

Search for the Standard Model Higgs boson in association with top quarks and decaying to $b\bar{b}$ at $\sqrt{s} = 7$ TeV using the ATLAS detector

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Abstract. A search for a Higgs boson produced in association with a pair of top quarks and decaying into a pair of b quarks is presented. The analysis uses an integrated luminosity of 4.7 fb^{-1} of pp collisions at a center-of-mass energy of $\sqrt{s} = 7$ TeV collected in 2011 with the ATLAS detector at the LHC. The search is focused on the semileptonic decay of the $t\bar{t}$ system and combines nine different topologies given by the jet and b -tagged jet multiplicities of the event. A kinematic reconstruction of the Higgs boson mass is performed in the signal enhanced region, which becomes the primary discriminant variable between signal and background. Background-dominated samples are exploited to constrain the leading systematic uncertainties affecting the background prediction. No significant excess of events above the background expectation is observed. For a Higgs boson with a mass of 125 GeV, an observed (expected) 95% confidence upper limit of 13.1 (10.5) times the Standard Model cross section is obtained.

1. Introduction

One of the major goals of the physics program at the LHC is the search for the Standard Model (SM) Higgs boson. Already wide mass ranges of a possible SM Higgs boson have been excluded by LEP, Tevatron and the two LHC experiments ATLAS and CMS [1, 2, 3], allowing the SM Higgs boson only within the mass window of $m_H \approx [122 - 127] \text{ GeV}$.

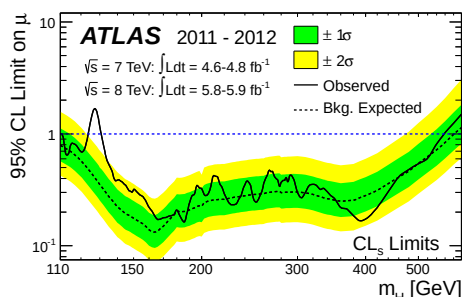


Figure 1. The observed (solid) 95% CL upper limit on the signal strength as a function of m_H and the expectation (dashed) under the background-only hypothesis. The dark and light shaded bands show the one and two sigma uncertainties on the background-only expectation [6].

In addition, an excess of events has been observed which is consistent with a Higgs boson in the mass range of 125 – 127 GeV with a local significance of 5.9σ and 5.0σ by ATLAS (Fig. 1) and CMS, respectively [4, 5, 6, 7]. These searches focused on di-bosonic decay modes of the Higgs boson, while no significant excess has been found yet in fermionic decays.



2. $t\bar{t}H$ Signature and Analysis Strategy

For a low-mass Higgs boson, the dominant decay mode is $H \rightarrow b\bar{b}$. In order to be able to distinguish this decay from QCD background, for these studies [8] the Higgs boson is required to be produced in association with a $t\bar{t}$ pair which decays semileptonically. This results typically in a final state with an isolated electron or muon with a high transverse momentum, large transverse missing energy and 6 jets, of which 4 jets originate from b quarks. Events are categorized in 13 independent topologies dependent on the number of jets and b -tags of which 4 are defined as signal regions (SR), 5 as background regions (BR) and 4 as control regions (CR). Depending on the topology either the scalar sum of the jet transverse momenta H_T^{had} or the invariant mass of the pair of jets $m_{b\bar{b}}$ which are not assigned to the $t\bar{t}$ decay are used as discriminating variables in the signal and background enriched regions (Tab. 1). The invariant

Table 1. Overview of the splitting in different topologies and the used discriminating variable.

	0 b -tags	1 b -tags	2 b -tags	3 b -tags	≥ 4 b -tags
4 jets	BR, H_T^{had}	BR, H_T^{had}	BR, H_T^{had}		
5 jets	CR	CR	BR, H_T^{had}	SR, H_T^{had}	SR, H_T^{had}
≥ 6 jets	CR	CR	BR, H_T^{had}	SR, $m_{b\bar{b}}$	SR, $m_{b\bar{b}}$

mass $m_{b\bar{b}}$ is obtained by a kinematic event reconstruction of the $t\bar{t}$ decay using the maximum likelihood approach which allows for asymmetric energy resolutions [9]. This helps to reduce the combinatorial background as well as it improves the energy resolution of the $m_{b\bar{b}}$ system. No assumptions on the Higgs boson candidate are made. Hypothesis testing is performed in the SR and BR using a profile likelihood fit of the predicted distributions of the discriminants to the data. This allows for constraining the systematic uncertainties by including them as nuisance parameters. The events in the SR provide most information for the limit setting on a Higgs boson production cross section, while the ones in the BR are important to constrain leading systematic uncertainties such as those arising from the jet energy calibration, b -tagging calibration or the modeling of the background. The samples in the CR are used to validate extrapolations across topologies of an improved background prediction resulting from the fit.

3. Post-Fit Event Yields

The post-fit event yields for each considered topology under the signal-plus-background hypothesis (assuming $m_H = 125$ GeV and SM signal contribution) for the combined electron and muon sample including statistical and constrained systematic uncertainties are summarized in Table 2.

Table 2. Summary of the post-fit event yields in each of the topologies considered, corresponding to the combined e +jets and μ +jets channels. The quoted uncertainties are the sum in quadrature of statistical and total systematic uncertainties on the yields taking correlations into account [8].

	4 jets, 0 b -tags	4 jets, 1 b -tags	4 jets, ≥ 2 b -tags	5 jets, 2 b -tags	5 jets, 3 b -tags
$t\bar{t}H(125)$	0.20 ± 0.03	1.1 ± 0.1	3.0 ± 0.2	2.7 ± 0.2	2.3 ± 0.1
Total bkg.	40200 ± 280	21240 ± 200	15040 ± 150	6640 ± 80	915 ± 24
Data	40209	21248	15066	6653	878
	5 jets, ≥ 4 b -tags	≥ 6 jets, 2 b -tags	≥ 6 jets, 3 b -tags	≥ 6 jets, ≥ 4 b -tags	
$t\bar{t}H(125)$	0.74 ± 0.04	3.4 ± 0.2	4.0 ± 0.2	2.2 ± 0.1	
Total bkg.	45 ± 3	3360 ± 80	634 ± 19	62 ± 5	
Data	41	3340	676	65	

The fractional contributions of the various backgrounds to the total background prediction are visualized in pie charts for the different topologies in Figure 2. In the signal region where at least 5

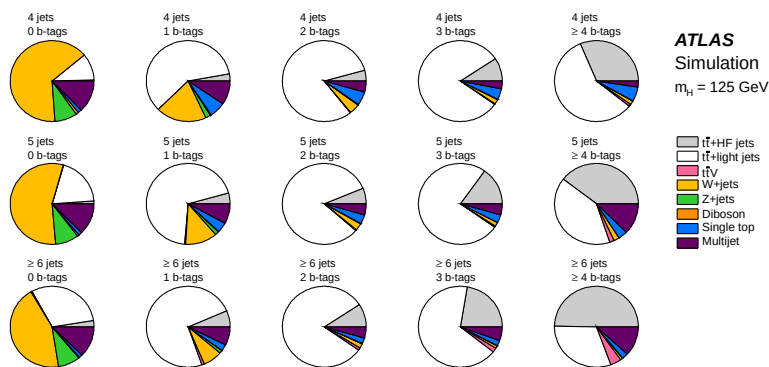


Figure 2. A series of pie charts showing the fractional contributions of the various backgrounds to the total background prediction in this analysis. Each row shows the plots for a specific jet multiplicity (4, 5, 6), and the columns show the b -tagged jet multiplicity (0, 1, 2, 3, 4) [8].

jets and at least 3 b -tags are required the sample is dominated by the $t\bar{t}$ background. While in the 3 b -tag bin this is mainly $t\bar{t}$ +light jets, in the 4 b -tag bin the contribution coming from $t\bar{t}$ +heavy-flavour decays becomes more important. Also the fraction of multi-jet background increases in the signal region, thus a good modeling of these backgrounds is crucial for this analysis.

4. Fits to Data

A comparison between data and simulation is shown in Figure 3 for H_T^{had} in a $t\bar{t}$ dominated region and for $m_{b\bar{b}}$ in a signal enriched region before and after fit to data under the signal-plus-background hypothesis assuming $m_H = 125$ GeV. As a consequence of including background regions and choosing discriminants sensitive to the main systematic uncertainties the latter are significantly constrained and the fit-corrected MC predictions agree much better with the data. In the signal regions the largest contributing uncertainty is the one on the heavy flavor fractions of the $t\bar{t}$ background due to the lack of NLO predictions. This uncertainty is conservatively estimated to be 50% which can be constrained to 30% by means of the fit.

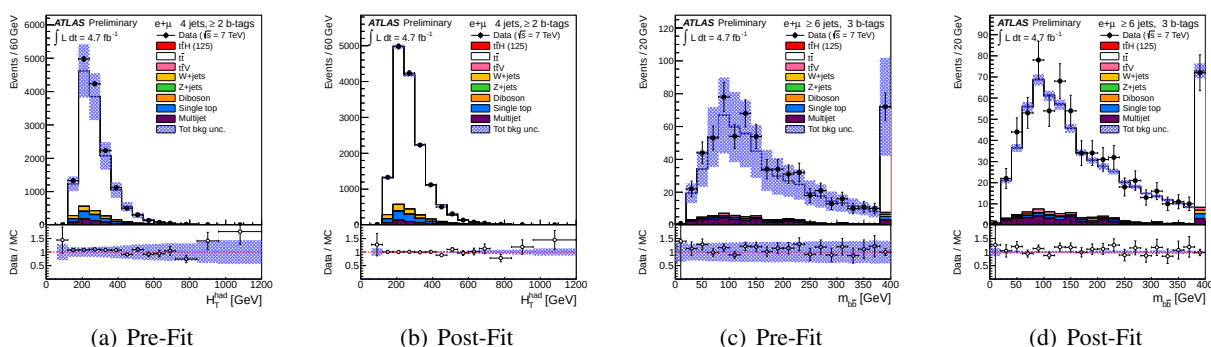


Figure 3. Comparison between data and simulation for the final discriminant variables used in the combined e +jets and μ +jets channels. H_T^{had} (a, b) is used in 4 jets and ≥ 2 b -tags and $m_{b\bar{b}}$ (c, d) in ≥ 6 jets, 3 b -tags. Both variables are shown before (a, c) and after (b, d) fitting of the nuisance parameters to data under the signal-plus-background hypothesis (assuming $m_H=125$ GeV). The bottom panel displays the ratio between data and background prediction. The shaded area represents the total background uncertainty [8].

All fitted nuisance parameters are found to have values within the 1σ interval defined by the original uncertainties assigned to the different systematic sources. A number of nuisance parameters are significantly constrained by the fit. The channels with 4 jets play an important role in constraining overall normalisation uncertainties on W +jets, multijet and $t\bar{t}$ background, as well as the b -tagging efficiency. The distribution of the $t\bar{t}$ background across the 0, 1 and 2 b -tags multiplicities provides a powerful constraint on uncertainties arising from the b -tagging efficiency. The 4, 5 and ≥ 6 jets channels with 2 b -tagged jets are almost pure in $t\bar{t}$ +jets background and provide an important constraint on $t\bar{t}$ modeling uncertainties. Finally, the consideration of the 4 channels with 3 and ≥ 4 b -tagged jets allows the uncertainty on the $t\bar{t}$ +heavy-flavour fraction to be constrained.

5. Cross Section Limits and Conclusions

Observed and expected 95% confidence level (CL) upper limits on the Higgs boson production cross section relative to the SM are derived as a function of m_H in the range between 110 and 140 GeV and shown in Figure 4. No significant excess of events above the background expectation is observed. For a Higgs boson with a mass of 125 GeV, an observed (expected) 95% confidence upper limit of 13.1 (10.5) times the SM cross section is obtained. The most significant systematic uncertainties are $t\bar{t}$ +heavy-flavour fractions, tagging efficiencies, multijet background normalisation and jet energy scale. Removing these systematic uncertainties improves the median sensitivity by 38% while removing all systematic uncertainties improves the median sensitivity by 45%.

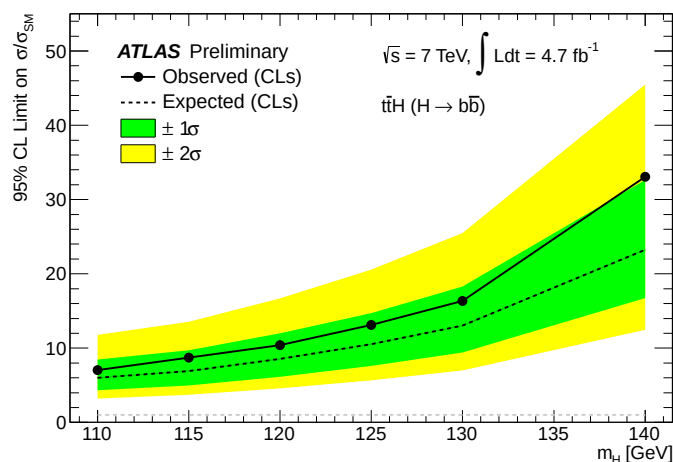


Figure 4. Observed and expected (median, for the background-only hypothesis) 95% CL upper limits on $\sigma(t\bar{t}H) \times \text{BR}(H \rightarrow b\bar{b})$ relative to the SM prediction, as functions of m_H . The points are joined by straight lines for better readability [8].

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