PROCEEDINGS OF SCIENCE

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

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A search for a Higgs boson produced in association with a pair of top quarks ($t\bar{t}H$) and decaying into a pair of bottom quarks $H \to b\bar{b}$ is presented. The search is focused on the semileptonic decay of the $t\bar{t}$ system and exploits different topologies given by the jet and b-tagged jet multiplicities of the event. A kinematic reconstruction of the $t\bar{t}H$ topology is performed in the signal enhanced region, which becomes the primary discriminant variable between signal and background. Using 4.7/fb of data collected with the ATLAS detector during Run 1 of the Large Hadron Collider, we obtain an observed (expected) 95% confidence-level upper limit of 13.1 (10.5) times the Standard Model cross section for a Higgs boson with a mass of 125 GeV.

The European Physical Society Conference on High Energy Physics -EPS-HEP2013
18-24 July 2013
Stockholm, Sweden

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 http://pos.sissa.it/

PoS(EPS-HEP 2013)118

ATL-PHYS-PROC-2013-223
13/09/2013

1. Introduction

One year after the discovery of a new particle in the search for the Standard Model (SM) Higgs boson at the LHC reported by the ATLAS and CMS collaborations [1], there is a clear signal of the observed particle in the $H \to \gamma\gamma$, $H \to ZZ^{(*)}$ and $H \to WW^{(*)}$ channels at a mass of around 125 GeV, while no significant excesses were found yet in searches targeting fermionic decay modes ($H \to b\bar{b}$ and $H \to \tau^+\tau^-$).

In the following, we review a search for $t\bar{t}H(H \to b\bar{b})$ production in proton-proton collisions at $\sqrt{s}$ = 7 TeV [2] using data corresponding to an integrated luminosity of 4.7 fb^{-1} collected by the ATLAS experiment [3]. This search is simultaneously sensitive to the Yukawa coupling between the top quark and the Higgs boson and the $H \to b\bar{b}$ branching ratio, and the only assumption made is that the Higgs boson is a narrow scalar particle.

2. Analysis overview

The analysis is focused on the semileptonic decay mode of the $t\bar{t}$ system, where the W boson from one top quark decays to a charged lepton (l) and its associated neutrino (ν), and the W boson from the other top quark decays to a quark-antiquark pair (q_1 and q_2). The signature of a $t\bar{t}H(H \to b\bar{b})$ event is determined by one high transverse momentum (p_T) electron or muon, a characteristic that is crucial for triggering, high missing transverse momentum (E_T^{miss}) from the undetected neutrino, and six jets, out of which 2 are b-jets (b_{had} and b_{lep}) from the top pair decay and 2 are b-jets from the Higgs boson decay. The main background to the search comes from $t\bar{t}$ events where there are at least two extra jets produced in association with the top quarks.

Events with one high-p_T isolated electron or muon, high E_T^{miss} and at least four reconstructed jets are selected, and they are categorized into nine different topologies depending on their jet and b-tagged jet multiplicities. Two different discriminants are employed depending on the category. Categories with fewer than six jets or fewer than three b-tagged jets are dominated by background and the discriminant used is H_T^{had}, the scalar sum of the jet transverse momenta (p_T^{jet}).

Categories with at least six reconstructed jets and with three or more b-tagged jets present the highest signal-to-background ratio and have the highest sensitivity to a SM Higgs boson signal. In these cases the Kinematic Likelihood Fitter algorithm [4] was used to perform kinematic reconstruction using the maximum likelihood method that allows to assign observed jets to the final state partons of the $t\bar{t}$ decay and finds good estimators for measured objects using kinematic constraints. Detector resolutions for energy measurements are described in terms of transfer functions (T) derived for electrons, muons, light-quark (u, d, s, c) jets and b-quark jets, and parametrized in p_T (for muons) or energy (E_i) in several η-regions of the ATLAS detector to reflect its structure. The likelihood function is built as a product of individual likelihood terms describing the kinematics of the $t\bar{t} \to l\nu b_{lep} q_1 q_2 b_{had}$ signature and contains constraints from the masses of the two W bosons (m_W) and the two top quarks (m_{top}):

$$L_{kin} = \prod_{jet=1}^{6} T(\widehat{E}_{jet}|E_{jet}) \cdot \begin{pmatrix} T(\widehat{E}_e|E_e) \\ T(\widehat{p}_{T,\mu}|p_{T,\mu}) \end{pmatrix} \cdot T(\widehat{E}_x^{miss}|E_x^{miss}) \cdot T(\widehat{E}_y^{miss}|E_y^{miss}) \cdot \tag{2.1}$$
$$BW(m_{q_1q_2}|m_W,\Gamma_W) \cdot BW(m_{l\nu}|m_W,\Gamma_W) \cdot BW(m_{q_1q_2b_{had}}|m_{top},\Gamma_{top}) \cdot BW(m_{l\nu b_{lep}}|m_{top},\Gamma_{top}),$$

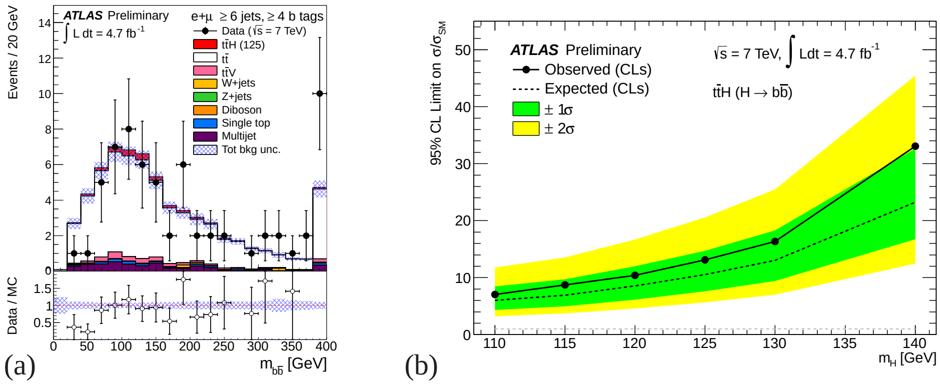

Figure 1: **(a)** Comparison between data and prediction for the final discriminant variable ($m_{b\bar{b}}$) used in the combined e+jets and μ+jets channels with $\geq$6 jets and $\geq$4 b-tags after fitting of the nuisance parameters to data under the background-only hypothesis. The last bin in the figure contains the overflow. **(b)** Observed and expected (median, for the background-only hypothesis) 95% C.L. upper limits on the ratios to the SM cross section, as functions of m_H.

where BW are the Breit-Wigner functions describing the W boson and top quark decays within widths of $\Gamma_W = 2.1$ GeV and $\Gamma_{top} = 1.5$ GeV, and the generator predicted quantities are marked with a circumflex (e.g. $\widehat{E}_e$), i.e. the energy of the electron. The best permutation is found by maximising the likelihood. The invariant mass of the two jets not assigned to the $t\bar{t}$ system ($m_{b\bar{b}}$) is used as a discriminant in the search for a Higgs boson resonance, as shown in Figure 1a.

Several sources of systematic uncertainties have been considered that can affect the normalisation of signal and background and/or the shape of their corresponding discriminant distributions. The dominating systematics are $t\bar{t}+$ heavy- and light-flavour modeling, b-, c- and light-tagging efficiencies, multijet background normalisation and jet energy scale.

3. Results and conclusions

A simultaneous fit to the background-dominated topologies and those with signal is performed to obtain an improved background prediction with reduced uncertainties, resulting in a better search sensitivity compared to fitting the signal region alone. No significant excess of events above the background expectation is observed and 95% confidence-level upper limits on $\sigma(t\bar{t}H) \times BR(H \to b\bar{b})$, are derived for a Higgs boson with a mass between 110 and 140 GeV, as shown in Figure 1b. At 125 GeV an observed (expected) 95% confidence-level upper limit of $13.1(10.5)$ times the SM Higgs boson cross section is obtained.

The author would like to acknowledge the support of CONACyT-DAAD scholarship program.

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