Search for $t\bar{t}H/tH$ with $H \to \gamma\gamma$ at $\sqrt{s}$ = 13 TeV with the ATLAS experiment

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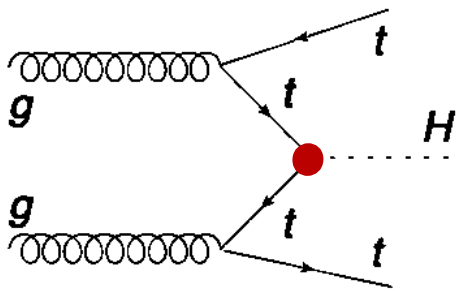
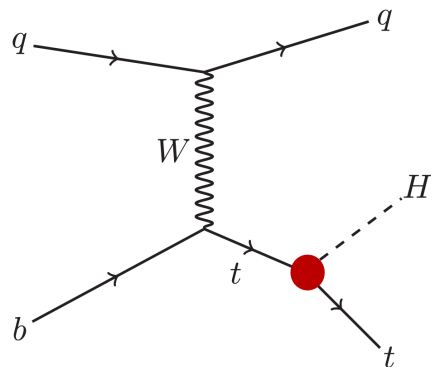
Introduction

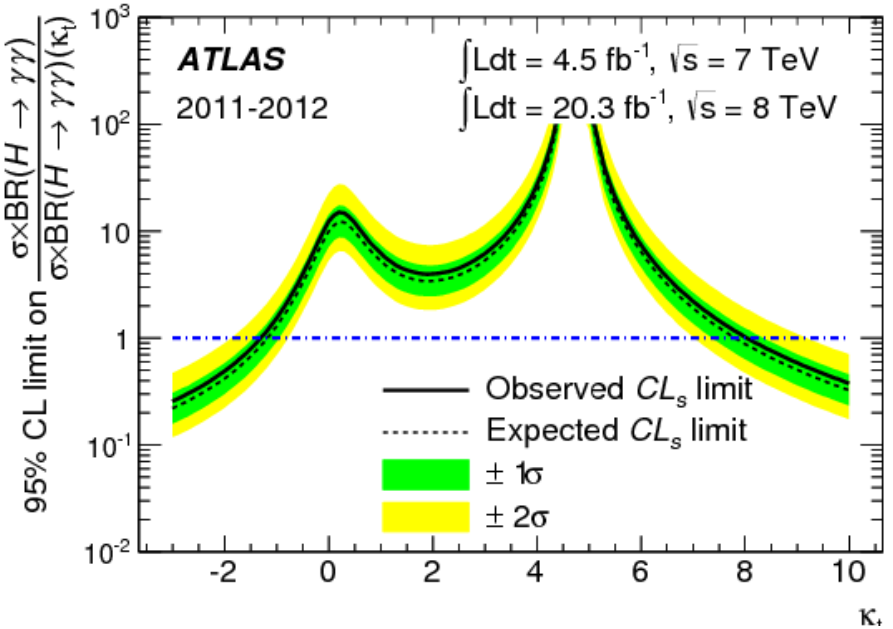
- Direct measurement of Yukawa coupling $Y_t = \kappa_t \times Y_t^{SM}$
- Diphoton final state:
  - Small branching ratio
  - Good photon resolution $\Rightarrow$ Narrow peak in $m_{\gamma\gamma}$ spectrum
  - Small backgrounds
- $t\bar{t}H(\gamma\gamma)$ considered in two ICHEP analyses with $\sqrt{s}$ = 13 TeV and 13.3 fb^{-1}
  - Measurement of production cross sections in the $H \to \gamma\gamma$ decay channel [ATLAS-CONF-2016-067]
  - Combination of $t\bar{t}H$ in the $\gamma\gamma$, multilepton, and $b\bar{b}$ decay channels [ATLAS-CONF-2016-068]
- No direct search for tH production by ATLAS so far

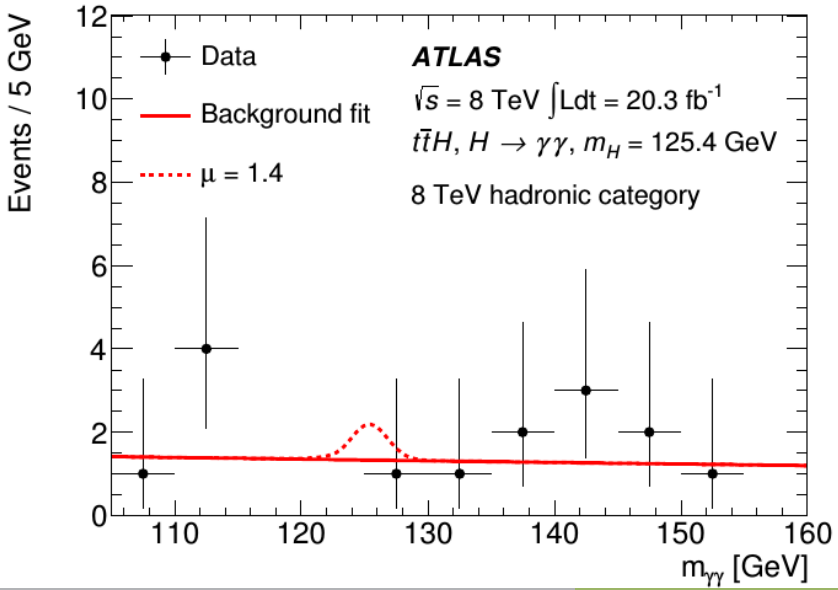


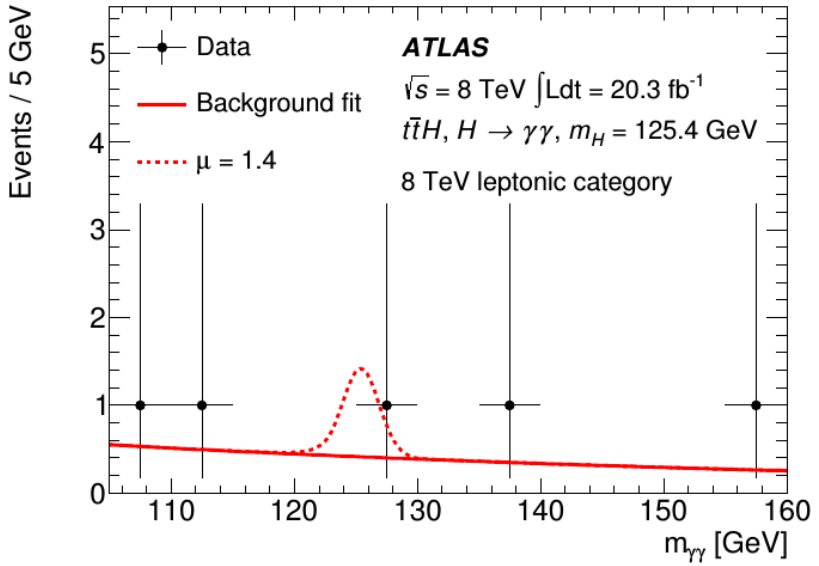


Review: Run 1

- Combined analysis of $ttH/tH(\gamma\gamma)$ (arXiv:1409.3122)
- No dedicated *tH* categories
- Statistically limited
- Interpretation in κ_t framework
  $\Rightarrow$ Limit set on $-1.3 \leq \kappa_t \leq 8.0$





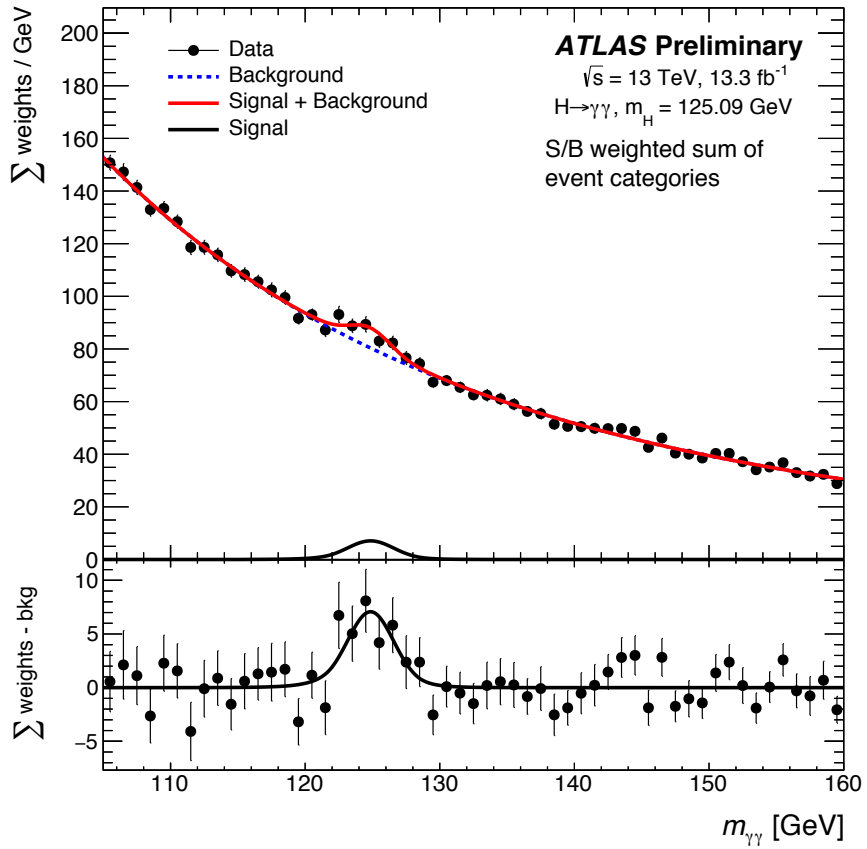


Analysis strategy in the diphoton channel

- Event selection optimization
- Studying the backgrounds
- Search for a resonance in $m_{\gamma\gamma}$ at $m_H = (125.09 \pm \approx 1.5)$ GeV
- Calculate expected significance & limit

Backgrounds:

- Continuum background
  - Estimated from data
  - Fit with an analytic function
- Higgs background
  - Estimated using MC samples



Inclusive $H \to \gamma\gamma$-production at $\sqrt{s} = 13$ TeV
[ATLAS-CONF-2016-067]

ICHEP Event selection for $t\bar{t}H(\gamma\gamma)$

Diphoton selection

- 2 tight & isolated photons
- Diphoton primary vertex
- $m_{\gamma\gamma}$ between 105 and 160 GeV
- Relative p_T cuts: $p_T > 0.35\ (0.25) \times m_{\gamma\gamma}$

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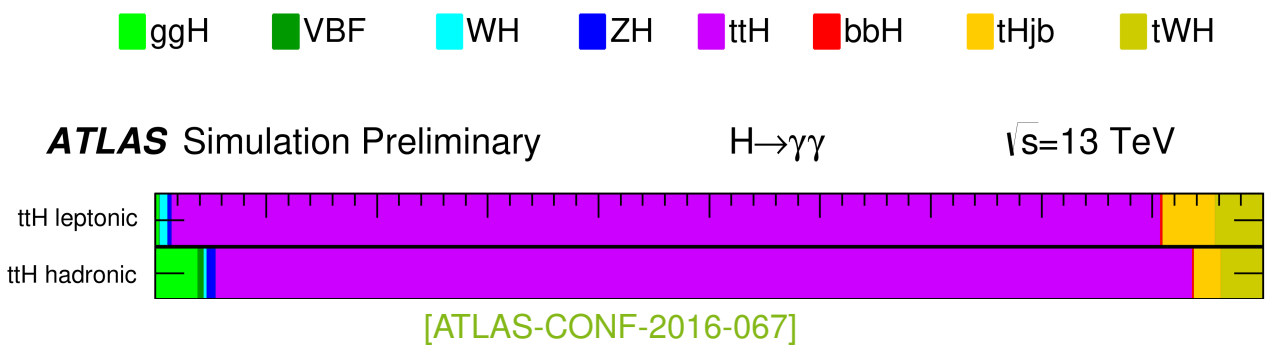
Leptonic category

- ≥ 1 lepton (e, μ)
- ≥ 2 jets with $p_T > 25$ GeV
- ≥ 1 b-tagged jet
- $E_T^{\text{miss}} > 20$ GeV for events with 1 b-tagged jet
- Z veto on $m_{\ell\ell}$ and $m_{e\gamma}$

Hadronic category

- No leptons
- ≥ 5 jets with $p_T > 30$ GeV
- ≥ 1 b-tagged jet



[ATLAS-CONF-2016-067]

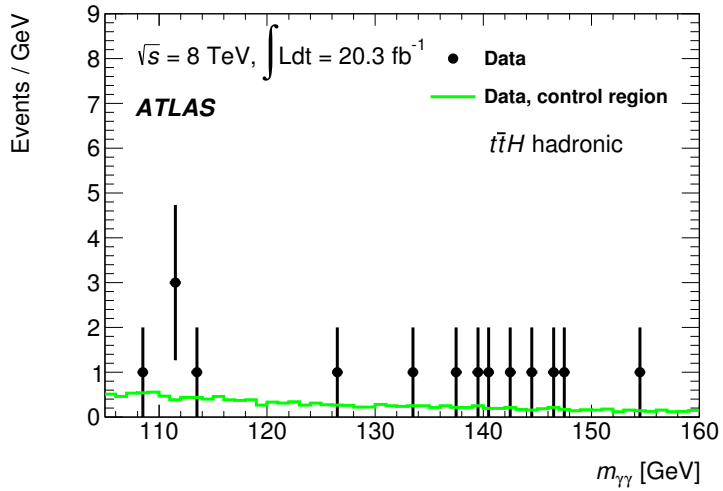
Signal & background modeling

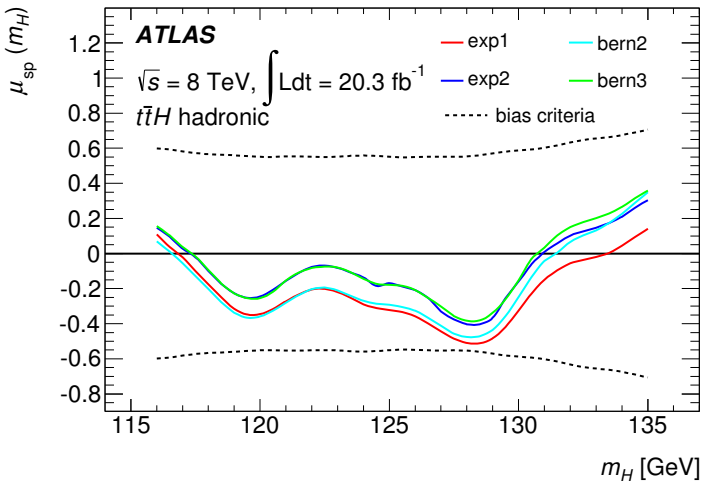
Background model

- Modelled with an analytic function
  $\Rightarrow$ Minimize bias in extracted signal yield
- Background composition not known for $t\bar{t}H$
  $\Rightarrow$ Data control regions are used to chose a function
- Exponential is chosen due to small statistics
- Uncertainty on choice of background model
  $\Rightarrow$ Spurious signal = Maximum bias from choice of function

Signal model

- double-sided Crystal Ball function
- Parameters determined using a fit to MC



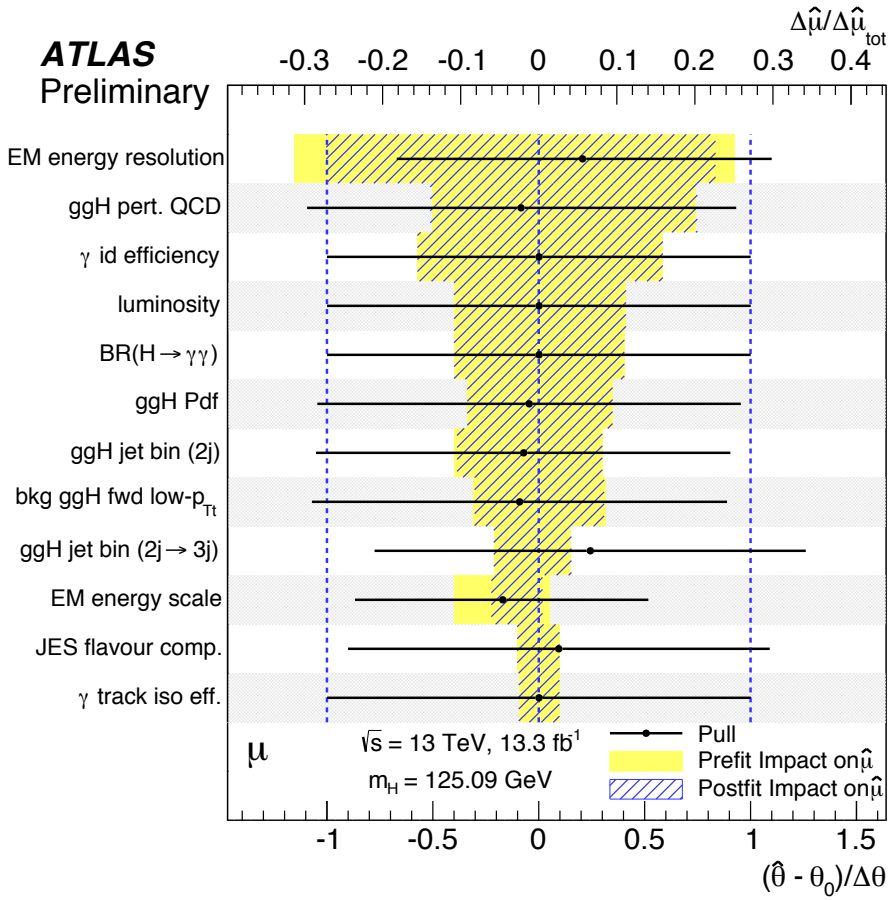


(arXiv:1408.7084)

Uncertainties

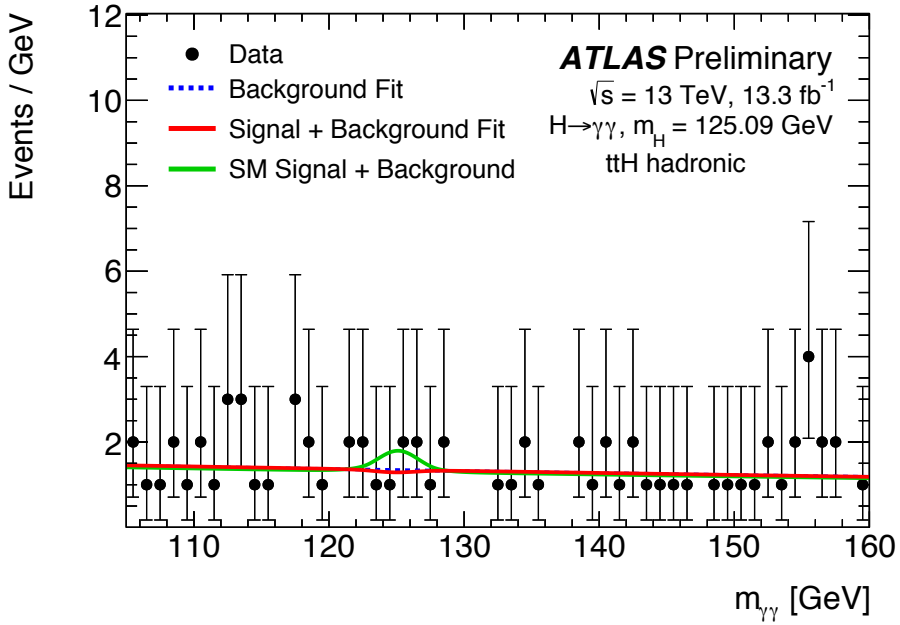
- **Statistical uncertainties are dominant**
- Main systematics
  - Photon energy scale & resolution
  - Photon ID & isolation
  - Spurious signal
  - Jet energy scale & resolution
  - Theoretical uncertainties: Heavy flavour content, QCD scale, PDF

Uncertainties for inclusive $H \rightarrow \gamma\gamma$

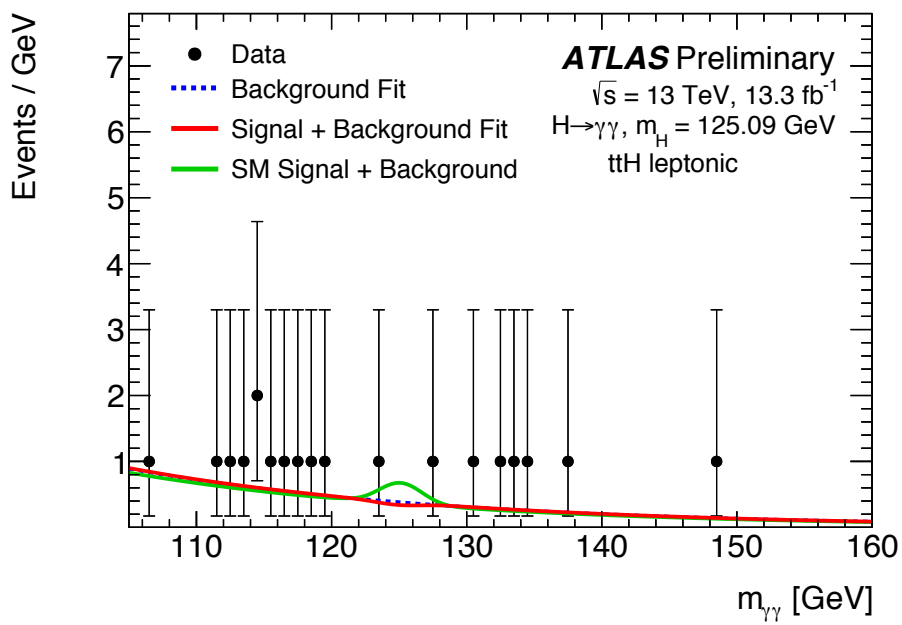


[ATLAS-CONF-2016-067]

Results: Cross section measurement



Hadronic category: 72 events



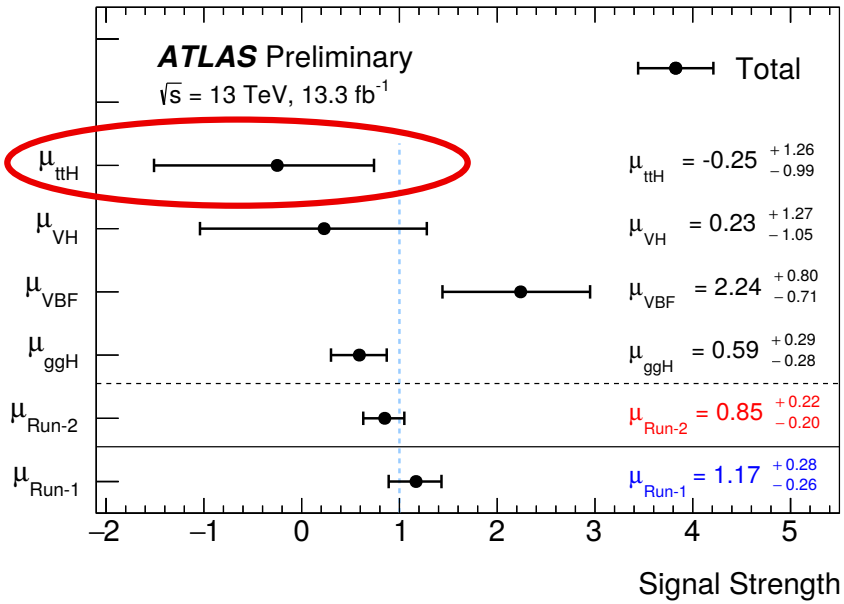
Leptonic category: 19 events

Total measured production cross section:

$$\sigma_{t\bar{t}H} \times \mathcal{B}(H \to \gamma\gamma) = -0.3\ ^{+1.4}_{-1.1}\ \text{fb}$$

[ATLAS-CONF-2016-067]

Results: Signal strength and 95% CL limit



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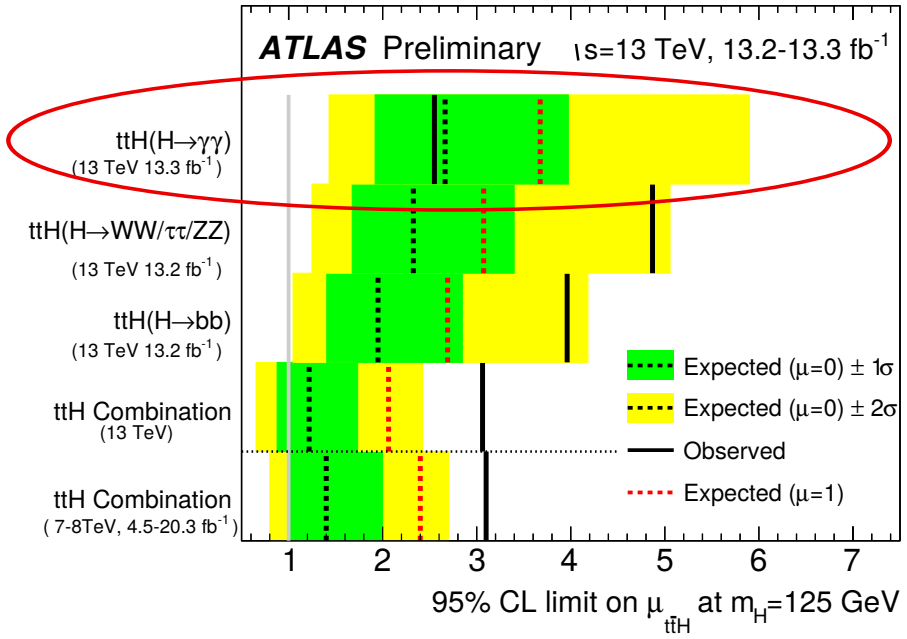
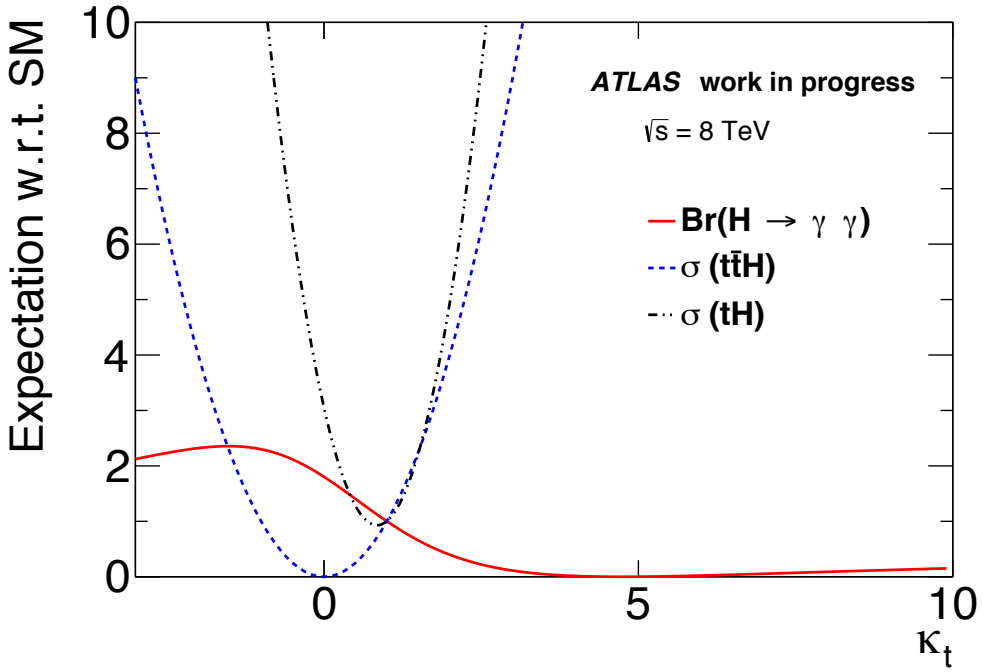


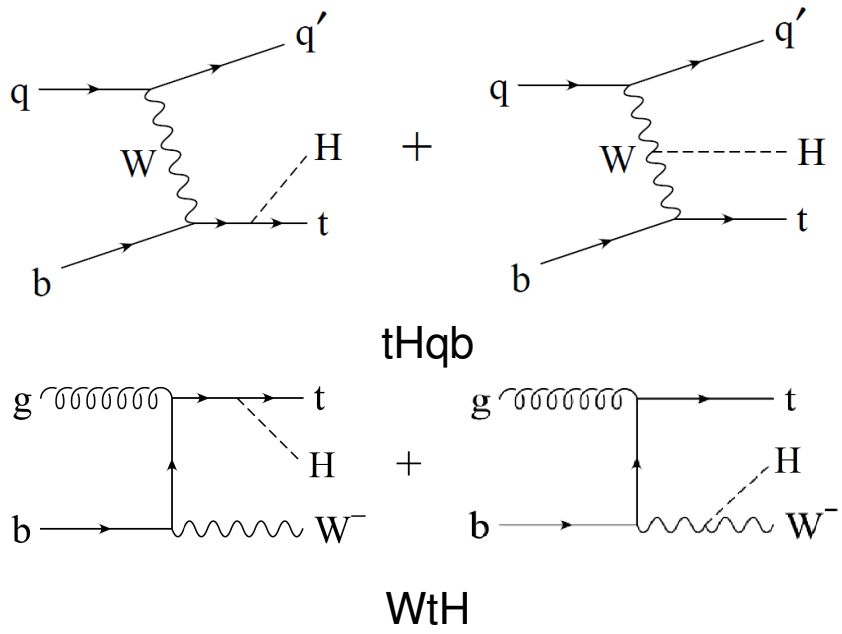
- Small downward fluctuation of $t\bar{t}H(\gamma\gamma)$
- Both combinations ($H \to \gamma\gamma$, $t\bar{t}H$) in agreement with SM expectation
- No couplings interpretation so far

Channel	Observed $\mu_{t\bar{t}H}$	Expected $\mu_{t\bar{t}H}$
$t\bar{t}H$, $H \to \gamma\gamma$	$-0.3\ ^{+1.2}_{-1.0}$ (tot.) [$^{+1.2}_{-1.0}$ (stat.)]	$1.0\ ^{+1.4}_{-1.1}$ (tot.) [$^{+1.4}_{-1.1}$ (stat.)]
$t\bar{t}H$, $H \to (WW, \tau\tau, ZZ)$	$2.5\ ^{+1.3}_{-1.1}$ (tot.) [$^{+0.7}_{-0.7}$ (stat.)]	$1.0\ ^{+1.2}_{-1.0}$ (tot.) [$^{+0.7}_{-0.6}$ (stat.)]
$t\bar{t}H$, $H \to b\bar{b}$	$2.1\ ^{+1.0}_{-0.9}$ (tot.) [$^{+0.5}_{-0.5}$ (stat.)]	$1.0\ ^{+0.8}_{-0.8}$ (tot.) [$^{+0.4}_{-0.4}$ (stat.)]
$t\bar{t}H$ combination	$1.8\ ^{+0.7}_{-0.7}$ (tot.) [$^{+0.4}_{-0.4}$ (stat.)]	$1.0\ ^{+0.6}_{-0.5}$ (tot.) [$^{+0.3}_{-0.3}$ (stat.)]

[ATLAS-CONF-2016-068]

Motivation for tH

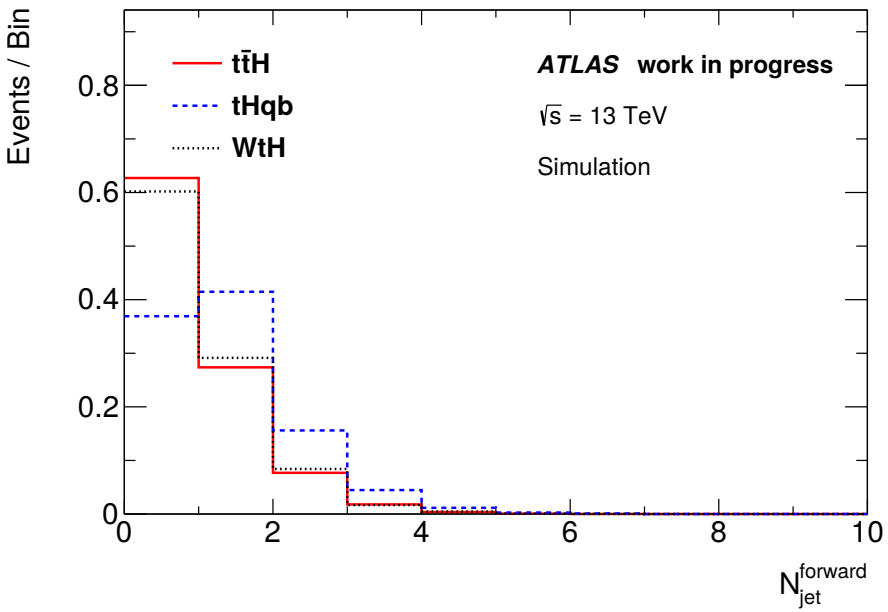


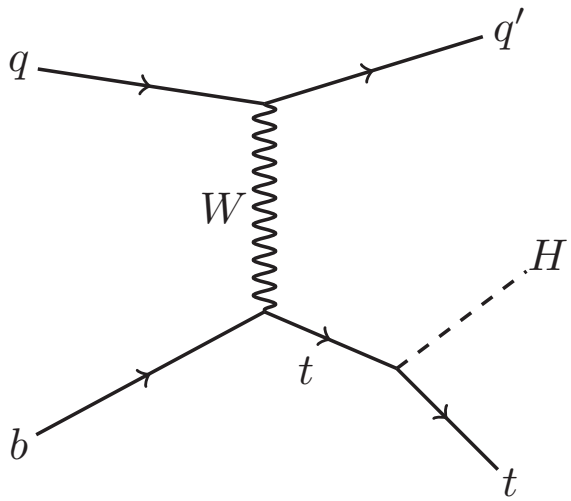


- SM: destructive interference
  $\Rightarrow$ Process is sensitive to the relative sign between Y_t and g_{HWW}
- $Y_t = \kappa_t \; Y_t^{SM}$
  $\Rightarrow$ Cross section strongly increases for $\kappa_t \neq 1$

Optimization of *tH*

- Analysis strategy similar to $t\bar{t}H(\gamma\gamma)$
- Leptonic & hadronic channel considered
- Event selection mainly aims for *tHqb*
- Main Higgs backgrounds:
  - $t\bar{t}H$ in the leptonic channel
  - $t\bar{t}H$, *ggF* in the hadronic channel
- Light quark jet is often forward in t-channel production
  $\Rightarrow$ Use this property for categorization





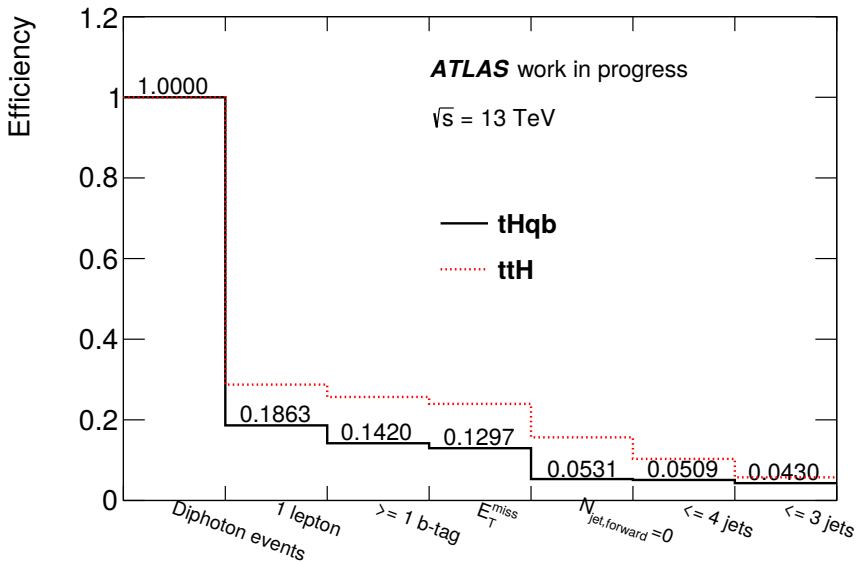
Leptonic *tH* categories

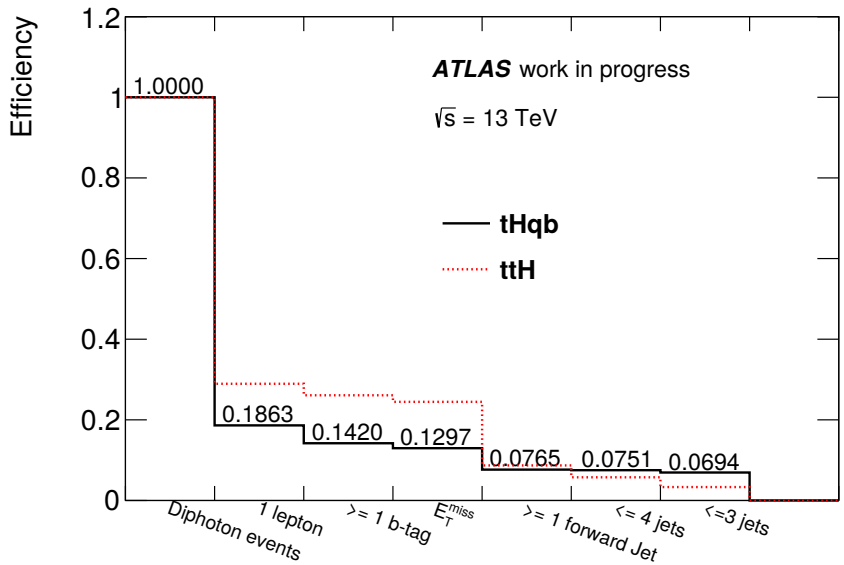
Category with $N_{\text{jet}}^{\text{forward}} = 0$

- 1 lepton
- $E_T^{\text{miss}} > 20$ GeV
- ≥ 1 b-tag (85% WP)
- $N_{\text{jet}}^{\text{central}} \leq 3$

Category with $N_{\text{jet}}^{\text{forward}} \geq 1$

- 1 lepton
- $E_T^{\text{miss}} > 20$ GeV
- ≥ 1 b-tag (85% WP)
- $N_{\text{jet}}^{\text{central}} \leq 4$





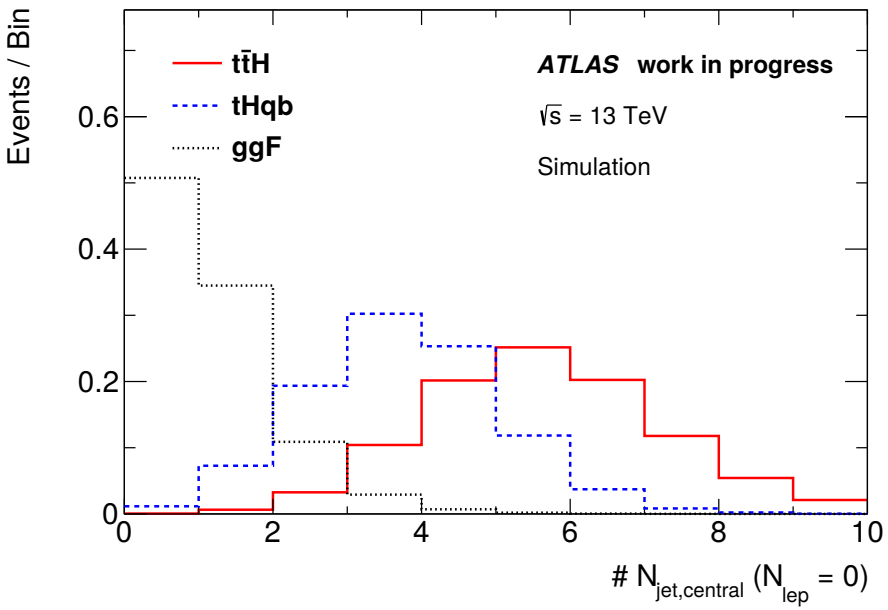
Requirement of $N_{\text{jet}}^{\text{forward}} \geq 1$ suppresses background

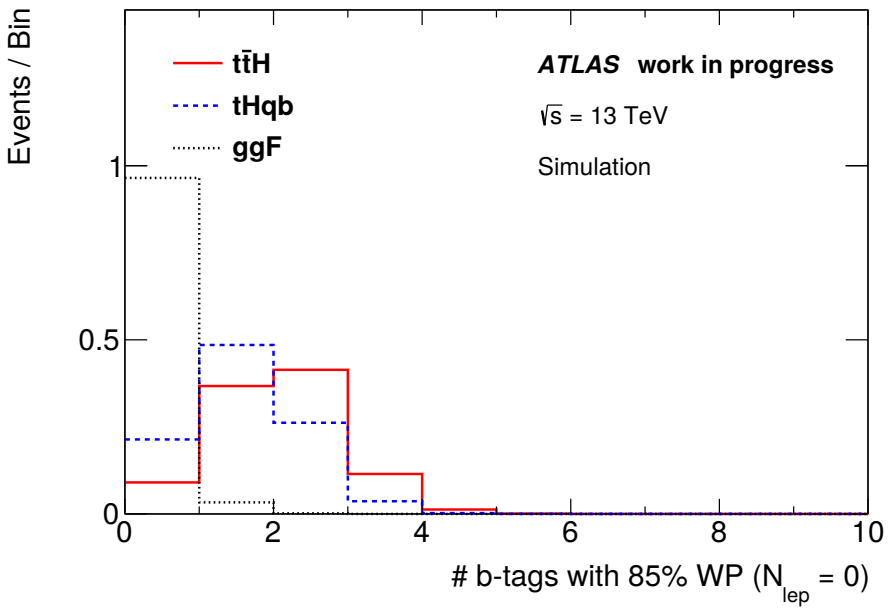
$\Rightarrow$ Two categories with different S/B

Hadronic *tH* category

- Events with 0 leptons and different jet and b-tag multiplicities are selected
  $\Rightarrow$ Main backgrounds: $t\bar{t}H$, *ggF*
- Require forward jet in 5j categories to reduce $t\bar{t}H$
- *ggF* + *Jets* has a large systematic uncertainty
  $\Rightarrow$ p_T cuts and WPs are varied to get a *ggF* fraction smaller than 10%

- **4j1b:** $p_T > 35$ GeV, 60% WP
- **4j2b:** $p_T > 35$ GeV, 85% WP
- **5j1b:** $p_T > 25$ GeV, 60% WP, $N_{\text{jet}}^{\text{forward}} \geq 1$
- **5j2b:** $p_T > 25$ GeV, 77% WP, $N_{\text{jet}}^{\text{forward}} \geq 1$





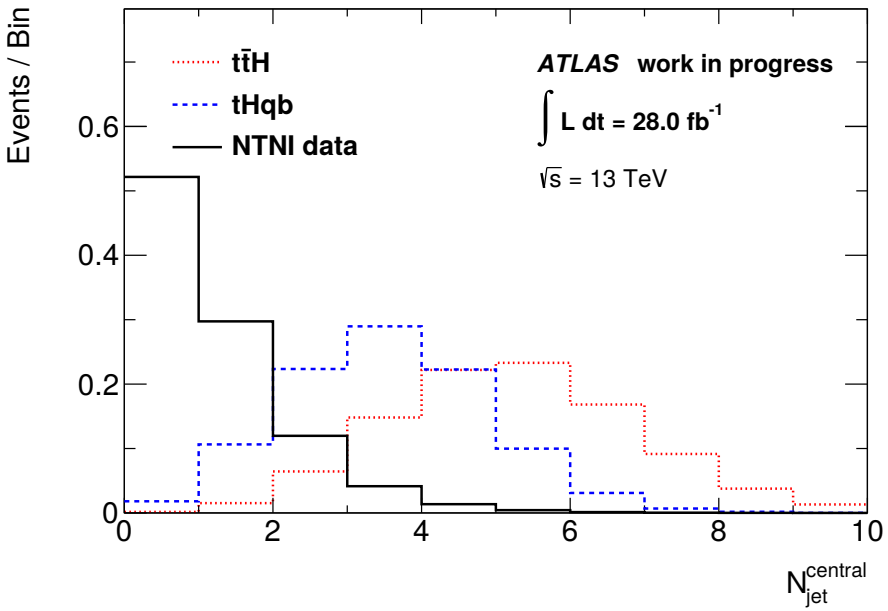
Continuum background

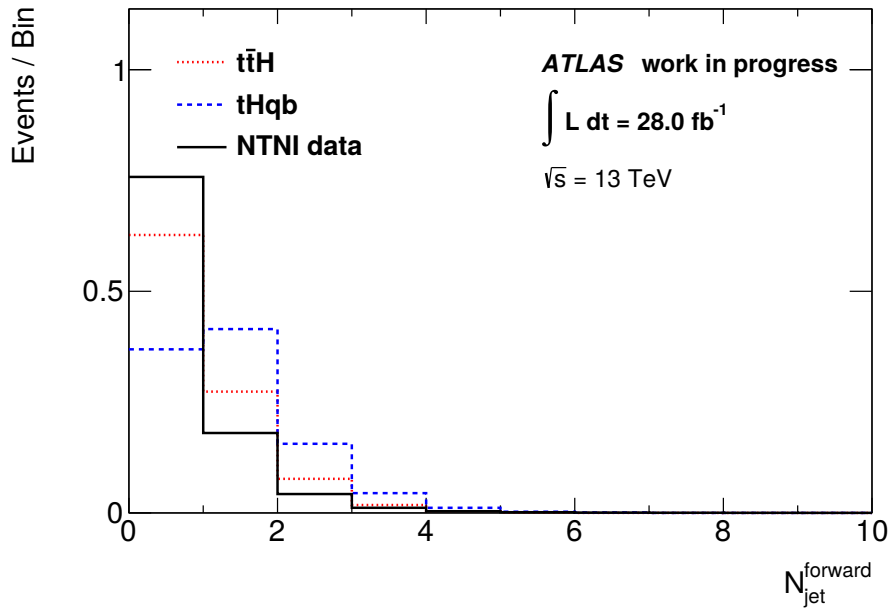
- Composition not known a priori
- Small statistics in data sidebands
- Estimate contribution using data control regions with loosened photon cuts

$\Rightarrow$ Avoid optimizing on statistical fluctuations in the sidebands

$$\frac{N_{\mathrm{tH,TI}}}{N_{\mathrm{tH,NTNI}}} \approx \frac{N_{\mathrm{sel2,TI}}}{N_{\mathrm{sel2,NTNI}}}$$

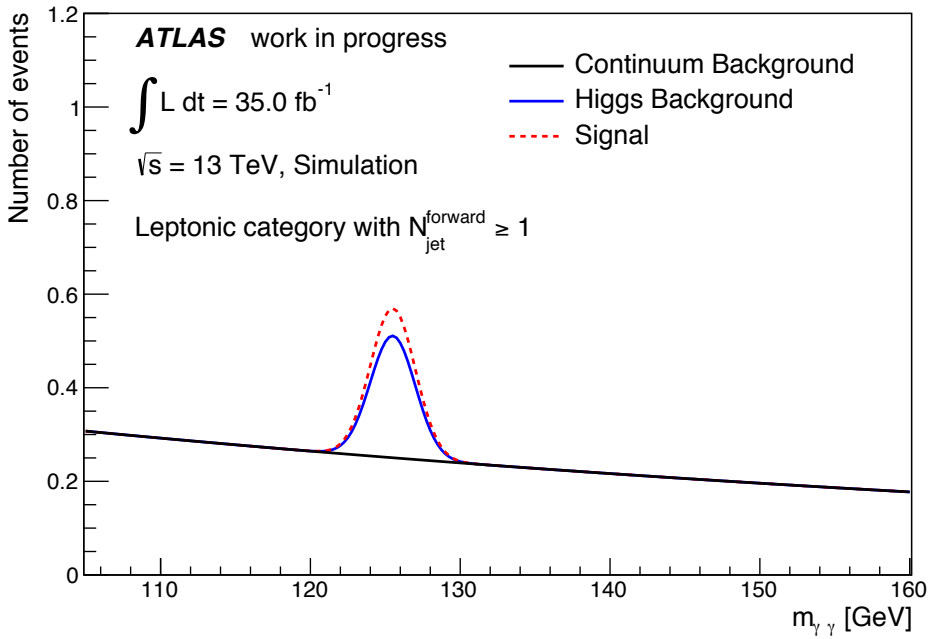
(TI = tight and isolated, NTNI = non-tight, non-isolated)





Expected sensitivity for 35 fb^{-1}

- Expected limit is calculated with an unbinned likelihood fit on $m_{\gamma\gamma}$
- Only statistical uncertainties considered so far
- Different models are assumed:
  - Signal/Higgs BG: Gaussian function
  - Cont. BG: Exponential function



Category	S	B	S/B	Cont. BG [105,160 GeV]	Expected Limit [μ]
Lep ($N_{\text{jet}}^{\text{forward}} = 0$)	0.15	1.08	0.14	22	35.0
Lep ($N_{\text{jet}}^{\text{forward}} \geq 1$)	0.22	0.98	0.22	13	21.0
Had	0.34	3.02	0.11	187	33.0
All combined					14.3

ATLAS work in progress

Conclusions

- First results of $t\bar{t}H(\gamma\gamma)$ with $\sqrt{s}$ = 13 TeV presented at ICHEP
- Still statistically limited, but already more statistics than in Run 1
- $tH(\gamma\gamma)$ has a small cross section, but also unique properties
  $\Rightarrow$ Sensitivity to BSM physics
- Leptonic & hadronic tH event selection optimized for limits
  $\Rightarrow$ Expected limit for SM-like tH with 35 fb^{-1}: 14.3μ