



Search for the SM Higgs boson produced in association with top quarks and decaying into $b\bar{b}$ -pair in ATLAS

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on behalf of the ATLAS Collaboration

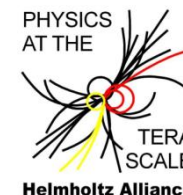
DAAD Deutscher Akademischer Austausch Dienst
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GEFÖRDERT VOM



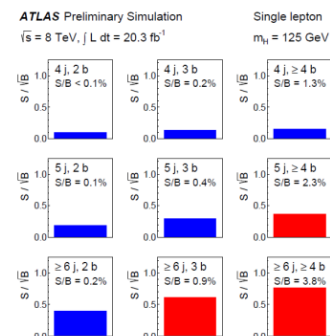
Bundesministerium
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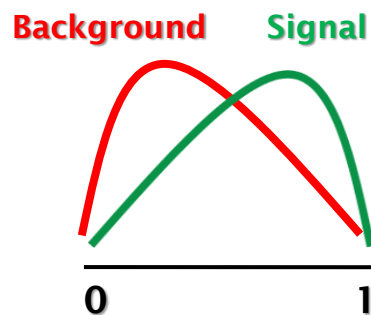
- Motivation



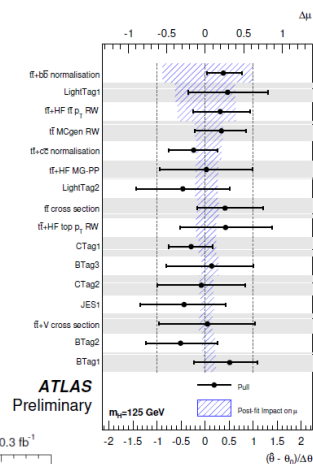
- Analysis strategy



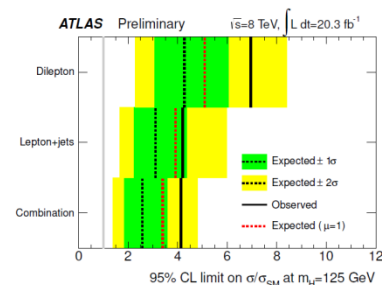
- Multivariate approach



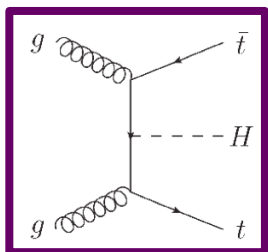
- Systematic uncertainties



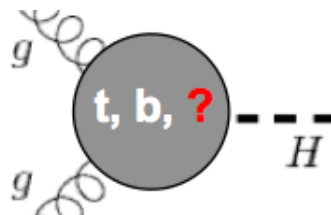
- Results and conclusions



- Existence of a “very” Higgs-like particle established
- Strong evidence of a coupling to fermions ($H \rightarrow \tau^+ \tau^-$)
ATLAS-CONF-2013-108, arxiv:1401.5041
- $t\bar{t}H$ allows direct probing of top-Higgs and H-b Yukawa couplings without assumption on new physics contribution to loop diagrams



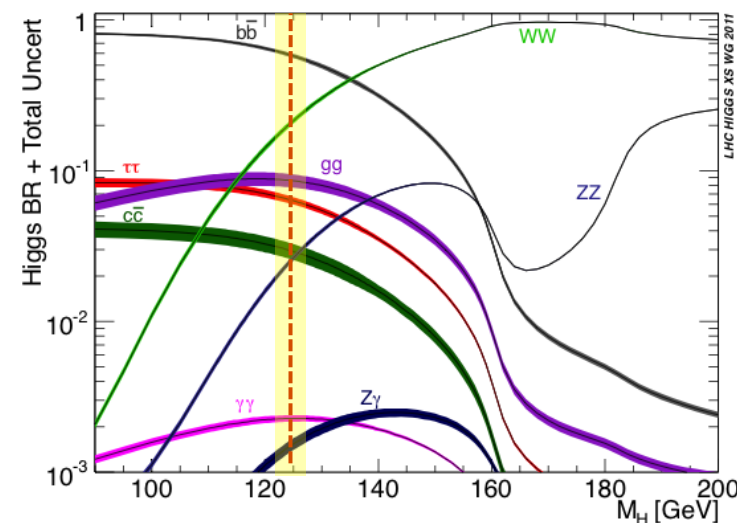
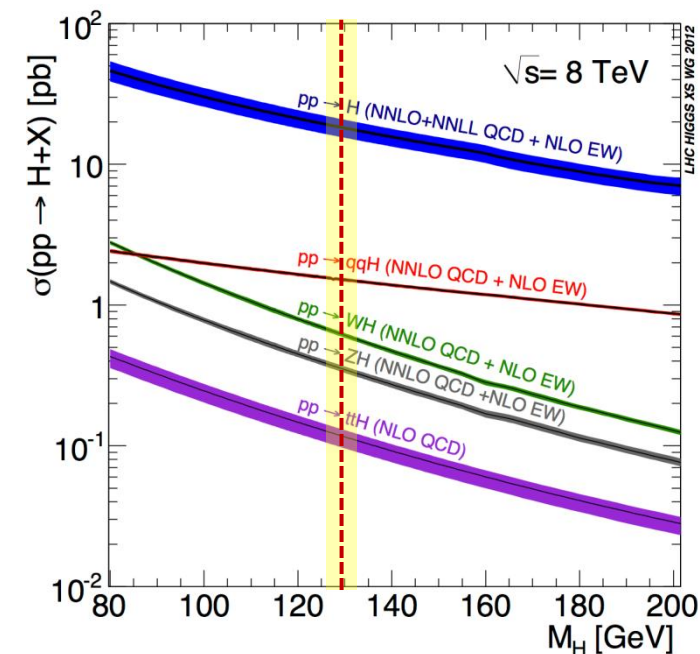
$$\sim g_Y^2$$



➤ NLO $t\bar{t}H$ cross-section @ 8 TeV: **130 fb**

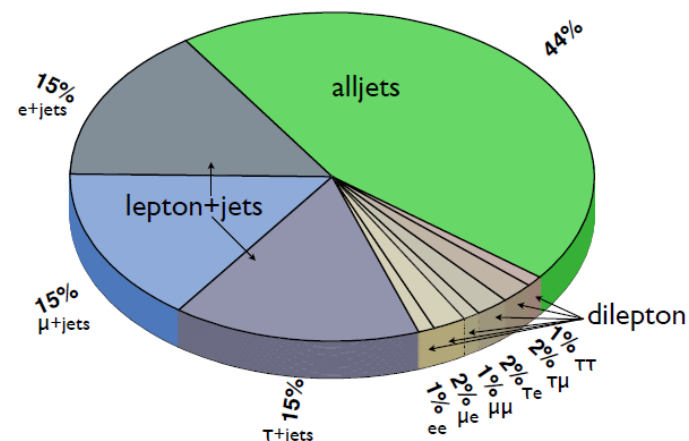
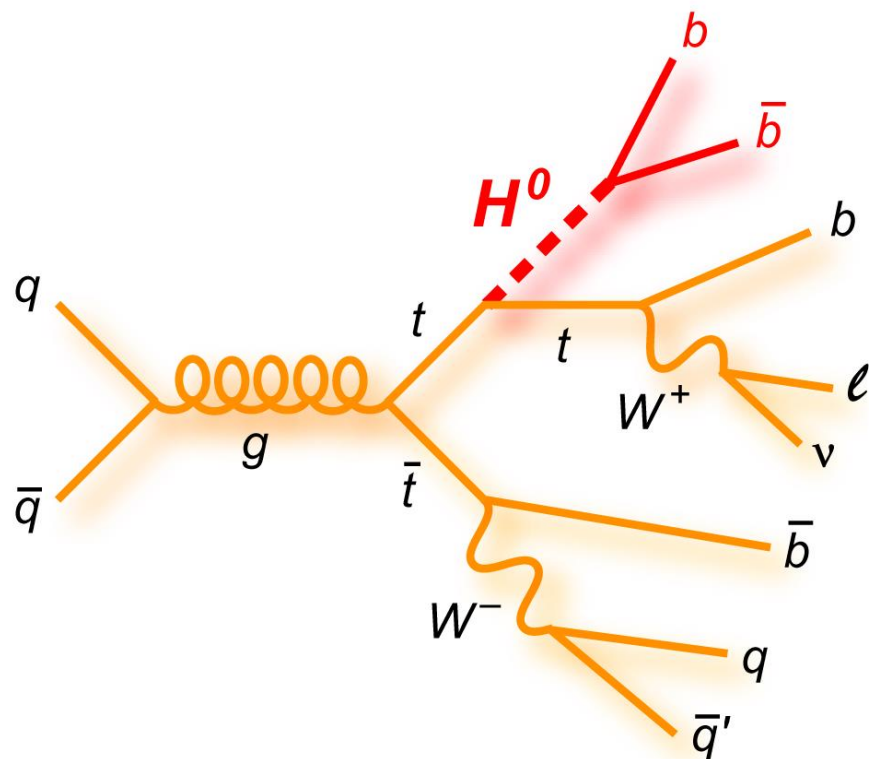
- Largest branching fraction @ 125 GeV:
 $H \rightarrow b\bar{b} \sim 60\%$

➤ Main background $t\bar{t} + \text{jets}$: $\sigma \sim 250 \text{ pb}$



➤ ATLAS is performing searches in all 3 decay modes of top quark pairs

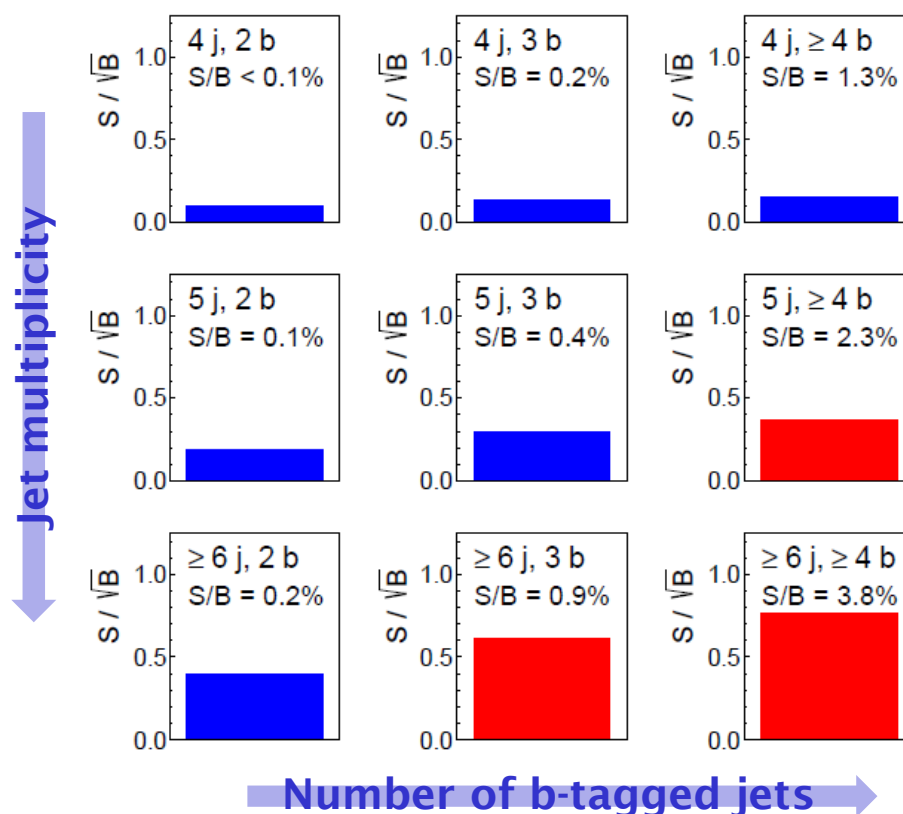
- Single lepton (public result): **discussed in more detail today**
- Dilepton (public result)
- All-hadronic (ongoing)



➤ Typical signal event:

- 1 isolated lepton (e/ μ)
- at least 6 jets (4 of them b-jets)

- Search for $t\bar{t}H$ ($H \rightarrow b\bar{b}$) - a search of a very small signal on top of a big and not so well known background
- Systematics dominated search: different topologies to control/reduce them
 - divide the events according to $n_{\text{Jets}}/n_{\text{Tag}}$
 - signal depleted regions are used to constrain backgrounds normalization



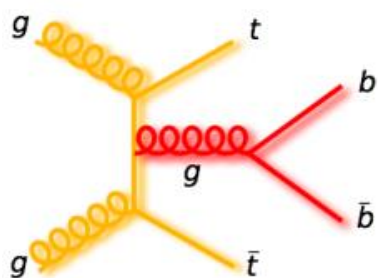
$\sqrt{s} = 8 \text{ TeV}, \int L dt = 20.3 \text{ fb}^{-1}$

$m_H = 125 \text{ GeV}$

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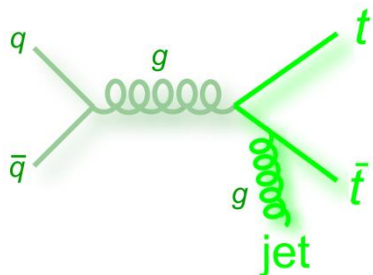
Irreducible backgrounds:

- $t\bar{t}+b\bar{b}$: pure QCD process, σ order of pb

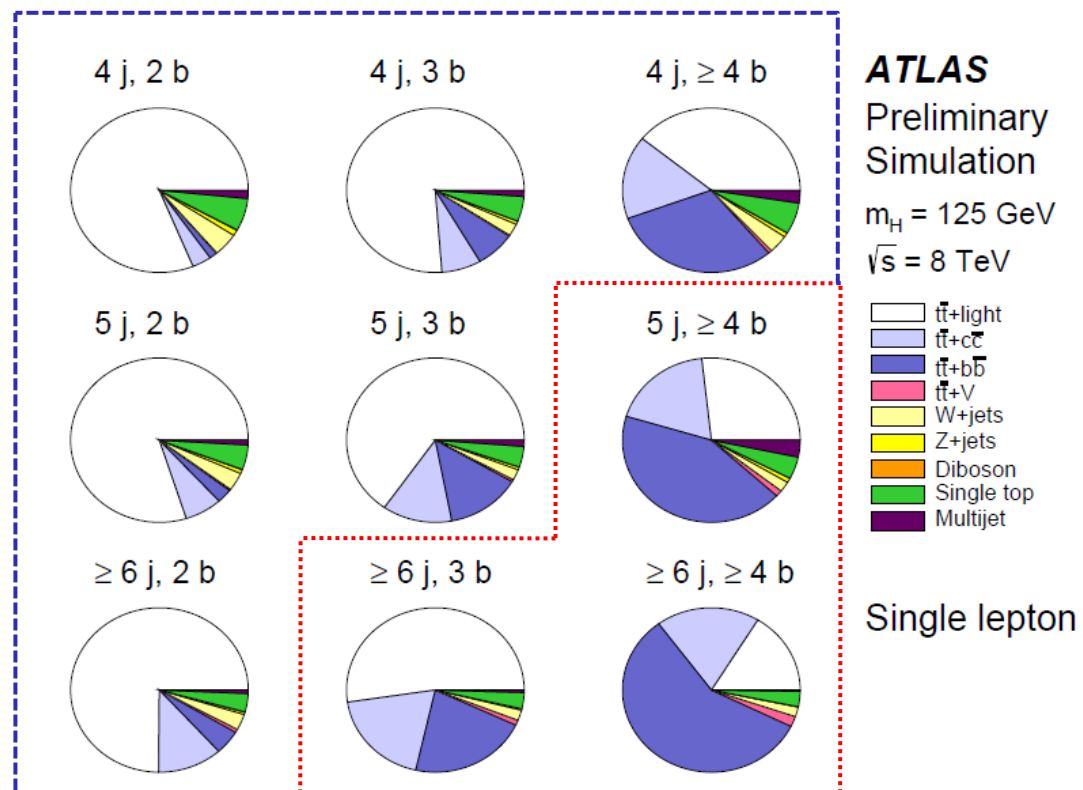
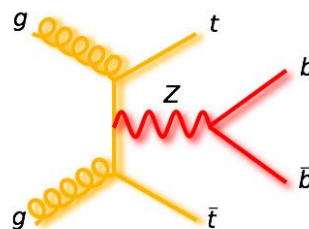


Reducible backgrounds:

- $t\bar{t}$ + light ($c\bar{c}$) jets: $\sigma \sim 250$ (5) pb
light jet can be mis-tagged



- $t\bar{t}V(W/Z)$, multijet, W+jets, Z+jets, dibosons, single top: contribution decreasing quickly with number of b-jets.



➤ **Simultaneous template fit to multiple regions**

- **Different discriminants used in various topologies:**

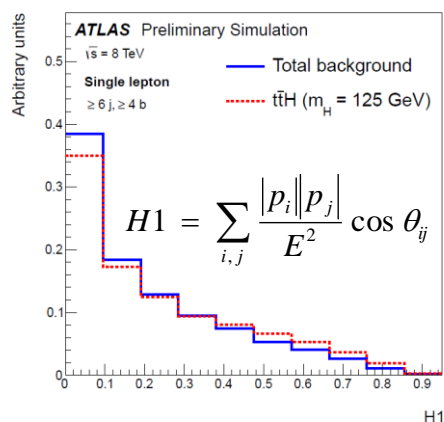
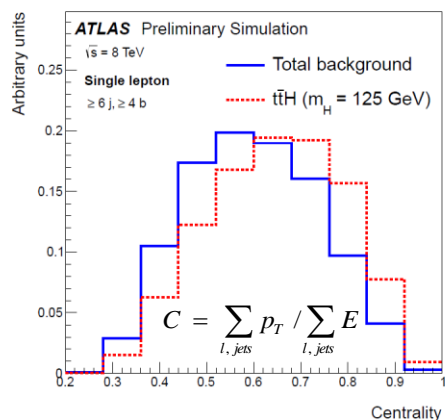
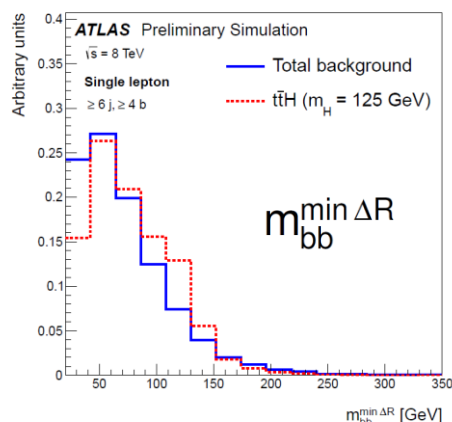
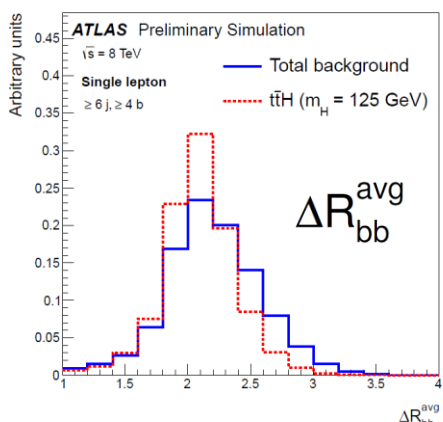
	2 b-tags	3 b-tags	≥ 4 b-tags
4 jets	HT	HT	HT
5 jets	HT	NN HF	NN
≥ 6 jets	HT	NN	NN

NNHF: separating $tt+\bar{l}light$ from $tt+\bar{H}F$

- **Control regions:** using $HT = \sum p_T(jets)$ as discriminant
- **Signal regions:** using Neural Network discriminant for signal extraction

➤ **Dedicated Bayesian Neural Network per signal region:**
different topologies of each signal region require different set of variables

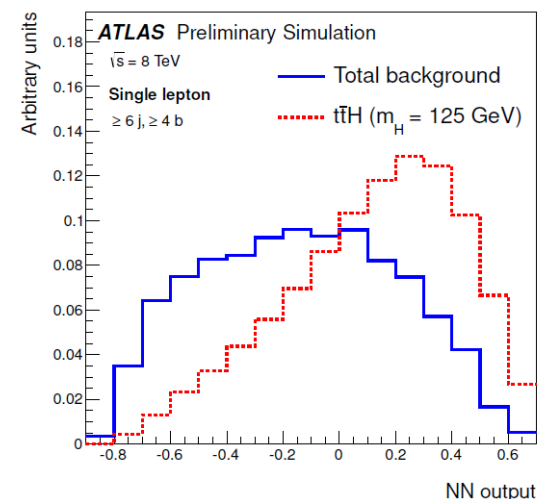
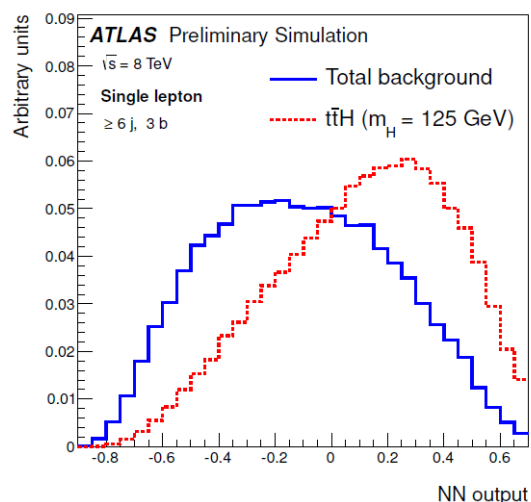
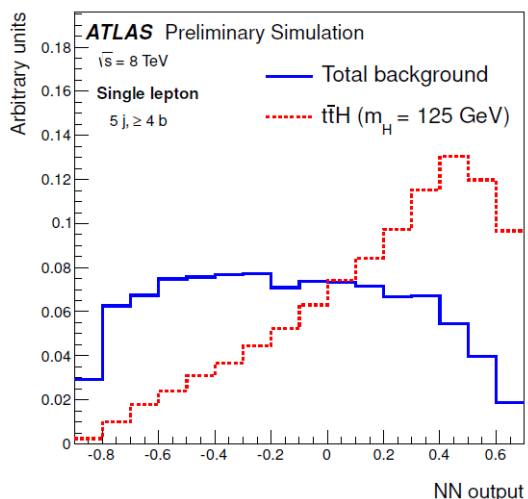
- object kinematics
- di-jet pairs properties
- global event variables



Variable	(≥ 6j, ≥ 4b)	(≥ 6j, 3b)	(5j, ≥ 4b)	(5j, 3b)
ΔR_{bb}^{avg}	1	5	5	-
$m_{bb}^{min} \Delta R$	2	9	3	1
Centrality	3	2	1	-
H1	4	3	2	-
p_T^{jet5}	5	8	-	-
Aplanarity _{b-jet}	6	-	7	-
$m_{uu}^{min} \Delta R$	7	7	-	2
$\Delta R_{bb}^{max} p_T$	8	-	-	-
$\Delta R_{lep-bb}^{min} \Delta R$	9	10	10	-
$m_{bj}^{max} p_T$	10	6	-	-
N_{40}^{jet}	-	1	4	-
$m_{bj}^{min} \Delta R$	-	4	-	-
$m_{lj}^{max} p_T$	-	-	6	-
H_T^{had}	-	-	8	-
$m_{lj}^{min} \Delta R$	-	-	9	-
$m_{bb}^{max} m$	-	-	-	3
$p_{T,uu}^{min} \Delta R$	-	-	-	4
m_{ij}	-	-	-	5
$\Delta R_{uu}^{min} \Delta R$	-	-	-	6
$m_{bb}^{max} p_T$	-	-	-	7

➤ 10 variables chosen in each region as a compromise of complexity VS separation

- Normalised NN output for **signal** and **background** show reasonable separation



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- Using HELAC-Oneloop $t\bar{t}H$ NLO MC prediction
- Powheg+Pythia NLO $t\bar{t}$ MC corrected to reproduce $t\bar{t}$ /top p_T measured in data (with associated uncertainties) from ATLAS measurement ([arXiv:1407.0371](https://arxiv.org/abs/1407.0371))

➤ Using profile likelihood to constrain systematic uncertainties

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- 50% uncorrel. normalization on $t\bar{t}+b\bar{b}/c\bar{c}$
- Dedicated $t\bar{t}+HF$ comparisons using Madgraph+Pythia for additional systs.

Constraining systematics by channels:

- c-tagging: 4j, 2b / 4j, 3b
- $t\bar{t}$ modelling: across 2b region
- $t\bar{t}+HF$: 3b / $\geq 4b$ -tags region

Detector systs

$t\bar{t}$ related

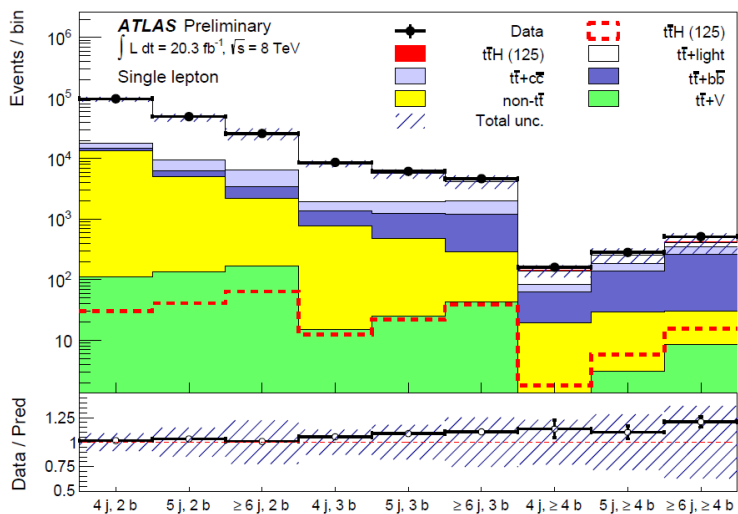
small bkg syst

Signal modelling

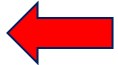
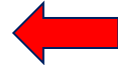
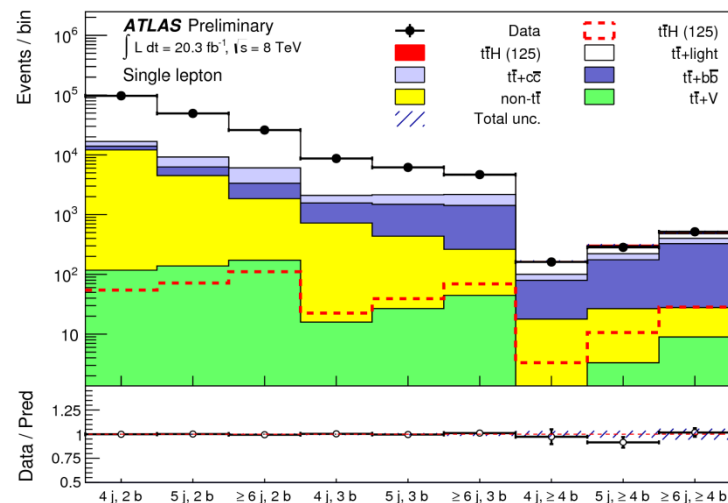
Systematic uncertainty	Type	Components
Luminosity	N	1
Physics Objects		
Electron	SN	5
Muon	SN	6
Jet energy scale	SN	22
Jet vertex fraction	SN	1
Jet energy resolution	SN	1
Jet reconstruction	SN	1
<i>b</i> -tagging efficiency	SN	6
<i>c</i> -tagging efficiency	SN	6
Light jet-tagging efficiency	SN	12
Background Model		
$t\bar{t}$ cross section	N	1
$t\bar{t}$ modelling: p_T reweighting	SN	9
$t\bar{t}$ modelling: parton shower	SN	2
$t\bar{t}+heavy-flavour$: normalisation	N	2
$t\bar{t}+heavy-flavour$: HF reweighting	SN	2
$t\bar{t}+heavy-flavour$: generator	SN	5
<i>W</i> +jets normalisation	N	3
<i>W</i> p_T reweighting	SN	1
<i>Z</i> +jets normalisation	N	2
<i>Z</i> p_T reweighting	SN	1
Multijet normalisation	N	3
Multijet shape dilepton	S	1
Single top cross section	N	1
Dibosons cross section	N	1
$t\bar{t}V$ cross section	N	1
Signal Model		
$t\bar{t}H$ modelling	SN	2

S = shape, N = normalization

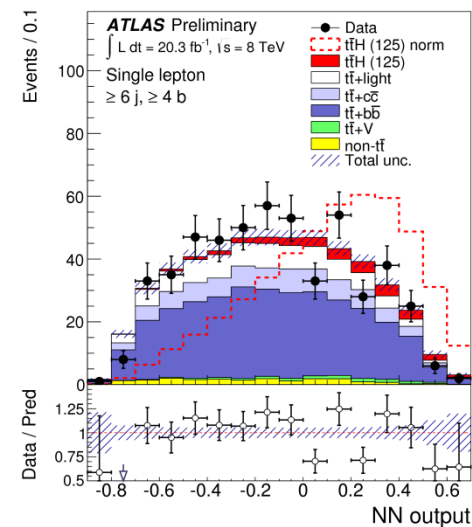
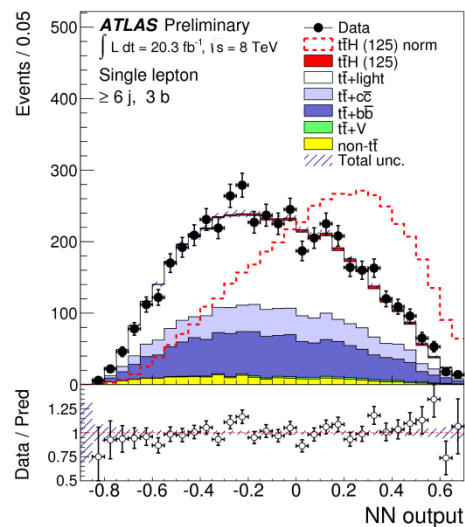
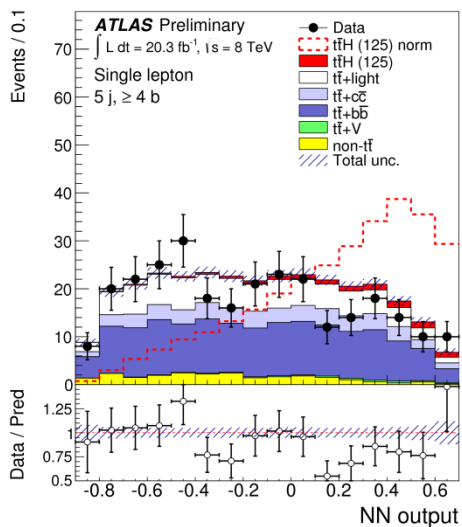
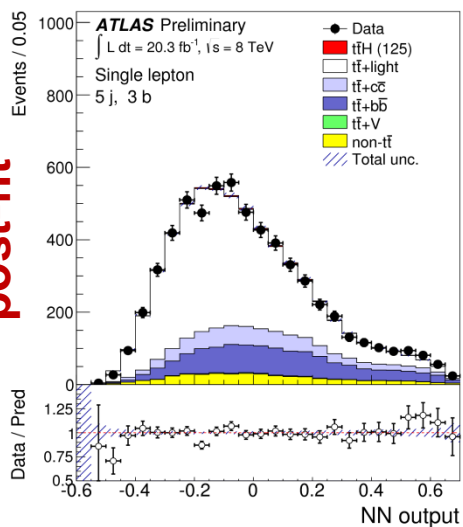
pre-fit



post-fit

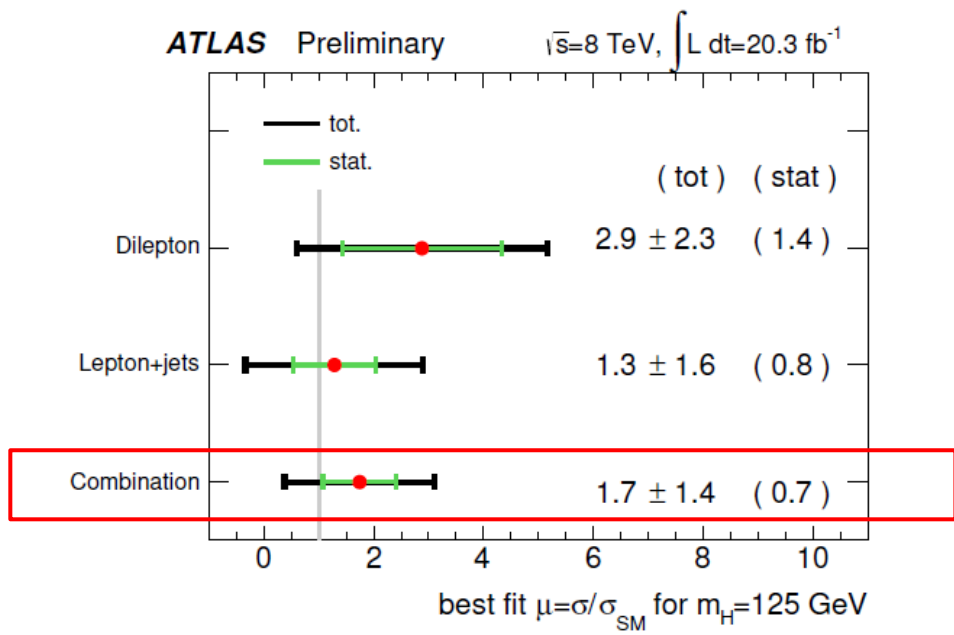
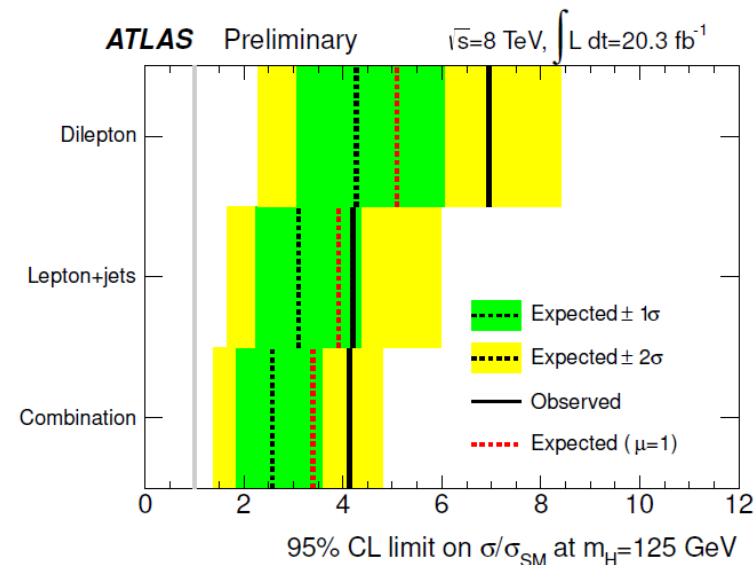


post-fit



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95% C.L. limit on $\sigma/\sigma^{\text{SM}}$	Observed	Median expected
Single Lepton	4.2	3.1
Dilepton	6.7	4.3
Combination	4.1	2.6



95% CL observed (expected) limit:
4.1 x SM (2.6 x SM) for $m_H = 125$ GeV

Best fit signal strength:

$$\mu = 1.7 \pm 1.4$$

Significance obs (exp): 1.3 σ (0.8 σ)

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- **Search for $t\bar{t}H$ ($H \rightarrow b\bar{b}$) - a search of a very small signal on top of a big and not so well known background**
- **A lot of effort and complexity put in the analysis in order to increase the sensitivity to the signal:**
 - **multiple multivariate discriminants**
 - **several control regions to constrain the background normalization and mitigate the effect of systematic uncertainties**
- **Result so far consistent with the SM prediction!**
- **Further updates to the analysis expected soon including ME technique...**

THANK YOU!

BACK UP

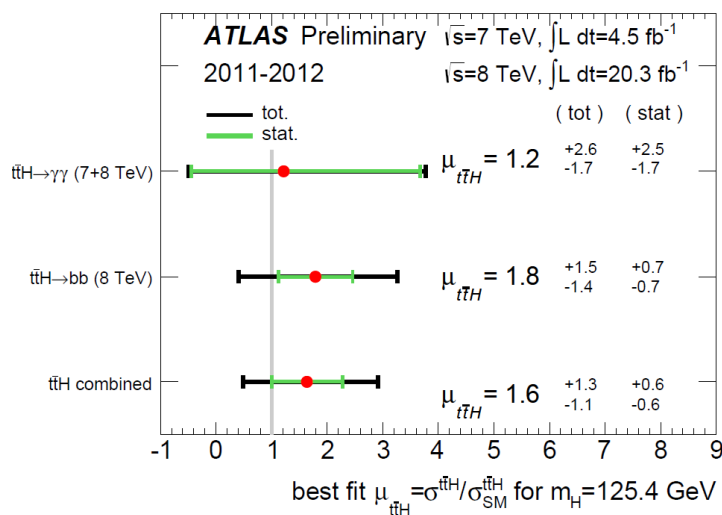
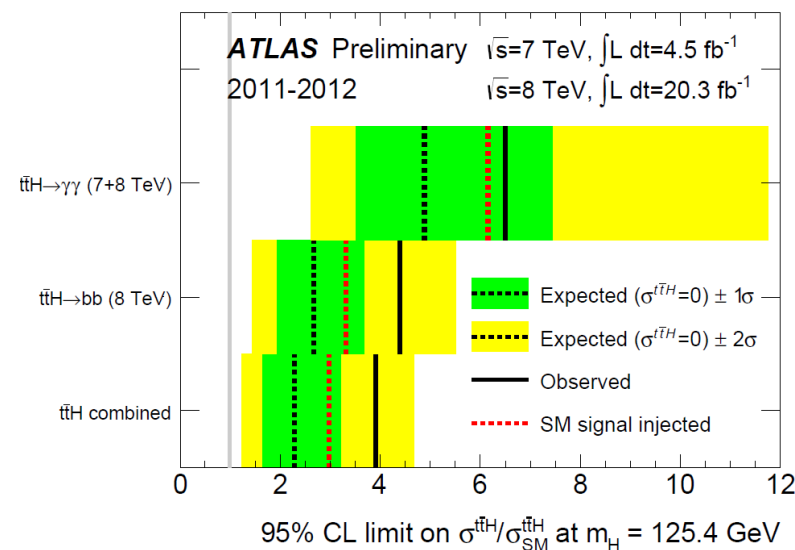
➤ Combine new $t\bar{t}H(H \rightarrow \gamma\gamma)$ with $t\bar{t}H(H \rightarrow b\bar{b})$

- Likelihood fit in 19 categories
- 15 from $t\bar{t}H(H \rightarrow b\bar{b})$
- 4 from $t\bar{t}H(H \rightarrow \gamma\gamma)$

➤ Modifications to $t\bar{t}H(H \rightarrow b\bar{b})$ result

- Higgs mass change to 125.4 GeV
- Uncertainty on $H \rightarrow b\bar{b}$ branching
- Th. uncert. on SM $t\bar{t}H$ cross-section

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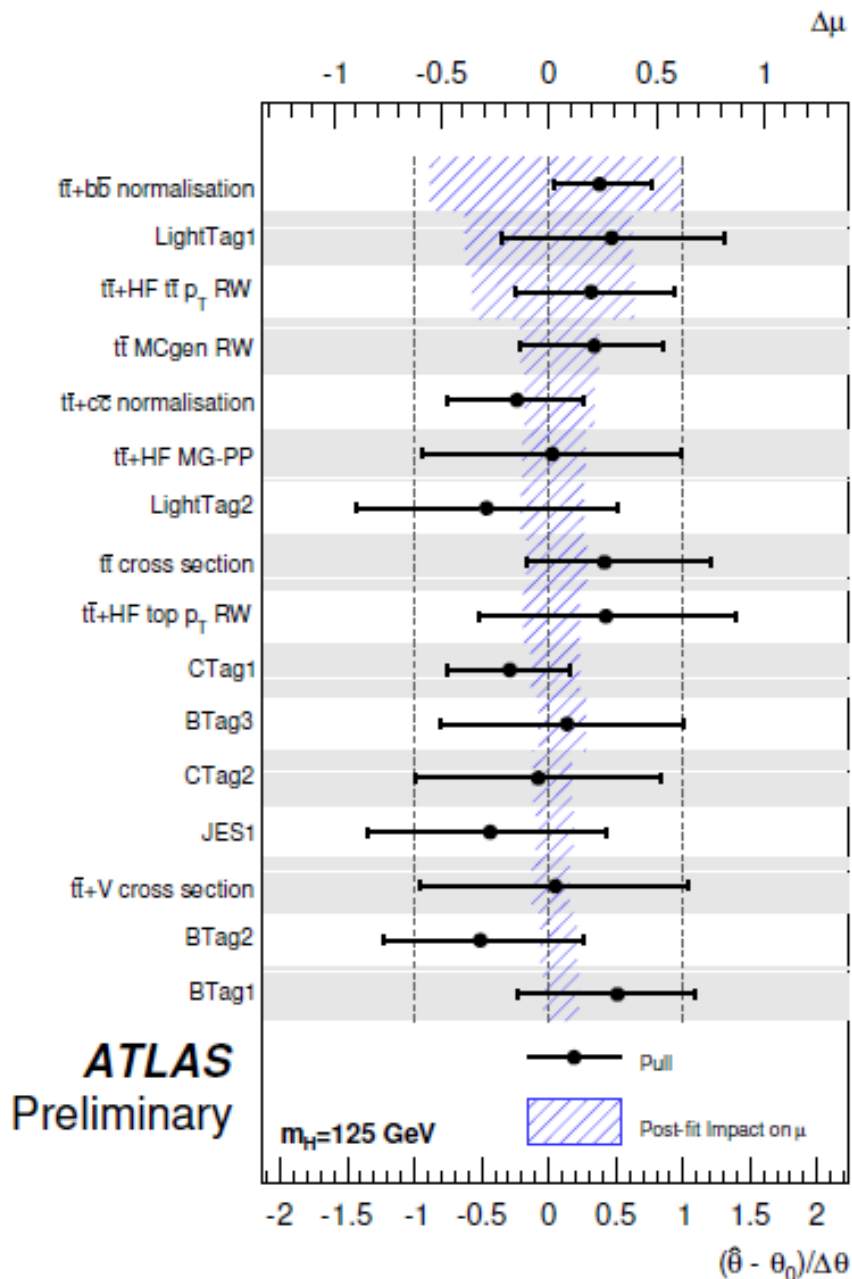
95% CL observed (expected) limit:

3.9 x SM (2.3 x SM) for $m_H = 125.4$ GeV

Best fit signal strength:

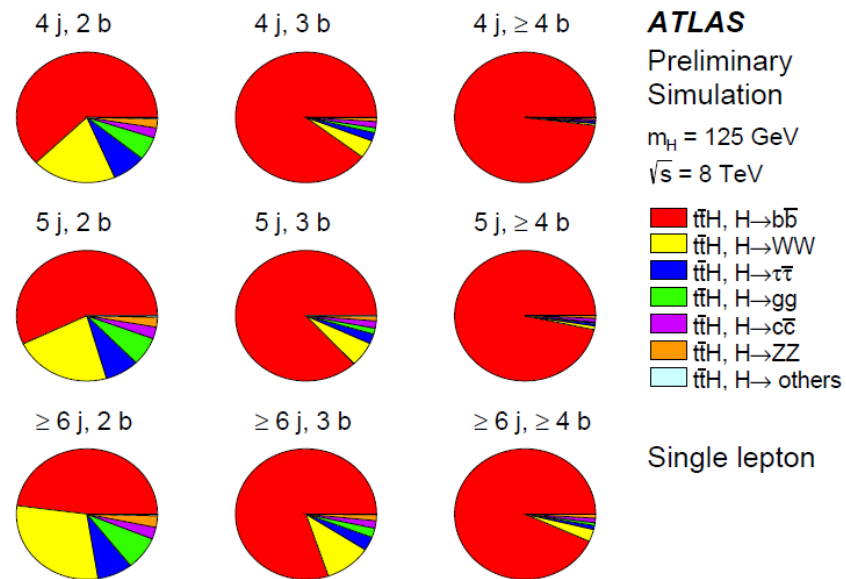
$$\mu_{t\bar{t}H} = 1.6 \pm 0.6 \text{ (stat.) } \begin{matrix} +1.1 \\ -1.0 \end{matrix} \text{ (sys.)}$$

Significance obs (exp): 1.5 σ (1.0 σ)

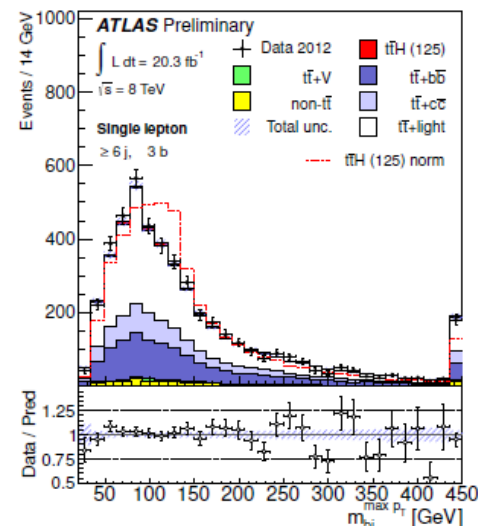
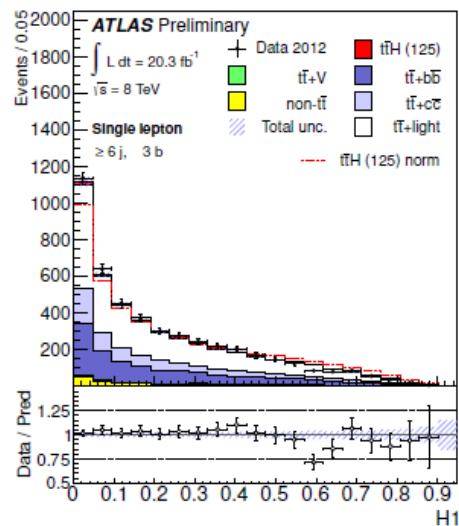
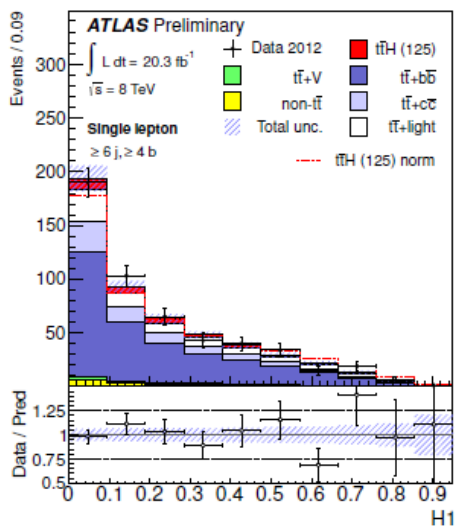
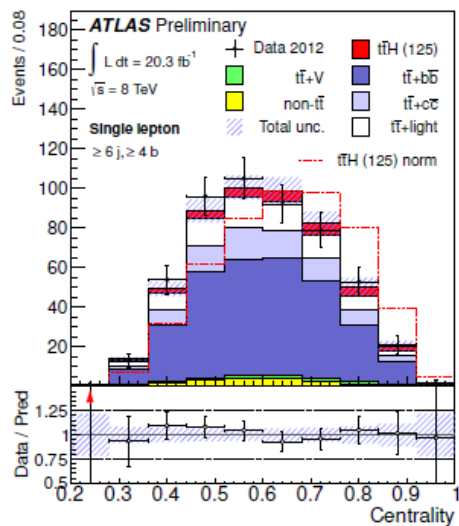
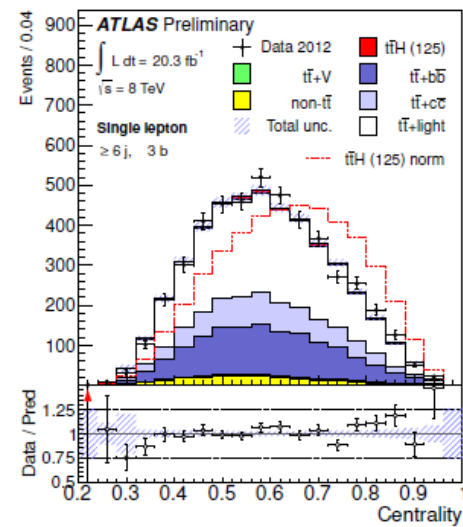
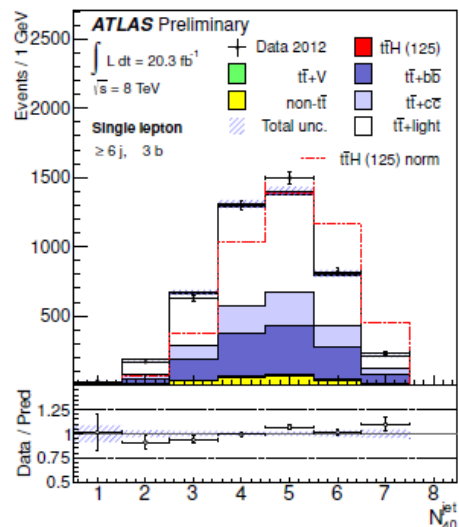
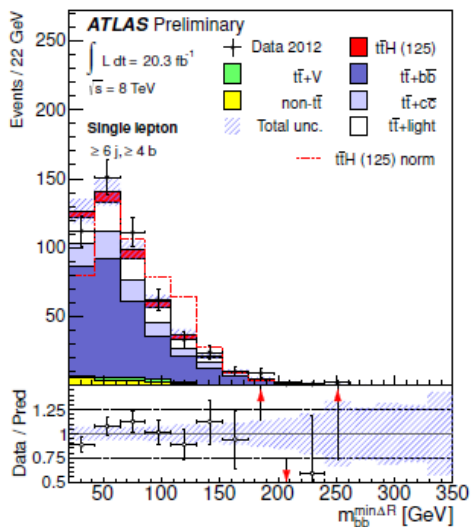
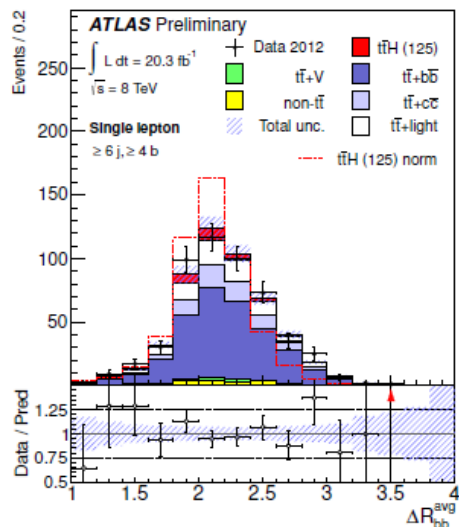


- BTag1, BTag2, BTag3: 3 components of b-tagging uncertainty, beginning with the largest normalisation effect
- CTag1, CTag2: 2 components of c-tagging uncertainties, beginning with the largest normalisation effect
- LightTag1, LightTag2: 2 components of light tag uncertainty, beginning with the largest normalisation effect
- JES1: one of 22 components of jet energy scale uncertainty
- $\bar{t}\bar{t}$ MCgen RW: choice of the MC generator for $\bar{t}\bar{t}$ in the differential cross section measurement
- $\bar{t}\bar{t}+HF$ top p_T RW and $\bar{t}\bar{t}+HF$ $\bar{t}\bar{t}$ p_T RW: uncertainties corresponding to switching top p_T and $\bar{t}\bar{t}$ p_T reweighting off, respectively, for $\bar{t}\bar{t}+HF$
- $\bar{t}\bar{t}+HF$ MG-PP: generator choice for $\bar{t}\bar{t}+HF$ (Powheg vs Madgraph)
- $\bar{t}\bar{t}$ cross section: $\bar{t}\bar{t}$ inclusive cross section
- $\bar{t}\bar{t}+b\bar{b}$ normalisation: $\bar{t}\bar{t}+b\bar{b}$ normalisation uncertainty for events with at least one b -jet
- $\bar{t}\bar{t}+c\bar{c}$ normalisation: $\bar{t}\bar{t}+c\bar{c}$ normalisation uncertainty for events with at least one c -jet
- $\bar{t}\bar{t}+V$ cross section: cross section for $\bar{t}\bar{t} + V$, ($V = Z, W$) production

Variable	Definition
Centrality	Sum of the p_T divided by sum of the E for all jets and the lepton
H1	Second Fox-Wolfram moment computed using all jets and the lepton
$m_{bb}^{\min \Delta R}$	Mass of the combination of two b -tagged jets with the smallest ΔR
N_{40}^{jet}	Number of jets with $p_T \geq 40$ GeV
$\Delta R_{bb}^{\text{avg}}$	Average ΔR for all b -tagged jet pairs
$m_{jj}^{\max p_T}$	Mass of the combination of any two jets with the largest vector sum p_T
Aplanarity $_{b\text{-jet}}$	$1.5\lambda_2$, where λ_2 is the second eigenvalue of the momentum tensor built with only b -tagged jets
H_T^{had}	Scalar sum of jet p_T
$m_{jj}^{\min \Delta R}$	Mass of the combination of any two jets with the smallest ΔR
$\Delta R_{\text{lep-bb}}^{\min \Delta R}$	ΔR between the lepton and the combination of two b -tagged jets with the smallest ΔR
$m_{bj}^{\min \Delta R}$	Mass of the combination of a b -tagged jet and any jet with the smallest ΔR
$m_{bj}^{\max p_T}$	Mass of the combination of a b -tagged jet and any jet with the largest vector sum p_T
$m_{uu}^{\min \Delta R}$	Mass of the combination of two untagged jets with the smallest ΔR
p_T^{jet5}	Fifth leading jet p_T
$\Delta R_{bb}^{\max p_T}$	ΔR between two b -tagged jets with the largest vector sum p_T
$m_{bb}^{\max m}$	Mass of the combination of two b -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 with the smallest ΔR
m_{jjj}	Mass of the jet triplet with the largest vector sum p_T
$\Delta R_{uu}^{\min \Delta R}$	Minimum ΔR between two untagged jets
$m_{bb}^{\max p_T}$	Mass of the combination of two b -tagged jets with the largest vector sum p_T



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$\geq 6 j, \geq 4 b$

	Pre-fit				Post-fit			
	$t\bar{t}H$ (125)	$t\bar{t} + \text{light}$	$t\bar{t} + c\bar{c}$	$t\bar{t} + b\bar{b}$	$t\bar{t}H$ (125)	$t\bar{t} + \text{light}$	$t\bar{t} + c\bar{c}$	$t\bar{t} + b\bar{b}$
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

	CMS	ATLAS
Lepton p_T	30 GeV	25 GeV
Muon η	$ \eta < 2.1$	$ \eta < 2.5$
Jet algo	anti- k_T 0.5	anti- k_T 0.4
Jet η	$ \eta < 2.4$	$ \eta < 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%

Single lepton	5 j, ≥ 4 b		≥ 6 j, ≥ 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

