstruction	+0.56	−0.64
Jet-vertex association, pileup modeling	+0.48	−0.36
$t\bar{t}W$ modeling	+0.29	−0.31
$t\bar{t}H$ modeling	+0.31	−0.15
Jet energy scale and resolution	+0.22	−0.18
$t\bar{t}Z$ modeling	+0.19	−0.19
Luminosity	+0.19	−0.15
Diboson modeling	+0.15	−0.14
Jet flavor tagging	+0.15	−0.12
Light lepton (e, μ) and τ_{had} ID, isolation, trigger	+0.12	−0.10
Other background modeling	+0.11	−0.11
Total systematic uncertainty	+1.1	−0.9

q $\bar{b}$