ttH related searches in the SM

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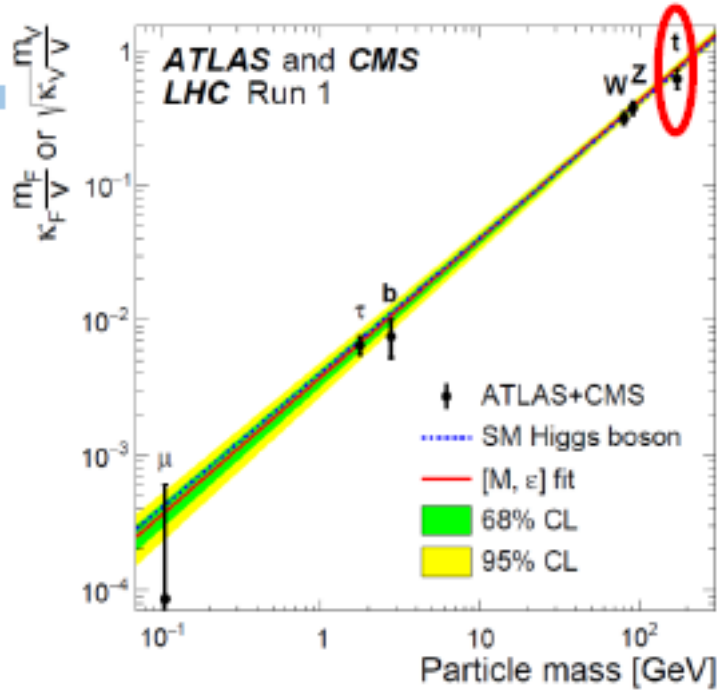
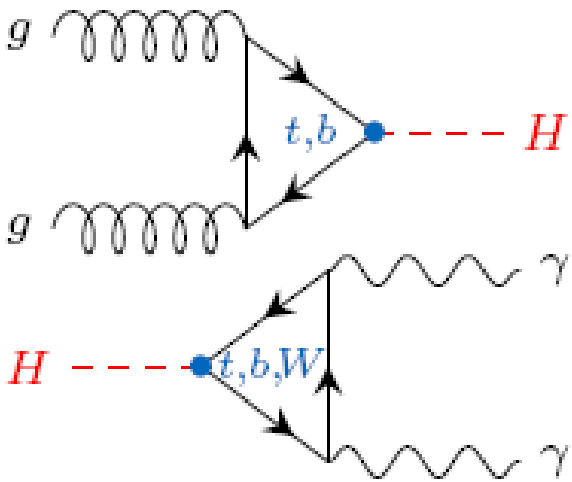
Mitchell2018, College Station, Texas, USA
23/05/18

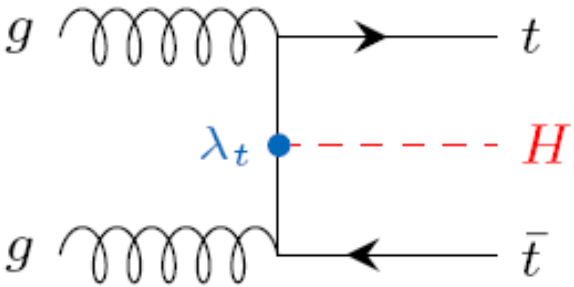
The Higgs-top coupling



Coupling proportional to the fermion mass, the strongest is the one with the top quark



Indirect measurement of the Yukawa coupling to the top quark through the virtual top loop of the Gluon-Gluon fusion production mechanism



Direct measurement to the Yukawa coupling to the top quark

The Higgs-top coupling

JHEP 1608 (2016) 045

Indirect measurement of the Yukawa coupling to the top quark

$$k_t = \frac{\lambda_t}{\lambda_t^{SM}} = 0.87 \pm 0.15$$ SM loops and no BSM decay

$$k_t = 1.40^{+0.24}_{-0.21}$$ BSM in loops

- Direct measurement to the Yukawa coupling to the top quark
- Tree-level process, cross-section proportional to λ_t^2

$$\mu_{t\bar{t}H} = \frac{\sigma_{t\bar{t}H}}{\sigma_{t\bar{t}H}^{SM}} = 2.3^{+0.7}_{-0.6}$$

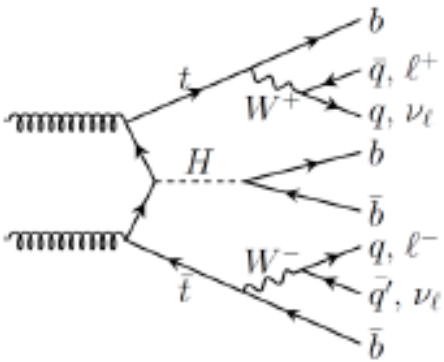
Observed significance of 4.4 σ (expected 2.0 σ), JHEP 1608 (2016)

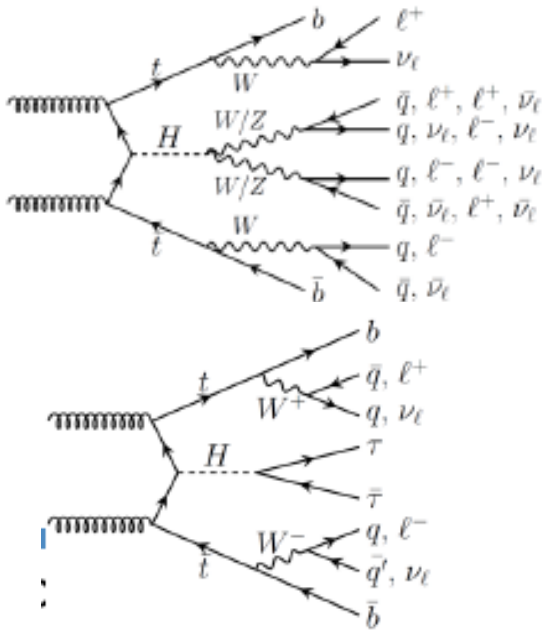
- Indirect measurement sensible to BSM effects, Tree-level process ideal to measure the Yukawa coupling
- Any deviation may lead to new physics

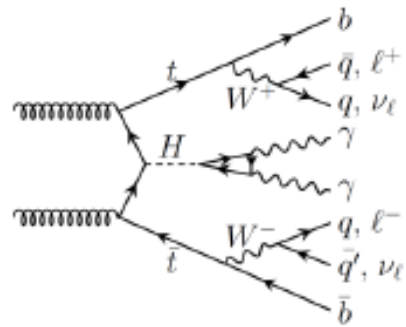
ttH signatures

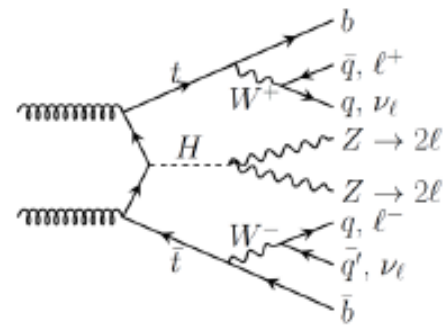
Higher Branching Ratio ← → Higher Significance

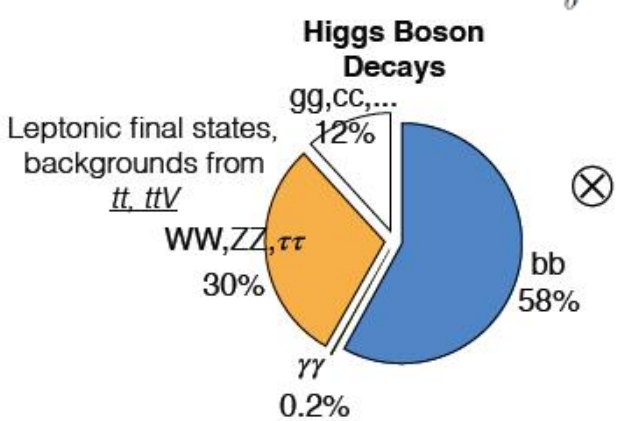
bb channel | Multi-lepton channel (4l Veto) | γγ channel | ZZ channel











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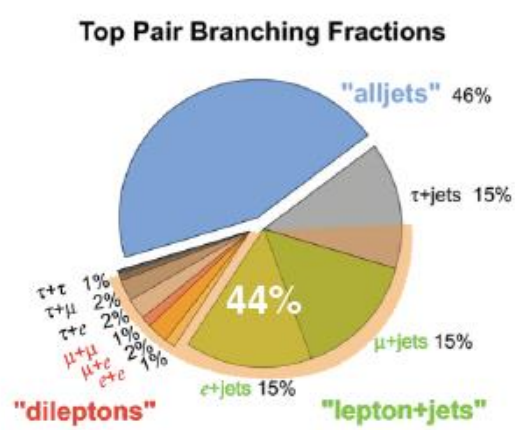


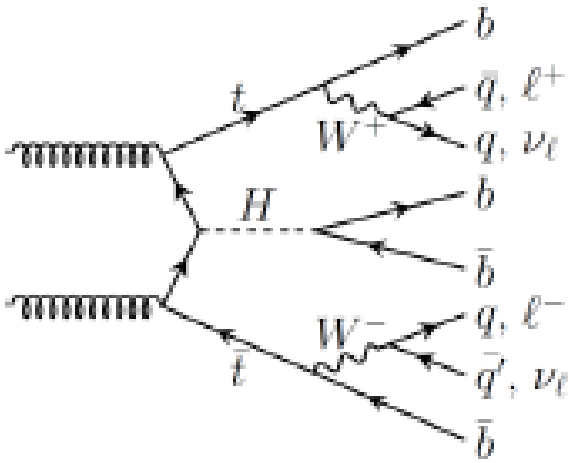
$$t\bar{t}H(H \to b\bar{b})$$

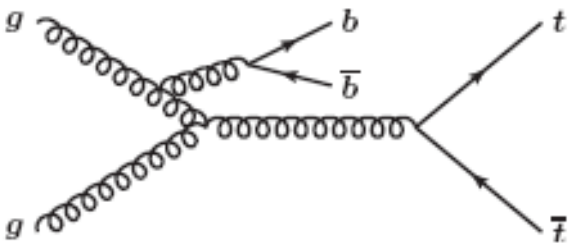
arXiv:1712.08895

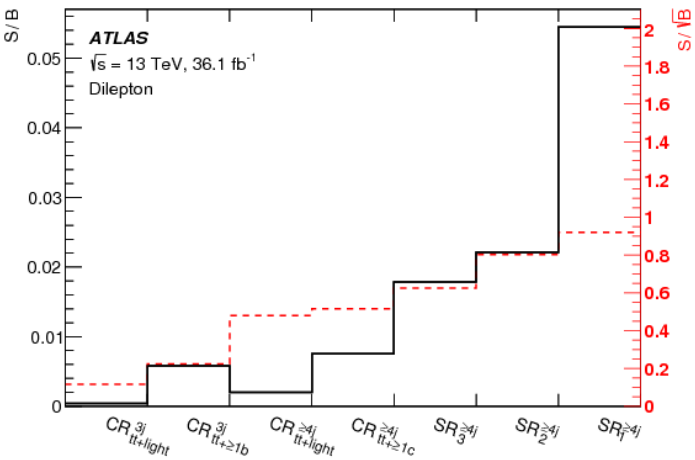
bb channel

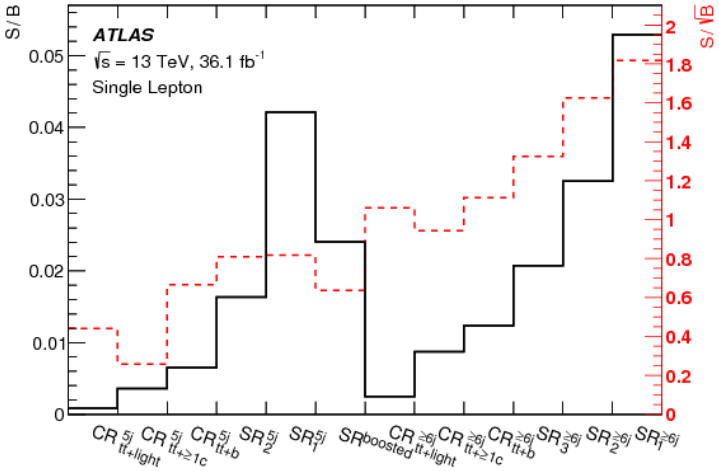
36.1 fb^{-1} of data at 13 TeV

- 2 possible decays in single and double lepton (ATLAS did not covered all modes)
- Event categorization based on lepton, jets and b-tagged (use of a discriminant) jet multiplicities
- Background due to tt+light flavours (uds), tt+cc and tt+bb (85% due to tt+jets)
- tt+bb irreducible background, large uncertainties
- Control Regions (CR) enhanced with tt+≥1b, tt+≥1c and tt+light events to improve background modelling

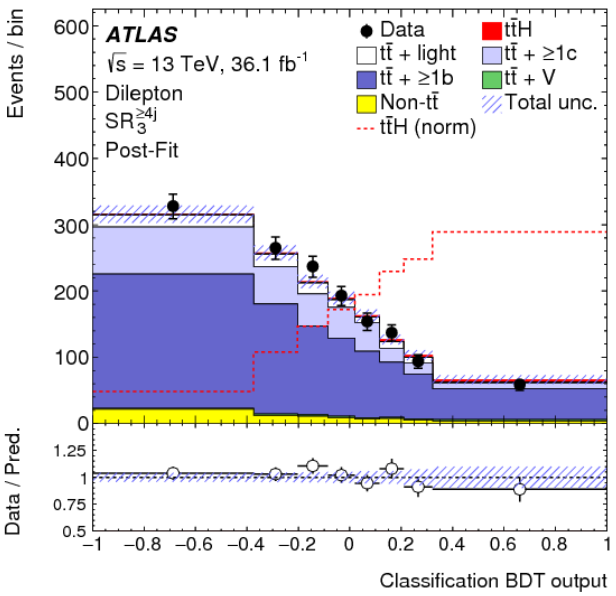






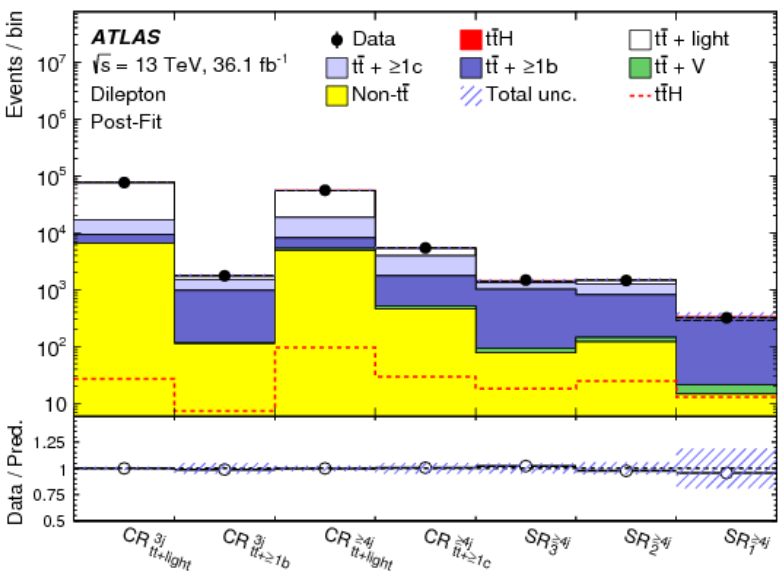


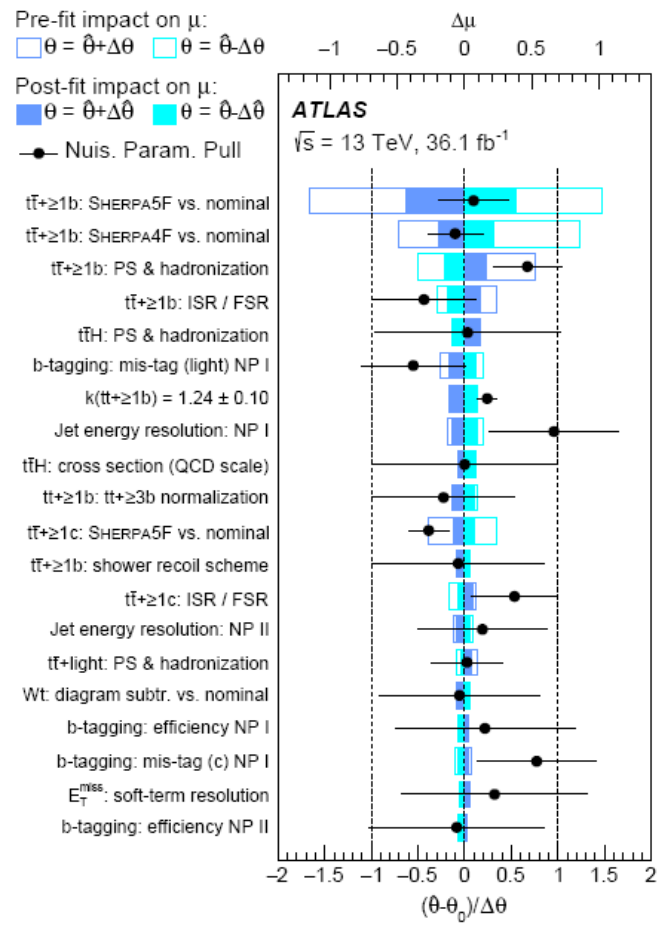
Systematics and MultiVariate Analysis



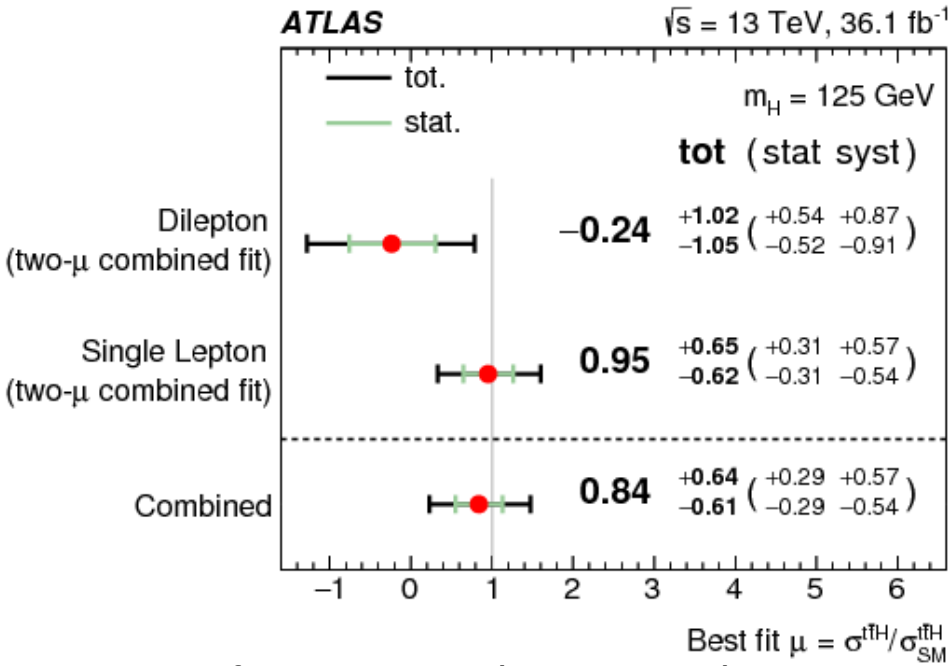
- Large systematics on *tt*+≥1b from variations in simulation and from comparison with alternative simulations
- 3 MVA techniques as input for BDT classification: the 'reconstruction BDT', a likelihood discriminant method, a matrix element method

Signal extracted from combined fit of classification BDT output in SRs and event yields in most of CRs





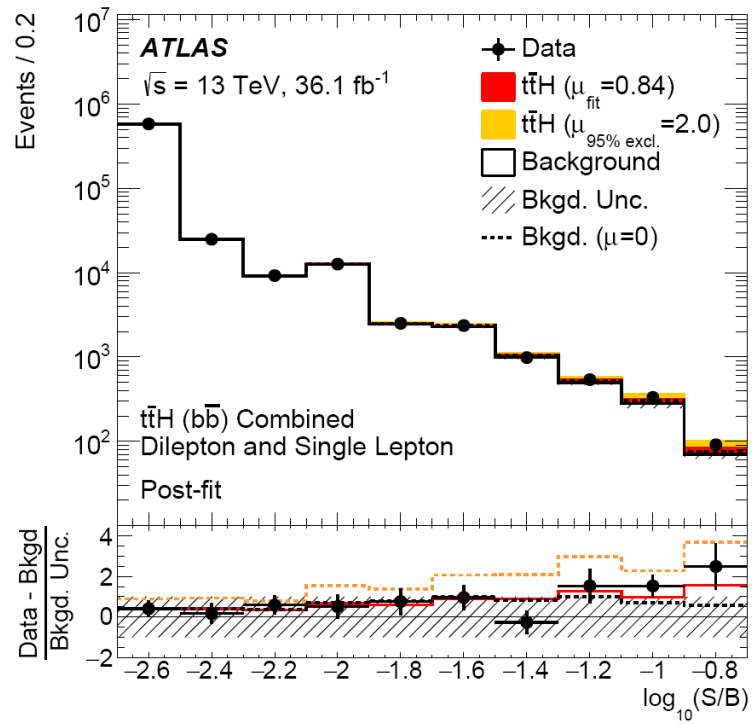
Results



$$\mu = 0.84 \pm 0.29\,(\text{stat.})\ ^{+0.57}_{-0.54}\,(\text{syst.}) = 0.84^{+0.64}_{-0.61}$$

Best μ fit, consistent with the expectation from the Standard Model.

- An excess of events over the expected SM background is found with an observed (expected) significance of 1.4 (1.6) standard deviations
- A value higher than 2.0 is excluded at the 95% confidence level, compared to an expected exclusion limit of 1.2 in the absence of signal.
- An improved modelling of this background will be important for future efforts to observe the ttH(H→bb) process.

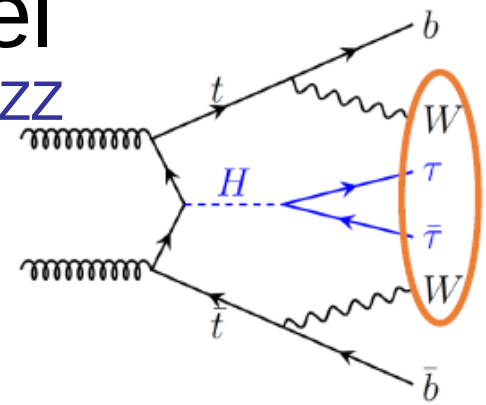


$t\bar{t}H \rightarrow \text{multilepton}$

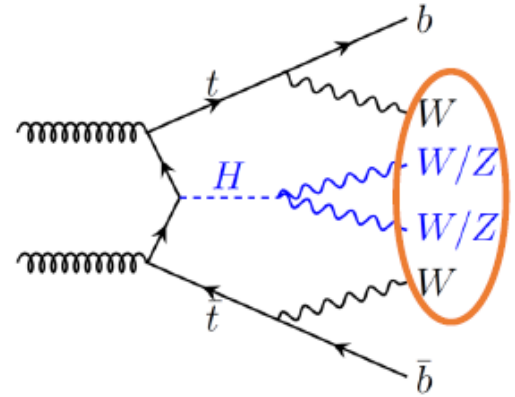
arXiv:1712.08891

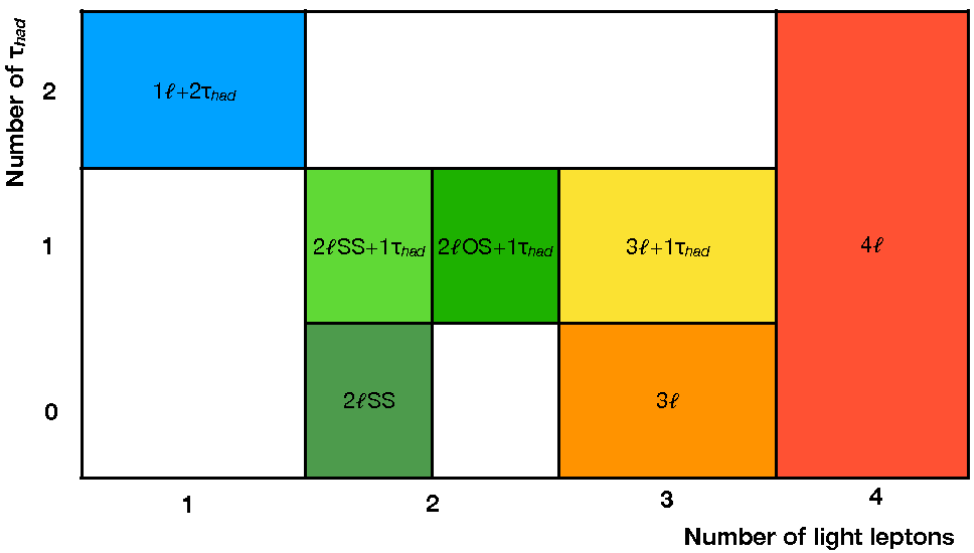
Multilepton channel

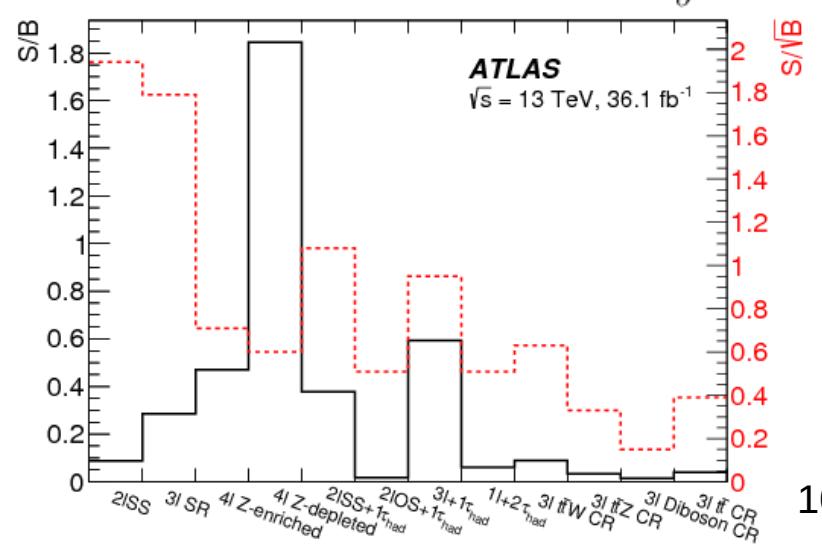
Sensitive to 3 decays mode: H→ττ, H→WW and H→ZZ
Veto on H→ZZ→4l
36.1 fb^{-1} of data at 13 TeV



7 final states dependent on the number and flavours of charged leptons
- additional b-jets requirements (multiplicities) to reject VV events
- ttV control regions with 3*l* events
- Non-prompt validation regions with 2*l*SS events

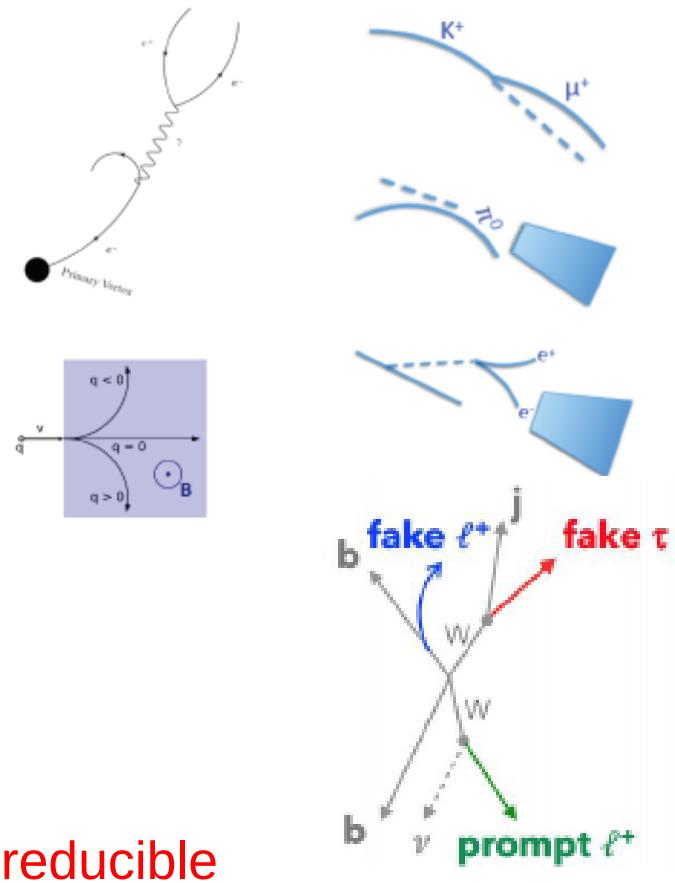






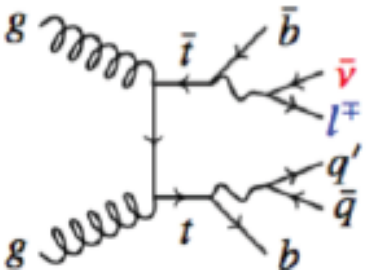
Background

Charge mis-Id **Fake leptons**



Reducible

ttbar or single top, riducible but large

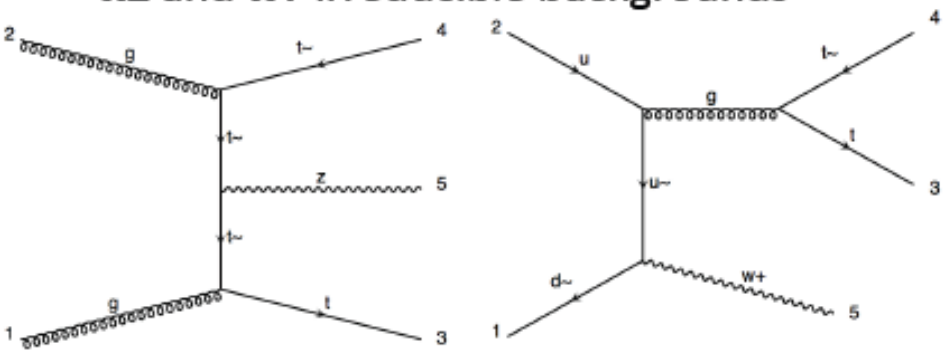


- Fake lepton selected as prompt
- Wrong charge identification
- multivariate approach (MVA) and classification of events based on kinematic properties

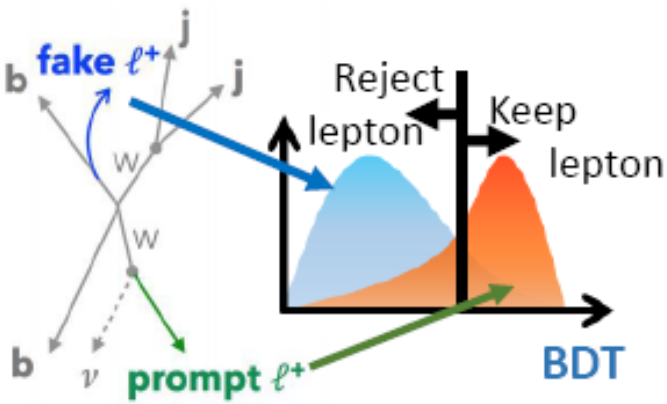
Irreducible

Final states are identical to signal

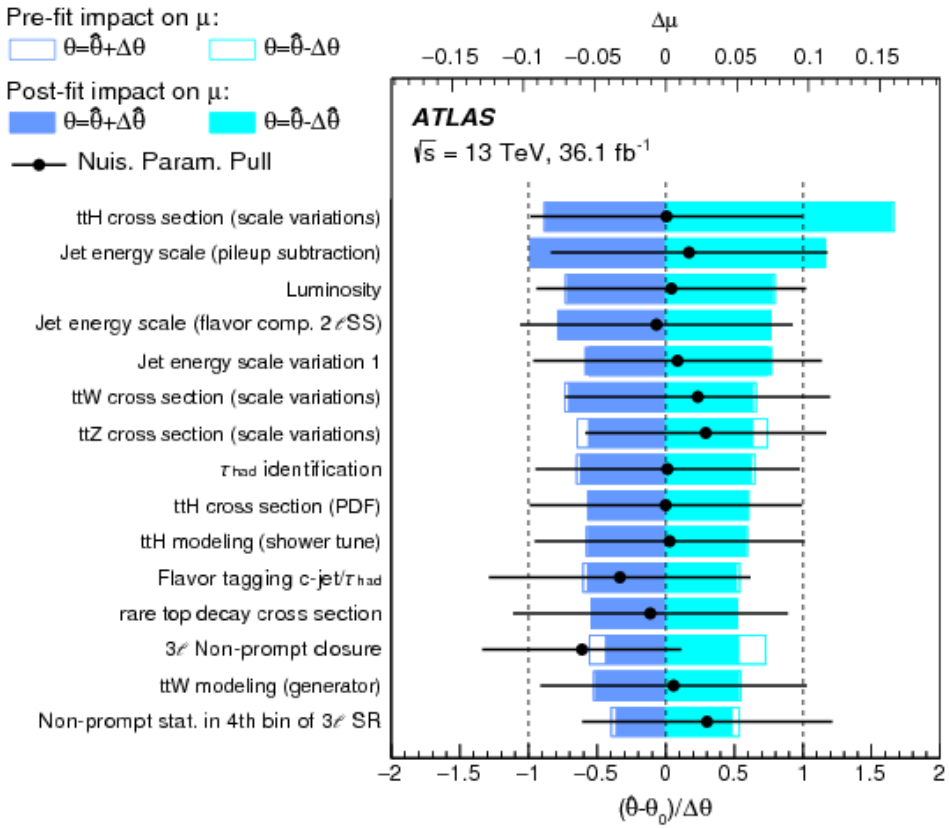
ttZ and ttV irreducible backgrounds



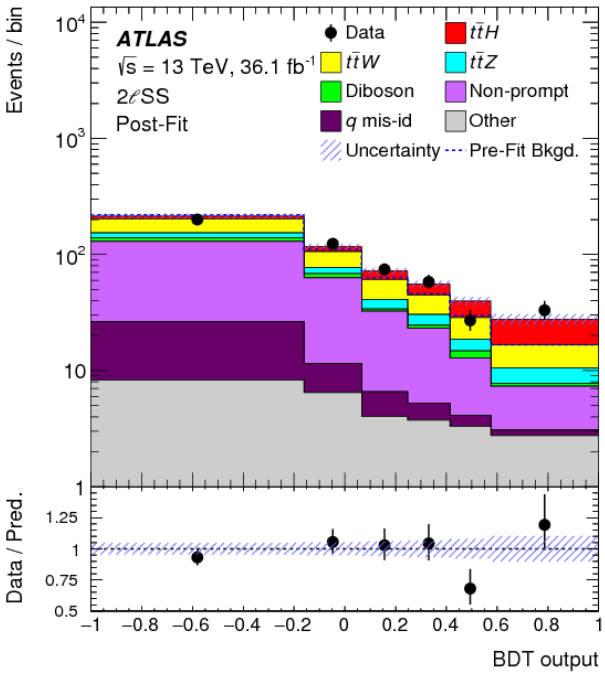
Systematics and MultiVariate Analysis



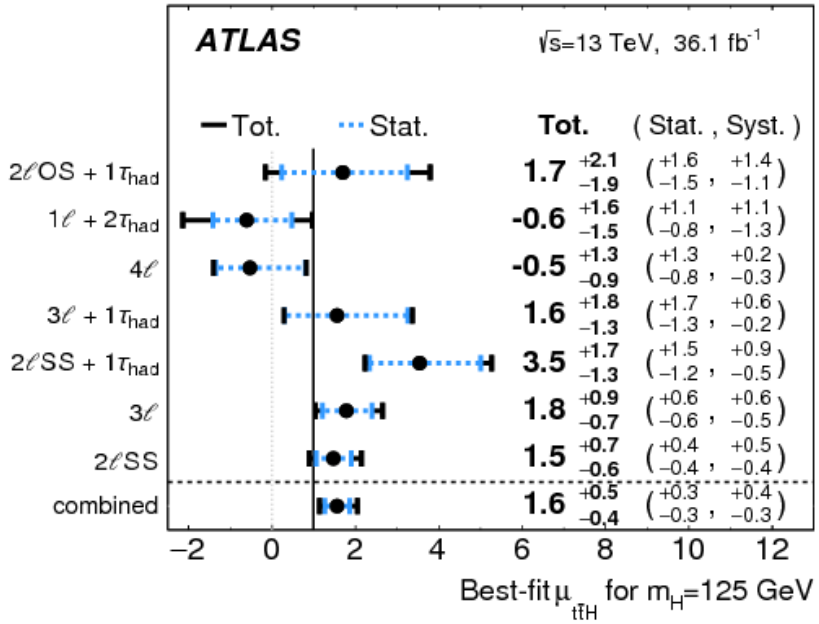
-The total systematic uncertainty is dominated by the uncertainties in the modeling of the ttH and ttV modelling, largest pull of the non-prompt lepton



In 6 of 7 channels event BDTs are used for best signal-background separation



Results



Individual channel results extracted from the full fit but with separate parameter of interest

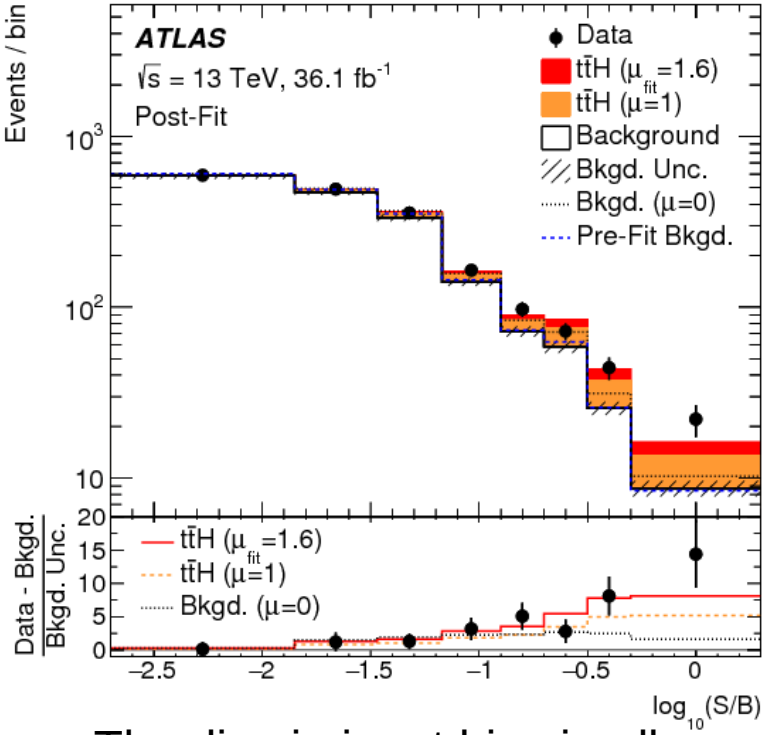
$$\mu_{t\bar{t}H} = 1.6^{+0.5}_{-0.4}$$

-Best μ fit, consistent with the expectation from the Standard Model

- Obs (exp) excess of 4.1(2.8)σ over SM background

$$\sigma_{t\bar{t}H} = 790^{+230}_{-210}\ fb \qquad \sigma_{t\bar{t}H} = 507^{+35}_{-50}\ fb$$

Expected



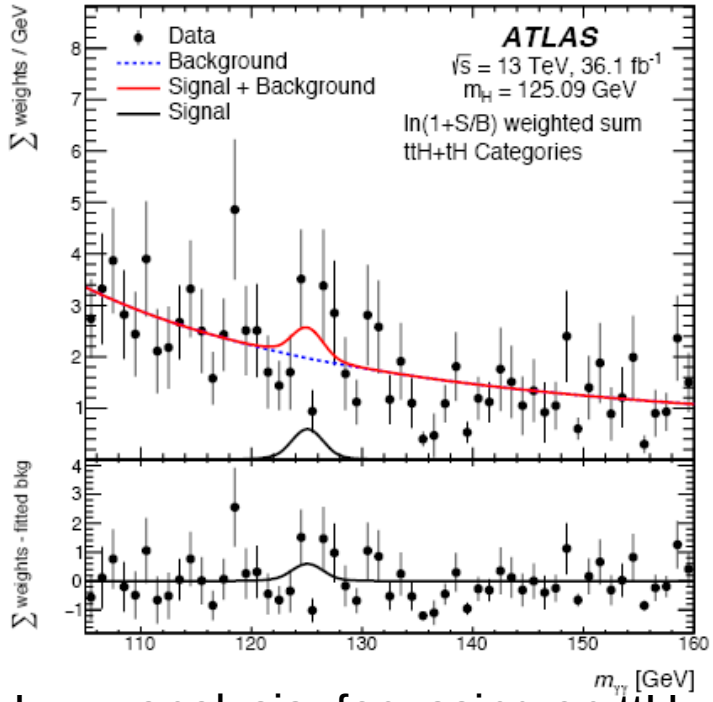
The discriminant bins in all signal regions are combined into bins of log(S/B)

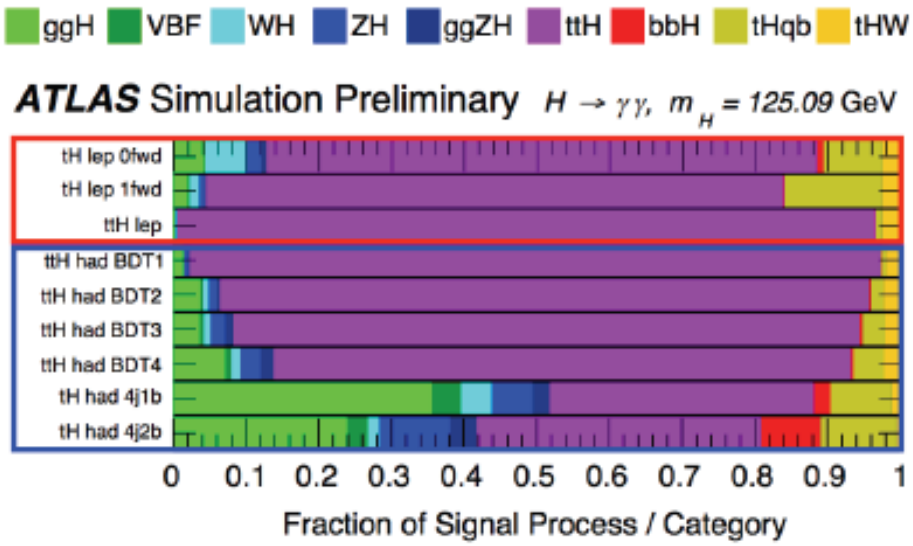
$$t\bar{t}H(H \rightarrow \gamma\gamma)$$

arXiv:1802.04146

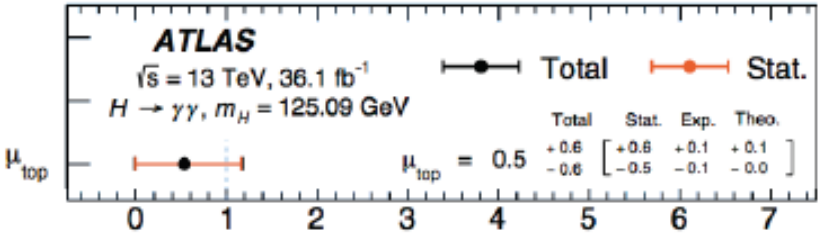
γγ channel

36.1 fb^{-1} of data at 13 TeV





- H→γγ analysis, focussing on ttH
- Low branching ratio but high photon reconstruction and identification efficiency at ATLAS



μ<1.7 at 95%CL

$$\text{ATLAS: } \mu_{top} = 0.5 \pm 0.6(tot)\ ^{+0.6}_{-0.5}(stat)\ ^{+0.1}_{-0.1}(syst)$$

Leptonic selection

- 2 central jet, within which at least 1 b-tagged
- at least 1 prompt lepton (with Z-mass veto)

Hadronic selection

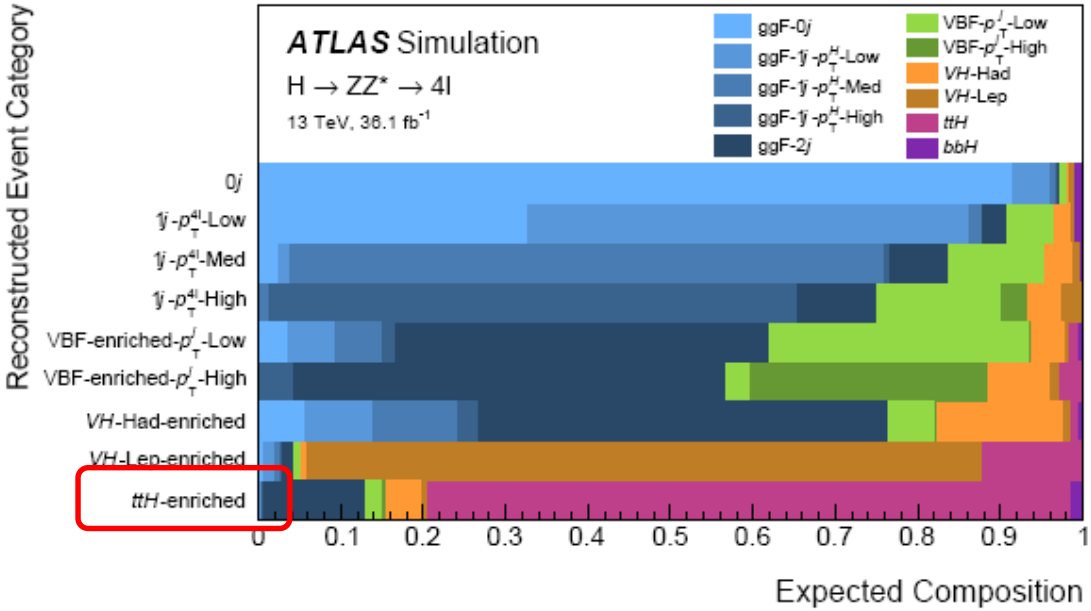
- at least 3 central jet, within which at least 1 b-tagged
- at least 1 prompt lepton
- further BDT categorization

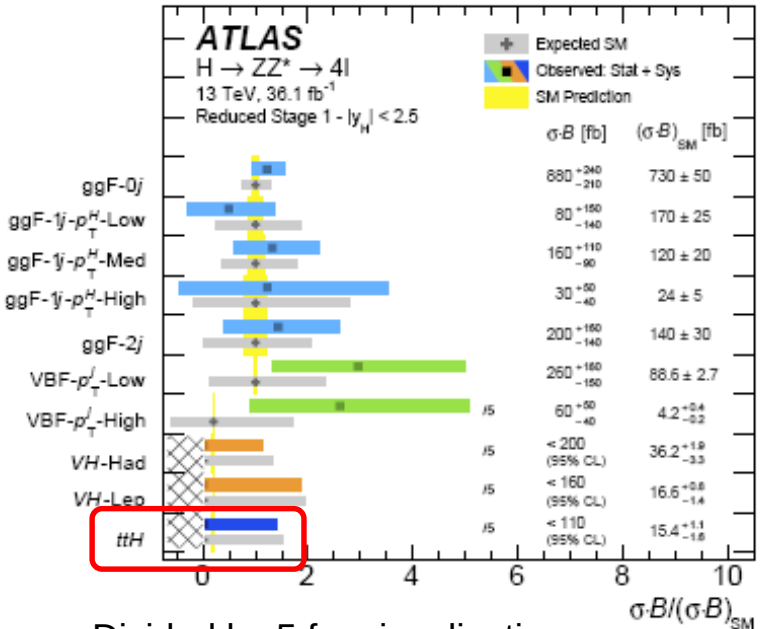
$$t\bar{t}H(H \rightarrow ZZ^{*} \rightarrow 4l)$$

arXiv:1712.02304

4l channel

36.1 fb^{-1} of data at 13 TeV





Divided by 5 for visualization purposes

H→ZZ*→4l main analysis, focussing on ttH

Selection

- at least 1 b-tagged jet
- at least 4 jets or 1 additional lepton+at least 2 jets

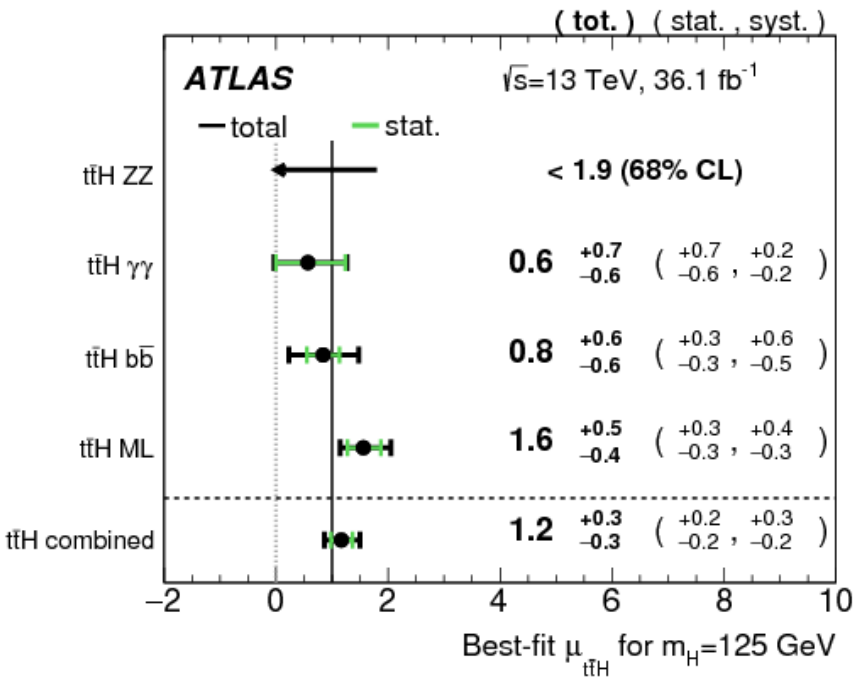
Reconstructed event category	Signal	ZZ* background	Other backgrounds	Total expected	Observed
ttH-enriched	0.39 ± 0.04	0.014 ± 0.006	0.07 ± 0.04	0.47 ± 0.05	0

$\mu_{t\bar{t}H} < 7.5$ at 95% CL

Combination

arXiv:1712.08891

Results



- Combination of ttH, with H→bb, ttH→multilepton and ttHenhanced categories in H→γγ and H→ZZ*→4l
- tHqb and WtH are considered backgrounds and fixed to their SM predictions
- all Higgs boson branching fractions are set to SM expectations

$$\mu = 1.17 \pm 0.19(\text{stat})\,^{+0.27}_{-0.23}\,(\text{syst})$$

- Evidence for ttH at 4.2σ (3.8σ expected)
- Compatibility of individual analysis with the combined value is 38%.

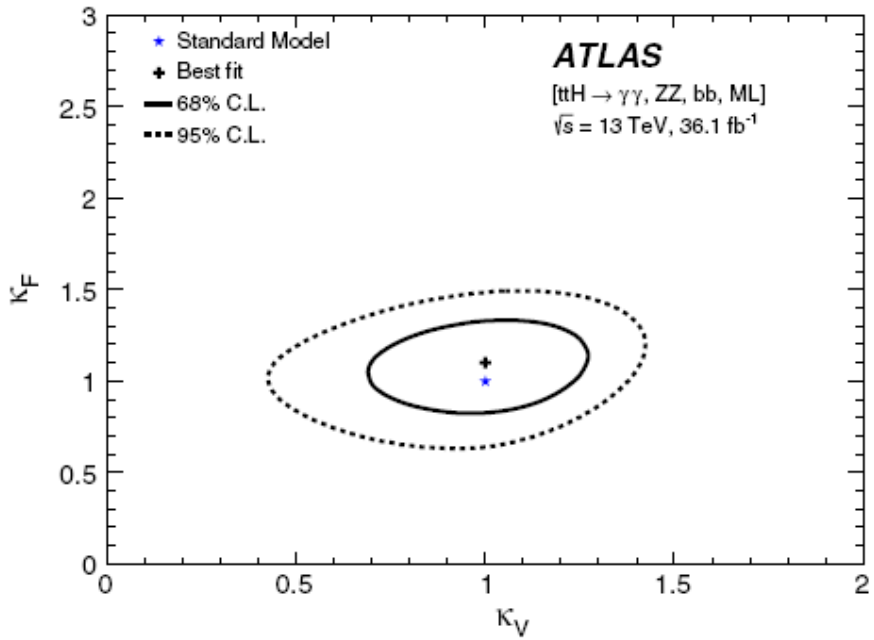
$$\sigma_{t\bar{t}H} = 507^{+35}_{-50}$$ Measured

$$\sigma_{t\bar{t}H} = 590^{+160}_{-150}$$ SM

Results

ttH analyses sensitive to the Htt, Hbb, and Hττ fermion couplings, the HWW and HZZ gauge boson couplings, and the effective Hγγ coupling.

Constraints can be placed on deviations of these couplings from the SM.



No contributions from non-SM particles are considered and no non-SM Higgs boson decay modes are allowed to modifications to loop-induced processes

Conclusions

- 36.1 fb^{-1} of data at 13 TeV
- ttH analysis conducted on 4 different channels: $H \rightarrow bb$, $H \rightarrow$multilepton, $H \rightarrow ZZ \rightarrow 4l$ and $H \rightarrow \gamma\gamma$
- low cross and challenging irreducible and reducible background
- huge use of MultiVariate Analysis (mainly BDT) to discriminate signal
- Evidence of ttH production at 4.2σ (3.8σ expected)
- Measured cross section of 590^{+160}_{-150} fb (507^{+35}_{-50} expected)
- Waiting for very soon results from Run II (80 fb^{-1} more) and one more year of Run II data taking just started

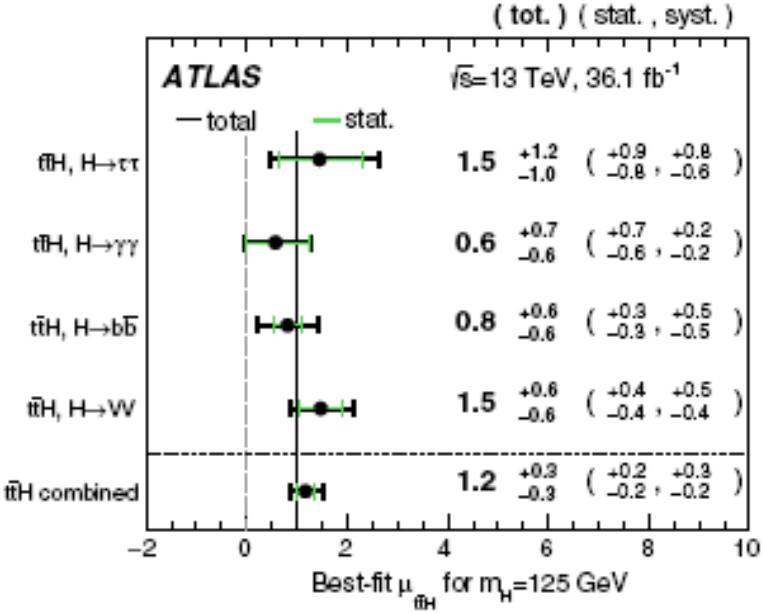
Back-up

Results

An alternative fit where ttW and ttZ were left free, same best fit for μ but with larger error (15%)

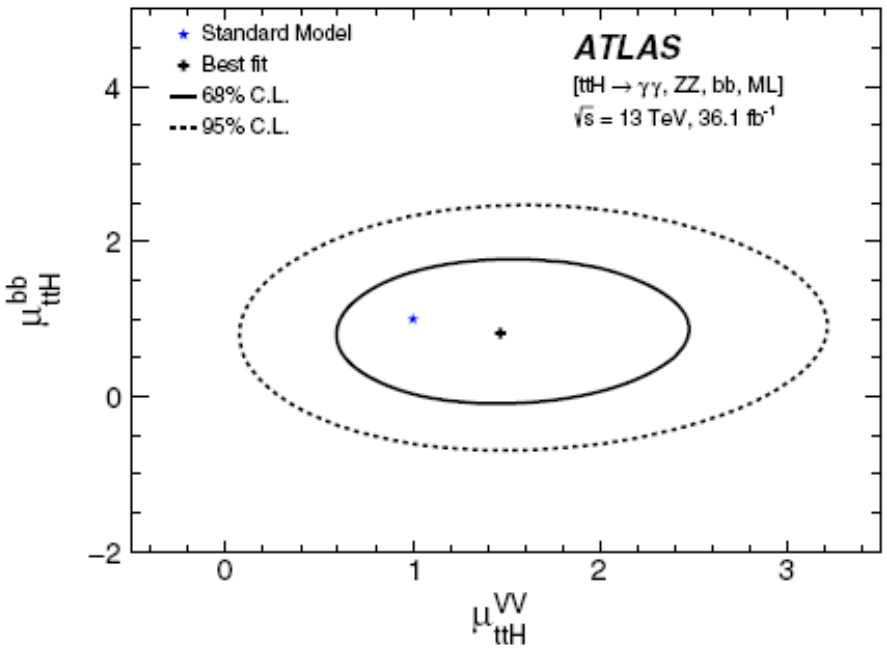
$$\mu_{t\bar{t}W} = 0.92 \pm 0.32 \quad \mu_{t\bar{t}Z} = 1.17^{+0.25}_{-0.22}$$

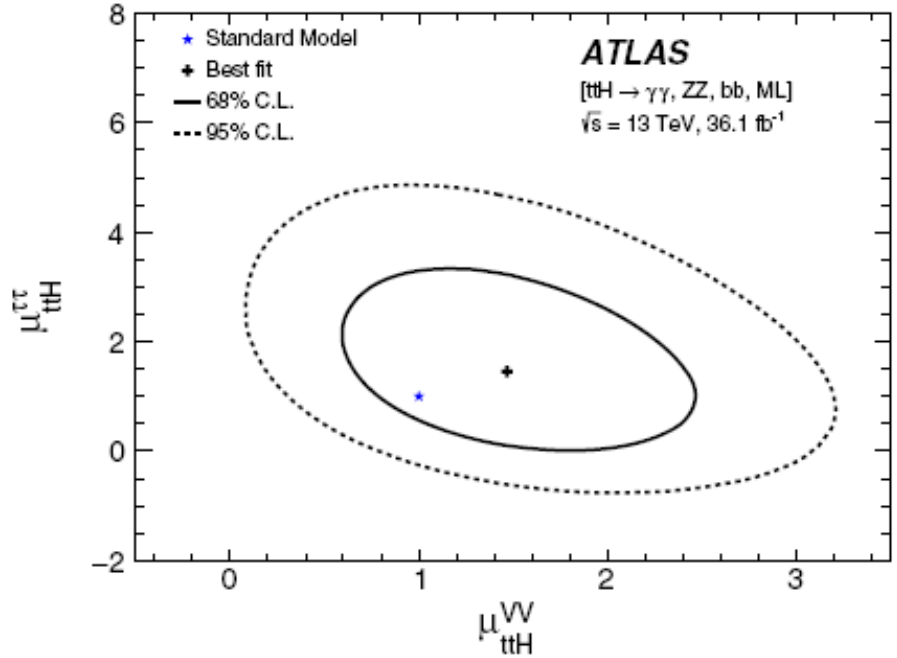
Results



Different acceptances for the different analysis categories, so independent determination of μ in different Higgs decay modes.

Results





In good agreement with the Standard Model values k_F=1 and k_V=1.
The possibility that k_F<0 is excluded at 95% C.L. in this parameterization