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Higgs searches in the $H \to b\bar{b}$ channel in ATLAS

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This paper summarizes results of the first ATLAS direct search for the Standard Model Higgs boson in the mass range $110 < m_H < 130$ GeV when produced in association with a W or Z boson and decaying to $b\bar{b}$. No evidence for Higgs boson production is observed in a dataset of 7 TeV pp collisions corresponding to 1.04 fb^{-1} of integrated luminosity, recorded by the ATLAS experiment at the LHC in 2011. Upper limits on Higgs-boson production cross-sections for the channels considered are presented and discussed.

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1. Introduction

The search for the Standard Model Higgs boson is one of the most important goals of the Large Hadron Collider (LHC) at CERN. If the Higgs mass is smaller than twice the W boson mass, it will decay mainly to a pair of b-quarks [1]. In this low mass region, the production process $gg \to H$ dominates, but the background from QCD multijet production is expected to be huge. However, the associated production of a Higgs and a vector boson, VH, despite its smaller cross-section is more promising due to the clear signatures provided by the leptonic decays of the vector bosons. The study presented here employs a simple and robust cut-based analysis to search for the Higgs boson in the $WH \to \ell\nu b\bar{b}$ and $ZH \to \ell\ell b\bar{b}$ channels, where $l = e, \mu$. These channels are characterized by the presence of one or two high p_T isolated leptons, two b-jets in the final state and missing transverse energy ($E_{\mathrm{T}}^{\mathrm{miss}}$) due to the escaping neutrino in the case of the WH. The most important SM backgrounds are due to W/Z+jets, QCD multijet production, top quark production (either $t\bar{t}$ or single top) and diboson production (WW, WZ, ZZ). Although the cross section of the ZH channel is about half of the WH, it is less affected by the top background, and therefore it can reach similar sensitivity to the WH.

The data sample used in this analysis was recorded by the ATLAS experiment [2] during the 2011 LHC run at a centre of mass energy of $\sqrt{s} = 7$ TeV and represents an integrated luminosity of 1.04 fb^{-1}. The data are required to satisfy a number of conditions ensuring essential elements of the ATLAS detector were operational with good efficiency while the data were collected.

2. Event selection

Events were selected using a single lepton trigger with a p_T threshold of 18 GeV for muons and 20 GeV for electrons. To ensure high efficiency in the electron channel for the ZH analysis, the single lepton trigger is complemented with a $p_T > 12$ GeV di-electron trigger. Only events with one good primary vertex, that contains at least three charged tracks are selected for further analysis.

The reconstruction of muons, electrons, missing transverse energy and jets follows the standard procedures in ATLAS. Electron candidates are reconstructed from electromagnetic calorimeter clusters matched to tracks reconstructed in the inner detector. The clusters must have shower profiles consistent with those expected from an electromagnetic shower. Muon candidates are reconstructed by matching tracks found in the inner tracking detector with either tracks or hit segments in the muon spectrometer. In order to suppress leptons produced in jets, the sum of track transverse momenta in an η-ϕ cone of radius 0.2 around the identified lepton track must be smaller than $0.1 \times p_T$, where p_T is the transverse momentum of the lepton. To further reduce semileptonic decays in the W channel the transverse (longitudinal) distance of the lepton track to the event vertex must be less than 0.1 (10) mm and muons are required to have an η-ϕ distance greater than 0.4 to any reconstructed jet satisfying the selection criteria described below.

Jets are reconstructed from topological energy clusters in the calorimeter using an anti-k_T algorithm [3] with a radius parameter $R = 0.4$ and are calibrated to the hadronic energy scale. In order to reduce the sensitivity to pile-up from additional proton-proton interactions occurring in the same or out-of-time bunch crossings, only jets associated to the main interaction vertex are used.

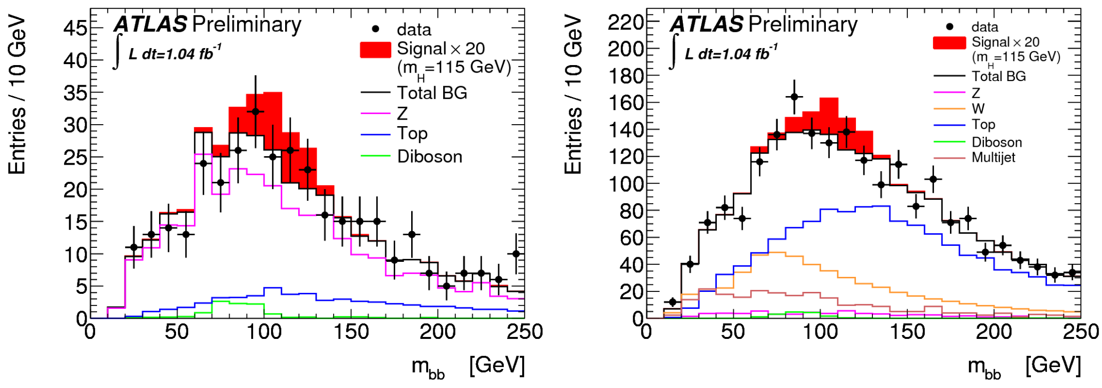

Figure 1: The di-b-jet invariant mass, $m_{b\bar{b}}$, for $ZH \to \ell\ell b\bar{b}$ (left) and $WH \to \ell\nu b\bar{b}$ (right) for $m_H = 115$GeV . The signal distribution is enhanced by a factor of 20 for visibility.

ATLAS b-tagging algorithms are used to distinguish jets containing decays of b hadrons from those containing only light quarks. In this analysis a combination of the three dimensional impact arameter information and the output of a secondary vertex finding algorithm is used. The b-tagging selection condition is chosen so that an efficiency of 70% for $b-$jets in $t\bar{t}$ events is obtained, while providing a light jet rejection factor of around 50.

The missing transverse energy, $E_{\mathrm{T}}^{\mathrm{miss}}$ is measured from the vector sum over all topological clusters in the calorimeters with $|\eta| < 4.5$ together with terms accounting explicitly for selected muons in the event.

After the object, trigger and common event requirements, the selection in the $ZH \to \ell\ell b\bar{b}$ search channel continues with the requirement that there must be exactly two leptons in the event that form a Z candidate with invariant mass in the range $76 < m_{\ell\ell} < 106$ GeV, and small missing transverse energy ($E_{\mathrm{T}}^{\mathrm{miss}} < 50$ GeV). At least two jets with $p_T > 25$ GeV are required, where the two highest p_T jets are both required to pass the b-tagging selection.

$WH \to \ell\nu b\bar{b}$ events are required to have exactly one lepton (e or μ) fulfilling the selections described above. The missing transverse energy in the event, $E_{\mathrm{T}}^{\mathrm{miss}}$, is required to be greater than 25 GeV and the transverse mass, defined as $m_T = \sqrt{2p_T^l p_T^\nu (1 - cos(\phi^l - \phi^\nu))}$, should be greater than 40 GeV. The number of jets with $p_T > 25$ GeV is required to be exactly two, to reduce background from top production that is significantly higher in this channel. In addition the two jets must pass the b-tagging selection. Further details of the event selection can be found in Ref. [4].

The invariant mass of the $b\bar{b}$ system for events surviving the $WH \to \ell\nu b\bar{b}$ and $ZH \to \ell\ell b\bar{b}$ selections are shown in Figure 1 for real and simulated events. Where possible, control regions are used to determine or verify the normalization and shape of different backgrounds in the data.

3. Systematic Uncertainties

The main detector-related contributions to the systematic uncertainties are related to the lepton, jet and missing transverse energy identification efficiencies and energy resolution or scale, the b-tagging efficiency and mis-tagging rates, and the trigger efficiencies [4].

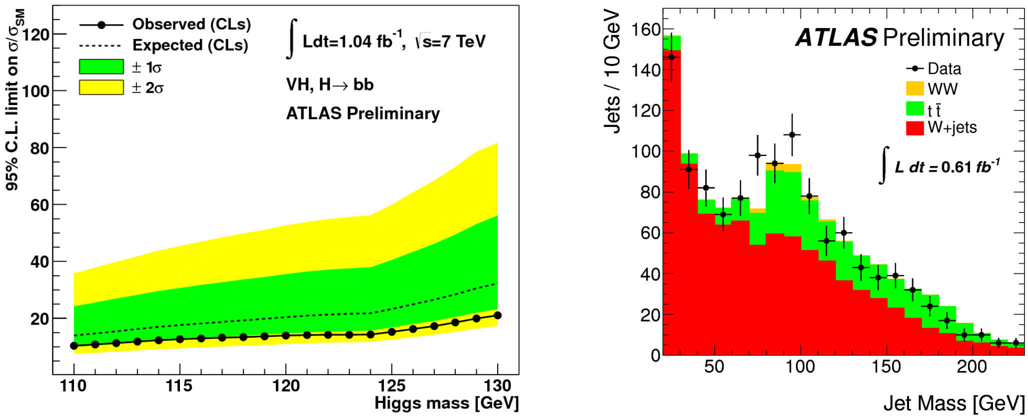

Figure 2: Left: expected (dashed) and observed (solid line) exclusion limits for the $ZH \to \ell\ell b\bar{b}$ and $WH \to \ell\nu b\bar{b}$ channels combined, expressed as the ratio to the Standard Model cross-section, using the profile-likelihood method with CL_s. The green and yellow areas represent the 1σ and 2σ ranges of the expectation in the absence of a signal. Right: The jet mass distribution of subjets with $p_T > 180$ GeV in events consistent with a $W \to \ell\nu$ boson decay with $p_T > 200$ GeV. The distribution is compared to the uncorrected MC simulation prediction for $t\bar{t}$, W+jets and WW processes.

The uncertainty on the Higgs production cross section was estimated to be 5% for both WH and ZH, in the mass range relevant for this analysis [1]. The uncertainty on the normalization of the Z+jets background for both analyses is 9%, taken from the statistical uncertainty on the data-driven method employed in the ZH analysis. A normalization uncertainty of 14% is assigned to the W+jets background based on the statistical precision of the data-driven normalization method. In both cases, additional terms to account for the uncertainty on the shape of the W/Z+jets distributions are computed. The normalization uncertainty for the multijet background is taken to be 100% for ZH and 50% for WH. The normalization error for the top background, determined using the Monte Carlo, is taken to be 9% for the ZH analysis, from comparisons of data and MC simulation in the control region, and 6% for the WH analysis from the statistical precision of the data-driven normalization determination.

The uncertainty in the integrated luminosity has been estimated to be 3.7%. This uncertainty is only applied to MC samples for which the normalization error is not taken directly from a comparison between data and MC.

4. Results and Future Prospects

The $ZH \to \ell\ell b\bar{b}$ and $WH \to \ell\nu b\bar{b}$ analyses are performed for five Higgs boson masses between 110 GeV and 130 GeV. The Higgs boson decay is searched in the di-b-jet invariant mass, $m_{b\bar{b}}$, distribution (see Figure 1) for each analysis [4].

For each Higgs boson mass hypothesis, a one-sided upper-limit is placed on the standardized cross-sections $\mu = \sigma/\sigma_{SM}$ at the 95% confidence level (C.L.). The exclusion limits are derived from the CL_s [5] treatment of the p-values computed with the profile likelihood ratio [6], of the binned distribution of $m_{b\bar{b}}$ as the test-statistic. The systematic uncertainties are treated as nuisance parameters and shape uncertainties are treated via morphing. Histogram morphing is also used to interpolate between the five mass points for which a simulated signal sample was available. The combined exclusion limit for both channels, shown in Figure 2 (left), ranges between 10 and 20 times the Standard Model cross-section, depending on the Higgs boson mass.

An alternative approach to identifying $H \to b\bar{b}$ in associated production with a W or Z boson is to consider only the high-p_T part of the cross-section [7]. Such "boosted Higgs" studies require that the Higgs boson p_T is at least 200 GeV, which rejects about 95% of the signal. However the main backgrounds are reduced by a larger factor and the remaining signal events tend to be within the detector acceptance. One of the key aspects of any such analysis is the identification of the $H \to b\bar{b}$ pair using jet substructure techniques. Figure 2 (right) shows the mass distribution for jets found using 610 pb^{-1} of 2011 LHC data, and reconstructed using these techniques [4]. Events are selected if they contain a high-$p_T W$ candidate decaying according to $W \to l\nu$ ($l = e, \mu$) and balanced by a high-$p_T$jet. The jet invariant mass is reconstructed with the help of the substructure techniques and shows a peak near the W mass. This is most clear in $t\bar{t}$ events, containing two W bosons, where one decays hadronically as $W \to qq'$ and the other to an electron or a muon and a neutrino. No energy scale or efficiency corrections were applied to jets, missing transverse energy or lepton.

5. Conclusions

A direct search for the Standard Model Higgs boson decaying to a b-quark pair was performed for the first time in ATLAS. An integrated luminosity of 1.04fb^{-1} of pp collision data at $\sqrt{s} =$ 7 TeV was examined and no evidence of the Higgs boson was found. Instead, upper limits on the Higgs production cross section of between 10 and 20 times the Standard Model value were determined, in a mass range between $110 GeV/c^2$ and $130 GeV/c^2$.

A first proof of principle of the jet substructure technique was shown for reconstructing the mass of highly boosted W bosons. In the future, this promising technique will be applied to the reconstruction of $H \to b\bar{b}$ decays.

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PoS(EPS-HEP2011)245