

Search for the 125 GeV Higgs boson in the $t\bar{t}H$ production mode with the ATLAS detector

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Results from the search for the 125 GeV Higgs boson in the $t\bar{t}H$ production mode, obtained with the ATLAS detector at the LHC, are presented. The results use the full Run I dataset and a subset of the Run II data.

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1. Introduction

The coupling of the Higgs boson to the top quarks, Y_t is an important parameter of the Standard Model (SM). It can be determined by measuring the signal strength, $\mu = \sigma_{ttH}/\sigma_{ttH}^{SM}$ of the ttH production, since it is proportional to Y_t^2 as illustrated in Figure 1. Here, σ_{ttH} is the cross section of the ttH production and σ_{ttH}^{SM} is its SM value. Any significant deviation of μ from 1 would be a signal for physics beyond the SM. In this talk results on μ will be presented obtained by the

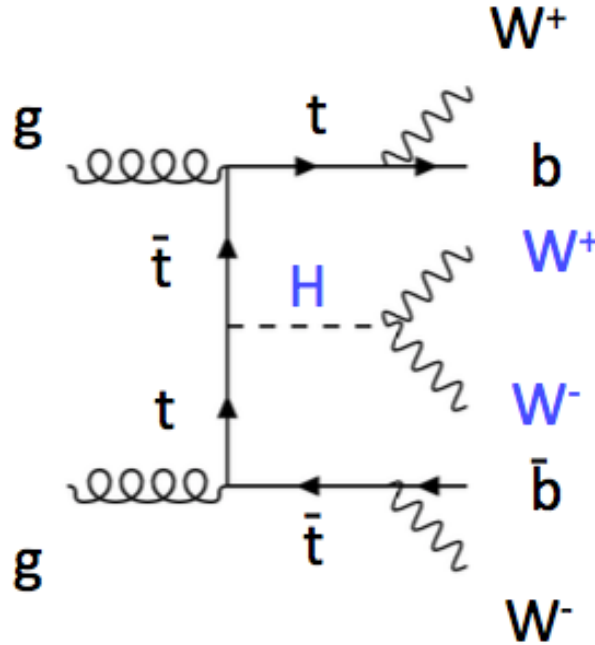


Figure 1: Representative Feynman diagram for the production of the Higgs boson (H) in association with a top-quark pair and the subsequent decay of the top quarks and of the Higgs boson in a pair of W 's.

ATLAS detector [1] at the LHC in Run I and in part of Run II with collision energy of $\sqrt{s} = 7-8$ and 13 GeV, and integrated luminosity of $L_{int} = 4.5 - 20.3$ and 13.3 fb^{-1} , respectively.

A large number of final states have been studied. The final state particles, in addition to the two b -jets from the decay of the top quarks are determined by the decay channels of the Higgs boson and by those of the two W 's (see Figure 1). For the latter there are 3 cases: (1) in the di-lepton (DL) channel both W 's decay to leptons, (2) in the single-lepton (SL) channel only one W decays to leptons and the other one to quarks and (3) in the hadronic channel both W 's decay to quarks. The $H \rightarrow bb$ and $H \rightarrow \gamma\gamma$ decays have been studied in all the three cases of the W decays. The $H \rightarrow WW^*$, $H \rightarrow ZZ^*$ and $H \rightarrow \tau\tau$ final states have been studied only in the SL and DL cases of the W decays. Moreover, the last three Higgs decay channels have been combined together into a so-called multilepton (ML) final state. In all cases the Higgs cross section is calculated and the signal is modelled to NLO [2].

2. $H \rightarrow bb$ (SL and DL channels) – Run II [3]

The largest branching ratio (BR) of the Higgs boson decays is in the bb channel (about 58%).

After having selected 1(2) high p_T isolated lepton(s)¹, at least 4(3) high p_T jets out of them 2 b -tagged jets (i.e. tagged as originating from b -quarks) in the SL (DL) channels the events are grouped according to the number of jets and b -tagged jets into signal (SR) and control (CR) regions. The dominant background is $t\bar{t}$ + light jets in the CR and $t\bar{t}$ + heavy flavor (HF) jets in the SR. It is simulated by Monte Carlo (MC) method [4]. $t\bar{t}$ + HF jets have been reweighted to match to NLO calculation [5]. The shape and normalization was constrained in the final fit of μ .

The signal and background has been discriminated using a series of boosted decision trees (BDT). The output of the BDT is displayed in Figure 2 in one of the SR's for the SL and DL channel after the final fit of μ .

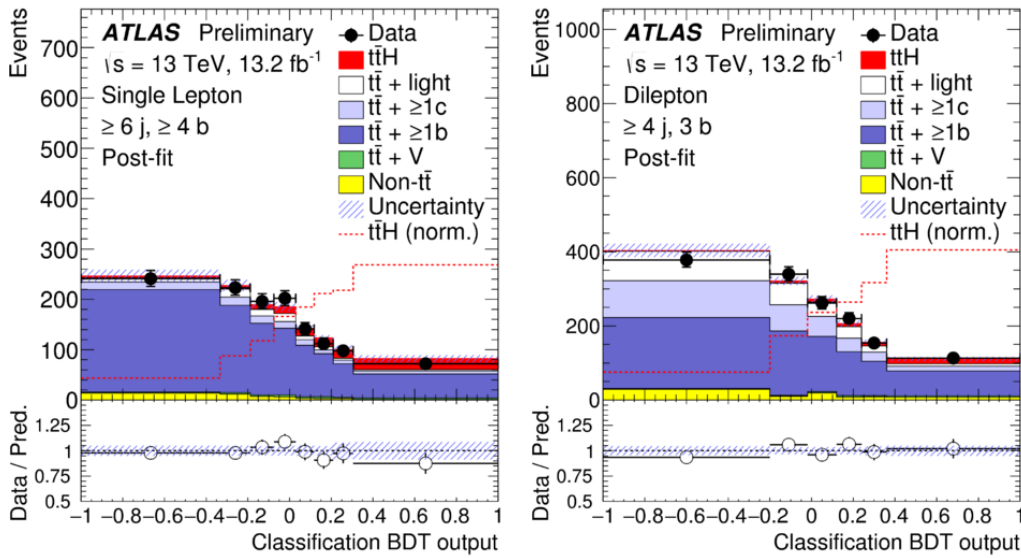


Figure 2: BDT output for the SL (left) and DL (right) channel in one of the SR's [3].

The most important systematic errors are due to the modelling of the signal and the background. To each systematic error a nuisance parameter has been associated. The signal strength has been obtained in a fit maximizing a profile likelihood ratio simultaneously with all nuisance parameters. Combining the SL and DL channels, $\mu = 2.1^{+1.0}_{-0.9}$ has been obtained.

3. $H \rightarrow bb$ (hadronic channel) – Run I [6]

This channel gives rise to high event rate since both W bosons from the top-quarks decay hadronically, i.e. with the highest BR (67.4%). At least 5 jets with $p_T > 55$ GeV were required at the trigger level. In the off-line selection, events with at least 6 jets were selected including at least two b -tagged jets. The main challenge of this analysis was the separation of the overwhelming multijet (MJ) background, and its estimation in the SR which contained at least 7 jets. This task was carried out using data by means of the so-called MJ tag rate function method. First, ϵ_b , the probability that a jet is b -tagged, has been derived from a data sample containing at least 2 b -jets and which was independent of the analysis sample. Next, ϵ_b was applied on events of the analysis

¹electron or muon

sample containing exactly 2 *b*-tagged jets to obtain a pseudo MJ sample with more than 2 *b*-tagged jets per event. After validating this sample in the CR where events contained exactly 6 jets it was established as the MJ background in the SR. BDT has been applied to discriminate signal from the background. Examples of the output of the BDT are shown in Figure 3 which also illustrates the good agreement between data and background in the CR region.

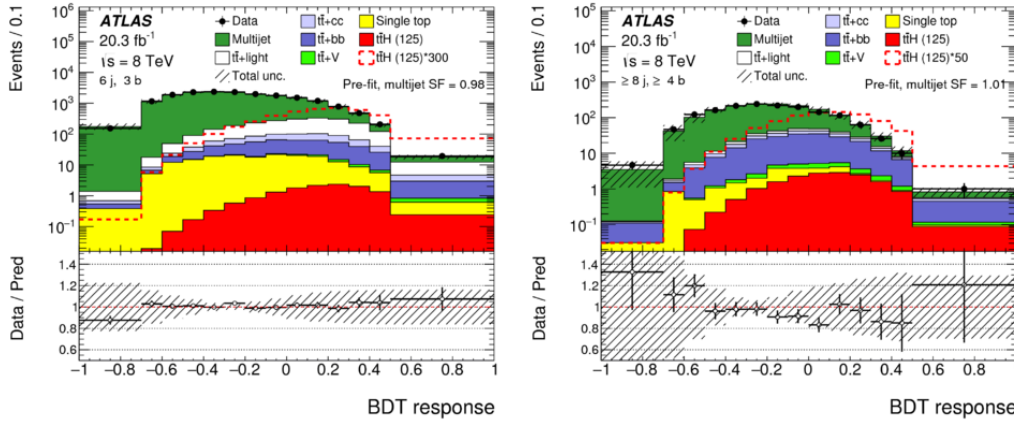


Figure 3: Distribution of the BDT output in one of the CR's (left) and SR's (right) [6].

The main sources of systematic uncertainties are the multijet and $t\bar{t}$ + jets modelling. Using the same statistical method as described in Section 2, $\mu = 1.6 \pm 0.8$ (stat) ± 2.5 (syst) has been obtained.

4. ML channel – Run II [7]

In this channel the Higgs boson decays to a pair of vector bosons or τ leptons (see Figure 1), representing 30.4% branching fraction. The decays of these particles, together with the decay of the top quarks give rise to several leptons and jets. The events are divided in 4 SR's: (i) 2 same sign (SS) leptons without hadronically decaying tau's (τ_{had}), (ii) 2 SS leptons with 1 τ_{had} , (iii) 3 leptons and (iv) 4 leptons. SR (i) is further divided according to the lepton flavor into ee , $\mu\mu$ and $e\mu$ subcategories. The main SM backgrounds with prompt leptons: ttW , ttZ and WZ are estimated by MC and validated in regions (VR) which don't overlap with the SR's. Background involving non-prompt leptons and fake τ_{had} candidates are estimated from data in the different SR's. Charge misreconstruction is estimated from data by comparing the Z-mass peak for SS and OS (opposite sign) lepton pairs. The dominant systematic error is due to non-prompt lepton determination and charge misreconstruction, as well as to jet-vertex association and pile-up modelling. The event yields in the ttW VR and in the SR's are shown in Figure 4. Combining all single regions, $\mu = 2.5^{+1.3}_{-1.1}$ was obtained using the same statistical treatment as described in Section 2.

5. $H \rightarrow \gamma\gamma$ – Run II [8]

In this analysis one exploits the excellent di-photon resolution of the ATLAS detector. The analysis is limited, however, by the small decay BR of the Higgs boson to two photons (0.23%).

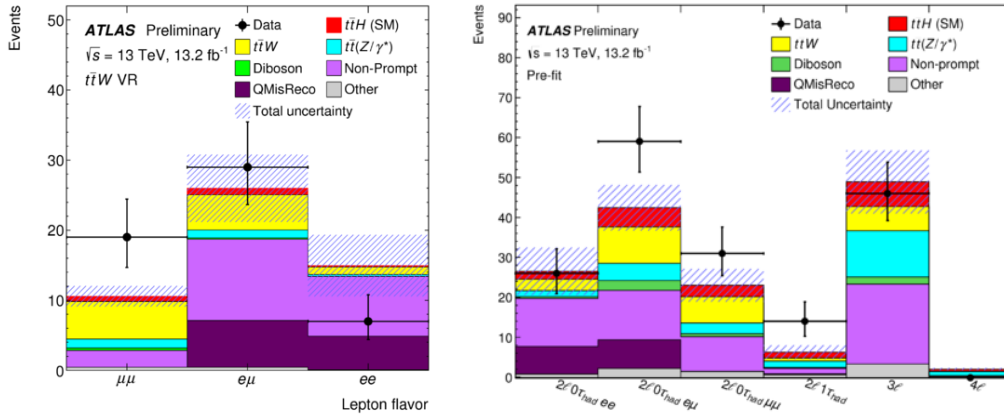


Figure 4: Event yield in the ttW VR (left) and in the SR's along with the estimated signal and backgrounds [7].

After having selected 2 isolated photons of $E_T > 25$ GeV, the events are grouped into leptonic and hadronic categories according to the accompanying number of leptons and jets. The obtained invariant mass distributions of the selected photon pairs are shown in Figure 5 along with the expected signal and background. The signal strength obtained using a maximum likelihood fit is $\mu = -0.3^{+1.2}_{-1.0}$.

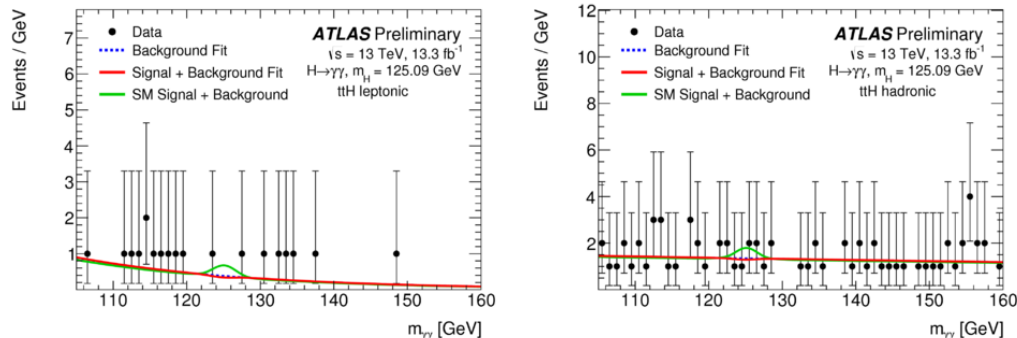


Figure 5: The invariant mass distribution of the two photons in the leptonic (left) and hadronic (right) selection. Also shown are the expected signal and background distributions [8].

6. Combined results [9]

The analyses in the different Higgs decay channels have been combined separately in Run I and Run II. The results, together with the individual channels in Run II are displayed in Figure 6. As one can see, in Run II the sensitivity has already surpassed that of Run I. Since we recorded already two times more data in Run II than included in the presented combination, significant improvement is expected in the near future.

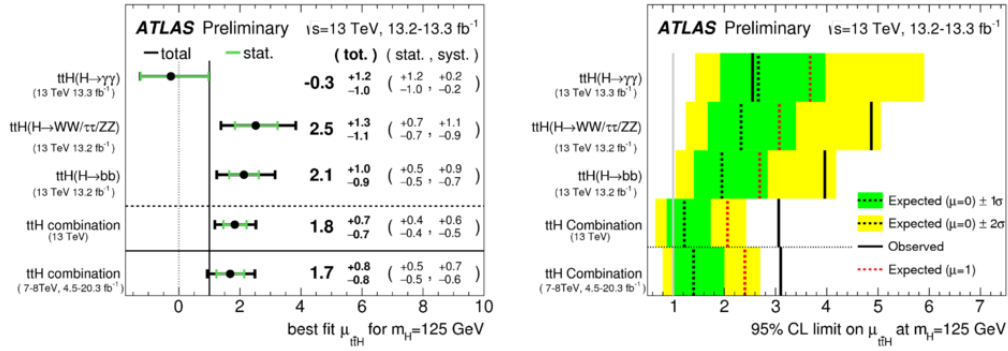


Figure 6: The values (left) and 95% CL upper limits (right) of the signal strength μ obtained in Run II in the individual Higgs decay channels and in the combined analysis. Also shown is the result of the Run I combined analysis [9].

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