ATLAS (t)tH searches

on behalf of the
ATLAS collaboration

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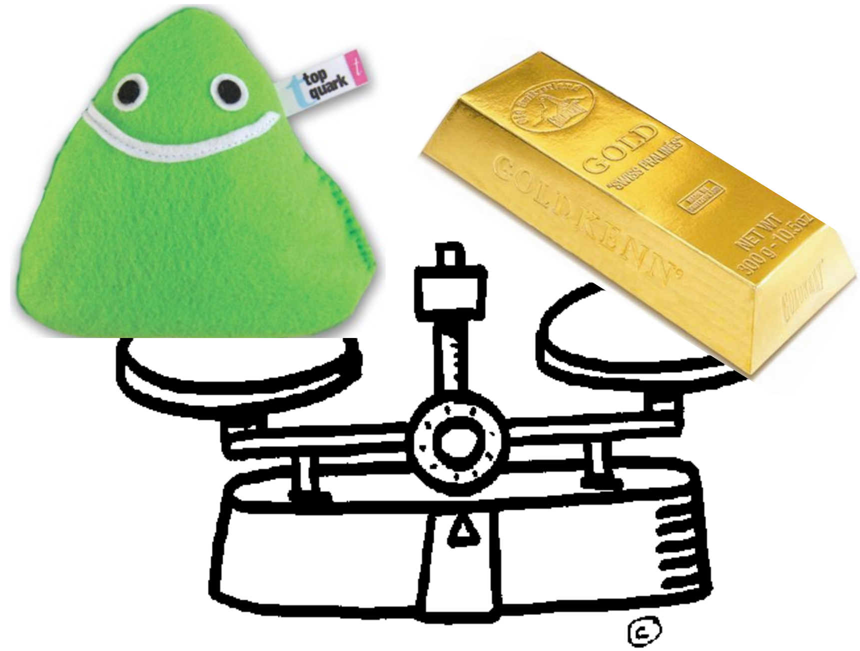
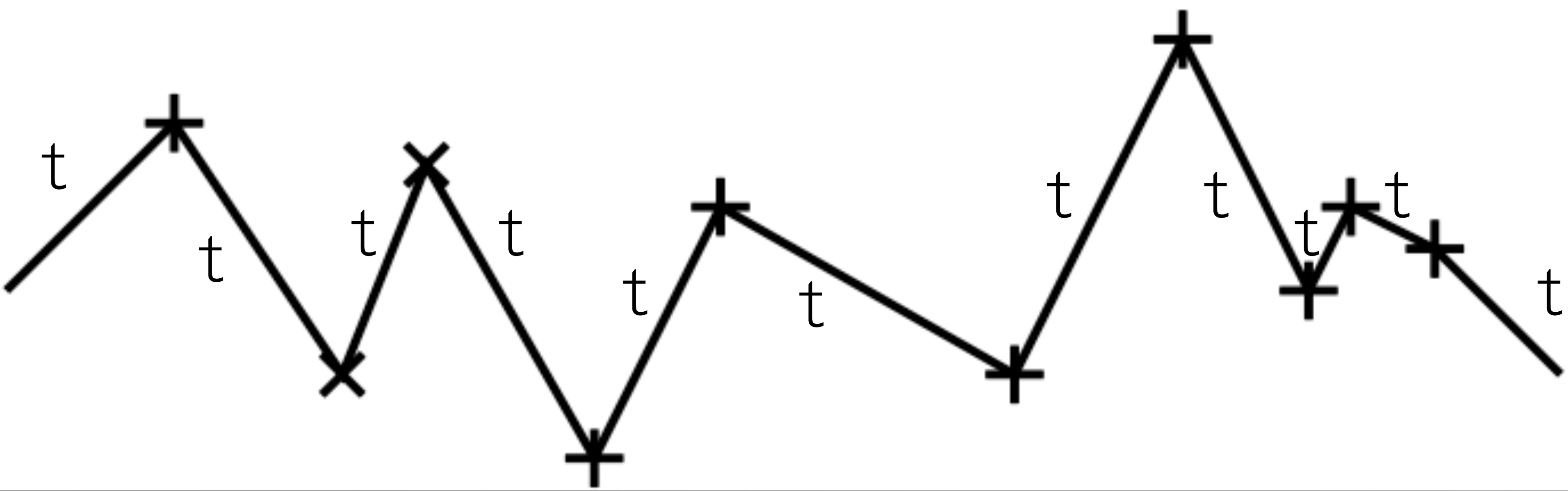
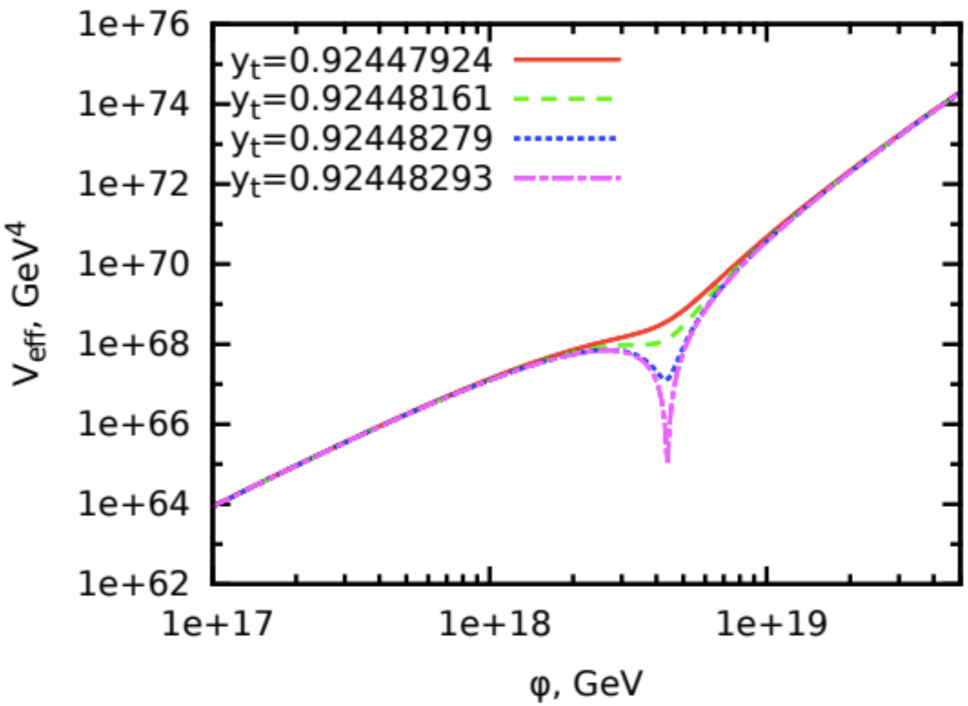
Top quark: Large Yukawa coupling near unity, the only fermion with such a natural coupling. Does this point to a special role in EWSB or BSM physics?





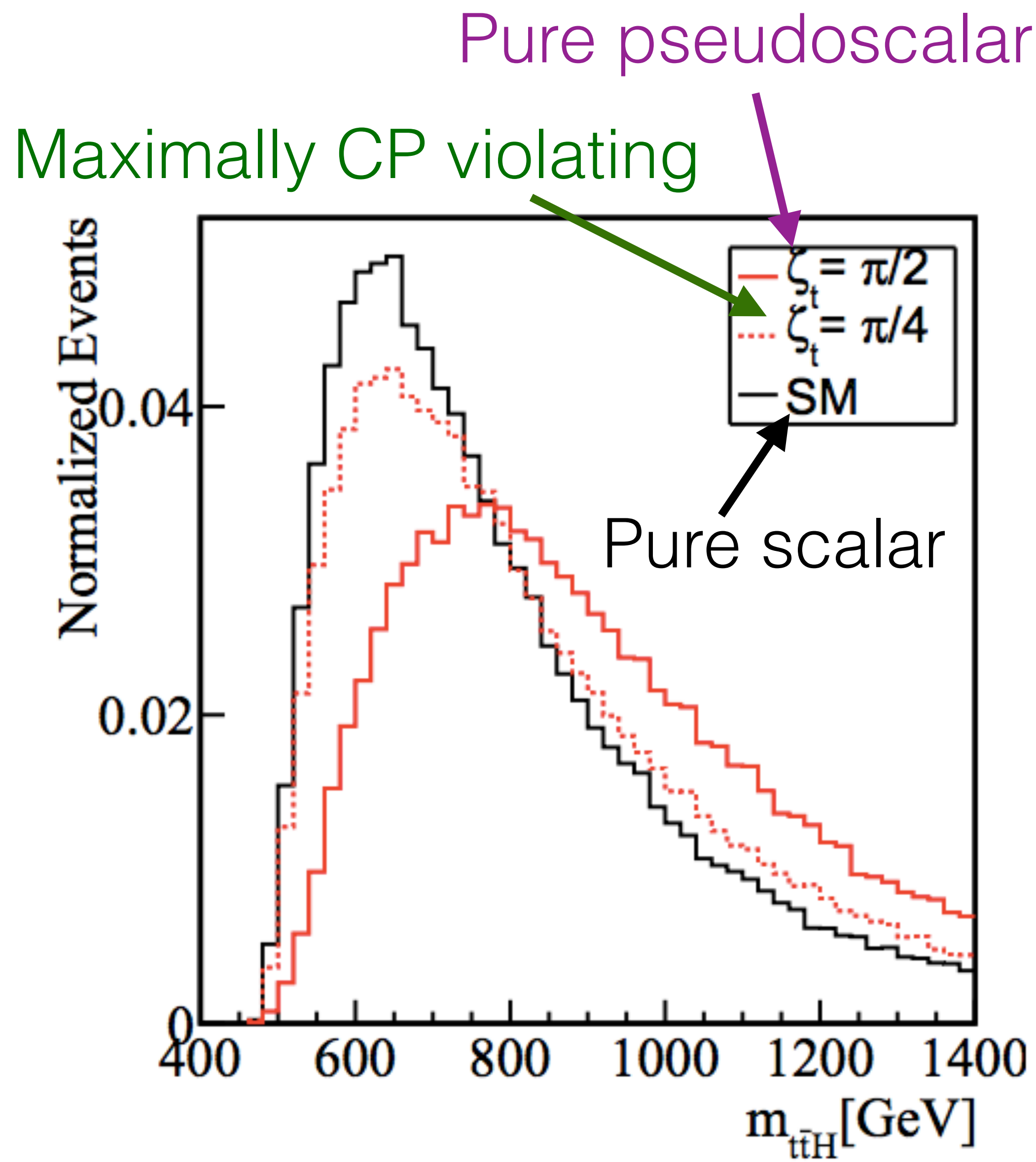
Top quark Yukawa coupling yells us about the stability of Universe and the required energy scale for new physics



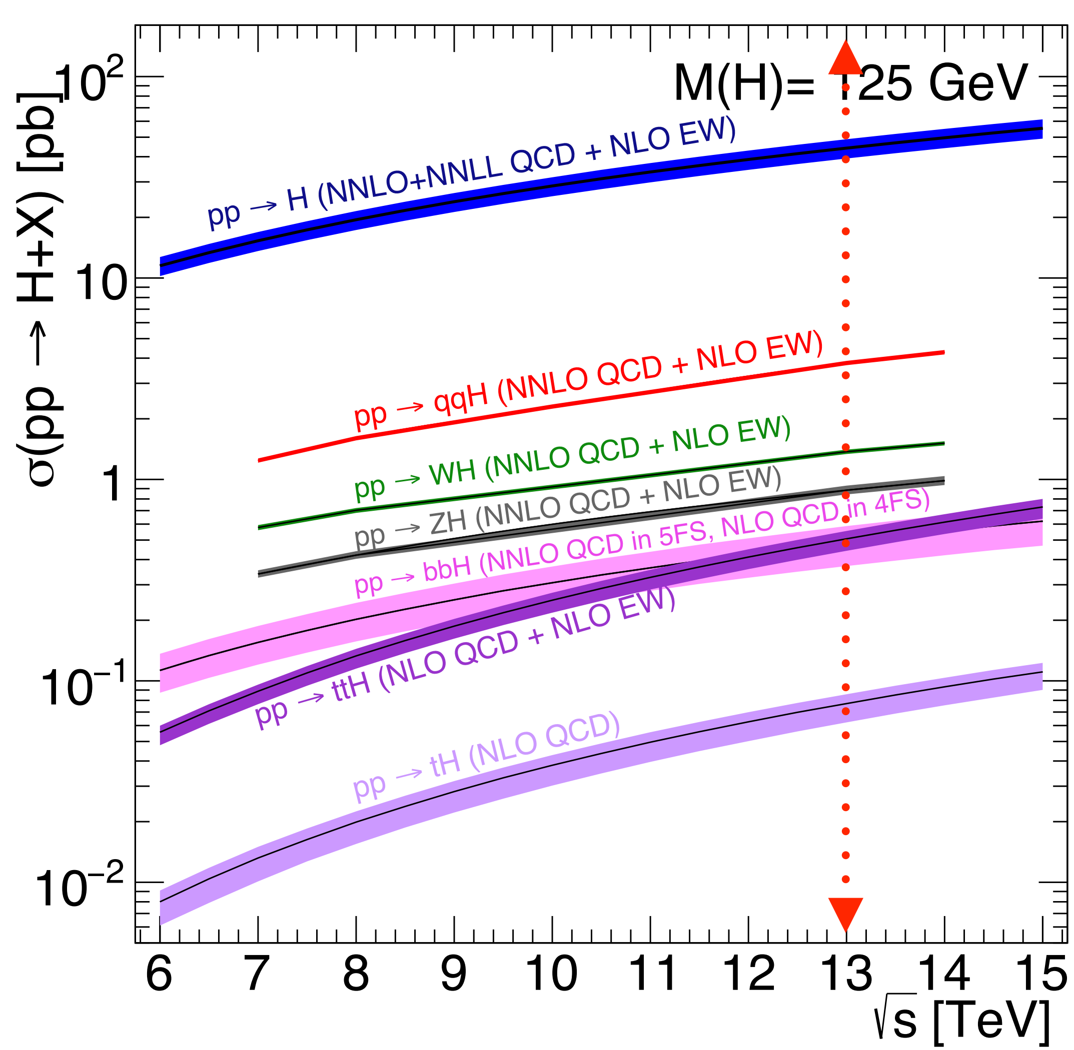
Is the universe stable or only metastable?

What is the CP nature of the Higgs boson?

A CP admixture is still allowed, and perhaps tth production can help us disentangle the BSM component



- tth production (~500fb @ 13TeV) two orders of magnitude smaller than ggF Higgs production
- tth 3 orders of magnitude smaller than inclusive ttbar production (~800 pb@13TeV)
- th production even smaller due to interference effects

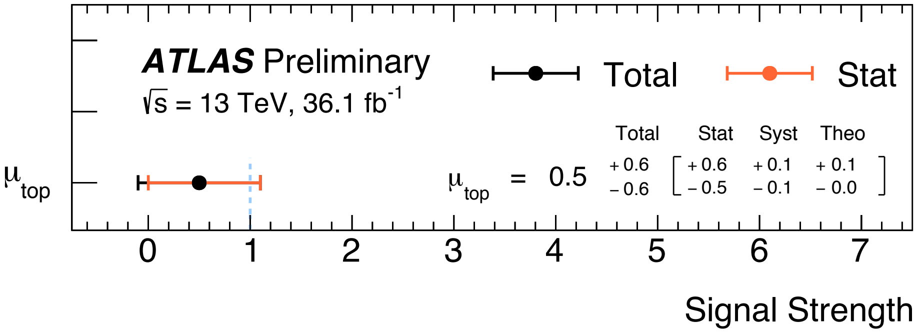


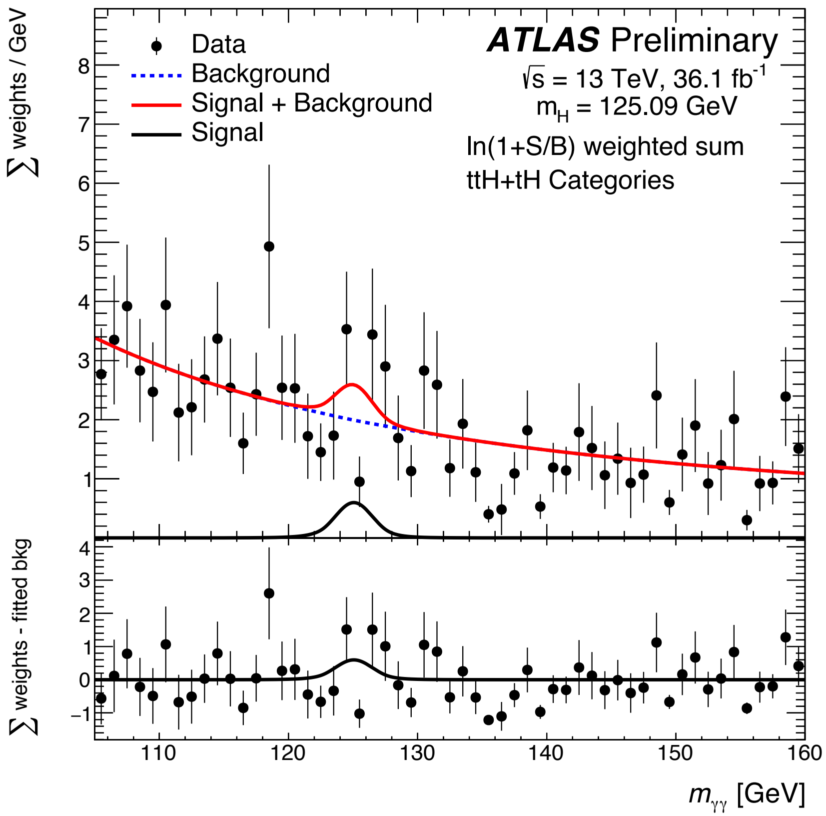
- Diphoton bump-hunting (data-driven background estimates)
- Split into leptonic and all-hadronic categories
- Further split based on number of central and forward jets and BDT categorization to separate S and B
- Sensitive to tth but also th production (probe anomalous coupling)

Category	Selection
tH lep 0fwd	$N_{\rm lep} = 1,\ N_{\rm jets}^{\rm cen} \leq 3,\ N_{\rm b-tag} \geq 1,\ N_{\rm jets}^{\rm fwd} = 0\ (p_{\rm T}^{\rm jet} > 25\,{\rm GeV})$
tH lep 1fwd	$N_{\rm lep} = 1,\ N_{\rm jets}^{\rm cen} \leq 4,\ N_{\rm b-tag} \geq 1,\ N_{\rm jets}^{\rm fwd} \geq 1\ (p_{\rm T}^{\rm jet} > 25\,{\rm GeV})$
ttH lep	$N_{\rm lep} \geq 1,\ N_{\rm jets}^{\rm cen} \geq 2,\ N_{\rm b-tag} \geq 1,\ Z_{\ell\ell}$ veto $(p_{\rm T}^{\rm jet} > 25\,{\rm GeV})$
ttH had BDT1	$N_{\rm lep} = 0,\ N_{\rm jets} \geq 3,\ N_{\rm b-tag} \geq 1,\ {\rm BDT}_{\rm ttH} > 0.92$
ttH had BDT2	$N_{\rm lep} = 0,\ N_{\rm jets} \geq 3,\ N_{\rm b-tag} \geq 1,\ 0.83 < {\rm BDT}_{\rm ttH} < 0.92$
ttH had BDT3	$N_{\rm lep} = 0,\ N_{\rm jets} \geq 3,\ N_{\rm b-tag} \geq 1,\ 0.79 < {\rm BDT}_{\rm ttH} < 0.83$
ttH had BDT4	$N_{\rm lep} = 0,\ N_{\rm jets} \geq 3,\ N_{\rm b-tag} \geq 1,\ 0.52 < {\rm BDT}_{\rm ttH} < 0.79$
tH had 4j1b	$N_{\rm lep} = 0,\ N_{\rm jets}^{\rm cen} = 4,\ N_{\rm b-tag} = 1\ (p_{\rm T}^{\rm jet} > 25\,{\rm GeV})$
tH had 4j2b	$N_{\rm lep} = 0,\ N_{\rm jets}^{\rm cen} = 4,\ N_{\rm b-tag} \geq 2\ (p_{\rm T}^{\rm jet} > 25\,{\rm GeV})$

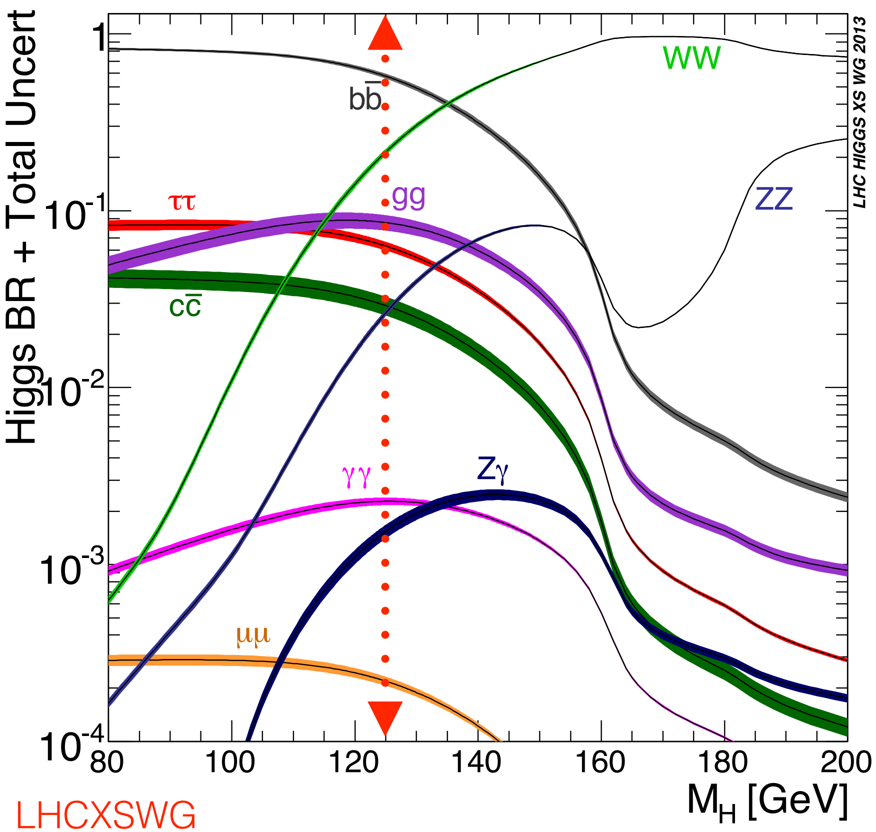
Check diphoton spurious signal by reversing ID or isolation requirements on photons or changing b-tagging requirements

Stat-limited analysis

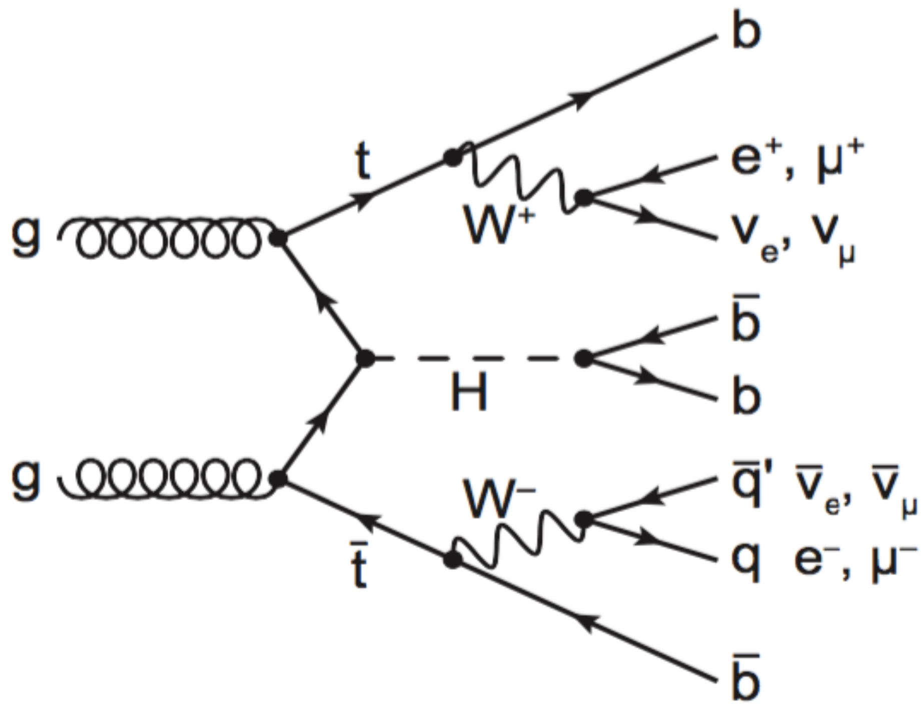




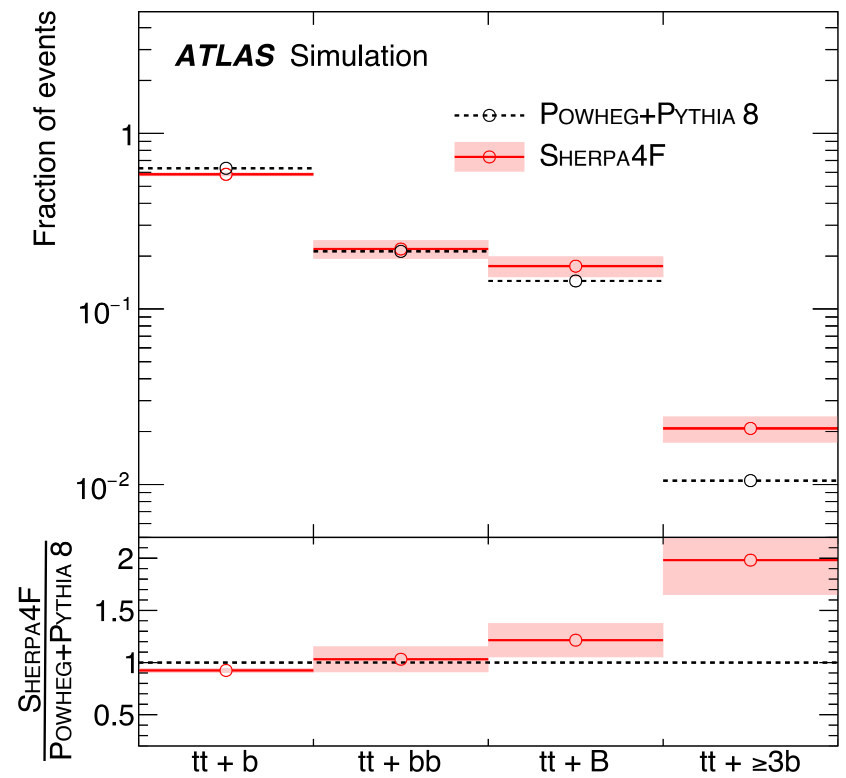
Largest BR of Higgs, focus on single or dilepton ttbar decays so we have a handle on triggering and large multi-jet backgrounds



LHCXSWG



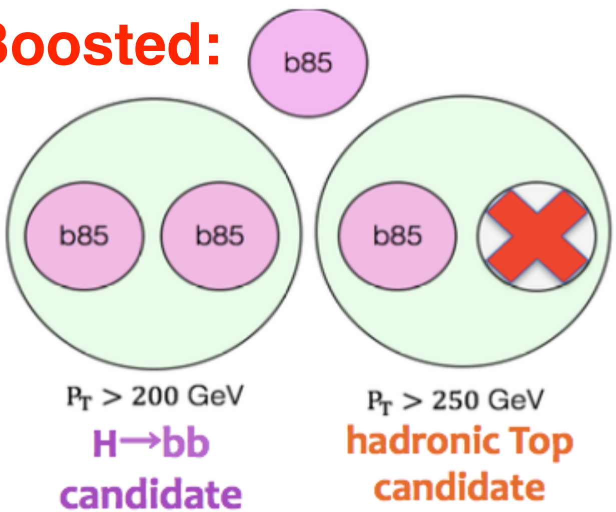
- Unknown and difficult-to-model background of ttbar + 2 or more jets with extra HF: no real measurements here
- Event classification based on flavor of jets (to hadrons) not matched to ttbar decay
  - tt+≥1b: At least one b-jet not matched to ttbar
  - tt+≥1c: Otherwise at least one c-jet not matched
  - tt+light: All others
  - tt+HF further categorized based on number of hadrons in the jet cone (b: one, B: two)



Nominal model: Powheg+Pythia8 reweighted in each subcategory to 4FS NLO Sherpa+OpenLoops calculation

Divide and conquer - single+dilepton selections, further subdivide based on number of jets and b-tagged jets, as well as a boosted category, to define multiple signal and control regions

Boosted:

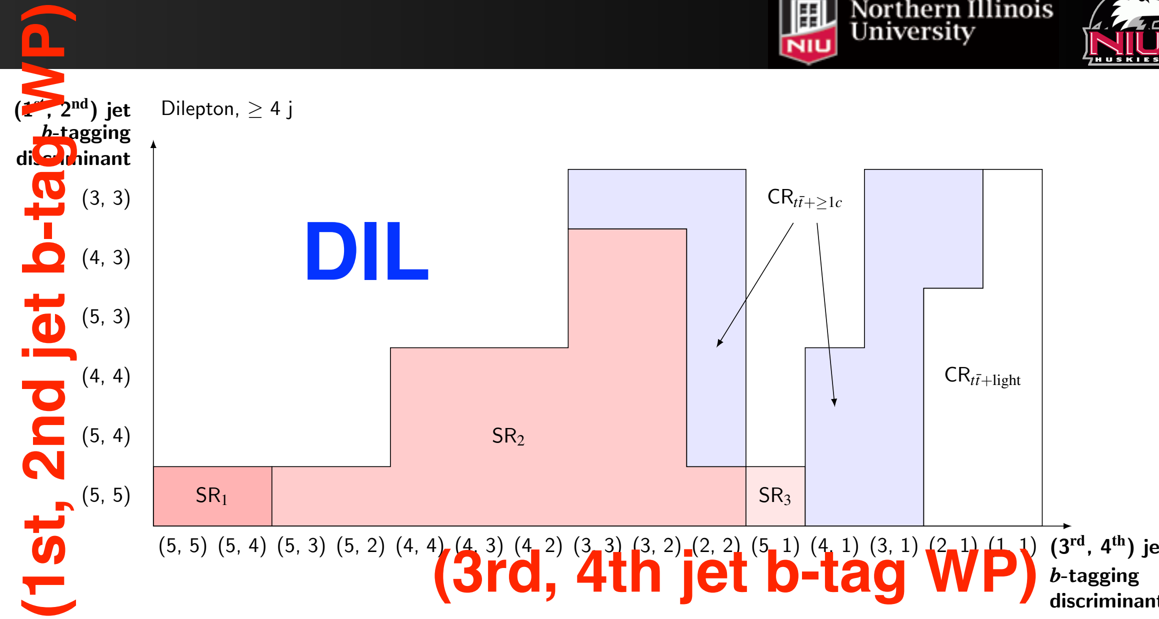


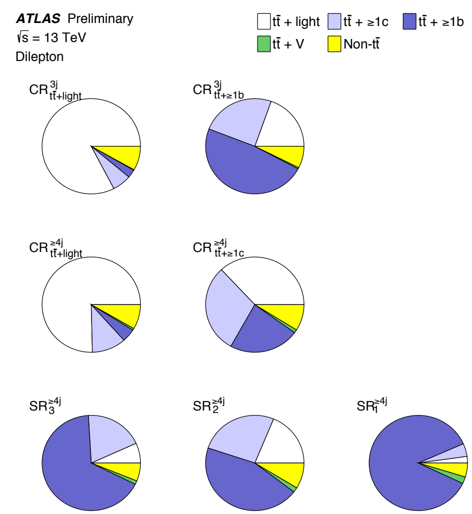
R=1.0 jets from R=0.4 jets

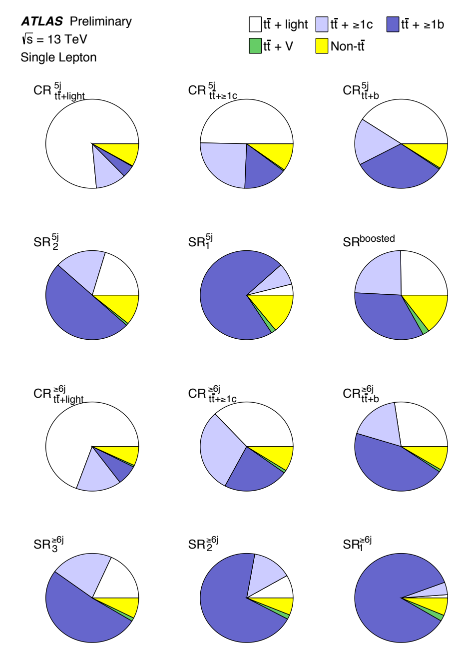
Profile likelihood fit to improve on prior knowledge of tt+HF (and ttbar in general)

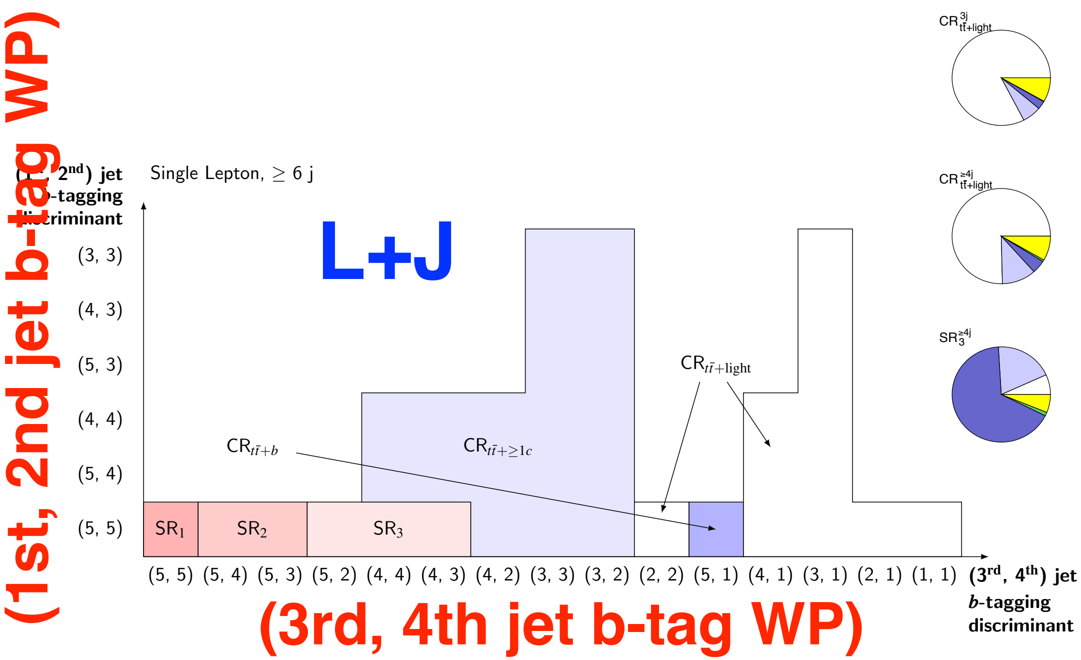
1-lepton		2-leptons
Single un-prescaled e/μ trigger		
= 1 e or μ p_T>27 GeV ≥ 5 jets with p_T>25 GeV		= 2 opposite sign e or μ ≥ 3 jets with p_T>25 GeV ≥ 2 jets tagged as b at 77% WP Z mass window veto |M_{ll}-91|<8 GeV = 0 hadronic τ (veto)
Resolved (low p_T)	Boosted (high p_T)	
≥ 2 jets tagged as b at 60% WP or ≥ 3 jets tagged as b at 77% WP < 2 hadronic τ (veto)	≥ 2 LRJ ≥ 1 jet outside of LRJ tagged as b at 85% 1 boosted H→bb candidate 1 boosted Top candidate	

B-tagging selection uses multiple working points (WP) for the jets



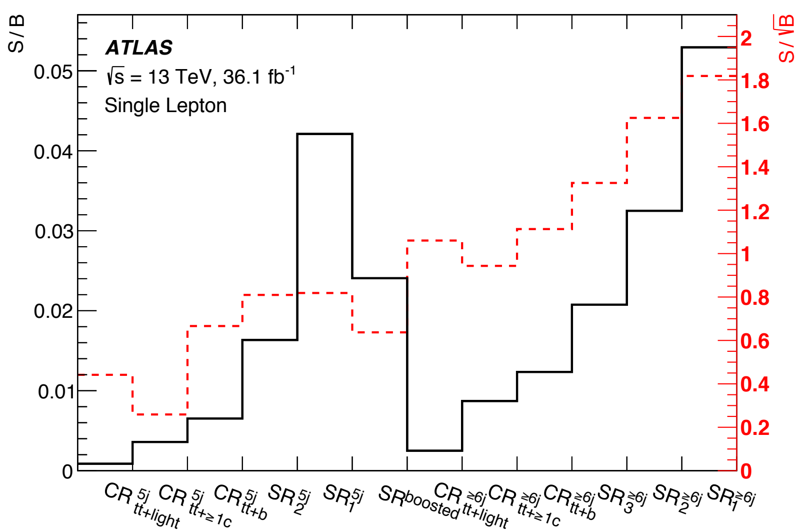


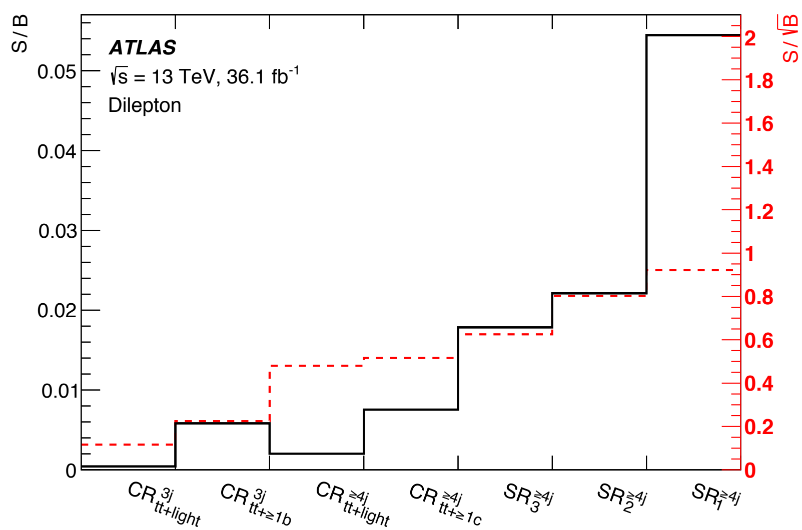




Classification BDTs to improve upon small S/B

- BDT inputs: Variety of kinematic information
- First assign jets to partons of ttbar and Higgs system using reconstruction BDT
- Most sensitive region(s) use likelihood discriminant+matrix element method as further inputs to classification BDTs





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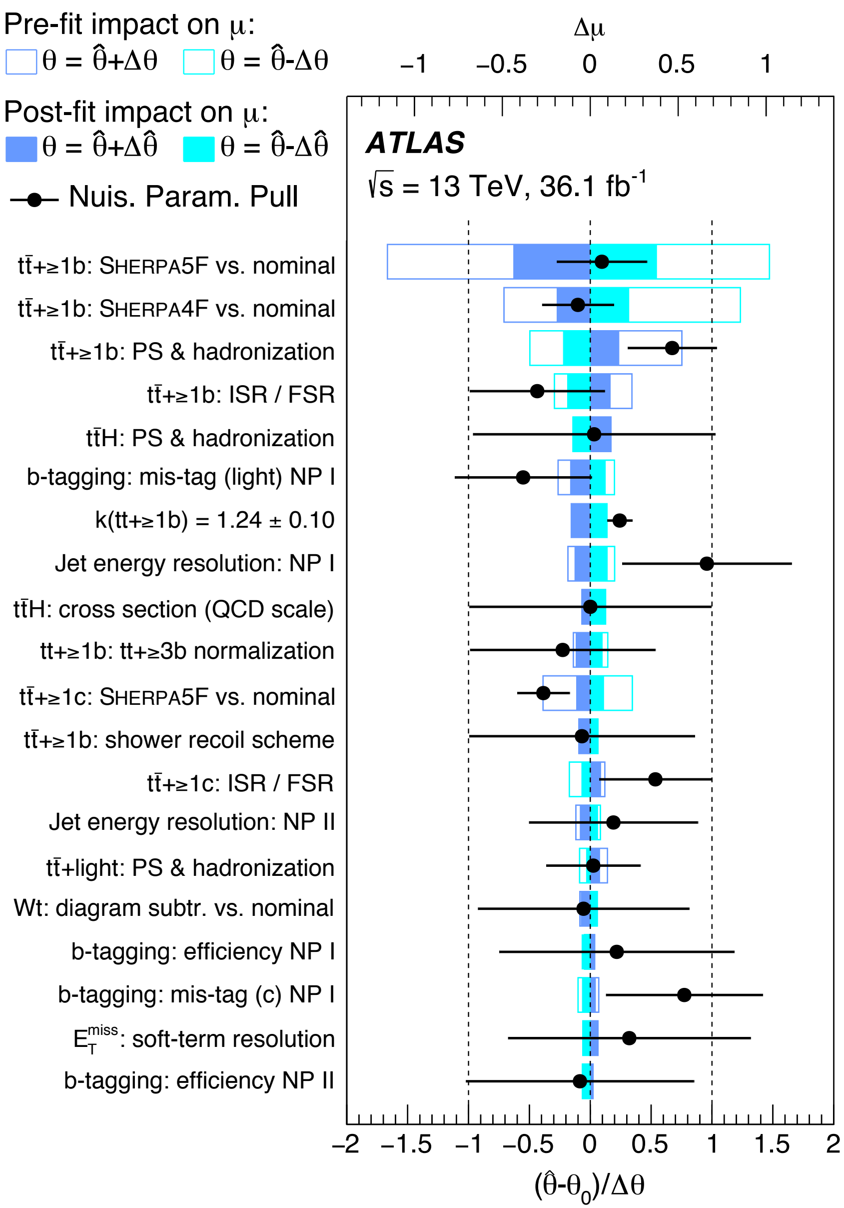
tt+≥1b and tt+≥1c are free-floating in the fit

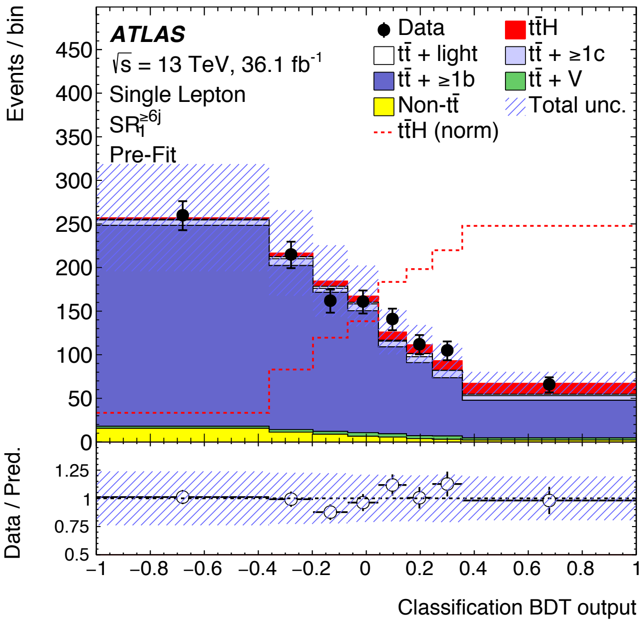
Large number of uncertainties related to ttbar modeling, particularly for ttbar+HF

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%	$t\bar{t}+\geq 1b$

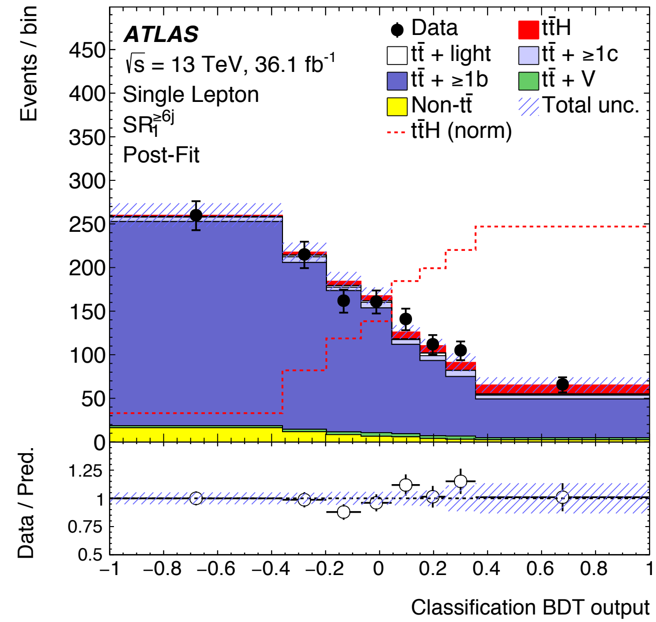


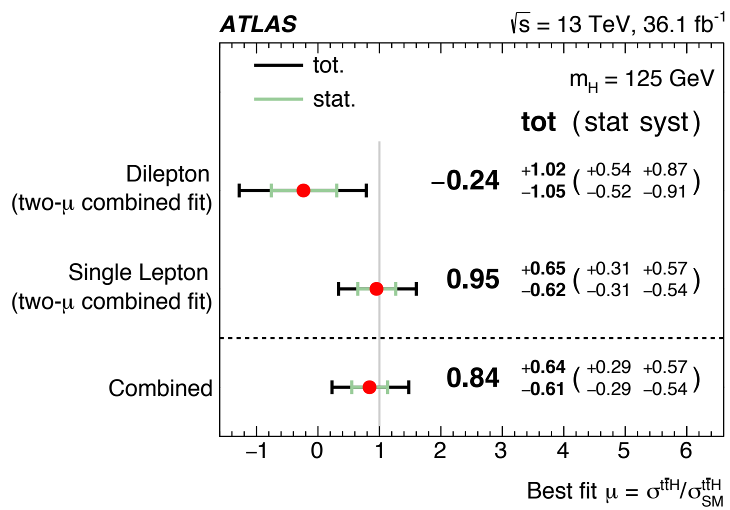
- Big uncertainty on tt+≥1b modeling
- Jet and b-tag requirements: Many samples have few events in the SR→large stat uncertainties

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

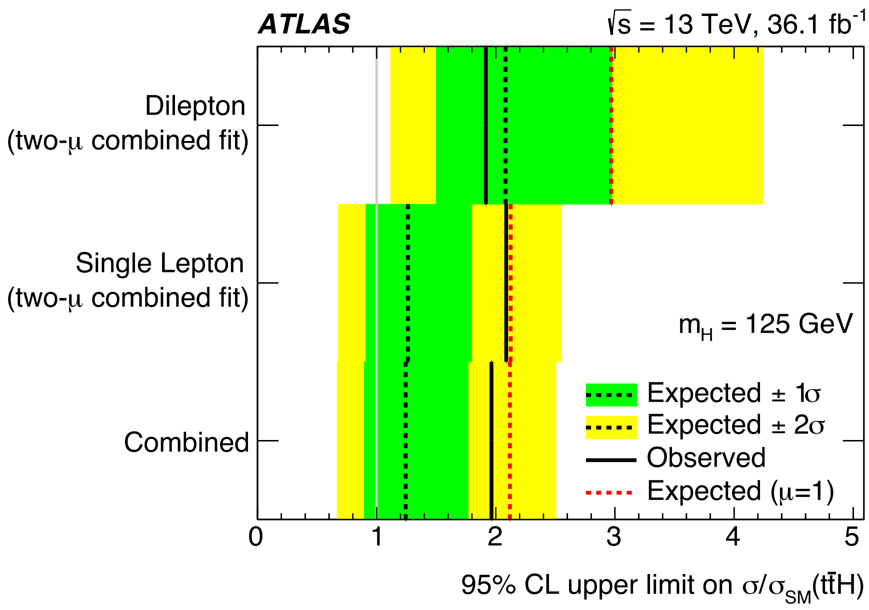


Example of what the profile fit brings

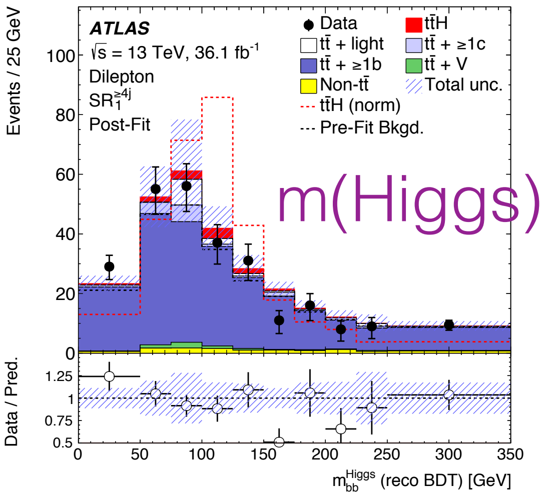


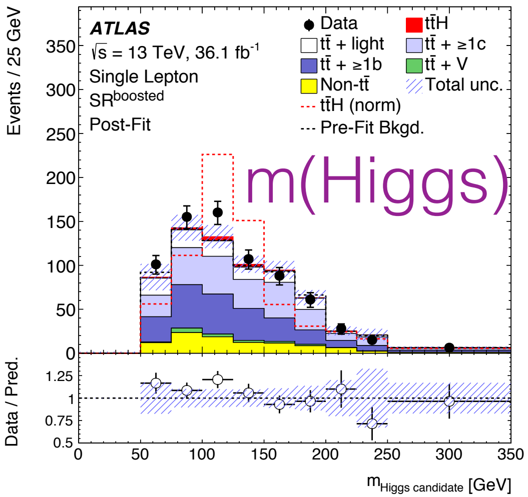


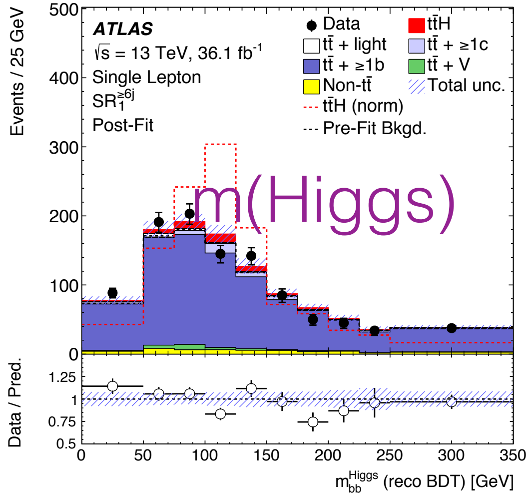
Fitted signal strengths



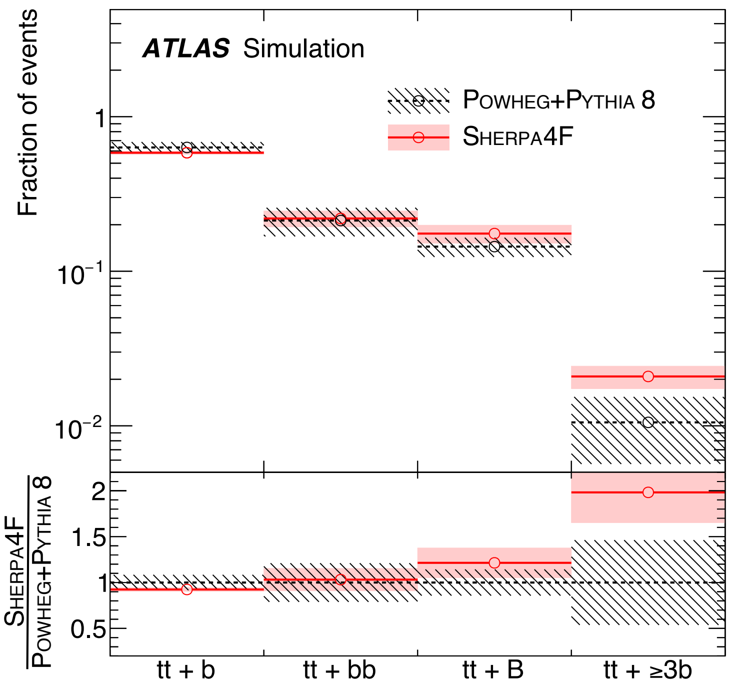
Exclude signal strength > 2 (expected 1.2)







- ttbar background modeling hugely important
  - Need tt+HF measurements to constrain models
  - MC stats - better filters? TRF to help with large btags?
  - Consider moving to more pure regions? Consider background modeling of shape in extrapolation of btagging or other variables, though not clear what it brings (still have uncertainties)



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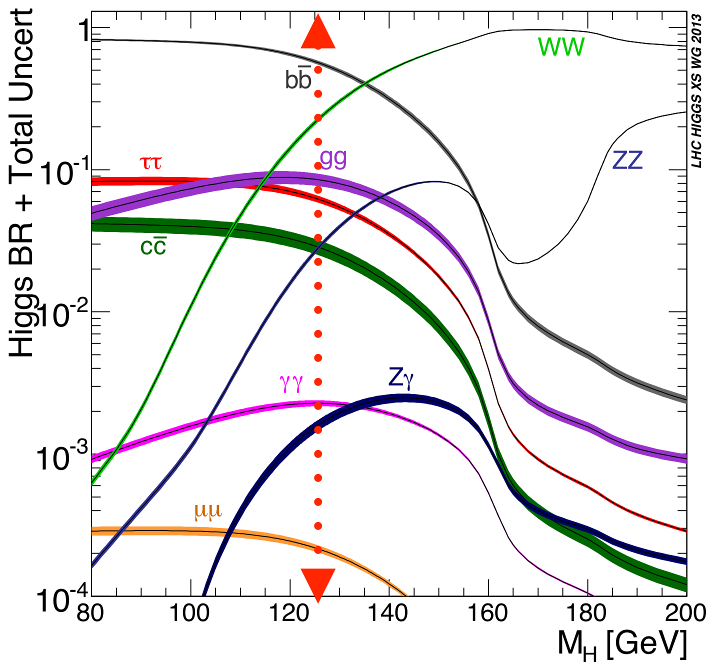
- Btagging continuing to be relevant (new algorithms in development, systematic uncertainties - and pileup?)
- MVAs critical earlier, but less so now unless we can use them to reduce systematics
- Largest higgs BR, so important to keep pushing forward
  - “Most complex analysis we have in ATLAS”



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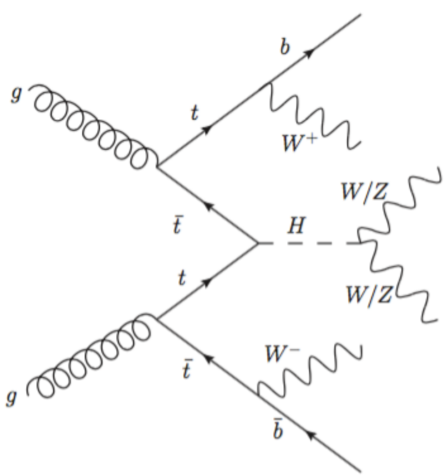
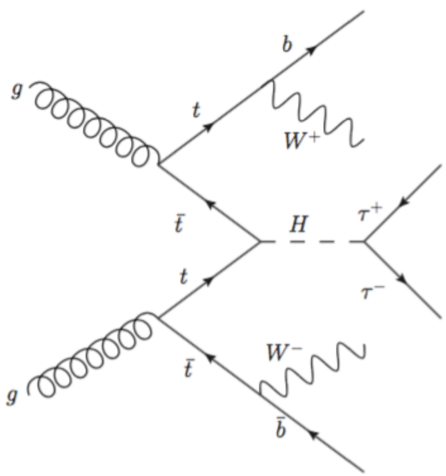
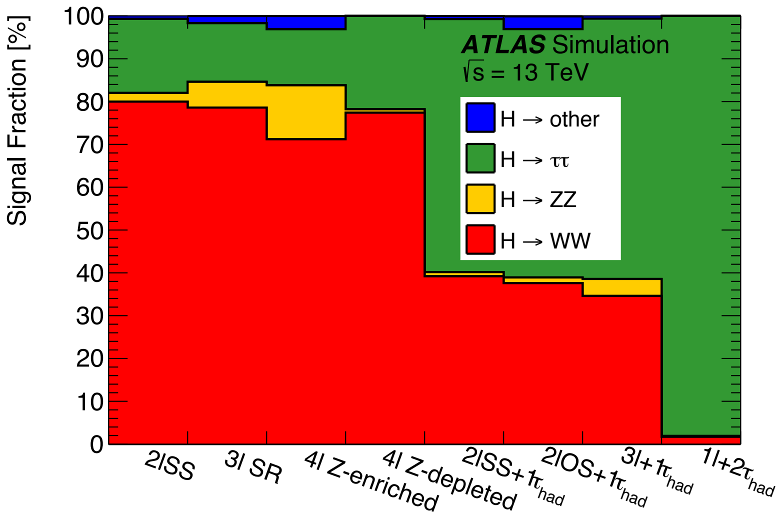
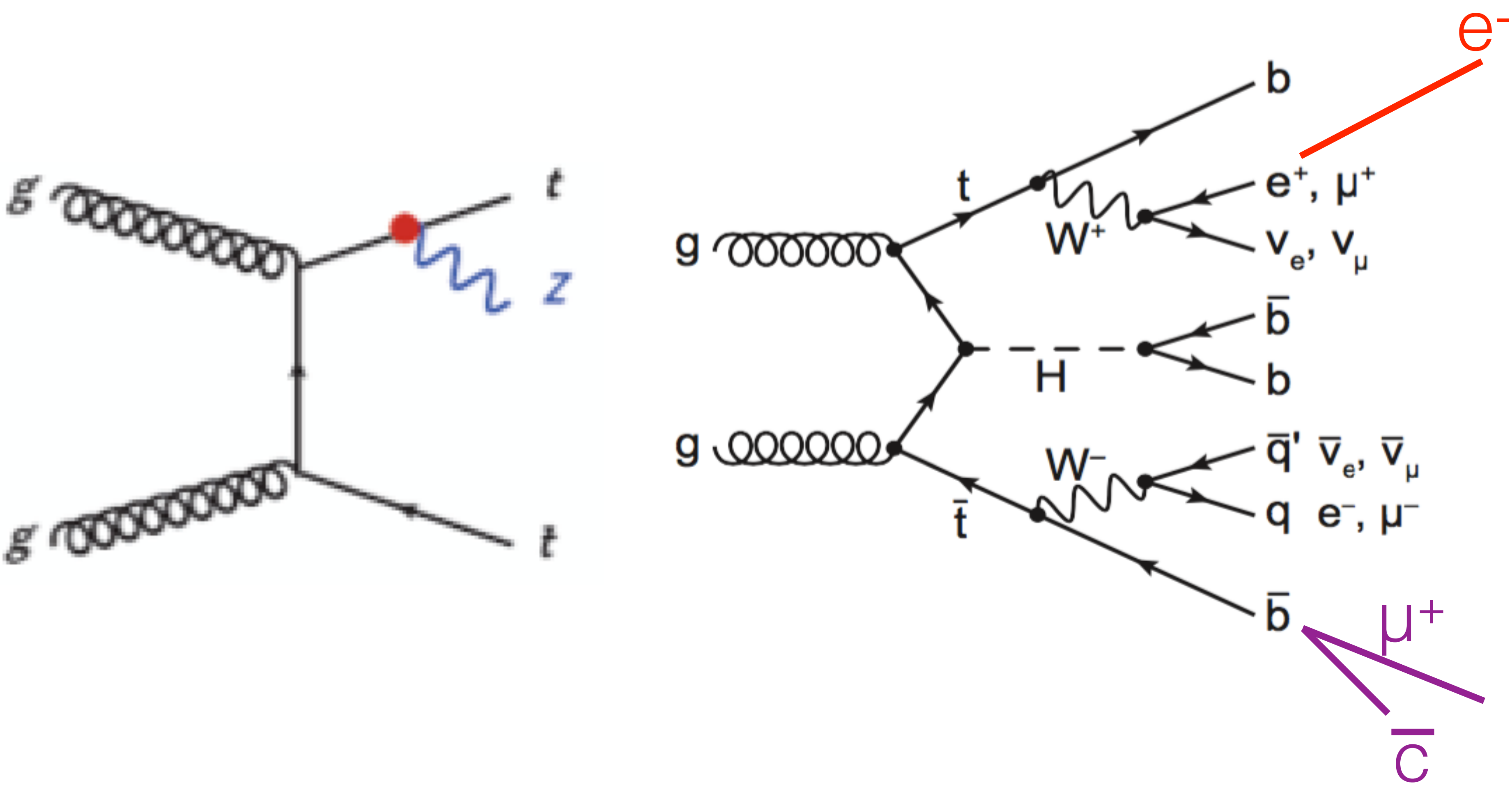
Focus on several combinations of BR of Higgs to final states with leptons as well as ttbar decays.

Primarily sensitive to h→WW, h→$\tau\tau$ and h→ZZ





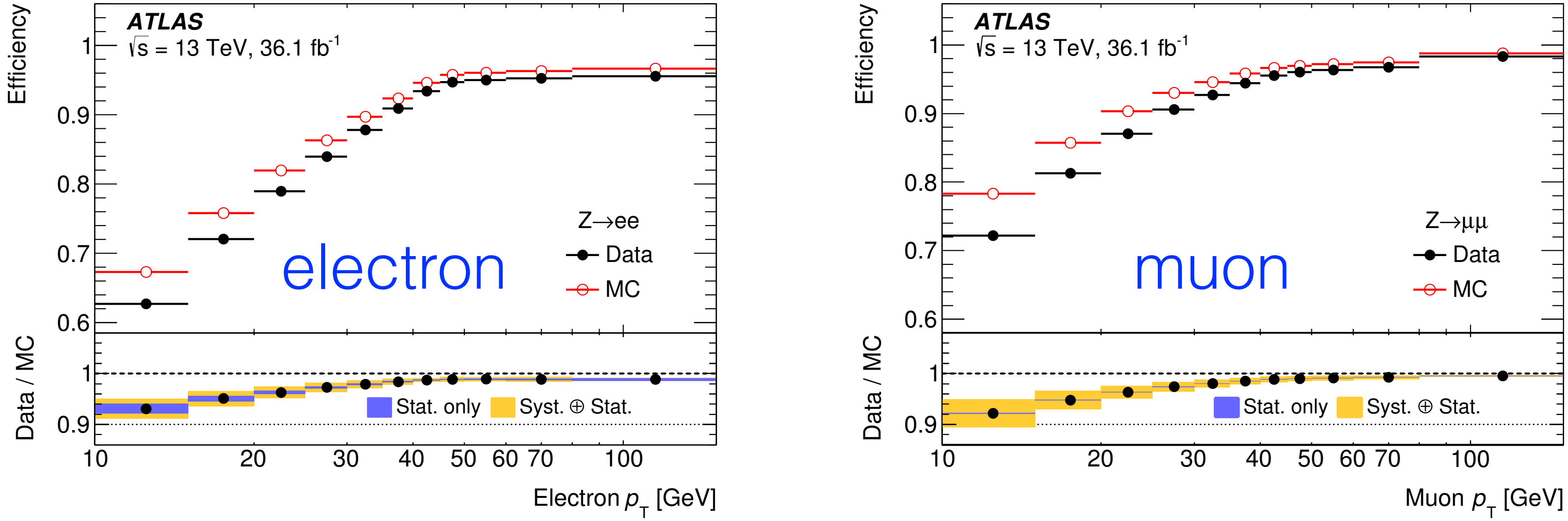




Backgrounds dominated by ttV, non-prompt leptons and charge misID

- Reject non-prompt leptons while maintaining high signal efficiency with a BDT using energy and tracks around the lepton, as well as b-tagging and track-jet information
  - Typically HF jets give the non-prompt leptons
  - Separate e/mu training
- Electron charge misID effects reduced with a BDT using electron p_T and eta, tracking+calorimeter info

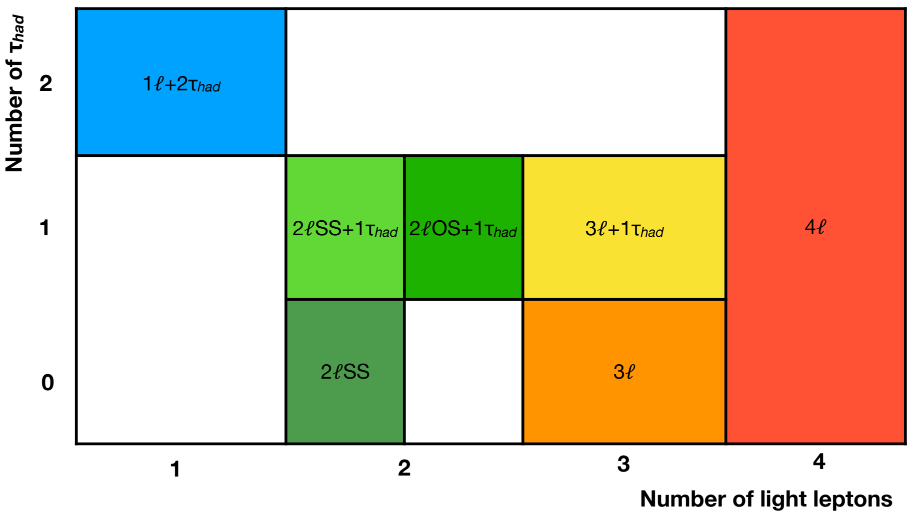
Non-prompt lepton BDT efficiency

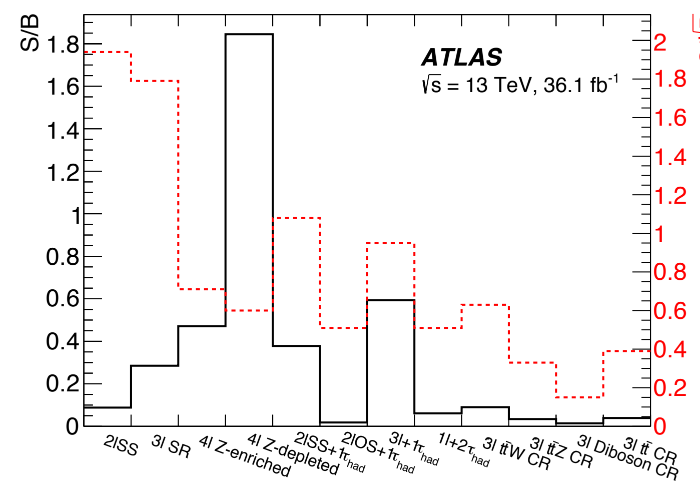


7 channels, separated by flavor, charge and number of leptons, which can have different selections

	2ℓSS	3ℓ	4ℓ	$1\ell+2\tau_{\text{had}}$	2ℓSS$+1\tau_{\text{had}}$	2ℓOS$+1\tau_{\text{had}}$	$3\ell+1\tau_{\text{had}}$
Light lepton	2T*	1L*, 2T*	2L, 2T	1T	2T*	2L†	1L†, 2T
τ_{had}	0M	0M	–	1T, 1M	1M	1M	1M
N_{jets}, $N_{b-\text{jets}}$	$\geq 4, =1,2$	$\geq 2, \geq 1$	$\geq 2, \geq 1$	$\geq 3, \geq 1$	$\geq 4, \geq 1$	$\geq 3, \geq 1$	$\geq 2, \geq 1$

	e					μ		
	L	L†	L*	T	T*	L	L†	L*/T/T*
Isolation	No	Yes				No	Yes	
Non-prompt lepton BDT	No		Yes			No		Yes
Identification	Loose			Tight		Loose		
Charge misassignment veto	No				Yes	No		
Transverse impact parameter significance, $\lvert d_0\rvert/\sigma_{d_0}$	< 5					< 3		
Longitudinal impact parameter, $\lvert z_0 \sin\theta\rvert$	< 0.5 mm							

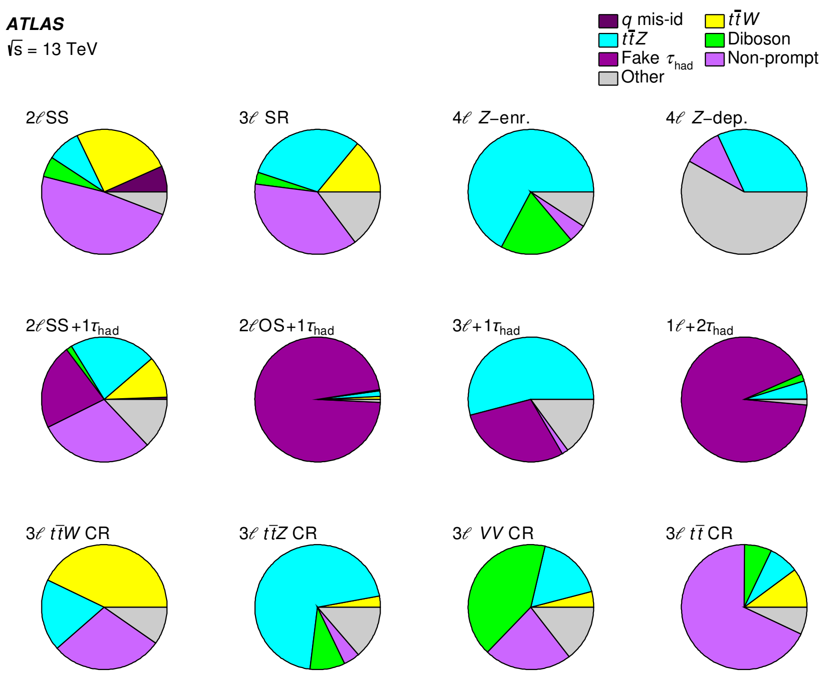


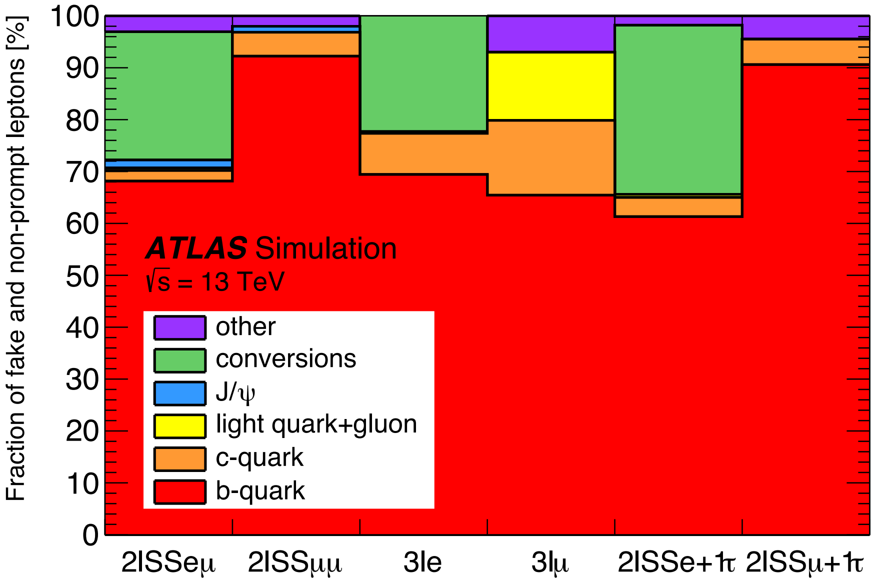


Sensitivity enhanced with BDT discriminants to separate signal from dominant backgrounds in each category

In some categories, multiple BDTs are used

BDT used to create 4 CRs (ttZ, ttW, fakes, diboson) from 3L, included in the fit





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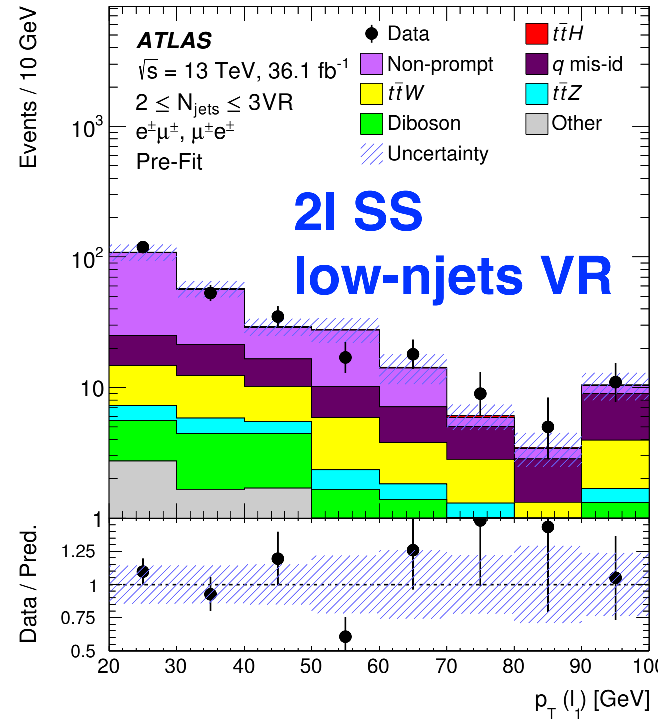
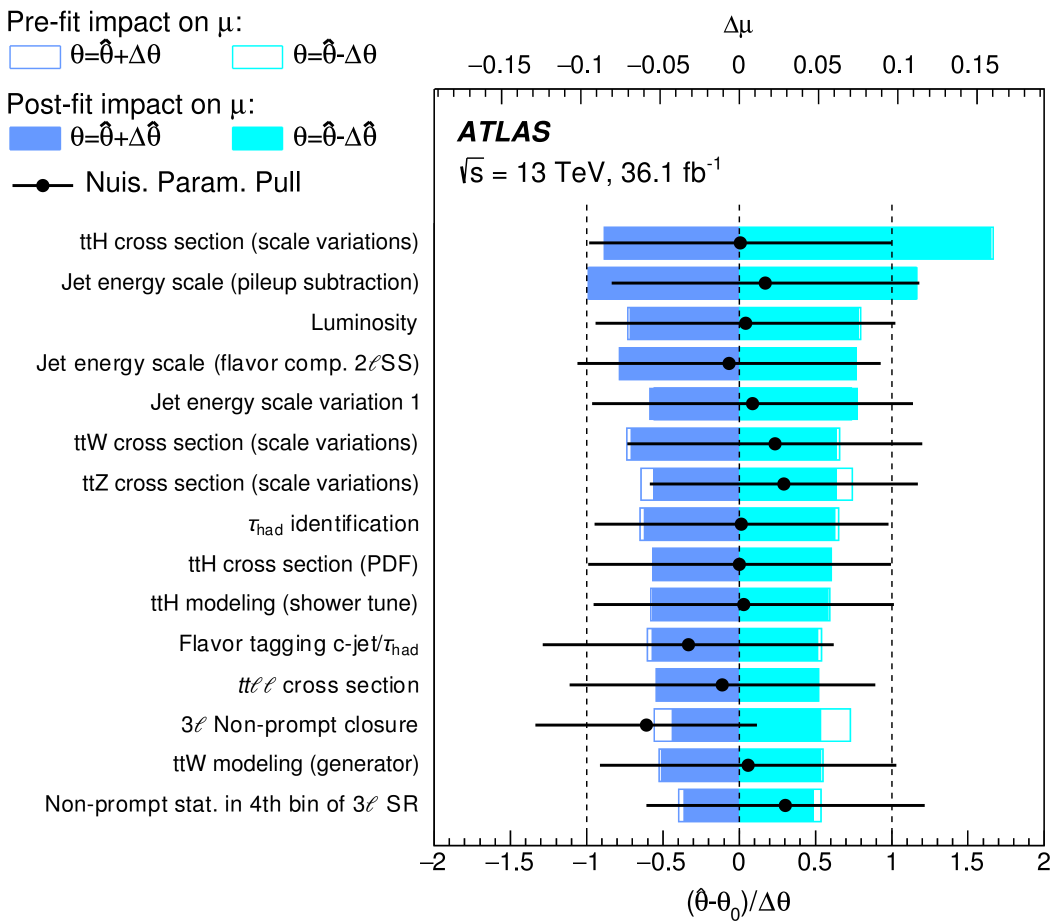
- Variety of data-driven and semi-DD methods to estimate non-prompt contributions based on control regions
- Uncertainties: closure tests, prompt subtraction, uncertainties on conversions in simulation, varying CRs

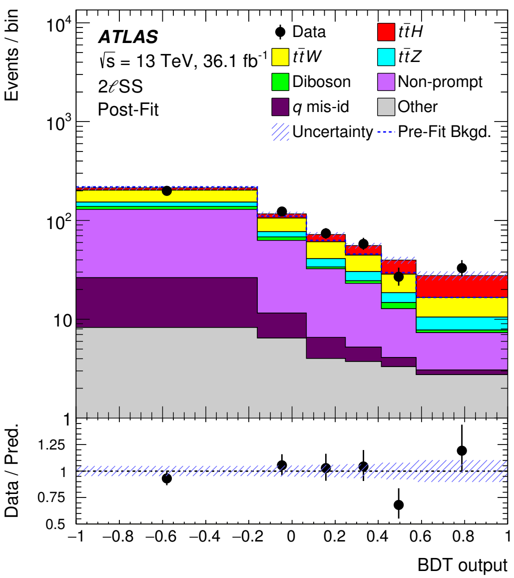


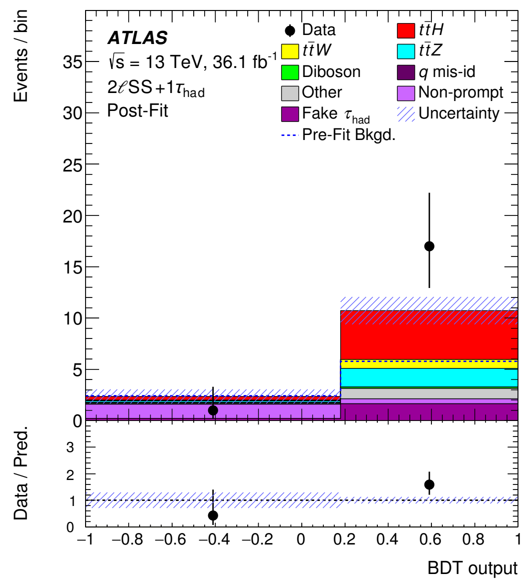
	2ℓSS	3ℓ	4ℓ	$1\ell+2\tau_{had}$	2ℓSS$+1\tau_{had}$	2ℓOS$+1\tau_{had}$	$3\ell+1\tau_{had}$
Non-prompt lepton strategy	DD (MM)	DD (MM)	semi-DD (SF)	MC	DD (FF)	MC	MC
Fake τ_{had} strategy	–	–	–	DD (SS data)	semi-DD (SF)	DD (FF)	semi-DD (SF)
Control Region Selection							
Light lepton	1T*, 1L		3L	1T	1T*, 1L	2L†	–
τ_{had}	0M			1T, 1M	$\leq$ 1M	1L	–
N_{jets}	$2 \leq N_{jets} \leq 3$		$1 \leq N_{jets} \leq 2$	≥ 3	$2 \leq N_{jets} \leq 3$	≥ 3	–
$N_{b\text{-jets}}$	≥ 1					$= 0$	–

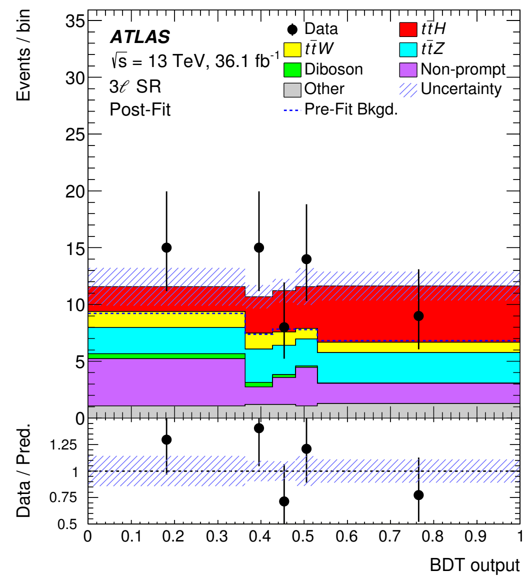


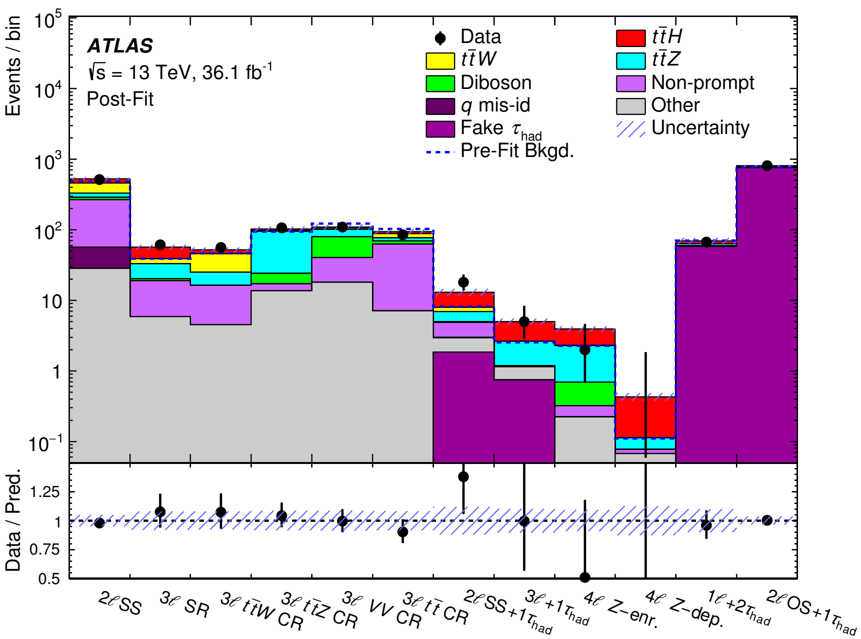
- Largest uncertainty - signal modeling
- Various jet energy scale variations and ttV cross sections and non-prompt leptons also very important

Uncertainty Source	$\Delta\mu$	
$t\bar{t}H$ modeling (cross section)	+0.20	−0.09
Jet energy scale and resolution	+0.18	−0.15
Non-prompt light-lepton estimates	+0.15	−0.13
Jet flavor tagging and τ_{had} identification	+0.11	−0.09
$t\bar{t}W$ modeling	+0.10	−0.09
$t\bar{t}Z$ modeling	+0.08	−0.07
Other background modeling	+0.08	−0.07
Luminosity	+0.08	−0.06
$t\bar{t}H$ modeling (acceptance)	+0.08	−0.04
Fake τ_{had} estimates	+0.07	−0.07
Other experimental uncertainties	+0.05	−0.04
Simulation sample size	+0.04	−0.04
Charge misassignment	+0.01	−0.01
Total systematic uncertainty	+0.39	−0.30









Can start to see tth in these plots, even by eye

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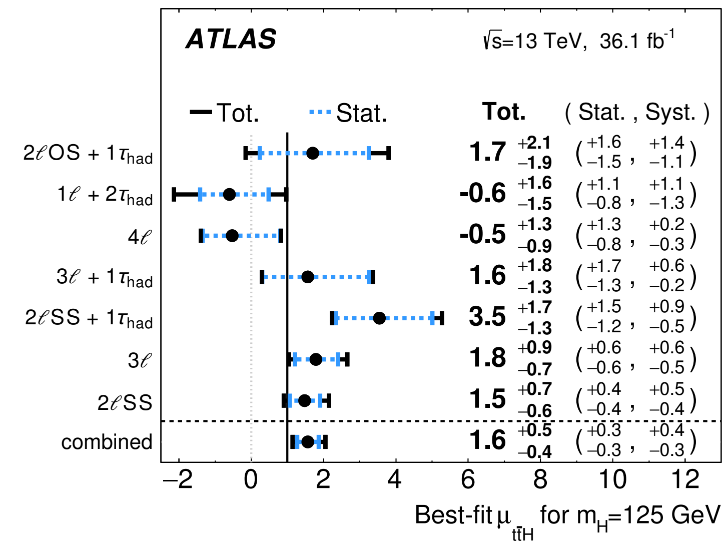
Channel	Best-fit μ Observed	Best-fit μ Expected	Significance Observed	Significance Expected
2ℓOS+$1\tau_{\text{had}}$	$1.7\ ^{+1.6}_{-1.5}$ (stat.) $^{+1.4}_{-1.1}$ (syst.)	$1.0\ ^{+1.5}_{-1.4}$ (stat.) $^{+1.2}_{-1.1}$ (syst.)	0.9σ	0.5σ
1ℓ+$2\tau_{\text{had}}$	$-0.6\ ^{+1.1}_{-0.8}$ (stat.) $^{+1.1}_{-1.3}$ (syst.)	$1.0\ ^{+1.1}_{-0.9}$ (stat.) $^{+1.2}_{-1.1}$ (syst.)	–	0.6σ
4ℓ	$-0.5\ ^{+1.3}_{-0.8}$ (stat.) $^{+0.2}_{-0.3}$ (syst.)	$1.0\ ^{+1.7}_{-1.2}$ (stat.) $^{+0.4}_{-0.2}$ (syst.)	–	0.8σ
3ℓ+$1\tau_{\text{had}}$	$1.6\ ^{+1.7}_{-1.3}$ (stat.) $^{+0.6}_{-0.2}$ (syst.)	$1.0\ ^{+1.5}_{-1.1}$ (stat.) $^{+0.4}_{-0.2}$ (syst.)	1.3σ	0.9σ
2ℓSS+$1\tau_{\text{had}}$	$3.5\ ^{+1.5}_{-1.2}$ (stat.) $^{+0.9}_{-0.5}$ (syst.)	$1.0\ ^{+1.1}_{-0.8}$ (stat.) $^{+0.5}_{-0.3}$ (syst.)	3.4σ	1.1σ
3ℓ	$1.8\ ^{+0.6}_{-0.6}$ (stat.) $^{+0.6}_{-0.5}$ (syst.)	$1.0\ ^{+0.6}_{-0.5}$ (stat.) $^{+0.5}_{-0.4}$ (syst.)	2.4σ	1.5σ
2ℓSS	$1.5\ ^{+0.4}_{-0.4}$ (stat.) $^{+0.5}_{-0.4}$ (syst.)	$1.0\ ^{+0.4}_{-0.4}$ (stat.) $^{+0.4}_{-0.4}$ (syst.)	2.7σ	1.9σ
Combined	$1.6\ ^{+0.3}_{-0.3}$ (stat.) $^{+0.4}_{-0.3}$ (syst.)	$1.0\ ^{+0.3}_{-0.3}$ (stat.) $^{+0.3}_{-0.3}$ (syst.)	4.1σ	2.8σ

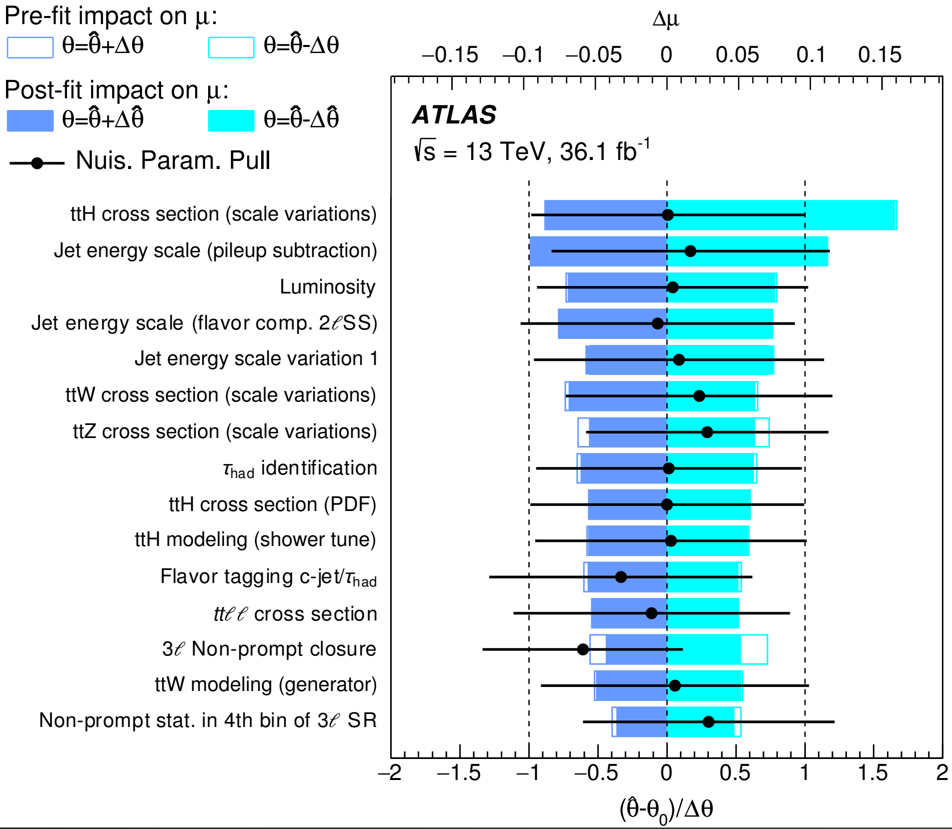
Ordered by expected significance

4.1σ significance observed (2.8σ expected)



- Signal modeling will become more important, not less
  - QCD scale, PDF and parton shower (Pythia8 vs Herwig7). What are the prospects for better calculations?
- Jet uncertainties critical, especially for such a complex analysis, and as pileup increases

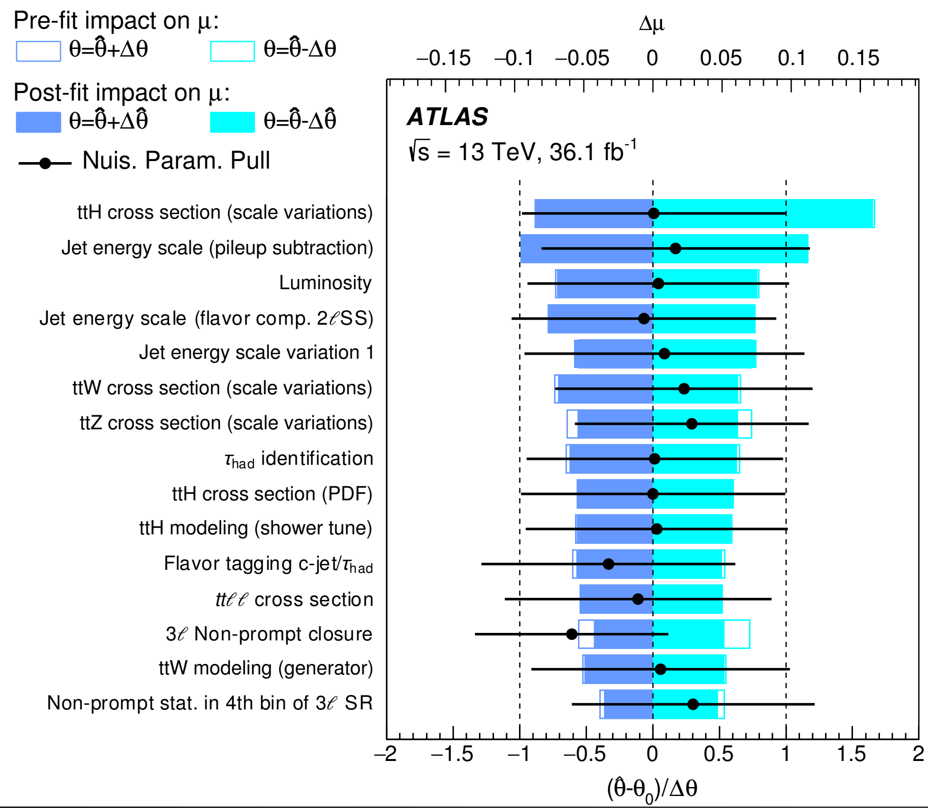
Uncertainty Source	$\Delta\mu$	
$t\bar{t}H$ modeling (cross section)	+0.20	−0.09
Jet energy scale and resolution	+0.18	−0.15
Non-prompt light-lepton estimates	+0.15	−0.13
Jet flavor tagging and τ_{had} identification	+0.11	−0.09
$t\bar{t}W$ modeling	+0.10	−0.09
$t\bar{t}Z$ modeling	+0.08	−0.07
Other background modeling	+0.08	−0.07
Luminosity	+0.08	−0.06
$t\bar{t}H$ modeling (acceptance)	+0.08	−0.04
Fake τ_{had} estimates	+0.07	−0.07
Other experimental uncertainties	+0.05	−0.04
Simulation sample size	+0.04	−0.04
Charge misassignment	+0.01	−0.01
Total systematic uncertainty	+0.39	−0.30

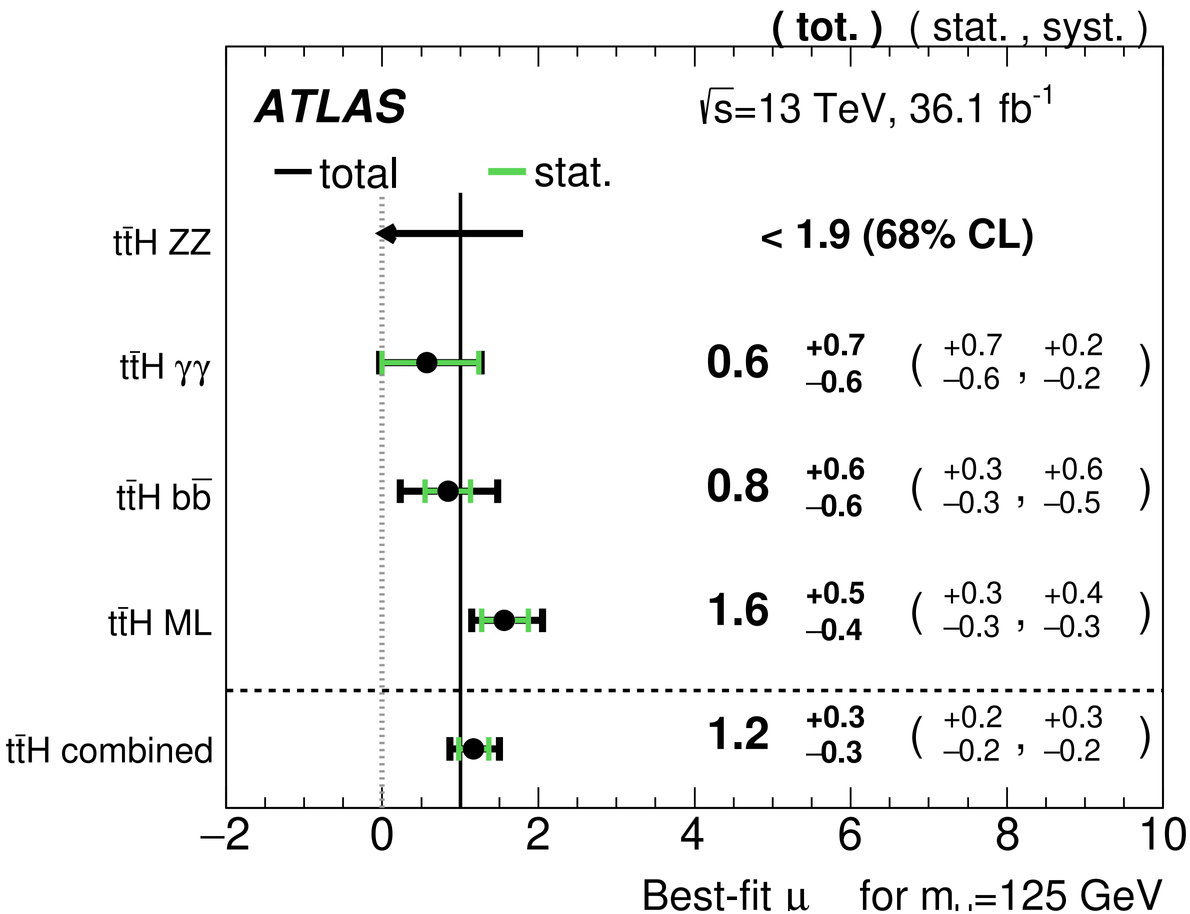


tth(multilepton) lessons learned and moving forward

- Non-prompt leptons important, have to be certain we get uncertainties right
- Need large stats for MC to evaluate fake estimates (filter on 3L, tt+photon, need to be certain this is combined correctly)
- tt+V uncertainties key moving forward
  - Renormalization and factorization scales lead to large shape changes
  - Control with measurements in situ?
  - Free-floating ttW/ttZ → 15% degradation in expected sensitivity to signal strength

Uncertainty Source	$\Delta\mu$	
$t\bar{t}H$ modeling (cross section)	+0.20	−0.09
Jet energy scale and resolution	+0.18	−0.15
Non-prompt light-lepton estimates	+0.15	−0.13
Jet flavor tagging and τ_{had} identification	+0.11	−0.09
$t\bar{t}W$ modeling	+0.10	−0.09
$t\bar{t}Z$ modeling	+0.08	−0.07
Other background modeling	+0.08	−0.07
Luminosity	+0.08	−0.06
$t\bar{t}H$ modeling (acceptance)	+0.08	−0.04
Fake τ_{had} estimates	+0.07	−0.07
Other experimental uncertainties	+0.05	−0.04
Simulation sample size	+0.04	−0.04
Charge misassignment	+0.01	−0.01
Total systematic uncertainty	+0.39	−0.30



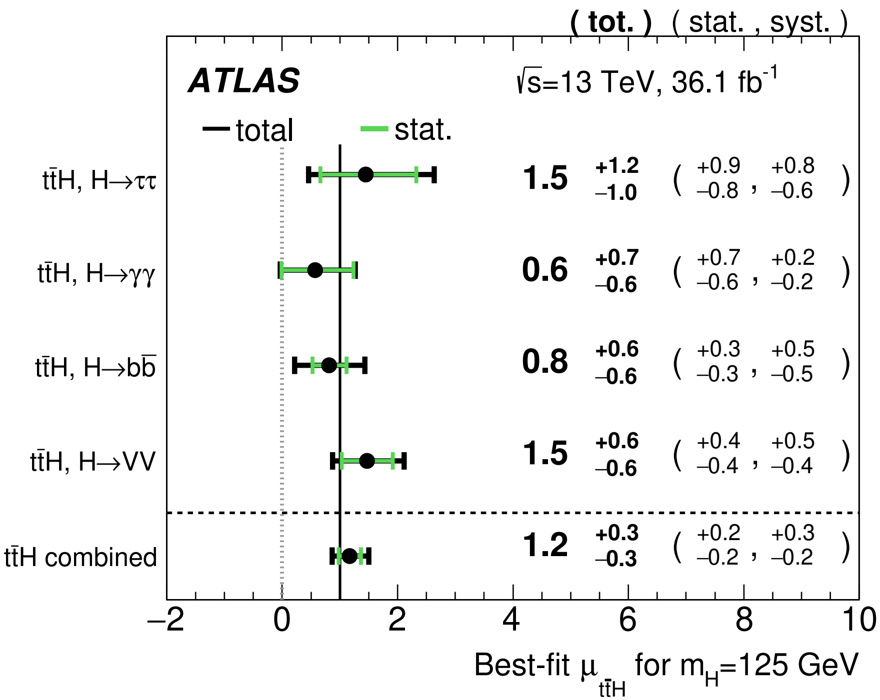


4.2σ significance observed (3.8σ expected)

Evidence for tth!

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

38% compatibility with combined result



Uncertainty Source	$\Delta\mu$	
$t\bar{t}$ modeling in $H \to b\bar{b}$ analysis	+0.15	−0.14
$t\bar{t}H$ modeling (cross section)	+0.13	−0.06
Non-prompt light-lepton and fake τ_{had} estimates	+0.09	−0.09
Simulation statistics	+0.08	−0.08
Jet energy scale and resolution	+0.08	−0.07
$t\bar{t}V$ modeling	+0.07	−0.07
$t\bar{t}H$ modeling (acceptance)	+0.07	−0.04
Other non-Higgs boson backgrounds	+0.06	−0.05
Other experimental uncertainties	+0.05	−0.05
Luminosity	+0.05	−0.04
Jet flavor tagging	+0.03	−0.02
Modeling of other Higgs boson production modes	+0.01	−0.01
Total systematic uncertainty	+0.27	−0.23
Statistical uncertainty	+0.19	−0.19
Total uncertainty	+0.34	−0.30

Signal modeling, non-prompt leptons and tt +HF modeling improvements needed

Channel	Best-fit μ		Significance	
	Observed	Expected	Observed	Expected
Multilepton	$1.6^{+0.5}_{-0.4}$	$1.0^{+0.4}_{-0.4}$	4.1σ	2.8σ
$H \to b\bar{b}$	$0.8^{+0.6}_{-0.6}$	$1.0^{+0.6}_{-0.6}$	1.4σ	1.6σ
$H \to \gamma\gamma$	$0.6^{+0.7}_{-0.6}$	$1.0^{+0.8}_{-0.6}$	0.9σ	1.7σ
$H \to 4\ell$	< 1.9	$1.0^{+3.2}_{-1.0}$	—	0.6σ
Combined	$1.2^{+0.3}_{-0.3}$	$1.0^{+0.3}_{-0.3}$	4.2σ	3.8σ

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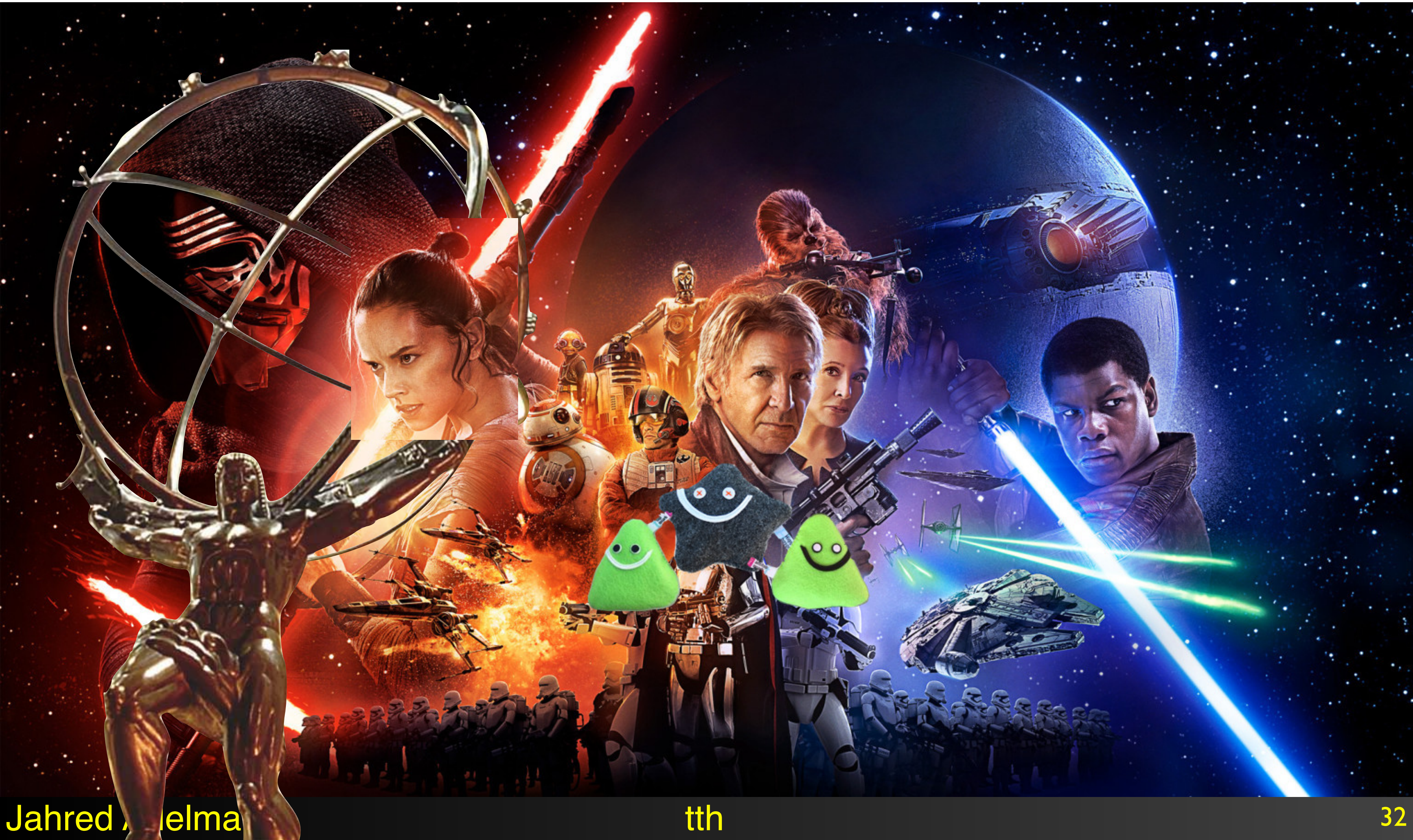
Lots of progress towards long-term future of precision tth studies, but a long way to go



BACKUP

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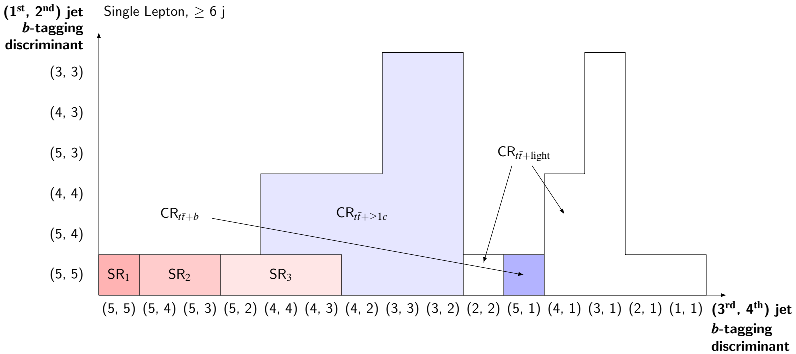
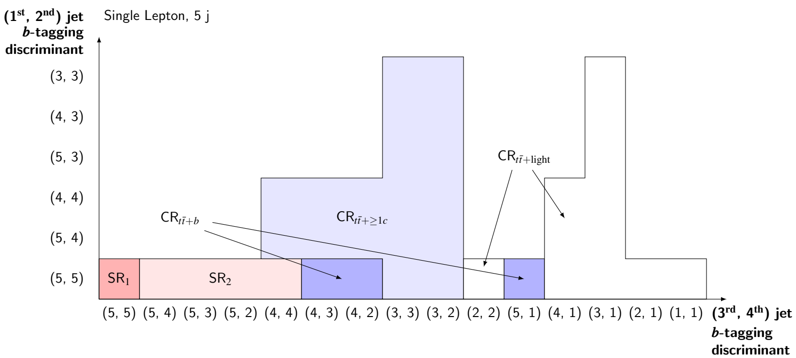
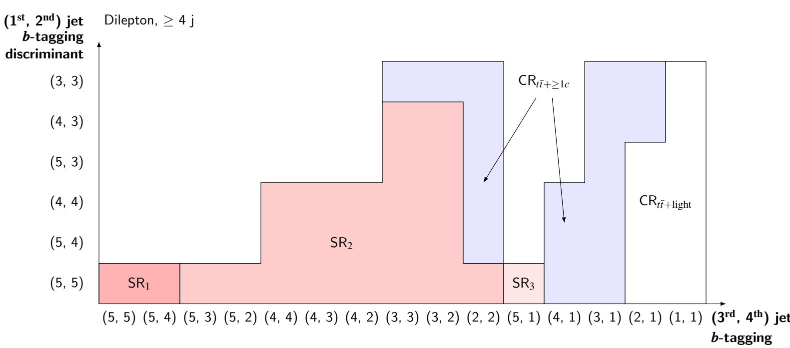
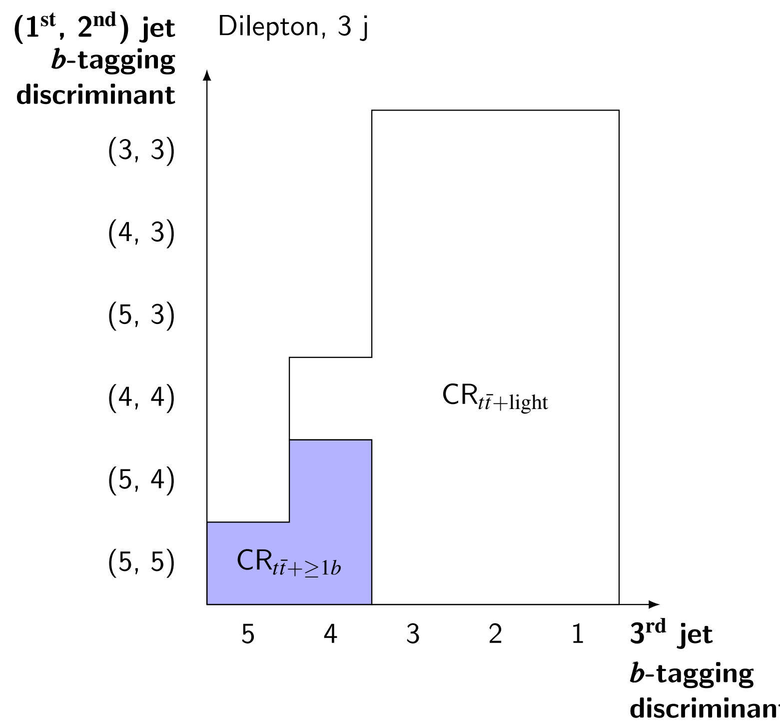
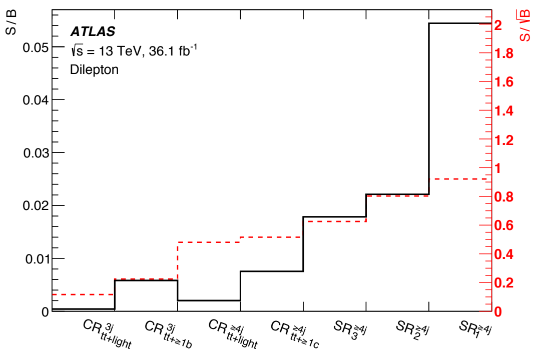
Working point	none	loose	medium	tight	Very tight
B-jet efficiency	100%	85%	77%	70%	60%
C-jet rejection	1	3	6	12	34
Light-jet rejection	1	33	134	381	1538
B-tag discriminant	1	2	3	4	5

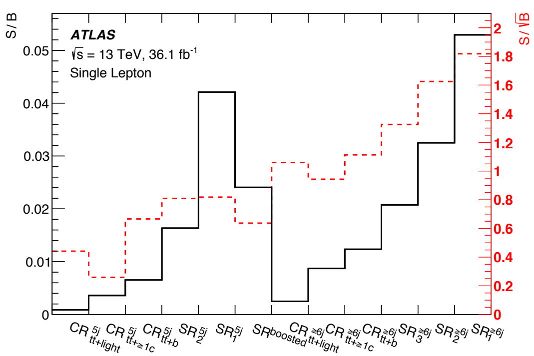

(1st, 2nd) jet b-tagging discriminant
Single Lepton, ≥ 6 j
(3, 3)
(4, 3)
(5, 3)
(4, 4)
(5, 4)
(5, 5)
CR$_{t\bar{t}+b}$
CR$_{t\bar{t}+\geq 1c}$
CR$_{t\bar{t}+\text{light}}$
SR$_1$
SR$_2$
SR$_3$
(5, 5) (5, 4) (5, 3) (5, 2) (4, 4) (4, 3) (4, 2) (3, 3) (3, 2) (2, 2) (5, 1) (4, 1) (3, 1) (2, 1) (1, 1)
(3rd, 4th) jet b-tagging discriminant

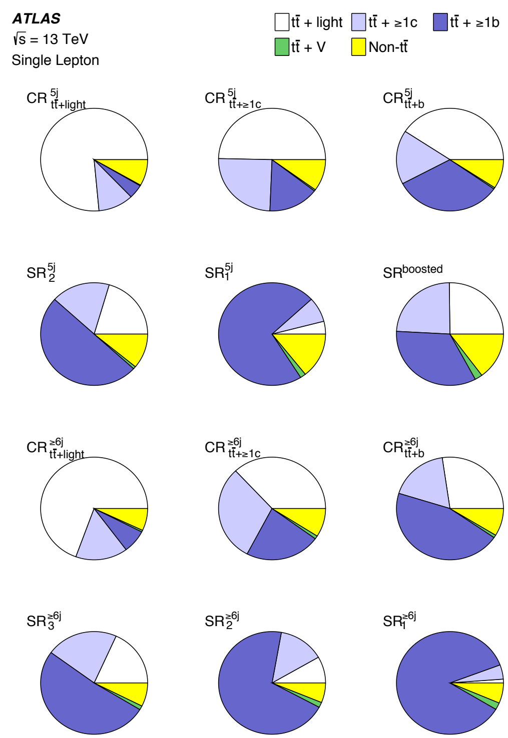

(1st, 2nd) jet b-tagging discriminant
Single Lepton, 5 j
(3, 3)
(4, 3)
(5, 3)
(4, 4)
(5, 4)
(5, 5)
CR$_{t\bar{t}+b}$
CR$_{t\bar{t}+\geq 1c}$
CR$_{t\bar{t}+\text{light}}$
SR$_1$
SR$_2$
(5, 5) (5, 4) (5, 3) (5, 2) (4, 4) (4, 3) (4, 2) (3, 3) (3, 2) (2, 2) (5, 1) (4, 1) (3, 1) (2, 1) (1, 1)
(3rd, 4th) jet b-tagging discriminant

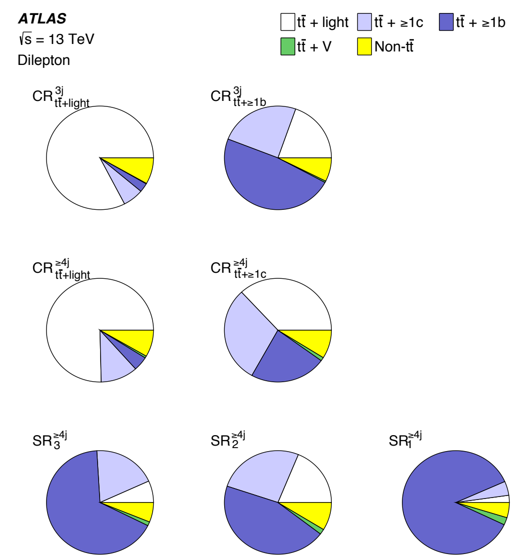

(1st, 2nd) jet b-tagging discriminant
Dilepton, ≥ 4 j
(3, 3)
(4, 3)
(5, 3)
(4, 4)
(5, 4)
(5, 5)
CR$_{t\bar{t}+\geq 1c}$
CR$_{t\bar{t}+\text{light}}$
SR$_1$
SR$_2$
SR$_3$
(5, 5) (5, 4) (5, 3) (5, 2) (4, 4) (4, 3) (4, 2) (3, 3) (3, 2) (2, 2) (5, 1) (4, 1) (3, 1) (2, 1) (1, 1)
(3rd, 4th) jet b-tagging discriminant

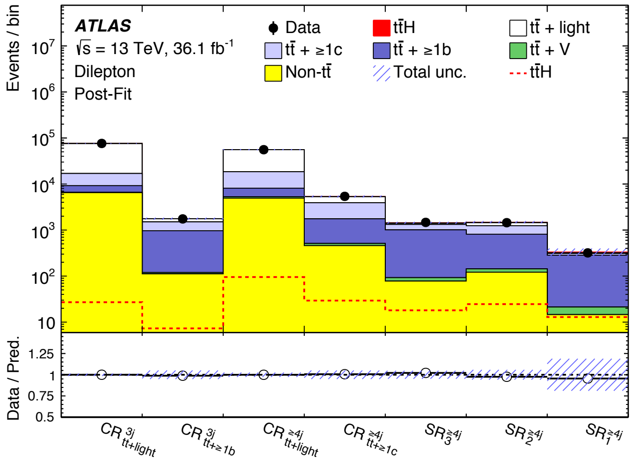

(1st, 2nd) jet b-tagging discriminant
Dilepton, 3 j
(3, 3)
(4, 3)
(5, 3)
(4, 4)
(5, 4)
(5, 5)
CR$_{t\bar{t}+\text{light}}$
CR$_{t\bar{t}+\geq 1b}$
5
4
3
2
1
3rd jet b-tagging discriminant

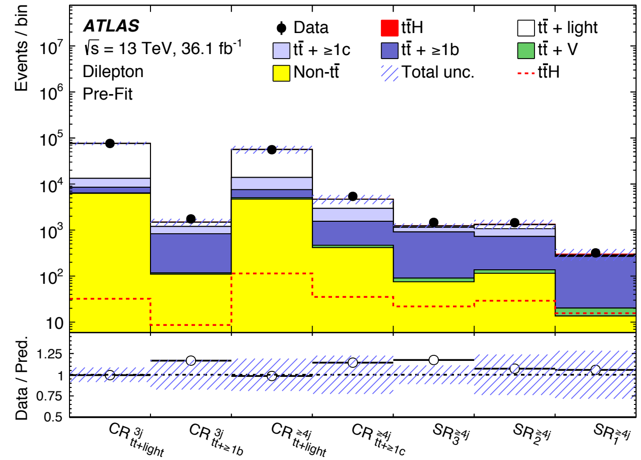

ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Dilepton
S / B
S / √B
0.05
0.04
0.03
0.02
0.01
0
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
CR 3j tt+light
CR 3j tt+≥1b
CR ≥4j tt+light
CR ≥4j tt+≥1c
SR ≥4j 3
SR ≥4j 2
SR ≥4j 1

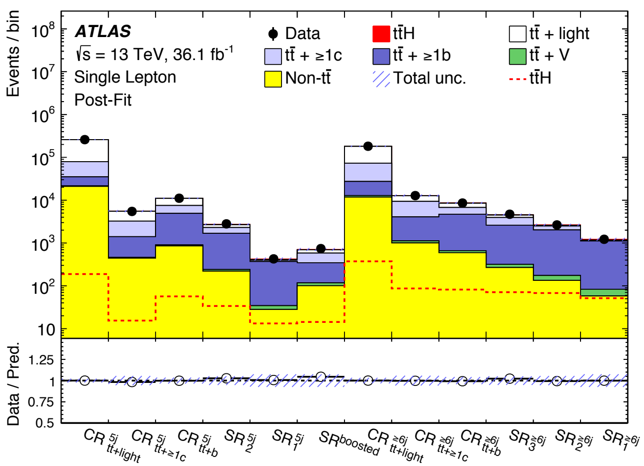

ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Single Lepton
S / B
S / √B
0.05
0.04
0.03
0.02
0.01
0
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
CR 5j tt+light
CR 5j tt+≥1c
CR 5j tt+b
SR 5j 2
SR 5j 1
SR boosted
CR ≥6j tt+light
CR ≥6j tt+≥1c
CR ≥6j tt+b
SR ≥6j 3
SR ≥6j 2
SR ≥6j 1

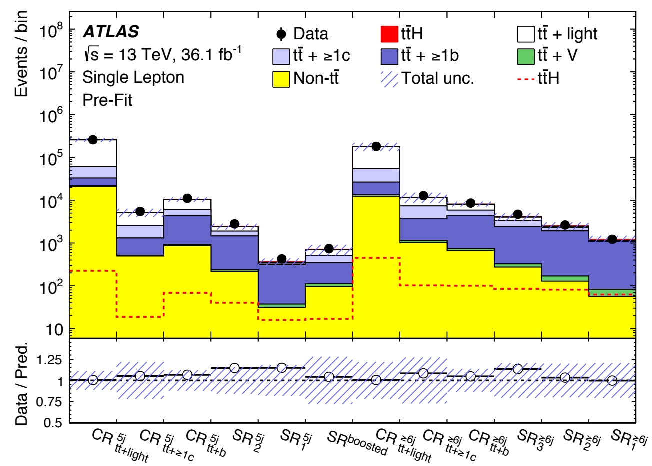

ATLAS
√s = 13 TeV
Single Lepton
tt̄ + light
tt̄ + ≥1c
tt̄ + ≥1b
tt̄ + V
Non-tt̄
CR 5j tt+light
CR 5j tt+≥1c
CR 5j tt+b
SR 5j 2
SR 5j 1
SR boosted
CR ≥6j tt+light
CR ≥6j tt+≥1c
CR ≥6j tt+b
SR ≥6j 3
SR ≥6j 2
SR ≥6j 1


ATLAS
√s = 13 TeV
Dilepton
tt̄ + light
tt̄ + ≥1c
tt̄ + ≥1b
tt̄ + V
Non-tt̄
CR 3j tt+light
CR 3j tt+≥1b
CR ≥4j tt+light
CR ≥4j tt+≥1c
SR ≥4j 3
SR ≥4j 2
SR ≥4j 1

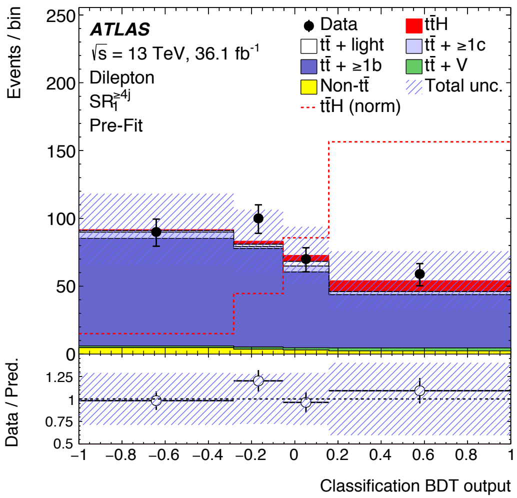

ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Dilepton
Post-Fit
Data
tt̄H
tt̄ + light
tt̄ + ≥1c
tt̄ + ≥1b
tt̄ + V
Non-tt̄
Total unc.
tt̄H
Events / bin
Data / Pred.
CR 3j tt+light
CR 3j tt+≥1b
CR ≥4j tt+light
CR ≥4j tt+≥1c
SR ≥4j 3
SR ≥4j 2
SR ≥4j 1


ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Dilepton
Pre-Fit
Data
tt̄H
tt̄ + light
tt̄ + ≥1c
tt̄ + ≥1b
tt̄ + V
Non-tt̄
Total unc.
tt̄H
Events / bin
Data / Pred.
CR 3j tt+light
CR 3j tt+≥1b
CR ≥4j tt+light
CR ≥4j tt+≥1c
SR ≥4j 3
SR ≥4j 2
SR ≥4j 1

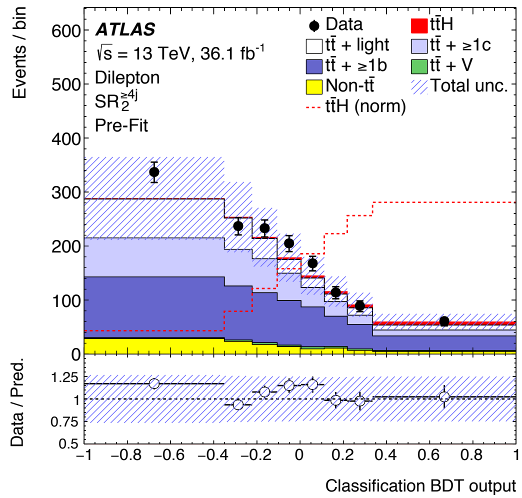

ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Single Lepton
Post-Fit
Data
tt̄H
tt̄ + light
tt̄ + ≥1c
tt̄ + ≥1b
tt̄ + V
Non-tt̄
Total unc.
tt̄H
Events / bin
Data / Pred.
CR 5j tt+light
CR 5j tt+≥1c
CR 5j tt+b
SR 5j 2
SR 5j 1
SR boosted
CR ≥6j tt+light
CR ≥6j tt+≥1c
CR ≥6j tt+b
SR ≥6j 3
SR ≥6j 2
SR ≥6j 1


ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Single Lepton
Pre-Fit
Data
tt̄H
tt̄ + light
tt̄ + ≥1c
tt̄ + ≥1b
tt̄ + V
Non-tt̄
Total unc.
tt̄H
Events / bin
Data / Pred.
CR 5j tt+light
CR 5j tt+≥1c
CR 5j tt+b
SR 5j 2
SR 5j 1
SR boosted
CR ≥6j tt+light
CR ≥6j tt+≥1c
CR ≥6j tt+b
SR ≥6j 3
SR ≥6j 2
SR ≥6j 1

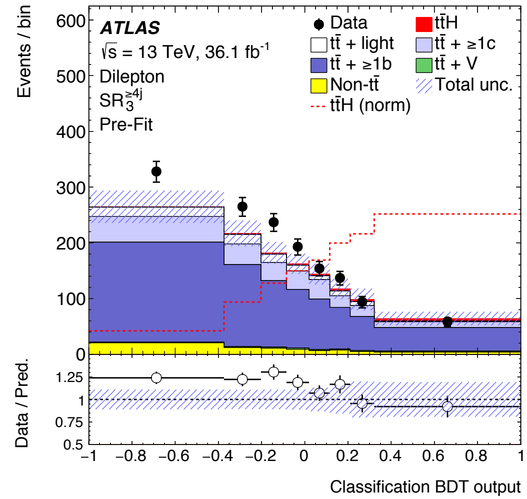
tth(bb)



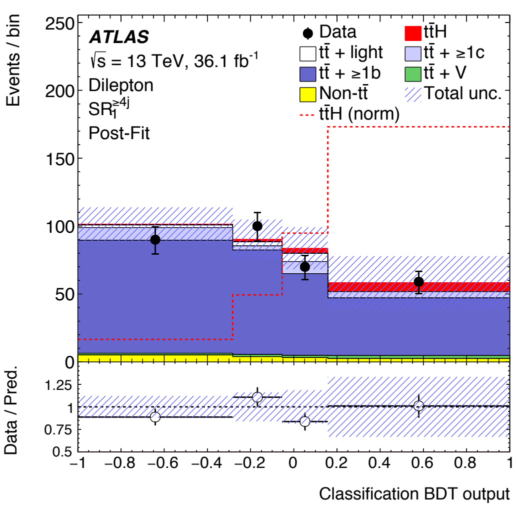
ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Dilepton
SR1≥4j
Pre-Fit
Data
tt̄ + light
tt̄ + ≥1b
Non-tt̄
tt̄H (norm)
tt̄H
tt̄ + ≥1c
tt̄ + V
Total unc.
Events / bin
Data / Pred.
Classification BDT output



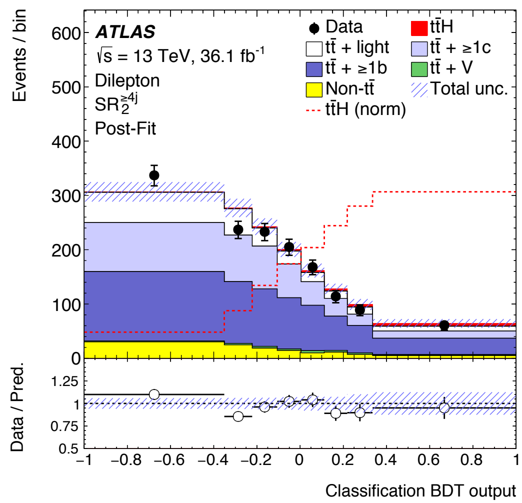
ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Dilepton
SR2≥4j
Pre-Fit
Data
tt̄ + light
tt̄ + ≥1b
Non-tt̄
tt̄H (norm)
tt̄H
tt̄ + ≥1c
tt̄ + V
Total unc.
Events / bin
Data / Pred.
Classification BDT output



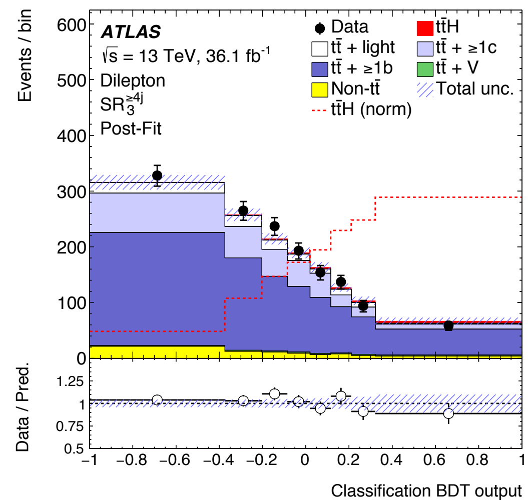
ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Dilepton
SR3≥4j
Pre-Fit
Data
tt̄ + light
tt̄ + ≥1b
Non-tt̄
tt̄H (norm)
tt̄H
tt̄ + ≥1c
tt̄ + V
Total unc.
Events / bin
Data / Pred.
Classification BDT output



ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Dilepton
SR1≥4j
Post-Fit
Data
tt̄ + light
tt̄ + ≥1b
Non-tt̄
tt̄H (norm)
tt̄H
tt̄ + ≥1c
tt̄ + V
Total unc.
Events / bin
Data / Pred.
Classification BDT output

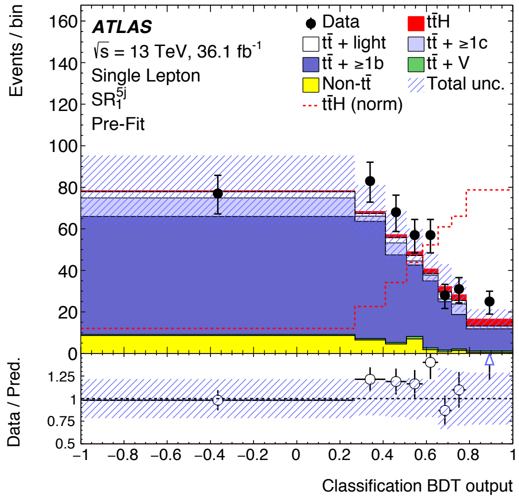


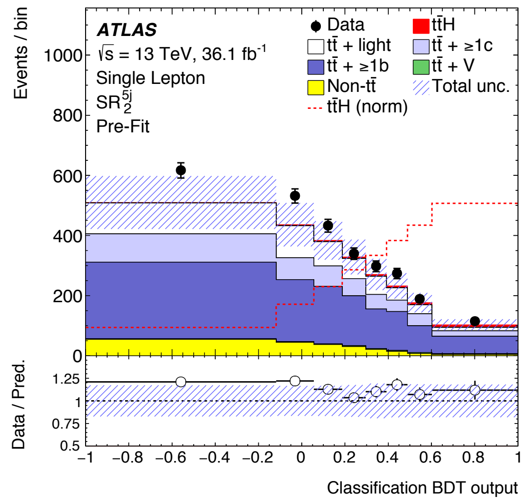
ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Dilepton
SR2≥4j
Post-Fit
Data
tt̄ + light
tt̄ + ≥1b
Non-tt̄
tt̄H (norm)
tt̄H
tt̄ + ≥1c
tt̄ + V
Total unc.
Events / bin
Data / Pred.
Classification BDT output

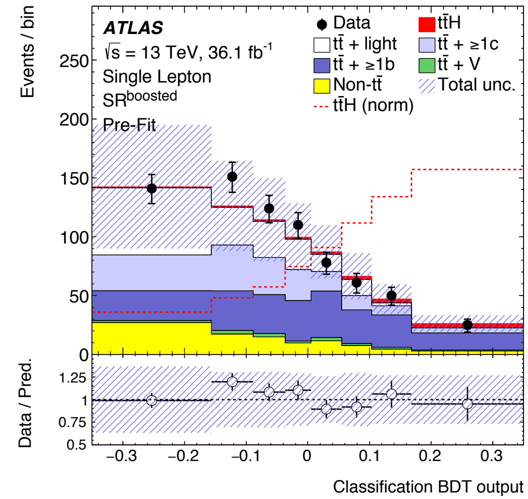


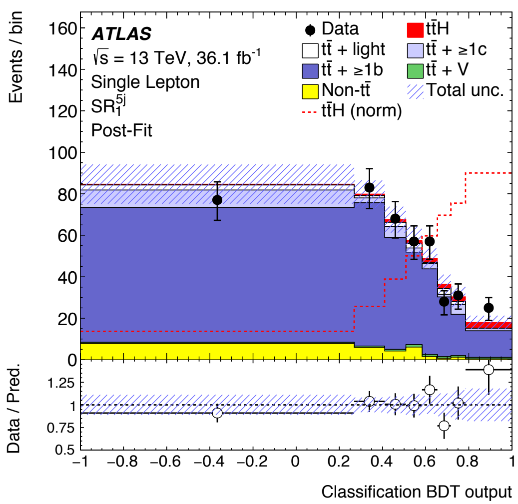
ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Dilepton
SR3≥4j
Post-Fit
Data
tt̄ + light
tt̄ + ≥1b
Non-tt̄
tt̄H (norm)
tt̄H
tt̄ + ≥1c
tt̄ + V
Total unc.
Events / bin
Data / Pred.
Classification BDT output

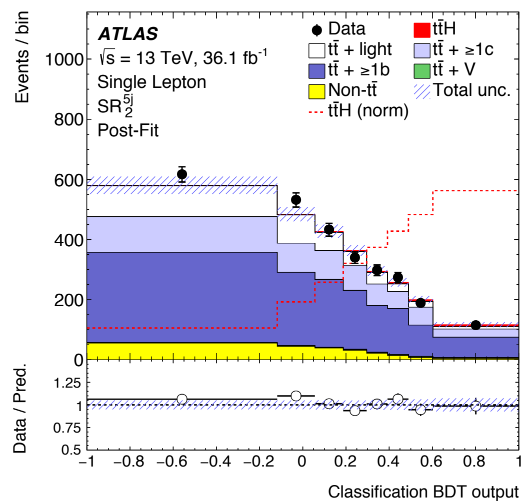
tth(bb)

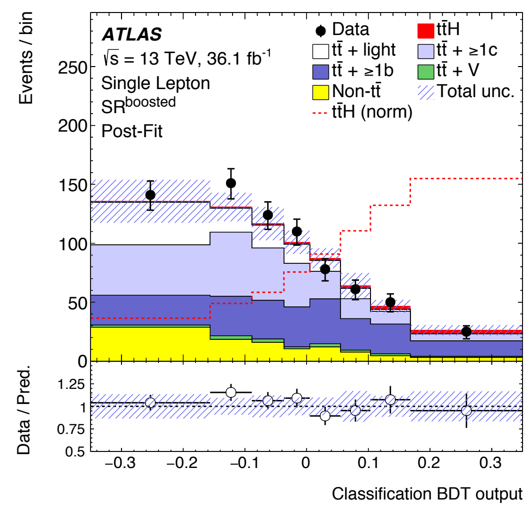

ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Single Lepton
SR₁⁵ʲ
Pre-Fit
Data
tt̄ + light
tt̄ + ≥1b
Non-tt̄
tt̄H (norm)
tt̄H
tt̄ + ≥1c
tt̄ + V
Total unc.
Events / bin
Data / Pred.
Classification BDT output

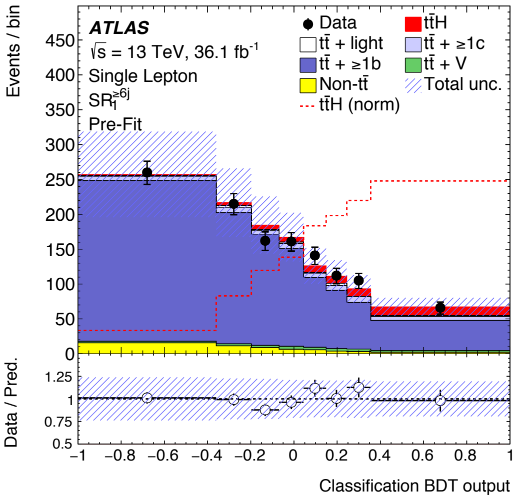

ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Single Lepton
SR₂⁵ʲ
Pre-Fit
Data
tt̄ + light
tt̄ + ≥1b
Non-tt̄
tt̄H (norm)
tt̄H
tt̄ + ≥1c
tt̄ + V
Total unc.
Events / bin
Data / Pred.
Classification BDT output

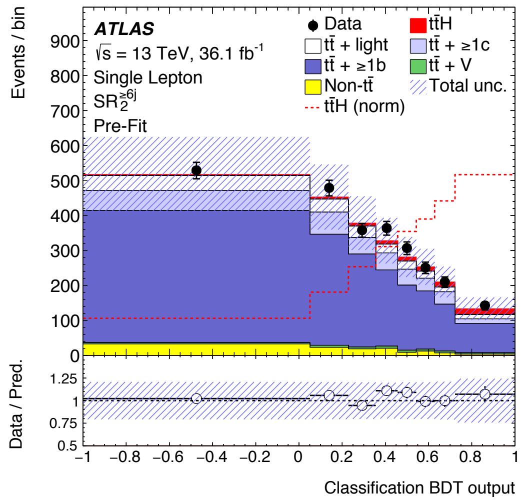

ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Single Lepton
SR^boosted
Pre-Fit
Data
tt̄ + light
tt̄ + ≥1b
Non-tt̄
tt̄H (norm)
tt̄H
tt̄ + ≥1c
tt̄ + V
Total unc.
Events / bin
Data / Pred.
Classification BDT output

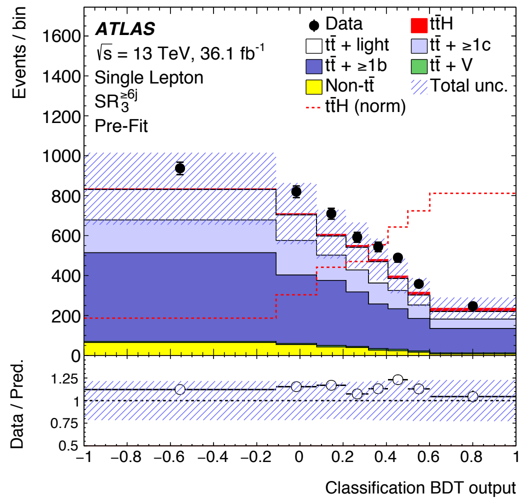

ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Single Lepton
SR₁⁵ʲ
Post-Fit
Data
tt̄ + light
tt̄ + ≥1b
Non-tt̄
tt̄H (norm)
tt̄H
tt̄ + ≥1c
tt̄ + V
Total unc.
Events / bin
Data / Pred.
Classification BDT output

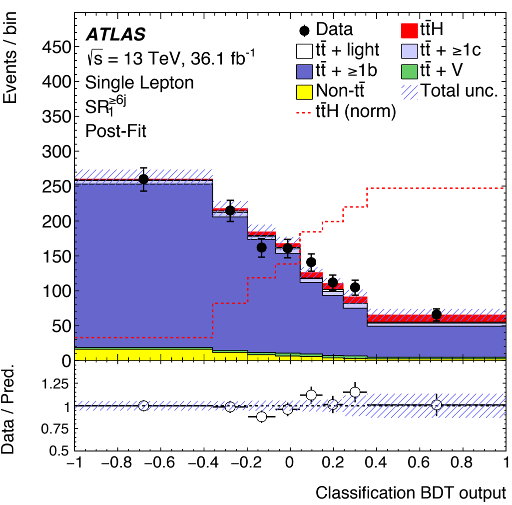

ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Single Lepton
SR₂⁵ʲ
Post-Fit
Data
tt̄ + light
tt̄ + ≥1b
Non-tt̄
tt̄H (norm)
tt̄H
tt̄ + ≥1c
tt̄ + V
Total unc.
Events / bin
Data / Pred.
Classification BDT output

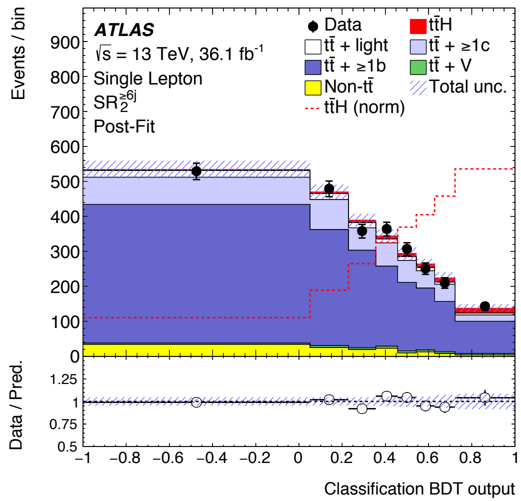

ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Single Lepton
SR^boosted
Post-Fit
Data
tt̄ + light
tt̄ + ≥1b
Non-tt̄
tt̄H (norm)
tt̄H
tt̄ + ≥1c
tt̄ + V
Total unc.
Events / bin
Data / Pred.
Classification BDT output

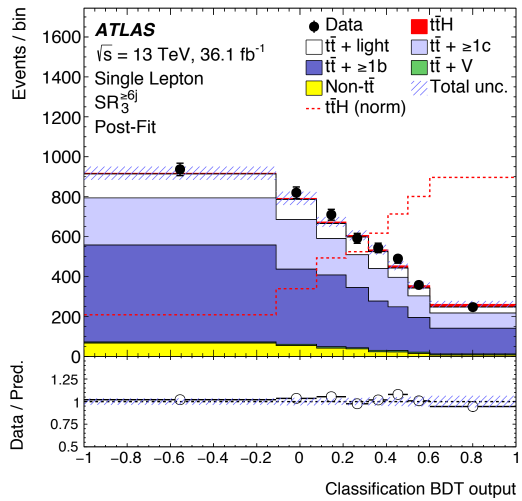

ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Single Lepton
SR1≥6j
Pre-Fit
Data
tt̄ + light
tt̄ + ≥1b
Non-tt̄
tt̄H (norm)
tt̄H
tt̄ + ≥1c
tt̄ + V
Total unc.
Events / bin
Data / Pred.
Classification BDT output

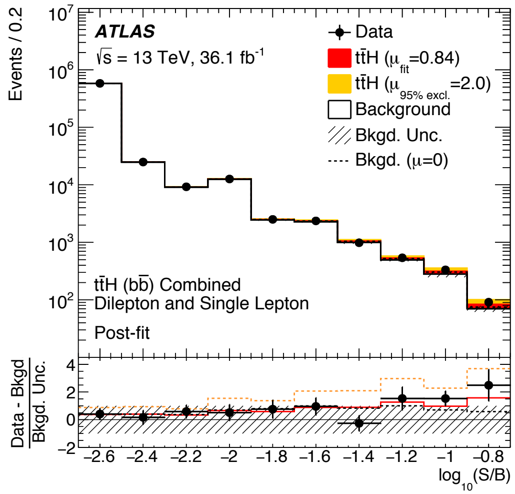

ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Single Lepton
SR2≥6j
Pre-Fit
Data
tt̄ + light
tt̄ + ≥1b
Non-tt̄
tt̄H (norm)
tt̄H
tt̄ + ≥1c
tt̄ + V
Total unc.
Events / bin
Data / Pred.
Classification BDT output

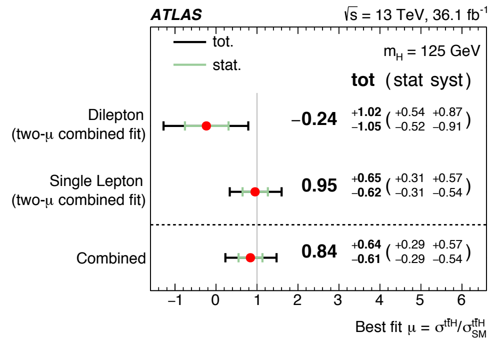

ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Single Lepton
SR3≥6j
Pre-Fit
Data
tt̄ + light
tt̄ + ≥1b
Non-tt̄
tt̄H (norm)
tt̄H
tt̄ + ≥1c
tt̄ + V
Total unc.
Events / bin
Data / Pred.
Classification BDT output

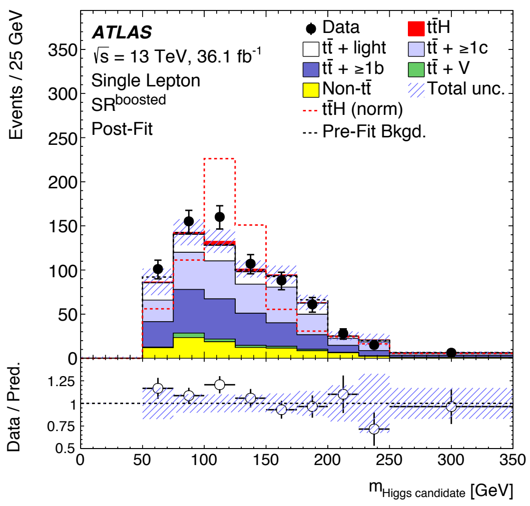

ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Single Lepton
SR1≥6j
Post-Fit
Data
tt̄ + light
tt̄ + ≥1b
Non-tt̄
tt̄H (norm)
tt̄H
tt̄ + ≥1c
tt̄ + V
Total unc.
Events / bin
Data / Pred.
Classification BDT output

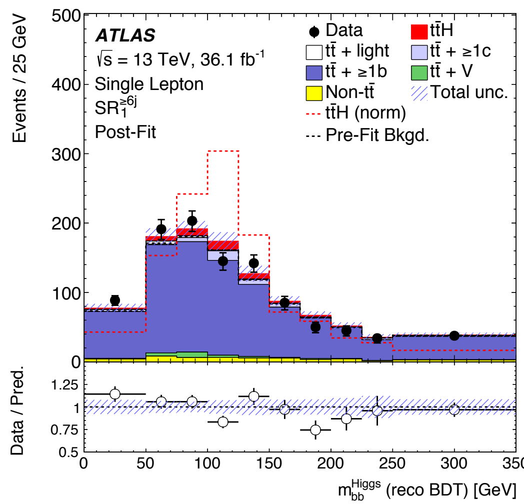

ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Single Lepton
SR2≥6j
Post-Fit
Data
tt̄ + light
tt̄ + ≥1b
Non-tt̄
tt̄H (norm)
tt̄H
tt̄ + ≥1c
tt̄ + V
Total unc.
Events / bin
Data / Pred.
Classification BDT output

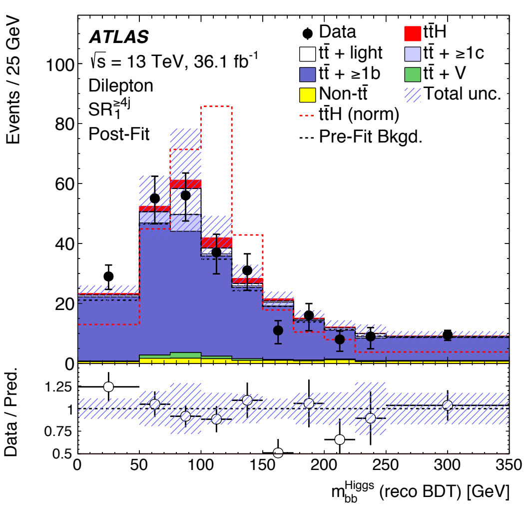

ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Single Lepton
SR3≥6j
Post-Fit
Data
tt̄ + light
tt̄ + ≥1b
Non-tt̄
tt̄H (norm)
tt̄H
tt̄ + ≥1c
tt̄ + V
Total unc.
Events / bin
Data / Pred.
Classification BDT output

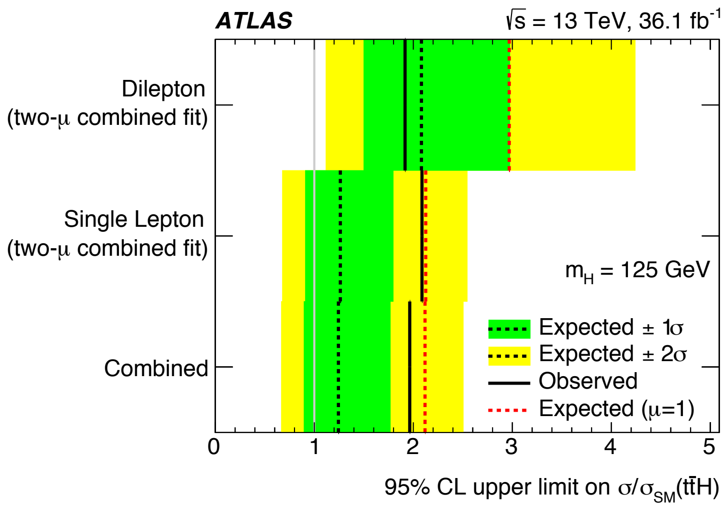

ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Data
tt̄H (μfit=0.84)
tt̄H (μ95% excl.=2.0)
Background
Bkgd. Unc.
Bkgd. (μ=0)
tt̄H (bb̄) Combined
Dilepton and Single Lepton
Post-fit
Events / 0.2
Data - Bkgd / Bkgd. Unc.
log10(S/B)

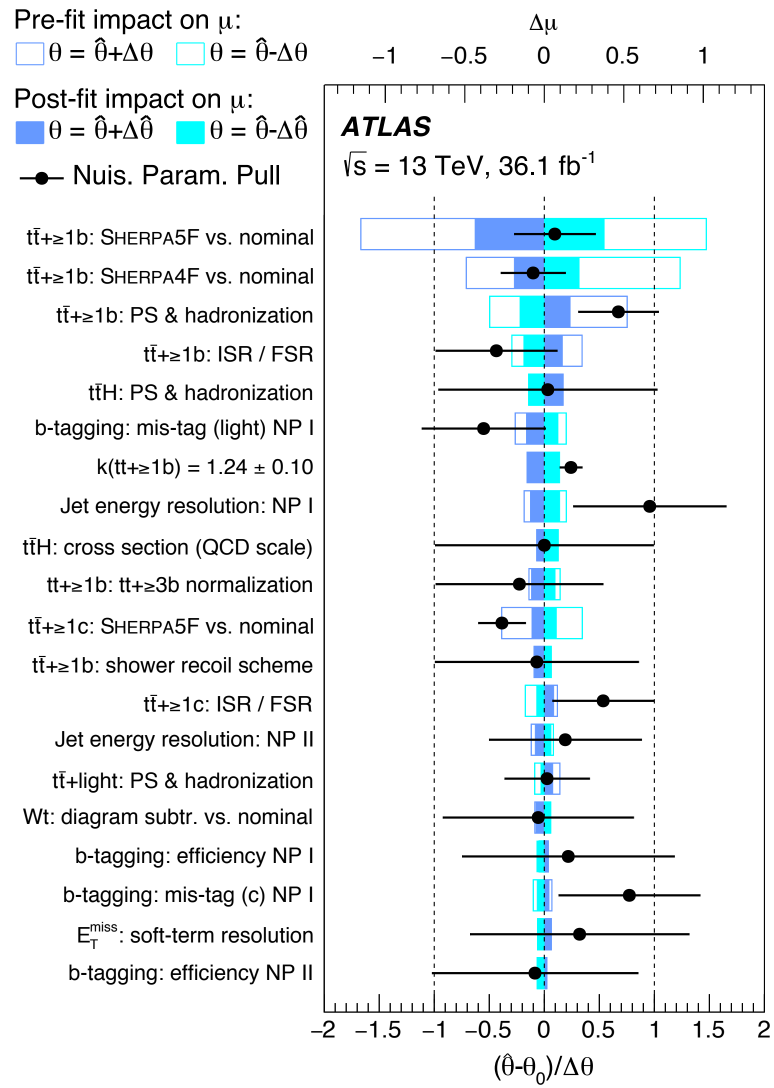

ATLAS
√s = 13 TeV, 36.1 fb⁻¹
tot.
stat.
mH = 125 GeV
tot (stat syst)
Dilepton (two-μ combined fit)
−0.24 +1.02 −1.05 (+0.54 −0.52 +0.87 −0.91)
Single Lepton (two-μ combined fit)
0.95 +0.65 −0.62 (+0.31 −0.31 +0.57 −0.54)
Combined
0.84 +0.64 −0.61 (+0.29 −0.29 +0.57 −0.54)
Best fit μ = σtt̄H/σtt̄H SM


ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Single Lepton
SRboosted
Post-Fit
Data
tt̄H
tt̄ + light
tt̄ + ≥1c
tt̄ + ≥1b
tt̄ + V
Non-tt̄
Total unc.
tt̄H (norm)
Pre-Fit Bkgd.
Events / 25 GeV
Data / Pred.
mHiggs candidate [GeV]


ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Single Lepton
SR1≥6j
Post-Fit
Data
tt̄H
tt̄ + light
tt̄ + ≥1c
tt̄ + ≥1b
tt̄ + V
Non-tt̄
Total unc.
tt̄H (norm)
Pre-Fit Bkgd.
Events / 25 GeV
Data / Pred.
mbbHiggs (reco BDT) [GeV]


ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Dilepton
SR1≥4j
Post-Fit
Data
tt̄H
tt̄ + light
tt̄ + ≥1c
tt̄ + ≥1b
tt̄ + V
Non-tt̄
Total unc.
tt̄H (norm)
Pre-Fit Bkgd.
Events / 25 GeV
Data / Pred.
mbbHiggs (reco BDT) [GeV]


ATLAS
√s = 13 TeV, 36.1 fb-1
Dilepton
(two-μ combined fit)
Single Lepton
(two-μ combined fit)
Combined
mH = 125 GeV
Expected ± 1σ
Expected ± 2σ
Observed
Expected (μ=1)
0
1
2
3
4
5
95% CL upper limit on σ/σSM(tt̄H)


Pre-fit impact on μ:
θ = θ̂+Δθ
θ = θ̂-Δθ
Post-fit impact on μ:
θ = θ̂+Δθ̂
θ = θ̂-Δθ̂
Nuis. Param. Pull
Δμ
−1
−0.5
0
0.5
1
ATLAS
√s = 13 TeV, 36.1 fb-1
tt̄+≥1b: SHERPA5F vs. nominal
tt̄+≥1b: SHERPA4F vs. nominal
tt̄+≥1b: PS & hadronization
tt̄+≥1b: ISR / FSR
tt̄H: PS & hadronization
b-tagging: mis-tag (light) NP I
k(tt+≥1b) = 1.24 ± 0.10
Jet energy resolution: NP I
tt̄H: cross section (QCD scale)
tt+≥1b: tt+≥3b normalization
tt̄+≥1c: SHERPA5F vs. nominal
tt̄+≥1b: shower recoil scheme
tt̄+≥1c: ISR / FSR
Jet energy resolution: NP II
tt̄+light: PS & hadronization
Wt: diagram subtr. vs. nominal
b-tagging: efficiency NP I
b-tagging: mis-tag (c) NP I
ETmiss: soft-term resolution
b-tagging: efficiency NP II
−2
−1.5
−1
−0.5
0
0.5
1
1.5
2
(θ̂-θ0)/Δθ

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	

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

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 $H_{\mathrm{T}}/2$ 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%	$t\bar{t} + \geq 1b$

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	-	-	✓
$m_{bb}^{\text{min}\ \Delta R}$	Invariant mass of the b-tagged jet pair with minimum ΔR	✓	-	✓
$m_{\text{jj}}^{\text{max}\ p_{\text{T}}}$	Invariant mass of the jet pair with maximum p_{T}	✓	-	-
$m_{bb}^{\text{max}\ p_{\text{T}}}$	Invariant mass of the b-tagged jet pair with maximum p_{T}	✓	-	✓
$\Delta\eta_{bb}^{\text{avg}}$	Average $\Delta\eta$ for all b-tagged jet pairs	✓	✓	✓
$\Delta\eta_{\ell,\text{j}}^{\text{max}}$	Maximum $\Delta\eta$ between a jet and a lepton	-	✓	✓
$\Delta R_{bb}^{\text{max}\ p_{\text{T}}}$	ΔR between the b-tagged jet pair with maximum p_{T}	-	✓	✓
$N_{bb}^{\text{Higgs}\ 30}$	Number of b-tagged jet pairs with invariant mass within 30 GeV of the Higgs-boson mass	✓	✓	-
$n_{\text{jets}}^{p_{\text{T}}>40}$	Number of jets with $p_{\text{T}} > 40$ GeV	-	✓	✓
$\text{Aplanarity}_{b\text{-jet}}$	$1.5\lambda_2$, where λ_2 is the second eigenvalue of the momentum tensor [100] built with all b-tagged jets	-	✓	-
$H_{\text{T}}^{\text{all}}$	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	✓*	-	-
$\Delta R_{H,\ell}^{\text{min}}$	Minimum ΔR between Higgs candidate and lepton	✓	✓	✓
$\Delta R_{H,b}^{\text{min}}$	Minimum ΔR between Higgs candidate and b-jet from top	✓	✓	-
$\Delta R_{H,b}^{\text{max}}$	Maximum ΔR between Higgs candidate and b-jet from top	-	✓	-
$\Delta R_{bb}^{\text{Higgs}}$	ΔR between the two jets matched to the Higgs candidate	-	✓	-
Variables from b-tagging				
$w_{b\text{-tag}}^{\text{Higgs}}$	Sum of b-tagging discriminants of jets from best Higgs candidate from the reconstruction BDT	-	✓	-

Sample	$\text{CR}^{5j}_{t\bar{t}+\text{light}}$ Pre-fit	$\text{CR}^{5j}_{t\bar{t}+\text{light}}$ Post-fit	$\text{CR}^{5j}_{t\bar{t}+\geq 1c}$ Pre-fit	$\text{CR}^{5j}_{t\bar{t}+\geq 1c}$ Post-fit	$\text{CR}^{5j}_{t\bar{t}+b}$ Pre-fit	$\text{CR}^{5j}_{t\bar{t}+b}$ 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	$\text{SR}^{\text{boosted}}$ Pre-fit	$\text{SR}^{\text{boosted}}$ 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	

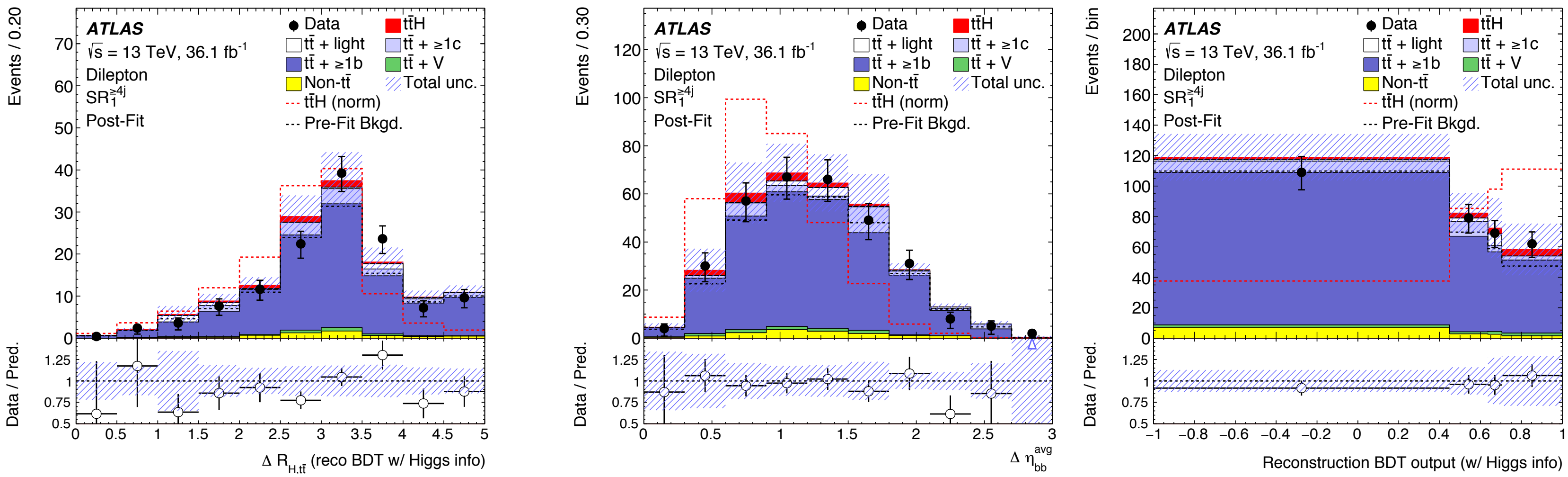
Sample	$\text{CR}^{\geq 6j}_{t\bar{t}+\text{light}}$ Pre-fit	$\text{CR}^{\geq 6j}_{t\bar{t}+\text{light}}$ Post-fit	$\text{CR}^{\geq 6j}_{t\bar{t}+\geq 1c}$ Pre-fit	$\text{CR}^{\geq 6j}_{t\bar{t}+\geq 1c}$ Post-fit	$\text{CR}^{\geq 6j}_{t\bar{t}+b}$ Pre-fit	$\text{CR}^{\geq 6j}_{t\bar{t}+b}$ Post-fit
$t\bar{t}H$	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	$\text{SR}^{\geq 6j}_{3}$ Pre-fit	$\text{SR}^{\geq 6j}_{3}$ Post-fit	$\text{SR}^{\geq 6j}_{2}$ Pre-fit	$\text{SR}^{\geq 6j}_{2}$ Post-fit	$\text{SR}^{\geq 6j}_{1}$ Pre-fit	$\text{SR}^{\geq 6j}_{1}$ 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	

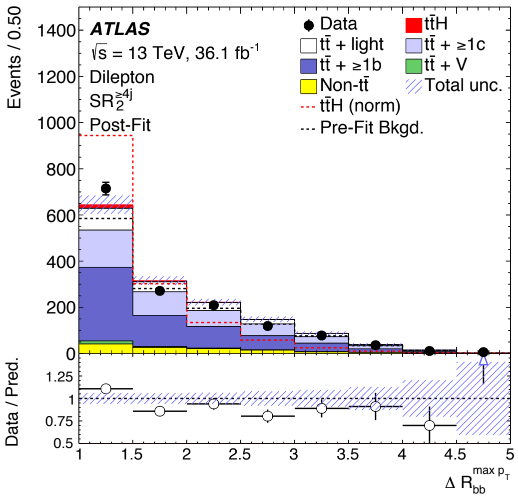
Northern Illinois University

Variable	Definition	$SR^{\geq 6j}_{1,2,3}$	$SR^{5j}_{1,2}$
General kinematic variables			
ΔR^{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	–	✓
$N^{Higgs\ 30}_{bb}$	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	✓	✓
$m_{H,b_{lep\ top}}$	Mass of Higgs candidate and b-jet from leptonic top candidate	✓	–
ΔR^{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	✓*	✓*
$\Delta R_{H,lep\ top}$	ΔR between Higgs candidate and leptonic top candidate	✓	–
$\Delta R_{H,b_{had\ top}}$	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 $SR^{\geq 6j}_1$ only)	✓	–
Variables from b-tagging (not in $SR^{\geq 6j}_1$)			
$w^{Higgs}_{b\text{-tag}}$	Sum of b-tagging discriminants of jets from best Higgs candidate from the reconstruction BDT	✓	✓
B^3_{jet}	3rd largest jet b-tagging discriminant	✓	✓
B^4_{jet}	4th largest jet b-tagging discriminant	✓	✓
B^5_{jet}	5th largest jet b-tagging discriminant	✓	✓

Variable	Definition
Variables from jet reclustering	
$\Delta R_{H,t}$	ΔR between the Higgs-boson and top-quark candidates
$\Delta R_{t,b^{add}}$	ΔR between the top-quark candidate and additional b-jet
$\Delta R_{H,b^{add}}$	ΔR between the Higgs-boson candidate and additional b-jet
$\Delta R_{H,\ell}$	ΔR between the Higgs-boson candidate and lepton
$m_{Higgs\ candidate}$	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
$w^{add}_{b\text{-tag}}/w_{b\text{-tag}}$	Ratio of sum of b-tagging discriminants of additional b-jets to all b-jets


ATLAS
√s = 13 TeV, 36.1 fb-1
Dilepton
SR≥4j 1
Post-Fit
Data
tt̄H
tt̄ + light
tt̄ + ≥1c
tt̄ + ≥1b
tt̄ + V
Non-tt̄
Total unc.
tt̄H (norm)
Pre-Fit Bkgd.
Events / 0.20
Data / Pred.
Δ RH,tt̄ (reco BDT w/ Higgs info)
Events / 0.30
Δ ηavg bb
Events / bin
Reconstruction BDT output (w/ Higgs info)

tth(bb)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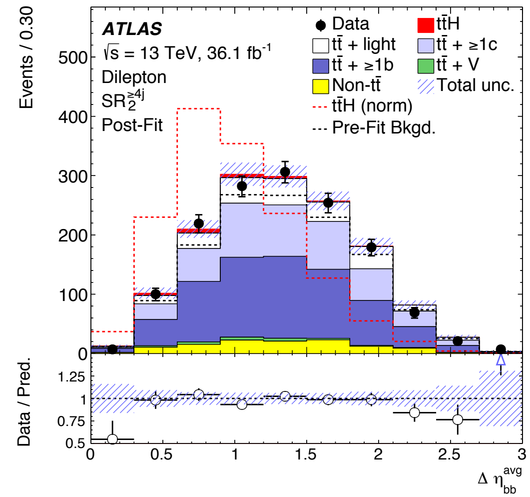
√s = 13 TeV, 36.1 fb-1
Dilepton
SR2≥4j
Post-Fit
Data
tt̄ + light
tt̄ + ≥1b
Non-tt̄
tt̄H (norm)
Pre-Fit Bkgd.
tt̄H
tt̄ + ≥1c
tt̄ + V
Total unc.
Events / 0.50
Data / Pred.
Δ R_bb^max pT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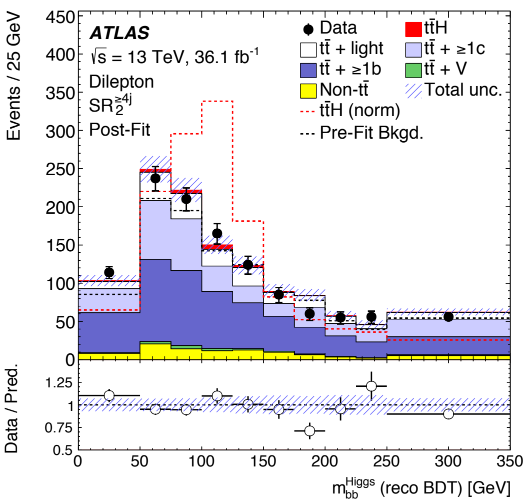
Dilepton
SR2≥4j
Post-Fit
Data
tt̄ + light
tt̄ + ≥1b
Non-tt̄
tt̄H (norm)
Pre-Fit Bkgd.
tt̄H
tt̄ + ≥1c
tt̄ + V
Total unc.
Events / 0.30
Data / Pred.
Δ η_bb^avg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Dilepton
SR2≥4j
Post-Fit
Data
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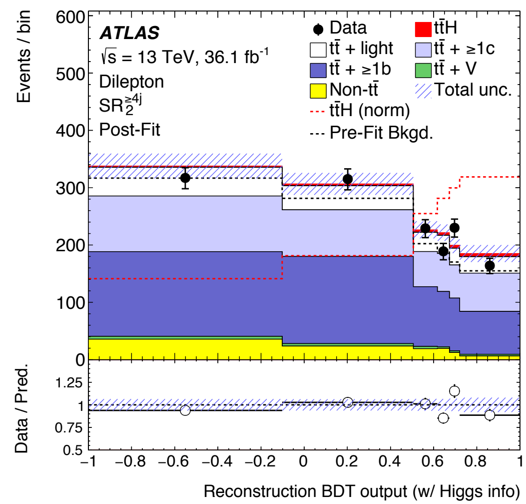
tt̄ + ≥1b
Non-tt̄
tt̄H (norm)
Pre-Fit Bkgd.
tt̄H
tt̄ + ≥1c
tt̄ + V
Total unc.
Events / 25 GeV
Data / Pred.
m_bb^Higgs (reco BDT) [GeV]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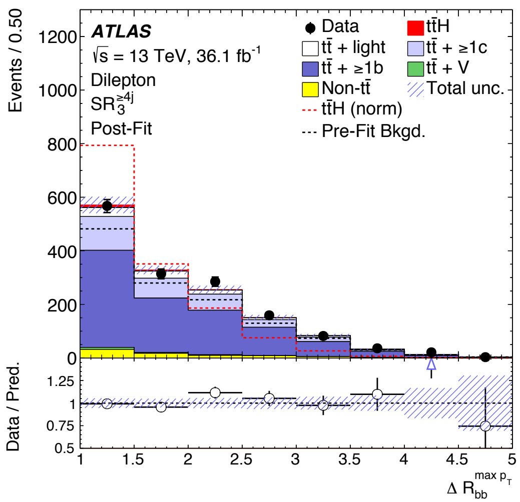
Dilepton
SR2≥4j
Post-Fit
Data
tt̄ + light
tt̄ + ≥1b
Non-tt̄
tt̄H (norm)
Pre-Fit Bkgd.
tt̄H
tt̄ + ≥1c
tt̄ + V
Total unc.
Events / bin
Data / Pred.
Reconstruction BDT output (w/ Higgs info)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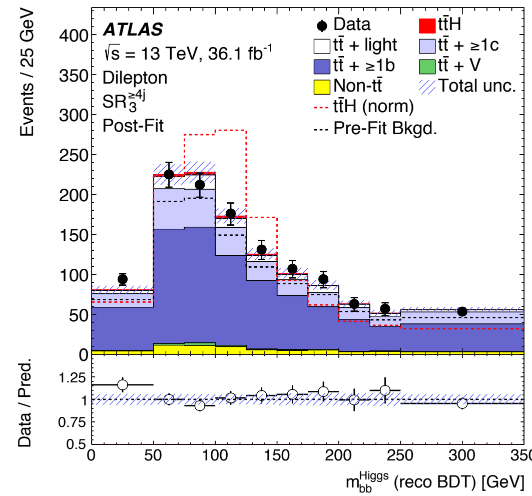
√s = 13 TeV, 36.1 fb⁻¹
Dilepton
SR≥4j 3
Post-Fit
Data
tt̄H
tt̄ + light
tt̄ + ≥1c
tt̄ + ≥1b
tt̄ + V
Non-tt̄
Total unc.
tt̄H (norm)
Pre-Fit Bkgd.
Events / 0.50
Data / Pred.
Δ R bb max pT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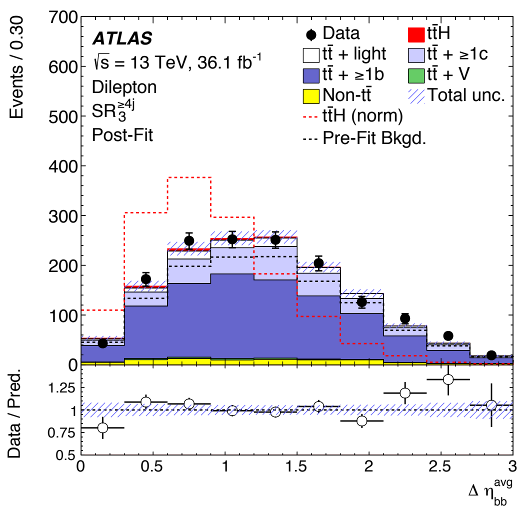
√s = 13 TeV, 36.1 fb⁻¹
Dilepton
SR≥4j 3
Post-Fit
Data
tt̄H
tt̄ + light
tt̄ + ≥1c
tt̄ + ≥1b
tt̄ + V
Non-tt̄
Total unc.
tt̄H (norm)
Pre-Fit Bkgd.
Events / 25 GeV
Data / Pred.
m bb Higgs (reco BDT) [GeV]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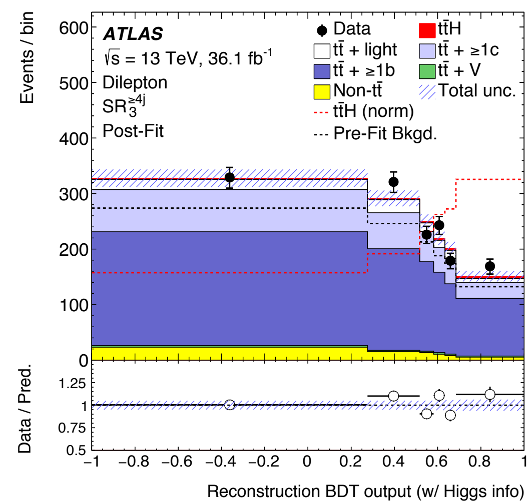
Dilepton
SR≥4j 3
Post-Fit
Data
tt̄H
tt̄ + light
tt̄ + ≥1c
tt̄ + ≥1b
tt̄ + V
Non-tt̄
Total unc.
tt̄H (norm)
Pre-Fit Bkgd.
Events / 0.30
Data / Pred.
Δ η bb avg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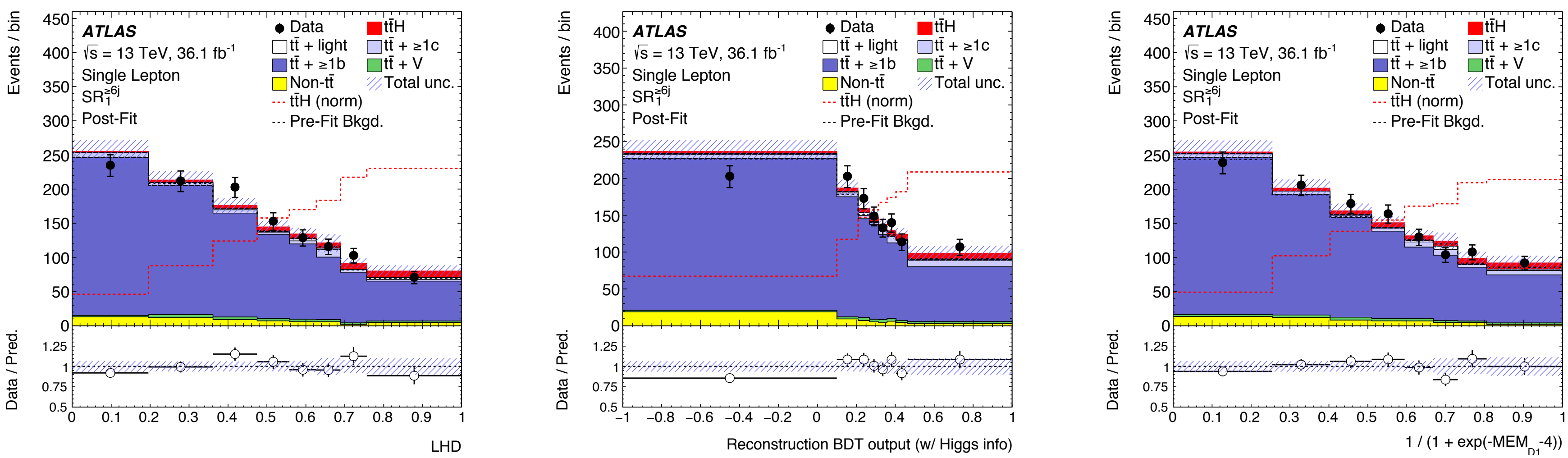
Dilepton
SR≥4j 3
Post-Fit
Data
tt̄H
tt̄ + light
tt̄ + ≥1c
tt̄ + ≥1b
tt̄ + V
Non-tt̄
Total unc.
tt̄H (norm)
Pre-Fit Bkgd.
Events / bin
Data / Pred.
Reconstruction BDT output (w/ Higgs info)

tth(bb)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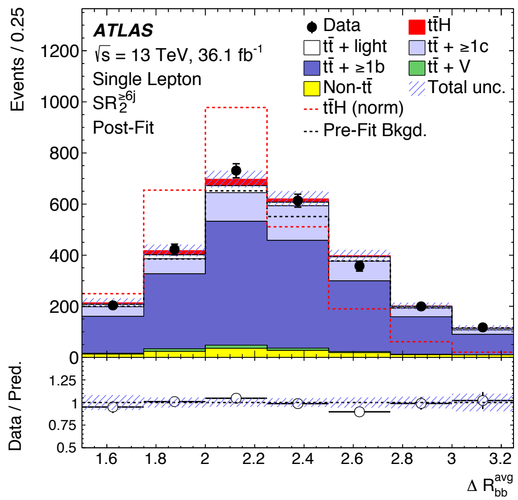
√s = 13 TeV, 36.1 fb-1
Single Lepton
SR1≥6j
Post-Fit
Data
tt̄H
tt̄ + light
tt̄ + ≥1c
tt̄ + ≥1b
tt̄ + V
Non-tt̄
Total unc.
tt̄H (norm)
Pre-Fit Bkgd.
Events / bin
Data / Pred.
LHD
Reconstruction BDT output (w/ Higgs info)
1 / (1 + exp(-MEMD1-4))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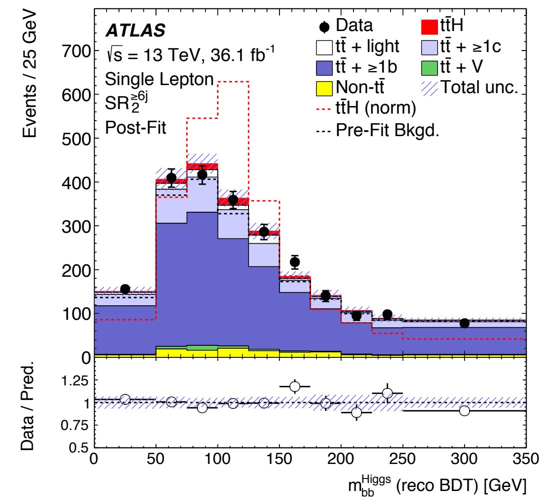
Single Lepton
SR2≥6j
Post-Fit
Data
tt̄H
tt̄ + light
tt̄ + ≥1c
tt̄ + ≥1b
tt̄ + V
Non-tt̄
Total unc.
tt̄H (norm)
Pre-Fit Bkgd.
Events / 0.25
Data / Pred.
Δ R bb avg


ATLAS
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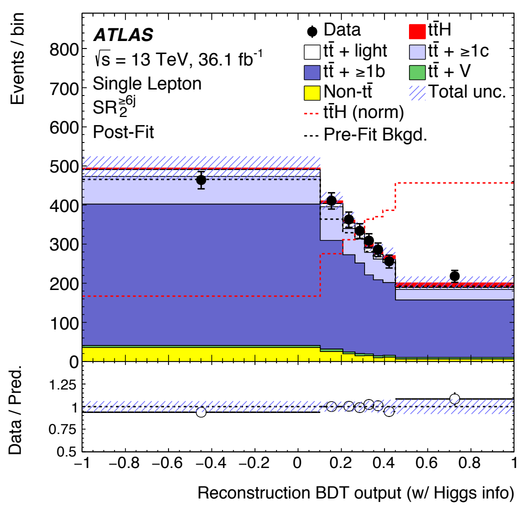
Single Lepton
SR2≥6j
Post-Fit
Data
tt̄H
tt̄ + light
tt̄ + ≥1c
tt̄ + ≥1b
tt̄ + V
Non-tt̄
Total unc.
tt̄H (norm)
Pre-Fit Bkgd.
Events / 25 GeV
Data / Pred.
m bb Higgs (reco BDT) [GeV]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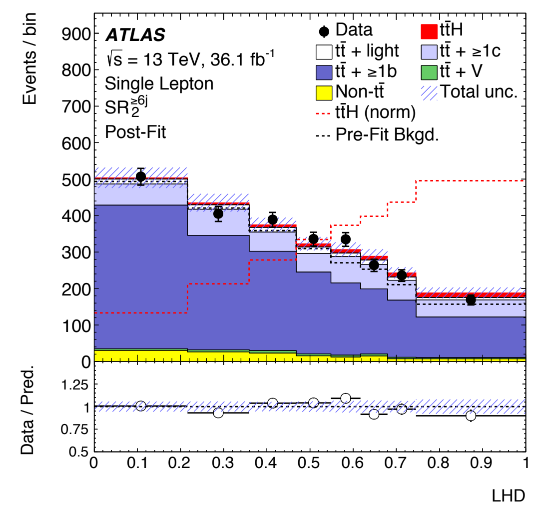
Single Lepton
SR2≥6j
Post-Fit
Data
tt̄H
tt̄ + light
tt̄ + ≥1c
tt̄ + ≥1b
tt̄ + V
Non-tt̄
Total unc.
tt̄H (norm)
Pre-Fit Bkgd.
Events / bin
Data / Pred.
Reconstruction BDT output (w/ Higgs info)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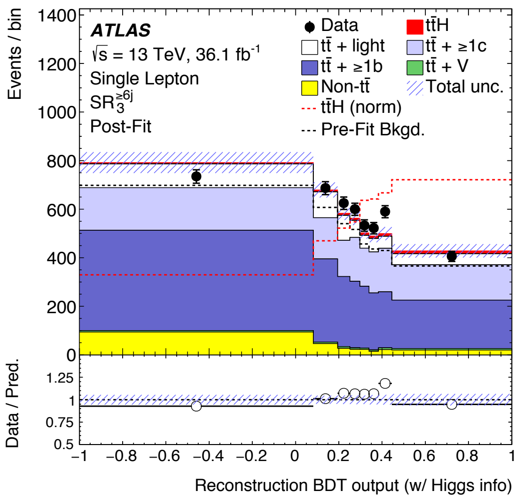
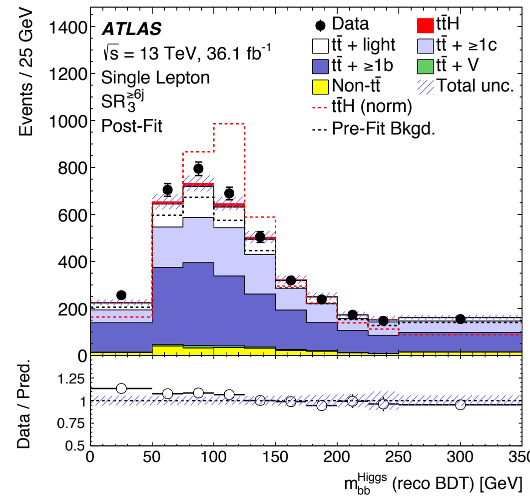
Single Lepton
SR2≥6j
Post-Fit
Data
tt̄H
tt̄ + light
tt̄ + ≥1c
tt̄ + ≥1b
tt̄ + V
Non-tt̄
Total unc.
tt̄H (norm)
Pre-Fit Bkgd.
Events / bin
Data / Pred.
LHD


ATLAS
√s = 13 TeV, 36.1 fb-1
Single Lepton
SR3≥6j
Post-Fit
Data
tt̄H
tt̄ + light
tt̄ + ≥1c
tt̄ + ≥1b
tt̄ + V
Non-tt̄
Total unc.
tt̄H (norm)
Pre-Fit Bkgd.
Events / bin
Data / Pred.
Reconstruction BDT output (w/ Higgs info)


ATLAS
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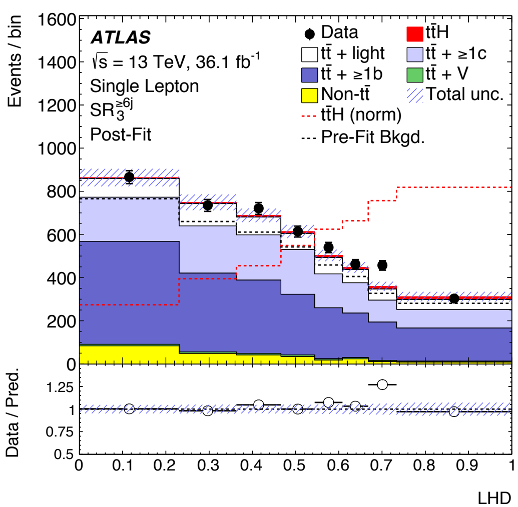
Single Lepton
SR3≥6j
Post-Fit
Data
tt̄H
tt̄ + light
tt̄ + ≥1c
tt̄ + ≥1b
tt̄ + V
Non-tt̄
Total unc.
tt̄H (norm)
Pre-Fit Bkgd.
Events / 25 GeV
Data / Pred.
mbbHiggs (reco BDT) [GeV]


ATLAS
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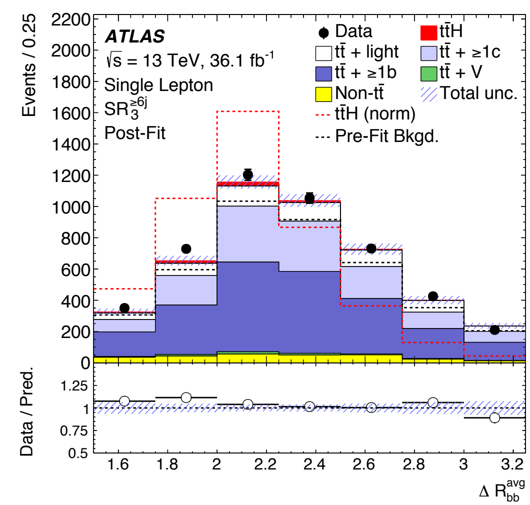
Single Lepton
SR3≥6j
Post-Fit
Data
tt̄H
tt̄ + light
tt̄ + ≥1c
tt̄ + ≥1b
tt̄ + V
Non-tt̄
Total unc.
tt̄H (norm)
Pre-Fit Bkgd.
Events / bin
Data / Pred.
LHD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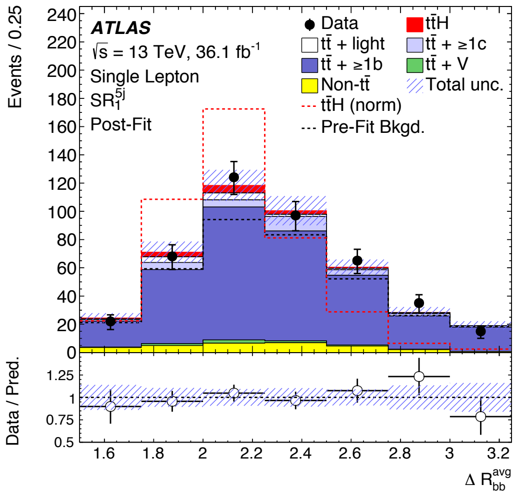
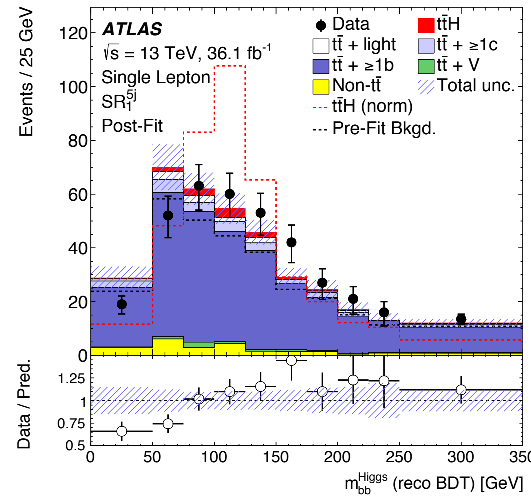
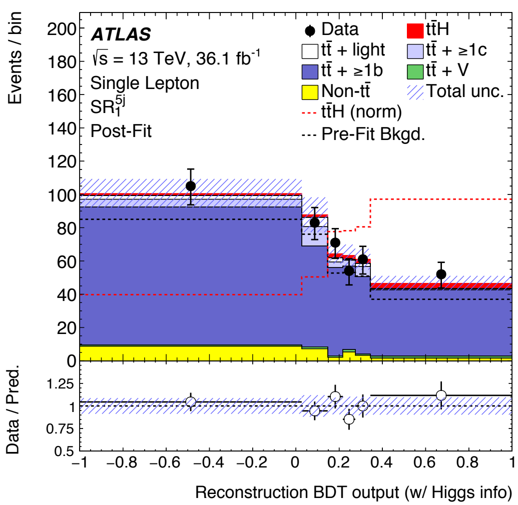
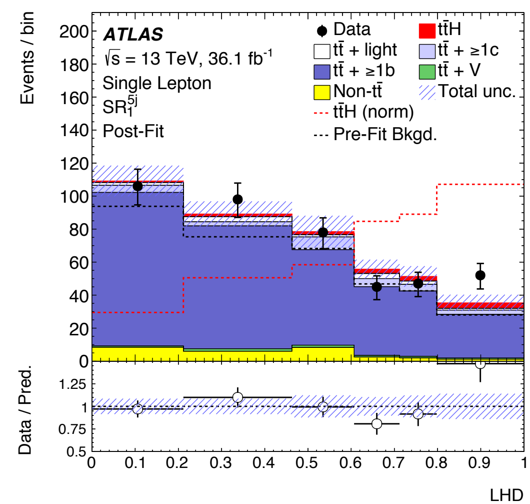
Single Lepton
SR3≥6j
Post-Fit
Data
tt̄H
tt̄ + light
tt̄ + ≥1c
tt̄ + ≥1b
tt̄ + V
Non-tt̄
Total unc.
tt̄H (norm)
Pre-Fit Bkgd.
Events / 0.25
Data / Pred.
Δ Rbbavg


ATLAS
√s = 13 TeV, 36.1 fb-1
Single Lepton
SR1 5j
Post-Fit
Data
tt̄ + light
tt̄ + ≥1b
Non-tt̄
tt̄H (norm)
Pre-Fit Bkgd.
tt̄H
tt̄ + ≥1c
tt̄ + V
Total unc.
Events / 0.25
Data / Pred.
Δ R bb avg


ATLAS
√s = 13 TeV, 36.1 fb-1
Single Lepton
SR1 5j
Post-Fit
Data
tt̄ + light
tt̄ + ≥1b
Non-tt̄
tt̄H (norm)
Pre-Fit Bkgd.
tt̄H
tt̄ + ≥1c
tt̄ + V
Total unc.
Events / 25 GeV
Data / Pred.
m bb Higgs (reco BDT) [GeV]


ATLAS
√s = 13 TeV, 36.1 fb-1
Single Lepton
SR1 5j
Post-Fit
Data
tt̄ + light
tt̄ + ≥1b
Non-tt̄
tt̄H (norm)
Pre-Fit Bkgd.
tt̄H
tt̄ + ≥1c
tt̄ + V
Total unc.
Events / bin
Data / Pred.
Reconstruction BDT output (w/ Higgs info)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Single Lepton
SR1 5j
Post-Fit
Data
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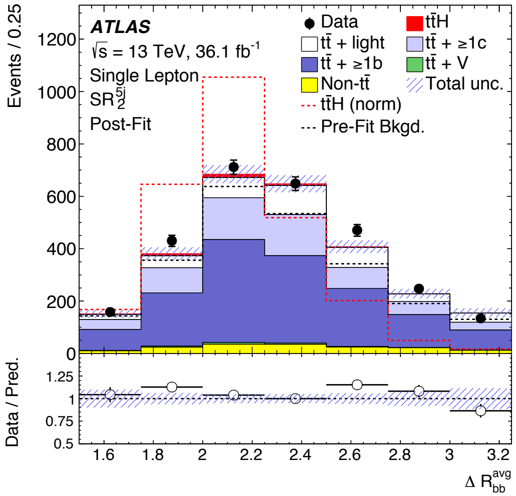
tt̄ + ≥1b
Non-tt̄
tt̄H (norm)
Pre-Fit Bkgd.
tt̄H
tt̄ + ≥1c
tt̄ + V
Total unc.
Events / bin
Data / Pred.
LHD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Single Lepton
SR^5j_2
Post-Fit
Data
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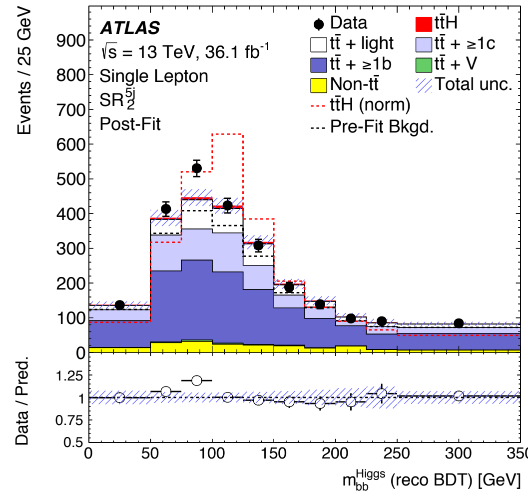
tt̄ + ≥1b
Non-tt̄
tt̄H (norm)
Pre-Fit Bkgd.
tt̄H
tt̄ + ≥1c
tt̄ + V
Total unc.
Events / 0.25
Data / Pred.
Δ R^avg_bb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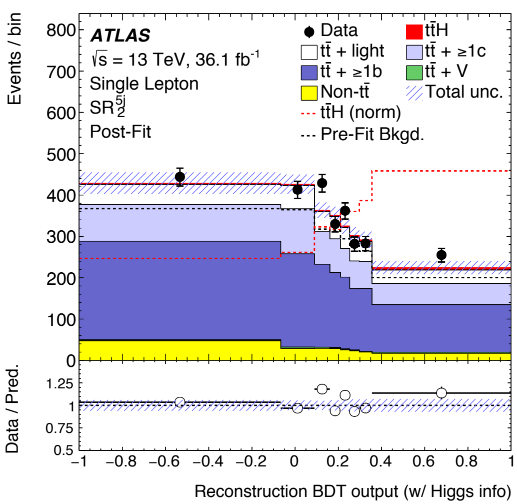
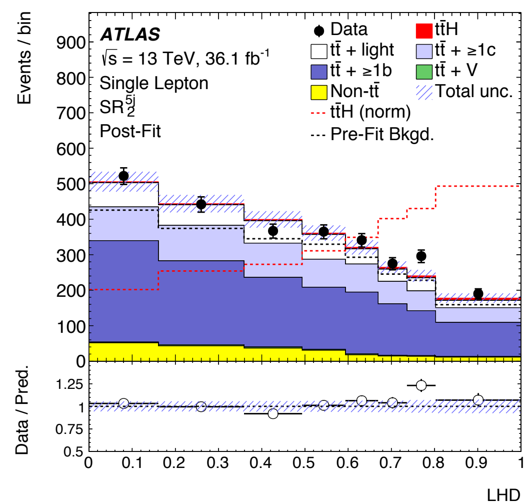
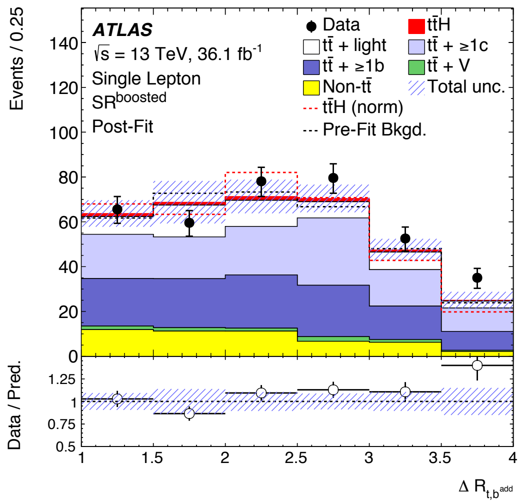
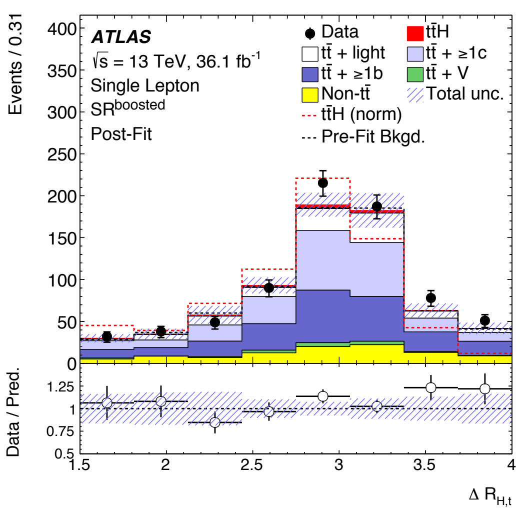
Single Lepton
SR^5j_2
Post-Fit
Data
tt̄ + light
tt̄ + ≥1b
Non-tt̄
tt̄H (norm)
Pre-Fit Bkgd.
tt̄H
tt̄ + ≥1c
tt̄ + V
Total unc.
Events / 25 GeV
Data / Pred.
m^Higgs_bb (reco BDT) [GeV]

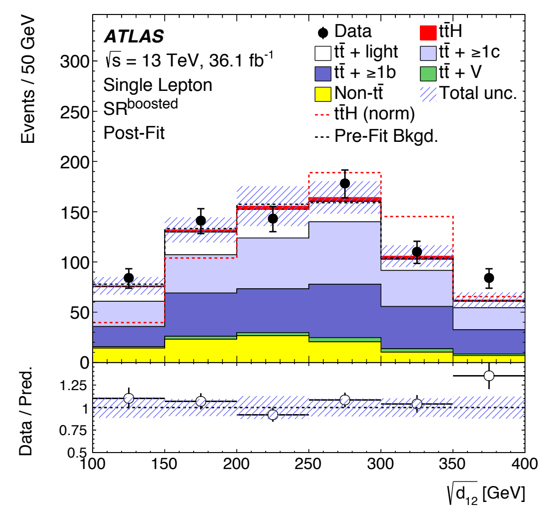

ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Single Lepton
SR^5j_2
Post-Fit
Data
tt̄ + light
tt̄ + ≥1b
Non-tt̄
tt̄H (norm)
Pre-Fit Bkgd.
tt̄H
tt̄ + ≥1c
tt̄ + V
Total unc.
Events / bin
Data / Pred.
Reconstruction BDT output (w/ Higgs info)

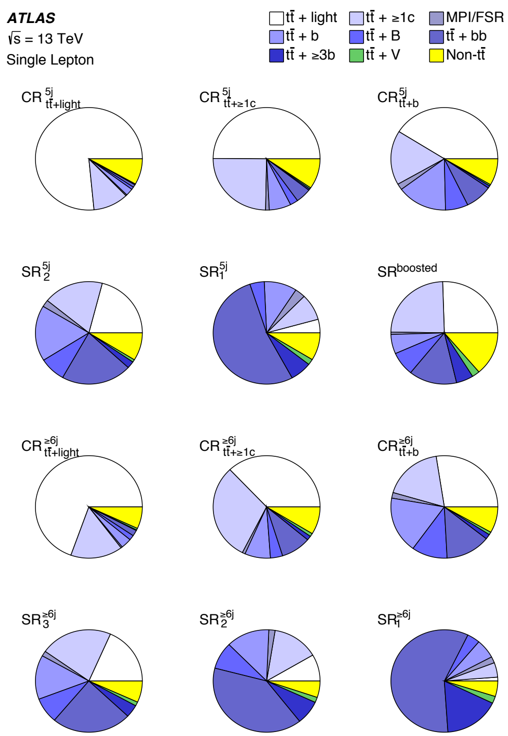

ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Single Lepton
SR^5j_2
Post-Fit
Data
tt̄ + light
tt̄ + ≥1b
Non-tt̄
tt̄H (norm)
Pre-Fit Bkgd.
tt̄H
tt̄ + ≥1c
tt̄ + V
Total unc.
Events / bin
Data / Pred.
LHD

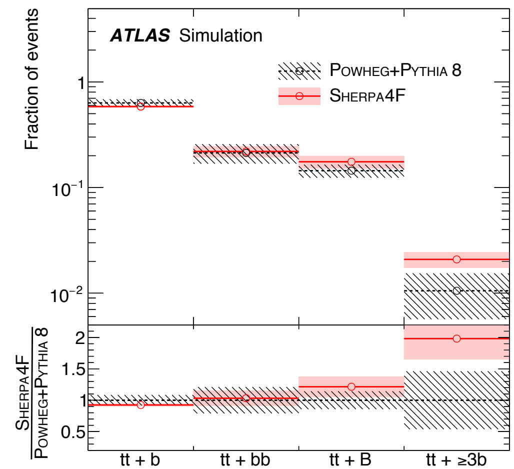
tth(bb)

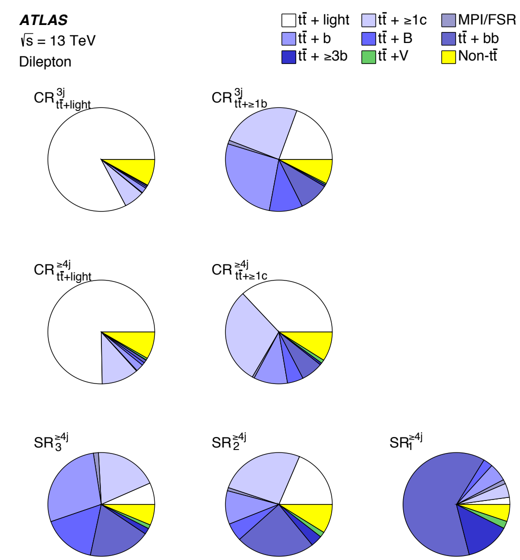

ATLAS
√s = 13 TeV, 36.1 fb-1
Single Lepton
SR boosted
Post-Fit
Data
tt̄H
tt̄ + light
tt̄ + ≥1c
tt̄ + ≥1b
tt̄ + V
Non-tt̄
Total unc.
tt̄H (norm)
Pre-Fit Bkgd.
Events / 0.25
Data / Pred.
Δ R t,b add

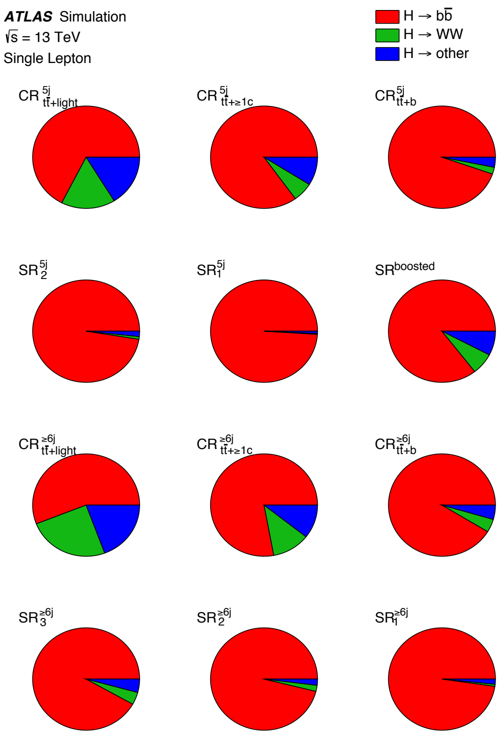

ATLAS
√s = 13 TeV, 36.1 fb-1
Single Lepton
SR boosted
Post-Fit
Data
tt̄H
tt̄ + light
tt̄ + ≥1c
tt̄ + ≥1b
tt̄ + V
Non-tt̄
Total unc.
tt̄H (norm)
Pre-Fit Bkgd.
Events / 0.31
Data / Pred.
Δ R H,t

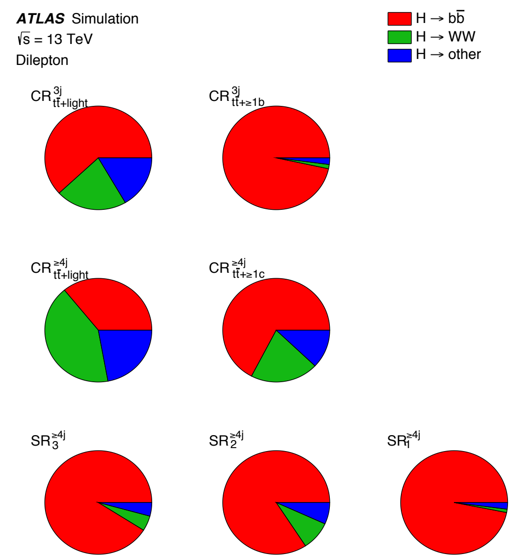

ATLAS
√s = 13 TeV, 36.1 fb-1
Single Lepton
SR boosted
Post-Fit
Data
tt̄H
tt̄ + light
tt̄ + ≥1c
tt̄ + ≥1b
tt̄ + V
Non-tt̄
Total unc.
tt̄H (norm)
Pre-Fit Bkgd.
Events / 50 GeV
Data / Pred.
√d12 [GeV]


ATLAS
√s = 13 TeV
Single Lepton
tt̄ + light
tt̄ + ≥1c
MPI/FSR
tt̄ + b
tt̄ + B
tt̄ + bb
tt̄ + ≥3b
tt̄ + V
Non-tt̄
CR 5j tt̄+light
CR 5j tt̄+≥1c
CR 5j tt̄+b
SR 5j 2
SR 5j 1
SR boosted
CR ≥6j tt̄+light
CR ≥6j tt̄+≥1c
CR ≥6j tt̄+b
SR ≥6j 3
SR ≥6j 2
SR ≥6j 1


ATLAS Simulation
Powheg+Pythia 8
Sherpa4F
Fraction of events
1
10⁻¹
10⁻²
Sherpa4F / Powheg+Pythia 8
2
1.5
1
0.5
tt + b
tt + bb
tt + B
tt + ≥3b


ATLAS
√s = 13 TeV
Dilepton
tt̄ + light
tt̄ + ≥1c
MPI/FSR
tt̄ + b
tt̄ + B
tt̄ + bb
tt̄ + ≥3b
tt̄ +V
Non-tt̄
CR 3j tt̄+light
CR 3j tt̄+≥1b
CR ≥4j tt̄+light
CR ≥4j tt̄+≥1c
SR ≥4j 3
SR ≥4j 2
SR ≥4j 1


ATLAS Simulation
√s = 13 TeV
Single Lepton
H → bb̄
H → WW
H → other
CR 5j tt̄+light
CR 5j tt̄+≥1c
CR 5j tt̄+b
SR 5j 2
SR 5j 1
SR boosted
CR ≥6j tt̄+light
CR ≥6j tt̄+≥1c
CR ≥6j tt̄+b
SR ≥6j 3
SR ≥6j 2
SR ≥6j 1


ATLAS Simulation
√s = 13 TeV
Dilepton
H → bb̄
H → WW
H → other
CR 3j tt̄+light
CR 3j tt̄+≥1b
CR ≥4j tt̄+light
CR ≥4j tt̄+≥1c
SR ≥4j 3
SR ≥4j 2
SR ≥4j 1

ATLAS $\sqrt{s}$ = 13 TeV, 36.1 fb^{-1}

	$\mu_{t\bar{t}H}$	k(tt+≥1b)	k(tt+≥1c)	$t\bar{t}$+≥1b: SHERPA5F vs. nominal	$t\bar{t}$+≥1b: SHERPA4F vs. nominal	$t\bar{t}$+≥1b: PS & hadronisation	$t\bar{t}$+≥1b: ISR / FSR	b-tagging: mis-tag (light), NP 0	Jet energy resolution: NP 1	tt+≥1b: tt+≥3b normalisation	$t\bar{t}$+≥1c: SHERPA5F vs. nominal	$t\bar{t}$+≥1b: shower recoil scheme	$t\bar{t}$+≥1c: ISR / FSR	Jet energy resolution: NP 0	$t\bar{t}$+light: PS & hadronisation	Wt: diagram subtr. vs. nominal	b-tagging: efficiency, NP 1	b-tagging: mis-tag (c), NP 0	b-tagging: efficiency, NP 0
$\mu_{t\bar{t}H}$	100.0	-14.8	0.8	-66.0	-32.8	26.4	19.0	-13.0	-15.2	-11.4	-14.9	-8.0	7.6	-9.8	4.9	-8.3	5.1	6.9	3.0
k(tt+≥1b)	-14.8	100.0	-38.8	24.8	-22.0	37.2	7.5	3.1	5.7	-17.0	8.8	-9.3	15.6	9.8	27.8	7.0	6.4	38.9	9.8
k(tt+≥1c)	0.8	-38.8	100.0	-2.8	-6.7	-19.2	2.5	33.8	4.0	16.8	-17.5	16.7	-13.1	-22.7	18.9	-1.3	3.9	-10.6	9.9
$t\bar{t}$+≥1b: SHERPA5F vs. nominal	-66.0	24.8	-2.8	100.0	16.4	-2.9	4.1	8.4	18.1	13.6	12.5	11.0	-17.6	-9.0	-5.6	5.4	-1.0	-10.7	-3.7
$t\bar{t}$+≥1b: SHERPA4F vs. nominal	-32.8	-22.0	-6.7	16.4	100.0	-43.2	-12.6	-4.0	8.5	-4.9	2.4	-3.2	-2.3	-0.3	-8.8	4.2	1.6	-5.7	-0.7
$t\bar{t}$+≥1b: PS & hadronisation	26.4	37.2	-19.2	-2.9	-43.2	100.0	29.9	-15.2	-16.3	24.2	-16.3	5.1	16.9	-9.3	-4.9	-7.2	-0.4	14.2	6.8
$t\bar{t}$+≥1b: ISR / FSR	19.0	7.5	2.5	4.1	-12.6	29.9	100.0	4.7	-19.6	-6.8	-13.1	8.6	-15.7	-16.8	6.4	2.1	-5.6	-24.6	-7.0
b-tagging: mis-tag (light), NP 0	-13.0	3.1	33.8	8.4	-4.0	-15.2	4.7	100.0	-5.6	3.1	23.4	4.3	0.3	-14.5	4.2	1.6	-2.4	-9.8	-5.5
Jet energy resolution: NP 1	-15.2	5.7	4.0	18.1	8.5	-16.3	-19.6	-5.6	100.0	-4.5	15.3	0.6	-16.4	7.3	0.1	-8.8	-1.0	8.7	-3.3
tt+≥1b: tt+≥3b normalisation	-11.4	-17.0	16.8	13.6	-4.9	24.2	-6.8	3.1	-4.5	100.0	-5.4	-25.8	1.5	-7.0	-3.6	-4.6	4.7	-2.7	8.2
$t\bar{t}$+≥1c: SHERPA5F vs. nominal	-14.9	8.8	-17.5	12.5	2.4	-16.3	-13.1	23.4	15.3	-5.4	100.0	3.1	-25.2	19.7	13.9	-4.2	-1.5	-3.8	-6.5
$t\bar{t}$+≥1b: shower recoil scheme	-8.0	-9.3	16.7	11.0	-3.2	5.1	8.6	4.3	0.6	-25.8	3.1	100.0	-8.0	1.7	-4.6	-1.4	4.9	-12.7	8.8
$t\bar{t}$+≥1c: ISR / FSR	7.6	15.6	-13.1	-17.6	-2.3	16.9	-15.7	0.3	-16.4	1.5	-25.2	-8.0	100.0	-11.3	6.9	0.5	-1.3	25.4	1.5
Jet energy resolution: NP 0	-9.8	9.8	-22.7	-9.0	-0.3	-9.3	-16.8	-14.5	7.3	-7.0	19.7	1.7	-11.3	100.0	24.8	-8.4	-3.1	-10.8	-9.3
$t\bar{t}$+light: PS & hadronisation	4.9	27.8	18.9	-5.6	-8.8	-4.9	6.4	4.2	0.1	-3.6	13.9	-4.6	6.9	24.8	100.0	-4.6	6.6	7.5	5.3
Wt: diagram subtr. vs. nominal	-8.3	7.0	-1.3	5.4	4.2	-7.2	2.1	1.6	-8.8	-4.6	-4.2	-1.4	0.5	-8.4	-4.6	100.0	-0.1	8.0	-2.1
b-tagging: efficiency, NP 1	5.1	6.4	3.9	-1.0	1.6	-0.4	-5.6	-2.4	-1.0	4.7	-1.5	4.9	-1.3	-3.1	6.6	-0.1	100.0	2.4	-7.5
b-tagging: mis-tag (c), NP 0	6.9	38.9	-10.6	-10.7	-5.7	14.2	-24.6	-9.8	8.7	-2.7	-3.8	-12.7	25.4	-10.8	7.5	8.0	2.4	100.0	5.4
b-tagging: efficiency, NP 0	3.0	9.8	9.9	-3.7	-0.7	6.8	-7.0	-5.5	-3.3	8.2	-6.5	8.8	1.5	-9.3	5.3	-2.1	-7.5	5.4	100.0

Variables	BDT with Higgs info. $SR^{\geq 4j}_{1,2}$	BDT with Higgs info. $SR^{\geq 4j}_{3}$	BDT w/o Higgs info. $SR^{\geq 4j}_{1,2}$	BDT w/o Higgs info. $SR^{\geq 4j}_{3}$
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)	✓	✓	-	-

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}	✓	✓
$\Delta R(W_{had}, b$ from $top_{had})$	✓	–
$\Delta R(q_1$ from W_{had}, b from $top_{had})$	–	✓
$\Delta R(W_{had}, b$ from $top_{lep})$	✓	–
$\Delta R(q_1$ from W_{had}, b from $top_{lep})$	–	✓
$\Delta R(\ell, b$ from $top_{lep})$	✓	✓
$\Delta R(\ell, b$ from $top_{had})$	✓	✓
$\Delta R(b$ from top_{lep}, b from $top_{had})$	✓	✓
$\Delta R(q_1$ from W_{had}, q_2 from $W_{had})$	✓	–
$\Delta R(b$ from t_{had}, q_1 from $W_{had})$	✓	–
$\Delta R(b$ from t_{had}, q_2 from $W_{had})$	✓	–
Min. $\Delta R(b$ from top_{had}, q_i from $W_{had})$	✓	–
ΔR(lep, b from top_{lep}) - min. $\Delta R(b$ from top_{had}, q_i from $W_{had})$	✓	✓
Topological information from the Higgs-boson candidate		
Mass of Higgs	✓	✓
Mass of Higgs and q_1 from W_{had}	✓	✓
$\Delta R(b_1$ from Higgs, b_2 from Higgs)	✓	✓
$\Delta R(b_1$ from Higgs, lepton)	✓	✓
$\Delta R(b_1$ from Higgs, b from $top_{lep})$	–	✓
$\Delta R(b_1$ from Higgs, b from $top_{had})$	–	✓

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

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ME gen. PS/UE gen.	POWHEG PYTHIA 8	POWHEG PYTHIA 8	POWHEG PYTHIA 8	POWHEG HERWIG 7	SHERPA 2.2.1	SHERPA 2.1
Ren. scale	$m_{\mathrm{T},t}$	$\frac{1}{2} \cdot m_{\mathrm{T},t}$	$2 \cdot m_{\mathrm{T},t}$	$m_{\mathrm{T},t}$	$\sqrt{\frac{m^2_{\mathrm{T},t}+m^2_{\mathrm{T},\bar{t}}}{2}}$	μ_{CMMPS}
Fact. scale	$m_{\mathrm{T},t}$	$\frac{1}{2} \cdot m_{\mathrm{T},t}$	$2 \cdot m_{\mathrm{T},t}$	$m_{\mathrm{T},t}$	$\sqrt{\frac{m^2_{\mathrm{T},t}+m^2_{\mathrm{T},\bar{t}}}{2}}$	$H_{\mathrm{T}}/2$
h_{damp}	$1.5 \cdot m_t$	$3 \cdot m_t$	$1.5 \cdot m_t$	$1.5 \cdot m_t$	–	–
ME PDF	NNPDF3.0NLO	NNPDF3.0NLO	NNPDF3.0NLO	NNPDF3.0NLO	NNPDF3.0NNLO	CT10 4F
PS/UE PDF	NNPDF2.3LO	NNPDF2.3LO	NNPDF2.3LO	MMHT2014LO		
Tune	A14	A14 Var3c up	A14 Var3c down	H7-UE-MMHT	Author's tune	Author's tune

	Observed	Expected ($\mu = 0$) Median	+/-1σ	+/-2σ	Expected ($\mu = 1$)
Dilepton	2.64	2.74	[1.98, 3.86]	[1.47, 5.43]	3.63
Single lepton	1.95	1.40	[1.01, 1.99]	[0.75, 2.82]	2.27
Dilepton (from two-μ fit)	1.84	2.47	[1.78, 3.48]	[1.32, 4.91]	3.39
Single Lepton (from two-μ fit)	2.09	1.26	[0.91, 1.80]	[0.68, 2.54]	2.13
Combined	1.96	1.24	[0.89, 1.77]	[0.67, 2.50]	2.12

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
$E_{\mathrm{T}}^{\mathrm{miss}}$	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

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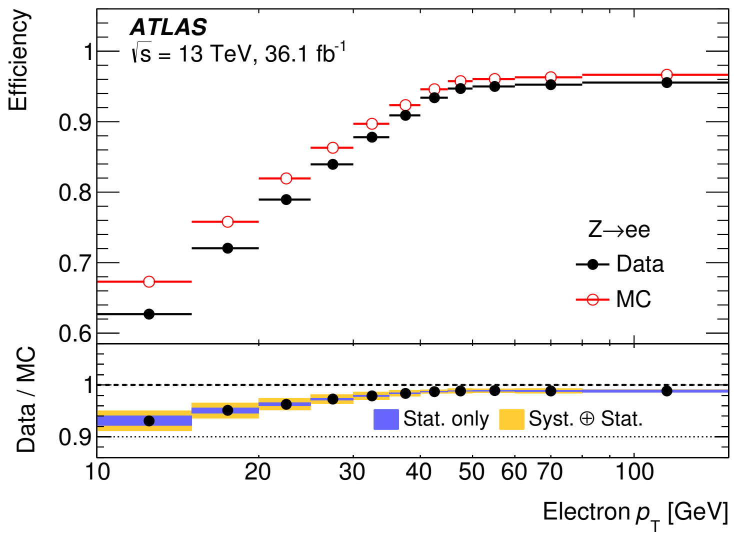
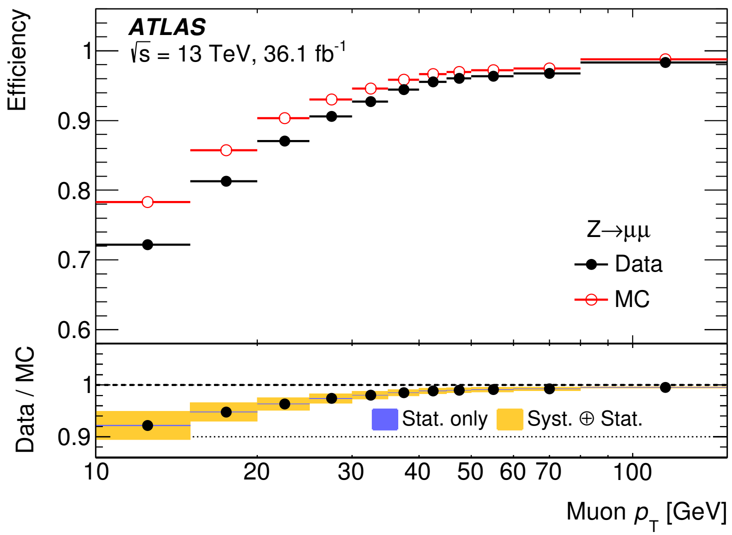
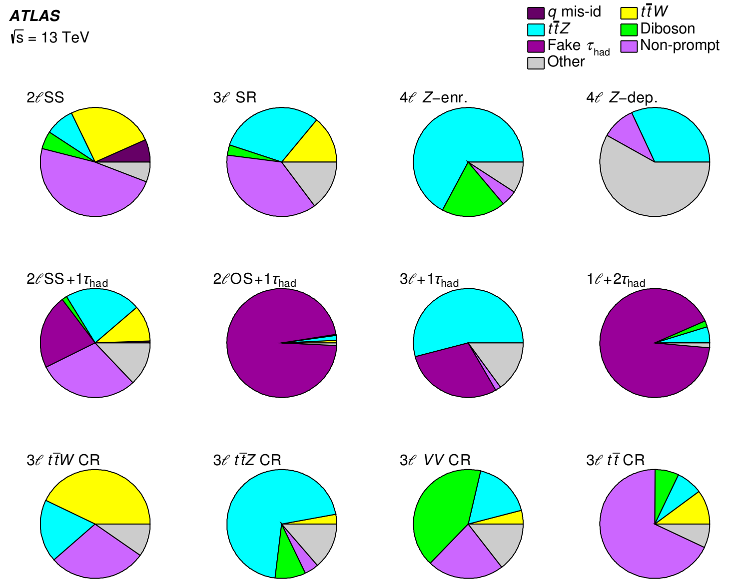
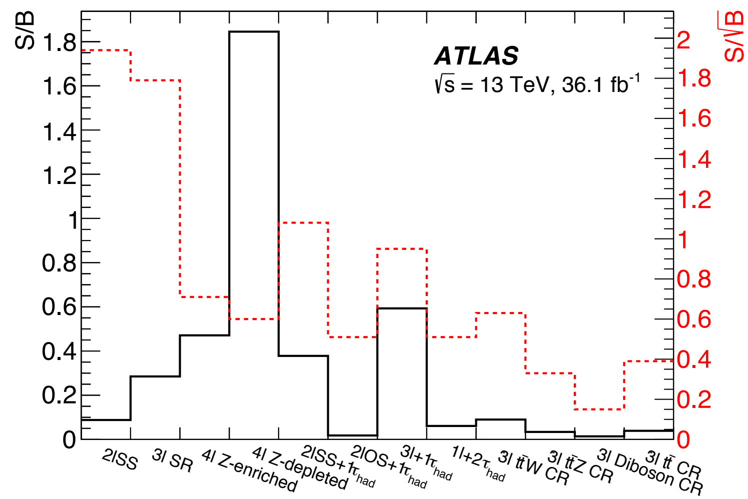


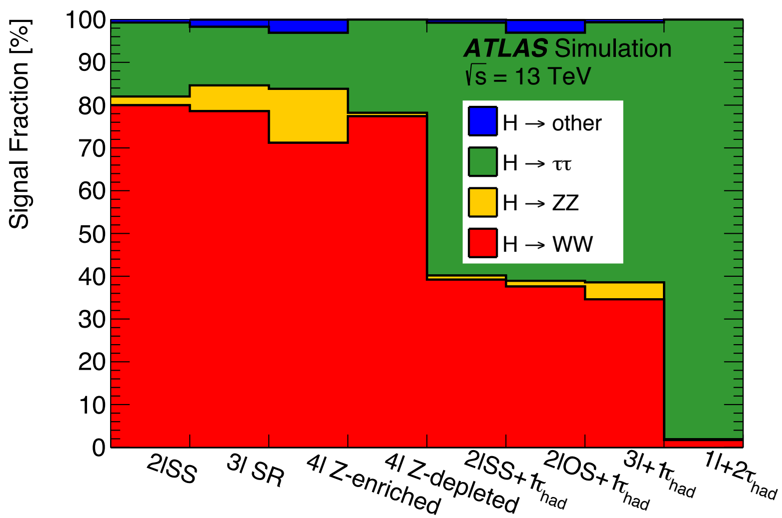




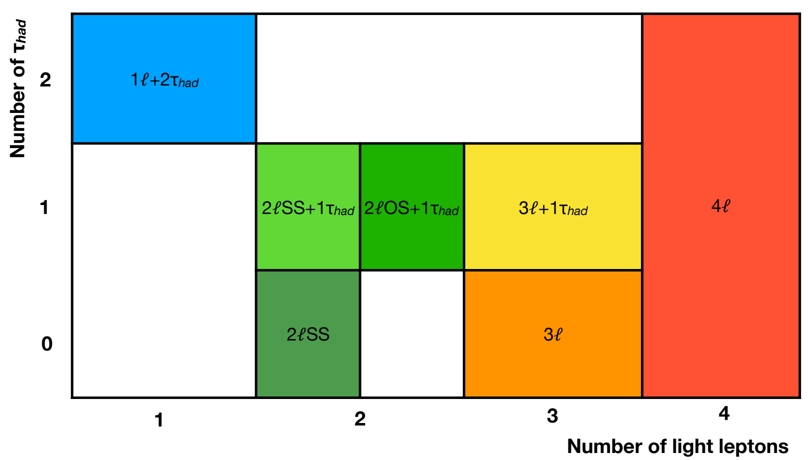
ATLAS
√s = 13 TeV
q mis-id
tt̄W
tt̄Z
Diboson
Fake τhad
Non-prompt
Other
2ℓSS
3ℓ SR
4ℓ Z-enr.
4ℓ Z-dep.
2ℓSS+1τhad
2ℓOS+1τhad
3ℓ+1τhad
1ℓ+2τhad
3ℓ tt̄W CR
3ℓ tt̄Z CR
3ℓ VV CR
3ℓ tt̄ CR



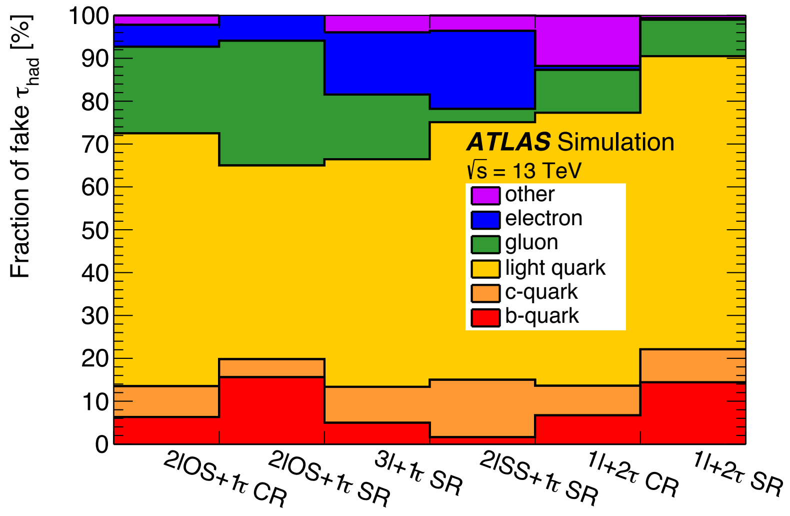
S/B
S/√B
ATLAS
√s = 13 TeV, 36.1 fb-1
2lSS
3l SR
4l Z-enriched
4l Z-depleted
2lSS+1τhad
2lOS+1τhad
3l+1τhad
1l+2τhad
3l tt̄W CR
3l tt̄Z CR
3l Diboson CR
3l tt̄ CR

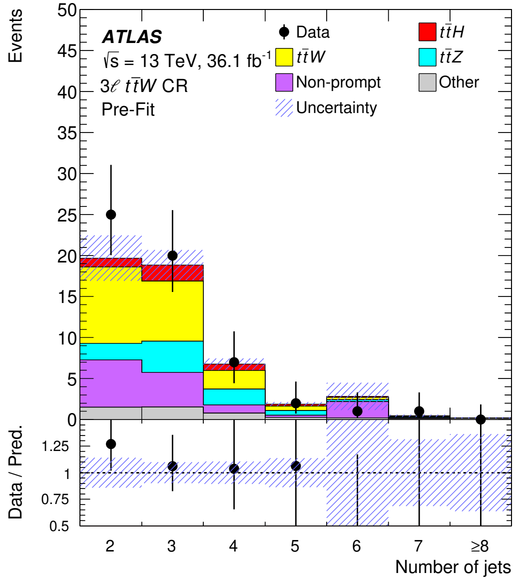


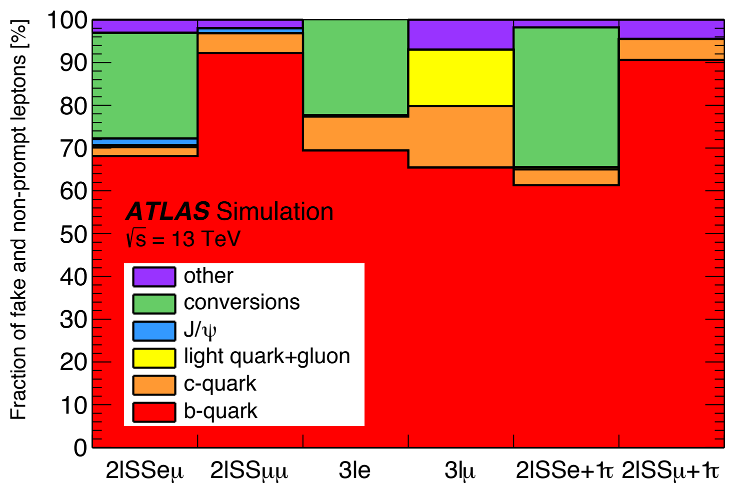
Signal Fraction [%]
ATLAS Simulation
√s = 13 TeV
H → other
H → ττ
H → ZZ
H → WW
2lSS
3l SR
4l Z-enriched
4l Z-depleted
2lSS+1τhad
2lOS+1τhad
3l+1τhad
1l+2τhad

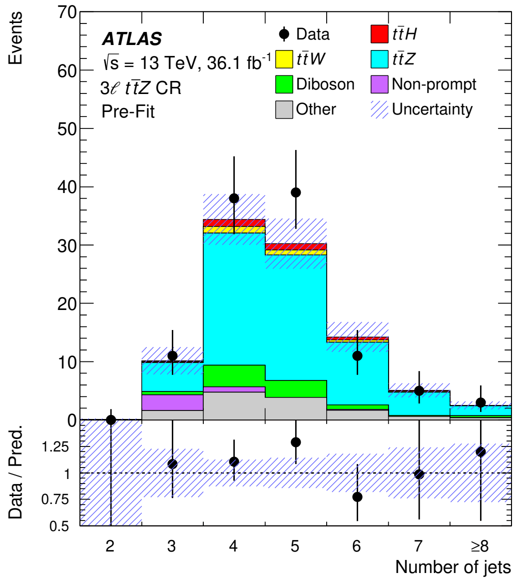


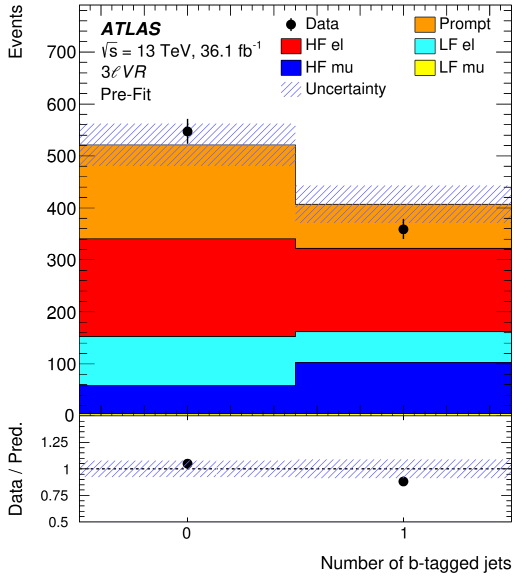
Number of τhad
Number of light leptons
1ℓ+2τhad
2ℓSS+1τhad
2ℓOS+1τhad
3ℓ+1τhad
4ℓ
2ℓSS
3ℓ

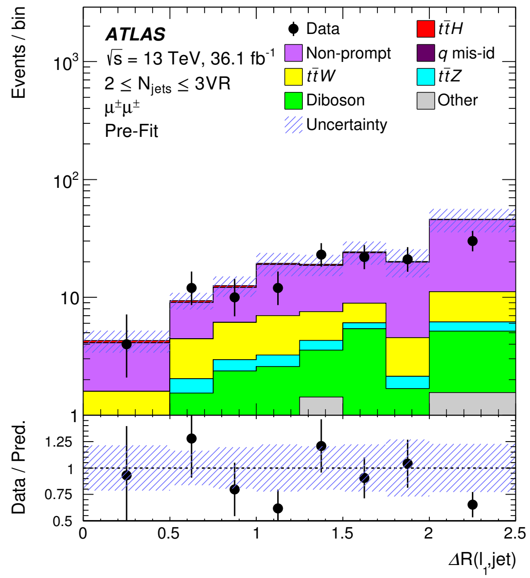

Fraction of fake τhad [%]
ATLAS Simulation
√s = 13 TeV
other
electron
gluon
light quark
c-quark
b-quark
2lOS+1τ CR
2lOS+1τ SR
3l+1τ SR
2lSS+1τ SR
1l+2τ CR
1l+2τ SR

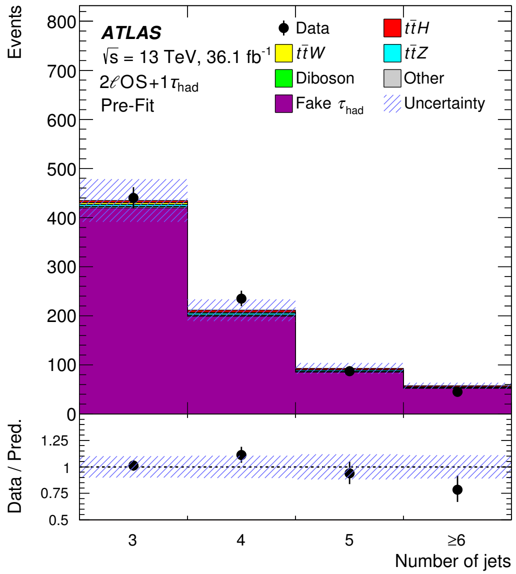

Events
ATLAS
√s = 13 TeV, 36.1 fb-1
3ℓ tt̄W CR
Pre-Fit
Data
tt̄W
Non-prompt
Uncertainty
tt̄H
tt̄Z
Other
Data / Pred.
Number of jets

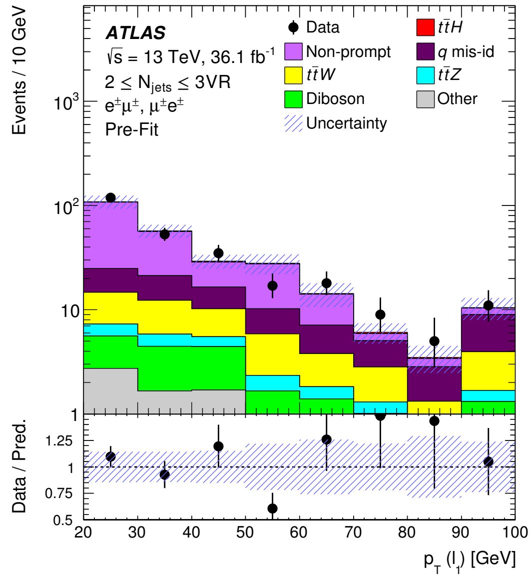

Fraction of fake and non-prompt leptons [%]
ATLAS Simulation
√s = 13 TeV
other
conversions
J/ψ
light quark+gluon
c-quark
b-quark
2lSSeμ
2lSSμμ
3le
3lμ
2lSSe+1τ
2lSSμ+1τ


Events
ATLAS
√s = 13 TeV, 36.1 fb-1
3ℓ tt̄Z CR
Pre-Fit
Data
tt̄W
Diboson
Other
tt̄H
tt̄Z
Non-prompt
Uncertainty
Data / Pred.
Number of jets

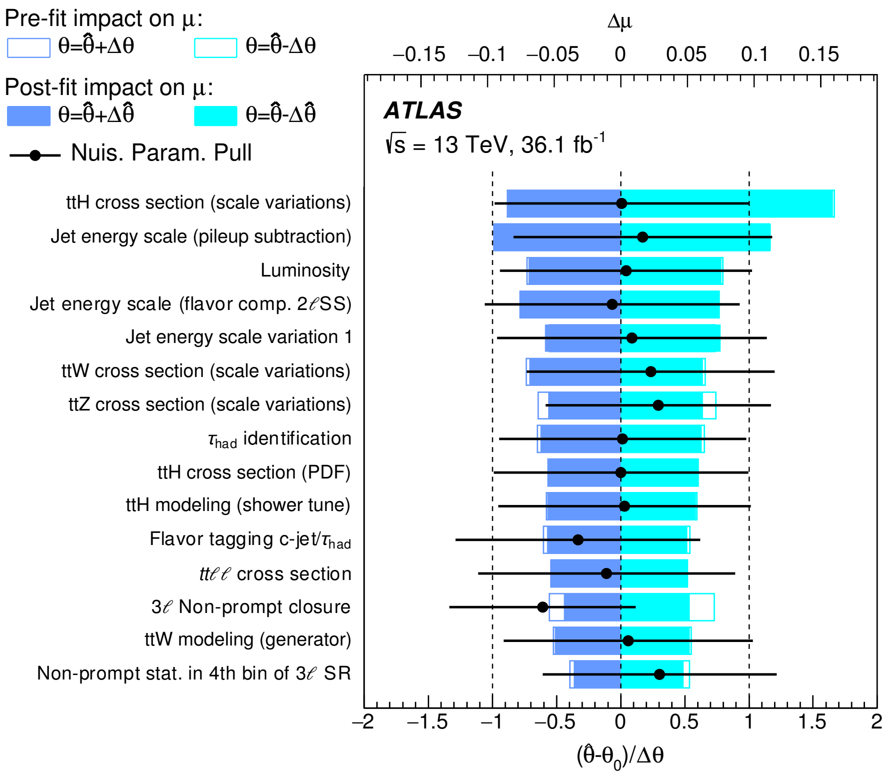

ATLAS
√s = 13 TeV, 36.1 fb-1
3ℓ VR
Pre-Fit
Data
HF el
HF mu
Uncertainty
Prompt
LF el
LF mu
Events
Data / Pred.
Number of b-tagged jets

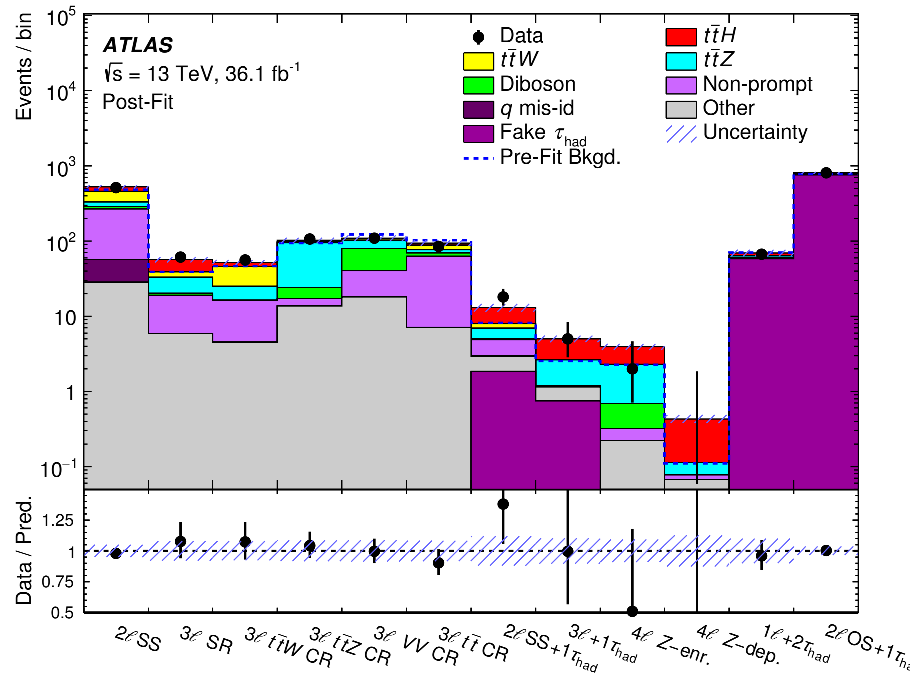

ATLAS
√s = 13 TeV, 36.1 fb-1
2 ≤ Njets ≤ 3VR
μ±μ±
Pre-Fit
Data
Non-prompt
ttW
Diboson
Uncertainty
ttH
q mis-id
ttZ
Other
Events / bin
Data / Pred.
ΔR(l1,jet)

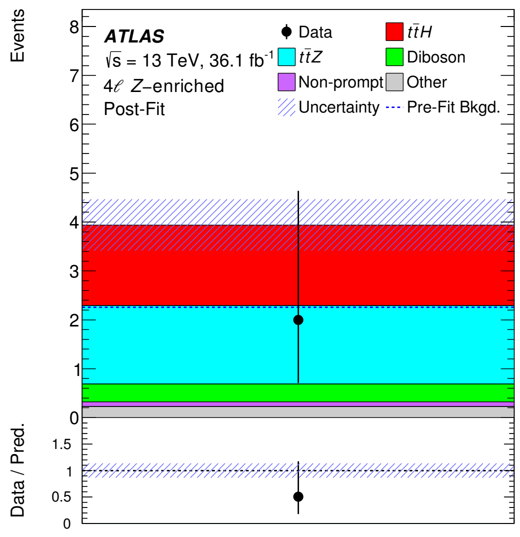

ATLAS
√s = 13 TeV, 36.1 fb-1
2ℓOS+1τhad
Pre-Fit
Data
ttW
Diboson
Fake τhad
ttH
ttZ
Other
Uncertainty
Events
Data / Pred.
Number of jets

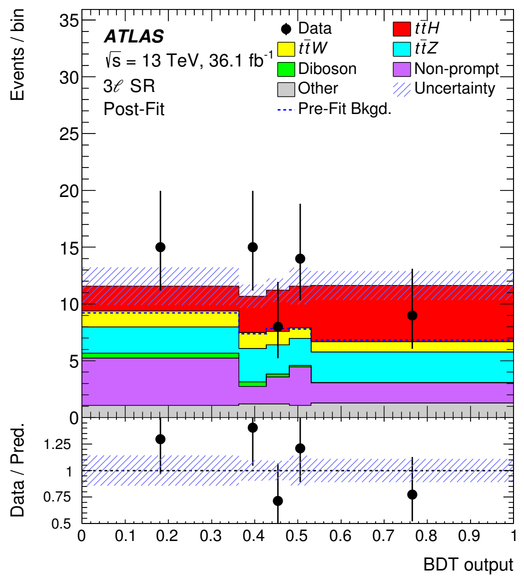

ATLAS
√s = 13 TeV, 36.1 fb-1
2 ≤ Njets ≤ 3VR
e±μ±, μ±e±
Pre-Fit
Data
Non-prompt
ttW
Diboson
Uncertainty
ttH
q mis-id
ttZ
Other
Events / 10 GeV
Data / Pred.
pT (l1) [GeV]

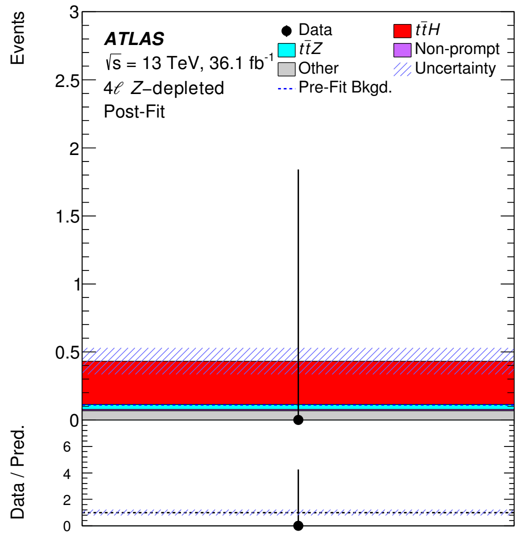
tth(ML)

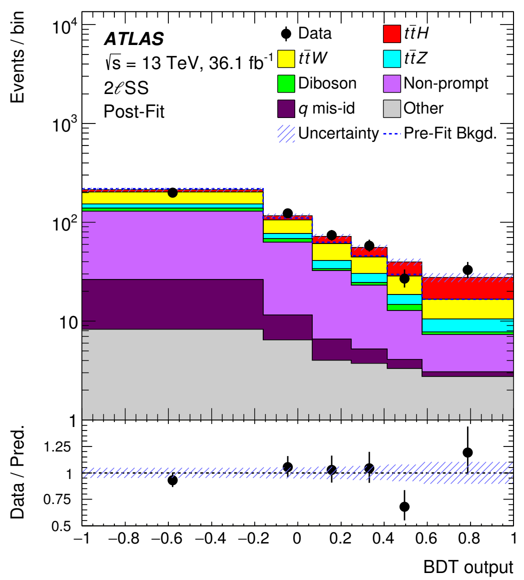

Pre-fit impact on μ:
θ=θ̂+Δθ
θ=θ̂-Δθ
Post-fit impact on μ:
θ=θ̂+Δθ̂
θ=θ̂-Δθ̂
Nuis. Param. Pull
Δμ
−0.15 −0.1 −0.05 0 0.05 0.1 0.15
ATLAS
√s = 13 TeV, 36.1 fb-1
ttH cross section (scale variations)
Jet energy scale (pileup subtraction)
Luminosity
Jet energy scale (flavor comp. 2ℓSS)
Jet energy scale variation 1
ttW cross section (scale variations)
ttZ cross section (scale variations)
τhad identification
ttH cross section (PDF)
ttH modeling (shower tune)
Flavor tagging c-jet/τhad
ttℓℓ cross section
3ℓ Non-prompt closure
ttW modeling (generator)
Non-prompt stat. in 4th bin of 3ℓ SR
−2 −1.5 −1 −0.5 0 0.5 1 1.5 2
(θ̂-θ0)/Δθ


Events / bin
ATLAS
√s = 13 TeV, 36.1 fb-1
Post-Fit
Data
tt̄W
Diboson
q mis-id
Fake τhad
Pre-Fit Bkgd.
tt̄H
tt̄Z
Non-prompt
Other
Uncertainty
Data / Pred.
2ℓSS
3ℓ SR
3ℓ tt̄W CR
3ℓ tt̄Z CR
3ℓ VV CR
3ℓ tt̄ CR
2ℓSS+1τhad
3ℓ+1τhad
4ℓ Z-enr.
4ℓ Z-dep.
1ℓ+2τhad
2ℓOS+1τhad


ATLAS
√s = 13 TeV, 36.1 fb-1
4ℓ Z–enriched
Post-Fit
Data
tt̄H
tt̄Z
Diboson
Non-prompt
Other
Uncertainty
Pre-Fit Bkgd.
Events
Data / Pred.


ATLAS
√s = 13 TeV, 36.1 fb-1
3ℓ SR
Post-Fit
Data
tt̄H
tt̄W
tt̄Z
Diboson
Non-prompt
Other
Uncertainty
Pre-Fit Bkgd.
Events / bin
Data / Pred.
BDT output


ATLAS
√s = 13 TeV, 36.1 fb-1
4ℓ Z–depleted
Post-Fit
Data
tt̄H
tt̄Z
Non-prompt
Other
Uncertainty
Pre-Fit Bkgd.
Events
Data / Pred.


ATLAS
√s = 13 TeV, 36.1 fb-1
2ℓSS
Post-Fit
Data
tt̄H
tt̄W
tt̄Z
Diboson
Non-prompt
q mis-id
Other
Uncertainty
Pre-Fit Bkgd.
Events / bin
Data / Pred.
BDT output

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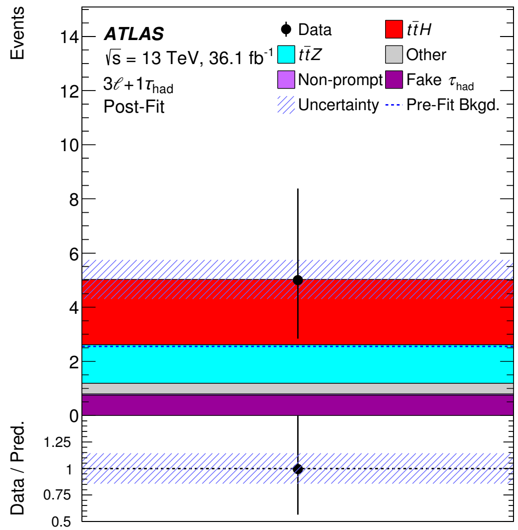
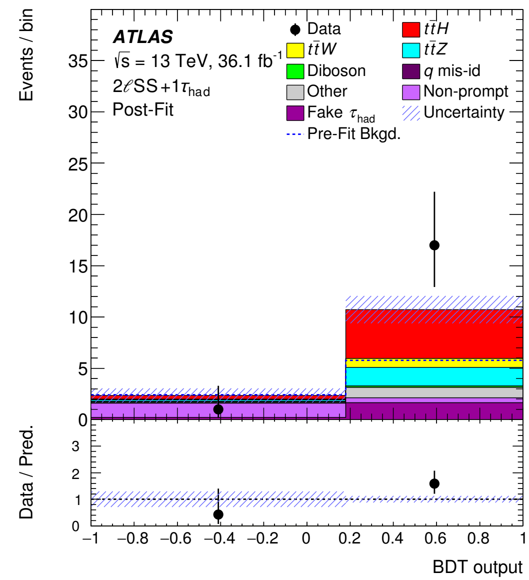
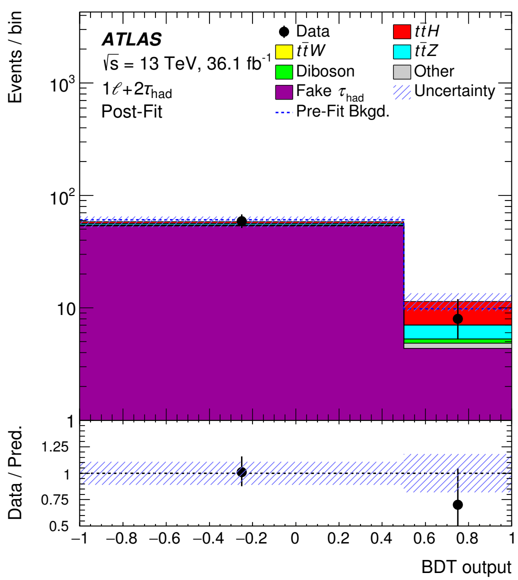
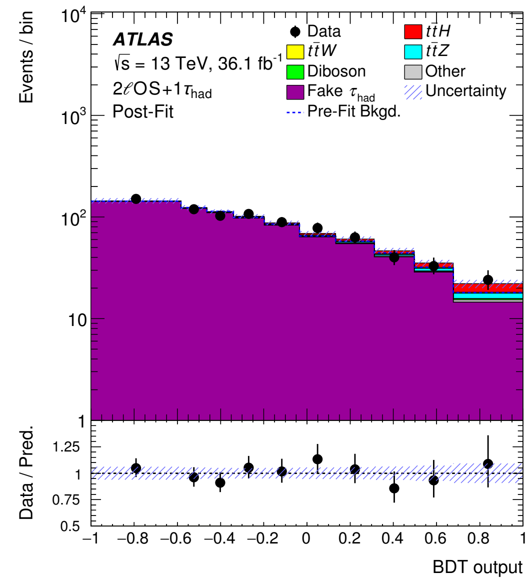
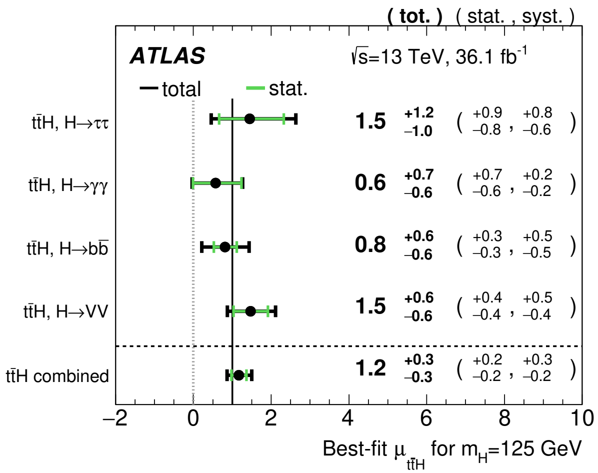


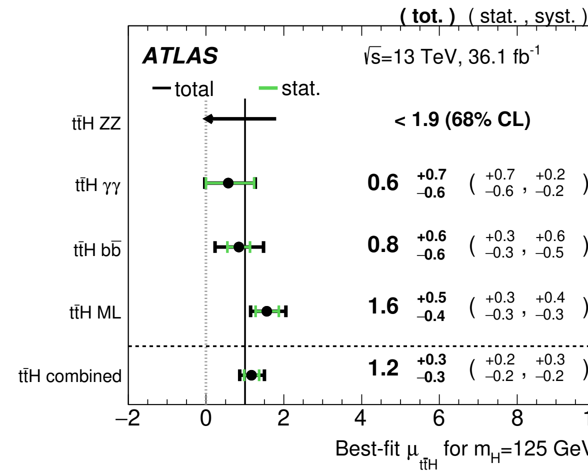


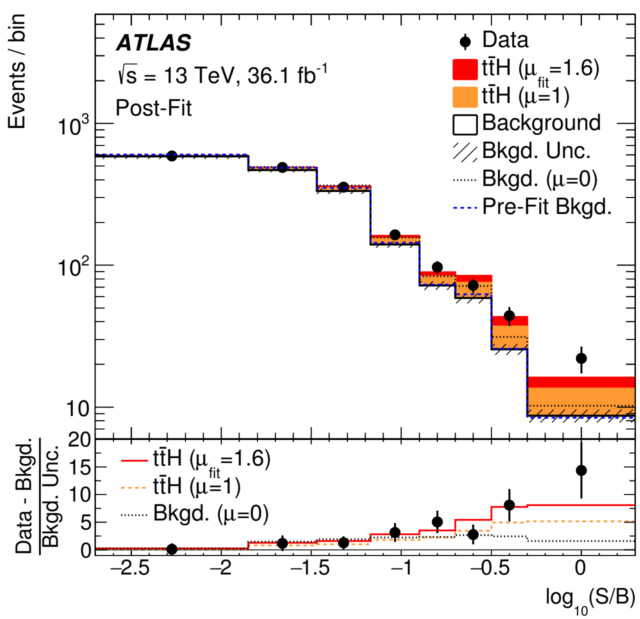


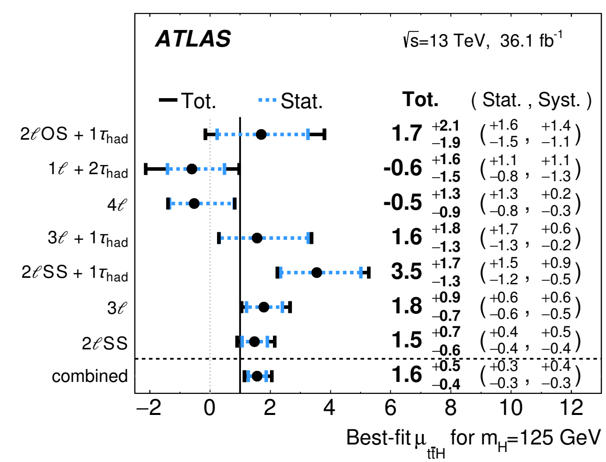


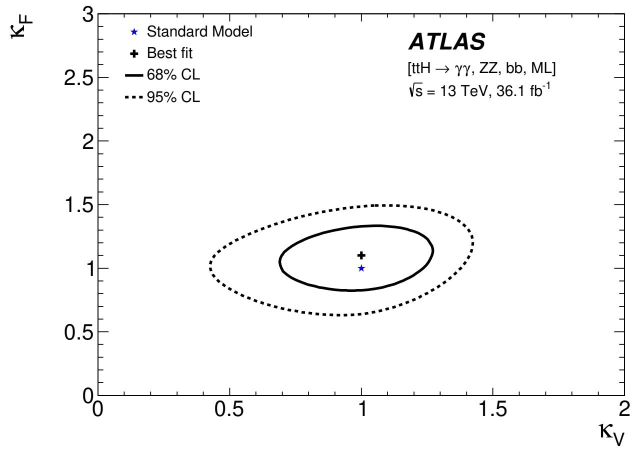
tth(ML) and combination

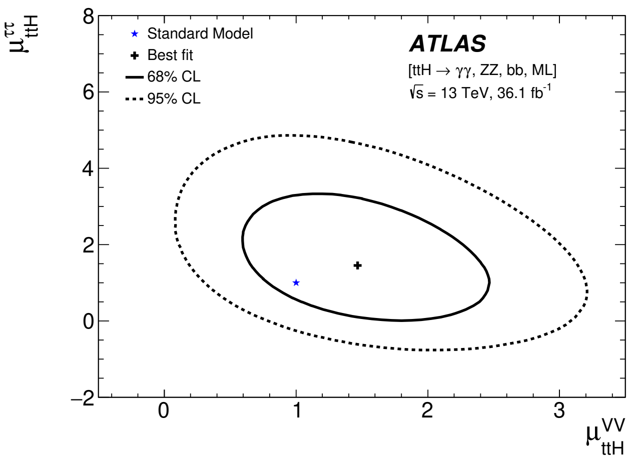


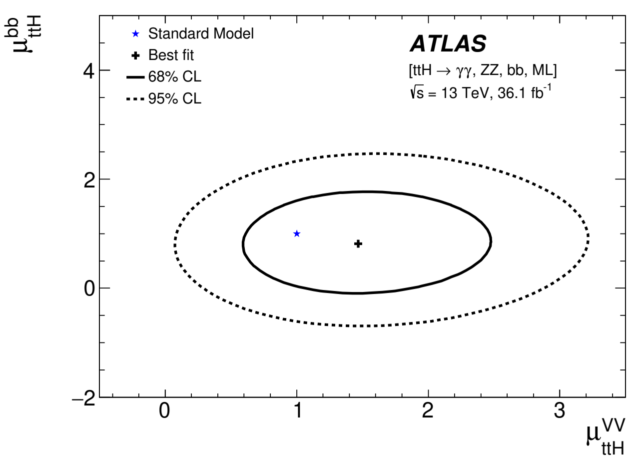







Standard Model
Best fit
68% CL
95% CL
ATLAS
[ttH → γγ, ZZ, bb, ML]
√s = 13 TeV, 36.1 fb⁻¹
κF
κV


Standard Model
Best fit
68% CL
95% CL
ATLAS
[ttH → γγ, ZZ, bb, ML]
√s = 13 TeV, 36.1 fb⁻¹
μ ttH γγ
μ ttH VV


Standard Model
Best fit
68% CL
95% CL
ATLAS
[ttH → γγ, ZZ, bb, ML]
√s = 13 TeV, 36.1 fb⁻¹
μ ttH bb
μ ttH VV

Process	Event generator	ME order	Parton Shower	PDF	Tune
$t\bar{t}H$	MG5_aMC	NLO	Pythia 8	NNPDF 3.0 NLO [71]	A14
	(MG5_aMC)	(NLO)	(Herwig++)	(CT10 [72])	(UE-EE-5)
$tHqb$	MG5_aMC	LO	Pythia 8	CT10	A14
tHW	MG5_aMC	NLO	Herwig++	CT10	UE-EE-5
$t\bar{t}W$	MG5_aMC	NLO	Pythia 8	NNPDF 3.0 NLO	A14
	(Sherpa 2.1.1)	(LO multileg)	(Sherpa)	(NNPDF 3.0 NLO)	(Sherpa default)
$t\bar{t}(Z/\gamma^* \to ll)$	MG5_aMC	NLO	Pythia 8	NNPDF 3.0 NLO	A14
	(Sherpa 2.1.1)	(LO multileg)	(Sherpa)	(NNPDF 3.0 NLO)	(Sherpa default)
tZ	MG5_aMC	LO	Pythia 6	CTEQ6L1	Perugia2012
tWZ	MG5_aMC	NLO	Pythia 8	NNPDF 2.3 LO	A14
$t\bar{t}t$, $t\bar{t}t\bar{t}$	MG5_aMC	LO	Pythia 8	NNPDF 2.3 LO	A14
$t\bar{t}W^+W^-$	MG5_aMC	LO	Pythia 8	NNPDF 2.3 LO	A14
$t\bar{t}$	Powheg-BOX v2 [73]	NLO	Pythia 8	NNPDF 3.0 NLO	A14
$t\bar{t}\gamma$	MG5_aMC	LO	Pythia 8	NNPDF 2.3 LO	A14
s-, t-channel, Wt single top	Powheg-BOX v1 [74,75,76]	NLO	Pythia 6	CT10	Perugia2012
$VV(\to llXX)$, $qqVV$, VVV	Sherpa 2.1.1	MEPS NLO	Sherpa	CT10	Sherpa default
$Z \to l^+l^-$	Sherpa 2.2.1	MEPS NLO	Sherpa	NNPDF 3.0 NLO	Sherpa default

	e					μ		
	L	L†	L*	T	T*	L	L†	L*/T/T*
Isolation	No	Yes				No	Yes	
Non-prompt lepton BDT	No		Yes			No		Yes
Identification	Loose			Tight		Loose		
Charge misassignment veto BDT	No				Yes	No		
Transverse impact parameter significance, $\lvert d_0\rvert/\sigma_{d_0}$	< 5					< 3		
Longitudinal impact parameter, $\lvert z_0 \sin\theta\rvert$	< 0.5 mm							

Channel	Selection criteria
Common	$N_{\text{jets}} \geq 2$ and $N_{b\text{-jets}} \geq 1$
2ℓSS	Two very tight light leptons with $p_{\text{T}} > 20$ GeV Same-charge light leptons Zero medium τ_{had} candidates $N_{\text{jets}} \geq 4$ and $N_{b\text{-jets}} < 3$
3ℓ	Three light leptons with $p_{\text{T}} > 10$ GeV; sum of light-lepton charges ± 1 Two same-charge leptons must be very tight and have $p_{\text{T}} > 15$ GeV The opposite-charge lepton must be loose, isolated and pass the non-prompt BDT Zero medium τ_{had} candidates $m(\ell^+\ell^-) > 12$ GeV and $\lvert m(\ell^+\ell^-) - 91.2\text{ GeV}\rvert > 10$ GeV for all SFOC pairs $\lvert m(3\ell) - 91.2\text{ GeV}\rvert > 10$ GeV
4ℓ	Four light leptons; sum of light-lepton charges 0 Third and fourth leading leptons must be tight $m(\ell^+\ell^-) > 12$ GeV and $\lvert m(\ell^+\ell^-) - 91.2\text{ GeV}\rvert > 10$ GeV for all SFOC pairs $\lvert m(4\ell) - 125\text{ GeV}\rvert > 5$ GeV Split 2 categories: Z-depleted (0 SFOC pairs) and Z-enriched (2 or 4 SFOC pairs)
1ℓ+$2\tau_{\text{had}}$	One tight light lepton with $p_{\text{T}} > 27$ GeV Two medium τ_{had} candidates of opposite charge, at least one being tight $N_{\text{jets}} \geq 3$
2ℓSS+$1\tau_{\text{had}}$	Two very tight light leptons with $p_{\text{T}} > 15$ GeV Same-charge light leptons One medium τ_{had} candidate, with charge opposite to that of the light leptons $N_{\text{jets}} \geq 4$ $\lvert m(ee) - 91.2\text{ GeV}\rvert > 10$ GeV for ee events
2ℓOS+$1\tau_{\text{had}}$	Two loose and isolated light leptons with $p_{\text{T}} > 25, 15$ GeV One medium τ_{had} candidate Opposite-charge light leptons One medium τ_{had} candidate $m(\ell^+\ell^-) > 12$ GeV and $\lvert m(\ell^+\ell^-) - 91.2\text{ GeV}\rvert > 10$ GeV for the SFOC pair $N_{\text{jets}} \geq 3$
3ℓ+$1\tau_{\text{had}}$	3ℓ selection, except: One medium τ_{had} candidate, with charge opposite to the total charge of the light leptons The two same-charge light leptons must be tight and have $p_{\text{T}} > 10$ GeV The opposite-charge light lepton must be loose and isolated

tth(ML) and combination

	2ℓSS	3ℓ	4ℓ	1ℓ+$2\tau_{\text{had}}$	2ℓSS+$1\tau_{\text{had}}$	2ℓOS+$1\tau_{\text{had}}$	3ℓ+$1\tau_{\text{had}}$
Light lepton	2T*	1L*, 2T*	2L, 2T	1T	2T*	$2L^{\dagger}$	$1L^{\dagger}$, 2T
τ_{had}	0M	0M	–	1T, 1M	1M	1M	1M
N_{jets}, $N_{b\text{-jets}}$	$\geq 4, = 1, 2$	$\geq 2, \geq 1$	$\geq 2, \geq 1$	$\geq 3, \geq 1$	$\geq 4, \geq 1$	$\geq 3, \geq 1$	$\geq 2, \geq 1$

	2ℓSS	3ℓ	4ℓ	1ℓ+$2\tau_{\mathrm{had}}$	2ℓSS+$1\tau_{\mathrm{had}}$	2ℓOS+$1\tau_{\mathrm{had}}$	3ℓ+$1\tau_{\mathrm{had}}$	Total
$A \times \epsilon$ $[10^{-4}]$	23	13	0.6+0.1	2.3	1.7	7.8	0.8	50

	Variable	2ℓSS	3ℓ	4ℓ	1ℓ+$2\tau_{had}$	2ℓSS+$1\tau_{had}$	2ℓOS+$1\tau_{had}$
Lepton properties	Leading lepton p_T		×				
	Second leading lepton p_T	×	×			×	
	Third lepton p_T		×				
	Dilepton invariant mass (all combinations)	×	×∗				×
	Three-lepton invariant mass		×				
	Four-lepton invariant mass			×			
	Best Z-candidate dilepton invariant mass			×			
	Other Z-candidate dilepton invariant mass			×			
	Scalar sum of all leptons p_T			×			×
	Second leading lepton track isolation					×	
	Maximum $\|\eta\|$ (lepton 0, lepton 1)	×				×∗	
	Lepton flavor	×∗	×∗				
	Lepton charge		×				
Jet properties	Number of jets	×∗	×∗		×	×	×
	Number of b-tagged jets	×∗	×∗		×	×	×
	Leading jet p_T						×
	Second leading jet p_T		×			×∗	
	Leading b-tagged jet p_T		×				
	Scalar sum of all jets p_T		×		×	×	×
	Scalar sum of all b-tagged jets p_T						×
	Has leading jet highest b-tagging weight?		×				
	b-tagging weight of leading jet		×				
	b-tagging weight of second leading jet		×			×	
	b-tagging weight of third leading jet					×	
	Pseudorapidity of fourth leading jet					×	
τ_{had}	Leading τ_{had} p_T				×		×
	Second leading τ_{had} p_T				×		
	Di-τ_{had} invariant mass				×		
	Invariant mass τ_{had}–furthest lepton					×	
Angular distances	ΔR(lepton 0, lepton 1)		×				
	ΔR(lepton 0, lepton 2)		×				
	ΔR(lepton 0, closest jet)	×	×				
	ΔR(lepton 0, leading jet)		×			×	
	ΔR(lepton 0, closest b-jet)		×				
	ΔR(lepton 1, closest jet)	×	×				
	ΔR(lepton 2, closest jet)		×				
	Smallest ΔR(lepton, jet)		×				×
	Smallest ΔR(lepton, b-tagged jet)						×
	Smallest ΔR(non-tagged jet, b-tagged jet)						×
	ΔR(lepton 0, τ_{had})						×
	ΔR(lepton 1, τ_{had})						×
	Minimum ΔR between all jets				×		
	ΔR between two leading jets					×	
$\vec{p}_T^{miss}$	Missing transverse momentum E_T^{miss}	×		×			
	Azimuthal separation $\Delta\phi$(leading jet, $\vec{p}_T^{miss}$)		×				
	Transverse mass leptons (H/Z decay) - $\vec{p}_T^{miss}$			×			
	Pseudo-Matrix-Element			×			

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Channel	Region	Selection criteria
2ℓSS		$2 \leq N_{\text{jets}} \leq 3$ and $N_{b\text{-jets}} \geq 1$
(3ℓ)		One very tight, one loose light lepton with $p_{\text{T}} > 20$ (15) GeV
		Zero τ_{had} candidates
	ϵ_{real}	Opposite charge; opposite flavor
	ϵ_{fake}	Same charge; opposite flavor or $\mu\mu$
4ℓ		$1 \leq N_{\text{jets}} \leq 2$
		Three loose light leptons; sum of light lepton charges ±1
		Subleading same-charge lepton must be tight
		Veto on 3ℓ selection
	Either	One SFOC pair with $\lvert m(\ell^+\ell^-) - 91.2\text{ GeV}\rvert < 10$ GeV
		$E_{\text{T}}^{\text{miss}} < 50$ GeV, $m_{\text{T}} < 50$ GeV
	or	No SFOC pair
		Subleading jet $p_{\text{T}} > 30$ GeV
2ℓSS+$1\tau_{\text{had}}$		$2 \leq N_{\text{jets}} \leq 3$ and $N_{b\text{-jets}} \geq 1$
		One very tight, one loose light lepton with $p_{\text{T}} > 15$ GeV
		A SFSC pair
		$\lvert m(ee) - 91.2\text{ GeV}\rvert > 10$ GeV
		Zero or one medium τ_{had} candidate, opposite in charge to the light leptons
1ℓ+$2\tau_{\text{had}}$		$N_{\text{jets}} \geq 3$ and $N_{b\text{-jets}} \geq 1$
		One tight light lepton, with $p_{\text{T}} > 27$ GeV
		Two τ_{had} candidates of same charge
		At least one τ_{had} candidate has to satisfy tight identification criteria
2ℓOS+$1\tau_{\text{had}}$		Two loose and isolated light leptons, with $p_{\text{T}} > 25$, 15 GeV
		One loose τ_{had} candidate
		$\lvert m(\ell^+\ell^-) - 91.2\text{ GeV}\rvert > 10$ GeV and $m(\ell^+\ell^-) > 12$ GeV
		$N_{\text{jets}} \geq 3$ and $N_{b\text{-jets}} = 0$

	2ℓSS	3ℓ	4ℓ	1ℓ+$2\tau_{\text{had}}$	2ℓSS+$1\tau_{\text{had}}$	2ℓOS+$1\tau_{\text{had}}$	3ℓ+$1\tau_{\text{had}}$
Non-prompt lepton strategy	DD (MM)	DD (MM)	semi-DD (SF)	MC	DD (FF)	MC	MC
Fake τ_{had} strategy	–	–	–	DD (SS data)	semi-DD (SF)	DD (FF)	semi-DD (SF)
Control Region Selection							
Light lepton	1T*, 1L	1T*, 1L	3L	1T	1T*, 1L	$2\text{L}^{\dagger}$	–
τ_{had}	0M	0M	0M	1T, 1M	$\leq$ 1M	1L	–
N_{jets}	$2 \leq N_{\text{jets}} \leq 3$	$2 \leq N_{\text{jets}} \leq 3$	$1 \leq N_{\text{jets}} \leq 2$	≥ 3	$2 \leq N_{\text{jets}} \leq 3$	≥ 3	–
$N_{b\text{-jets}}$	≥ 1	≥ 1	≥ 1	≥ 1	≥ 1	$= 0$	–

Systematic uncertainty	Type	Components
Luminosity	N	1
Pileup reweighting	SN	1
Physics Objects		
Electron	SN	6
Muon	SN	15
τ_{had}	SN	10
Jet energy scale and resolution	SN	28
Jet vertex fraction	SN	1
Jet flavor tagging	SN	126
$E_{\mathrm{T}}^{\mathrm{miss}}$	SN	3
Total (Experimental)	–	191
Data-driven non-prompt/fake leptons and charge misassignment		
Control region statistics	SN	38
Light-lepton efficiencies	SN	22
Non-prompt light-lepton estimates: non-closure	N	5
γ-conversion fraction	N	5
Fake τ_{had} estimates	N/SN	12
Electron charge misassignment	SN	1
Total (Data-driven reducible background)	–	83
$t\bar{t}H$ modeling		
Cross section	N	2
Renormalization and factorization scales	S	3
Parton shower and hadronization model	SN	1
Higgs boson branching fraction	N	4
Shower tune	SN	1
$t\bar{t}W$ modeling		
Cross section	N	2
Renormalization and factorization scales	S	3
Matrix-element MC event generator	SN	1
Shower tune	SN	1
$t\bar{t}Z$ modeling		
Cross section	N	2
Renormalization and factorization scales	S	3
Matrix-element MC event generator	SN	1
Shower tune	SN	1
Other background modeling		
Cross section	N	15
Shower tune	SN	1
Total (Signal and background modeling)	–	41
Total (Overall)	–	315

Category	Non-prompt	Fake τ_{had}	q mis-id	$t\bar{t}W$	$t\bar{t}Z$	Diboson	Other	Total Bkgd.	$t\bar{t}H$	Observed
					Pre-fit yields					
2ℓSS	233 ± 39	–	33 ± 11	123 ± 18	41.4 ± 5.6	25 ± 15	28.4 ± 5.9	484 ± 38	42.6 ± 4.2	514
3ℓ SR	14.5 ± 4.3	–	–	5.5 ± 1.2	12.0 ± 1.8	1.2 ± 1.2	5.8 ± 1.4	39.1 ± 5.2	11.2 ± 1.6	61
3ℓ $t\bar{t}W$ CR	13.3 ± 4.3	–	–	19.9 ± 3.1	8.7 ± 1.1	< 0.2	4.53 ± 0.92	46.5 ± 5.4	4.18 ± 0.46	56
3ℓ $t\bar{t}Z$ CR	3.9 ± 2.5	–	–	2.71 ± 0.56	66 ± 11	8.4 ± 5.3	12.9 ± 4.2	93 ± 13	3.17 ± 0.41	107
3ℓ VV CR	27.7 ± 8.7	–	–	4.9 ± 1.0	21.3 ± 3.4	51 ± 30	17.9 ± 6.1	123 ± 32	1.67 ± 0.25	109
3ℓ $t\bar{t}$ CR	70 ± 17	–	–	10.5 ± 1.5	7.9 ± 1.1	7.2 ± 4.8	7.3 ± 1.9	103 ± 17	4.00 ± 0.49	85
4ℓ Z-enr.	0.11 ± 0.07	–	–	< 0.01	1.52 ± 0.23	0.43 ± 0.23	0.21 ± 0.09	2.26 ± 0.34	1.06 ± 0.14	2
4ℓ Z-dep.	0.01 ± 0.01	–	–	< 0.01	0.04 ± 0.02	< 0.01	0.06 ± 0.03	0.11 ± 0.03	0.20 ± 0.03	0
1ℓ+$2\tau_{\text{had}}$	–	65 ± 21	–	0.09 ± 0.09	3.3 ± 1.0	1.3 ± 1.0	0.98 ± 0.35	71 ± 21	4.3 ± 1.0	67
2ℓSS+$1\tau_{\text{had}}$	2.4 ± 1.4	1.80 ± 0.30	0.05 ± 0.02	0.88 ± 0.24	1.83 ± 0.37	0.12 ± 0.18	1.06 ± 0.24	8.2 ± 1.6	3.09 ± 0.46	18
2ℓOS+$1\tau_{\text{had}}$	–	756 ± 80	–	6.5 ± 1.3	11.4 ± 1.9	2.0 ± 1.3	5.8 ± 1.5	782 ± 81	14.2 ± 2.0	807
3ℓ+$1\tau_{\text{had}}$	–	0.75 ± 0.15	–	0.04 ± 0.04	1.38 ± 0.24	0.002 ± 0.002	0.38 ± 0.10	2.55 ± 0.32	1.51 ± 0.23	5
					Post-fit yields					
2ℓSS	211 ± 26	–	28.3 ± 9.4	127 ± 18	42.9 ± 5.4	20.0 ± 6.3	28.5 ± 5.7	459 ± 24	67 ± 18	514
3ℓ SR	13.2 ± 3.1	–	–	5.8 ± 1.2	12.9 ± 1.6	1.2 ± 1.1	5.9 ± 1.3	39.0 ± 4.0	17.7 ± 4.9	61
3ℓ $t\bar{t}W$ CR	11.7 ± 3.0	–	–	20.4 ± 3.0	8.9 ± 1.0	< 0.2	4.54 ± 0.88	45.6 ± 4.0	6.6 ± 1.9	56
3ℓ $t\bar{t}Z$ CR	3.5 ± 2.1	–	–	2.82 ± 0.56	70.4 ± 8.6	7.1 ± 3.0	13.6 ± 4.2	97.4 ± 8.6	5.1 ± 1.4	107
3ℓ VV CR	22.4 ± 5.7	–	–	5.05 ± 0.94	22.0 ± 3.0	39 ± 11	18.1 ± 5.9	106.8 ± 9.4	2.61 ± 0.82	109
3ℓ $t\bar{t}$ CR	56.0 ± 8.1	–	–	10.7 ± 1.4	8.1 ± 1.0	5.9 ± 2.7	7.1 ± 1.8	87.8 ± 7.9	6.3 ± 1.8	85
4ℓ Z-enr.	0.10 ± 0.07	–	–	< 0.01	1.60 ± 0.22	0.37 ± 0.15	0.22 ± 0.10	2.29 ± 0.28	1.65 ± 0.47	2
4ℓ Z-dep.	0.01 ± 0.01	–	–	< 0.01	0.04 ± 0.02	< 0.01	0.07 ± 0.03	0.11 ± 0.03	0.32 ± 0.09	0
1ℓ+$2\tau_{\text{had}}$	–	58.0 ± 6.8	–	0.11 ± 0.11	3.31 ± 0.90	0.98 ± 0.75	0.98 ± 0.33	63.4 ± 6.7	6.5 ± 2.0	67
2ℓSS+$1\tau_{\text{had}}$	1.86 ± 0.91	1.86 ± 0.27	0.05 ± 0.02	0.97 ± 0.26	1.96 ± 0.37	0.15 ± 0.20	1.09 ± 0.24	7.9 ± 1.2	5.1 ± 1.3	18
2ℓOS+$1\tau_{\text{had}}$	–	756 ± 28	–	6.6 ± 1.3	11.5 ± 1.7	1.64 ± 0.92	6.1 ± 1.5	782 ± 27	21.7 ± 5.9	807
3ℓ+$1\tau_{\text{had}}$	–	0.75 ± 0.14	–	0.04 ± 0.04	1.42 ± 0.22	0.002 ± 0.002	0.40 ± 0.10	2.61 ± 0.30	2.41 ± 0.68	5

	2ℓSS	3ℓ	4ℓ	$1\ell+2\tau_{\text{had}}$	2ℓSS$+1\tau_{\text{had}}$	2ℓOS$+1\tau_{\text{had}}$	$3\ell+1\tau_{\text{had}}$
BDT trained against	Fakes and $t\bar{t}V$	$t\bar{t}$, $t\bar{t}W$, $t\bar{t}Z$, VV	$t\bar{t}Z$ / -	$t\bar{t}$	all	$t\bar{t}$	-
Discriminant	2×1D BDT	5D BDT	Event count	BDT	BDT	BDT	Event count
Number of bins	6	5	1 / 1	2	2	10	1
Control regions	-	4	-	-	-	-	-

Uncertainty Source	$\Delta\mu$	
$t\bar{t}H$ modeling (cross section)	+0.20	−0.09
Jet energy scale and resolution	+0.18	−0.15
Non-prompt light-lepton estimates	+0.15	−0.13
Jet flavor tagging and τ_{had} identification	+0.11	−0.09
$t\bar{t}W$ modeling	+0.10	−0.09
$t\bar{t}Z$ modeling	+0.08	−0.07
Other background modeling	+0.08	−0.07
Luminosity	+0.08	−0.06
$t\bar{t}H$ modeling (acceptance)	+0.08	−0.04
Fake τ_{had} estimates	+0.07	−0.07
Other experimental uncertainties	+0.05	−0.04
Simulation sample size	+0.04	−0.04
Charge misassignment	+0.01	−0.01
Total systematic uncertainty	+0.39	−0.30

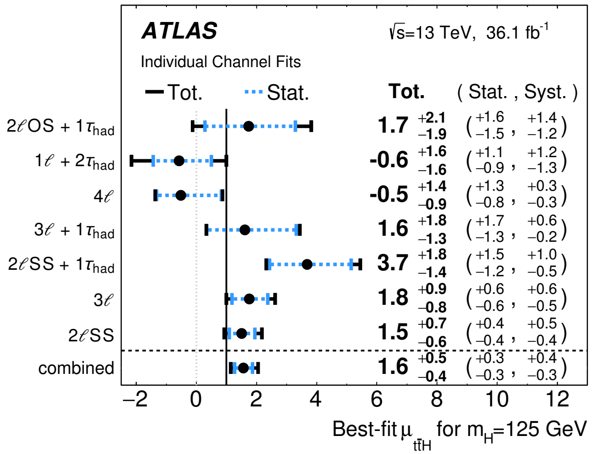
tth(ML) and combination

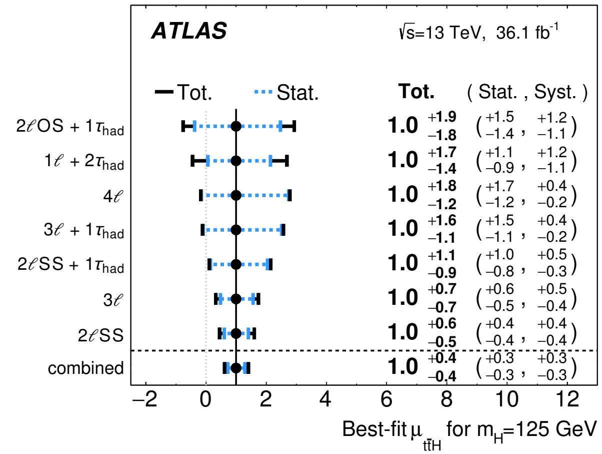
Channel	Best-fit μ		Significance	
	Observed	Expected	Observed	Expected
2ℓOS+$1\tau_{\text{had}}$	$1.7\ ^{+1.6}_{-1.5}$ (stat.) $^{+1.4}_{-1.1}$ (syst.)	$1.0\ ^{+1.5}_{-1.4}$ (stat.) $^{+1.2}_{-1.1}$ (syst.)	0.9σ	0.5σ
1ℓ+$2\tau_{\text{had}}$	$-0.6\ ^{+1.1}_{-0.8}$ (stat.) $^{+1.1}_{-1.3}$ (syst.)	$1.0\ ^{+1.1}_{-0.9}$ (stat.) $^{+1.2}_{-1.1}$ (syst.)	–	0.6σ
4ℓ	$-0.5\ ^{+1.3}_{-0.8}$ (stat.) $^{+0.2}_{-0.3}$ (syst.)	$1.0\ ^{+1.7}_{-1.2}$ (stat.) $^{+0.4}_{-0.2}$ (syst.)	–	0.8σ
3ℓ+$1\tau_{\text{had}}$	$1.6\ ^{+1.7}_{-1.3}$ (stat.) $^{+0.6}_{-0.2}$ (syst.)	$1.0\ ^{+1.5}_{-1.1}$ (stat.) $^{+0.4}_{-0.2}$ (syst.)	1.3σ	0.9σ
2ℓSS+$1\tau_{\text{had}}$	$3.5\ ^{+1.5}_{-1.2}$ (stat.) $^{+0.9}_{-0.5}$ (syst.)	$1.0\ ^{+1.1}_{-0.8}$ (stat.) $^{+0.5}_{-0.3}$ (syst.)	3.4σ	1.1σ
3ℓ	$1.8\ ^{+0.6}_{-0.6}$ (stat.) $^{+0.6}_{-0.5}$ (syst.)	$1.0\ ^{+0.6}_{-0.5}$ (stat.) $^{+0.5}_{-0.4}$ (syst.)	2.4σ	1.5σ
2ℓSS	$1.5\ ^{+0.4}_{-0.4}$ (stat.) $^{+0.5}_{-0.4}$ (syst.)	$1.0\ ^{+0.4}_{-0.4}$ (stat.) $^{+0.4}_{-0.4}$ (syst.)	2.7σ	1.9σ
Combined	$1.6\ ^{+0.3}_{-0.3}$ (stat.) $^{+0.4}_{-0.3}$ (syst.)	$1.0\ ^{+0.3}_{-0.3}$ (stat.) $^{+0.3}_{-0.3}$ (syst.)	4.1σ	2.8σ

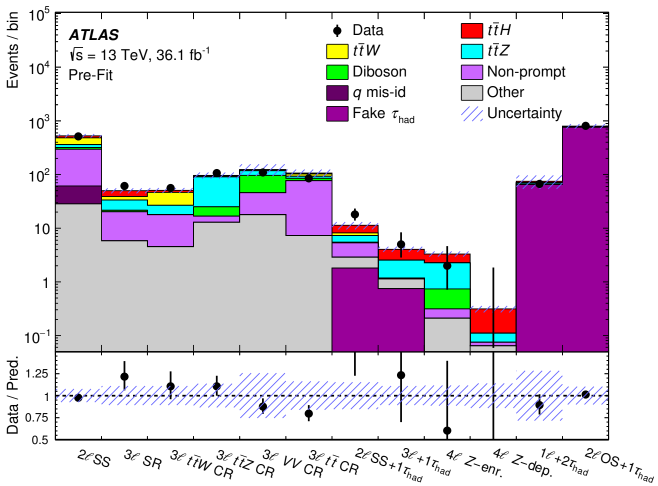
Channel	Best-fit μ		Significance	
	Observed	Expected	Observed	Expected
Multilepton	$1.6\ ^{+0.5}_{-0.4}$	$1.0\ ^{+0.4}_{-0.4}$	4.1σ	2.8σ
$H \to b\bar{b}$	$0.8\ ^{+0.6}_{-0.6}$	$1.0\ ^{+0.6}_{-0.6}$	1.4σ	1.6σ
$H \to \gamma\gamma$	$0.6\ ^{+0.7}_{-0.6}$	$1.0\ ^{+0.8}_{-0.6}$	0.9σ	1.7σ
$H \to 4\ell$	< 1.9	$1.0\ ^{+3.2}_{-1.0}$	—	0.6σ
Combined	$1.2\ ^{+0.3}_{-0.3}$	$1.0\ ^{+0.3}_{-0.3}$	4.2σ	3.8σ

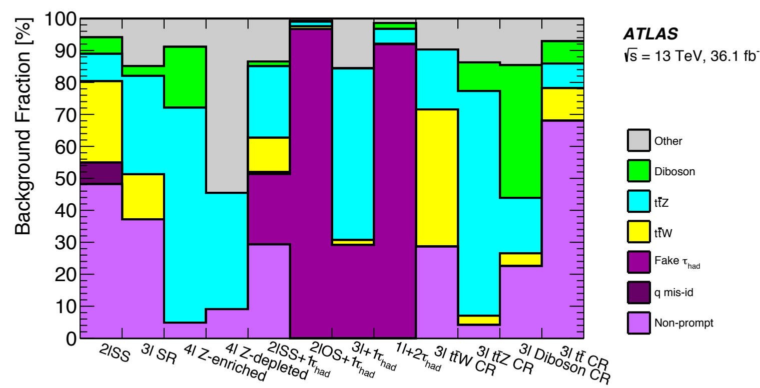
Uncertainty Source	$\Delta\mu$	
$t\bar{t}$ modeling in $H \to bb$ analysis	+0.15	−0.14
$t\bar{t}H$ modeling (cross section)	+0.13	−0.06
Non-prompt light-lepton and fake τ_{had} estimates	+0.09	−0.09
Simulation statistics	+0.08	−0.08
Jet energy scale and resolution	+0.08	−0.07
$t\bar{t}V$ modeling	+0.07	−0.07
$t\bar{t}H$ modeling (acceptance)	+0.07	−0.04
Other non-Higgs boson backgrounds	+0.06	−0.05
Other experimental uncertainties	+0.05	−0.05
Luminosity	+0.05	−0.04
Jet flavor tagging	+0.03	−0.02
Modeling of other Higgs boson production modes	+0.01	−0.01
Total systematic uncertainty	+0.27	−0.23
Statistical uncertainty	+0.19	−0.19
Total uncertainty	+0.34	−0.30

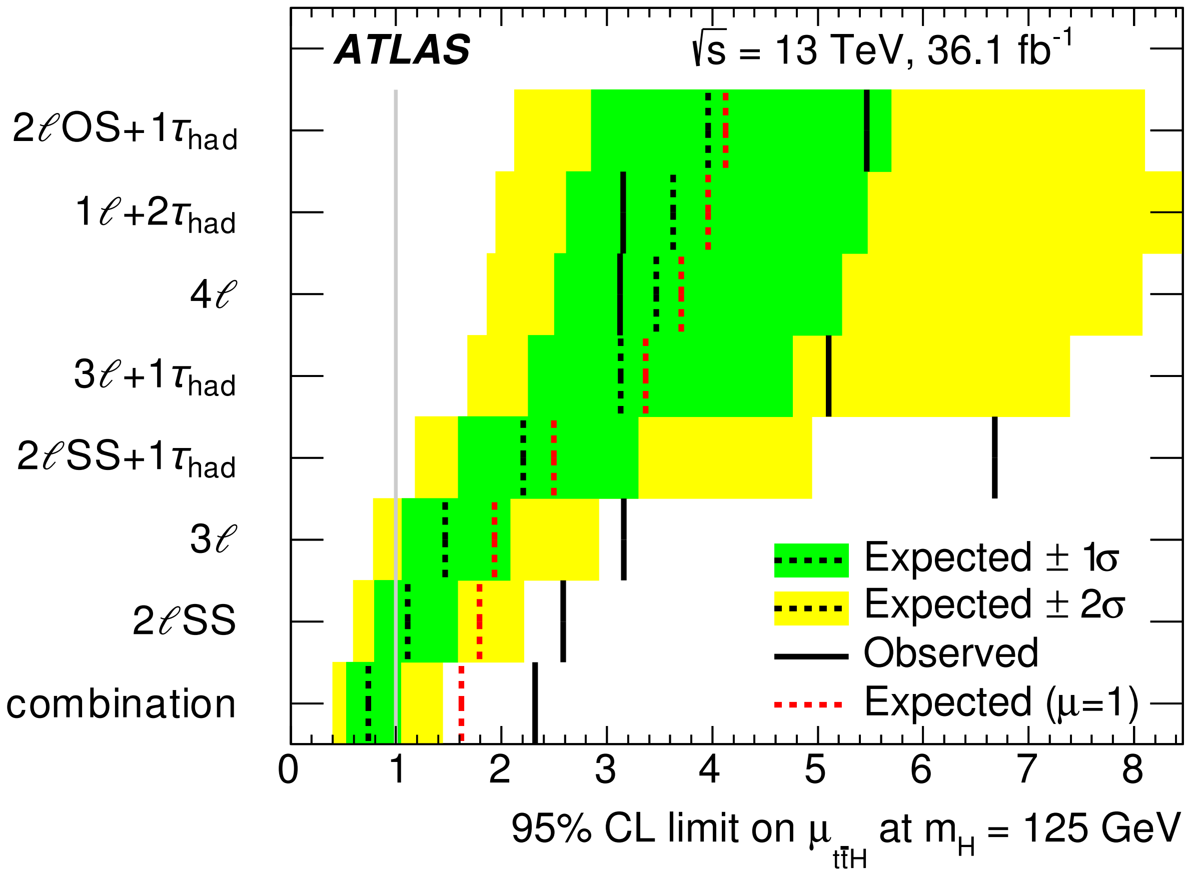
tth(ML) and combination







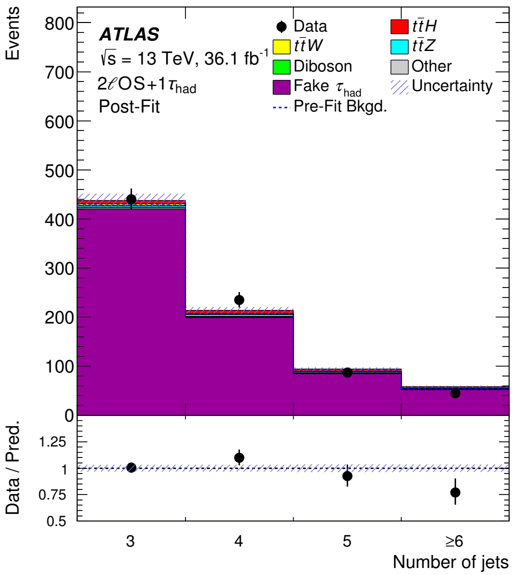


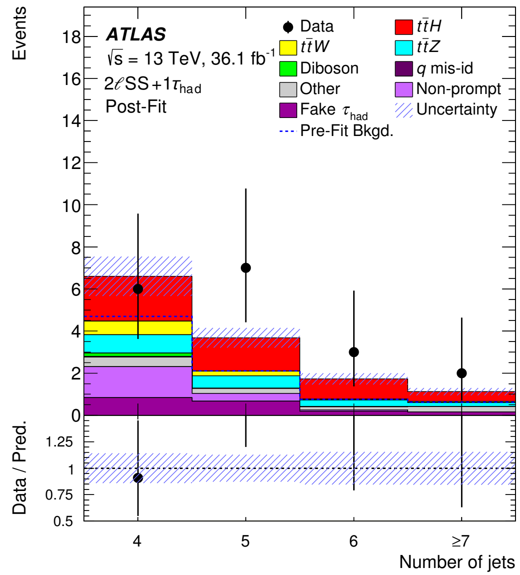

ATLAS
√s = 13 TeV, 36.1 fb-1
2ℓOS+1τhad
1ℓ+2τhad
4ℓ
3ℓ+1τhad
2ℓSS+1τhad
3ℓ
2ℓSS
combination
Expected ± 1σ
Expected ± 2σ
Observed
Expected (μ=1)
0
1
2
3
4
5
6
7
8
95% CL limit on μtt̄H at mH = 125 GeV

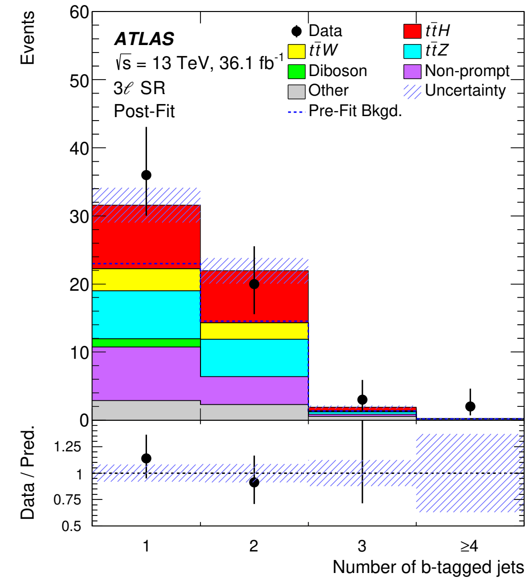
ATLAS $\sqrt{s}$ = 13 TeV, 36.1 fb^{-1}

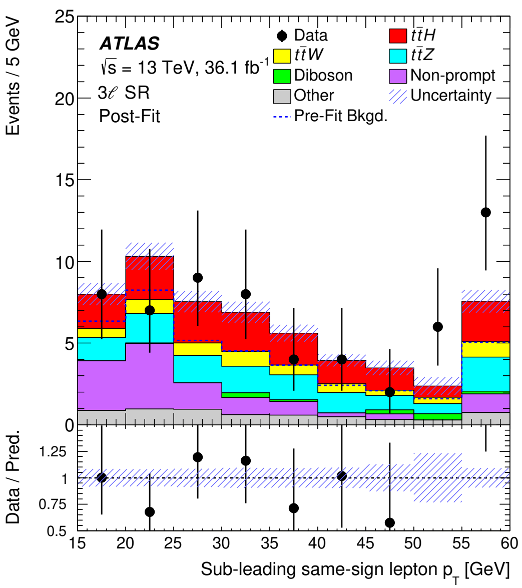
	ttH signal strength	ttH cross section (scale variations)	tZ cross section	3ℓ Non-prompt closure	Non-prompt stat. in $3\ell\, t\bar{t}$ CR	Fake τ_{had} stat. in 1st bin of 1ℓ+$2\tau_{had}$	Fake τ_{had} modeling (1ℓ + $2\tau_{had}$)	Fake τ_{had} low p_T (2ℓOS+$1\tau_{had}$)	Fake τ_{had} comp. tt (2ℓOS+$1\tau_{had}$)	Fake τ_{had} comp. Z (2ℓOS+$1\tau_{had}$)	VV modeling (shower tune)	VV cross section	Jet energy scale (pileup subtraction)	Jet energy resolution
ttH signal strength	100.0	-26.3	-0.7	-11.0	2.8	1.6	-4.9	-2.0	-1.9	-1.3	1.7	4.0	-22.4	-1.9
ttH cross section (scale variations)	-26.3	100.0	0.0	0.0	-0.0	-0.0	0.0	-0.2	0.1	-0.1	-0.0	-0.0	0.0	0.0
tZ cross section	-0.7	0.0	100.0	-2.9	0.4	-0.1	-0.4	0.0	0.2	0.1	4.7	-21.1	1.1	-0.3
3ℓ Non-prompt closure	-11.0	0.0	-2.9	100.0	-24.5	-0.2	0.9	0.4	0.2	0.2	3.7	-9.4	4.7	1.3
Non-prompt stat. in $3\ell\, t\bar{t}$ CR	2.8	-0.0	0.4	-24.5	100.0	0.0	-0.3	-0.1	-0.1	-0.1	0.2	4.2	-0.8	0.1
Fake τ_{had} stat. in 1st bin of 1ℓ+$2\tau_{had}$	1.6	-0.0	-0.1	-0.2	0.0	100.0	-58.9	-0.1	-0.0	-0.0	0.0	0.1	-0.4	-0.1
Fake τ_{had} modeling (1ℓ + $2\tau_{had}$)	-4.9	0.0	-0.4	0.9	-0.3	-58.9	100.0	0.5	0.1	0.3	-1.7	-2.4	1.2	-0.5
Fake τ_{had} low p_T (2ℓOS+$1\tau_{had}$)	-2.0	-0.2	0.0	0.4	-0.1	-0.1	0.5	100.0	30.4	13.9	-0.3	-0.4	0.1	-0.1
Fake τ_{had} comp. tt (2ℓOS+$1\tau_{had}$)	-1.9	0.1	0.2	0.2	-0.1	-0.0	0.1	30.4	100.0	-63.4	-0.1	0.0	0.1	0.3
Fake τ_{had} comp. Z (2ℓOS+$1\tau_{had}$)	-1.3	-0.1	0.1	0.2	-0.1	-0.0	0.3	13.9	-63.4	100.0	-0.2	-0.4	0.3	0.1
VV modeling (shower tune)	1.7	-0.0	4.7	3.7	0.2	0.0	-1.7	-0.3	-0.1	-0.2	100.0	61.4	1.2	-3.3
VV cross section	4.0	-0.0	-21.1	-9.4	4.2	0.1	-2.4	-0.4	0.0	-0.4	61.4	100.0	-1.3	24.9
Jet energy scale (pileup subtraction)	-22.4	0.0	1.1	4.7	-0.8	-0.4	1.2	0.1	0.1	0.3	1.2	-1.3	100.0	-6.1
Jet energy resolution	-1.9	0.0	-0.3	1.3	0.1	-0.1	-0.5	-0.1	0.3	0.1	-3.3	24.9	-6.1	100.0

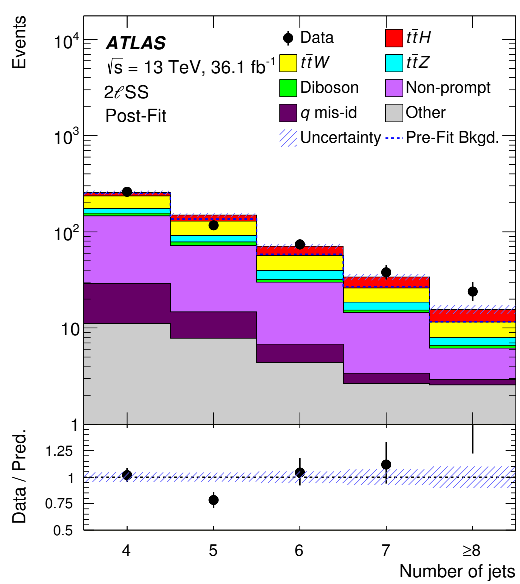
tth(ML) and combination

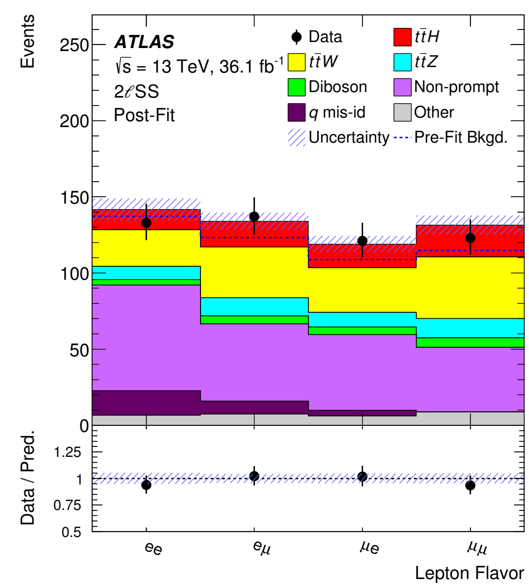




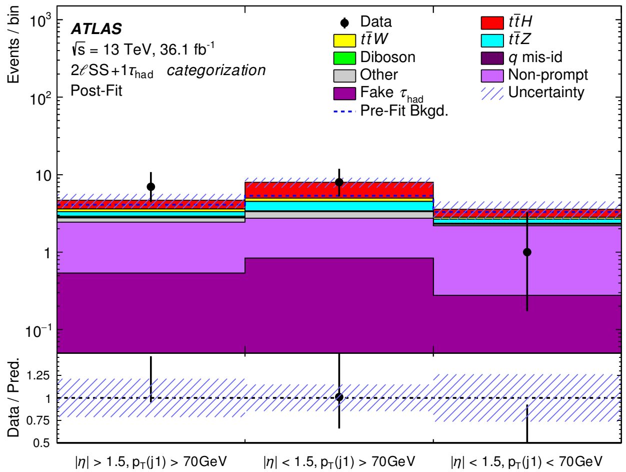


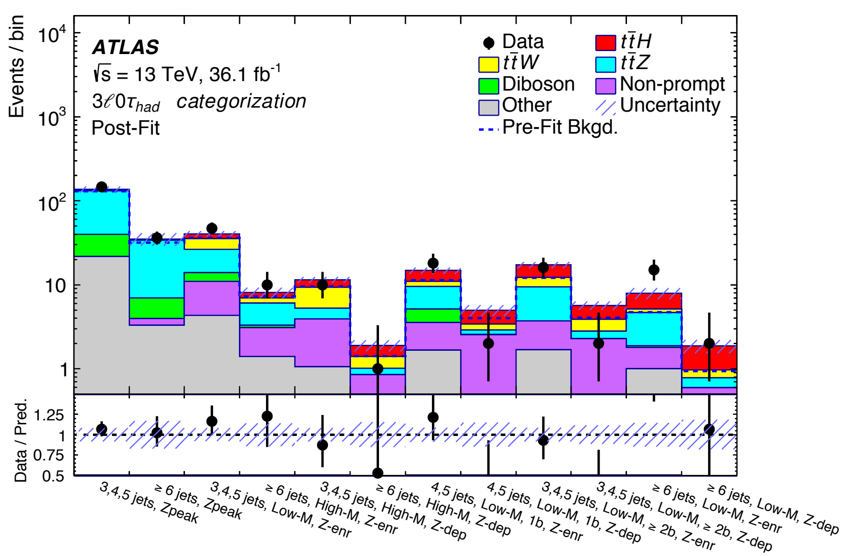


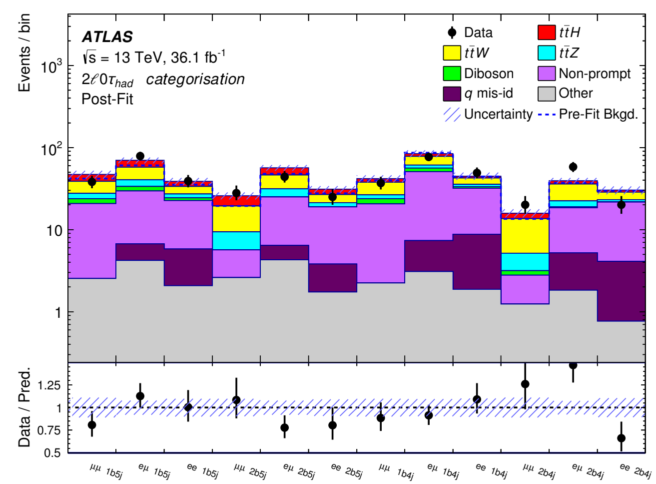




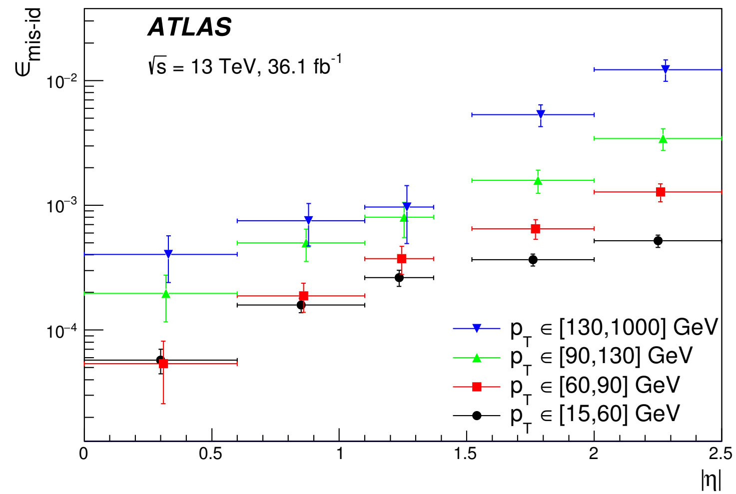
tth(ML) and combination

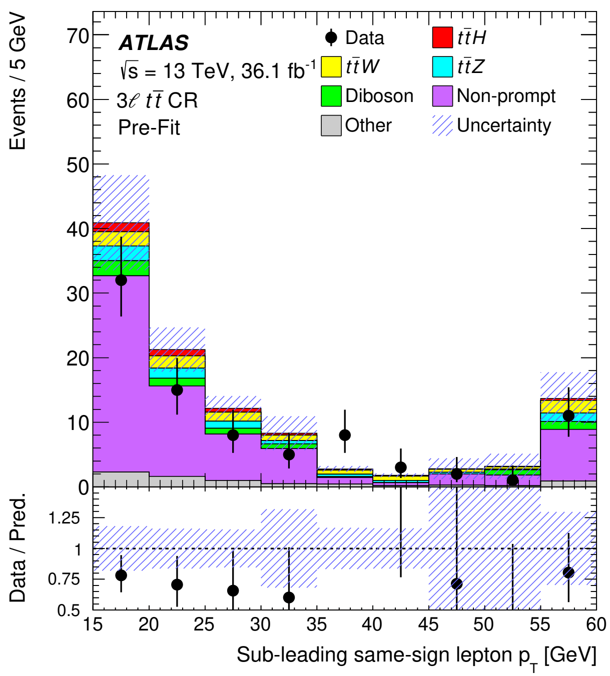


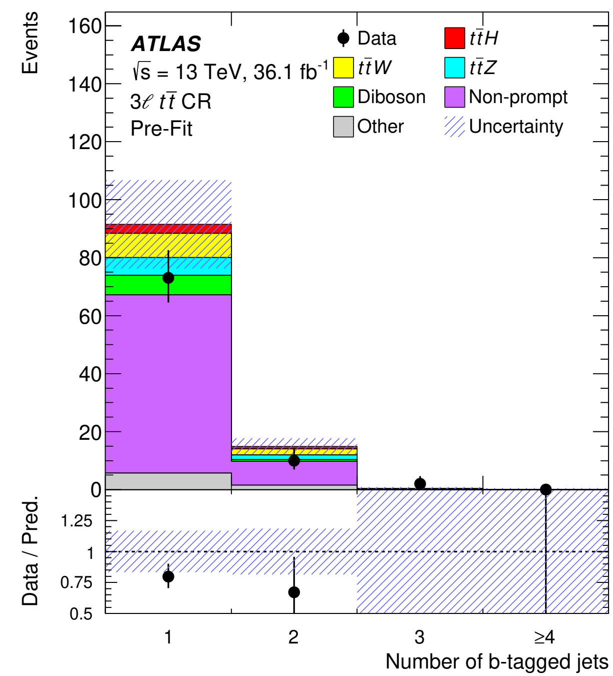


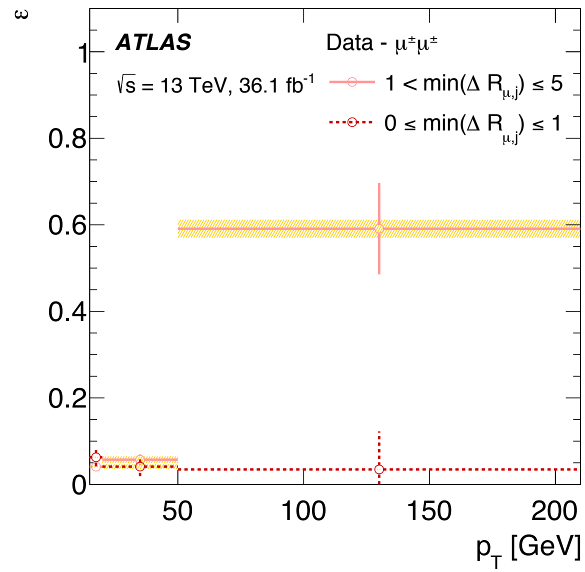


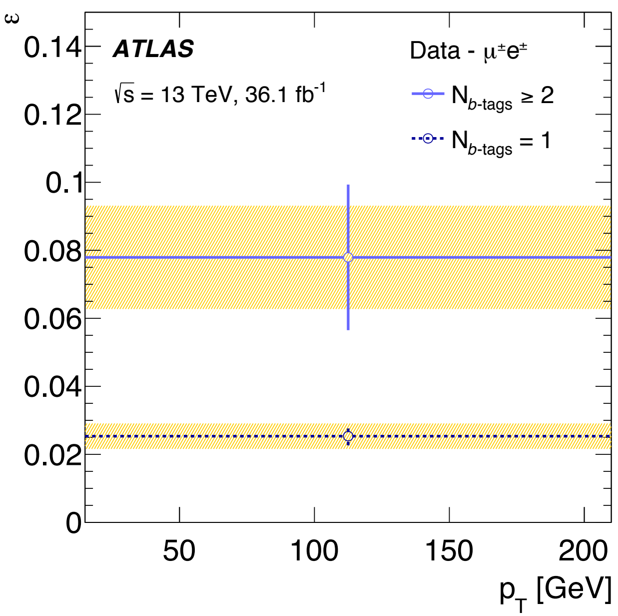
tth(ML) and combination

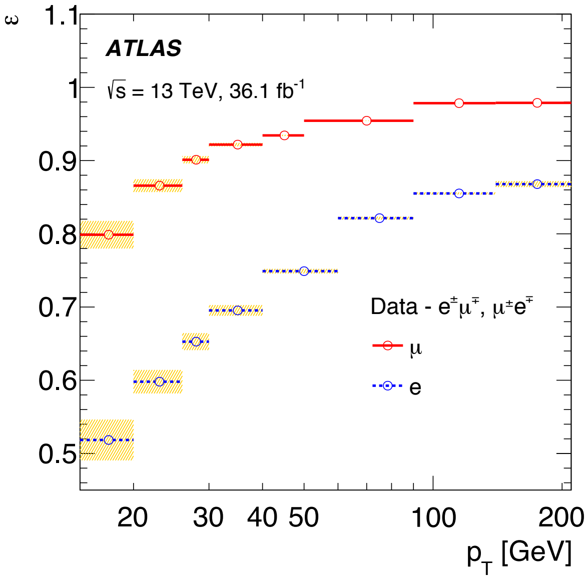


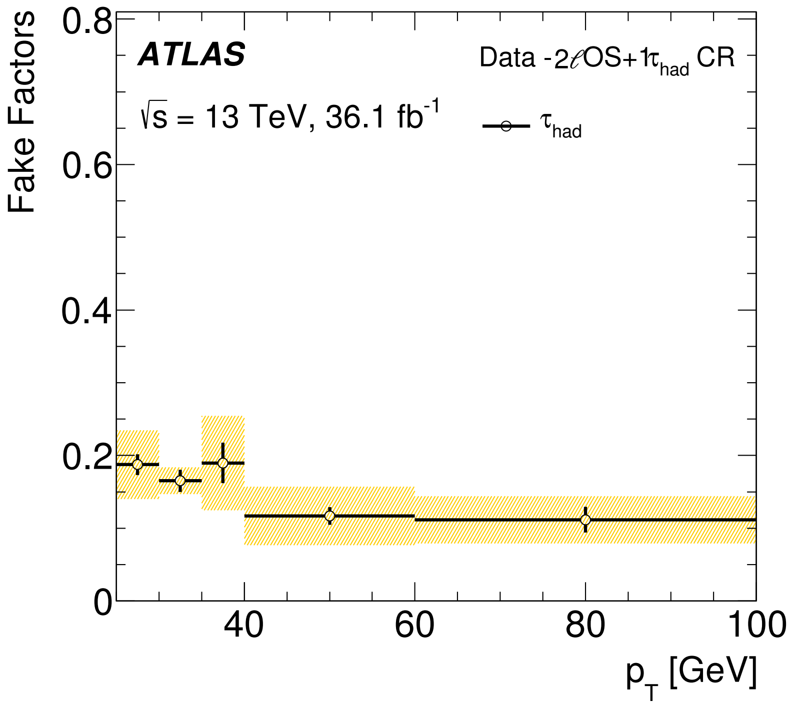


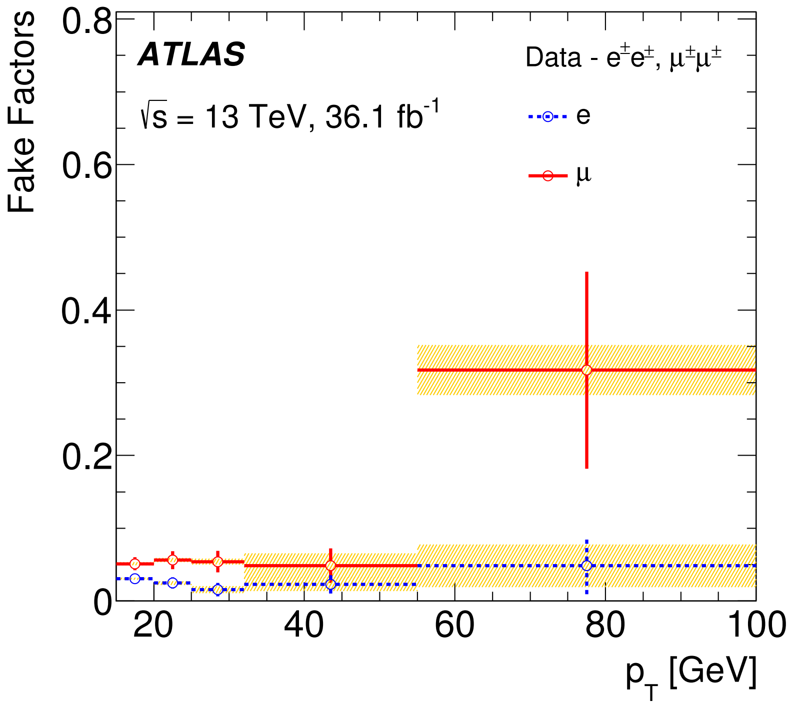



ATLAS
√s = 13 TeV, 36.1 fb-1
Data - μ±μ±
1 < min(Δ R_μ,j) ≤ 5
0 ≤ min(Δ R_μ,j) ≤ 1
ε
p_T [GeV]


ATLAS
√s = 13 TeV, 36.1 fb-1
Data - μ±e±
N_b-tags ≥ 2
N_b-tags = 1
ε
p_T [GeV]


ATLAS
√s = 13 TeV, 36.1 fb-1
Data - e±μ∓, μ±e∓
μ
e
ε
p_T [GeV]


Fake Factors
ATLAS
Data - 2ℓOS+1τ_{had} CR
$\sqrt{s}$ = 13 TeV, 36.1 fb^{-1}
τ_{had}
0.8
0.6
0.4
0.2
0
40
60
80
100
p_T [GeV]


Fake Factors
ATLAS
Data - $e^{\pm}e^{\pm}$, $\mu^{\pm}\mu^{\pm}$
$\sqrt{s}$ = 13 TeV, 36.1 fb^{-1}
e
μ
0.8
0.6
0.4
0.2
0
20
40
60
80
100
p_T [GeV]

Northern Illinois University

Process	Cross section [pb]	QCD scale [%]	PDF+α_S [%]	Order
$t\bar{t}H$	0.51	$^{+5.8}_{-9.2}$	±3.6	NLO QCD+EWK
$tHqb$	0.074	$^{+6.5}_{-15}$	±3.7	NLO QCD
tHW	0.015	$^{+4.9}_{-6.7}$	±6.3	NLO QCD
$t\bar{t}W$	0.60	$^{+13}_{-12}$	±3.4	NLO QCD+EWK
$t\bar{t}(Z/\gamma^* \to ll)$	0.12	$^{+9.6}_{-11}$	±4.0	NLO QCD+EWK
$t\bar{t}t\bar{t}$	0.0092	$^{+31}_{-26}$	$^{+5.5}_{-5.9}$	NLO QCD
$t\bar{t}W^+W^-$	0.0099	$^{+11}_{-12}$	±2.1	NLO QCD
$t\bar{t}$	832	$^{+2.4}_{-3.5}$	±4.2	NNLO QCD + NNLL
$t\bar{t}\gamma$	5.7	±50		NLO QCD
tZ	0.61	±50		LO QCD
tWZ	0.16	±50		NLO QCD
Single t (s-channel)	10	±4		NLO QCD
Single t (t-channel)	217	±4		NLO QCD
Single t (Wt)	72	±5		NLO QCD + NNLL
$VV(\to llXX)$	37	±50		NLO QCD
$Z \to l^+l^-$	2070	±5		NNLO QCD