Associated Standard Model Higgs boson search with ATLAS

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Abstract. The observation with the ATLAS detector at the LHC of a Standard Model Higgs boson produced in association with $t\bar{t}$, W or Z bosons, and decaying to WW or $b\bar{b}$ final is reported. Events characterized by the presence of two or three leptons are analyzed to search for the Higgs boson produced in association with vector bosons. Events with two b-tagged jets are selected in association with $t\bar{t}$ topologies. The studies are based on the analysis of Monte Carlo signal and background data simulated in detail through the experimental apparatus.

Keywords: associated production, Higgs, $t\bar{t}H$, $H \rightarrow WW$, $H \rightarrow b\bar{b}$, WH

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INTRODUCTION

The dominant decay mode for a Standard Model Higgs boson in the mass region between 115 and 130 GeV is $H \rightarrow b\bar{b}$. Nevertheless, the large background of jet production from QCD makes the signal extraction of the direct Higgs boson production via gluon fusion or vector boson fusion (VBF) very difficult. The associated Higgs boson production channels ($t\bar{t}H$, WH , ZH) have the lowest production cross-sections at the LHC, but the production of a Higgs boson together with a $t\bar{t}$ -pair gives good suppressions of the large backgrounds. In the intermediate mass region, around 160 GeV, the decay to two W bosons is dominant and a discovery is expected through gluon fusion or VBF. Once the Higgs boson has been observed, the associated production channels will be able to provide access to the Yukawa-couplings of the Higgs boson. All studies presented in this article have been performed with Monte Carlo samples, using a detailed simulation of the ATLAS detector and assuming an integrated luminosity of 30 fb^{-1} . A more detailed description of these studies and also of other decay modes of associated production at ATLAS can be found here [1].

$$t\bar{t}H(H \rightarrow b\bar{b})$$

The semileptonic final state $t\bar{t}H \rightarrow b\bar{b} b\bar{\nu} \bar{b}q\bar{q}'$ is the most promising final state. The main background for this channel, the production of $t\bar{t}$ events can be greatly reduced by asking for four jets to be identified as b -jets. The irreducible background arises from $t\bar{t}b\bar{b}$ production via QCD or electroweak interactions. Other backgrounds, such as W +jets, tW production and QCD multijet production are expected to be negligible due to the complete reconstruction of the $t\bar{t}$ -system including b -tagging.

The analysis consists of an initial preselection, including trigger requirements and off-

FIGURE 1. Left: Reconstructed invariant mass spectrum for Higgs boson candidates in the signal sample. The red dotted line indicates the candidates formed by assigning the correct b -jets. Right: Reconstructed invariant mass spectrum for signal and background.

line criteria that require the presence of exactly one isolated, identified electron or muon and at least six jets with $p_T > 20$ GeV, reconstructed with a $\Delta R = 0.4$ cone algorithm. At least four jets have to be identified by a b -tagging algorithm whose discriminating variable is a weight based on track impact parameters and the secondary vertex of the b -hadron [2]. Only the four jets with the largest b -tag weights are then treated as b -jets. Following the preselection, three different analysis techniques are implemented to improve the signal-to-background ratio, S/B . The simplest approach is cut-based, starting with the reconstruction of the hadronic and leptonic W bosons. The W candidates are then paired with b -jets to reconstruct the top quark candidates, applying a mass cut on the hadronic W boson and the top quark masses to reduce the considered number of combinations. A χ^2 is defined to evaluate the deviation of the reconstructed top masses from their nominal values. The combination with the smallest χ^2 -value is selected. The two remaining b -jets are then assigned to the Higgs boson decay. Figure 1 shows the invariant $b\bar{b}$ mass distribution for signal (left) and signal and background (right). Applying a mass window cut around the nominal Higgs boson mass improves S/B . A straightforward improvement to a cut-based approach is to use multivariate methods to reject combinatorial and other backgrounds. The so-called pairing likelihood uses several discriminating topological distributions of the top system as input to a combinatorial likelihood. Another analysis uses a constrained fit to adjust lepton and jet momenta and E_T^{miss} to match the W and top masses and the resulting four-momenta are used to calculate a χ^2 . This is then used as one of the inputs to a two-step likelihood, trained to reduce combinatorial and other backgrounds.

Table 1 summarises the signal and background conditions at the working points of the analysis, as well as the fraction of events for which the jets associated to the Higgs boson and all four b -jets are assigned correctly. The quoted significance, $S/\sqrt{B}$, ignores systematic uncertainties. Figure 2 (left) shows a comparison of choosing the correct combinations of b -jets in terms of signal selection efficiency and $b\bar{b}$ purity for the three different approaches. Generally, all analyses suffer from a low $b\bar{b}$ purity mainly due to incorrect assignments of b -jets to the $t\bar{t}$ and H systems.

However, the total significance depends on the systematic uncertainties of the background estimation. Detector performance uncertainties for the background were esti-

TABLE 1. Comparison of the working points for the cut-based, pairing likelihood and constrained fit analyses. $\sigma_{tot.}^{signal} \times BR(H \rightarrow b\bar{b})$ denotes the total signal cross section, including the probability for the decay ($H \rightarrow b\bar{b}$), $\sigma_{acc.}^{signal}$ the accepted signal cross-section after cuts.

	Cuts	Pairing likelihood	Constrained fit
$\sigma_{tot.}^{signal} \times BR(H \rightarrow b\bar{b})$ [fb]	517	517	517
$\sigma_{acc.}^{signal}$ [fb]	1.0	1.2	1.3
S/B	0.11	0.10	0.12
$S/\sqrt{B}$ for 30 fb^{-1}	1.82	1.92	2.18
Irred. BG contribution	46%	45%	50%
Higgs boson jets correct	29.4%	34.0%	32.0%
Four b -jets correct	23.3%	27.5%	27.1%
Higgs boson mass resolution [GeV]	22.8%	20.1%	22.3%

FIGURE 2. Left: Comparison of the purity of reconstructed $b\bar{b}$ invariant mass before the final mass window cut versus selection efficiency for three analyses. The solid markers indicate the selected working points. Right: Comparison of the total significance as a function of systematic uncertainties (ΔB), for the three analyses. Markers indicate the significance corresponding to the estimated detector performance uncertainties.

mated to be of the order $\sim 25\%$ with the main contributions coming from jet measurement and b -tagging uncertainties [1]. A large contribution for the Monte Carlo based analysis is the theoretical uncertainty on the backgrounds. Therefore Monte Carlo driven background estimation is not feasible and strategies to determine the background from data are under study. Figure 2 shows the strong dependence of the total significance on the background uncertainty, $\Delta B/B$. Accuracies at the level of few percent are needed for the background determination in order to achieve sensitivity at the the order of 2σ and enable coupling measurements.

$H \rightarrow WW$ FINAL STATES

Cut-based feasibility studies have been performed for the two- and three lepton final states in the $t\bar{t}H(H \rightarrow WW)$ and the three lepton final states in the $WH(H \rightarrow WW)$

TABLE 2. Accepted signal and background cross-sections and S/B for the two lepton- (2L) and three-lepton (3L) final states of the $H \rightarrow WW$ analyses. The cross-sections are given in fb. If no numbers are given, the background was not considered in the corresponding analysis.

	$\sigma_{acc.}^{signal}$	$\sigma_{acc.}^{t\bar{t}}$	$\sigma_{acc.}^{t\bar{t}Z}$	$\sigma_{acc.}^{t\bar{t}W}$	$\sigma_{acc.}^{WZ}$	$\sigma_{acc.}^{totalbg}$	S/B
$t\bar{t}H(H \rightarrow WW)$ (2L, $M_H = 160$ GeV)	1.85	7.4	1.1	1.7	-	10.3	0.19
$t\bar{t}H(H \rightarrow WW)$ (3L, $M_H = 160$ GeV)	0.82	2.1	0.9	0.5	-	3.4	0.24
$WH(H \rightarrow WW)$ (3L, $M_H = 170$ GeV)	0.31	0.34	-	0	0.10	0.45	0.75

channel. The main background for both $t\bar{t}H(H \rightarrow WW)$ final states arises from the production of $t\bar{t}$ +jets, where one lepton originates from a heavy quark decay. Therefore powerful lepton isolation tools are important for the analysis of these channels. Other relevant backgrounds are $t\bar{t}W$, $t\bar{t}Z$, $t\bar{t}t\bar{t}$ and $t\bar{t}b\bar{b}$. Due to limited statistics, jet production from QCD processes, Wt , WZ and $Wb\bar{b}$ could not be studied in detail. The signal efficiency for the two lepton analysis was found to be 0.38% and 0.17% for the three lepton analysis, with an initial cross-section of 484 fb for a Higgs boson mass $M_H = 160$ GeV.

The most promising final state for the WH production is the fully leptonic one with three isolated leptons with a low jet activity and E_T^{miss} despite the low branching fraction. The main background is $t\bar{t}$, but also the WZ production has to be considered. Smaller contributions are expected from ZZ and $t\bar{t}W$ production. Backgrounds from WWW , $t\bar{t}Z$, $Wb\bar{b}$ and W +jets have not yet been considered. At a Higgs mass $M_H = 170$ GeV the signal-to-background ratio is 0.75, but with a low signal rate due to the low selection efficiency of 0.17% on the initial 184 fb. Table 2 summarises the results of all selections for all final states for the most promising Higgs boson masses.

SUMMARY

For the analysis of the semi-leptonic final state of the $t\bar{t}H(H \rightarrow b\bar{b})$ channel, cut- and likelihood based analyses have been performed, leading to accepted cross-sections of about 1 fb at a signal-to-background ratio of about 10%. The Higgs boson mass peak is obscured by the limited jet resolution and incorrect b-jet assignments as well as a large and complex background. The large systematic errors on a Monte Carlo driven background subtraction strongly dilute the signal significance. Therefore the background needs to be estimated from data, which is currently under study.

$H \rightarrow WW$ channels have to deal with small signals and it is not possible to reconstruct the Higgs boson mass. Also here the background estimation has to be determined from data, which makes the analysis of these channels a challenge.

REFERENCES

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