Search for $t\bar{t}H$, $H \to b\bar{b}$ production in ATLAS

Rencontres de Moriond 2014

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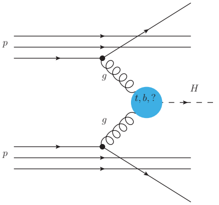
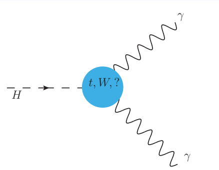
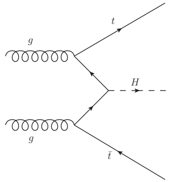
On behalf of the ATLAS Collaboration

Introduction

- Higgs boson discovered in bosonic decay modes ($H \to \gamma\gamma$, ZZ)
  - Higgs mass ~ 125.6 GeV
  - $J^P = 0^+$ strongly favored
- Evidence for fermionic decay modes:
  - ATLAS: $H \to \tau\tau$ (4.1 σ)
  - CMS: combination of $H \to \tau\tau$ and $H \to b\bar{b}$ (4.0 σ)
- ggH production (and $H \to \gamma\gamma$ decays) yield indirect evidence for top-Higgs Yukawa coupling
- Direct measurement of the top-Higgs Yukawa coupling via $t\bar{t}H$ production: $\sigma_{t\bar{t}H} \propto g^2_{t\bar{t}H}$
  - Sensitive to New Physics (via higher-dimension operators)
  - Allows probing New Physics in loop-induced couplings (ggH, $H\gamma\gamma$, $HZ\gamma$)
- Latest results on $t\bar{t}H$, $H \to b\bar{b}$

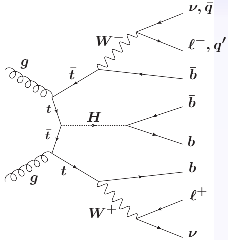


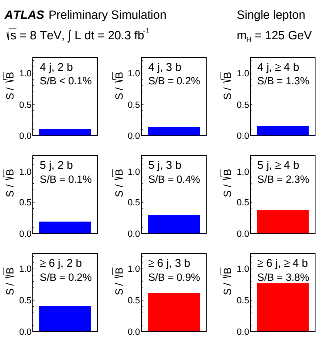




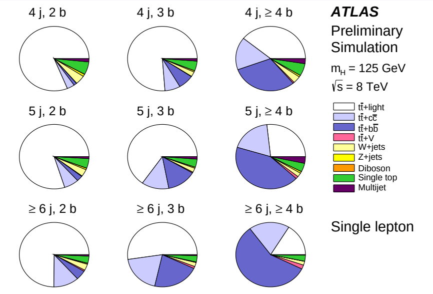
Analysis strategy

- Focusing on $t\bar{t}H$, $H \to b\bar{b}$ in two $t\bar{t}$ final states:
  - ℓ+jets: 1 lepton (e or μ), 4 to $\geq$ 6 jets with 2 to $\geq$ 4 b-tagged jets
  - Dilepton: 2 leptons (ee, $\mu\mu$ and $e\mu$) with opposite charge, 2 to $\geq$ 4 jets with 2 to $\geq$ 4 b-tagged jets
- Categorize events by jet and b-tag multiplicities
  - Improve sensitivity by keeping separate regions with different $S/\sqrt{B}$
  - Signal-depleted regions used to constrain systematic uncertainties
- Choose suitable discriminant variable in each region (simple kinematic variable for signal-depleted channels, multivariate discriminant in signal-rich channels)
- Perform hypothesis testing including in-situ constraining of systematic uncertainties via global fit to all regions





Background modelling



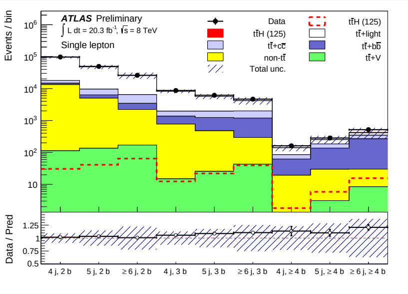
Background samples used:

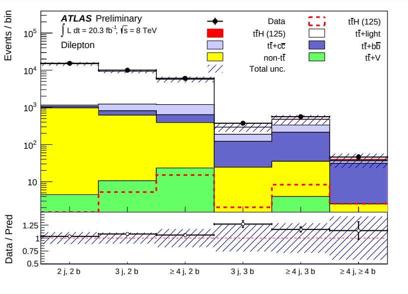
- $t\bar{t}$+jets: Powheg+Pythia
- $t\bar{t}Z$, $t\bar{t}W$: Madgraph+Pythia
- W+jets: Alpgen+Pythia
- Z+jets: Alpgen+Herwig
- Dibosons: Alpgen+Herwig
- Single top: Powheg/AcerMC + Pythia
- Multijet: data driven

Main background after selection: $t\bar{t}$+jets

- Modelling improved by applying MC/data scaling as a function of top p_T and $t\bar{t}$ p_T determined using $\sqrt{s} = 7$ TeV data (ATL-CONF-2013-099)
- Powheg+Pythia modelling of $t\bar{t}$+HF jets (in normalisation and kinematics) comparable to dedicated ME-PS MCs such as Madgraph.
- Overall rate of $t\bar{t} + b\bar{b}$ and $t\bar{t} + c\bar{c}$ calibrated to data using background-enriched bins in signal-rich regions.

Background modelling





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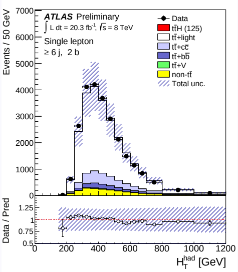
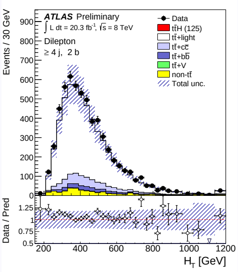
Signal-to-background discrimination

	2 b-tags	3 b-tags	$\geq$ 4 b-tags
4 jets	H_T^{had}	H_T^{had}	H_T^{had}
5 jets	H_T^{had}	NN	NN
$\geq$ 6 jets	H_T^{had}	NN	NN

	2 b-tags	3 b-tags	$\geq$ 4 b-tags
2 jets	H_T		
3 jets	H_T	NN	
$\geq$ 4 jets	H_T	NN	NN

- Signal-depleted regions: use $H_T^{had} = \sum p_T^{jets}$ for ℓ+jets and $H_T = \sum p_T^{jets} + \sum p_T^{\ell}$ for dilepton
- ℓ+jets, 5 jets, 3 b-tags region: use NN trained to separate $t\bar{t} + b\bar{b}/c\bar{c}$ from $t\bar{t}$+light jets
- Signal-rich regions: use NN trained to separate $t\bar{t}H$ from $t\bar{t}$+jets in each of the region



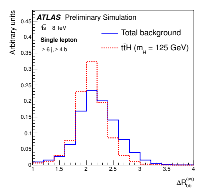


Multivariate discriminants

Make use of event kinematics

- Object kinematics: p_T^{jet5}, ...
- Global event variables: H_T^{had}, $N^{jet}_{p_T>40GeV}$, ...
- Event shape variables: centrality, Fox-Wolfram moments, ...
- Object pair properties: $M_{bb}^{\min\Delta R}$, ΔR_{bb}^{avg}, ...

ℓ+jets



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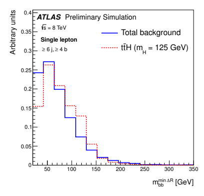

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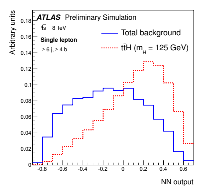
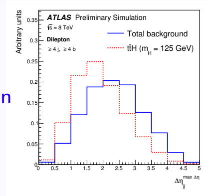


Dilepton



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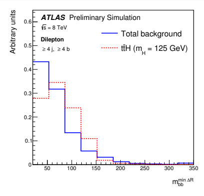

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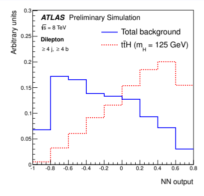


Systematics uncertainties

Main instrumental uncertainties

- Jet energy scale (split into 22 uncorrelated components)
- b/c/light tagging (split into 6/6/12 uncorrelated components)

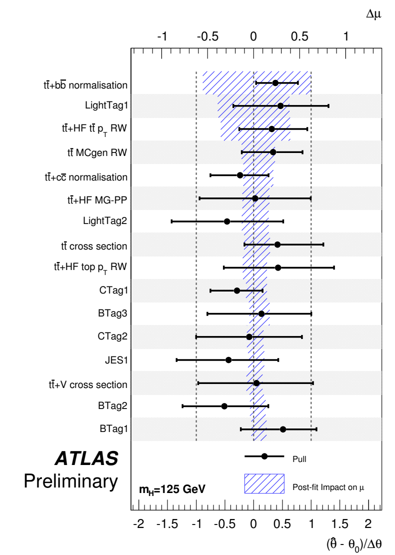
Main $t\bar{t}$+jets modelling uncertainties

- 9 leading systematic uncertainties from differential cross-section measurement of top p_T and $t\bar{t}$ p_T
- $t\bar{t}$+light jets
  - Vary parton shower + fragmentation model (Powheg+Pythia vs Powheg+Herwig)
- $t\bar{t}$+HF (uncorrelated with $t\bar{t}$+light uncertainties)
  - Reweighting of top p_T and $t\bar{t}$ p_T ON/OFF (uncorrelated)
  - Vary parton shower + fragmentation model (Powheg+Pythia vs Powheg+Herwig)
  - Vary generator: Powheg+Pythia vs Madgraph+Pythia
  - Normalisation of $t\bar{t} + b\bar{b}$ and $t\bar{t} + c\bar{c}$ (50% uncorrelated)

Summary of systematics uncertainties

$\geq$ 6 jets, $\geq$ 4 b tags (pre-fit)

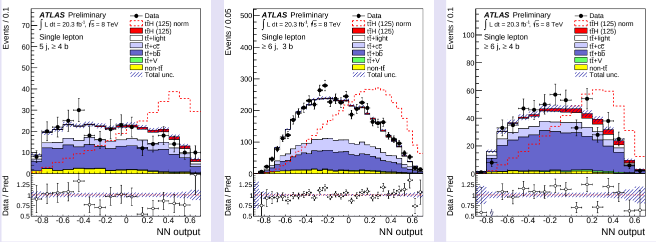
	$t\bar{t}H$ (125)	$t\bar{t}$ + light	$t\bar{t}$ + $c\bar{c}$	$t\bar{t}$ + $b\bar{b}$
Luminosity	$\pm$2.8	$\pm$2.8	$\pm$2.8	$\pm$2.8
Lepton efficiencies	$\pm$1.4	$\pm$1.4	$\pm$1.4	$\pm$1.5
Jet energy scale	$\pm$6.5	$\pm$14	$\pm$10	$\pm$8.2
Jet efficiencies	$\pm$1.6	$\pm$5.4	$\pm$2.5	$\pm$2.4
Jet energy resolution	$\pm$0.1	$\pm$8.5	$\pm$4.1	$\pm$4.3
b-tagging efficiency	$\pm$9.0	$\pm$5.8	$\pm$5.1	$\pm$9.2
c-tagging efficiency	$\pm$1.9	$\pm$7.3	$\pm$14	$\pm$2.8
Light jet-tagging efficiency	$\pm$1.0	$\pm$17	$\pm$4.4	$\pm$1.5
$t\bar{t}$ modelling: reweighting	–	$\pm$11	$\pm$13	$\pm$13
$t\bar{t}$ modelling: parton shower	–	$\pm$7.5	$\pm$1.8	$\pm$10
$t\bar{t}$ heavy-flavour: normalisation	–	–	$\pm$50	$\pm$50
$t\bar{t}$ heavy-flavour: reweighting	–	–	$\pm$11	$\pm$12
$t\bar{t}$ heavy-flavour: generator	–	–	$\pm$2.2	$\pm$2.9
Theoretical cross sections	–	$\pm$6.2	$\pm$6.3	$\pm$6.3
$t\bar{t}H$ modelling	$\pm$1.9	–	–	–
Total	$\pm$12	$\pm$30	$\pm$57	$\pm$56



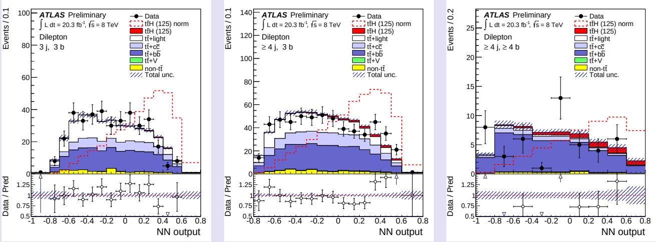
NN output distributions in signal-rich regions

- Perform global fit under S+B hypothesis
- ℓ+jets and dilepton fits consistent with each other
- Fit reduces background uncertainty by a factor ∼5-6 in most sensitive regions

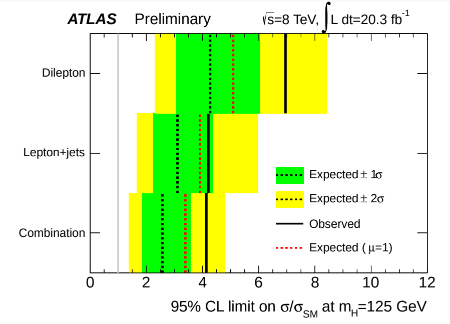
ℓ+jets

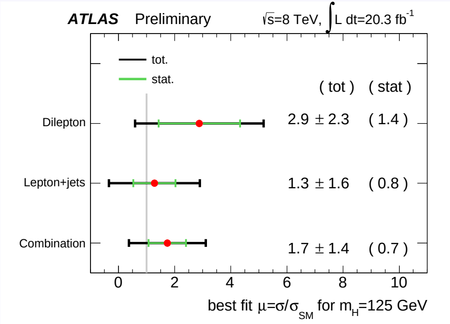


Dilepton



Results





Reminder of 7 TeV analysis

ℓ+jets channel

95% CL observed (expected) limit:

13.1 × SM (10.5 × SM)

ATLAS-CONF-2012-135

Combination of ℓ+jets and dilepton channels

95% CL observed (expected) limit:

4.1 × SM (2.6 × SM)

Best fit μ =1.7±1.4

ATLAS-CONF-2014-011

Result consistent with SM prediction.

Summary and outlook

Combination ℓ+jets and dilepton channels

95% CL observed (expected) limit:
4.1 $\times$ SM (2.6 $\times$ SM)
Best fit μ =1.7$\pm$1.4

- Most sensitive $t\bar{t}H$, $H \to b\bar{b}$ result at the LHC
  - Reminder: CMS @ 8 TeV combination of ℓ+jets, dilepton and τ channels: obs (exp) = 5.2 (4.1) @ m_H = 125 GeV, CMS-PAS-HIG-13-019
- Most sensitive $t\bar{t}H$ search in ATLAS for the moment
  - Reminder: $t\bar{t}H$, $H \to \gamma\gamma$: obs (exp) = 4.7 (5.4) @ m_H = 126.8 GeV, ATLAS-CONF-2013-080
- Full program of $t\bar{t}H$ searches in $H \to \gamma\gamma$, $b\bar{b}$, $\tau\tau$ and WW/ZZ underway. Stay tuned!

Thank you for your attention

Event selection

- pp collisions data at $\sqrt{s} = 8$ TeV in 2012: $\mathcal{L}_{int} = 20.3$ fb^{-1}
- Single lepton trigger used, $\ell = e,\mu$
- b-tagging: 70% efficiency of tagging b-jets, 1% of light-jets mistag rate

ℓ+jets

- Exactly 1 lepton with $p_T > 25$ GeV
- At least 4 jets with $p_T > 25$ GeV, with at least 2 b-tagged ones
- Veto on dilepton events

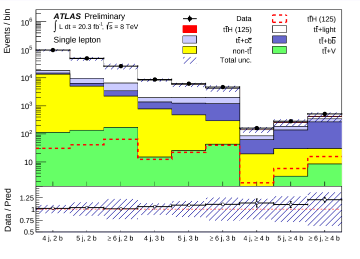
Dilepton

- Exactly 2 leptons of opposite charge with $p_T^1 > 25$ GeV and $p_T^2 > 15$ GeV
- At least 2 jets with $p_T > 25$ GeV, with at least 2 b-tagged ones
- In $e\mu$ channel: $H_T > 130$ GeV
- In ee and $\mu\mu$ channels: $m_{\ell\ell} > 60$ GeV in 2 b-tags channels and $|m_{\ell\ell} - m_Z| > 8$ GeV

Pre-fit and post-fit yields

Effect of the combined S+B fit on yields per channel:

ℓ+jets



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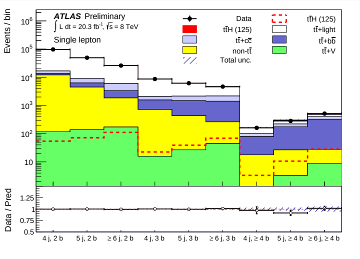

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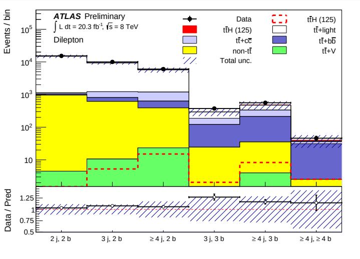

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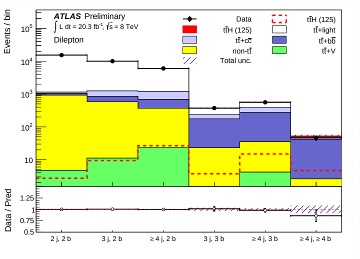


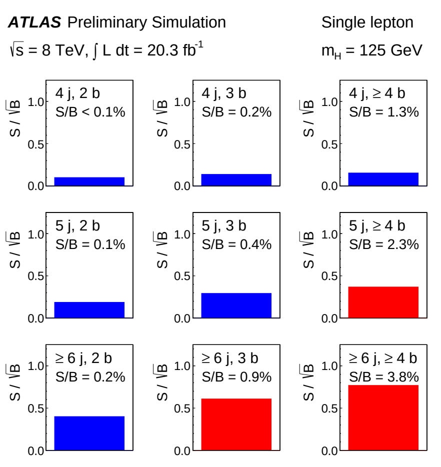
Variables used in ℓ+jets NN

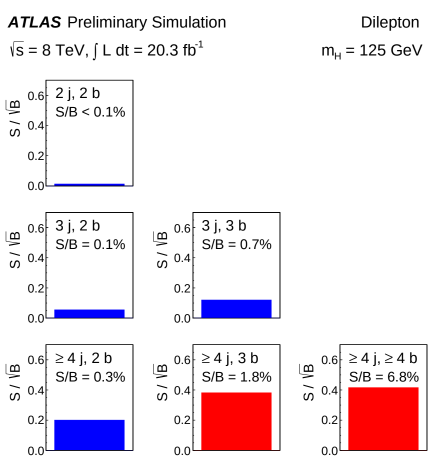
Variable	Definition
Centrality	Sum of p_T divided by sum of E for all jets and lepton
$H1$	2nd Fox-Wolfram moment
$m_{bb}^{\min\Delta R}$	Mass of the combination between two tagged jets with the smallest ΔR
N_{40}^{jet}	Number of jets with $p_T \geq 40$ GeV
ΔR_{bb}^{avg}	Average ΔR for all tagged jet pairs
$M_{jj}^{\max p_T}$	Mass of the combination between any two jets with the largest vector sum p_T
Aplanarity$_b$	$1.5\lambda_2$, where λ_2 is the second eigenvalue of the 3-dimensional linear momentum tensor built with only tagged jets
H_T^{had}	Scalar sum of jet p_T
$M_{jj}^{\min\Delta R}$	Mass of the combination between any two jets with the smallest ΔR
$\Delta R_{\ell-bb}^{\min\Delta R}$	ΔR between the lepton and two tagged jets with the smallest ΔR
$M_{bj}^{\min\Delta R}$	Mass of the combination between a tagged jet and any jet with the smallest ΔR
$M_{bj}^{\max p_T}$	Mass of the combination between a tagged jet and any jet with the largest vector sum p_T
$M_{uu}^{\min\Delta R}$	Mass of the combination between two untagged jets with the smallest ΔR
p_T^{jet5}	Fifth leading jet p_T
$\Delta R_{bb}^{\max p_T}$	ΔR between two tagged jets with the largest vector sum p_T
$M_{bb}^{\max M}$	Mass of the combination between two tagged jets with the largest invariant mass
$p_{T,uu}^{\min\Delta R}$	Scalar sum of the p_T's of the pair of untagged jets closest in ΔR
M_{jjj}	Mass of the jet triplets with the largest vectorial sum p_T
$\min\Delta R_{uu}$	Smallest ΔR between untagged jets
$M_{bb}^{\max p_T}$	Mass of the combination between two tagged jets with the largest vector sum p_T

Variables used in dilepton NN

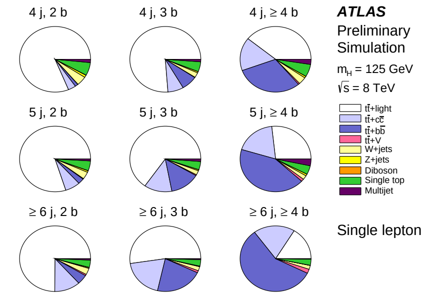
Variable	Definition
M_{bb}	Mass of the two b jets from the Higgs candidate system
H_T	Scalar sum of jet p_T and lepton p_T
p_T^{jet3}	3rd Leading jet p_T
p_T^{jet4}	4th Leading jet p_T
Centrality	Sum of p_T divided by sum of E for all jets
Aplanarity$_j$	$1.5\lambda_2$ (Second eigenvalue of the momentum tensor constructed from jets)
$H1$	Second Fox-Wolfram Moment
$H4$	Fifth Fox-Wolfram Moment
$\Delta R_{hl}^{\max\Delta R}$	Maximum ΔR between the Higgs candidate and the two leptons
$\Delta R_{hl}^{\min\Delta R}$	Minimum ΔR between the Higgs candidate and the two leptons
H_{30}^{Higgs}	Number of Higgs candidates within 30 GeV of the defined Higgs mass (e.g. 125 GeV)
$M_{jj}^{\mathrm{closest}}$	Dijet mass closest to the defined Higgs mass
$\Delta\eta_{jj}^{\max\Delta\eta}$	Maximum $\Delta\eta$ between two jets in the event
$M_{jj}^{\min M}$	Minimum di-jet mass
$M_{jj}^{\max p_T}$	Mass of the two jet system with maximum p_T in the event
$M_{bb}^{\min\Delta R}$	Mass of the two b-jet system with minimum ΔR in the event
$\Delta R_{bj}^{\min\Delta R}$	Minimum ΔR between b-jets and untagged jets
$\Delta R_{\ell j}^{\min\Delta R}$	Minimum ΔR between leptons and untagged jets
$\Delta R_{bb}^{\max p_T}$	ΔR between the b-jet pair with maximum p_T in the event
$\Delta R_{bb}^{\max M}$	ΔR between the b-jet pair with maximum mass in the event

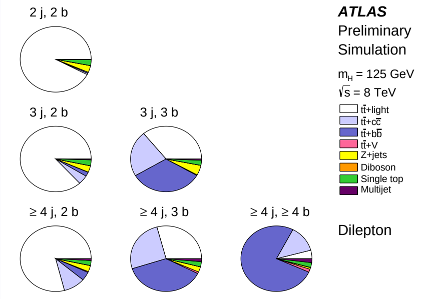
$S/\sqrt{B}$ plots



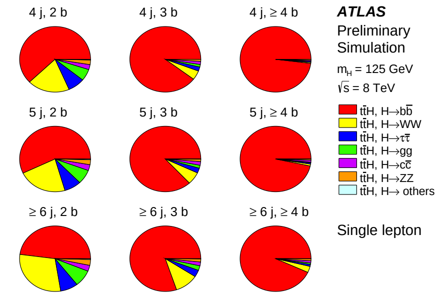


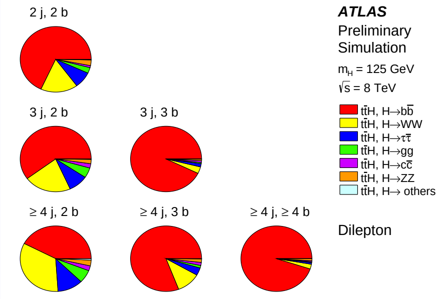
Background composition



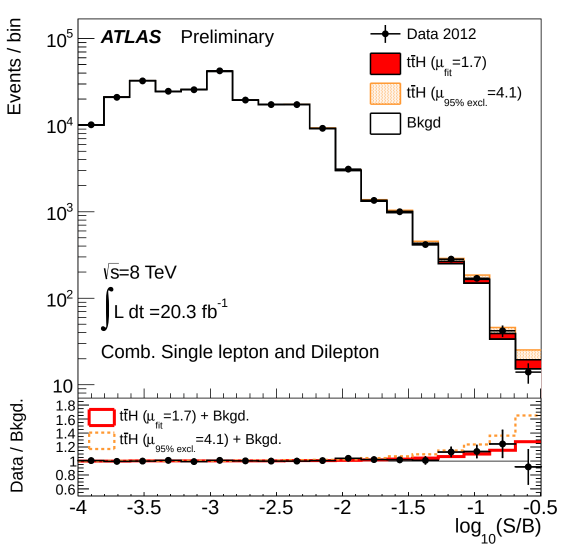


Signal composition



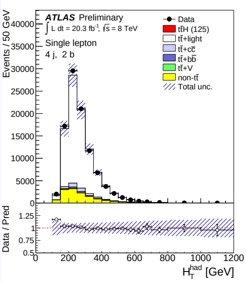


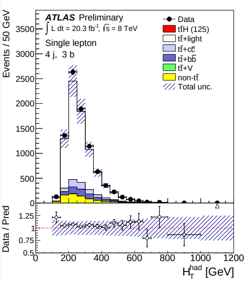
S/B plot

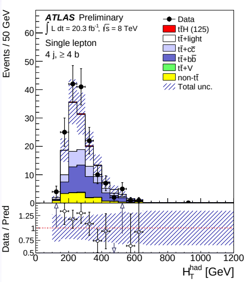


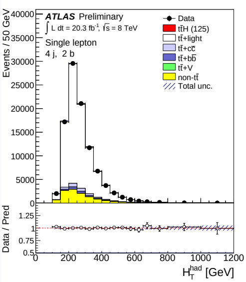
ATLAS Preliminary
Data 2012
$t\bar{t}H$ (μ_{fit}=1.7)
$t\bar{t}H$ ($\mu_{95\% excl.}$=4.1)
Bkgd
$\sqrt{s}$=8 TeV
$\int L dt$ =20.3 fb^{-1}
Comb. Single lepton and Dilepton
Events / bin
$t\bar{t}H$ (μ_{fit}=1.7) + Bkgd.
$t\bar{t}H$ ($\mu_{95\% excl.}$=4.1) + Bkgd.
Data / Bkgd.
log_{10}(S/B)

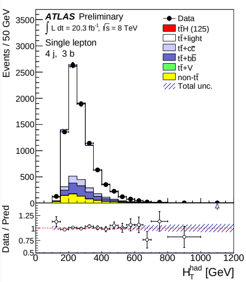
Fit results: single lepton, 4 jets

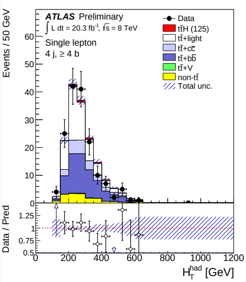




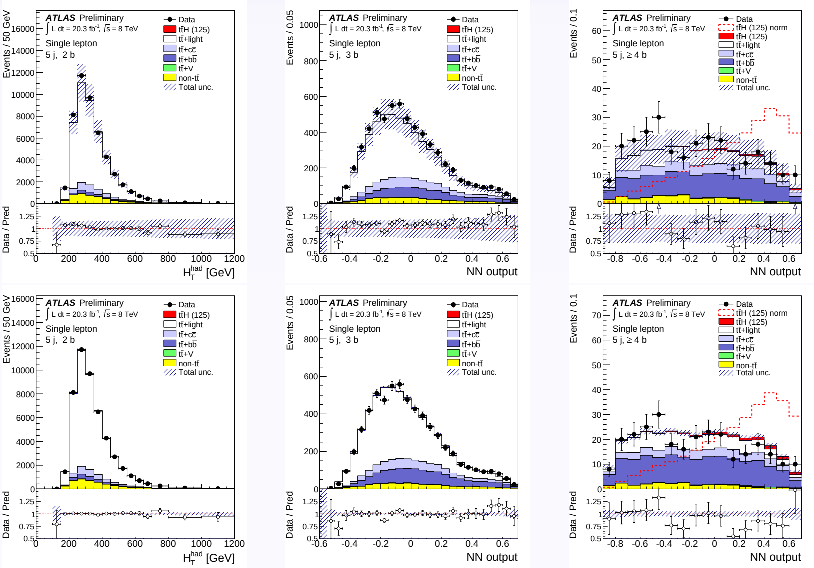




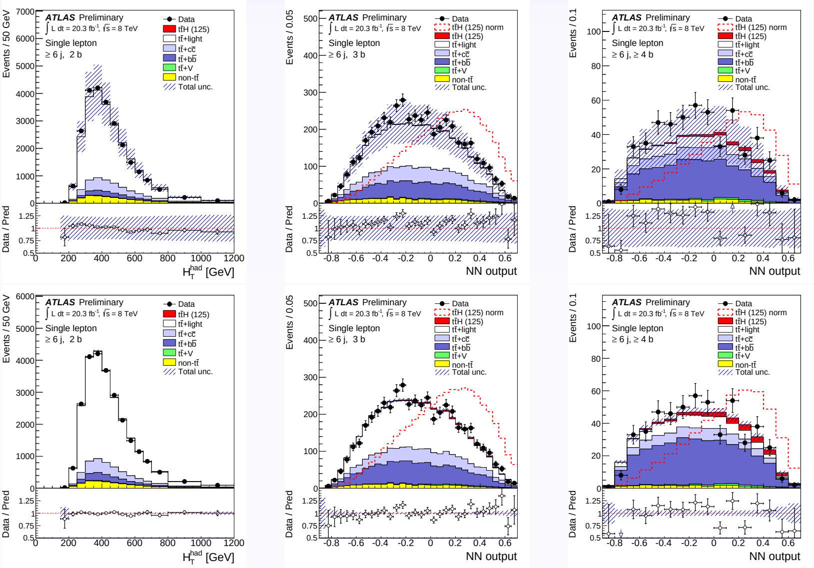




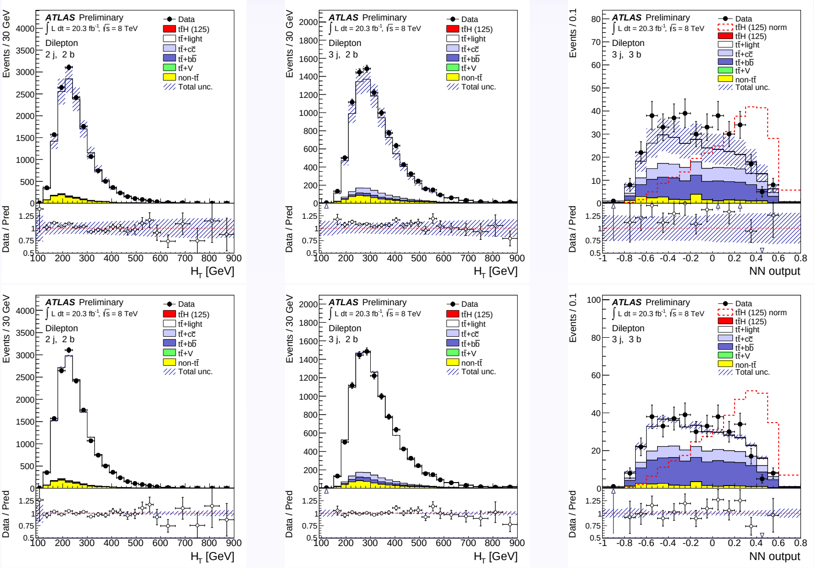
Fit results: single lepton, 5 jets



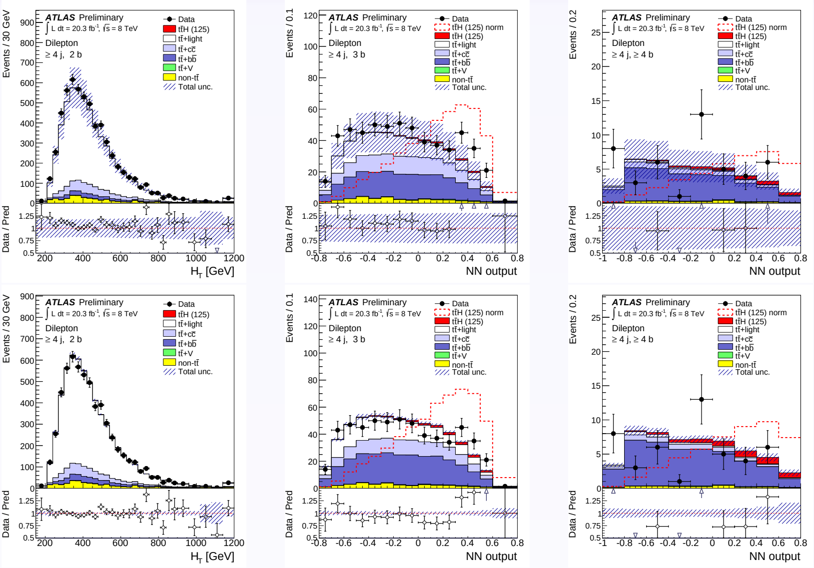
Fit results: single lepton, $\geq$ 6 jets



Fit results: dilepton, 2 and 3 jets

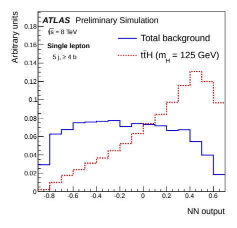


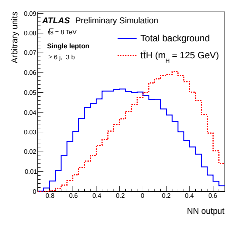
Fit results: dilepton, $\geq$ 4 jets

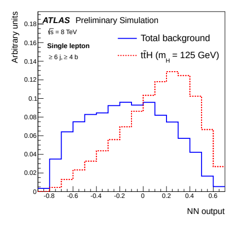


NN outputs

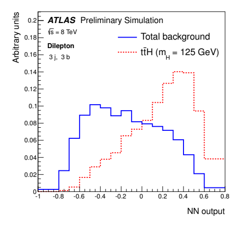
ℓ+jets

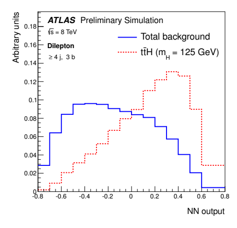


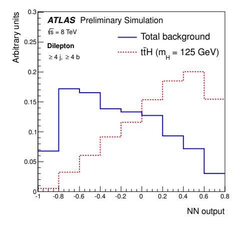




Dilepton







Prefit yields: ℓ+jets

	4 jets, 2 b-tags	4 jets, 3 b-tags	4 jets, $\geq$ 4 b-tags	5 jets, 2 b-tags	5 jets, 3 b-tags	$\geq$ 6 jets, 2 b-tags
$t\bar{t}H$ (125)	31 ± 3 ± 3	12 ± 1 ± 1	1.8 ± 0.2 ± 0.2	41 ± 2 ± 4	22 ± 2 ± 2	64 ± 5 ± 7
$t\bar{t}$+ light	78000 ± 8000	6300 ± 800	55 ± 12	38000 ± 6000	3700 ± 700	19000 ± 5000
$t\bar{t} + c\bar{c}$	3300 ± 1700	590 ± 310	23 ± 12	3300 ± 1700	700 ± 400	3000 ± 1600
$t\bar{t} + b\bar{b}$	1300 ± 700	600 ± 310	43 ± 23	1300 ± 700	800 ± 400	1200 ± 700
$t\bar{t} + V$	113 ± 35	15 ± 5	0.90 ± 0.29	140 ± 40	25 ± 8	170 ± 50
non-$t\bar{t}$	13200 ± 2300	760 ± 110	18.4 ± 3.1	4900 ± 1000	450 ± 80	2000 ± 500
Total	96000 ± 9000	8200 ± 1100	142 ± 32	48000 ± 7000	5700 ± 1000	26000 ± 6000
Data	97450	8692	161	49402	6168	26033

	5 jets, $\geq$ 4 b-tags	$\geq$ 6 jets, 3 b-tags	$\geq$ 6 jets, $\geq$ 4 b-tags
$t\bar{t}H$ (125)	5.8 ± 0.7 ± 0.6	39 ± 3 ± 4	16 ± 2 ± 2
$t\bar{t}$+ light	67 ± 16	2200 ± 600	67 ± 20
$t\bar{t} + c\bar{c}$	47 ± 25	800 ± 400	80 ± 40
$t\bar{t} + b\bar{b}$	110 ± 60	900 ± 500	240 ± 130
$t\bar{t} + V$	3.1 ± 1.0	43 ± 14	8.4 ± 2.8
non-$t\bar{t}$	26 ± 5	250 ± 50	22 ± 5
Total	260 ± 70	4200 ± 1100	430 ± 160
Data	283	4671	516

Prefit yields: dilepton

	2 jets, 2 b-tags	3 jets, 2 b-tags	3 jets, 3 b-tags	$\geq$ 4 jets, 2 b-tags	$\geq$ 4 jets, 3 b-tags	$\geq$ 4 jets, $\geq$ 4 b-tags
$t\bar{t}H$ (125)	$1.5 \pm 0.2 \pm 0.2$	$5.3 \pm 0.4 \pm 0.6$	$2.0 \pm 0.2 \pm 0.2$	$15.1 \pm 0.8 \pm 1.6$	$8.3 \pm 0.6 \pm 0.9$	$2.5 \pm 0.3 \pm 0.3$
$t\bar{t}$+ light	13700 $\pm$ 1700	8000 $\pm$ 900	105 $\pm$ 20	4500 $\pm$ 800	138 $\pm$ 34	1.6 $\pm$ 0.7
$t\bar{t} + c\bar{c}$	100 $\pm$ 50	410 $\pm$ 210	70 $\pm$ 40	560 $\pm$ 300	120 $\pm$ 70	5.0 $\pm$ 2.8
$t\bar{t} + b\bar{b}$	80 $\pm$ 40	190 $\pm$ 100	100 $\pm$ 60	240 $\pm$ 130	180 $\pm$ 100	29 $\pm$ 16
$t\bar{t} + V$	4.5 ± 1.4	10.6 ± 3.3	0.9 ± 0.3	23 $\pm$ 7	4.0 ± 1.3	0.56 ± 0.18
non-$t\bar{t}$	960 $\pm$ 140	610 $\pm$ 80	24 $\pm$ 4	370 $\pm$ 60	31 $\pm$ 5	2.0 ± 0.4
Total	14800 $\pm$ 1700	9300 $\pm$ 1000	290 $\pm$ 80	5700 $\pm$ 1000	480 $\pm$ 140	40 $\pm$ 17
Data	15296	9997	374	6026	561	46

Postfit yields: ℓ+jets

	4 jets, 2 b-tags	4 jets, 3 b-tags	4 jets, $\geq$ 4 b-tags	5 jets, 2 b-tags	5 jets, 3 b-tags	$\geq$ 6 jets, 2 b-tags
$t\bar{t}H$ (125)	$54 \pm 3 \pm 44$	$22 \pm 1 \pm 18$	$3.3 \pm 0.3 \pm 2.7$	$72 \pm 2 \pm 59$	$39 \pm 2 \pm 32$	$111 \pm 4 \pm 91$
$t\bar{t}$+ light	80700 ± 1100	6550 ± 150	62 ± 7	40100 ± 800	4000 ± 140	20000 ± 600
$t\bar{t} + c\bar{c}$	2800 ± 800	530 ± 150	21 ± 6	2900 ± 800	670 ± 180	2700 ± 700
$t\bar{t} + b\bar{b}$	1830 ± 280	840 ± 120	61 ± 8	1790 ± 300	1050 ± 150	1500 ± 240
$t\bar{t} + V$	117 ± 35	16 ± 5	0.95 ± 0.29	140 ± 40	27 ± 8	170 ± 50
non-$t\bar{t}$	12000 ± 1100	700 ± 50	16.8 ± 1.6	4400 ± 400	410 ± 40	1670 ± 200
Total	97550 ± 300	8660 ± 80	165 ± 5	49220 ± 220	6190 ± 70	26170 ± 180
Data	97450	8692	161	49402	6168	26033

	5 jets, $\geq$ 4 b-tags	$\geq$ 6 jets, 3 b-tags	$\geq$ 6 jets, $\geq$ 4 b-tags
$t\bar{t}H$ (125)	$11 \pm 1 \pm 9$	$69 \pm 3 \pm 57$	$28 \pm 2 \pm 23$
$t\bar{t}$+ light	78 ± 9	2380 ± 130	78 ± 11
$t\bar{t} + c\bar{c}$	45 ± 12	750 ± 190	75 ± 19
$t\bar{t} + b\bar{b}$	149 ± 20	1160 ± 170	300 ± 40
$t\bar{t} + V$	3.3 ± 1.0	44 ± 13	8.9 ± 2.7
non-$t\bar{t}$	23.2 ± 2.5	218 ± 23	18.8 ± 2.2
Total	309 ± 11	4620 ± 80	507 ± 27
Data	283	4671	516

Postfit yields: dilepton

	2 jets, 2 b-tags	3 jets, 2 b-tags	3 jets, 3 b-tags	$\geq$ 4 jets, 2 b-tags	$\geq$ 4 jets, 3 b-tags	$\geq$ 4 jets, $\geq$ 4 b-tags
$t\bar{t}H$ (125)	$2.7 \pm 0.2 \pm 2.2$	$9.4 \pm 0.5 \pm 7.7$	$3.7 \pm 0.3 \pm 3.0$	$27 \pm 1 \pm 22$	$14.9 \pm 0.6 \pm 12.3$	$4.7 \pm 0.3 \pm 3.9$
$t\bar{t}+$ light	14140 ± 150	8700 ± 140	122 ± 14	4810 ± 130	161 ± 20	2.0 ± 0.4
$t\bar{t} + c\bar{c}$	99 ± 29	390 ± 110	67 ± 18	520 ± 140	119 ± 31	4.9 ± 1.2
$t\bar{t} + b\bar{b}$	121 ± 19	270 ± 40	153 ± 23	320 ± 50	242 ± 35	39 ± 5
$t\bar{t} + V$	4.7 ± 1.4	11.2 ± 3.3	1.0 ± 0.3	24 ± 7	4.2 ± 1.3	0.59 ± 0.18
non-$t\bar{t}$	920 ± 100	570 ± 60	22.3 ± 3.2	340 ± 40	31 ± 4	2.0 ± 0.4
Total	15290 ± 110	9960 ± 80	369 ± 14	6040 ± 60	572 ± 17	53 ± 4
Data	15296	9997	374	6026	561	46

Systematics treatment

	Systematic uncertainty	Type	Components
Detector systematics	Luminosity	N	1
	Electron	SN	5
	Muon	SN	6
	Jet vertex fraction	SN	1
	Jet energy scale	SN	22
	Jet energy resolution	SN	1
	Jet reconstruction efficiency	SN	1
	b-tagging efficiency	SN	6
	c-tagging efficiency	SN	6
	Light jet-tagging efficiency	SN	12
	$t\bar{t}$ cross section	N	1
Small backgrounds	$t\bar{t}V$ cross section	N	1
	Single top cross section	N	1
	Diboson+jets normalisation	N	1
	W+jets normalisation	N	3
	W p_T correction	SN	1
	Z+jets normalisation	N	2
	Z p_T correction	SN	1
	Multijet normalisation	N	3
	Multijet shape dilepton	S	1
$t\bar{t}$ modelling	$t\bar{t}$ modelling: parton shower	SN	2
	$t\bar{t}$ modelling: reweighting	SN	9
	$t\bar{t}$ modelling: reweighting heavy flavor	SN	2
	$t\bar{t}$+heavy-flavour normalisation	N	2
	$t\bar{t}$+heavy-flavour shape	SN	5
	$t\bar{t}H$ modelling	SN	2

S = shape systematics
N = normalisation

Dominant systematics:

- $t\bar{t}$+HF normalisation
- Flavour-tagging
- $t\bar{t}$ reweighting

Perform likelihood fit to data taking into account systematics uncertainties as nuisance parameters

Systematics, pre-fit and post-fit, single lepton

$\geq$ 6 j, $\geq$ 4 b

	Pre-fit				Post-fit			
	$t\bar{t}H$ (125)	$t\bar{t}$ + light	$t\bar{t} + c\bar{c}$	$t\bar{t} + b\bar{b}$	$t\bar{t}H$ (125)	$t\bar{t}$ + light	$t\bar{t} + c\bar{c}$	$t\bar{t} + b\bar{b}$
Luminosity	± 2.8	± 2.8	± 2.8	± 2.8	± 2.6	± 2.6	± 2.6	± 2.6
Lepton efficiencies	± 1.4	± 1.4	± 1.4	± 1.5	± 1.3	± 1.3	± 1.3	± 1.3
Jet energy scale	± 6.5	± 14	± 10	± 8.2	± 2.6	± 5.9	± 4.2	± 3.5
Jet efficiencies	± 1.6	± 5.4	± 2.5	± 2.4	± 0.7	± 2.3	± 1.1	± 1.1
Jet energy resolution	± 0.1	± 8.5	± 4.1	± 4.3	± 0.1	± 5.6	± 3.7	± 3.9
b-tagging efficiency	± 9.0	± 5.8	± 5.1	± 9.2	± 6.4	± 4.2	± 3.7	± 6.5
c-tagging efficiency	± 1.9	± 7.3	± 14	± 2.8	± 0.8	± 4.0	± 7.8	± 1.6
Light jet-tagging efficiency	± 1.0	± 17	± 4.4	± 1.5	± 0.8	± 14	± 3.7	± 1.2
$t\bar{t}$ modelling: reweighting	–	± 11	± 13	± 13	–	± 5.3	± 6.0	± 6.4
$t\bar{t}$ modelling: parton shower	–	± 7.5	± 1.8	± 10	–	± 2.3	± 0.7	± 4.0
$t\bar{t}$ heavy-flavour: normalisation	–	–	± 50	± 50	–	–	± 29	± 15
$t\bar{t}$ heavy-flavour: reweighting	–	–	± 11	± 12	–	–	± 6.3	± 6.8
$t\bar{t}$ heavy-flavour: generator	–	–	± 2.2	± 2.9	–	–	± 2.2	± 2.8
Theoretical cross sections	–	± 6.2	± 6.3	± 6.3	–	± 4.3	± 4.3	± 4.3
$t\bar{t}H$ modelling	± 1.9	–	–	–	± 1.9	–	–	–
Total	± 12	± 30	± 57	± 56	± 7.2	± 14	± 25	± 14

Systematics, pre-fit and post-fit, dilepton

$\geq$ 4 j, $\geq$ 4 b

	Pre-fit				Post-fit			
	$t\bar{t}H$ (125)	$t\bar{t}$ + light	$t\bar{t}+c\bar{c}$	$t\bar{t}+b\bar{b}$	$t\bar{t}H$ (125)	$t\bar{t}$ + light	$t\bar{t}+c\bar{c}$	$t\bar{t}+b\bar{b}$
Luminosity	±2.8	±2.8	±2.8	±2.8	±2.6	±2.6	±2.6	±2.6
Lepton efficiencies	±2.6	±2.5	±2.6	±2.5	±2.0	±2.0	±2.0	±2.0
Jet energy scale	±4.4	±19	±8.5	±6.8	±2.1	±7.8	±3.4	±3.2
Jet efficiencies	±0.3	±5.3	±1.6	±0.9	±0.1	±2.3	±0.7	±0.4
Jet energy resolution	±0.1	±13	±4.2	±4.2	±0.1	±7.9	±3.8	±3.9
b-tagging efficiency	±10	±7.9	±5.4	±11	±7.2	±5.3	±3.8	±7.3
c-tagging efficiency	±0.6	±1.8	±14	±0.7	±0.3	±1.0	±6.9	±0.3
Light jet-tagging efficiency	±0.7	±23	±5.7	±1.4	±0.6	±18	±4.7	±1.2
$t\bar{t}$ modelling: reweighting	–	±11	±13	±13	–	±5.2	±6.1	±6.2
$t\bar{t}$ modelling: parton shower	–	±23	±0.3	±1.1	–	±6.8	±0.1	±0.4
$t\bar{t}$ heavy-flavour: normalisation	–	–	±50	±50	–	–	±29	±15
$t\bar{t}$ heavy-flavour: reweighting	–	–	±11	±11	–	–	±6.0	±6.4
$t\bar{t}$ heavy-flavour: generator	–	–	±3.3	±3.4	–	–	±3.2	±3.3
Theoretical cross sections	–	±6.3	±6.3	±6.3	–	±4.3	±4.3	±4.3
$t\bar{t}H$ modelling	±0.8	–	–	–	±0.8	–	–	–
Total	±12	±43	±56	±55	±7.4	±21	±25	±14

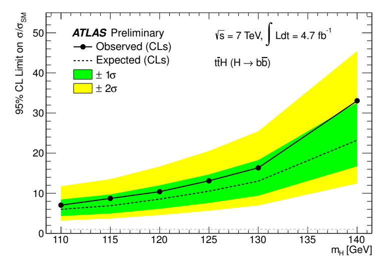
Previous ATLAS result

Result can be found in ATLAS-CONF-2012-135

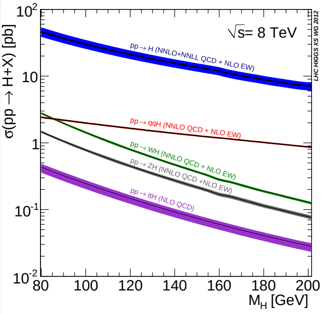
- On 7 TeV data, $\mathcal{L} = 4.7\ \text{fb}^{-1}$
- Using only ℓ+jets channels
- Using $m_{b\bar{b}}$ from a kinematic fit in ≥ 6 jets, ≥ 3 b-tags channels, H_T^{had} in the others
- Using Alpgen as $t\bar{t}$ generator (now Powheg+Pythia)

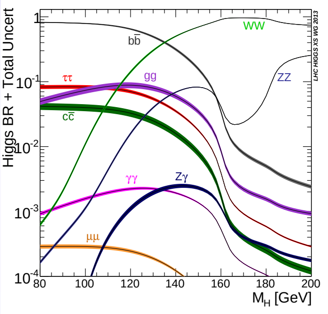
Limit @ 125 GeV

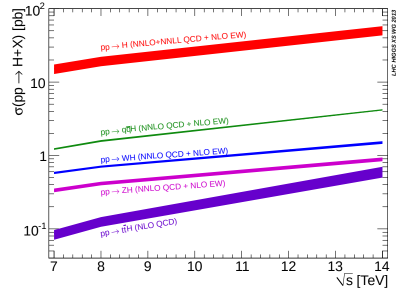
Observed: $10.5 \times$ SM
Expected: $13.1 \times$ SM



Cross section and branching ratios from theory







ATLAS vs CMS: differences in selection

	CMS	ATLAS
Lepton p_T	30 GeV	25 GeV
Muon η	$\lvert\eta\rvert < 2.1$	$\lvert\eta\rvert < 2.5$
Jet algo	anti-k_T 0.5	anti-k_T 0.4
Jet η	$\lvert\eta\rvert < 2.4$	$\lvert\eta\rvert < 2.5$
3 leading jets	$p_T > 40$ GeV	$p_T > 25$ GeV
Other jets	$p_T > 30$ GeV	$p_T > 25$ GeV
Other cuts	No E_T^{miss}, no M_T^W	No E_T^{miss}, no M_T^W
B-tagging	70% / 20% / 2%	70% / 20% / 1%

ATLAS vs CMS: Pre-fit yields comparison

Single lepton	5 j, $\geq$ 4 b		$\geq$ 6 j, $\geq$ 4 b	
	CMS	ATLAS	CMS	ATLAS
$t\bar{t}H$	5.3	5.8	8.3	16
$t\bar{t}$+light	79	70	71	70
$t\bar{t}+c\bar{c}$	32	50	52	80
$t\bar{t}+b\bar{b}$	67	110	111	200
S/B	2.7%	2.3%	3.5%	4%
$S/\sqrt{B}$	0.37	0.36	0.54	0.84

Dilepton	CMS	ATLAS		
	$\geq$ 3 j, $\geq$ 3 b	3 j, 3 b	$\geq$ 4 j, 3 b	$\geq$ 4 j, $\geq$ 4 b
$t\bar{t}H$	11.2	2.0	8.3	2.5
$t\bar{t}$+light	289	105	138	1.6
$t\bar{t}+c\bar{c}$	147	70	120	5
$t\bar{t}+b\bar{b}$	229	100	180	29
S/B	0.02	0.01	0.02	0.06
$S\sqrt{B}$	0.43	0.12	0.39	0.40

ATLAS vs CMS: differences in systematic model

- Many differences in the systematic model
- HF normalisation
  - CMS: 50% on $t\bar{t}+b\bar{b}$, 50% on $t\bar{t}+b$, 50% on $t\bar{t}+c\bar{c}$ and additional 50% on $t\bar{t}$+HF
  - ATLAS: 50% on $t\bar{t}+b\bar{b}$,50% on $t\bar{t}+c\bar{c}$
- Modelling
  - CMS: using Madgraph sample, top p_T reweighting ON/OFF, 1 Madgraph scale variation uncorrelated in $t\bar{t}+b\bar{b}$, $t\bar{t}+b$, $t\bar{t}+c\bar{c}$ and $t\bar{t}$+light
  - ATLAS: using Powheg+Pythia, 9 components from top p_T and $t\bar{t}$ p_T measurements for $t\bar{t}$+light; reweighting ON/OFF for $t\bar{t}$+HF uncorrelated; parton shower; generator (comparison with Madgraph)
- Jet energy scale
  - CMS: 1 JES
  - ATLAS: 22 JES components
- b-tagging
  - CMS: fully continuous MVA spectrum; linear and parabolic shape distortions; no calibration for c-jets
  - ATLAS: components for b, c and light jets (6/6/12)
- Checked ATLAS sensitivity only mildly-dependent on assumed systematics model.
- Difference in sensitivity primarily originates from the better $S/\sqrt{B}$. Also helpful is the higher background statistics in the signal-depleted regions, which allows greater constraining power of systematic uncertainties.