IL NUOVO CIMENTO **43 C** (2020) 85
DOI 10.1393/ncc/i2020-20085-4

Colloquia: IFAE 2019

Measurement of $t\bar{t}H$ production cross section times branching ratio in the $\gamma\gamma$ decay channel with the full Run2 pp collision dataset collected by the ATLAS experiment at $\sqrt{s} = 13$ TeV

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received 8 June 2020

Summary. — In this study, the measurement of Higgs boson production in association with a top quark-antiquark pair in the two photons decay channel is presented. The analysis is based on 139 fb^{-1} of proton-proton collision data recorded by the ATLAS detector at the Large Hadron Collider at center-of-mass energy of $\sqrt{s} = 13$ TeV. The analysis is performed using a simultaneous fit in seven signal-enriched event categories. The $t\bar{t}H$ process is observed in the diphoton decay channel with a significance of 4.9σ relative to the background-only hypothesis, while the expected significance is 4.2σ. The $t\bar{t}H$ cross-section times the $H \to \gamma\gamma$ branching ratio is measured to be $\sigma_{t\bar{t}H} \times B_{\gamma\gamma} = 1.59^{+0.43}_{-0.39}$ fb, in agreement with the Standard Model prediction.

1. – Introduction

Since its discovery by the ATLAS and CMS Collaborations [1, 2], the Higgs boson interactions with other fundamental particles have been deeply studied in order to test the Standard Model (SM) predictions. The coupling to fermions and in particular to the heaviest particle in the SM, the top quark, is of particular interest since it could be modified by Beyond Standard Model processes. The strength of this interaction can be studied through the analysis of Higgs production cross-section when associated to a top anti-top pair ($t\bar{t}H$), which provides a tree-level probe of the top Yukawa coupling. This process was observed by both the ATLAS and CMS Collaborations in 2018 [3, 4] through the combination of several decay channels. In this study we have observed the $t\bar{t}H$ production in the single $H \to \gamma\gamma$ decay channel alone, which was the leading channel in the combination.

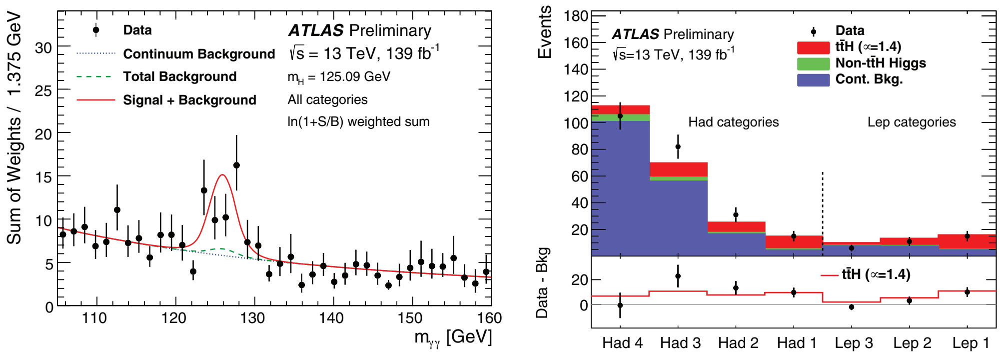
2. – Analysis strategy

The diphoton channel is characterized by a clear final-state signature, where the Higgs boson is observed as a narrow peak over a continuous falling background. The main selection requires two well-identified and isolated photons to suppress the γj and jj backgrounds. Then the (sub-)leading photon is required to pass $p_{\mathrm{T}}^{\gamma} > 35(25)$ GeV and to be in the photon detector acceptance of $|\eta| < 2.37$, excluding the transition region $1.37 < |\eta| < 1.52$. Finally the invariant mass of the diphoton pair is required to be between 105 and 160 GeV in order to be able to constrain the background shape on data sidebands.

The selected events are classified in two classes, targeting the hadronic and semi-leptonic W boson decay modes: both require at least one b-tagged jet at the 77% efficiency working point with $p_{\mathrm{T}} > 25$ GeV. Then the first requires two more jets and a lepton veto, while the second requires at least one isolated lepton. For each of these classes a Boosted Decision Tree is trained on $t\bar{t}H$ signal MC against a control region built on data inverting the identification or isolation criteria of one of the two photons. Both the BDTs are trained with low level variables: the hadronic BDT uses $p_{\mathrm{T}}/m_{\gamma\gamma}$, η, ϕ of the two photons, the four momenta and the b-tag scores of up to six jets and the module and direction of $E_{\mathrm{T}}^{\mathrm{miss}}$. The semi-leptonic BDT is instead limited to 4 jets but uses the four-momenta of up to two leptons too. With their outputs, 7 categories are defined optimizing the $t\bar{t}H$ significance, four hadronic and three semi-leptonic.

For each of them, analytical functional forms are chosen to describe the $m_{\gamma\gamma}$ distribution: a Double-Sided Crystal Ball function for the signal, while a low degrees-of-freedom failing function with the smallest signal bias for the background.

A simultaneous maximum likelihood fit is performed over all the categories. The results are reported in fig. 1. The parameter of interest is the signal strength μ, defined as $\mu = \sigma_{meas}/\sigma_{SM}$. In the fit, the contribution of other production modes is fixed to SM prediction while the Higgs boson mass is fixed to 125.09 ± 0.24 GeV [6]. The main systematic uncertainties come theoretically from underlying event, parton shower, cross-sections of non-$t\bar{t}H$ signals associated with production of heavy flavour jets, higher-order QCD corrections and experimentally from jet reconstruction, photons identification and photon energy resolution.



(a) **(b)**

Fig. 1. – (a) Sum of observed $m_{\gamma\gamma}$ spectra over all categories weighted by $\ln(1+S_{90}/B_{90})$, where S_{90} (B_{90}) is the number of events in the smallest $m_{\gamma\gamma}$ window containing 90% of signal (background) events. Error bars are 68% confidence intervals of the weighted sum [5]. (b) Number of events in the smallest $m_{\gamma\gamma}$ window containing 90% of $t\bar{t}H$ signal. The expected background is extracted from fit and shown in violet. The resonant background not-$t\bar{t}H$ is shown in green, while the signal for $\mu = 1.4$ in red [5].

3. – Results

The observed signal significance with respect to the background-only hypothesis is 4.9σ, while the expected significance is 4.2σ. The measured cross-section times the Higgs to diphoton branching ratio is

$$\sigma_{t\bar{t}H} \times \mathrm{BR}_{\gamma\gamma} = 1.59^{+0.43}_{-0.39}\ \mathrm{fb} = 1.59^{+0.38}_{-0.36}\ (\mathrm{stat})\ ^{+0.15}_{-0.12}\ (\mathrm{exp})\ ^{+0.15}_{-0.11}\ (\mathrm{theo})\ \mathrm{fb}$$

which is compatible with the Standard Model expectation.

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