# Measurements of Top-Higgs Yukawa Interaction Using the Higgs to Diphoton Decay Channel

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## Introduction

- The coupling of the Higgs boson to the top quark is of particular importance as the top quark is the heaviest particle in the Standard Model.
- The top Yukawa coupling can be probed at tree-level through Higgs production in association with a pair of top quarks ($t\bar{t}H$) or a single top quark ($tH$).
- In ATLAS, the $\gamma\gamma$ decay channel is currently the most sensitive one due to the excellent ATLAS photon momentum resolution.
- Main backgrounds include non-resonant $\gamma\gamma$ events with heavy flavor and the $t\bar{t}\gamma\gamma$ process.

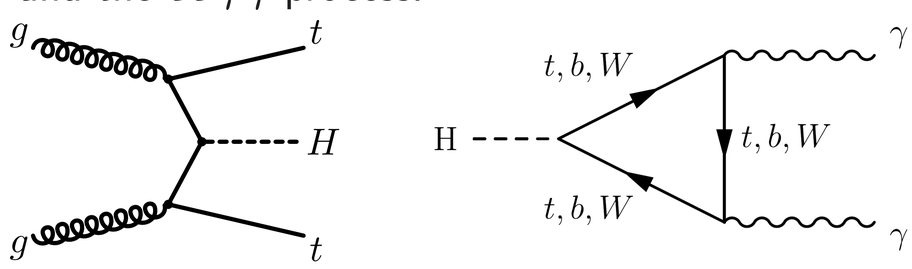


Figure 1: Representative diagrams for $t\bar{t}H$ production and $H \to \gamma\gamma$ decay.

- Measurements of the $CP$ properties of the top Yukawa coupling (**Phys. Rev. Lett. 125 (2020) 061802**) and the $ttH + tH$ cross-sections (**ATLAS-CONF-2020-026**) are presented.
- For both analyses, events are selected by a diphoton trigger. Boosted decision trees (BDTs) are used to create signal sensitive categories and finally a fit is performed to the diphoton invariant mass $m_{\gamma\gamma}$.
- BDT training variables generally include kinematic variables related to the photons, jets, and leptons.
- In particular, one training variable is a top reconstruction score indicating whether the event contains top quarks.

## $CP$ properties of the top Yukawa coupling

- The top Yukawa coupling is parametrized as $\mathcal{L} = -\frac{m_t}{v}\{\bar{\psi}_t\kappa_t[\cos(\alpha) + i\sin(\alpha)\gamma_5]\psi_t\}H$, where the SM corresponds to $\kappa_t = 1$ and the $CP$ mixing angle $\alpha = 0$.
- Deviations from the SM coupling would impact $t\bar{t}H$ and $tH$ production rates and kinematics.
- Two independent BDTs are trained: one to separate $t\bar{t}H$-like events from non-resonant background, and one to separate $CP$-even $(\alpha = 0°)$ and $CP$-odd $(\alpha = 90°)$ $t\bar{t}H$ and $tH$ processes.
- 20 categories are defined by 2D cuts on the two BDT scores and the expected yield in each is parametrized by $\kappa_t$ and $\alpha$.

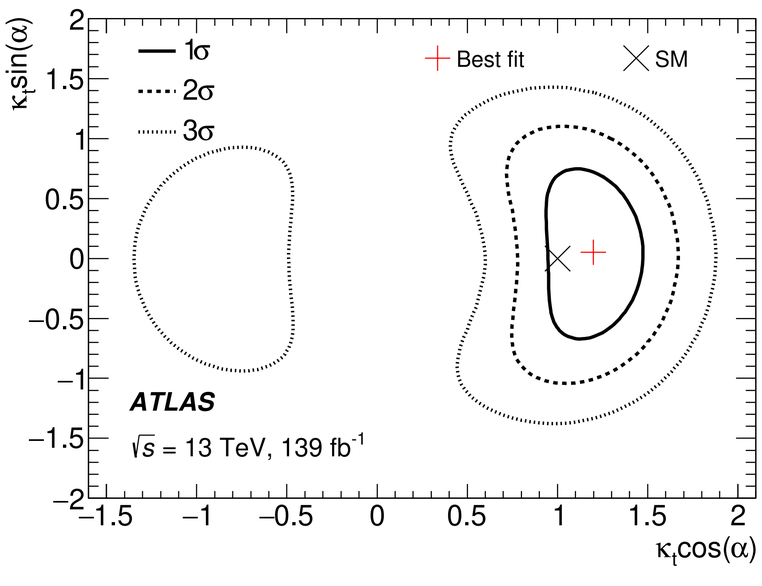


Figure 2: The likelihood as a function of $\kappa_t \sin(\alpha)$ and $\kappa_t \cos(\alpha)$

- From a simultaneous fit to $m_{\gamma\gamma}$ in all categories and no prior constraint on $\kappa_t$, $|\alpha| > 43°$ is excluded at 95% CL.

## $t\bar{t}H$ and $tH$ cross-sections

- $t\bar{t}H$ and $tH$ production cross-sections are measured simultaneously with other Higgs production modes as part of a larger $H \to \gamma\gamma$ measurement.
  - Measurement of $ggH$, $VBF$, $WH$, $ZH$, and $t\bar{t}H + tH$ cross-sections.
  - Measurements of STXS (Simplified Template Cross Section) regions, in which Higgs production is partitioned by production process as well as kinematic and event properties.
- A multi-class BDT creates various categories sensitive to particular STXS regions.
- A second binary BDT then rejects non-resonant background in each category.

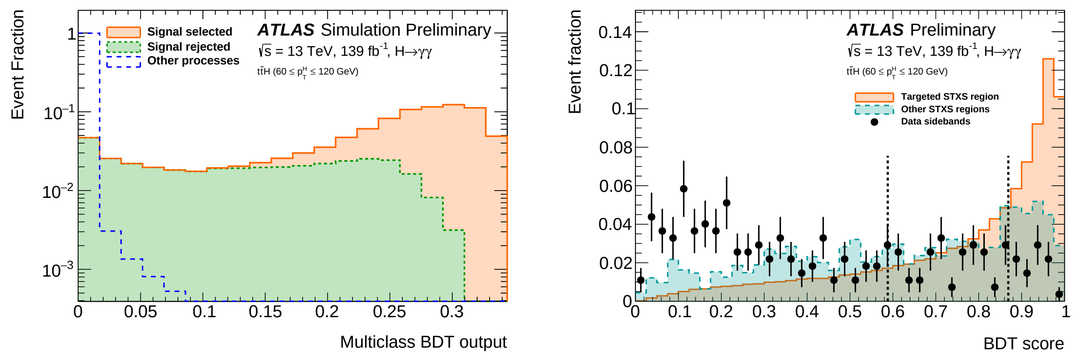


Figure 3: The multi-class (left) and binary (right) BDT discriminants for a representative $t\bar{t}H$ STXS category

- There are both $t\bar{t}H$ and $tH$ dedicated categories. $t\bar{t}H$ STXS bins are separated by $p_T^H$ as this can be sensitive to modifications to the Higgs self coupling or the CP property of the top Yukawa coupling.
- Higgs production cross sections are obtained from a simultaneous fit to the $m_{\gamma\gamma}$ spectra across all categories.

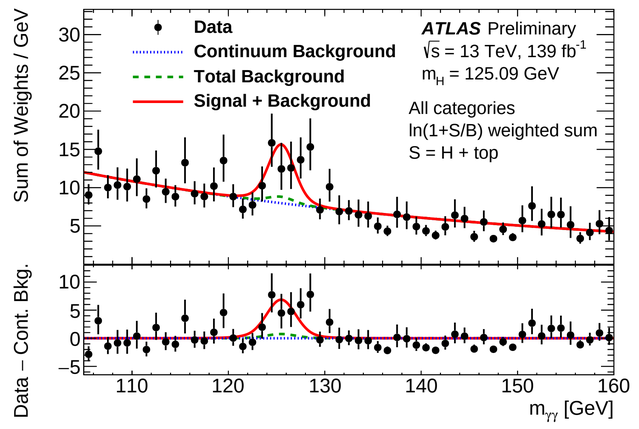


Figure 4: The weighted diphoton mass spectrum of all categories

- In the 5 cross section measurement, the observed (expected) $t\bar{t}H + tH$ significance is $\mathbf{4.7\sigma}$ $(\mathbf{5.0\sigma})$. The measured $t\bar{t}H + tH$ cross section times branching ratio is compatible with the SM prediction.
- $t\bar{t}H$ and $tH$ STXS bins are probed as part of the STXS measurement. The observed limit on the $tH$ cross-section is 8 times the SM expectation at 95% CL.

| STXS region ($\sigma_i \times \mathcal{B}_{\gamma\gamma}$) | Observed [fb] | SM prediction [fb] |
|---|---|---|
| $t\bar{t}H$ $p_T^H \in [0, 60]$ GeV | $0.2^{+0.2}_{-0.2}$ | $0.27 \pm 0.04$ |
| $t\bar{t}H$ $p_T^H \in [60, 120]$ GeV | $0.3^{+0.2}_{-0.2}$ | $0.40^{+0.05}_{-0.04}$ |
| $t\bar{t}H$ $p_T^H \in [120, 200]$ GeV | $0.3^{+0.2}_{-0.2}$ | $0.29 \pm 0.03$ |
| $t\bar{t}H$ $p_T^H \in [200, \infty]$ GeV | $0.2^{+0.09}_{-0.08}$ | $0.18 \pm 0.02$ |
| $tH$ | $0.2^{+0.6}_{-0.5}$ | $0.19^{+0.01}_{-0.02}$ |

## Summary and outlook

- The CP properties and strength of the top Yukawa coupling are probed using $t\bar{t}H$ and $tH$ production in the $H \to \gamma\gamma$ channel.
- No deviations from the Standard Model are observed so far but many results are still statistically limited.