$t\bar{t}H(H \to b\bar{b})$: ATLAS and CMS latest run-2 results in the leptonic channels

Ateliers Top-LHC-France, Paris

Timothée Theveneaux-Pelzer

Deutsches Elektronen-Synchrotron (DESY) - Zeuthen

Thursday, May 24th 2018

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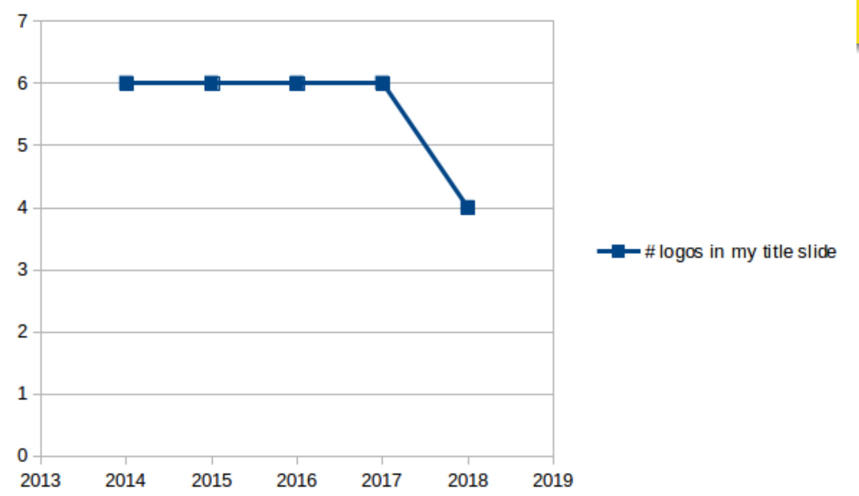
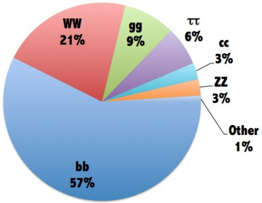
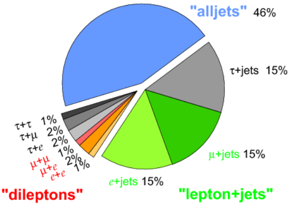


Introduction

- $t\bar{t}H$ is an important process for LHC run-2 physics program
  - → cf. yesterday's excellent talks
- $H \to b\bar{b}$ decay mode provides the most abundant $t\bar{t}H$ event sample
  - → reconstruction of $t\bar{t}H$ system kinematics is possible
- ATLAS and CMS recently published 13 TeV data results using the leptonic $t\bar{t}$ decays
  Phys. Rev. D **97** (2018) 072016 - 1804.03682 [hep-ex]
  - → both using 2015+2016 dataset
- Presenting here these two recent results, and comparing them
  - → see also this review at last week's LHCTopWG open meeting (K. El Morabit, M. Pinamonti)



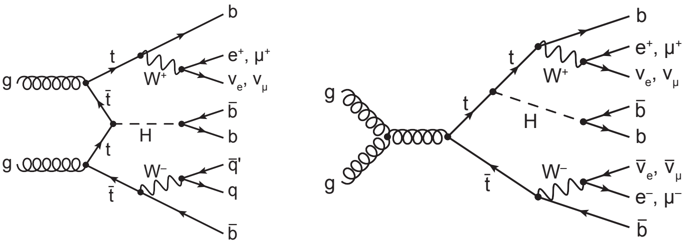
Higgs branching ratios



$t\bar{t}$ branching ratios

Signal phenomenology

- Targetting $H \to b\bar{b}$ and $t\bar{t} \to 1\ell/2\ell$, with $\ell = e$ or μ
  - $\to$ fully-hadronic : more challenging - see 1803.06986 (CMS 13 TeV), JHEP05(2016)160 (ATLAS 8 TeV)



- 4 b-jets (H or t) + additional c- and light-jets (additional radiations or W decays)
  - $\to$ b-jet (mis)tagging performance is crucial for this analysis
  - $\to$ combinatorial background : aiming to select the b-jets from the H
- Main background : $t\bar{t} + b\bar{b}$
  - $\to$ same final state as signal - additional 2 b-quarks from gluon splitting
  - $\to$ MC prediction challenging - QCD vertices with very different scales

Event Preselection

- Exactly 1 or 2 electrons or muons
  - → ATLAS : single-lepton triggers in both channels
  - → CMS : combine single- and di-lepton triggers in dilepton channels
- Summary of offline pre-selections :

	1ℓ		2ℓ	
	ATLAS	CMS	ATLAS	CMS
$p_T(\ell 1)$ [GeV]	> 27	$> 30(26)$ for $e(\mu)$	> 27	> 25
$p_T(\ell 2)$ [GeV]	> 10	> 15	$> 15(10)$ for $ee(\mu\mu\&e\mu)$	> 15
$\|\eta(\ell)\|$	< 2.5	< 2.1	< 2.5	< 2.4
$m_{\ell\ell}$ [GeV]	-	-	> 15	> 20
$m_{\ell\ell}$ Z veto [GeV]	-	-	$83-99$	$76-106$
Number of τ_{had}	≤ 1	-	$= 0$	-
MET [GeV]	-	> 20	-	> 40
Jet $p_T(j)$ [GeV]	> 25	> 30	> 25	> 25 (30 for ≥ 2 jets)
Jet $\|\eta\|$	< 2.5	< 2.4	< 2.5	< 2.4

- ATLAS : boosted 1 ℓ sub-category (see also CMS earlier preliminary result)
  - → top- and Higgs-jets built by re-clustering small-R jets, and using b-tagging

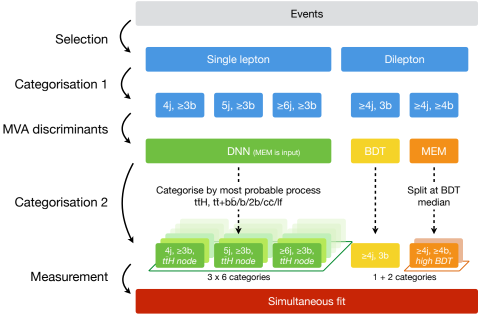
General analysis strategy

- Select events with $t\bar{t}H(H \to b\bar{b})$ single- and di-lepton topologies
- Categories/regions enriched in signal or in different background processes
- Multivariate techniques and MEM to separate signal and backgrounds
- Profile likelihood fit to extract signal strength (μ), combining all regions

ATLAS

- 8 SR (+1 boosted), 10 CR
  - → 5 or $\geq$6 (3 or $\geq$4) in 1ℓ (2ℓ)
  - → pseudo-continuous b-tagging : using 4 working points (85% to 60%)
- One BDT in each SR, with several inputs :
  - → general kin. variables, b-tag discriminant
  - → top and Higgs kinematic variables reconstructed with dedicated BDTs
  - → 1D likelihood discriminants, MEM (1ℓ)
- In CRs : use total yield or $\mathrm{H_T}$

CMS



Signal and background estimates

- Simulated samples used to estimate the expected contribution of each process
- List of nominal MC generators :

	ATLAS			CMS		
	ME	PS	tune	ME	PS	tune
$t\bar{t}H$	aMC@NLO	Pythia8	A14	Powheg	Pythia8	CUETP8M2T4
$t\bar{t}$	Powheg	Pythia8	A14	Powheg	Pythia8	CUETP8M2T4
$t\bar{t}V$	aMC@NLO	Pythia8	A14	aMC@NLO	Pythia8	CUETP8M1
sgtop tW	Powheg	Pythia6	Perugia	Powheg	Pythia8	CUETP8M1
sgtop t-chan.	Powheg(4fs)	Pythia6	Perugia	Powheg(5fs)	Pythia8	CUETP8M1
sgtop s-chan.	Powheg	Pythia6	Perugia	aMC@NLO	Pythia8	CUETP8M1
V+jets	Sherpa	Sherpa	author	aMC@NLO [FxFx]	Pythia8	CUETP8M1
diboson	Sherpa	Sherpa	author	Pythia8	Pythia8	CUETP8M1

- NLO+PS for almost all processes - V+jets : additional partons @NLO
- Powheg+Pythia8 for main $t\bar{t}$ background used by both experiments
  - → ATLAS : A14 tune + optimisation of h_{damp}
  - → CMS : CUETP8M2T4 tune = CUETP8M1 tune + combined tune of h_{damp} and $\alpha_S(ISR)$

$t\bar{t}+\mathrm{HF}$ categories

- $t\bar{t}+\mathrm{jets}$ process subdivided at truth level depending on origin of the additional jets
  → different physics processes, with different diagrams and uncertainties
- First match hadrons not-from-top to particle-level jets :

	ATLAS	CMS
Particle level jet p_T cuts	15 GeV	20 GeV
Particle level jet $\|\eta\|$ cuts	< 2.5	< 2.4
Hadron p_T cut	5 GeV	no cut
jet-hadron matching	$\Delta R < 0.4$	ghost hadron

- Then, count the number of jets matched to additional HF hadrons :

ATLAS

process	#jets	w/ #hadrons
$t\bar{t}+\geq 1b$	≥ 1	$\geq 1b$
$t\bar{t}+b$	$= 1$	$= 1b$
$t\bar{t}+bb$	$= 2$	$= 1b$
$t\bar{t}+B$	$= 1$	$\geq 2b$
$t\bar{t}+\geq 3b$	other $t\bar{t}+\geq 1b$ events	
$t\bar{t}+b(MPI/FSR)$	all b-jets from MPI/FSR	
$t\bar{t}+\geq 1c$	≥ 1	$\geq 1c$
$t\bar{t}+\mathrm{light}$	other $t\bar{t}+\mathrm{jets}$ events	

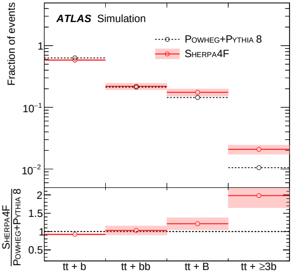
CMS

process	#jets	w/ #hadrons
$t\bar{t}+bb$	≥ 2	$\geq 1b$
$t\bar{t}+1b$	$= 1$	$= 1b$
$t\bar{t}+2b$	$= 1$	$\geq 2b$
$t\bar{t}+cc$	≥ 1	$\geq 1c$
$t\bar{t}+\mathrm{light}$	else	

Modelling $t\bar{t}+\text{jets}$

ATLAS

- $t\bar{t}+\text{jets}$ with Powheg+Pythia8 (A14)
  - → $\alpha_S(ISR) = \alpha_S(FSR) = 0.127$
  - → h_{damp}=1.5 m_{top}
  - → normalised to NNLO+NNLL prediction
- $t\bar{t}+\geq 1b$, $t\bar{t}+\geq 1c$ fractions from PP8
  - → let free-floating in fit
- $t\bar{t}+\geq 1b$ sub-categories fractions from Sherpa(4fs) $t\bar{t}+b\bar{b}$ prediction



CMS

- $t\bar{t}+\text{jets}$ with Powheg+Pythia8 (CUETP8M2T4)
  - → $\alpha_S(ISR) = 0.1108$, $\alpha_S(FSR) = 0.1365$
  - → h_{damp}=1.581 m_{top}
  - → normalised to NNLO+NNLL prediction
- $t\bar{t}+\geq 1b$ shape and norm. from PP8
  - → fractions NOT free-floating in fit

Uncertainties on $t\bar{t}+\text{jets}$: CMS

- Uncertainties on $t\bar{t}$ cross-section, correlated accross $t\bar{t}+\text{jets}$ components
- Additional uncorrelated 50% on $t\bar{t}+b\bar{b}$, $t\bar{t}+b$, $t\bar{t}+2b$, $t\bar{t}+c\bar{c}$ - several checks :
  - $\rightarrow$ vary a-priory uncertainty, vary $t\bar{t}+b$ rate by 30%, let $t\bar{t}+b$ normalisation free-floating
- Indepentent μ_R & μ_F ME variations, correlated accross $t\bar{t}+\text{jets}$ components
- Uncertainties on ISR, FSR, PS/ME matching, uncorrelated accross $t\bar{t}+\text{jets}$ components
  - $\rightarrow$ from CUETP8M2T4 tune
- PDF uncertainty (NNPDF3.0 replicas), correlated accross $t\bar{t}+\text{jets}$ components and $t\bar{t}H$

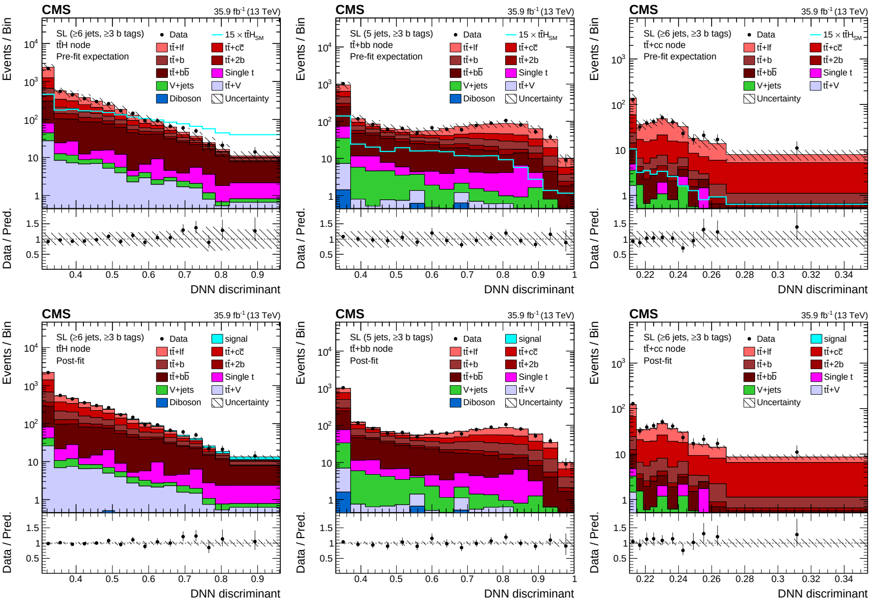
Source	Type	Remarks
Renorm./fact. scales ($t\bar{t}$)	rate	Scale uncertainty of NLO $t\bar{t}$ prediction
Renorm./fact. scales ($t\bar{t}$+hf)	rate	Additional 50% rate uncertainty of $t\bar{t}$+hf predictions
PDF (gg)	rate	PDF uncertainty for gg initiated processes except $t\bar{t}$H
μ_R scale ($t\bar{t}$)	shape	Renormalisation scale uncertainty of the $t\bar{t}$ ME generator, independent for additional jet flavours
μ_F scale ($t\bar{t}$)	shape	Factorisation scale uncertainty of the $t\bar{t}$ ME generator, independent for additional jet flavours
PS scale: ISR ($t\bar{t}$)	rate	Initial state radiation uncertainty of the PS (for $t\bar{t}$ events), jet multiplicity dependent rate uncertainty, independent for additional jet flavours
PS scale: FSR ($t\bar{t}$)	rate	Final state radiation uncertainty (for $t\bar{t}$ events), jet multiplicity dependent rate uncertainty, independent for additional jet flavours
ME-PS matching ($t\bar{t}$)	rate	NLO ME to PS matching, *hdamp* [**?**] (for $t\bar{t}$ events), jet multiplicity dependent rate uncertainty, independent for additional jet flavours
Underlying event ($t\bar{t}$)	rate	Underlying event (for $t\bar{t}$ events), jet multiplicity dependent rate uncertainty, independent for additional jet flavours
NNPDF3.0NLO ($t\bar{t}$H, $t\bar{t}$)	shape	Based on the NNPDF replicas, same for $t\bar{t}$H and additional jet flavours

Uncertainties on $t\bar{t}+\text{jets}$: ATLAS

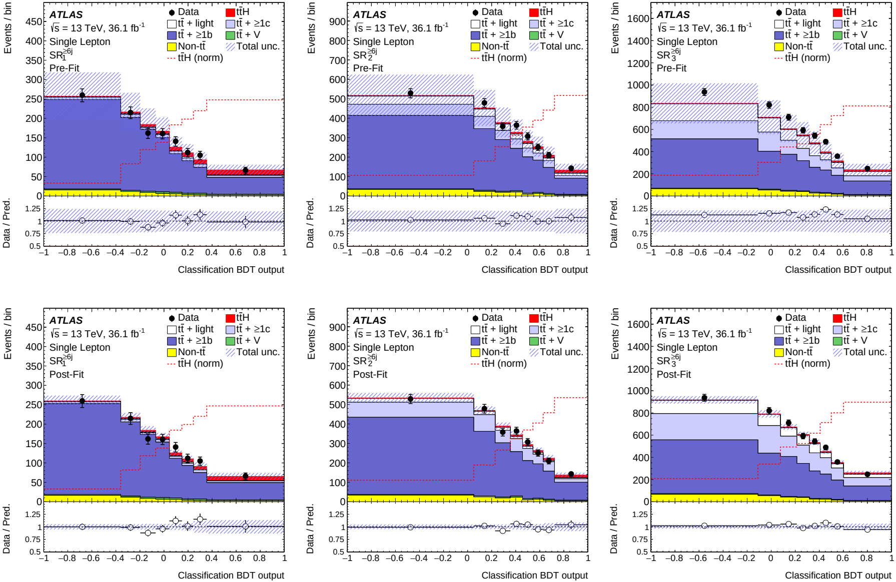
- Uncertainties on $t\bar{t}$ cross-section correlated accross all $t\bar{t}+\text{jets}$ components
- Uncertainties on $t\bar{t}+b\bar{b}$, $t\bar{t}+b$, $t\bar{t}+B$, $t\bar{t}+\geq 3b$ fractions, from Sherpa(4fs) $t\bar{t}+b\bar{b}$ prediction
  - → additional 50% uncertainties on $t\bar{t}+\geq 3b$ and $t\bar{t}+b(MPI/FSR)$ rates
- Shape uncertainty on $t\bar{t}+\geq 1b$: comparison of Powheg+P8 to Sherpa(4fs)
- Shape uncertainties on $t\bar{t}+\text{jets}$, uncorrelated accross $t\bar{t}+\geq 1b$, $t\bar{t}+\geq 1c$, and $t\bar{t}+\text{light}$
  - → comparisons to alternative setups - NLO matching, PS model, additional radiations
- Shape uncertainty on $t\bar{t}+\geq 1c$ - comparison of Powheg+P8 to aMC@NLO+P8 (3fs) $t\bar{t}+c\bar{c}$

Systematic source	Description	$t\bar{t}$ categories
$t\bar{t}$ cross-section	Up or down by 6%	All, correlated
$k(t\bar{t}+\geq 1c)$	Free-floating $t\bar{t}+\geq 1c$ normalization	$t\bar{t}+\geq 1c$
$k(t\bar{t}+\geq 1b)$	Free-floating $t\bar{t}+\geq 1b$ normalization	$t\bar{t}+\geq 1b$
SHERPA5F vs. nominal	Related to the choice of NLO event generator	All, uncorrelated
PS & hadronization	POWHEG+HERWIG 7 vs. POWHEG+PYTHIA 8	All, uncorrelated
ISR / FSR	Variations of μ_R, μ_F, h_{damp} and A14 Var3c parameters	All, uncorrelated
$t\bar{t}+\geq 1c$ ME vs. inclusive	MG5_aMC@NLO+HERWIG++: ME prediction (3F) vs. incl. (5F)	$t\bar{t}+\geq 1c$
$t\bar{t}+\geq 1b$ SHERPA4F vs. nominal	Comparison of $t\bar{t}+b\bar{b}$ NLO (4F) vs. POWHEG+PYTHIA 8 (5F)	$t\bar{t}+\geq 1b$
$t\bar{t}+\geq 1b$ renorm. scale	Up or down by a factor of two	$t\bar{t}+\geq 1b$
$t\bar{t}+\geq 1b$ resumm. scale	Vary μ_Q from $H_T/2$ to μ_{CMMPS}	$t\bar{t}+\geq 1b$
$t\bar{t}+\geq 1b$ global scales	Set μ_Q, μ_R, and μ_F to μ_{CMMPS}	$t\bar{t}+\geq 1b$
$t\bar{t}+\geq 1b$ shower recoil scheme	Alternative model scheme	$t\bar{t}+\geq 1b$
$t\bar{t}+\geq 1b$ PDF (MSTW)	MSTW vs. CT10	$t\bar{t}+\geq 1b$
$t\bar{t}+\geq 1b$ PDF (NNPDF)	NNPDF vs. CT10	$t\bar{t}+\geq 1b$
$t\bar{t}+\geq 1b$ UE	Alternative set of tuned parameters for the underlying event	$t\bar{t}+\geq 1b$
$t\bar{t}+\geq 1b$ MPI	Up or down by 50%	$t\bar{t}+\geq 1b$
$t\bar{t}+\geq 3b$ normalization	Up or down by 50%	$t\bar{t}+\geq 1b$

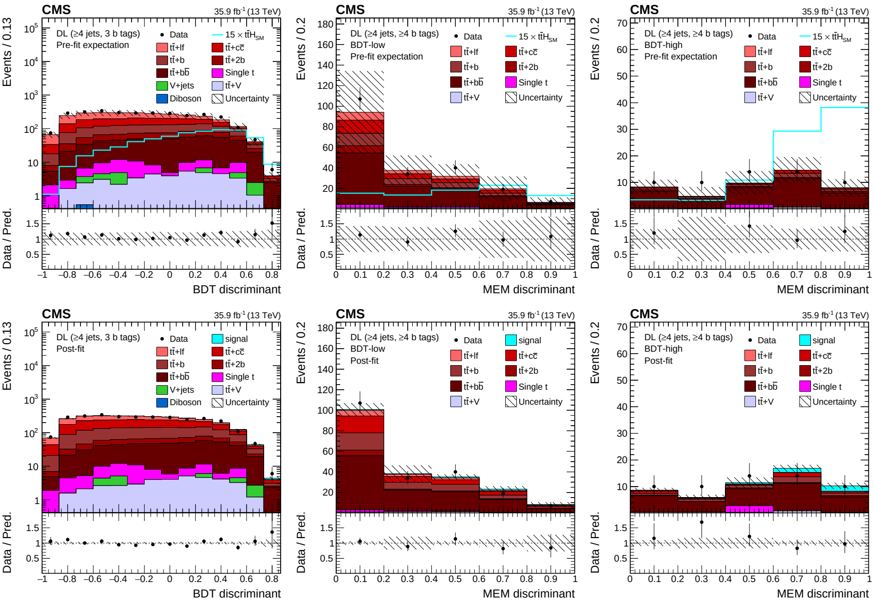
CMS fitted discriminants, single-lepton



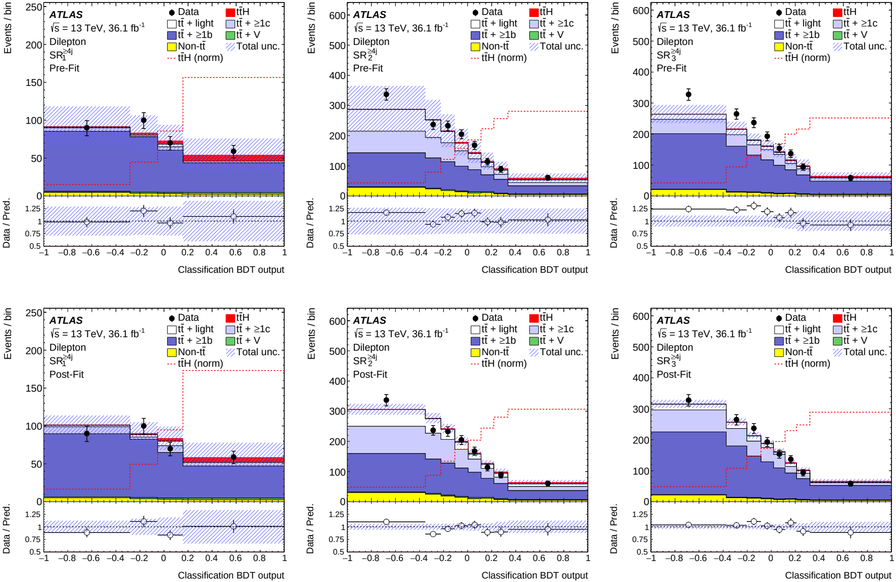
ATLAS fitted discriminants, single-lepton



CMS fitted discriminants, dilepton

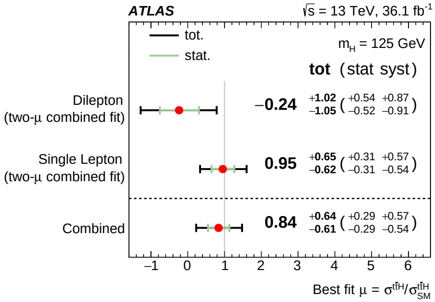


ATLAS fitted discriminants, dilepton

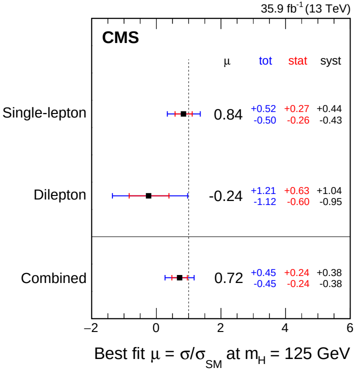


Results

ATLAS



CMS



- Significance : 1.4 (1.6) σ obs. (exp.)
- Obs. (exp.) limit : μ<2.0(1.2) @95%CL
  - → @8 TeV : μ<3.4(2.2) @95%CL

- Significance : 1.6 (2.2) σ obs. (exp.)
- Obs. (exp.) limit : μ<1.51(0.92) @95%CL
  - → @8 TeV : μ<4.1(3.5) @95%CL

- Both ATLAS and CMS are unlucky, as they were in run-1
- ATLAS quotes μ in the two channels from combined 2-μ fit (with correlations)

Summary of uncertainties

ATLAS

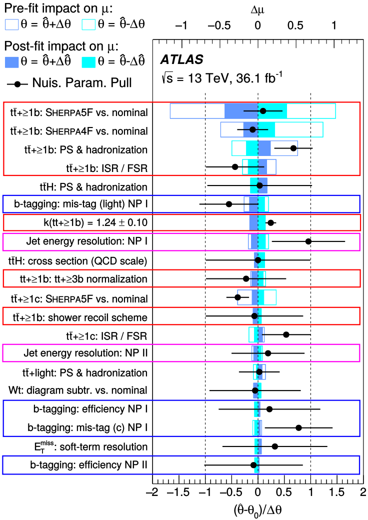
Uncertainty source	$\Delta\mu$	
$t\bar{t}+\geq 1b$ modeling	+0.46	−0.46
Background-model stat. unc.	+0.29	−0.31
b-tagging efficiency and mis-tag rates	+0.16	−0.16
Jet energy scale and resolution	+0.14	−0.14
$t\bar{t}H$ modeling	+0.22	−0.05
$t\bar{t}+\geq 1c$ modeling	+0.09	−0.11
JVT, pileup modeling	+0.03	−0.05
Other background modeling	+0.08	−0.08
$t\bar{t}$ + light modeling	+0.06	−0.03
Luminosity	+0.03	−0.02
Light lepton (e, μ) id., isolation, trigger	+0.03	−0.04
Total systematic uncertainty	+0.57	−0.54
$t\bar{t}+\geq 1b$ normalization	+0.09	−0.10
$t\bar{t}+\geq 1c$ normalization	+0.02	−0.03
Intrinsic statistical uncertainty	+0.21	−0.20
Total statistical uncertainty	+0.29	−0.29
Total uncertainty	+0.64	−0.61

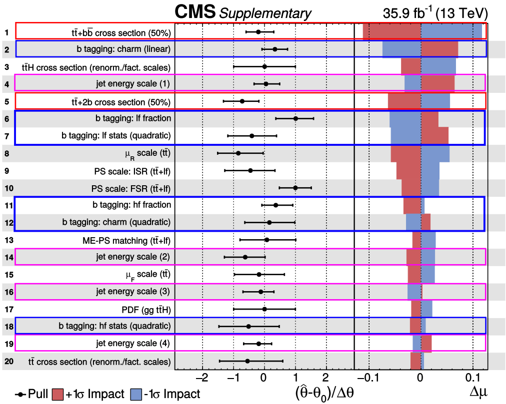
CMS

Uncertainty source	$\pm\Delta\mu$ (observed)
Total experimental	+0.15/−0.16
b tagging	+0.11/−0.14
jet energy scale and resolution	+0.06/−0.07
Total theory	+0.28/−0.29
tt̄+hf cross section and parton shower	+0.24/−0.28
Size of the simulated samples	+0.14/−0.15
Total systematic	+0.38/−0.38
Statistical	+0.24/−0.24
Total	+0.45/−0.45

- Total : ATLAS ±76% (35% stat, 68% syst), CMS ±63% (34% stat, 45% syst)
- Largest source : systematic uncertainties on $t\bar{t}+\mathrm{HF}$ modelling
- Other large sources : MC stat, $t\bar{t}H$ modelling, Data stat, b-tagging, JES & JER

Ranking plots





- In general : larger impact of experimental (modelling) systs. in CMS (ATLAS)
- CMS consider fewer shape uncertainties on $t\bar{t} + \mathrm{jets}$
- ATLAS has more $t\bar{t} + \mathrm{HF}$ modelling components

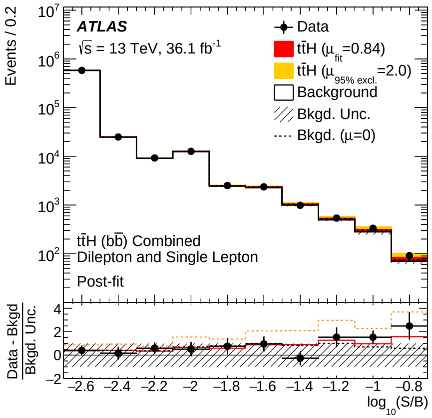
Conclusions

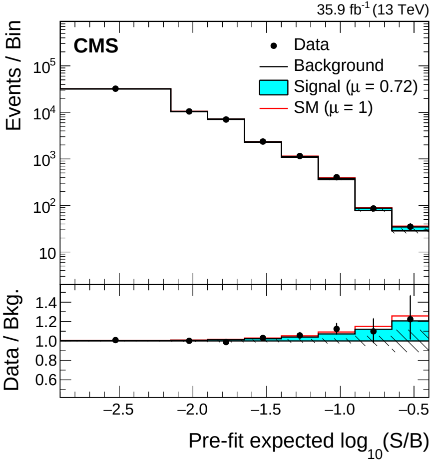
- Both collaborations are using the $b\bar{b}$ channel in their quest for $t\bar{t}H$
- Key ingredients : b-tagging, MVA techniques
- Very challenging $t\bar{t}+b\bar{b}$ background - largest uncertainty
  - $\rightarrow$ conversations between experiments about $t\bar{t}+b\bar{b}$ modelling and uncertainties
- Latest run-2 results use 2015+2016 dataset
  - $\rightarrow$ ATLAS : 76% on measured cross-section - 1.4(1.6) σ observed (expected)
  - $\rightarrow$ CMS : 63% on measured cross-section - 1.6(2.2) σ observed (expected)
- Combination with other channels with the same dataset :
  - $\rightarrow$ ATLAS : 29% on measured cross-section - Phys. Rev. D **97** (2018) 072003
  - $\rightarrow$ CMS : 26% on measured cross-section - CMS-PAS-HIG-17-031

Backup

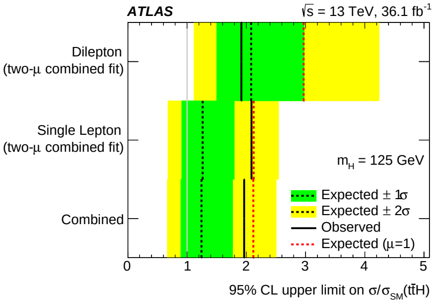
Backup

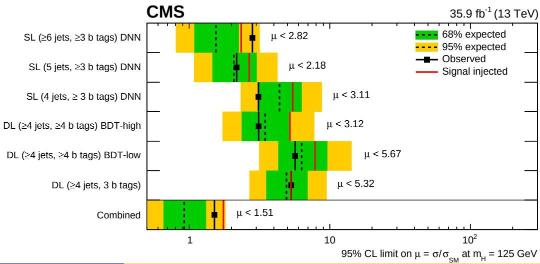
Distribution of final discriminant bins





Limits on the signal strength





ATLAS : variables in reconstruction BDT, 1ℓ

Variable	$SR^{\geq 6j}_{1,2,3}$	$SR^{5j}_{1,2}$
Topological information from $t\bar{t}$		
Mass of top_{lep}	✓	✓
Mass of top_{had}	✓	–
Mass of q_1 from W_{had} and b from top_{had}	–	✓
Mass of W_{had}	✓	–
Mass of W_{had} and b from top_{lep}	✓	–
Mass of q_1 from W_{had} and b from top_{lep}	–	✓
Mass of W_{lep} and b from top_{had}	✓	✓
$\Delta R(W_{had}, b \text{ from } top_{had})$	✓	–
$\Delta R(q_1 \text{ from } W_{had}, b \text{ from } top_{had})$	–	✓
$\Delta R(W_{had}, b \text{ from } top_{lep})$	✓	–
$\Delta R(q_1 \text{ from } W_{had}, b \text{ from } top_{lep})$	–	✓
$\Delta R(\ell, b \text{ from } top_{lep})$	✓	✓
$\Delta R(\ell, b \text{ from } top_{had})$	✓	✓
$\Delta R(b \text{ from } top_{lep}, b \text{ from } top_{had})$	✓	✓
$\Delta R(q_1 \text{ from } W_{had}, q_2 \text{ from } W_{had})$	✓	–
$\Delta R(b \text{ from } t_{had}, q_1 \text{ from } W_{had})$	✓	–
$\Delta R(b \text{ from } t_{had}, q_2 \text{ from } W_{had})$	✓	–
Min. $\Delta R(b \text{ from } top_{had}, q_i \text{ from } W_{had})$	✓	–
$\Delta R(\text{lep}, b \text{ from } top_{lep})$ - min. $\Delta R(b \text{ from } top_{had}, q_i \text{ from } W_{had})$	✓	✓
Topological information from the Higgs-boson candidate		
Mass of Higgs	✓	✓
Mass of Higgs and q_1 from W_{had}	✓	✓
$\Delta R(b_1 \text{ from Higgs}, b_2 \text{ from Higgs})$	✓	✓
$\Delta R(b_1 \text{ from Higgs, lepton})$	✓	✓
$\Delta R(b_1 \text{ from Higgs}, b \text{ from } top_{lep})$	–	✓
$\Delta R(b_1 \text{ from Higgs}, b \text{ from } top_{had})$	–	✓

ATLAS : variables in reconstruction BDT, 2ℓ

Variables	BDT with Higgs info. $\mathrm{SR}_{1,2}^{\geq 4j}$	BDT with Higgs info. $\mathrm{SR}_{3}^{\geq 4j}$	BDT w/o Higgs info. $\mathrm{SR}_{1,2}^{\geq 4j}$	BDT w/o Higgs info. $\mathrm{SR}_{3}^{\geq 4j}$
Topological information from $t\bar{t}$				
Mass of top	✓	✓	✓	✓
Mass of anti-top	✓	✓	✓	✓
Mass difference between top and anti-top	✓	✓	✓	✓
$\Delta R(\ell, b)$ from top	✓	✓	✓	✓
$\Delta R(\ell, b)$ from anti-top	✓	✓	✓	✓
—$\Delta R(\ell, b)$ from top - $\Delta R(\ell, b)$ from anti-top—	-	-	✓	✓
$\Delta\phi(b$ from top, b from anti-top)	-	✓	✓	✓
$\Delta R(b$ from top, b from anti-top)	✓	-	-	-
p_T b from top	-	-	✓	✓
p_T b from anti-top	-	-	✓	✓
Min. $\Delta\eta(\ell, b$ from top or anti-top)	-	-	✓	✓
Topological information from the Higgs-boson candidate				
Min. $\Delta R(b$ from Higgs, $\ell)$	-	✓	-	-
Max. ΔR(Higgs, b from top or anti-top)	✓	-	-	-
Mass of Higgs	✓	✓	-	-
$\Delta\phi$(Higgs,$t\bar{t}$)	-	✓	-	-
ΔR(Higgs,$t\bar{t}$)	✓	-	-	-
p_T b from Higgs with lowest b-tagging discriminant	-	✓	-	-
$\Delta R(b_1$ from Higgs, b_2 from Higgs)	✓	✓	-	-

ATLAS : PDFs used in likelihood discriminant, 1ℓ

$\mathrm{SR}^{\geq 6j}_{1,2,3}$	$\mathrm{SR}^{5j}_{1,2}$
$M_H(b_1, b_2)$	$M_H(b_1, b_2)$
$M_{t_l}(l, \nu, b_l)$	$M_{t_l}(l, \nu, b_l)$
$M_{W_h}(q_1, q_2)$	–
$[M_{t_h} - M_{W_h}](b_h, q_1, q_2)$	$M_{t_h}(b_h, q_1)$
$[M_{t_h t_l} - M_{t_h} - M_{t_l}](l, \nu, b_l, b_h, q_1, q_2)$	$[M_{t_h t_l} - M_{t_h} - M_{t_l}](l, \nu, b_l, b_h, q_1)$
$[M_{t_h t_l b_1 b_2} - M_{t_l t_h} - M_H](l, \nu, b_l, b_h, q_1, q_2, b_1, b_2)$	$[M_{t_h t_l b_1 b_2} - M_{t_l t_h} - M_H](l, \nu, b_l, b_h, q_1, b_1, b_2)$
$\cos\theta^*_{b_{1/2},H}(b_1, b_2)$	$\cos\theta^*_{b,H}(b_1, b_2)$
$\cos\theta^*_{b_1 b_2, t_h t_l b_1 b_2}(l, \nu, b_l, b_h, q_1, q_2, b_1, b_2)$	$\cos\theta^*_{b_1 b_2, t_h t_l b_1 b_2}(l, \nu, b_l, b_h, q_1, b_1, b_2)$

ATLAS : variables in classification BDT, 1ℓ (resolved)

Variable	Definition	$\mathrm{SR}^{\geq 6j}_{1,2,3}$	$\mathrm{SR}^{5j}_{1,2}$
General kinematic variables			
$\Delta R^{\text{avg}}_{bb}$	Average ΔR for all b-tagged jet pairs	✓	✓
$\Delta R^{\max p_T}_{bb}$	ΔR between the two b-tagged jets with the largest vector sum p_T	✓	–
$\Delta\eta^{\max}_{jj}$	Maximum $\Delta\eta$ between any two jets	✓	✓
$m^{\min \Delta R}_{bb}$	Mass of the combination of two b-tagged jets with the smallest ΔR	✓	–
$m^{\min \Delta R}_{jj}$	Mass of the combination of any two jets with the smallest ΔR	–	✓
$N^{\text{Higgs } 30}_{bb}$	Number of b-tagged jet pairs with invariant mass within 30 GeV of the Higgs-boson mass	✓	✓
H^{had}_{T}	Scalar sum of jet p_T	–	✓
$\Delta R^{\min}_{\ell,bb}$	ΔR between the lepton and the combination of the two b-tagged jets with the smallest ΔR	–	✓
Aplanarity	$1.5\lambda_2$, where λ_2 is the second eigenvalue of the momentum tensor [100] built with all jets	✓	✓
H_1	Second Fox–Wolfram moment computed using all jets and the lepton	✓	✓
Variables from reconstruction BDT			
BDT output	Output of the reconstruction BDT	✓*	✓*
m^{Higgs}_{bb}	Higgs candidate mass	✓	✓
$m_{H,b_{\text{lep top}}}$	Mass of Higgs candidate and b-jet from leptonic top candidate	✓	–
$\Delta R^{\text{Higgs}}_{bb}$	ΔR between b-jets from the Higgs candidate	✓	✓
$\Delta R_{H,t\bar{t}}$	ΔR between Higgs candidate and $t\bar{t}$ candidate system	✓*	✓*
$\Delta R_{H,\text{lep top}}$	ΔR between Higgs candidate and leptonic top candidate	✓	–
$\Delta R_{H,b_{\text{had top}}}$	ΔR between Higgs candidate and b-jet from hadronic top candidate	–	✓*
Variables from likelihood and matrix element method calculations			
LHD	Likelihood discriminant	✓	✓
MEM_{D1}	Matrix element discriminant (in $\mathrm{SR}^{\geq 6j}_{1}$ only)	✓	–
Variables from b-tagging (not in $\mathrm{SR}^{\geq 6j}_{1}$)			
$w^{\text{Higgs}}_{b\text{-tag}}$	Sum of b-tagging discriminants of jets from best Higgs candidate from the reconstruction BDT	✓	✓
B^{3}_{jet}	3^{rd} largest jet b-tagging discriminant	✓	✓
B^{4}_{jet}	4^{th} largest jet b-tagging discriminant	✓	✓
B^{5}_{jet}	5^{th} largest jet b-tagging discriminant	✓	✓

ATLAS : variables in classification BDT, 2ℓ

Variable	Definition	$SR_1^{\geq 4j}$	$SR_2^{\geq 4j}$	$SR_3^{\geq 4j}$
General kinematic variables				
$m_{bb}^{\min}$	Minimum invariant mass of a b-tagged jet pair	✓	✓	-
$m_{bb}^{\max}$	Maximum invariant mass of a b-tagged jet pair	-	-	✓
$m_{bb}^{\min\ \Delta R}$	Invariant mass of the b-tagged jet pair with minimum ΔR	✓	-	✓
$m_{jj}^{\max\ p_T}$	Invariant mass of the jet pair with maximum p_T	✓	-	-
$m_{bb}^{\max\ p_T}$	Invariant mass of the b-tagged jet pair with maximum p_T	✓	-	✓
$\Delta\eta_{bb}^{\mathrm{avg}}$	Average $\Delta\eta$ for all b-tagged jet pairs	✓	✓	✓
$\Delta\eta_{\ell,j}^{\max}$	Maximum $\Delta\eta$ between a jet and a lepton	-	✓	✓
$\Delta R_{bb}^{\max\ p_T}$	ΔR between the b-tagged jet pair with maximum p_T	-	✓	✓
$N_{bb}^{\mathrm{Higgs}\ 30}$	Number of b-tagged jet pairs with invariant mass within 30 GeV of the Higgs-boson mass	✓	✓	-
$n_{\mathrm{jets}}^{p_T>40}$	Number of jets with $p_T > 40$ GeV	-	✓	✓
$\mathrm{Aplanarity}_{b\text{-jet}}$	$1.5\lambda_2$, where λ_2 is the second eigenvalue of the momentum tensor [100] built with all b-tagged jets	-	✓	-
H_T^{all}	Scalar sum of p_T of all jets and leptons	-	-	✓
Variables from reconstruction BDT				
BDT output	Output of the reconstruction BDT	✓**	✓**	✓
m_{bb}^{Higgs}	Higgs candidate mass	✓	-	✓
$\Delta R_{H,t\bar{t}}$	ΔR between Higgs candidate and $t\bar{t}$ candidate system	✓*	-	-
$\Delta R_{H,\ell}^{\min}$	Minimum ΔR between Higgs candidate and lepton	✓	✓	✓
$\Delta R_{H,b}^{\min}$	Minimum ΔR between Higgs candidate and b-jet from top	✓	✓	-
$\Delta R_{H,b}^{\max}$	Maximum ΔR between Higgs candidate and b-jet from top	-	✓	-
$\Delta R_{bb}^{\mathrm{Higgs}}$	ΔR between the two jets matched to the Higgs candidate	-	✓	-
Variables from b-tagging				
$w_{b\text{-tag}}^{\mathrm{Higgs}}$	Sum of b-tagging discriminants of jets from best Higgs candidate from the reconstruction BDT	-	✓	-

ATLAS : variables in classification BDT, 1ℓ (boosted)

Variable	Definition
Variables from jet reclustering	
$\Delta R_{H,t}$	ΔR between the Higgs-boson and top-quark candidates
$\Delta R_{t,b^{\text{add}}}$	ΔR between the top-quark candidate and additional b-jet
$\Delta R_{H,b^{\text{add}}}$	ΔR between the Higgs-boson candidate and additional b-jet
$\Delta R_{H,\ell}$	ΔR between the Higgs-boson candidate and lepton
$m_{\text{Higgs candidate}}$	Higgs-boson candidate mass
$\sqrt{d_{12}}$	Top-quark candidate first splitting scale [101]
Variables from b-tagging	
$w_{b\text{-tag}}$	Sum of b-tagging discriminants of all b-jets
$w^{\text{add}}_{b\text{-tag}}/w_{b\text{-tag}}$	Ratio of sum of b-tagging discriminants of additional b-jets to all b-jets

CMS : variables in the DNN or BDT (1/3)

Variable	Definition	SL (4 jets, $\geq$ 3 b tags)	SL (5 jets, $\geq$ 3 b tags)	SL ($\geq$ 6 jets, $\geq$ 3 b tags)	DL ($\geq$ 4 jets, 3 b tags)	DL ($\geq$ 4 jets, $\geq$ 4 b tags)
p_T(jet 1)	p_T of the highest-p_T jet	+	+	-	-	-
η(jet 1)	η of the highest-p_T jet	-	+	+	-	-
d(jet 1)	b tagging discriminant of the highest-p_T jet	+	+	+	-	-
p_T(jet 2)	p_T of the second highest-p_T jet	-	+	-	-	-
η(jet 2)	η of the second highest-p_T jet	+	+	+	-	-
d(jet 2)	b tagging discriminant of the second highest-p_T jet	+	+	+	-	-
p_T(jet 3)	p_T of the third highest-p_T jet	-	+	-	-	-
η(jet 3)	η of the third highest-p_T jet	+	+	+	-	-
d(jet 3)	b tagging discriminant of the third highest-p_T jet	+	+	+	-	-
p_T(jet 4)	p_T of the fourth highest-p_T jet	+	+	-	-	-
η(jet 4)	η of the fourth highest-p_T jet	+	+	+	-	-
d(jet 4)	b tagging discriminant of the fourth highest-p_T jet	+	-	+	-	-
p_T(lep 1)	p_T of the highest-p_T lepton	-	+	+	-	-
η(lep 1)	η of the highest-p_T lepton	+	-	+	-	-
d_j^{avg}	average b tagging discriminant value of all jets	+	+	+	-	-
d_b^{avg}	average b tagging discriminant value of b-tagged jets	+	+	+	+	+
$d_{non\text{-}b}^{avg}$	average b tagging discriminant value of non-b-tagged jets	-	-	-	+	+
$\sum_b (d - d_b^{avg})$	squared difference between the b tagging discriminant value of a b-tagged jet and the average b tagging discriminant values of all b-tagged jets, summed over all b-tagged jets	+	+	+	-	-
d_j^{max}	maximal b tagging discriminant value of all jets	+	+	+	-	-
d_b^{max}	maximal b tagging discriminant value of b-tagged jets	+	+	+	-	-
d_j^{min}	minimal b tagging discriminant value of all jets	+	+	+	-	-
d_j^{min}	minimal b tagging discriminant value of b-tagged jets	+	+	+	-	-
d_2	second highest b tagging discriminant value of all jets	+	+	+	-	-

CMS : variables in the DNN or BDT (2/3)

Variable	Definition	SL (4 jets, ≥ 3 b tags)	SL (5 jets, ≥ 3 b tags)	SL (≥ 6 jets, ≥ 3 b tags)	DL (≥ 4 jets, 3 b tags)	DL (≥ 4 jets, ≥ 4 b tags)
N_b(tight)	number of b-tagged jets at a working point with a 0.1% probability of tagging gluon and light-flavour jets	+	+	+	-	-
BLR	likelihood ratio discriminating between 4 b quark jets and 2 b quark jets events	+	+	+	-	-
$\text{BLR}^{\text{trans}}$	transformed BLR defined as $\ln[\text{BLR}/(1.0-\text{BLR})]$	+	+	+	-	-
$\Delta R^{\text{min}}_{\text{j,j}}$	ΔR between the two closest jets	+	+	+	-	-
$\Delta R^{\text{min}}_{\text{b,b}}$	ΔR between the two closest b-tagged jets	+	+	+	-	-
$\Delta R^{\text{max}}_{\text{j,j}}$	ΔR between the two jets furthest apart	-	+	-	-	-
$\Delta R^{\text{max}}_{\text{b,b}}$	ΔR between the two b-tagged jets furthest apart	-	-	+	-	-
$\Delta \eta^{\text{max}}_{\text{j,j}}$	$\Delta \eta$ between the two jets furthest apart in η	-	-	-	-	+
$\Delta \eta^{\text{max}}_{\text{b,b}}$	$\Delta \eta$ between the two b-tagged jets furthest apart in η	-	-	-	+	+
$\Delta \eta^{\text{avg}}_{\text{b,b}}$	average $\Delta \eta$ between b-tagged jets	-	-	+	-	-
$\Delta R^{\text{avg}}_{\text{b,b}}$	average ΔR between b-tagged jets	-	+	+	-	-
$\Delta R^{\text{avg}}_{\text{j,b}}$	average ΔR between jets of which at least one is b-tagged	-	-	-	+	-
$\Delta R^{\text{min}\Delta R}_{\text{lep,j}}$	ΔR between lepton and closest jet	+	+	-	-	-
$\Delta R^{\text{min}\Delta R}_{\text{lep,b}}$	ΔR between lepton and closest b-tagged jet	-	+	+	-	-
$m^{\text{min}\Delta R}_{\text{lep,b}}$	mass of lepton and closest b-tagged jet	+	+	+	-	-
$m^{\text{min}\Delta R}_{\text{b,b}}$	mass of closest b-tagged jets	+	+	+	-	+
$m^{\text{min}\Delta R}_{\text{j,b}}$	mass of closest jets of which at least one is b-tagged	-	-	-	+	-
$m^{\text{max mass}}_{\text{b,b}}$	maximal mass of pairs of b-tagged jets	-	-	-	+	+
$p_{\text{T}}{}^{\text{min}\Delta R}_{\text{b,b}}$	combined p_{T} of closest b-tagged jets	-	-	-	+	-
$p_{\text{T}}{}^{\text{min}\Delta R}_{\text{j,b}}$	combined p_{T} of closest jets of which at least one is b-tagged	-	-	-	-	+
$m^{\text{avg}}_{\text{j}}$	average mass of all jets	+	+	+	-	-
$(m^2)^{\text{avg}}_{\text{b}}$	average squared mass of all b-tagged jets	+	-	+	-	-
$m^{\text{closest to 125}}_{\text{b,b}}$	mass of pair of b-tagged jets closest to 125 GeV	-	+	+	-	-
$N^{\text{j,j}}$	number of pairs of b-tagged jets with an invariant mass within 15 GeV of 125 GeV	-	-	-	+	+
MEM	matrix element method discriminant	+	+	+	-	-

CMS : variables in the DNN or BDT (3/3)

Variable	Definition	SL (4 jets, ≥ 3 b tags)	SL (5 jets, ≥ 3 b tags)	SL (≥ 6 jets, ≥ 3 b tags)	DL (≥ 4 jets, 3 b tags)	DL (≥ 4 jets, ≥ 4 b tags)
H_T^j	scalar sum of jet p_T	-	+	-	+	-
H_T^b	scalar sum of b-tagged jet p_T	+	+	+	-	-
A^j	$\frac{3}{2}\lambda_3$ where λ_i are the eigenvalues of the momentum tensor built with jets [?]	-	+	+	-	-
A^b	$\frac{3}{2}\lambda_3$ where λ_i are the eigenvalues of the momentum tensor built with b-tagged jets [?]	+	+	+	-	-
C^j	H_T^j divided by the sum of the energies of all jets	-	-	+	-	-
C^b	H_T^b divided by the sum of the energies of all b-tagged jets	-	-	+	-	+
S^j	$\frac{3}{2}(\lambda_2+\lambda_3)$ where λ_i are the eigenvalues of the momentum tensor built with jets [?]	+	+	+	-	-
S^b	$\frac{3}{2}(\lambda_2+\lambda_3)$ where λ_i are the eigenvalues of the momentum tensor built with b-tagged jets [?]	-	+	+	-	-
S_T^j	$\frac{2\lambda_2}{\lambda_2+\lambda_1}$ where λ_i are the eigenvalues of the momentum tensor built with jets [?]	+	+	+	-	-
S_T^b	$\frac{2\lambda_2}{\lambda_2+\lambda_1}$ where λ_i are the eigenvalues of the momentum tensor built with b-tagged jets [?]	+	+	+	-	-
I^b	a measure of how spherical or linear in $r-\phi$ space b-tagged jets are in the event	-	-	-	+	-
H_2	second Fox–Wolfram moment [?]	-	+	-	-	-
H_3	third Fox–Wolfram moment [?]	+	+	-	-	-
H_3^b	third Fox–Wolfram moment calculated with b-tagged jets [?]	-	-	-	-	+
R_3	ratio of Fox–Wolfram moments H_3/H_0 [?]	-	-	-	+	-
H_4	fourth Fox–Wolfram moment [?]	+	-	+	-	-

Detailed list of uncertainties

Systematic uncertainty	Type	Comp.
Experimental uncertainties		
Luminosity	N	1
Pileup modeling	SN	1
Physics Objects		
Electron	SN	6
Muon	SN	15
Taus	SN	3
Jet energy scale	SN	20
Jet energy resolution	SN	2
Jet vertex tagger	SN	1
E_T^{miss}	SN	3
b-tagging		
Efficiency	SN	30
Mis-tag rate (c)	SN	15
Mis-tag rate (light)	SN	80
Mis-tag rate (extrapolation $c \to \tau$)	SN	1
Signal and background modeling		
Signal		
$t\bar{t}H$ cross-section	N	2
H branching fractions	N	3
$t\bar{t}H$ modeling	SN	1
$t\bar{t}$ Background		
$t\bar{t}$ cross-section	N	1
$t\bar{t} + \geq 1c$ normalization	N (free floating)	1
$t\bar{t} + \geq 1b$ normalization	N (free floating)	1
$t\bar{t}$ + light modeling	SN	3
$t\bar{t} + \geq 1c$ modeling	SN	4
$t\bar{t} + \geq 1b$ modeling	SN	13
Other Backgrounds		
$t\bar{t}W$ cross-section	N	2
$t\bar{t}Z$ cross-section	N	2
$t\bar{t}W$ modeling	SN	1
$t\bar{t}Z$ modeling	SN	1
Single top cross-section	N	3
Single top modeling	SN	5
W+jets normalization	N	3
Z+jets normalization	N	3
Diboson normalization	N	1
Fakes and non-prompt normalization	N	7
$t\bar{t}t\bar{t}$ cross-section	N	1
Small background cross-sections	N	9

ATLAS

Source	Type	Remarks
Integrated luminosity	rate	Signal and all backgrounds
Lepton identification/isolation	shape	Signal and all backgrounds
Trigger efficiency	shape	Signal and all backgrounds
Pileup	shape	Signal and all backgrounds
Jet energy scale	shape	Signal and all backgrounds
Jet energy resolution	shape	Signal and all backgrounds
b tag hf fraction	shape	Signal and all backgrounds
b tag hf stats (linear)	shape	Signal and all backgrounds
b tag hf stats (quadratic)	shape	Signal and all backgrounds
b tag lf fraction	shape	Signal and all backgrounds
b tag lf stats (linear)	shape	Signal and all backgrounds
b tag lf stats (quadratic)	shape	Signal and all backgrounds
b tag charm (linear)	shape	Signal and all backgrounds
b tag charm (quadratic)	shape	Signal and all backgrounds
Renorm./fact. scales (tt̄H)	rate	Scale uncertainty of NLO tt̄H prediction
Renorm./fact. scales (tt̄)	rate	Scale uncertainty of NLO tt̄ prediction
Renorm./fact. scales (tt̄+hf)	rate	Additional 50% rate uncertainty of tt̄+hf predictions
Renorm./fact. scales (t)	rate	Scale uncertainty of NLO single t prediction
Renorm./fact. scales (V)	rate	Scale uncertainty of NNLO W and Z prediction
Renorm./fact. scales (VV)	rate	Scale uncertainty of NLO diboson prediction
PDF (gg)	rate	PDF uncertainty for gg initiated processes except tt̄H
PDF (gg tt̄H)	rate	PDF uncertainty for tt̄H
PDF (qq̄)	rate	PDF uncertainty of qq̄ initiated processes (tt̄+W,W,Z)
PDF (qg)	rate	PDF uncertainty of qg initiated processes (single t)
μ_R scale (tt̄)	shape	Renormalisation scale uncertainty of the tt̄ ME generator, independent for additional jet flavours
μ_F scale (tt̄)	shape	Factorisation scale uncertainty of the tt̄ ME generator, independent for additional jet flavours
PS scale: ISR (tt̄)	rate	Initial state radiation uncertainty of the PS (for tt̄ events), jet multiplicity dependent rate uncertainty, independent for additional jet flavours
PS scale: FSR (tt̄)	rate	Final state radiation uncertainty (for tt̄ events), jet multiplicity dependent rate uncertainty, independent for additional jet flavours
ME-PS matching (tt̄)	rate	NLO ME to PS matching, *hdamp* [?] (for tt̄ events), jet multiplicity dependent rate uncertainty, independent for additional jet flavours
Underlying event (tt̄)	rate	Underlying event (for tt̄ events), jet multiplicity dependent rate uncertainty, independent for additional jet flavours
NNPDF3.0NLO (tt̄H, tt̄)	shape	Based on the NNPDF replicas, same for tt̄H and additional jet flavours
Bin-by-bin event count	shape	Statistical uncertainty of the signal and background prediction due to the limited sample size

CMS

ATLAS : pre-and post-fit yields, 1ℓ (resolved)

Sample	$CR^{5j}_{t\bar{t}+light}$ Pre-fit	$CR^{5j}_{t\bar{t}+light}$ Post-fit	$CR^{5j}_{t\bar{t}+\geq 1c}$ Pre-fit	$CR^{5j}_{t\bar{t}+\geq 1c}$ Post-fit	$CR^{5j}_{t\bar{t}+b}$ Pre-fit	$CR^{5j}_{t\bar{t}+b}$ Post-fit
$t\bar{t}H$	224 ± 22	190 ± 140	18.7 ± 2.5	15 ± 12	68.0 ± 7.6	57 ± 42
$t\bar{t}$ + light	197 000 ± 26 000	179 900 ± 4900	2580 ± 720	2300 ± 210	4250 ± 920	3560 ± 240
$t\bar{t} + \geq 1c$	27 500 ± 4300	44 100 ± 5500	1280 ± 500	1840 ± 250	1770 ± 270	2590 ± 390
$t\bar{t} + \geq 1b$	11 300 ± 1100	13 500 ± 1300	790 ± 130	944 ± 94	3400 ± 440	4030 ± 320
$t\bar{t} + V$	589 ± 55	584 ± 54	23.2 ± 4.1	21.3 ± 2.9	48.1 ± 5.9	46.6 ± 5.4
Non-$t\bar{t}$	21 300 ± 4100	20 900 ± 3200	520 ± 180	440 ± 100	960 ± 190	860 ± 160
Total	258 000 ± 29 000	259 320 ± 910	5200 ± 1100	5560 ± 160	10 400 ± 1300	11 140 ± 290
Data	259 320		5465		11 095	

Sample	SR^{5j}_{2} Pre-fit	SR^{5j}_{2} Post-fit	SR^{5j}_{1} Pre-fit	SR^{5j}_{1} Post-fit	$SR^{boosted}$ Pre-fit	$SR^{boosted}$ Post-fit
$t\bar{t}H$	40.1 ± 5.1	34 ± 25	15.9 ± 2.1	13.3 ± 9.8	16.9 ± 1.9	14 ± 10
$t\bar{t}$ + light	500 ± 210	393 ± 67	15 ± 33	12.5 ± 9.3	180 ± 120	112 ± 32
$t\bar{t} + \geq 1c$	436 ± 92	610 ± 100	30 ± 17	28 ± 14	168 ± 70	235 ± 39
$t\bar{t} + \geq 1b$	1230 ± 200	1450 ± 110	273 ± 53	335 ± 25	236 ± 89	229 ± 33
$t\bar{t} + V$	19.9 ± 2.9	19.7 ± 2.4	6.4 ± 1.3	6.4 ± 1.2	16.1 ± 2.9	16.6 ± 2.4
Non-$t\bar{t}$	269 ± 64	220 ± 52	54 ± 11	28.1 ± 8.4	104 ± 30	101 ± 26
Total	2440 ± 390	2724 ± 70	371 ± 68	423 ± 23	710 ± 200	708 ± 40
Data	2798		426		740	

ATLAS : pre-and post-fit yields, 2ℓ

Sample	$\mathrm{CR}^{3j}_{t\bar{t}+\mathrm{light}}$ Pre-fit	$\mathrm{CR}^{3j}_{t\bar{t}+\mathrm{light}}$ Post-fit	$\mathrm{CR}^{3j}_{t\bar{t}+\geq 1b}$ Pre-fit	$\mathrm{CR}^{3j}_{t\bar{t}+\geq 1b}$ Post-fit	$\mathrm{CR}^{\geq 4j}_{t\bar{t}+\mathrm{light}}$ Pre-fit	$\mathrm{CR}^{\geq 4j}_{t\bar{t}+\mathrm{light}}$ Post-fit	$\mathrm{CR}^{\geq 4j}_{t\bar{t}+\geq 1c}$ Pre-fit	$\mathrm{CR}^{\geq 4j}_{t\bar{t}+\geq 1c}$ Post-fit
$t\bar{t}H$	32.2 ± 3.8	27 ± 20	8.7 ± 1.1	7.3 ± 5.4	114 ± 11	95 ± 70	35.3 ± 3.6	29 ± 22
$t\bar{t}$ + light	63 100 ± 5500	59 100 ± 1400	290 ± 110	255 ± 44	42 500 ± 9700	37 100 ± 1300	1730 ± 730	1410 ± 180
$t\bar{t} + \geq 1c$	4800 ± 2100	7700 ± 1100	360 ± 160	536 ± 89	6300 ± 2800	10 300 ± 1400	1410 ± 590	2160 ± 290
$t\bar{t} + \geq 1b$	2130 ± 230	2620 ± 240	710 ± 140	848 ± 75	2510 ± 280	2850 ± 290	1080 ± 120	1240 ± 110
$t\bar{t} + V$	113 ± 31	112 ± 29	7 ± 27	7 ± 30	350 ± 180	330 ± 170	52 ± 41	50 ± 39
Non-$t\bar{t}$	6300 ± 1500	6500 ± 1200	110 ± 29	112 ± 23	4700 ± 1100	4930 ± 910	420 ± 120	460 ± 100
Total	76 400 ± 6500	76 010 ± 390	1500 ± 260	1765 ± 60	56 000 ± 11 000	55 650 ± 420	4700 ± 1100	5350 ± 120
Data	76 025		1744		55 627		5389	

Sample	$\mathrm{SR}^{\geq 4j}_{3}$ Pre-fit	$\mathrm{SR}^{\geq 4j}_{3}$ Post-fit	$\mathrm{SR}^{\geq 4j}_{2}$ Pre-fit	$\mathrm{SR}^{\geq 4j}_{2}$ Post-fit	$\mathrm{SR}^{\geq 4j}_{1}$ Pre-fit	$\mathrm{SR}^{\geq 4j}_{1}$ Post-fit
$t\bar{t}H$	21.9 ± 2.5	18 ± 13	29.1 ± 4.2	25 ± 18	15.6 ± 2.5	12.9 ± 9.5
$t\bar{t}$ + light	83 ± 41	95 ± 30	250 ± 110	215 ± 43	6.4 ± 9.9	11.1 ± 9.3
$t\bar{t} + \geq 1c$	235 ± 61	313 ± 53	340 ± 210	427 ± 89	12.6 ± 9.4	25.8 ± 7.8
$t\bar{t} + \geq 1b$	819 ± 85	917 ± 71	590 ± 96	669 ± 59	247 ± 61	263 ± 20
$t\bar{t} + V$	15 ± 35	15 ± 34	22 ± 38	22 ± 39	7 ± 56	7 ± 57
Non-$t\bar{t}$	75 ± 17	78 ± 16	115 ± 36	121 ± 29	13.6 ± 3.8	14.6 ± 3.8
Total	1250 ± 140	1436 ± 55	1350 ± 320	1479 ± 66	302 ± 85	334 ± 59
Data	1467		1444		319	

ATLAS : pre-and post-fit yields, 1ℓ (boosted)

Sample	$CR^{\geq 6j}_{t\bar{t}+light}$ Pre-fit	$CR^{\geq 6j}_{t\bar{t}+light}$ Post-fit	$CR^{\geq 6j}_{t\bar{t}+\geq 1c}$ Pre-fit	$CR^{\geq 6j}_{t\bar{t}+\geq 1c}$ Post-fit	$CR^{\geq 6j}_{t\bar{t}+b}$ Pre-fit	$CR^{\geq 6j}_{t\bar{t}+b}$ Post-fit
$t\bar{t}H$	450 ± 48	370 ± 280	102 ± 13	87 ± 64	100 ± 12	83 ± 61
$t\bar{t}$ + light	125 000 ± 34 000	108 200 ± 4300	4300 ± 2000	3350 ± 430	2220 ± 520	1820 ± 170
$t\bar{t} + \geq 1c$	28 400 ± 7200	45 700 ± 5100	3600 ± 1300	5300 ± 680	1460 ± 330	2080 ± 300
$t\bar{t} + \geq 1b$	13 100 ± 1800	14 600 ± 1400	2660 ± 540	2950 ± 280	3670 ± 500	4080 ± 320
$t\bar{t} + V$	1010 ± 120	996 ± 91	118 ± 21	118 ± 14	70.5 ± 8.5	67.9 ± 7.2
Non-$t\bar{t}$	12 600 ± 3000	11 800 ± 2000	1060 ± 340	1000 ± 210	710 ± 160	600 ± 110
Total	181 000 ± 39 000	181 690 ± 860	11 800 ± 3200	12 810 ± 260	8200 ± 1100	8730 ± 230
Data	181 706		12 778		8576	

Sample	$SR^{\geq 6j}_{3}$ Pre-fit	$SR^{\geq 6j}_{3}$ Post-fit	$SR^{\geq 6j}_{2}$ Pre-fit	$SR^{\geq 6j}_{2}$ Post-fit	$SR^{\geq 6j}_{1}$ Pre-fit	$SR^{\geq 6j}_{1}$ Post-fit
$t\bar{t}H$	85 ± 10	71 ± 52	81 ± 10	68 ± 50	62 ± 11	51 ± 38
$t\bar{t}$ + light	750 ± 370	586 ± 98	210 ± 210	96 ± 33	14 ± 10	12.1 ± 5.8
$t\bar{t} + \geq 1c$	880 ± 350	1330 ± 190	350 ± 100	473 ± 99	53 ± 33	44 ± 20
$t\bar{t} + \geq 1b$	2100 ± 420	2290 ± 170	1750 ± 370	1850 ± 130	1010 ± 240	1032 ± 59
$t\bar{t} + V$	51.2 ± 7.4	50.8 ± 5.9	40.8 ± 5.7	40.3 ± 4.8	25.8 ± 3.7	25.3 ± 3.2
Non-$t\bar{t}$	303 ± 82	267 ± 63	155 ± 52	134 ± 46	75 ± 20	58 ± 17
Total	4140 ± 850	4590 ± 110	2550 ± 510	2657 ± 82	1220 ± 250	1223 ± 42
Data	4698		2641		1222	

CMS : pre-and post-fit yields, 1ℓ ($\geq 4j$, $\geq 3b$)

Process	pre-fit (post-fit) yields					
	$t\bar{t}$H node	$t\bar{t}$+$b\bar{b}$ node	$t\bar{t}$+2b node	$t\bar{t}$+b node	$t\bar{t}$+$c\bar{c}$ node	$t\bar{t}$+lf node
$t\bar{t}$+lf	1249 (962)	727 (572)	1401 (1090)	1035 (823)	2909 (2296)	8463 (6829)
$t\bar{t}$+$c\bar{c}$	298 (458)	232 (359)	428 (678)	251 (400)	686 (1068)	1022 (1652)
$t\bar{t}$+b	253 (356)	215 (311)	370 (530)	326 (484)	308 (437)	469 (683)
$t\bar{t}$+2b	124 (96)	77 (62)	317 (254)	90 (73)	100 (79)	134 (108)
$t\bar{t}$+$b\bar{b}$	139 (137)	191 (192)	149 (140)	105 (103)	119 (114)	133 (128)
Single t	96 (96)	117 (109)	167 (162)	93 (96)	231 (232)	304 (307)
V+jets	37 (37)	76 (74)	48 (46)	27 (27)	97 (89)	69 (69)
$t\bar{t}$+V	13 (13)	6 (6)	12 (11)	6 (6)	10 (10)	16 (16)
Diboson	4 (4)	5 (5)	0.9 (0.8)	0.6 (0.7)	2 (2)	4 (4)
Total bkg.	2213 (2158)	1645 (1688)	2892 (2911)	1935 (2012)	4462 (4328)	10614 (9795)
± tot unc.	±508 (±58)	±415 (±53)	±588 (±89)	±402 (±67)	±1051 (±120)	±2359 (±270)
$t\bar{t}$H	27 (21)	9 (7)	16 (12)	7 (5)	9 (7)	16 (13)
± tot unc.	±4 (±3)	±1 (±1)	±2 (±2)	±1 (±1)	±1 (±1)	±2 (±2)
Data	2125	1793	2896	2027	4366	9693

CMS : pre-and post-fit yields, 1ℓ ($\geq 5j$, $\geq 3b$)

	pre-fit (post-fit) yields					
Process	$t\bar{t}H$ node	$t\bar{t}+b\bar{b}$ node	$t\bar{t}+2b$ node	$t\bar{t}+b$ node	$t\bar{t}+c\bar{c}$ node	$t\bar{t}+lf$ node
$t\bar{t}+lf$	785 (570)	647 (467)	830 (604)	683 (525)	1148 (848)	4903 (3697)
$t\bar{t}+c\bar{c}$	336 (455)	341 (469)	445 (633)	264 (382)	552 (756)	1207 (1726)
$t\bar{t}+b$	257 (351)	290 (399)	355 (494)	321 (477)	219 (301)	494 (692)
$t\bar{t}+2b$	136 (104)	128 (99)	324 (253)	89 (73)	85 (65)	184 (143)
$t\bar{t}+b\bar{b}$	266 (251)	410 (397)	224 (207)	150 (143)	144 (132)	228 (212)
Single t	62 (63)	82 (84)	98 (96)	45 (58)	114 (113)	189 (193)
V+jets	25 (23)	54 (53)	34 (31)	11 (12)	46 (41)	54 (51)
$t\bar{t}+V$	20 (20)	14 (13)	17 (16)	7 (7)	11 (10)	25 (24)
Diboson	1 (1)	3 (3)	0.4 (0.4)	— (—)	0.6 (0.4)	3 (3)
Total bkg.	1889 (1838)	1969 (1985)	2326 (2332)	1570 (1676)	2320 (2268)	7287 (6742)
± tot unc.	±459 (±57)	±485 (±70)	±489 (±71)	±334 (±47)	±597 (±79)	±1655 (±219)
$t\bar{t}H$	53 (41)	21 (17)	20 (15)	8 (6)	11 (8)	28 (22)
± tot unc.	±7 (±6)	±3 (±3)	±2 (±2)	±1 (±1)	±1 (±1)	±3 (±3)
Data	1848	2040	2299	1690	2302	6918

CMS : pre-and post-fit yields, 1ℓ ($\geq 6j$, $\geq 3b$)

Process	$t\bar{t}$H node	$t\bar{t}$+$b\bar{b}$ node	$t\bar{t}$+2b node	$t\bar{t}$+b node	$t\bar{t}$+$c\bar{c}$ node	$t\bar{t}$+lf node
	pre-fit (post-fit) yields					
$t\bar{t}$+lf	1982 (1381)	1280 (897)	852 (595)	916 (661)	243 (172)	50 (36)
$t\bar{t}$+$c\bar{c}$	1150 (1415)	998 (1230)	636 (805)	444 (567)	115 (147)	16 (19)
$t\bar{t}$+b	549 (705)	575 (746)	314 (409)	253 (338)	28 (35)	4 (5)
$t\bar{t}$+2b	306 (233)	282 (215)	372 (293)	78 (62)	10 (8)	1 (0.8)
$t\bar{t}$+$b\bar{b}$	834 (769)	1156 (1082)	299 (266)	145 (129)	17 (15)	3 (2)
Single t	110 (116)	146 (145)	92 (82)	53 (53)	4 (4)	3 (3)
V+jets	38 (37)	78 (76)	34 (30)	10 (9)	7 (6)	0.6 (0.6)
$t\bar{t}$+V	80 (75)	58 (54)	31 (28)	11 (11)	4 (4)	0.4 (0.4)
Diboson	0.9 (0.9)	0.5 (0.5)	0.4 (0.4)	0.4 (0.4)	— (—)	— (—)
Total bkg.	5049 (4733)	4575 (4447)	2629 (2509)	1911 (1831)	429 (392)	77 (67)
$\pm$ tot unc.	$\pm$1216 ($\pm$186)	$\pm$1156 ($\pm$142)	$\pm$603 ($\pm$80)	$\pm$422 ($\pm$65)	$\pm$107 ($\pm$14)	$\pm$18 ($\pm$3)
$t\bar{t}$H	142 (108)	53 (40)	24 (18)	10 (7)	2.1 (1.5)	0.30 (0.23)
$\pm$ tot unc.	$\pm$19 ($\pm$15)	$\pm$8 ($\pm$6)	$\pm$3 ($\pm$2)	$\pm$1 ($\pm$1)	$\pm$0.2 ($\pm$0.2)	$\pm$0.03 ($\pm$0.03)
Data	4822	4400	2484	1852	422	76

CMS : pre-and post-fit yields, 2ℓ

Process	pre-fit (post-fit) yields					
	$\geq$ 4 jets, 3 b tags		$\geq$ 4 jets, $\geq$ 4 b tags			
			BDT-low		BDT-high	
$t\bar{t}$+lf	845	(637)	16	(11)	0.7	(0.5)
$t\bar{t}$+$c\bar{c}$	712	(966)	25	(31)	3	(4)
$t\bar{t}$+b	546	(747)	26	(35)	4	(6)
$t\bar{t}$+2b	252	(196)	11	(8)	2	(1)
$t\bar{t}$+$b\bar{b}$	439	(415)	103	(109)	33	(32)
Single t	47	(51)	5	(3)	1	(2)
V+jets	10	(8)	—	(—)	—	(—)
$t\bar{t}$+V	40	(38)	4	(4)	2	(2)
Diboson	0.9	(0.7)	—	(—)	—	(—)
Total bkg.	2893	(3058)	190	(201)	46	(48)
$\pm$ tot unc.	$\pm$705	($\pm$98)	$\pm$67	($\pm$10)	$\pm$17	($\pm$3)
$t\bar{t}$H	42	(32)	6	(5)	6	(5)
$\pm$ tot unc.	$\pm$6	($\pm$5)	$\pm$1	($\pm$1)	$\pm$1	($\pm$1)
Data	3077		207		58	