Recent ATLAS measurements in Higgs to diboson channels

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On behalf of the ATLAS collaboration

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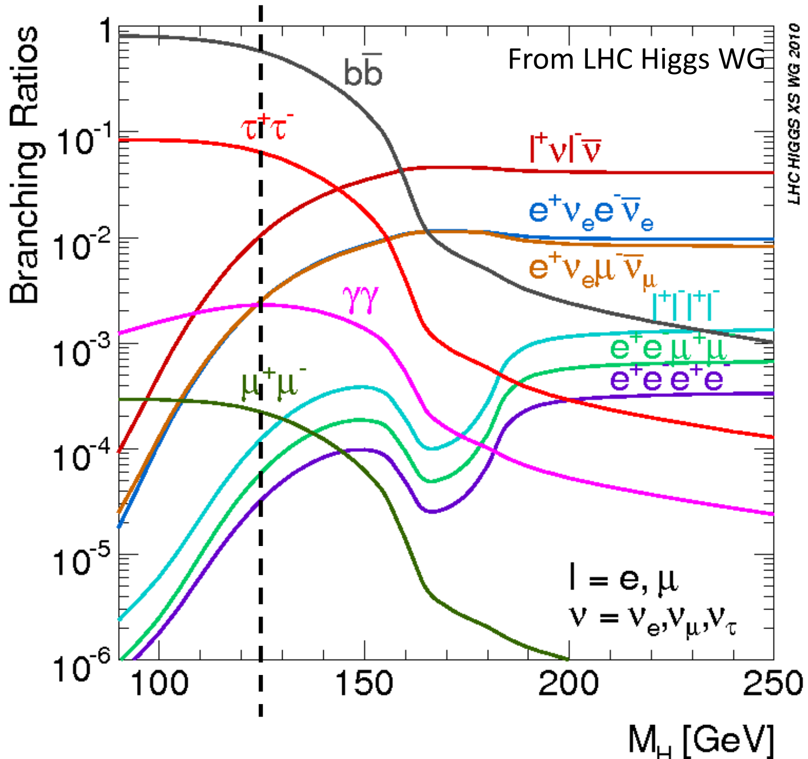
Introduction

- Higgs boson measurements with diboson channels
  - $H \rightarrow \gamma\gamma$, $H \rightarrow ZZ^* \rightarrow llll$, $H \rightarrow WW^* \rightarrow l\nu l\nu$
    - Small but accessible branching fractions
    - Final states relatively clean, good signal-over-background ratio
    - Kinematic information (mostly) reconstructable
      - 4l, $\gamma\gamma$ fully reconstructable, $l\nu l\nu$ with missing neutrinos but have larger Br.



Expected total production σ at 13 TeV (from YR4) with mH=125.09 GeV:
$\sigma_{H\rightarrow WW\rightarrow l\nu l\nu}$ = 591 fb, $\sigma_{H\rightarrow\gamma\gamma}$ = 126 fb,
$\sigma_{H\rightarrow ZZ\rightarrow llll}$ = 7 fb

Contribution from different production modes: ggF (~87%), VBF (~7%), VH, ttH, … (~6%)

Outline

Observation of the Higgs boson at 13 TeV

Measurements of total and fiducial cross-sections

Measurements of different production modes

Determination of Higgs couplings

Determination of Higgs spin / CP, mass, width

Thanks for machine and detector teams to smoothly deliver impressive amount of 13 TeV data!

"Observation" of the Higgs boson with 13 TeV data
$\Rightarrow$ An important milestone towards future precision measurement

Measurements of $H \rightarrow ZZ^* \rightarrow llll$ (14.8 fb^{-1} at 13 TeV)[1]
Measurements of $H \rightarrow \gamma\gamma$ (13.3 fb^{-1} at 13 TeV)[2]

+ other recent updates in diboson channels

Search for ttH production with multilepton and $\gamma\gamma$ final states (13.3fb^{-1} at 13 TeV)[3]
Differential cross-section measurement of $H \rightarrow WW^* \rightarrow e\nu\mu\nu$ (20.3fb^{-1} at 8 TeV)[4]

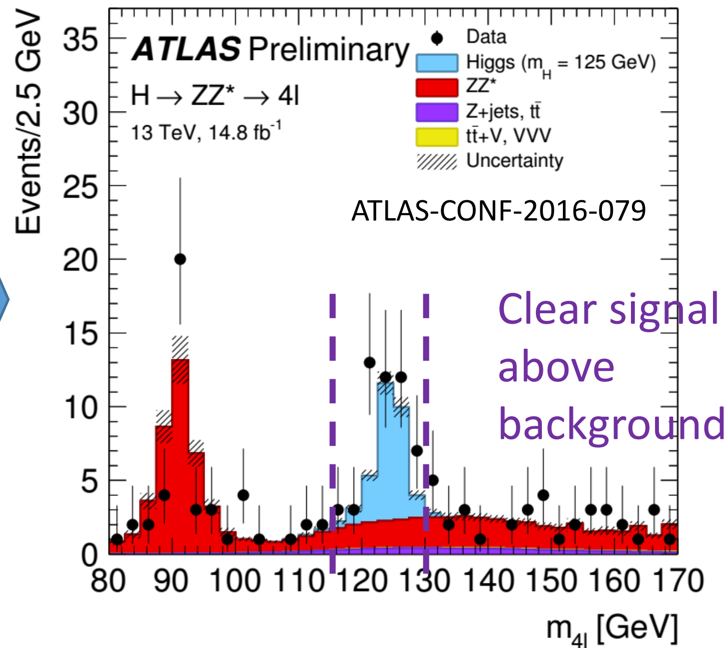
1. ATLAS-CONF-2016-079; 2. ATLAS-CONF-2016-067
3. ATLAS-CONF-2016-058; 13 TeV ttH combination covered in E.Shabalina's talk in the afternoon
4. arXiv:1604.02997v1, submitted to JHEP

H→ZZ*→llll 13 TeV

Selecting four charged leptons

Fiducial phase space

Lepton definition	
Muons: $p_T > 5$ GeV, $\|\eta\| < 2.7$	Electrons: $p_T > 7$ GeV, $\|\eta\| < 2.47$
Pairing	
Leading pair:	SFOS lepton pair with smallest $\|m_Z - m_{\ell\ell}\|$
Sub-leading pair:	Remaining SFOS lepton pair with smallest $\|m_Z - m_{\ell\ell}\|$
Event selection	
Lepton kinematics:	Leading leptons $p_T > 20, 15, 10$ GeV
Mass requirements:	$50 < m_{12} < 106$ GeV; $12 < m_{34} < 115$ GeV
Lepton separation:	$\Delta R(\ell_i, \ell_j) > 0.1(0.2)$ for same(opposite)-flavour leptons
J/ψ veto:	$m(\ell_i, \ell_j) > 5$ GeV for all SFOS lepton pairs
Mass window:	$115 < m_{4\ell} < 130$ GeV



Fiducial and total cross-sections for pp→H with mH=125.09 GeV

Measured

$$\sigma^{4\ell}_{\text{fid,comb}} = 4.54^{+1.02}_{-0.90}\ \text{fb}$$

$$\sigma_{\text{tot}} = 81^{+18}_{-16}\ \text{pb}$$

Predicted

$$\sigma^{4\ell}_{\text{fid,SM}} = 3.07^{+0.21}_{-0.25}\ \text{fb}^{1)}$$

$$\sigma_{\text{tot,SM}} = 55.5^{+3.8}_{-4.4}\ \text{pb}$$

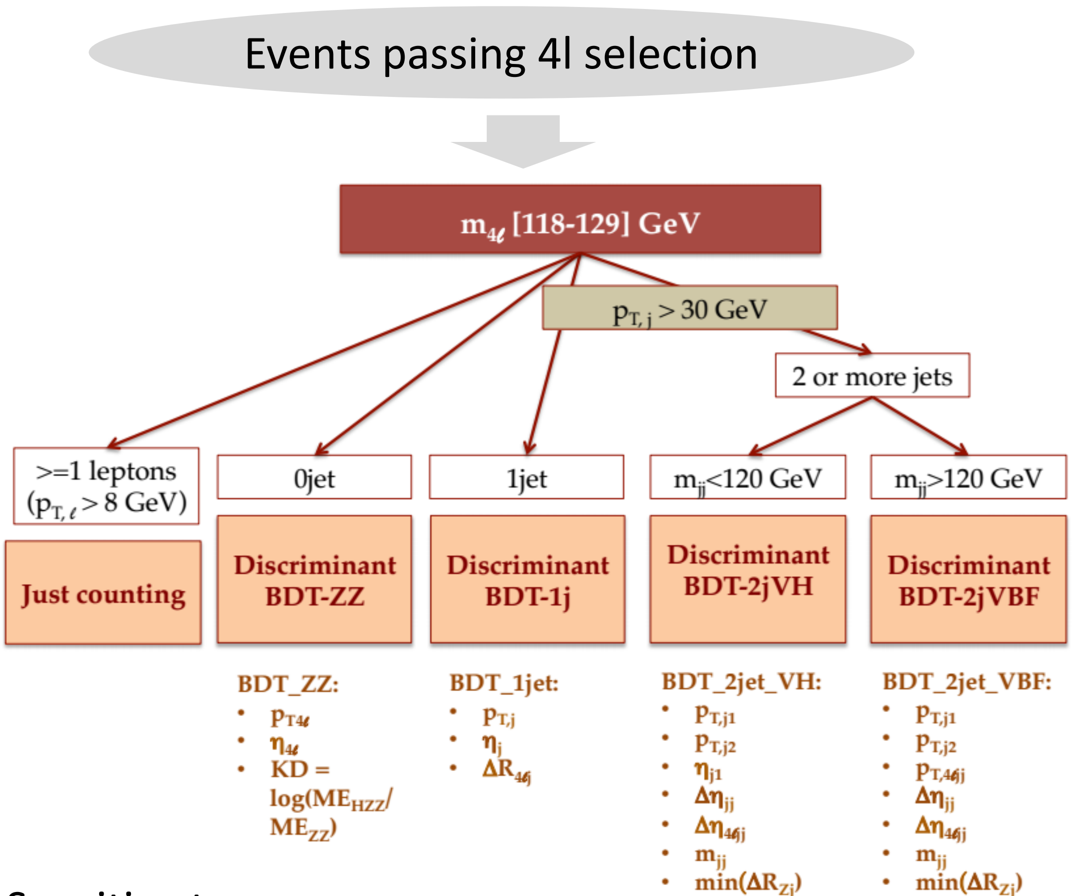
- Measured σ higher than SM prediction
- Total uncertainty O(20%), dominated by the data statistical unc.

1) total σ from YR4 x MC acceptance

H→ZZ*→llll 13 TeV

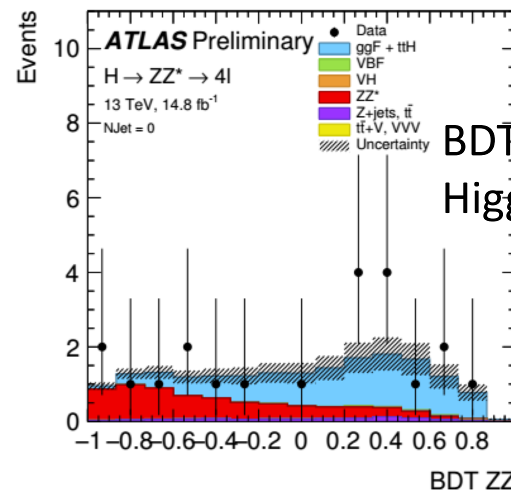
- Event categorization to explore different production modes

ATLAS-CONF-2016-079

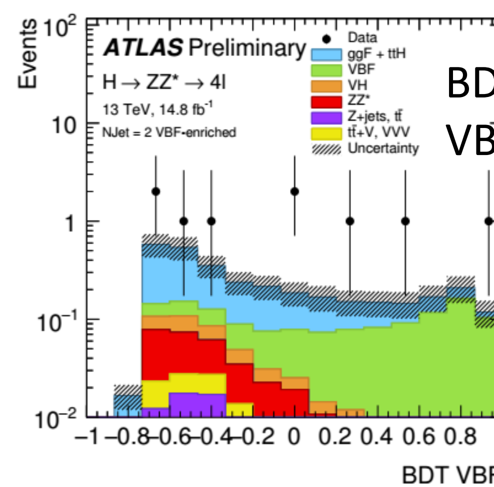


Sensitive to:

VH	ggF	ggF/VBF	VH	VBF



BDT in 0j: Higgs v.s. ZZ



BDT in VBF: VBF v.s. ggF

H→ZZ*→llll 13 TeV

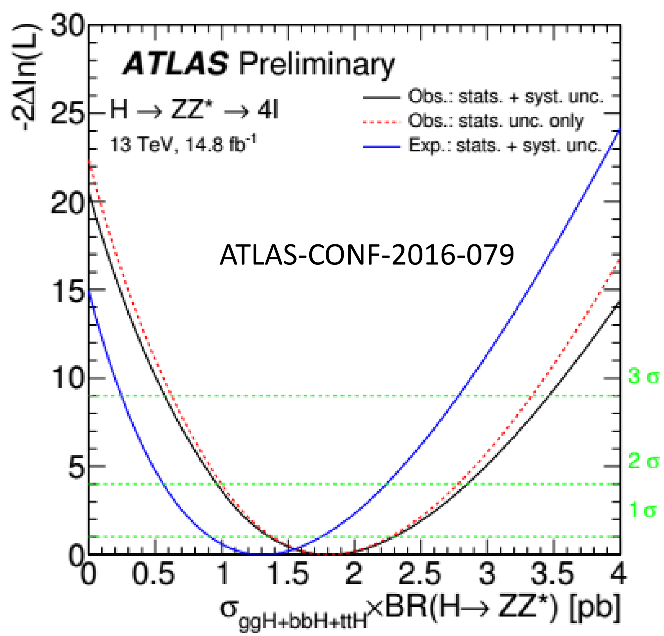
- Cross-section measurement for each production mode
  - A likelihood fit in each region to the BDT distributions, to extract the cross-section at total phase space

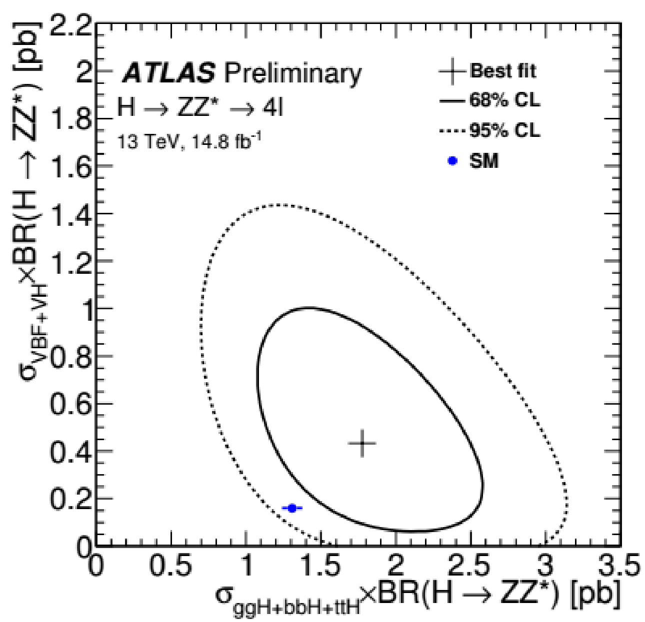
Measured

$$\sigma_{\mathrm{ggF}+b\bar{b}H+t\bar{t}H} \cdot \mathcal{B}(H \to ZZ^*) = 1.80^{+0.49}_{-0.44}\ \mathrm{pb}$$
$$\sigma_{\mathrm{VBF}} \cdot \mathcal{B}(H \to ZZ^*) = 0.37^{+0.28}_{-0.21}\ \mathrm{pb}$$
$$\sigma_{\mathrm{VH}} \cdot \mathcal{B}(H \to ZZ^*) = 0^{+0.15}\ \mathrm{pb}$$

Predicted

$$\sigma_{\mathrm{SM,ggF}+b\bar{b}H+t\bar{t}H} \cdot \mathcal{B}(H \to ZZ^*) = 1.31 \pm 0.07\ \mathrm{pb}$$
$$\sigma_{\mathrm{SM,VBF}} \cdot \mathcal{B}(H \to ZZ^*) = 0.100 \pm 0.003\ \mathrm{pb}$$
$$\sigma_{\mathrm{SM,VH}} \cdot \mathcal{B}(H \to ZZ^*) = 0.059 \pm 0.002\ \mathrm{pb}$$



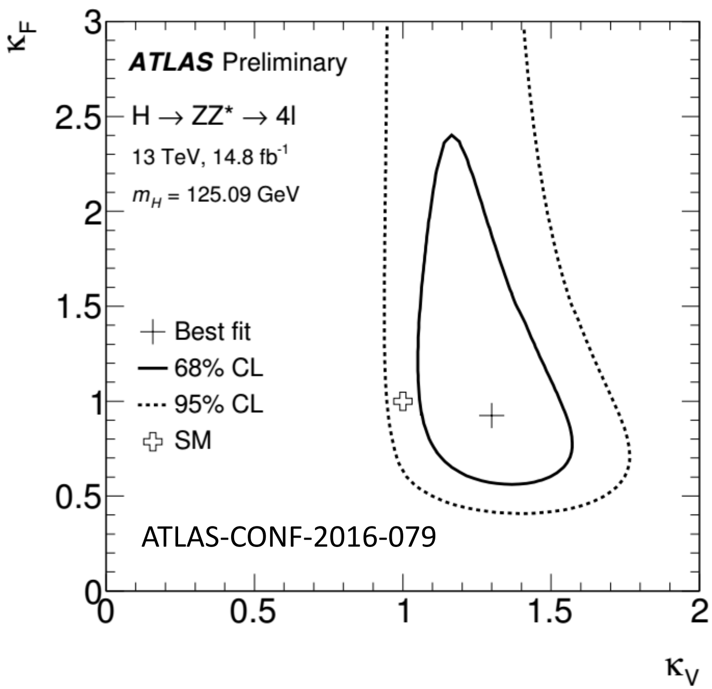


- Good significance in ggF, sensitivity to VBF, VH, … limited by data statistics

H→ZZ*→llll 13 TeV

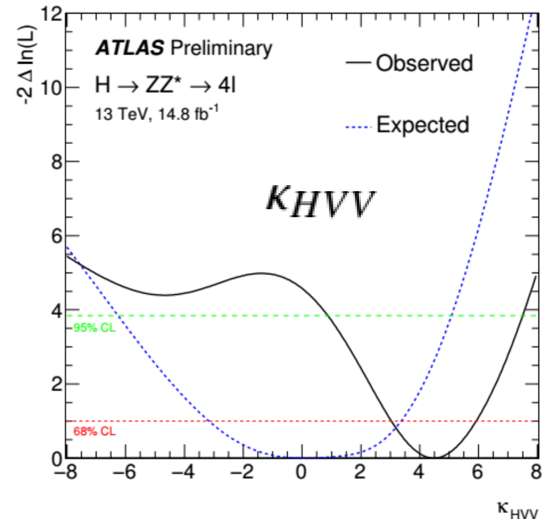
❑ Coupling measurements

In terms of LO coupling modifiers:



No obvious excess from the SM
Constrains similar (or slightly better) to Run I

In terms of EFT couplings defined in Higgs characterization model:



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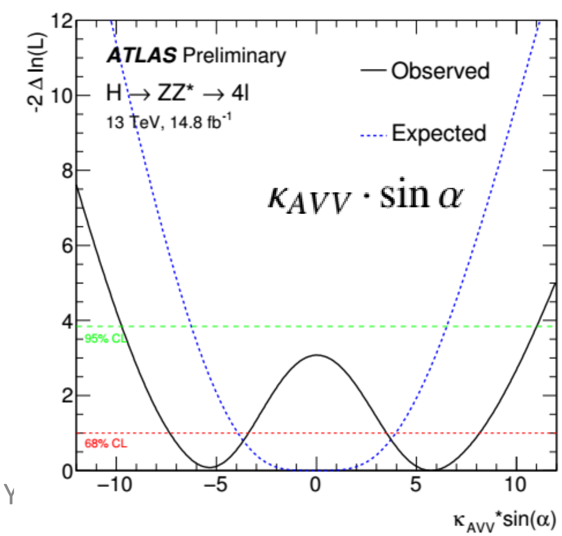


Non-zero minimum driven by data excess seen both in overall region and in VBF regions

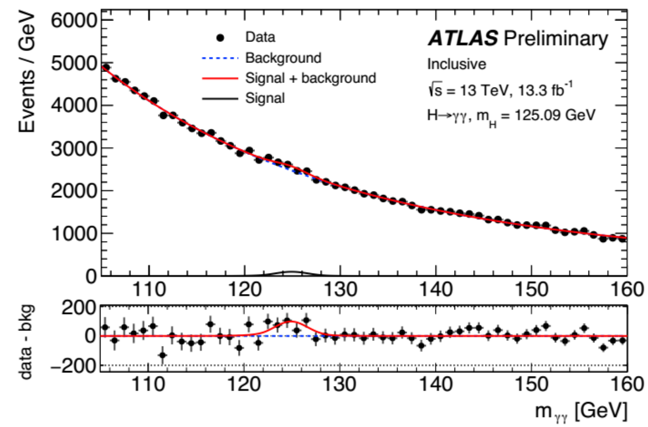
α is the mixing angle between 0^+ and 0^-

H→γγ 13 TeV

Fiducial cross-section measurements in three regions + 105< m(γγ) < 160 GeV

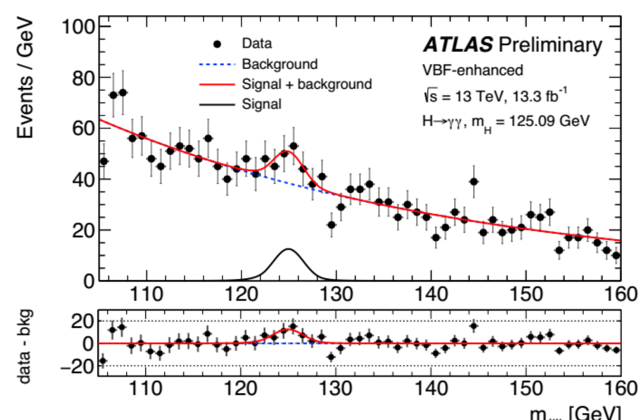
	diphoton baseline	VBF enhanced	single lepton
Photons	$\lvert\eta\rvert < 1.37$ or $1.52 < \lvert\eta\rvert < 2.37$ $p_T^{\gamma_1} > 0.35\, m_{\gamma\gamma}$ and $p_T^{\gamma_2} > 0.25\, m_{\gamma\gamma}$		
Jets	- - -	$p_T > 30$ GeV, $\lvert y\rvert < 4.4$ $m_{jj} > 400$ GeV, $\lvert\Delta y_{jj}\rvert > 2.8$ $\lvert\Delta\phi_{\gamma\gamma,jj}\rvert > 2.6$	- - -
Leptons	-	-	$p_T > 15$ GeV $\lvert\eta\rvert < 2.47$

Diphoton baseline region



Fiducial σ measured through a likelihood fit to observed m(γγ) spectrum in each region
- Signal parametrized via double-sided Crystal Ball
- Background modelled by exp. and polynomial functions

VBF enhanced region



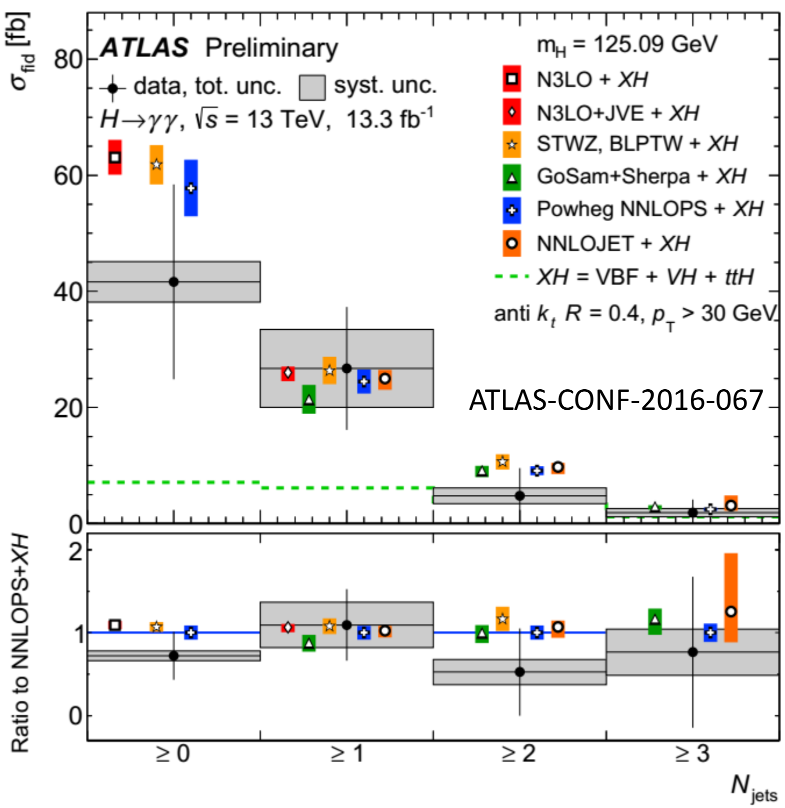
ATLAS-CONF-2016-067

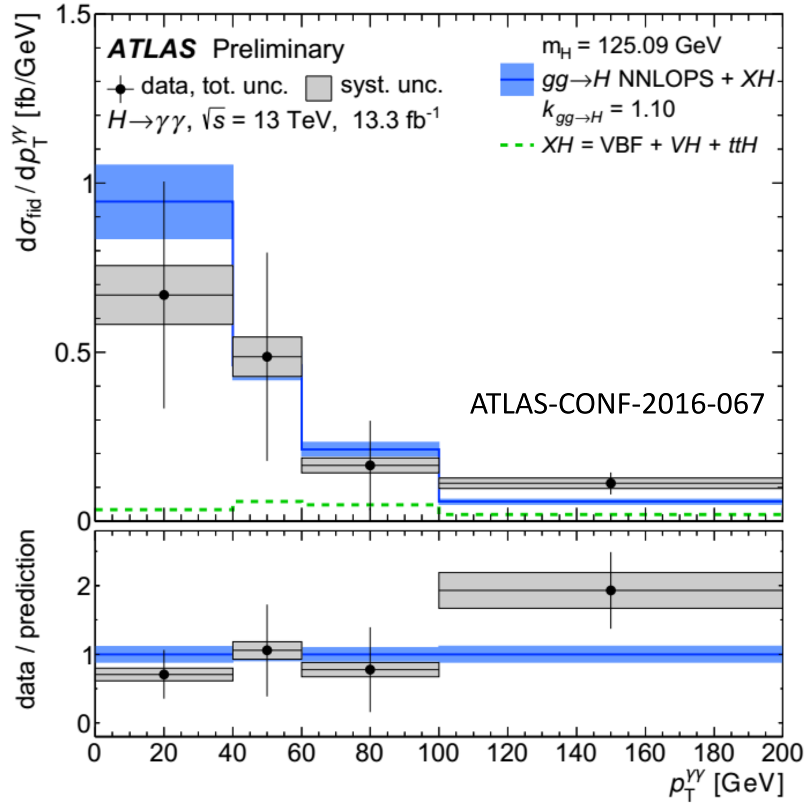
Fiducial region	Measured cross section (fb)	SM prediction (fb)	
Baseline	43.2 ± 14.9 (stat.) ± 4.9 (syst.)	$62.8^{+3.4}_{-4.4}$	[N^{3}LO + XH]
VBF-enhanced	4.0 ± 1.4 (stat.) ± 0.7 (syst.)	2.04 ± 0.13	[NNLOPS + XH]
single lepton	1.5 ± 0.8 (stat.) ± 0.2 (syst.)	0.56 ± 0.03	[NNLOPS + XH]

- Dominated by statistical uncertainty
- Main systematics: photon reconstruction and calibration, fit modelling, jet

H→γγ 13 TeV

- Differential measurement (N$_{jet}$, $p_T^{\gamma\gamma}$)





Measured for diphoton baseline region*

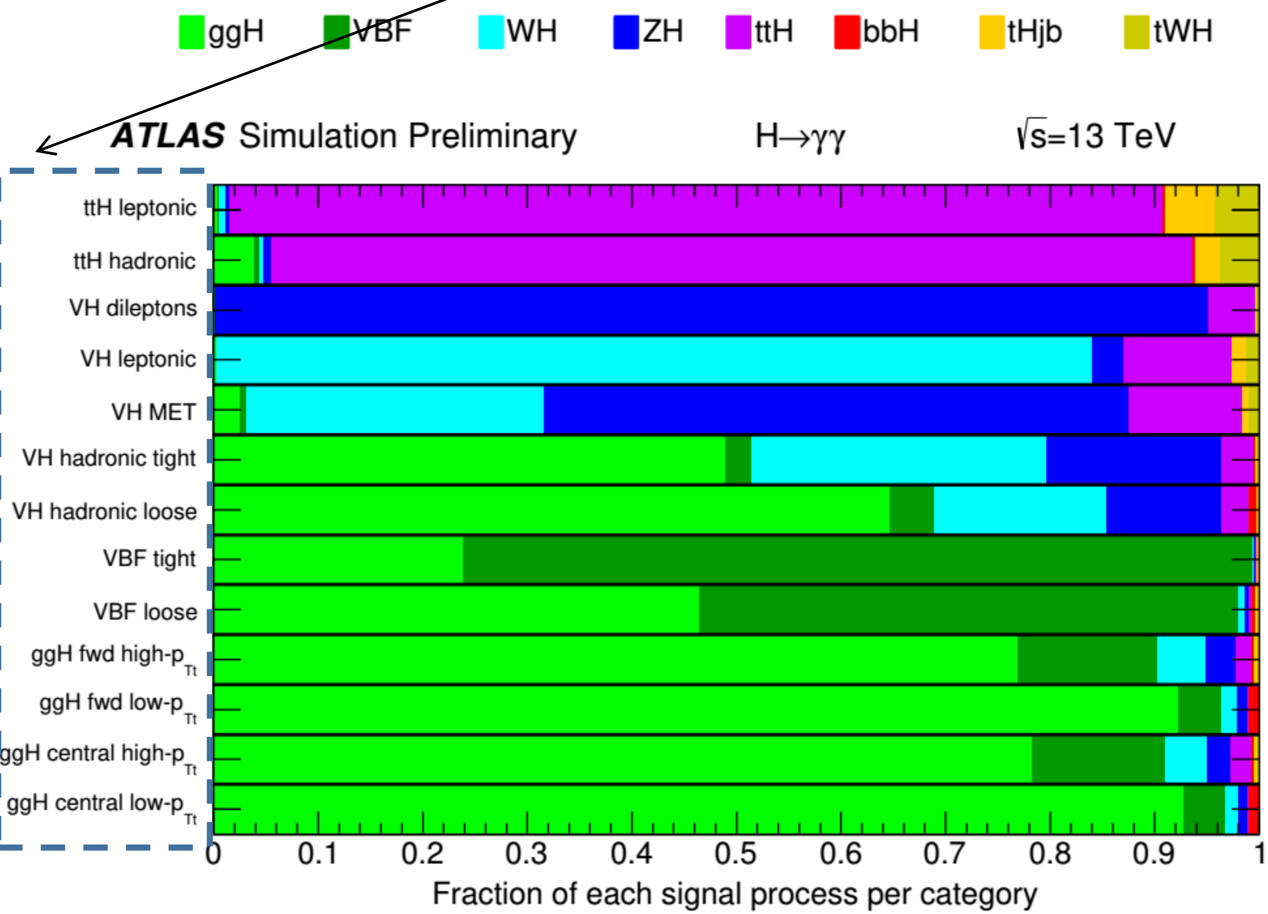
Slight discrepancy in 0-jet or low pT region; large data statistical error

* In addition to criteria listed on previous page, photon isolation pTcone20/pT<0.05

H→γγ 13 TeV

Events passing diphoton baseline selection

Event categorization and production mode contributions to each category



→ ≥ 1lepton, ≥ 2jets, b-tagging

→ = 0lepton, ≥ 5jets, b-tagging

→ ≥ 2lepton, 70<m(ll)<110 GeV

→ = 1lepton, cut MET

→ Harsh cut on MET

→ 50<m(jj)<150 GeV, tight BDT cut

→ 50<m(jj)<150 GeV, loose BDT cut

→ ≥ 2jets, tight VBF-BDT cut

→ ≥ 2jets, loose VBF-BDT cut

→ ≥ 1γ with |η|>0.95, pT(γγ)>70 GeV

→ ≥ 1γ with |η|>0.95, pT(γγ)<70 GeV

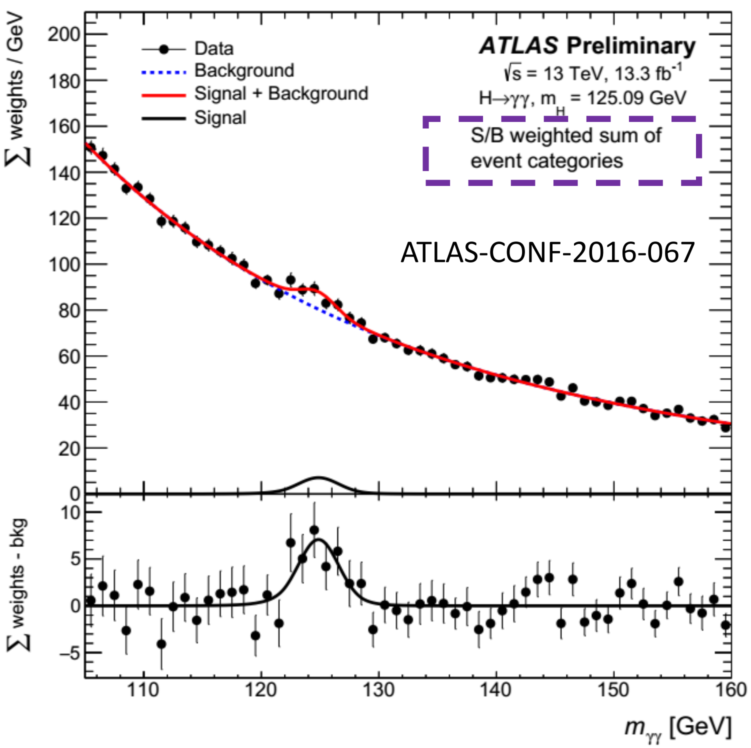
→ = 2γ with |η|<0.95, pT(γγ)>70 GeV

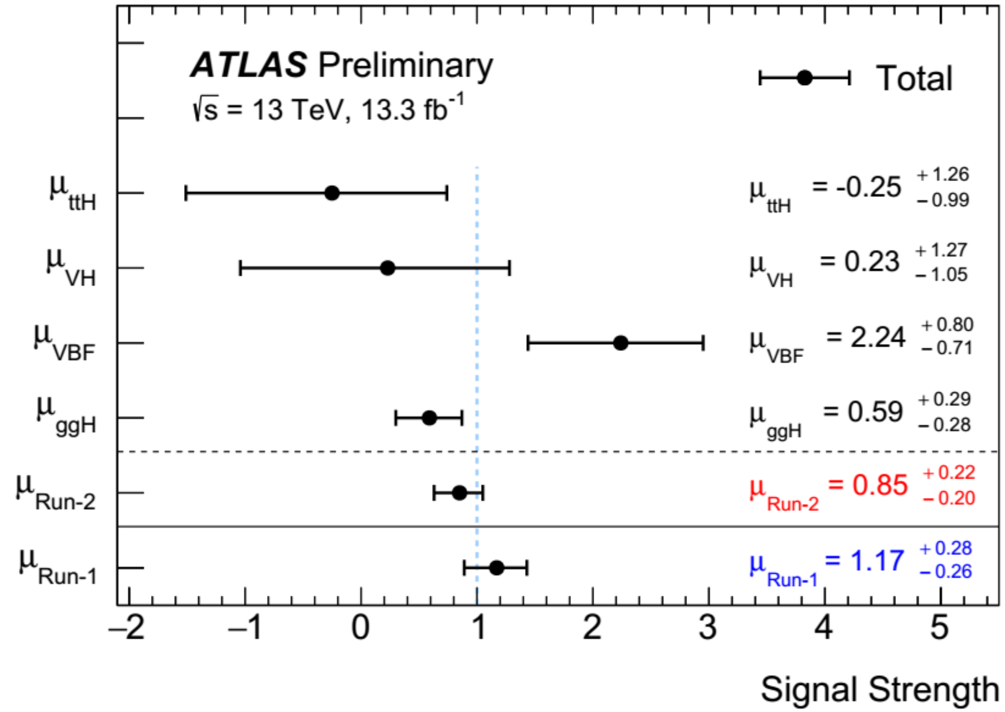
→ = 2γ with |η|<0.95, pT(γγ)<70 GeV

H→γγ 13 TeV

ATLAS-CONF-2016-067

Main sensitivity from high-pT ggF and VBF categories



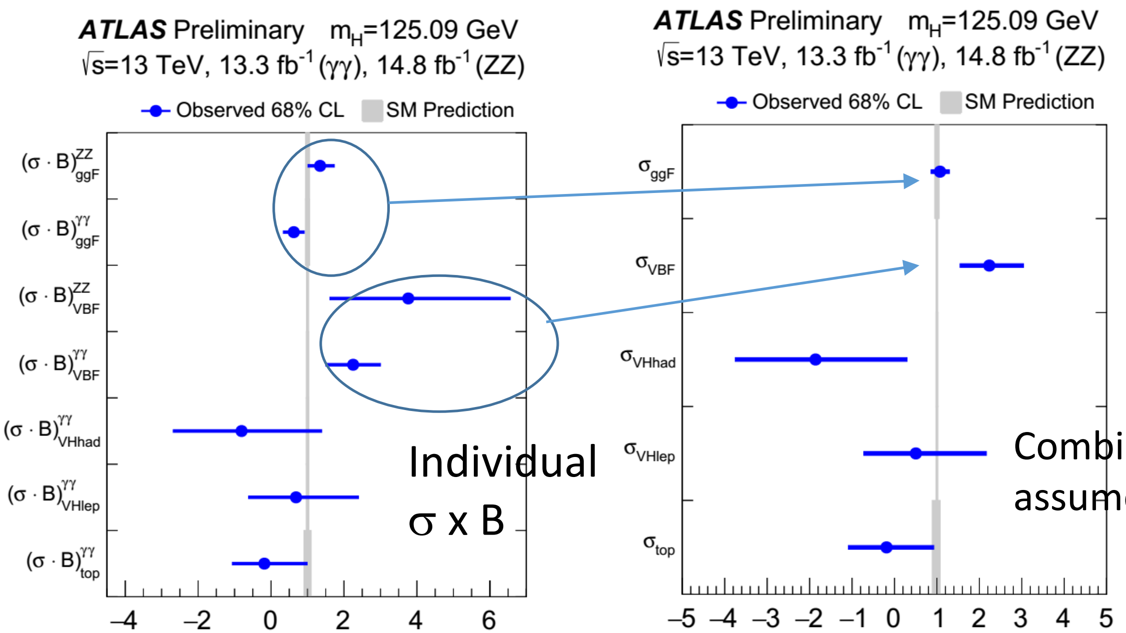


Total observed (expected) detection significance of H->γγ is about 4.7 (5.4) σ

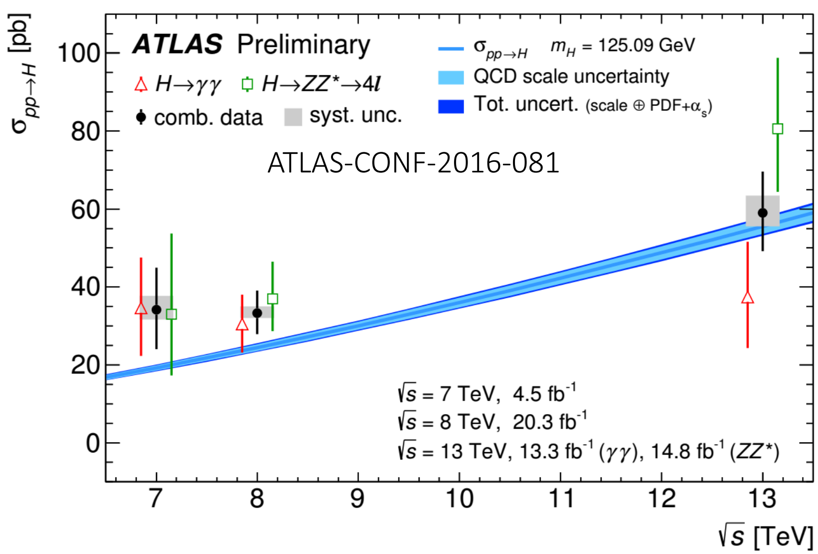
Comparable to Run I significance*: 5.0 (4.6) σ

* JHEP 08 (2016) 045

H→γγ + H→ZZ*→llll Combination at 13 TeV



Observed local significance for total Higgs production: 10σ, for VBF-only: 4σ

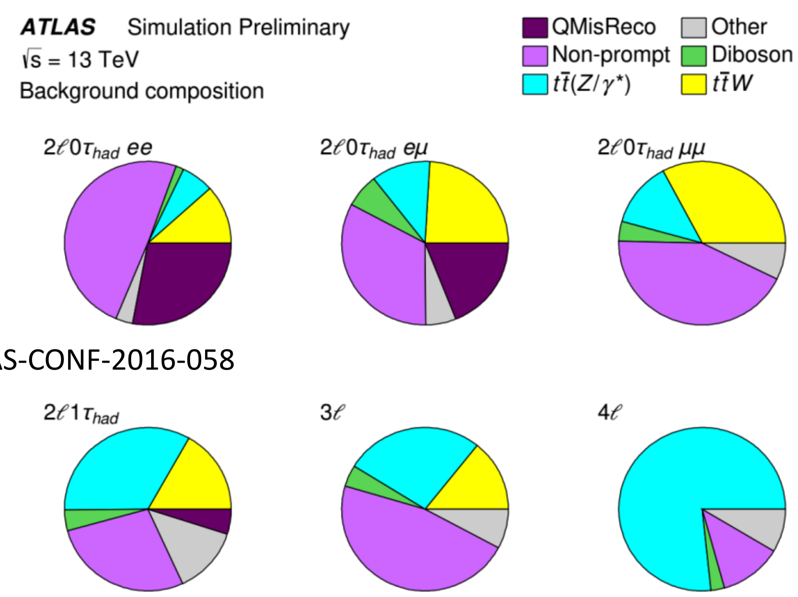


Combined cross-section agrees better with prediction

Total unc. ~ 18%
Similar to the precision at 8 TeV

ttH with multilepton final state 13 TeV

- Search for ttH production in multilepton final states
  - Relatively less background
  - Mainly sensitive to ttH with H→WW* or H→ττ
  - Four sub-channels defined depending on number of e or μ & hadronic τ decays
    - 2 leptons (e or μ) with same charge and no hadronic τ ($2\ell 0\tau_{had}$)
    - 2 leptons (e or μ) with same charge and 1 hadronic τ ($2\ell 1\tau_{had}$)
    - 3 leptons (3ℓ), 4 leptons (4ℓ)
    - in each channel, two or more jets (or b-jets) are required



ATLAS-CONF-2016-058

Backgrounds:

Prompt Lepton – ttV, WZ, …

MC simulation, checked in validation regions

Non-prompt Lepton – jet faking leptons or τ_{had}

Charge Mis-ID – mainly in electron channels

Data-driven

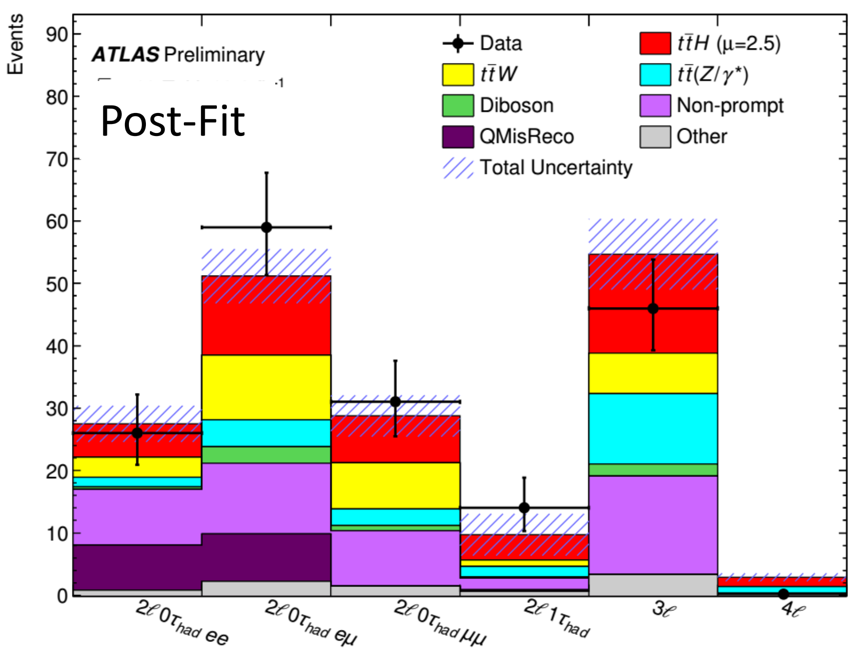
ttH with multilepton final state 13 TeV

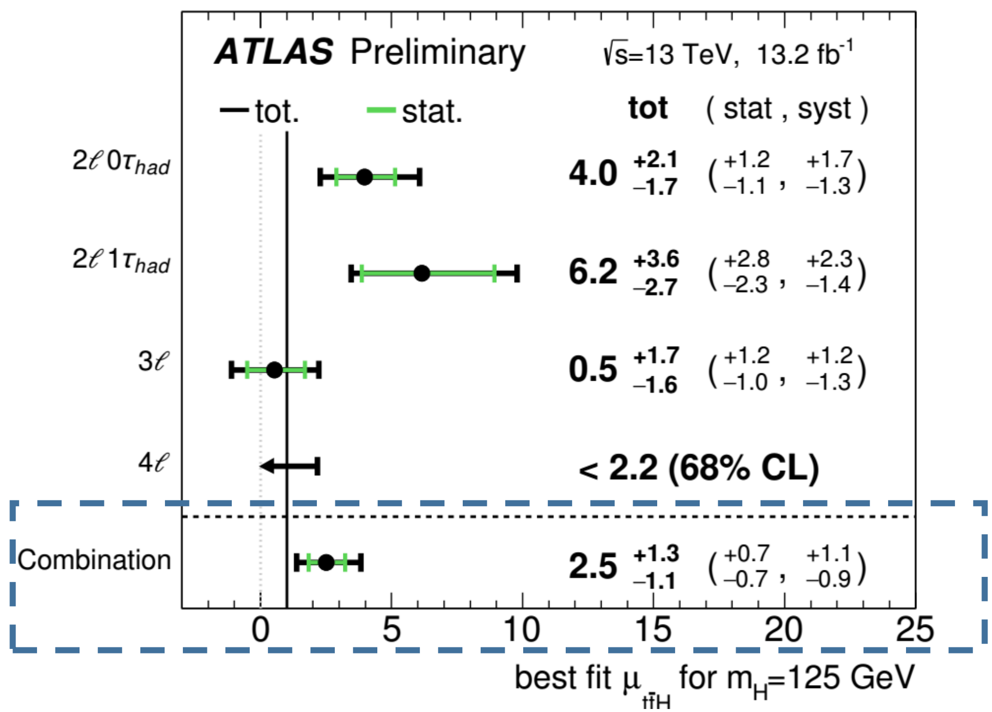
Best-fit μ_{ttH} $2.5 \pm 0.7\ \text{(stat)}\ ^{+1.1}_{-0.9}\ \text{(syst)}$

- Main systematic uncertainty: fake backgrounds, jets, pile-up
- Observed (expected) significance to non-ttH hypothesis is 2.2 (1.3) σ
  comparable to Run 1 significance in the same final state: 1.8 (0.9) σ
  Phys. Lett. B **749** (2015) 519

Observed (expected) Upper limit on μ_{ttH} (95% CL) is 4.9 (2.3)

ATLAS-CONF-2016-058



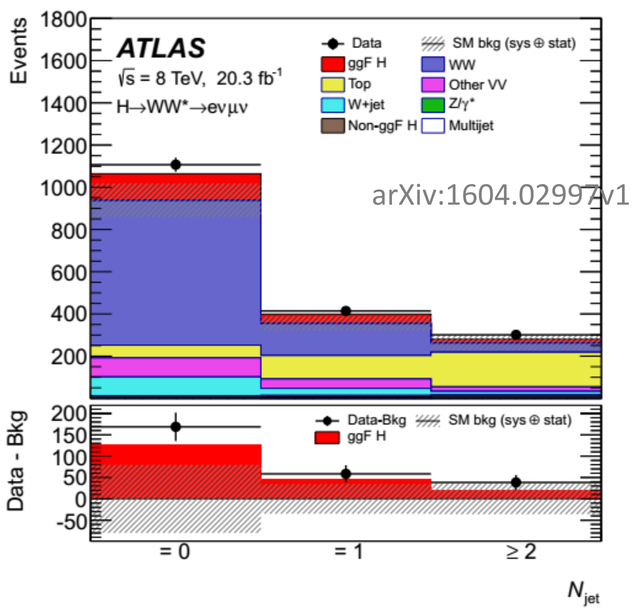


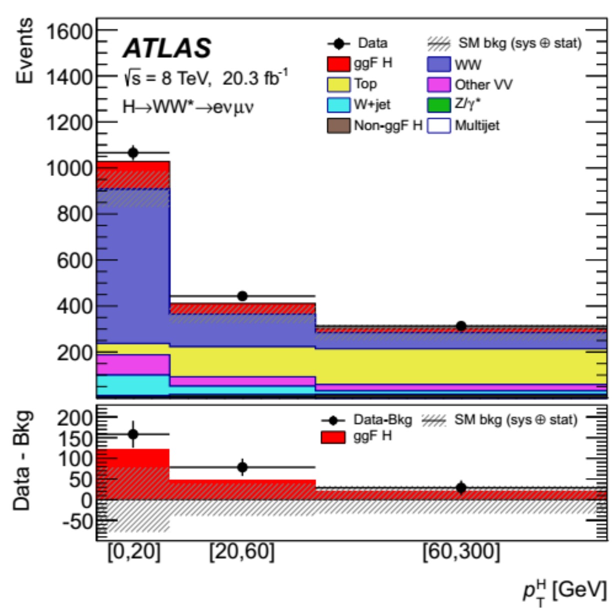
Differential H→WW→eνμν measurement 8 TeV

- eμ channel only (avoids DY background)
- "unfold" $N_{jet}, p_T^{j1}, p_T^H, |y_{ll}|$: sensitive to high-order QCD correction, resummation, PDF
- Only ggF H→WW considered as signal

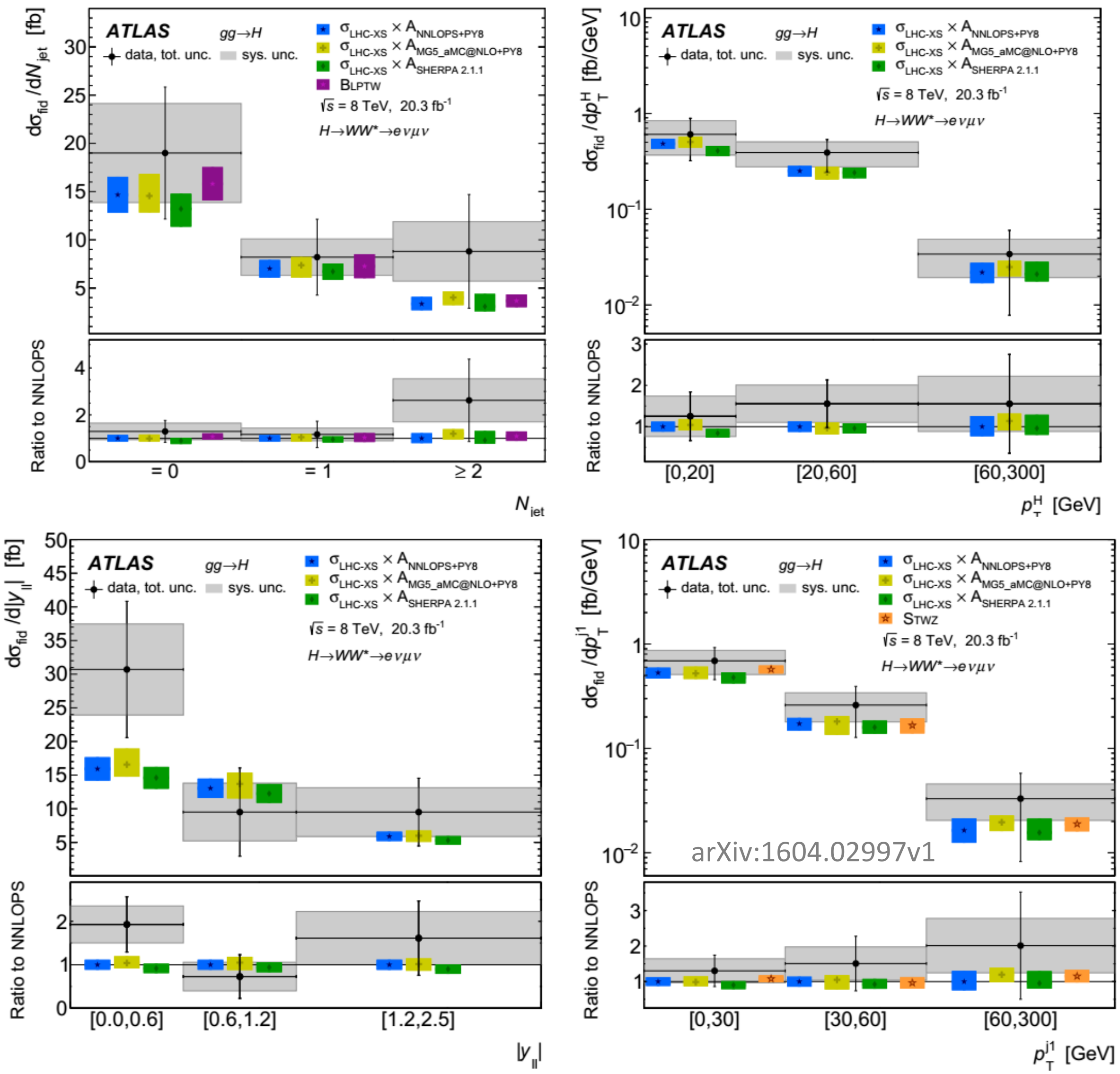
Category	$N_{\rm jet}=0$	$N_{\rm jet}=1$	$N_{\rm jet}\geq 2$
Preselection	Two isolated leptons ($\ell = e, \mu$) with opposite charge $p_{\rm T}^{\rm lead} > 22$ GeV, $p_{\rm T}^{\rm sublead} > 15$ GeV $m_{\ell\ell} > 10$ GeV $p_{\rm T}^{\rm miss} > 20$ GeV		
Background rejection	- $\Delta\phi(\ell\ell, p_{\rm T}^{\rm miss}) > 1.57$ $p_{\rm T}^{\ell\ell} > 30$ GeV	$N_{b\text{-jet}}=0$ $\max(m_{\rm T}^{\ell}) > 50$ GeV $m_{\tau\tau} < m_Z - 25$ GeV	$N_{b\text{-jet}}=0$ - $m_{\tau\tau} < m_Z - 25$ GeV
VBF veto	-	-	$m_{jj} < 600$ GeV or $\Delta y_{jj} < 3.6$
$H\to WW^* \to \ell\nu\ell\nu$ topology	$m_{\ell\ell} < 55$ GeV $\Delta\phi_{\ell\ell} < 1.8$ 85 GeV $< m_{\rm T} <$ 125 GeV		

Fiducial





Differential eνμν measurement 8 TeV



Dominant uncertainty: Data statistics, Background modelling

Measurement compared to different predictions with kinematics models ranging from NLO+PS to NNLO+PS or even parton-level NNLO+NNLL calculations (BLPTW, STWZ)

Slight difference in first bin of Njet and Rapidity(ll), however measurement suffer from larger error

Summary

- Reported recent Higgs "re-discovery" in $H \rightarrow ZZ^* \rightarrow 4l$ and $H \rightarrow \gamma\gamma$ channels with 13 TeV data at ATLAS, significant signal has been established (>10σ local significance)

- Reported recent search to detect ttH signature in multilepton and diphoton final state (about 2.2σ from multilepton channel)

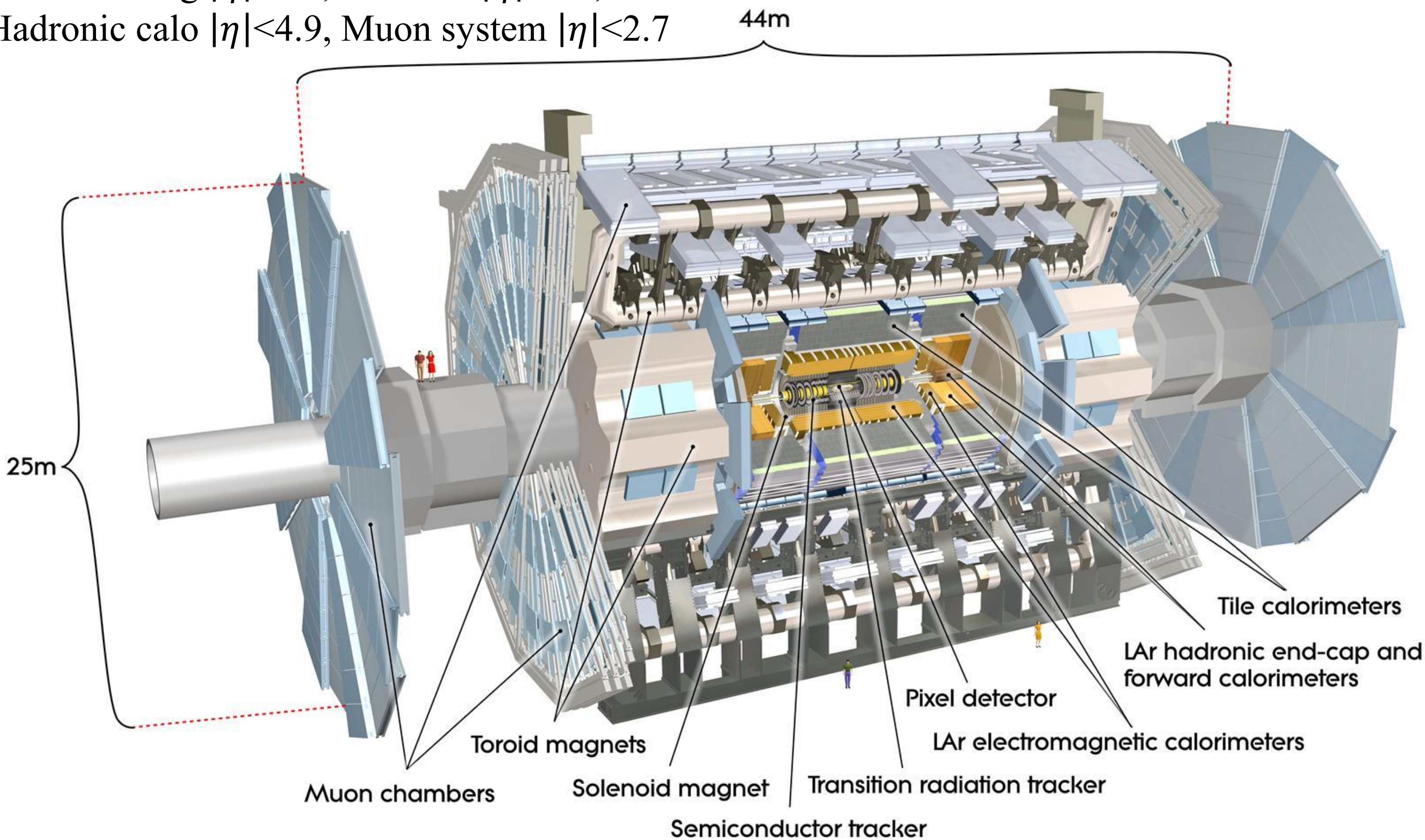
- Reported (differential) cross-section measurements in diboson channels (13 TeV $H \rightarrow ZZ^* \rightarrow 4l$ and $H \rightarrow \gamma\gamma$, 8 TeV $H \rightarrow WW^* \rightarrow e\nu\mu\nu$); 13 TeV precision already comparable to Run I

- Stay tuned for more (precision) results with full 2016 data and beyond!

Backup

ATLAS Detector

Inner tracking $|\eta|<2.5$, EM calo $|\eta|<3.2$,
Hadronic calo $|\eta|<4.9$, Muon system $|\eta|<2.7$



H->ZZ*->4l Event Selection

Leptons and Jets requirements	
Electrons	
Loose Likelihood quality electrons with hit in innermost layer, $E_T > 7$ GeV and $\lvert\eta\rvert < 2.47$	
Muons	
Loose identification $\lvert\eta\rvert < 2.7$ Calo-tagged muons with $p_T > 15$ GeV and $\lvert\eta\rvert < 0.1$ Combined, stand-alone (with ID hits if available) and segment tagged muons with $p_T > 5$ GeV	
Jets	
anti-k_t jets with $p_T > 30$ GeV, $\lvert\eta\rvert < 4.5$ and passing pile-up jet rejection requirements	
Event Selection	
Quadruplet Selection	Require at least one quadruplet of leptons consisting of two pairs of same flavour opposite-charge leptons fulfilling the following requirements: p_T thresholds for three leading leptons in the quadruplet - 20, 15 and 10 GeV Maximum of one calo-tagged or standalone muon per quadruplet Select best quadruplet to be the one with the (sub)leading dilepton mass (second) closest the Z mass Leading dilepton mass requirement: 50 GeV $< m_{12} <$ 106 GeV Sub-leading dilepton mass requirement: $12 < m_{34} <$ 115 GeV Remove quadruplet if alternative same-flavour opposite-charge dilepton gives $m_{\ell\ell} < 5$ GeV $\Delta R(\ell, \ell') > 0.10$ (0.20) for all same(different)-flavour leptons in the quadruplet
Isolation	Contribution from the other leptons of the quadruplet is subtracted Muon track isolation ($\Delta R \leq 0.30$): $\Sigma p_T/p_T < 0.15$ Muon calorimeter isolation ($\Delta R = 0.20$): $\Sigma E_T/p_T < 0.30$ Electron track isolation ($\Delta R \leq 0.20$) : $\Sigma E_T/E_T < 0.15$ Electron calorimeter isolation ($\Delta R = 0.20$) : $\Sigma E_T/E_T < 0.20$
Impact Parameter Significance	Apply impact parameter significance cut to all leptons of the quadruplet. For electrons : $\lvert d_0/\sigma_{d_0}\rvert < 5$ For muons : $\lvert d_0/\sigma_{d_0}\rvert < 3$
Vertex Selection	Require a common vertex for the leptons χ^2/ndof < 6 for 4μ and < 9 for others.

H->ZZ*->4l Yield Table

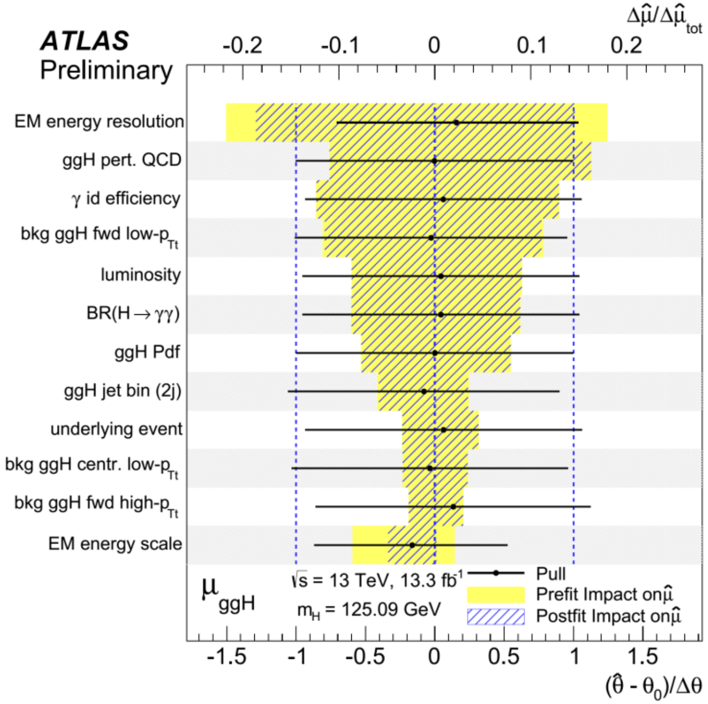
Table 9: The number of events expected and observed for a m_H=125 GeV hypothesis for the four-lepton final states. The second column gives the expected signal without any cut on $m_{4\ell}$. The other columns give for the 118–129 GeV mass range the number of expected signal events, the number of expected ZZ^* and other background events, and the signal-to-background ratio (S/B), together with the number of observed events, for 14.8 fb^{-1} at $\sqrt{s}$ = 13 TeV. Full uncertainties are provided.

Final State	Signal full mass range	Signal	ZZ^*	Z + jets, $t\bar{t}$ ttV, VVV, WZ	S/B	Expected	Observed
4μ	8.8 ± 0.6	8.2 ± 0.6	3.11 ± 0.30	0.31 ± 0.04	2.4	11.6 ± 0.7	16
$2e2\mu$	6.1 ± 0.4	5.5 ± 0.4	2.19 ± 0.21	0.30 ± 0.04	2.2	8.0 ± 0.4	12
$2\mu2e$	4.8 ± 0.4	4.4 ± 0.4	1.39 ± 0.16	0.47 ± 0.05	2.3	6.2 ± 0.4	10
$4e$	4.8 ± 0.5	4.2 ± 0.4	1.46 ± 0.18	0.46 ± 0.05	2.2	6.1 ± 0.4	6
Total	24.5 ± 1.8	22.3 ± 1.6	8.2 ± 0.8	1.54 ± 0.18	2.3	32.0 ± 1.8	44

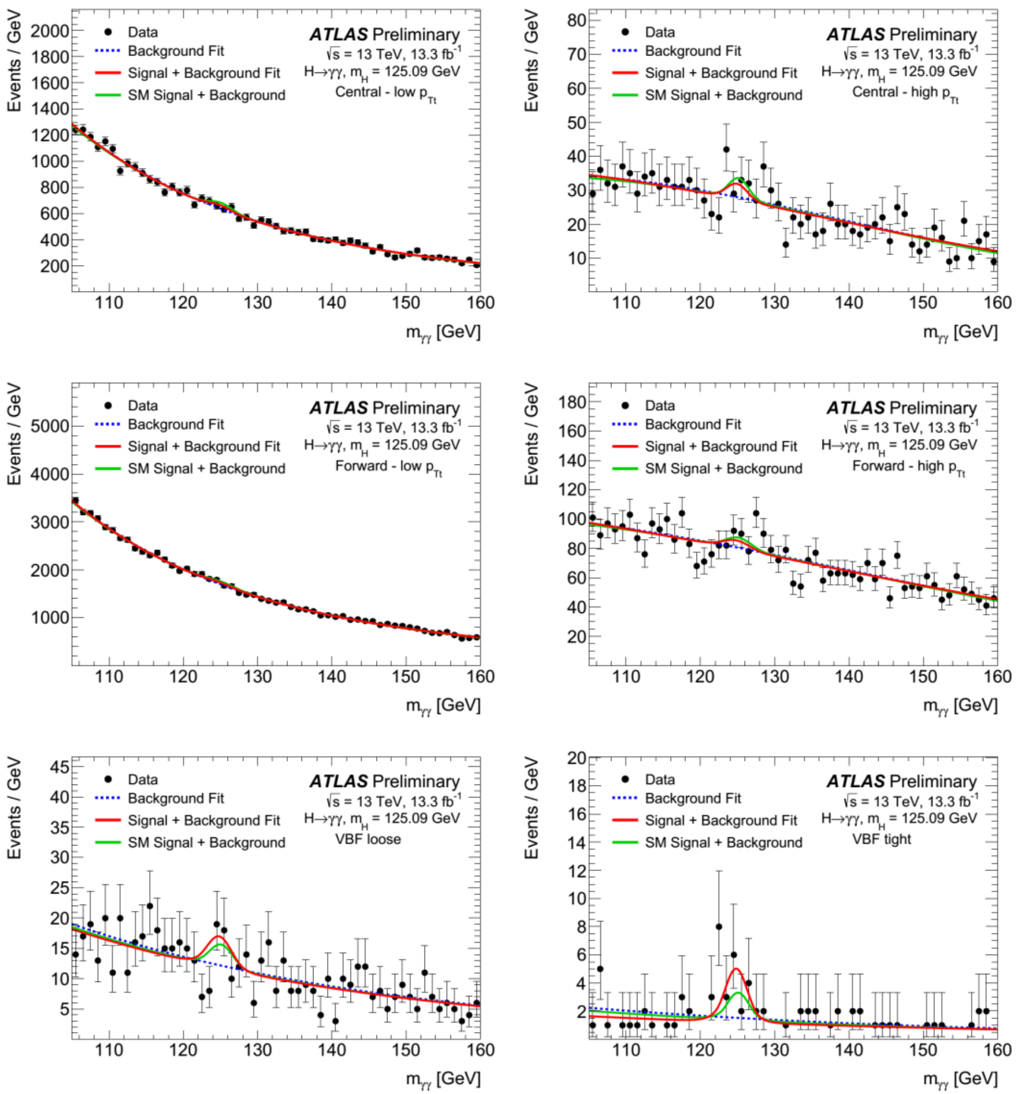
H->γγ Systematic Table

Table 4: The uncertainties, expressed in percent, on the cross sections measured in the baseline, VBF-enhanced, single-lepton and high-E_T^{miss} fiducial regions. The fit systematic uncertainty contains the effect of the photon energy scale and resolution, the impact of the background modelling on the signal yield and the uncertainty on the fitted peak position from the chosen background parameterisation.

Source	Uncertainty on fiducial cross section (%)		
	Baseline	VBF-enhanced	single-lepton
Fit (stat.)	34.5	35.0	52.9
Fit (syst.)	9.0	11.1	9.3
Photon efficiency	4.4	4.4	4.4
Jet energy scale/resolution	-	9.4	-
Lepton selection	-	-	0.8
Pileup	1.1	2.0	1.4
Theoretical modelling	4.3	9.4	8.4
Luminosity	2.9	2.9	2.9



H->γγ Category m(γγ) Plots and Contributions



Category	Events	B_{90}	S_{90}	f_{90}	Z_{90}	S_{90}^{fit}
Central low-$p_{\text{T}t}$	31907	3500	180	0.05	3.04	120
Central high-$p_{\text{T}t}$	1319	140	20	0.13	1.66	15
Forward low-$p_{\text{T}t}$	85129	13000	310	0.02	2.73	200
Forward high-$p_{\text{T}t}$	3977	540	33	0.06	1.38	25
VBF loose	604	76	15	0.16	1.62	21
VBF tight	76	8.8	7.3	0.45	2.19	13
VH hadronic loose	937	120	8.9	0.07	0.81	4.7
VH hadronic tight	66	6.7	2.3	0.26	0.86	1.0
VH E_T^{miss}	20	2.4	0.81	0.26	0.50	0.18
VH one-lepton	8	1.0	0.57	0.37	0.53	0.12
VH dilepton	3	0.4	0.30	0.43	0.43	0.07
$t\bar{t}H$ hadronic	72	8.1	1.8	0.18	0.60	-0.23
$t\bar{t}H$ leptonic	19	2.3	1.3	0.36	0.78	-0.18

ttH Systematic Table

Table 6: Summary of the effects of the systematic uncertainties on μ. Due to correlations between the different sources of uncertainties, the total systematic uncertainty can be different from the sum in quadrature of the individual sources. The impact of the systematic uncertainties is evaluated after the fit described in Section 8.

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

ttH Yield Table & Upper Limits

Table 7: Expected and observed yields in the six signal region categories in 13.2 fb^{-1} of data at $\sqrt{s}$ = 13 TeV. Uncertainties in the background expectations due to systematic effects and MC statistics are shown. "Other" backgrounds include tZ, tWZ, $tHqb$, tHW, $t\bar{t}t\bar{t}$, $t\bar{t}WW$, and triboson production. Values are obtained pre-fit, i.e., using the initial values of background systematic uncertainty nuisance parameters.

	$2\ell 0\tau_{\text{had}}$ ee	$2\ell 0\tau_{\text{had}}$ $e\mu$	$2\ell 0\tau_{\text{had}}$ $\mu\mu$	$2\ell 1\tau_{\text{had}}$	3ℓ	4ℓ
$t\bar{t}W$	2.9 ± 0.7	9.1 ± 2.5	6.6 ± 1.6	0.8 ± 0.4	6.1 ± 1.3	—
$t\bar{t}(Z/\gamma^*)$	1.55 ± 0.29	4.3 ± 0.9	2.6 ± 0.6	1.6 ± 0.4	11.5 ± 2.0	1.12 ± 0.20
Diboson	0.38 ± 0.25	2.5 ± 1.4	0.8 ± 0.5	0.20 ± 0.15	1.8 ± 1.0	0.04 ± 0.04
Non-prompt leptons	12 ± 6	12 ± 5	8.7 ± 3.4	1.3 ± 1.2	20 ± 6	0.18 ± 0.10
Charge misreconstruction	6.9 ± 1.3	7.1 ± 1.7	—	0.24 ± 0.03	—	—
Other	0.81 ± 0.22	2.2 ± 0.6	1.4 ± 0.4	0.63 ± 0.15	3.3 ± 0.8	0.12 ± 0.05
Total background	25 ± 6	38 ± 6	20 ± 4	4.8 ± 1.4	43 ± 7	1.46 ± 0.25
$t\bar{t}H$ (SM)	2.0 ± 0.5	4.8 ± 1.0	2.9 ± 0.6	1.43 ± 0.31	6.2 ± 1.1	0.59 ± 0.10
Data	26	59	31	14	46	0

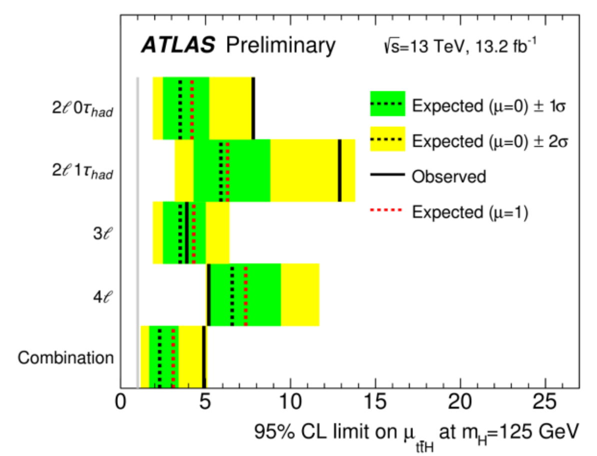


Figure 6: Upper limits on the $t\bar{t}H$ signal strength $\mu_{t\bar{t}H}$ at 95% CL by final state category and combined. The SM prediction is $\mu_{t\bar{t}H}$ = 1. The median upper limit that would be set in the presence of a SM $t\bar{t}H$ signal (μ = 1) is also shown.

H->WW Yield Table & MC Precision

Table 6: Predicted and observed event yields in the three signal regions. Predicted numbers are given with their statistical (first) and systematic (second) uncertainties evaluated as described in Section 8. The "Non-ggF H" row includes the contributions from VBF and VH with $H \to WW^*$ and from $H \to \tau\tau$. The total background in the third-from-last row is the sum of these and of all other backgrounds.

	$N_{\text{jet}} = 0$	$N_{\text{jet}} = 1$	$N_{\text{jet}} \geq 2$
Non-ggF H	$2.2 \pm 0.2 \pm 0.2$	$7.1 \pm 0.3 \pm 0.5$	$8.2 \pm 0.3 \pm 0.4$
WW	$686 \pm 19 \pm 43$	$153 \pm 7 \pm 13$	$44 \pm 1 \pm 11$
Other VV	$88 \pm 3 \pm 12$	$44 \pm 3 \pm 11$	$21.6 \pm 1.6 \pm 3.3$
Top	$60.2 \pm 1.5 \pm 3.8$	$111.2 \pm 2.7 \pm 8.2$	$164 \pm 2 \pm 16$
Z/γ^*	$8.7 \pm 2.3 \pm 2.3$	$6.2 \pm 1.3 \pm 2.2$	$7.3 \pm 1.5 \pm 2.2$
W+jets	$90 \pm 2 \pm 21$	$33.5 \pm 2.0 \pm 7.6$	$16.9 \pm 1.2 \pm 3.9$
Multijet	$1.3 \pm 0.5 \pm 0.5$	$0.7 \pm 0.2 \pm 0.3$	$0.9 \pm 0.1 \pm 0.4$
Total background	$936 \pm 21 \pm 41$	$355 \pm 9 \pm 12$	$263 \pm 6 \pm 9$
Observed	1107	414	301
Observed − background	$171 \pm 39 \pm 41$	$59 \pm 22 \pm 12$	$38 \pm 18 \pm 9$
ggF H	$125.9 \pm 0.4 \pm 5.7$	$43.4 \pm 0.2 \pm 1.7$	$17.6 \pm 0.2 \pm 1.4$

Table 10: Summary of the ggF predictions used in comparison with the measured fiducial cross sections. The right column states the accuracy of each prediction in QCD.

Total cross-section predictions	
LHC-XS [71]	NNLO+NNLL
Differential cross-section predictions	
JetVHeto [72–74]	NNLO+NNLL
ST [75]	NNLO
BLPTW [66]	NNLO+NNLL
STWZ [76]	NNLO+NNLL′
N^3LO+NNLL+LL_R [77]	N^3LO+NNLL+LL_R
Monte Carlo event generators	
Powheg NNLOPS [78, 79]	$\text{NNLO}_{\geq 0j}$, $\text{NLO}_{\geq 1j}$
Sherpa 2.1.1 [37, 80–83]	H + 0, 1, 2 jets @NLO
MG5_aMC@NLO [67, 84, 85]	H + 0, 1, 2 jets @NLO

H->WW Systematic Table

Table 11: Relative uncertainties (in %) in the measured total fiducial cross secti

Source	$\Delta\sigma^{\text{fid}}_{\text{ggF}}/\sigma^{\text{fid}}_{\text{ggF}}$ [%]
SR data statistical	17
MC statistical	3.0
CR data statistical	9.9
Exp. JER	4.9
Exp. JES	2.1
Exp. b-tag	3.3
Exp. leptons	5.5
Exp. $p_{\text{T}}^{\text{miss}}$	2.2
Exp. other	4.2
Theory (WW)	14
Theory (top)	7.1
Theory (other backgrounds)	5.6
Theory (signal)	2.5
Detector corrections	0.4
Total	27

N_{jet}	0	1	≥ 2
$d\sigma/dN_{\text{jet}}$ [fb]	19.0	8.2	8.8
Statistical uncertainty	4.5	3.5	5.0
Total uncertainty	6.8	4.0	5.9
Predicted $d\sigma/dN_{\text{jet}}$ [fb] (NNLOPS)	14.7	7.0	3.4
Uncertainty in prediction	1.8	0.9	0.6
SR data statistical	20%	38%	54%
MC statistical	4%	7%	9%
CR data statistical	12%	18%	14%
Exp. JER	5%	4%	7%
Exp. JES	1%	10%	6%
Exp. b-tag	1%	4%	8%
Exp. leptons	6%	6%	6%
Exp. $p_{\text{T}}^{\text{miss}}$	2%	4%	4%
Exp. other	5%	4%	3%
Theory (WW)	24%	15%	5%
Theory (top)	2%	4%	24%
Theory (other backgrounds)	5%	6%	21%
Theory (signal)	4%	6%	3%
Detector corrections	<1%	4%	5%
Total uncertainty	36%	48%	67%