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Search for the SM Higgs boson produced in association with top quarks (ttH) at $\sqrt{s} = 13$ TeV with the ATLAS detector at the LHC

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Introduction and motivations

• Presented today: associated top-Higgs production (ttH)

• Due to its small production cross-section ($\sim 1\%$ of total Higgs boson cross-section), this production mechanism has not been directly observed

- Indirect constraints on the top-Higgs Yukawa coupling come from ggF and $H \rightarrow \gamma \gamma$ (through loop)

• ttH production allows direct (tree level) probe of top-Higgs Yukawa coupling

- Any deviation could be a hint of new physics



- Can be studied in a variety of final states/channels, depending on the top quark decay topology and the Higgs boson decay mode: γγ, WW/ZZ/ττ (multi-lepton) and bb

• Results here based on 2015 + partial 2016 data, 13.2 fb^{-1}



• ATLAS+CMS Run I result: observation at 4.4 σ (2.0 σ exp.) [1]

Analyses presented

• ttH, $H \rightarrow \gamma \gamma$ [2]

- Clean signature thanks to excellent mass resolution, but small branching ratio (BR $\sim 0.23\%$)

- 2 channels, depending on the top quark pair system decay: all-hadronic and (semi)leptonic

- Events selected and categorised in regions enriched with ttH production mode



- Looking for narrow signal peak in the di-photon invariant mass spectrum on top of a smothly falling background

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• ttH, H \rightarrow WW/ZZ/ $\tau\tau$ [3]

• (Semi)-leptonic final states with low background, but with additional sensitivity to ttW/ttZ background

- Cut-and-count analysis in 4 categories, depending on the number, charge and flavour of leptons (ℓ): 2 same sign (ss) $\ell + 0\tau_{had}$, 2ss $\ell + 1\tau_{had}$, 3 ℓ and 4 ℓ



~					
	Higgs	s boson	decay	mode	$A \times \epsilon$
Category	WW^*	au au	ZZ^*	Other	$(\times 10^{-4})$
$2\ell 0 au_{ m had}$	77%	17%	3%	3%	14
$2\ell 1 au_{ m had}$	46%	51%	2%	1%	2.2
3ℓ	74%	20%	4%	2%	9.2
4ℓ	72%	18%	9%	2%	0.88

- 3 validation regions in order to study ttV background, data driven estimations of non-prompt lepton, fake τ , and processes with mis-identified charged lepton

• ttH, $H \rightarrow bb$ [4]

Small signal on top of large background dominated by production of tt+heavy flavour (HF) jets

2 channels, depending on the top quark pair system decay: single lepton (1ℓ) and opposite-sign dilepton (2ℓ) Events categorised according to jet and b-jet multiplicities: 6 control (CR) and 3 signal regions (SR) in 1l and 2 CR and 3 SR in 2l channels



- Analysis strategy uses 2-step multivariate technique: reconstruction BDT (match jets) and discrimination



- Control regions with inverted photon identification for background (yy, y-jet and jet-jet) estimation

Search dominated by statistical uncertainties





- Main systematic uncertainty: fakes and charge mis-ID





150 200

ttH, all events 🔲 tīH, Higgs bosor correctly matche

300

Higgs mass [GeV]

250

		$ \ge 6j, \ge 4b$	≥ 6 j, 3b	$ 5j, \ge 4b$
General kinen	natic variables			
$\Delta R_{\rm bb}^{\rm avg}$	Average ΔR for all <i>b</i> -tagged jet pairs	~	~	√
$\Delta R_{bb}^{\max p_T}$	ΔR between the two $b\text{-tagged}$ jets with the largest vector sum p_{T}	\checkmark	_	_
$\Delta \eta_{jj}^{max}$	Maximum $\Delta \eta$ between any two jets	\checkmark	\checkmark	 ✓
$m_{\rm bb}^{\rm min \ \Delta R}$	Mass of the combination of the two <i>b</i> -tagged jets with the smallest ΔR	~	~	_
$m_{jj}^{\min \Delta R}$	Mass of the combination of any two jets with the smallest ΔR	-	-	~
$m_{\rm bj}^{\rm max \ p_T}$	Mass of the combination of a <i>b</i> -tagged jet and any jet with the largest vector sum $p_{\rm T}$	-	\checkmark	-
p_T^{jet5}	p_T of the fifth leading jet	 ✓ 	✓	 ✓
$N_{bb}^{Higgs \ 30}$	Number of <i>b</i> -jet pairs with invariant mass within 30 GeV of the Higgs boson mass	~	_	~
N_{40}^{jet}	Number of jets with $p_{\rm T} \ge 40 GeV$	_	√	-
$H_{\rm T}^{\rm had}$	Scalar sum of jet p_T	-	✓	 ✓
$\Delta R_{\rm lep-bb}^{\rm min\ \Delta R}$	ΔR between the lepton and the combination of the two <i>b</i> -tagged jets with the smallest ΔR	_	_	~
Aplanarity	$1.5\lambda_2$, where λ_2 is the second eigenvalue of the momentum tensor [42] built with all jets	~	\checkmark	~
Centrality	Scalar sum of the $p_{\rm T}$ divided by sum of the E for all jets and the lepton	\checkmark	\checkmark	~
H1	Second Fox–Wolfram moment computed using all jets and the lepton	\checkmark	\checkmark	\checkmark
Variables from	n reconstruction BDT output			
BDT output		√*	√*	√*
$m_{\rm H}$	Higgs boson mass	✓	√	 ✓
$m_{\mathrm{H},b_{\mathrm{lep}}\ \mathrm{top}}$	Mass of Higgs boson and b -jet from leptonic top	✓	-	-
$\Delta R_{\rm Higgs\ bb}$	ΔR between b-jets from the Higgs boson	✓	 ✓ 	 ✓
$\Delta R_{\mathrm{H},tar{t}}$	ΔR between Higgs boson and $t\bar{t}$ system	√*	√*	√*
$\Delta R_{\rm H, lep\ top}$	ΔR between Higgs boson and leptonic top	 ✓ 	-	-
$\Delta R_{\mathrm{H},b_{\mathrm{hud}}}$ top	ΔR between Higgs boson and b-jet from hadronic top	-	√*	√*

• Theory uncertainty on tt+HF dominates the search



- Combination and prospects

• Combination of the three presented ATLAS ttH analyses [5]:

ATLAS Preliminary √s=13 TeV, 13.2-13.3 fb **-0.3** ^{+1.2} (^{+1.2}, ^{+0.2} -1.0, ^{-0.2}

• Projections with full 2015+2016 LHC data

• Optimistic projection with $2015 + \text{full } 2016 \text{ data } (36.5 \text{ fb}^{-1})$, after several optimisations, combination could achieve 3σ

• Measured signal strength $\mu = 1.8 \pm 0.7$

• Corresponds to an observed (expected) significance of 2.8σ (1.8 σ) and exceeds the Run I ATLAS expected significance (1.5σ) • Observed (expected) 95% C.L. limit on μ is 3.0 (2.1)

• All three analyses are within 1.5σ of the central value

- Largest systematic uncertainty contribution is related tt+b/c modelling uncertainties affecting the $ttH(H\rightarrow bb)$ analysis



• Work in progress within ATLAS: updates soon!

• At HL-LHC with L=3000 fb⁻¹, expected precision on ttH signal strength using only $H \rightarrow \gamma \gamma$ [6]:

	$\Delta \hat{\mu} / \hat{\mu}$ (%)							
Production mode	Total	Statistical	Experimental	Theoretical				
tīH	+21 -17	+13 -12	+5 -4	+17 -11				

[1] ATLAS and CMS Collaborations, JHEP 08 (2016) 045 [2] ATLAS Collaboration: ATLAS-CONF-2016-067 (2016) [3] ATLAS Collaboration: ATLAS-CONF-2016-058 (2016)

References

[4] ATLAS Collaboration: ATLAS-CONF-2016-080 (2016) [5] ATLAS Collaboration: ATLAS-CONF-2016-068 (2016) [6] ATLAS Collaboration: ATL-PUB-2014-012 (2014)