

6th International Conference on New Frontiers in Physics (ICNFP 2017)

Mini-Workshop on Latest Results and New Physics in the Higgs Sector

Conference Center of the Orthodox Academy of Creta (OAC)

Greece

ttH Coupling Measurement with the ATLAS Detector at the LHC

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On Behalf of the ATLAS Collaboration

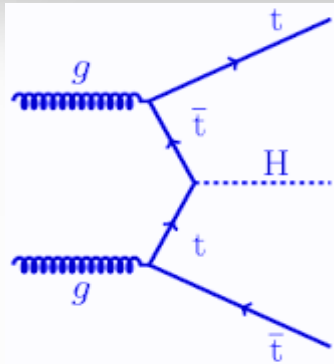


CPPM, CNRS/IN2P3, Aix-Marseille Université



19-08-2017

Introduction / Motivation



$\sigma_{ttH} = 507 \text{ fb @ } 13 \text{ TeV}$

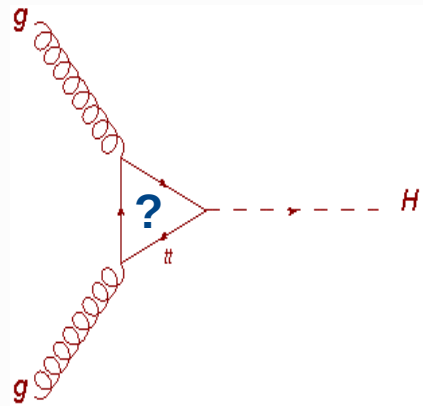
→ ttH is 1% of Higgs production

Insufficient statistics in Run 1 to probe SM
($20.3 \text{ fb}^{-1} @ 8 \text{ TeV}$)

Cross section @ 13 TeV **3.9** times higher than @ 8 TeV

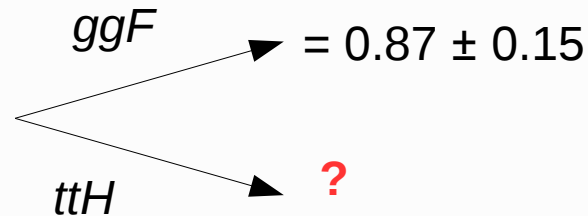
→ Direct measurement of the top Yukawa coupling: $g_{t\bar{t}H}$

$g_{t\bar{t}H} \sim 1$



$\sigma_{ttH} / \sigma_{ggF} \sim 0.01$

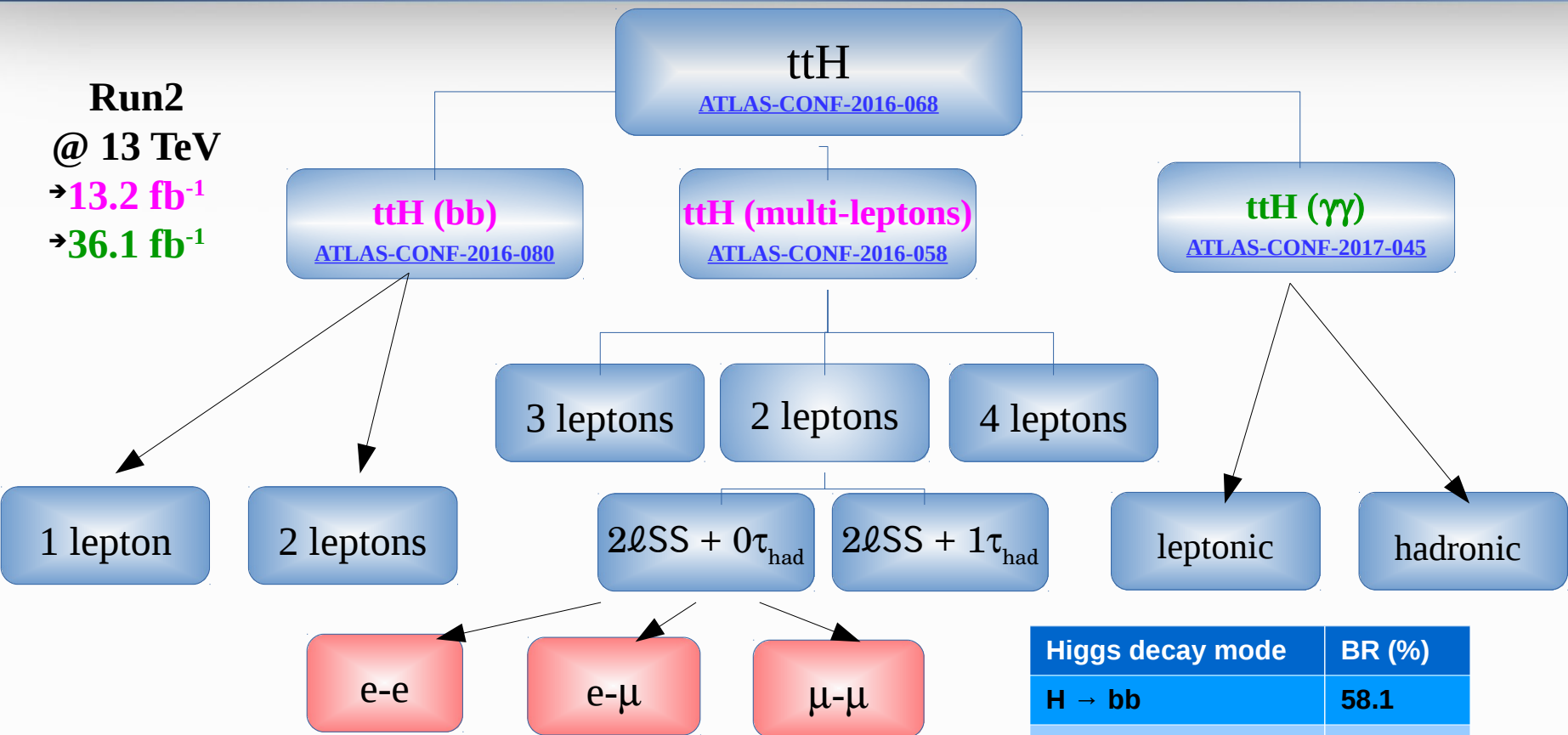
$$\kappa_t = \frac{g_{t\bar{t}H}(\text{observed})}{g_{t\bar{t}H}(\text{SM})}$$



Any deviation might be hint for new physics!

Searches for ttH at ATLAS @ 13TeV

Run2
@ 13 TeV
→ 13.2 fb⁻¹
→ 36.1 fb⁻¹

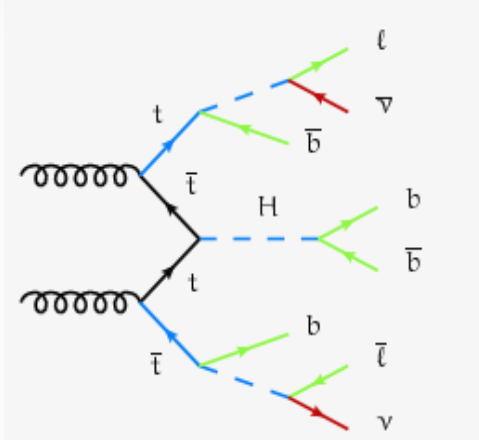


Higgs decay mode	BR (%)
$H \rightarrow bb$	58.1
$H \rightarrow WW$	21.5
$H \rightarrow \tau\tau$	6.3
$H \rightarrow ZZ$	2.8
$H \rightarrow \gamma\gamma$	0.2

$ttH (bb)$ Analysis – Signal Regions

ATLAS-CONF-2016-080

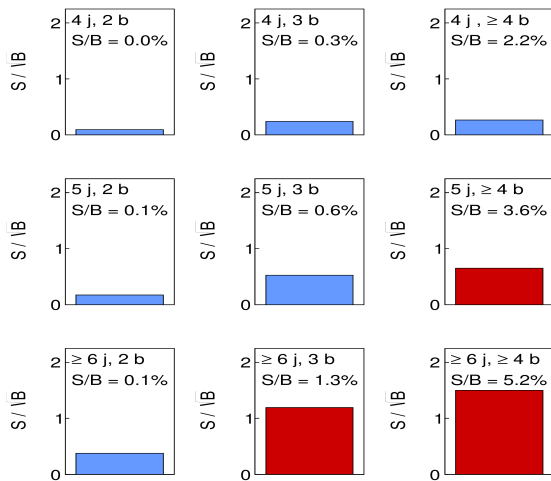
- Largest branching fraction ($H \rightarrow bb$)



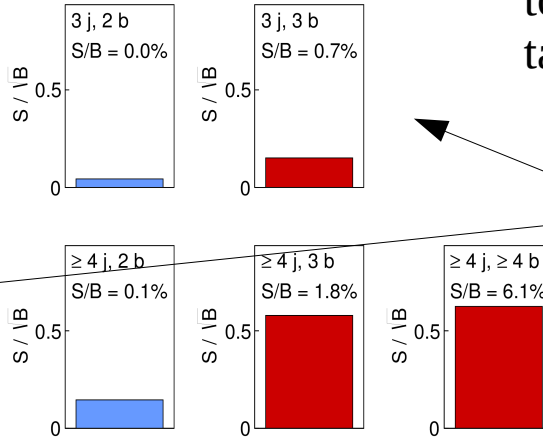
- single lepton and di-lepton channels.
- No “all hadronic” channel → backgrounds are very different.

SR	Single Lepton	Di-lepton
Leptons	1	2 OS
Jets	≥ 4	≥ 3
b-jets	≥ 2	≥ 2

ATLAS Simulation Preliminary
 $\sqrt{s} = 13$ TeV, 13.2 fb^{-1}
 Single Lepton



ATLAS Simulation Preliminary
 $\sqrt{s} = 13$ TeV, 13.2 fb^{-1}
 Dilepton



- Event categorisation according to no. of leptons, jets and b -tagged jets.

• 6 (8) **signal regions** (control regions).

ttH (bb) Analysis – Background Estimate

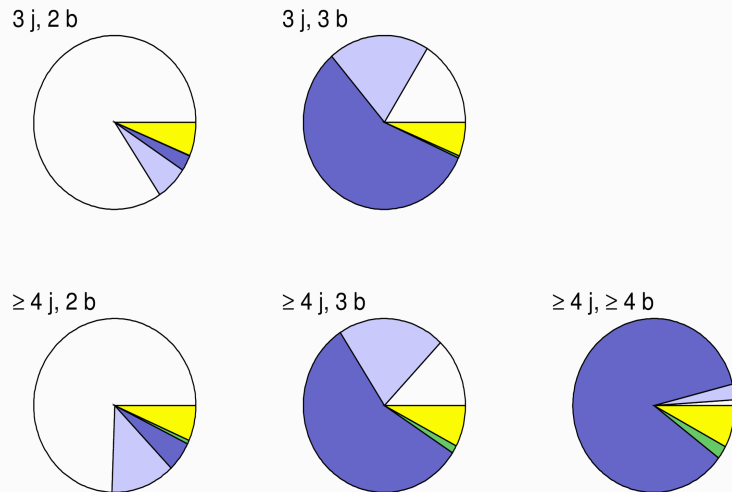
ATLAS-CONF-2016-080

- Dominated by $tt+jets$ background.
- Main background in signal region: $tt+bb$.
- Non- tt background: single top, $W/Z+jets$, VV , fake leptons.

- Background is estimated from simulation normalized to the prediction before the fit:

ATLAS Simulation Preliminary
 $\sqrt{s} = 13$ TeV
Dilepton

□ $t\bar{t} + \text{light}$ □ $t\bar{t} + \geq 1c$ □ $t\bar{t} + \geq 1b$
■ $t\bar{t} + V$ ■ Non- $t\bar{t}$



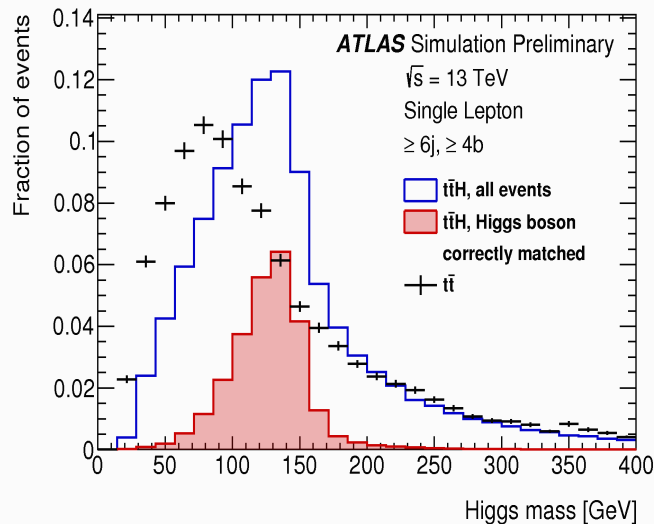
→ $tt+b$ (c) normalizations are free parameters of the fit.

- fake lepton background in single channel is estimated using data driven method.

$t\bar{t}H$ (bb) Analysis – Strategy

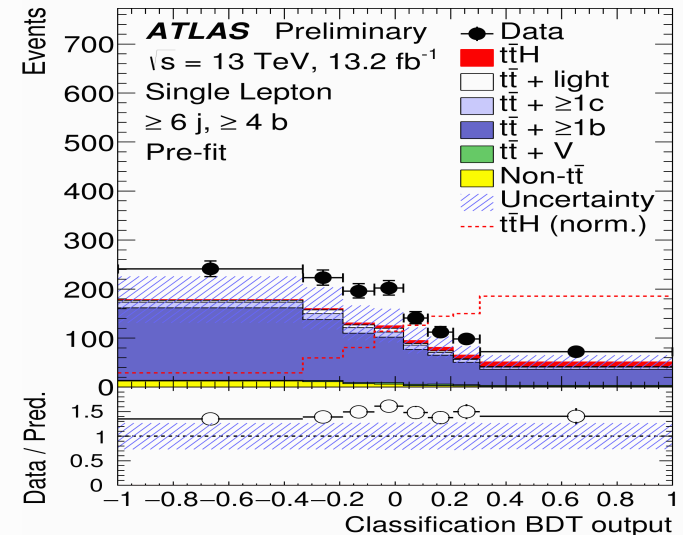
ATLAS-CONF-2016-080

- Multivariate technique (NN or BDT) in signal regions:
 - ➔ for signal/background reconstruction (reco) and separation (classification).



Input

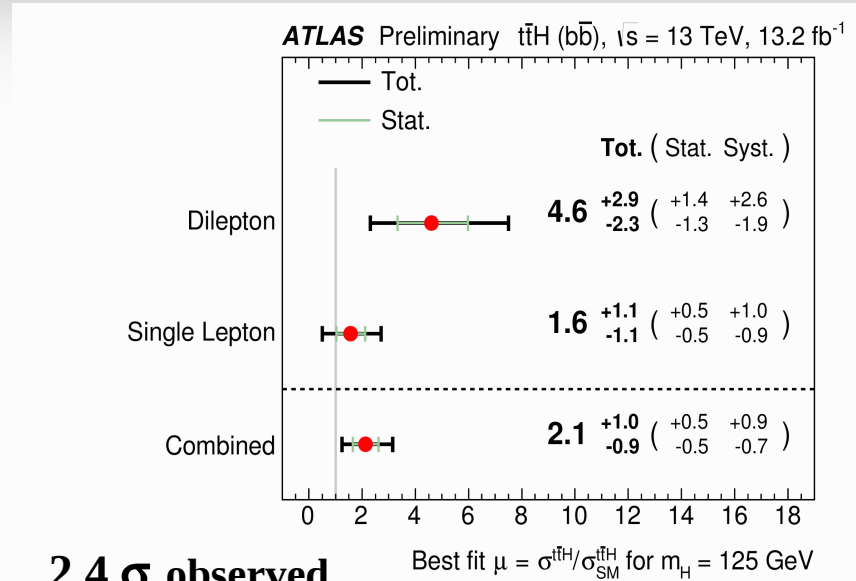
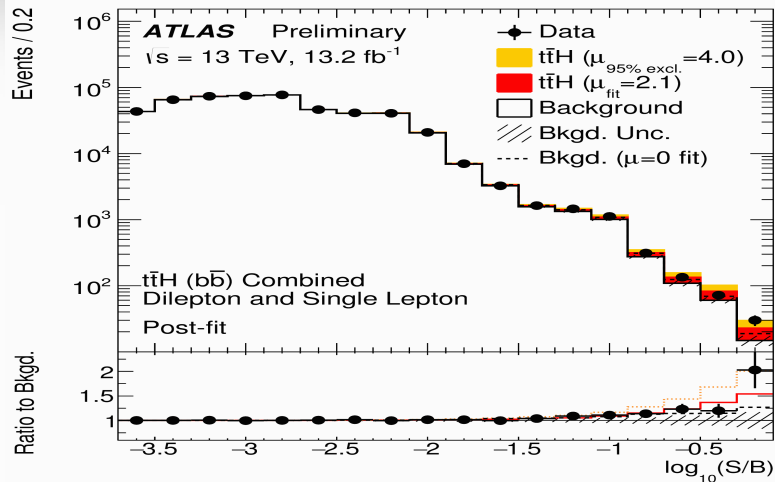
- ➔ 18 (26) input variables in di-lepton (single lepton) for **BDT reco**.



- ➔ 23 (21) input variables in di-lepton (single lepton) for **BDT classification**.
- ➔ 14 input for **NN classification** ($3j, 3b$ SR).

ttH (bb) Analysis – Results

ATLAS-CONF-2016-080



2.4 σ observed

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

- $\mu_{t\bar{t}H}$ is obtained from a Profile likelihood fit.
- Systematic uncertainties are dominating.
- **Normalisation and modeling of $tt+b$ -jets** are driving the error on the total background.
- Observed (expected) 95% C.L. upper limit on $\mu_{t\bar{t}H}$: 4.0 (2.7).

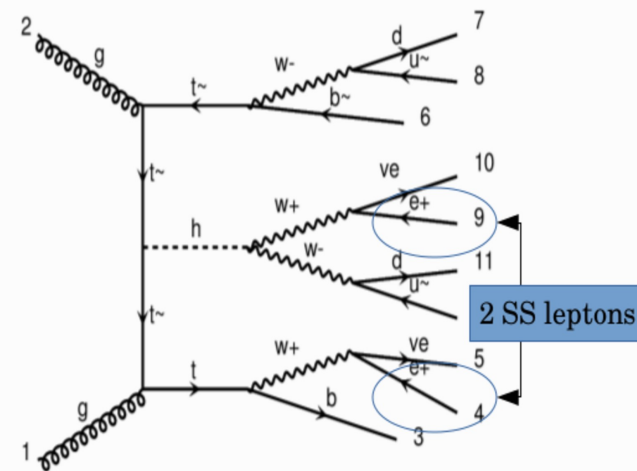
ttH (multileptons) Analysis – Signal Regions

ATLAS-CONF-2016-058

- 6 signal regions (SR):
- $2\ell SS 0\tau_{\text{had}}$ (ee, eμ, μμ), $2\ell SS 1\tau_{\text{had}}$, 3ℓ and 4ℓ .

Category	Higgs boson decay mode			
	WW*	$\tau\tau$	ZZ*	Other
$2\ell 0\tau_{\text{had}}$	77%	17%	3%	3%
$2\ell 1\tau_{\text{had}}$	46%	51%	2%	1%
3ℓ	74%	20%	4%	2%
4ℓ	72%	18%	9%	2%

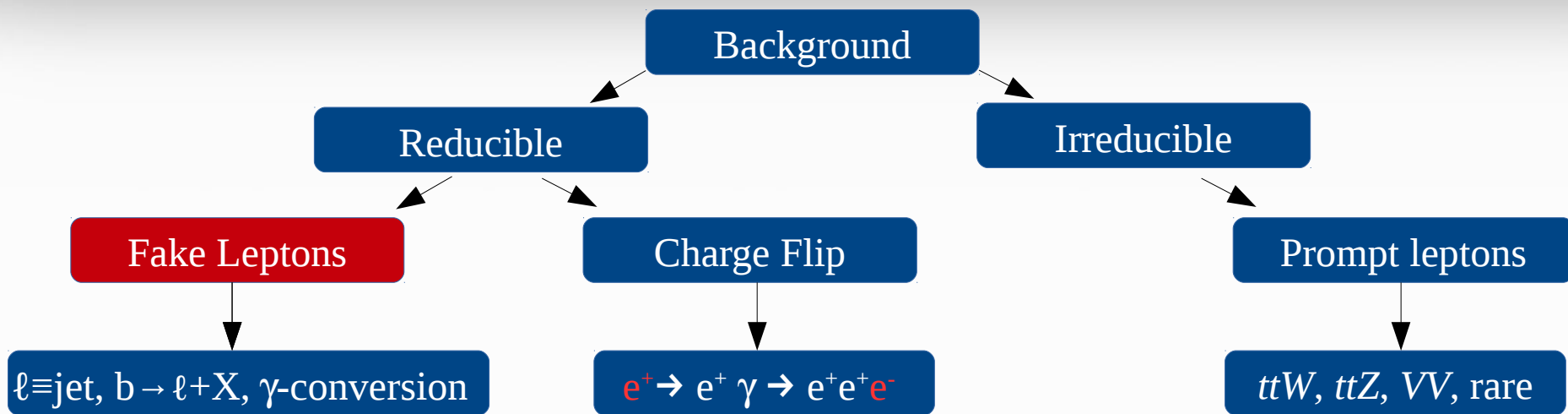
- Three main decays: WW, $\tau\tau$, ZZ.
- The ZZ contribution is mostly $\ell\ell\nu\nu$ / $\ell\ell jj$ ($H \rightarrow 4\ell$ is explicitly excluded in this analysis).
- Event categorisation according to no. of leptons.
 - Cut & Count analysis.



SR	$2\ell SS 0\tau_{\text{had}}$	$2\ell SS 1\tau_{\text{had}}$	3ℓ	4ℓ
Light Leptons	2 SS	2 SS	3	4
Jets	≥ 5	≥ 4	$\geq 3 4$	≥ 2
b-jets	≥ 1	≥ 1	$\geq 1 2$	≥ 1
τ_{had}	0	1	-	-

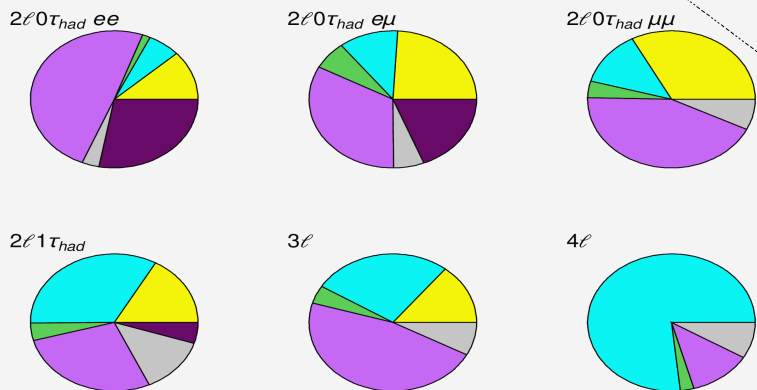
ttH (multileptons) Analysis – Background Estimate

ATLAS-CONF-2016-058



ATLAS Simulation Preliminary
 $\sqrt{s} = 13$ TeV
 Background composition

■ QMisRec
■ Non-prompt
■ $t\bar{t}(Z/\gamma^*)$
■ Other
■ Diboson
■ $t\bar{t}W$



- Reducible background is estimated using data-driven methods:

- **Charge Flip** estimated from $Z+jets$ OS events control region (CR).

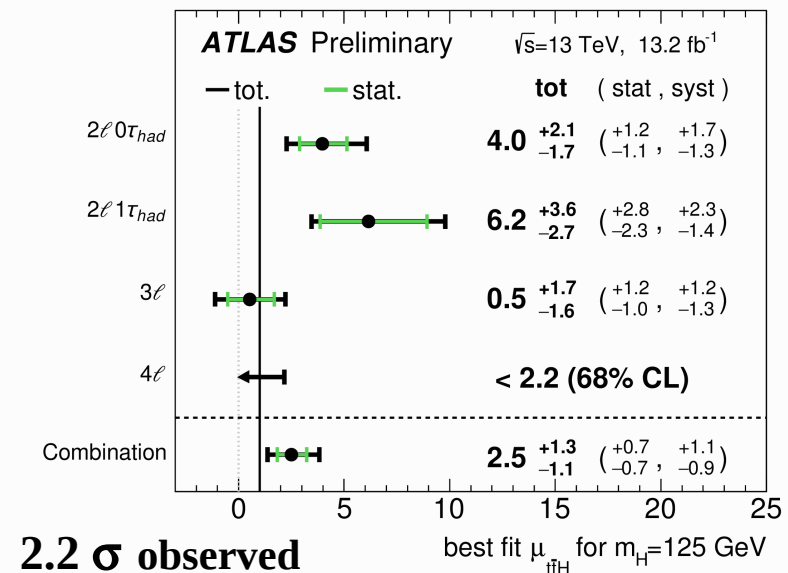
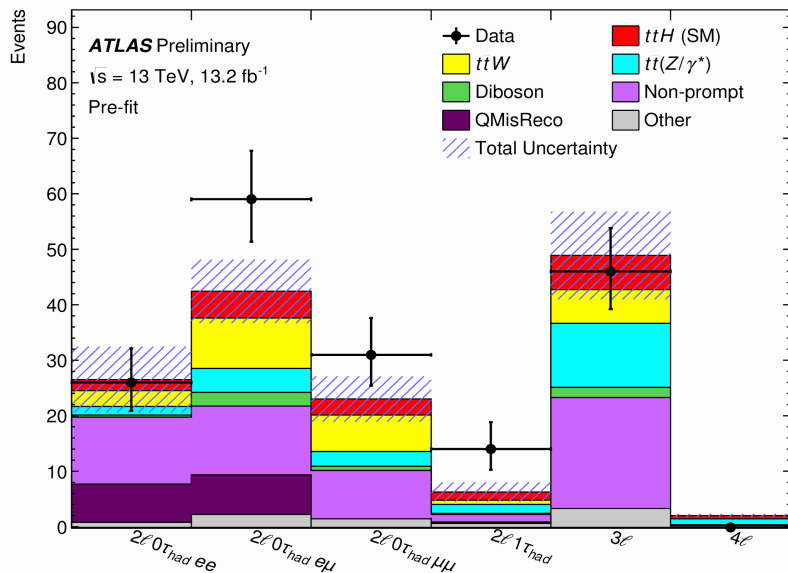
- **Fake leptons** estimated from $t\bar{t}$ SS/OS events CR.

- **Prompt leptons** are estimated from simulation validated using 4 validation regions (VR).

Fake leptons are the dominant background in $2\ell SS$ and 3ℓ channels.

ttH (multileptons) Analysis – Results

ATLAS-CONF-2016-058



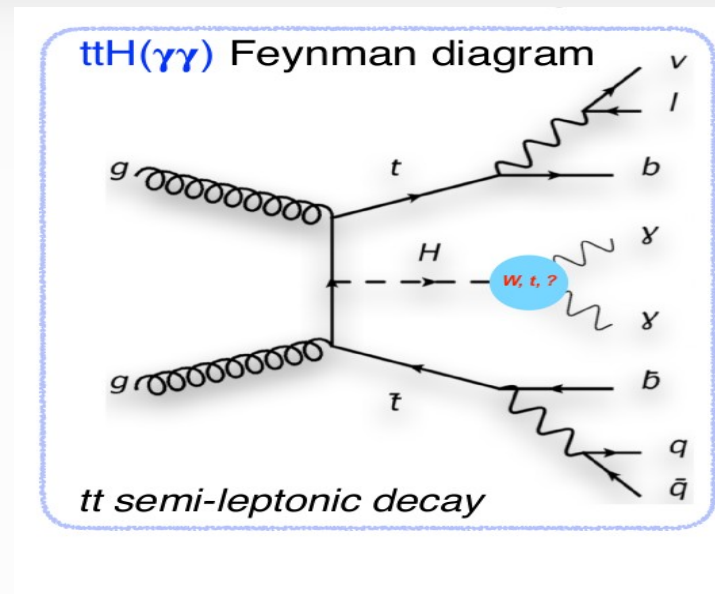
Uncertainty Source	$\Delta\mu$
Non-prompt leptons and charge misreconstruction	+0.56 -0.64
Jet-vertex association, pileup modeling	+0.48 -0.36
$t\bar{t}W$ modeling	+0.29 -0.31
$t\bar{t}H$ modeling	+0.31 -0.15
Jet energy scale and resolution	+0.22 -0.18
$t\bar{t}Z$ modeling	+0.19 -0.19
Luminosity	+0.19 -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

- μ_{ttH} is obtained from a Profile likelihood fit.
- Systematic uncertainties on combination are dominating.
- **Fakes** are driving the error on the total background estimated in the $2\ell SS$ and 3ℓ channels.
- Observed (expected) 95% C.L. upper limit on μ_{ttH} : 4.9 (2.3).

$ttH (\gamma\gamma)$ Analysis – Signal Regions

ATLAS-CONF-2017-045

- excellent di-photon mass resolution.
- Also sensitive to tH ($\sigma_{tH} = 74$ fb).
- 9 signal regions:
 - Leptonic:
 - 2 Cut&Count ' tH '.
 - 1 Cut&Count ' ttH '.
 - Hadronic:
 - 2 Cut&Count ' tH '.
 - 4 BDT ' ttH '.

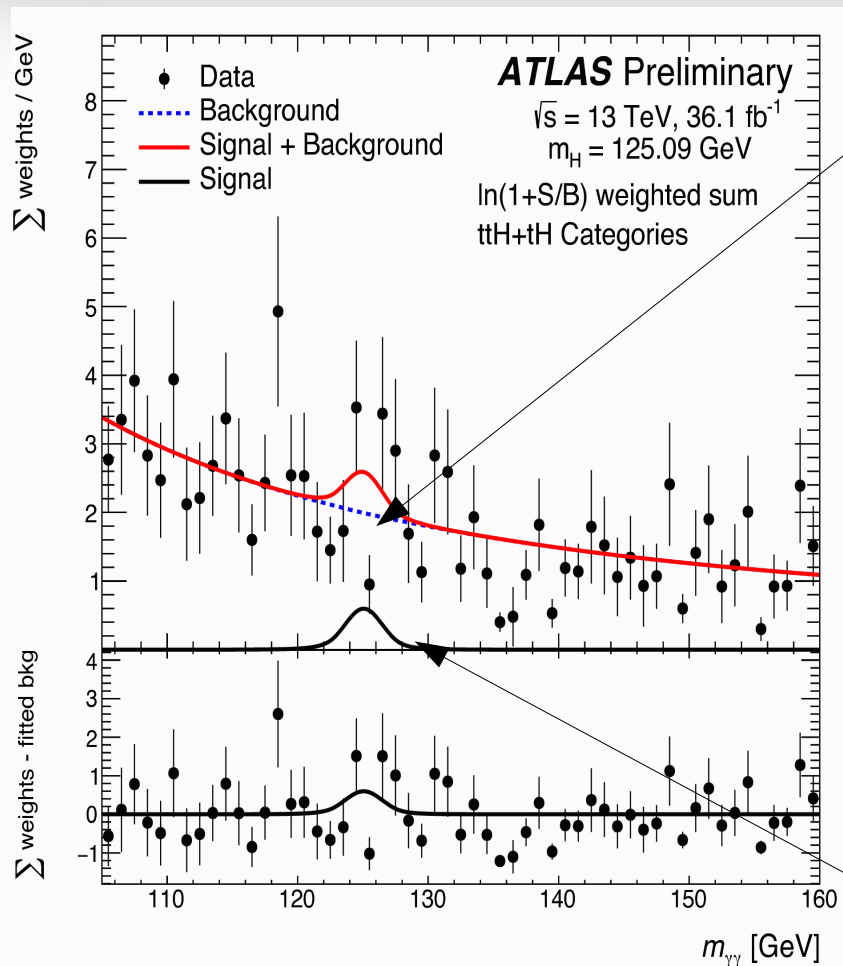


- Event categorisation according to no. of leptons and tH/ttH channels.

SR	Leptonic	Hadronic
Leptons	≥ 1	0
Jets	multiple	≥ 3
b -jets	≥ 1 central	≥ 1

$ttH(\gamma\gamma)$ Analysis – Background Estimate

ATLAS-CONF-2017-045



- Continuum background:
 $\gamma\gamma$ +jets, γ +jets and multijets.

- Data driven background:
 - Reverting γ identification or isolation.
 - Removing b -tagging.
 - Shape+normalisation from fit to $m_{\gamma\gamma}$.

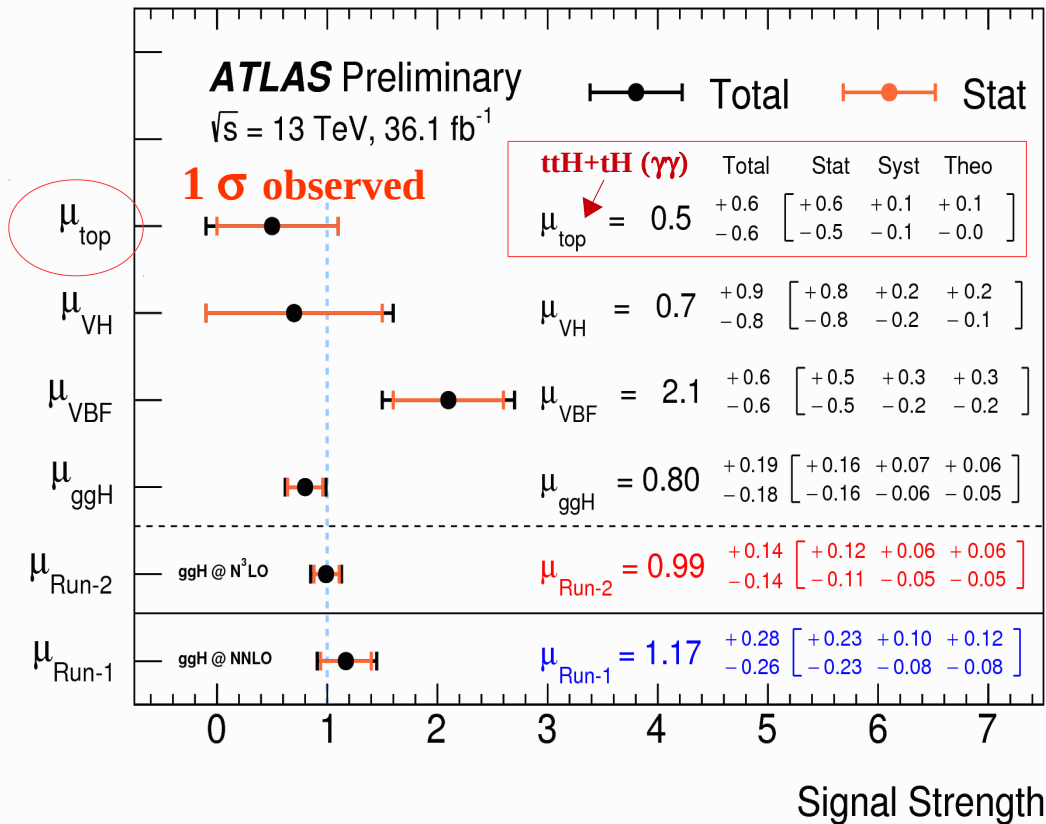
- $\gamma\gamma$ and $V\gamma$ backgrounds are estimated from simulation.

Signal model: double-sided Crystal Ball

↓
fits to the simulated signal samples.

ttH ($\gamma\gamma$) Analysis - Results

ATLAS-CONF-2017-045

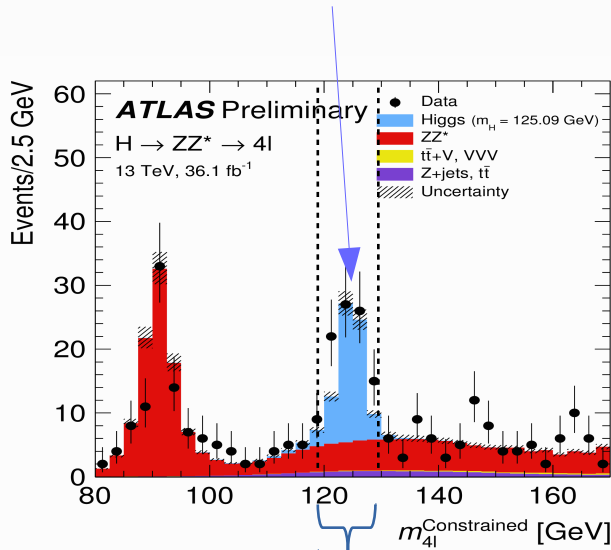


- μ_{ttH} is obtained from a Max likelihood fit for each event category.
- Statistical uncertainties are dominating.
- Observed (expected) 95% C.L. upper limit on μ_{ttH} : 1.7 (2.3).

$ttH (ZZ^* \rightarrow 4\ell)$ Analysis

ATLAS-CONF-2017-043

- BR[H → ZZ → 4ℓ] ~ 0.01 %
- Clear signature + high S/B ratio.



- Main background: non-resonant ZZ* .
- Other backgrounds: triboson, tt+Z.
- Data-driven reducible background: tt, Z+jets, WZ.

- Selected quadruplet leptons originating from a Higgs boson decay.

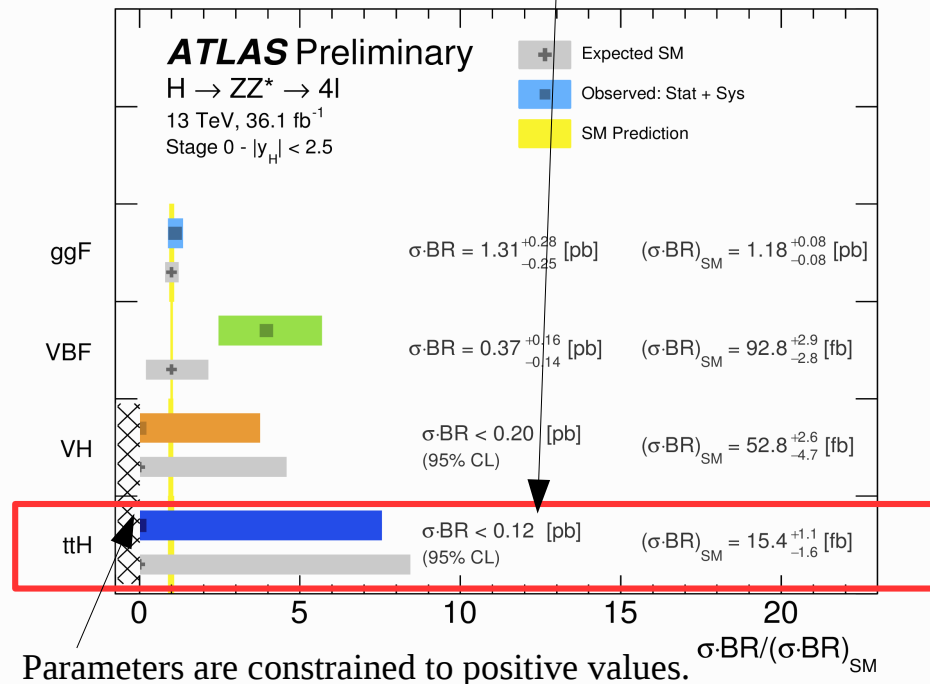
- Lepton flavour classification:

4e, 2e2μ, 2μ 2e, 4μ.

- >=1 b-jet.

- >= 4 jets or >= 2jets + 1 additional lepton ($p_T > 15$ GeV).

Due to the limited number of events: $\mu_{ttH} < 7.5$



ttH Analyses Combination

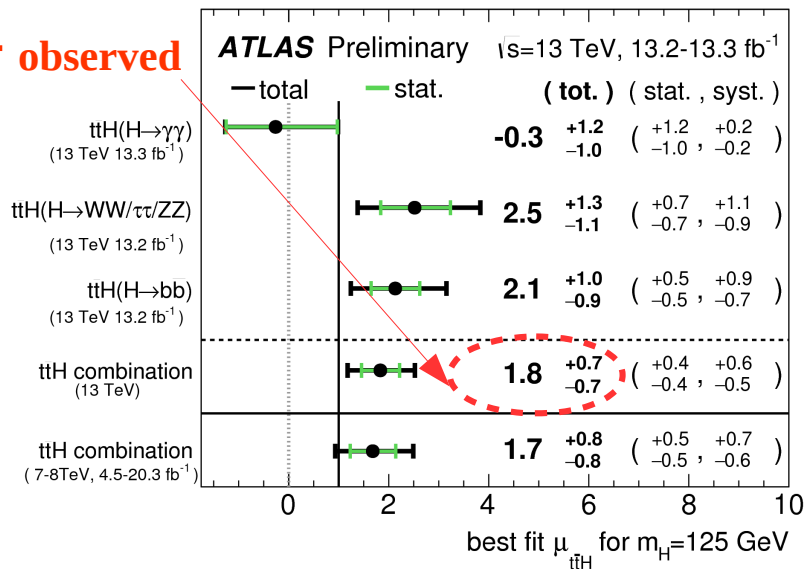
ATLAS-CONF-2016-068 || ATLAS-CONF-2017-047

Run2 @ 13 TeV

13.2 fb⁻¹

➤ 95% C.L. upper limit on μ_{ttH} : 3.0 (1.2)

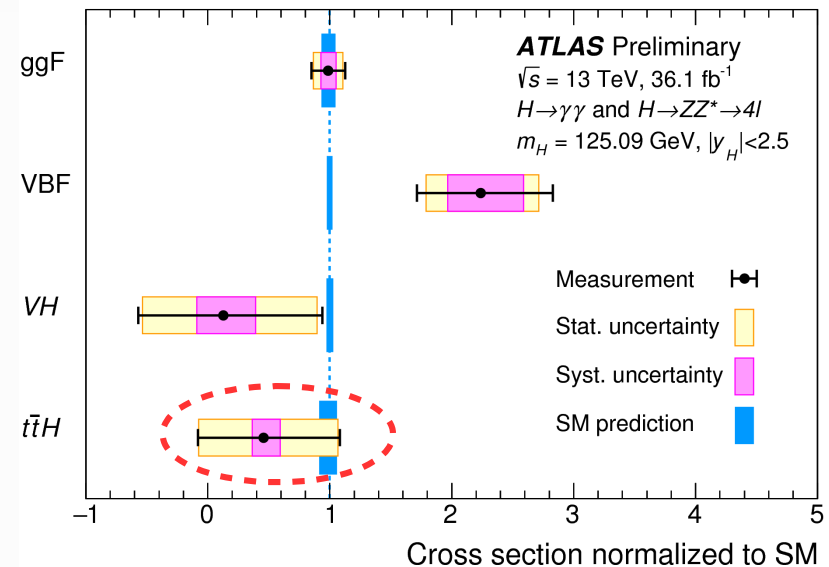
2.8 σ observed



Run2 @ 13 TeV

36.1 fb⁻¹

➤ ttH+tH ($\gamma\gamma$ and ZZ* $\rightarrow 4\ell$) only.



➔ 13.2 fb⁻¹ combination has smaller uncertainty than Run-1.

➔ 10-60% uncertainty reduction for 36.1 fb⁻¹ combination with respect to Run1 ttH ($\gamma\gamma$).

➔ Combined results are consistent with the SM prediction.

$$\sigma_{ttH}(obs) = (0.007^{+0.010}_{-0.009}) \sigma_{ggF}(obs)$$

$$\lambda_{tg} = \frac{K_t}{K_g} = 0.74^{+0.41}_{-0.63}$$

Conclusion

- Searches for the ttH production performed in $ttH (bb)$, ttH (multileptons) and $ttH (\gamma\gamma)$ using 13.2 fb^{-1} of pp collision data @ 13 TeV recorded by the ATLAS experiment.
- The best fit value of the ttH signal strength is 1.8 ± 0.7 ; corresponds to 2.8σ observed significance.
- Results with full 2015-2016 data (36.1 fb^{-1}) obtained for $ttH (\gamma\gamma)$ and $ttH (ZZ^* \rightarrow 4l)$ only combining ttH and tH production modes.
- Consistency with the Standard Model expectation.

