Combined Run 2 and Run 3 measurement of $t\bar{t}H$ and tH production in $H \to \tau\tau$ with ATLAS

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On behalf the ATLAS Collaboration

Topical Talks
Paper: arXiv:2607.27276

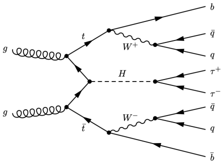
Higgs Hunting 2026

Cofinanciado por la Unión Europea

Physics Motivation: top-Yukawa coupling at tree level

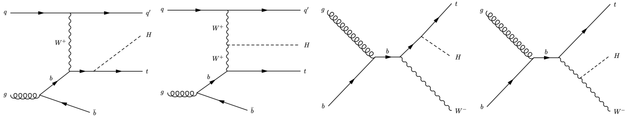
- Measuring the $t\bar{t}H$ cross-section provides a direct probe of the top-Higgs coupling y_t ($\sigma_{t\bar{t}H} \propto y_t^2$)
- Fewer theoretical assumptions than indirect top-quark loop-based measurements

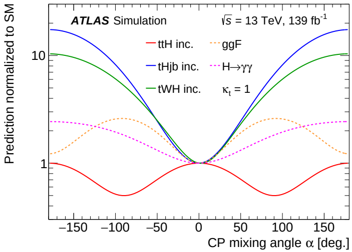
$t\bar{t}H$



- Different tH production modes: $tHqb$+tWH (tHb neglected)
- tH diagrams feature interference between the Higgs couplings to top-quarks and W-bosons
- $H \to \tau\tau$ (fully hadronic) channel: unambiguous Higgs boson candidate, very low contamination from other Higgs boson decay modes

$tHqb$ (κ_t) $tHqb$ (κ_W) tWH (κ_t) tWH (κ_W)

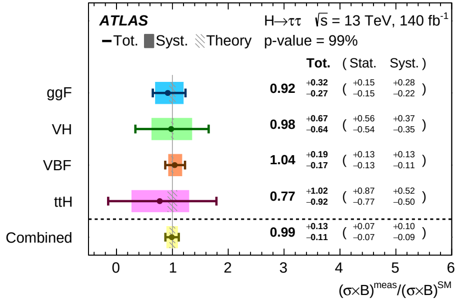




Phys. Rev. Lett. 125 (2020) 061802

- $H \to \tau\tau$ Run 2 Legacy analysis (JHEP03(2025)010):
  - Inclusive $t\bar{t}H$ and Simplified Template Cross-Section (STXS) measurement
- $t\bar{t}H$ Multilepton analysis (arXiv:2510.23755):
  - targeting $\tau_{lep}\tau_{had}$ and $\tau_{lep}\tau_{lep}$ topologies
- Several Run 2 tH leptonic analyses (arXiv:2607.27708) showed mild excesses, motivating an independent measurement in the fully hadronic channel

JHEP03(2025)010



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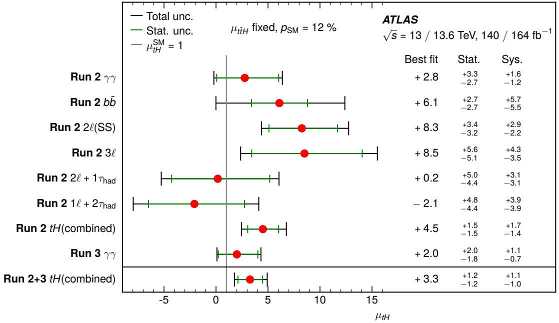

Novelties of this measurement: event selection

- First simultaneous $t\bar{t}H$ and tH measurement in the $H \to \tau\tau$ fully hadronic channel
- Run 2 + Run 3 dataset: 140 fb^{-1} at $\sqrt{s} = 13$ TeV + 161 fb^{-1} at $\sqrt{s} = 13.6$ TeV (2022–2024)
- First ATLAS analysis to use GNTau; all details about GNTau in Sudev's talk

Requirement	Selection
Leptons	$N_e = N_\mu = 0,\ N_{\tau_{had}} = 2$
τ_{had} p_T	Leading,Subleading $> 40, 30$ GeV
τ_{had} ID	GNTau Medium
Charge	Opposite sign
b-tagging	GN2v01 @70%
E_T^{miss}	> 20 GeV
Leading jet	$p_T > 70$ GeV, $\lvert\eta\rvert < 3.2$
$\Delta R(\tau, \tau)$	$0.6 < \Delta R < 2.5$, $\lvert\Delta\eta\rvert < 1.5$
Collinear approx.	$0.1 < x_1 < 1.4,\ 0.1 < x_2 < 1.4$
Jet selection	$N_{jets} \geq 5,\ N_{b-jets} \geq 1$

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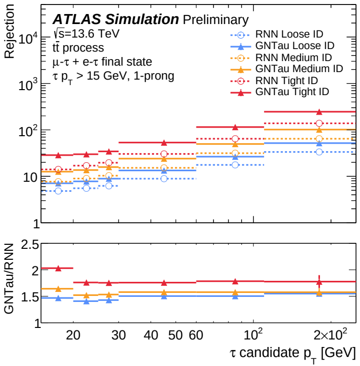
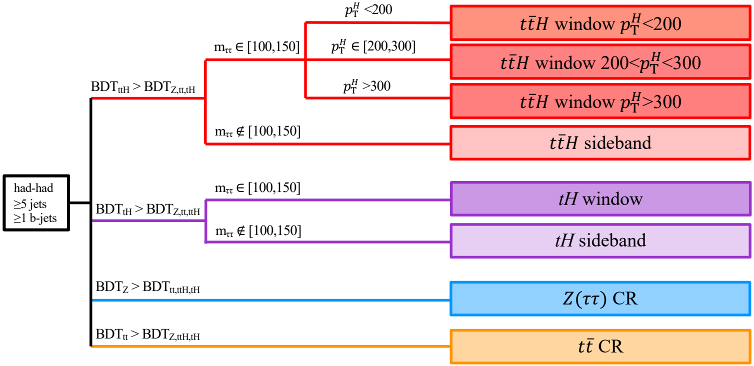
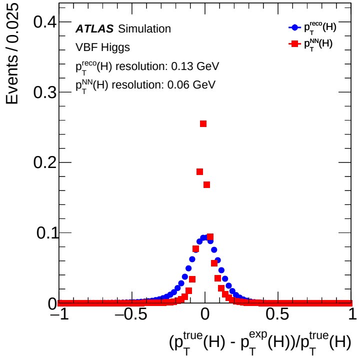


- Require two τ_{had} passing Medium GNTau ID, veto on electrons or muons
- Improved GN2 b—tagging efficiency working point
- At least 5 jets and 1 b-jet: relaxed to gain $tHqb$ acceptance

Analysis strategy for event categorisation

- Multiclass BDT (TMVA), 4 classes: $t\bar{t}H$, tH , $Z(\to\tau\tau)$, $t\bar{t}$
- Events assigned to the class with the highest score $\Rightarrow$ 6 SRs + 2 CRs, mutually exclusive
- SRs split by the invariant di-τ mass (MMC)
- $t\bar{t}H$ window further split in three p_T^H STXS bins (NN regression of JHEP 03 (2025) 010)

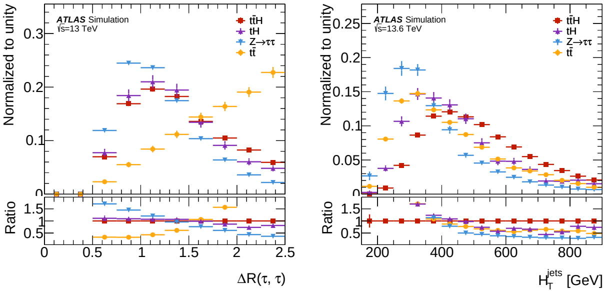




Multiclass BDT: input variables

Group	Variable
Jet properties	η of the 5 leading jets
	Scalar sum of all jets p_{T}
	W-candidate dijet invariant mass
	Top-quark-candidate three-jet invariant mass
	Ratio of the p_{T} of jet pairs ($p_{\mathrm{T}}^{\mathrm{jet},2}/p_{\mathrm{T}}^{\mathrm{jet},1}$, $p_{\mathrm{T}}^{\mathrm{jet},3}/p_{\mathrm{T}}^{\mathrm{jet},2}$, $p_{\mathrm{T}}^{\mathrm{jet},4}/p_{\mathrm{T}}^{\mathrm{jet},2}$)
ΔR, $\Delta\eta$	Minimum ΔR between two jets
	Minimum ΔR between a b-tagged jet and a τ
	$\lvert\Delta\eta(\tau,\tau)\rvert$
	$\Delta R(\tau,\tau)$
τ-lepton	$p_{\mathrm{T}}(\tau\tau)$
	Sub-leading τ p_{T}
	Leading τ η
	Di-τ invariant mass ($m_{\tau\tau}^{\mathrm{MMC}}$)
$E_{\mathrm{T}}^{\mathrm{miss}}$	Missing transverse momentum E_T^{miss}
	Smallest $\Delta\phi(\tau,\vec{E}_T^{\mathrm{miss}})$
$t\bar{t}H$ vs. tH	Number of light (non-b-tagged) jets
	Number of light jets with the same η sign
	b-jets multiplicity
	η of the leading b-jet
	p_{T} of the leading b-jet
	Largest $\Delta\eta$ between any light-jet and b-jet pair
	Maximum $\Delta\eta$ between the visible Higgs decay products and any b-jet
	Largest invariant mass of any pair of light jets

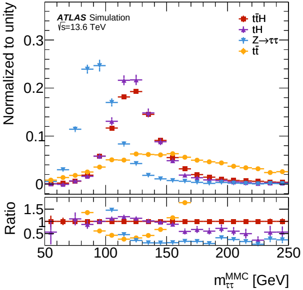
- 29 variables: di-τ system, jet and b-jet kinematics, and reconstructed-top observables
- $t\bar{t}H$ vs tH : same visible final state $\Rightarrow$ the separation comes from the forward jet and from the b-jet content

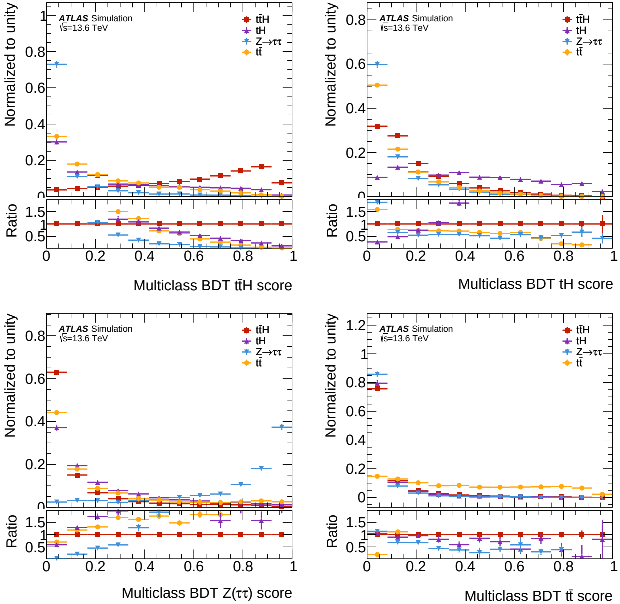


Two of the most discriminating inputs

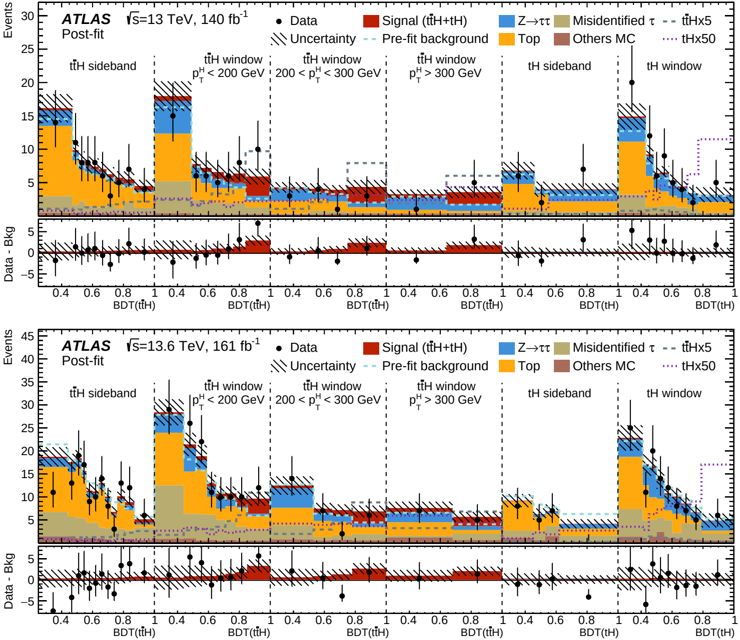
Multiclass BDT: output scores

- Fit the BDT score instead of the invariant di-τ mass (one of the training inputs)
- Excellent $Z(\to \tau\tau)$ classification
- Good $t\bar{t}H$ purity (77%)
- $\sim$ 30% cross contamination between $t\bar{t}H$ and tH (limited by statistics)





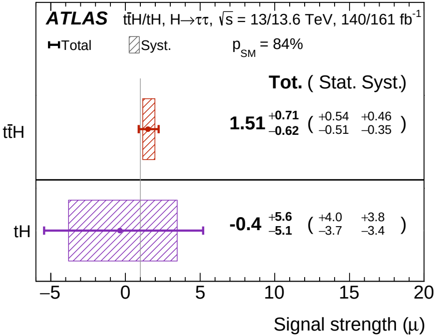
Signal regions

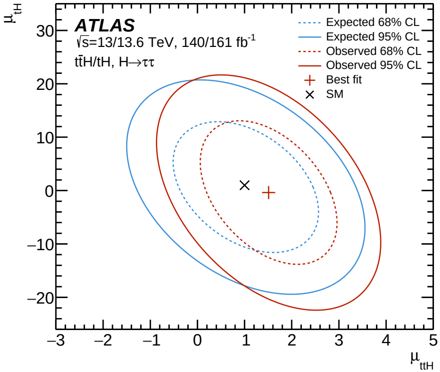


- Combined profile-likelihood fit over all SR and CR bins
- $\mu_{t\bar{t}H}$ and μ_{tH} measured simultaneously
- Signal overlaid $\times 5$ ($t\bar{t}H$) and $\times 50$ (tH) to be visible, gives an estimate for the S/B in this channel

Results: inclusive signal strength measurement

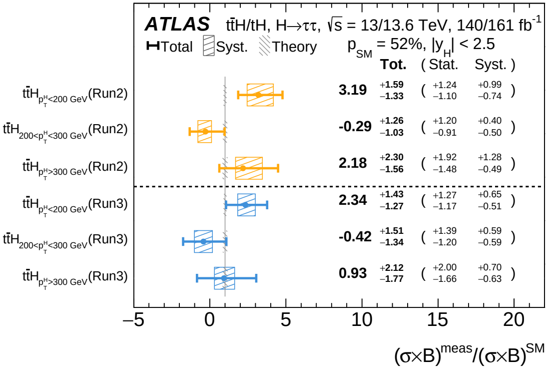
- $t\bar{t}H$ signal strength: $\mu_{t\bar{t}H} = 1.51^{+0.71}_{-0.62} = 1.51^{+0.54}_{-0.51}(\text{stat.})\ ^{+0.46}_{-0.35}(\text{syst.})$
  - Observed (expected) significance of 2.6σ (1.8σ)
- tH signal strength: $\mu_{tH} = -0.4^{+5.6}_{-5.1} = -0.37^{+4.0}_{-3.7}(\text{stat.})\ ^{+3.8}_{-3.4}(\text{syst.})$
- Good compatibility with the SM predictions
- Correlation -34% between the POIs

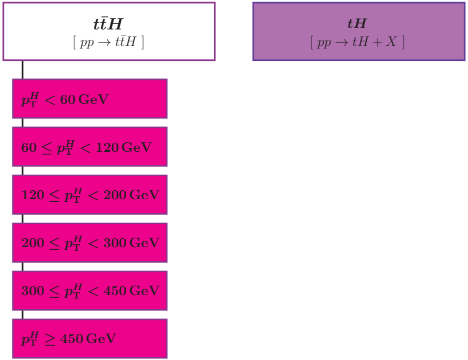




Results: STXS measurement

- STXS cross-section measurements for three p_T^H bins in Run 2 and Run 3
- Good compatibility with the SM predictions
- The fiducial ($|y_H| < 2.5$) cross-section is mesured independently per Run since it is defined at a specific $\sqrt{s}$ value





Summary

- First simultaneous measurement of $t\bar{t}H$ and tH production in the $H \to \tau\tau$ fully hadronic channel, with 140 fb^{-1} (Run 2) + 161 fb^{-1} (Run 3) arXiv:2607.27276
- First ATLAS analysis using the GNTau identification algorithm, combined with a multiclass-BDT event categorisation
- Measured signal strengths:

$$\mu_{t\bar{t}H} = 1.51^{+0.71}_{-0.62} \qquad (2.6\sigma \text{ observed})$$

$$\mu_{tH} = -0.4^{+5.6}_{-5.1}$$

- $t\bar{t}H$ also measured differentially in p_{T}^{H} (STXS), all results consistent with the SM
- Still limited by data statistics in every bin $\Rightarrow$ the full Run 3 dataset will translate almost directly into precision

Acknowledgments

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BACKUP

Novelties of this measurement: event selection

- Require two τ_{had} passing Medium GNTau ID, veto on electrons or muons
- Leading jet with $p_T > 70$ GeV and $|\eta| < 3.2$: keeps the trigger on its efficiency plateau
- Improved GN2 $b-$tagging efficiency working point

Requirement	**Selection**
Leptons	$N_e = N_\mu = 0,\ N_{\tau_{had}} = 2$
τ_{had} p_T	Leading,Subleading $> 40, 30$ GeV
τ_{had} ID	GNTau Medium
Charge	Opposite sign
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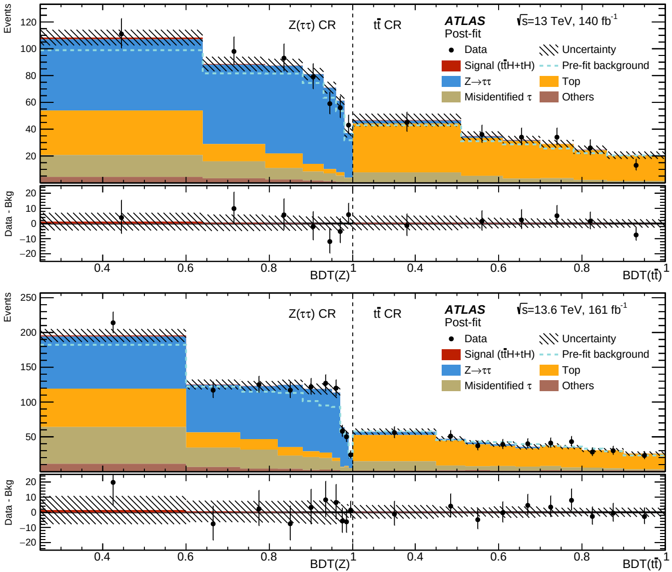
Collinear approx.	$0.1 < x_1 < 1.4,\ 0.1 < x_2 < 1.4$
Jet selection	$N_{jets} \geq 5,\ N_{b-jets} \geq 1$

- At least 5 jets and 1 b-jet: relaxed with respect to the previous analysis (5j2b or 6j1b) to gain $tHqb$ acceptance
- 4 jets + 1 b-jet was also studied: more $tHqb$, but considerably more $Z \to \tau\tau$ and $t\bar{t}$ as well

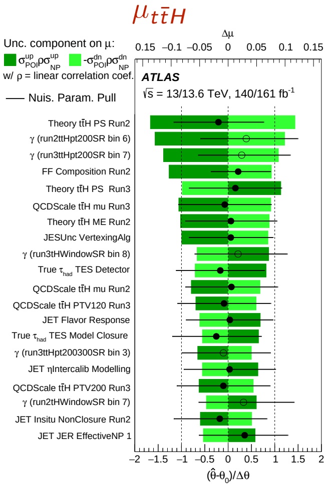
Background estimation

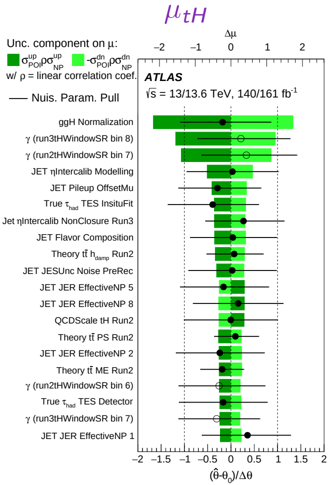
- $Z(\to \tau\tau)$ and $t\bar{t}$: irreducible, normalised in BDT-score control regions (free-floating NFs, separately per Run)
- Misidentified-τ: data-driven fake-factor (FF) method
  - FFs from W+jets CRs ($1\ell + 1\tau_{had\text{-}vis}$), binned in ($p_{\mathrm{T}}, \eta$), per Run
- Validated in same-sign $\tau\tau$ regions: prediction agrees with data within 10%
- Post-fit normalisation factors consistent with unity and compatible between Run 2 and Run 3



- Statistically limited: the data sample size dominates for both $\mu_{t\bar{t}H}$ and μ_{tH}
- Leading systematics on $\mu_{t\bar{t}H}$: signal theory (0.22) and MC sample size (γ: 0.21)
- Leading experimental source: jet energy scale and resolution (0.17)

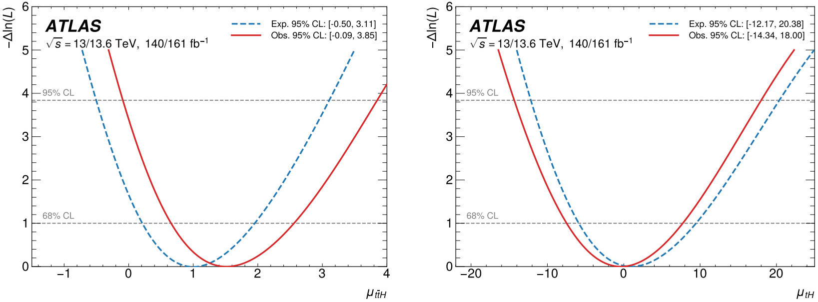
Source of uncertainty	$\mu_{t\bar{t}H}$	μ_{tH}
Jet and $E_{\mathrm{T}}^{\mathrm{miss}}$	0.17	1.5
Background sample size	0.21	2.0
$\tau_{\text{had-vis}}$	0.09	0.7
Flavour tagging	0.01	0.1
Misidentified τ_{had}	0.11	0.4
$Z(\tau\tau)$ theoretical uncertainty	0.01	0.3
$t\bar{t}$ Theoretical uncertainty	0.06	0.6
Signal theoretical uncertainty	0.22	2.0
Total systematic uncertainty	0.38	3.4
Data sample size	0.52	3.8
Total	0.65	5.2





Backup: observed vs expected significance

- Observed 2.6σ vs expected 1.8σ; best fit $\mu_{t\bar{t}H} = 1.51$, i.e. $\sim 0.8\sigma$ above the SM
- 95% CL intervals:
  - $\mu_{t\bar{t}H}$: observed $[-0.09, 3.85]$, expected $[-0.50, 3.11]$
  - μ_{tH}: observed $[-14.34, 18.00]$, expected $[-12.17, 20.38]$
- Expected sensitivity: $\mu_{t\bar{t}H} = 1.00^{+0.65}_{-0.57}$, $\mu_{tH} = 1.0^{+5.8}_{-5.0}$
- Global compatibility of the 2-POI fit with the SM: 84%

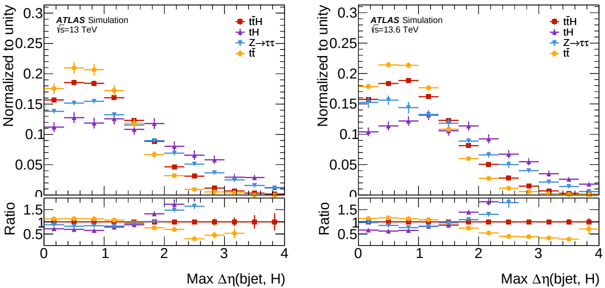


Improvements in $t\bar{t}H$ and tH separation

Same visible final state $\Rightarrow$ separation relies on the forward jet and the *b*-jet content:

$t\bar{t}H$ vs. tH	Number of light (non-*b*-tagged) jets
	Number of light jets with the same η sign
	b-jets multiplicity
	η of the leading *b*-jet
	p_T of the leading *b*-jet
	Largest $\Delta\eta$ between any light-jet and *b*-jet pair
	Maximum $\Delta\eta$ between the visible Higgs decay products and any *b*-jet
	Largest invariant mass of any pair of light jets

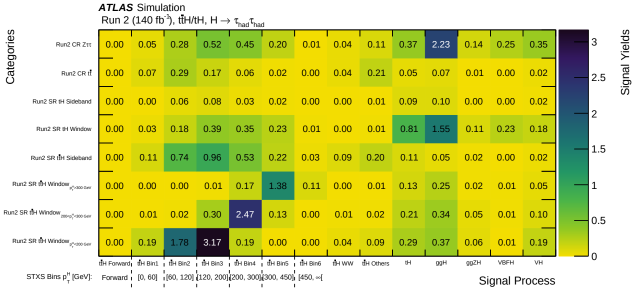
Run 2 Run 3



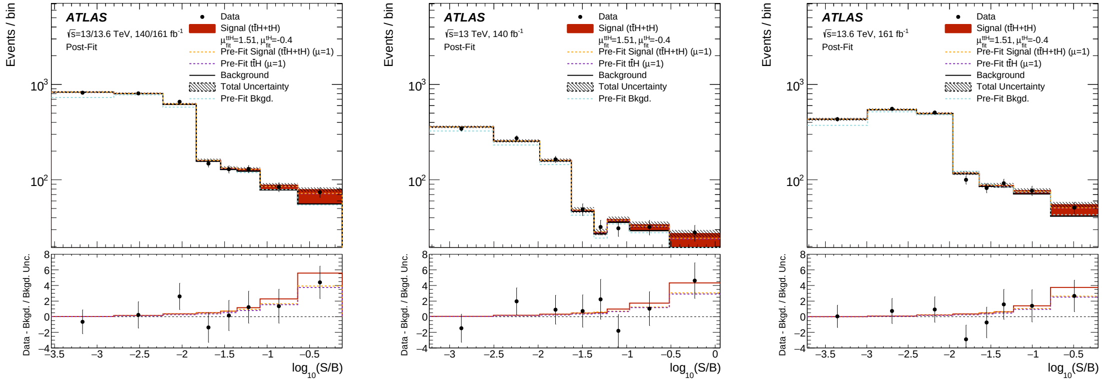
$\Rightarrow$ dedicated tH signal region, with ggH the dominant signal contamination

- ggH dominates through its much larger cross-section, despite its tiny acceptance
- Run-3 effects further enhance ggH with the forward-jet simulation issue increases the acceptance by $\sim 2-3$ times in this high jet multiplicity
- $t\bar{t}H$ and tH are maximized in their respective signal regions

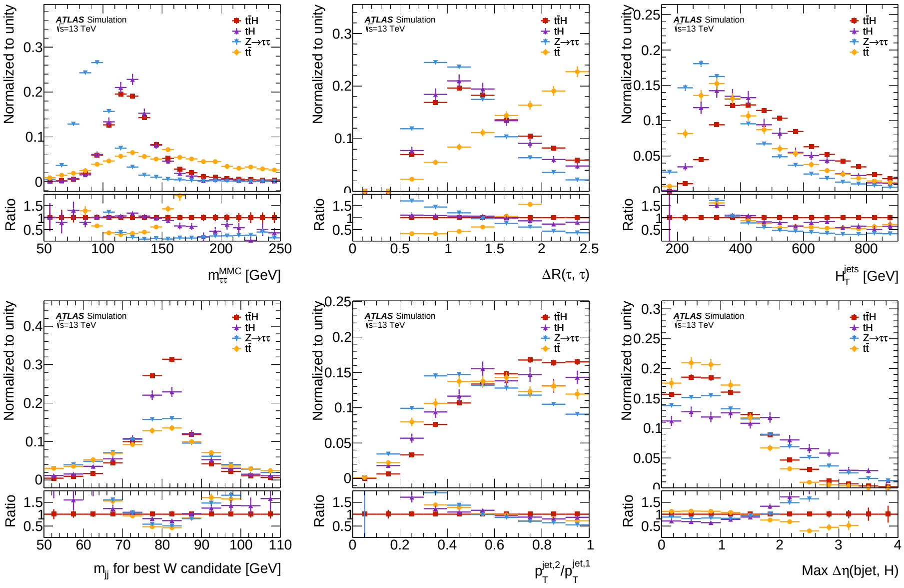
Pre-fit Higgs-process yields per region (Run 2)



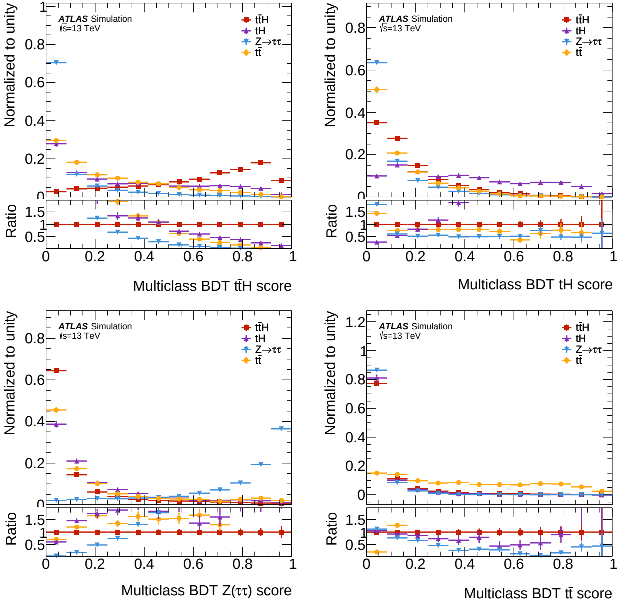
Backup: event yields vs $\log_{10}(S/B)$



Backup: multiclass BDT input variables



Backup: multiclass BDT scores, Run 2



Backup: GN2 *b*-tagging

- GN2: GNN-based *b*-tagging, improved efficiency and rejection with respect to the previous algorithm
- τ-jet rejection increased by about a factor five
- The GNTau architecture is inspired by GN2
- This analysis uses the GN2v01 70% efficiency working point

arXiv:2505.19689