# t anti-t and W associated Standard Model Higgs search in H—> b anti-b, WW(*) final states at ATLAS

H. Zhang

# $t\bar{t}$ and $W$ Associated Standard Model Higgs Boson Search in $H \to b\bar{b}, WW^{(*)}$ Final States at ATLAS

H. Zhang, on Behalf of the ATLAS Collaboration

*Institute of High Energy Physics, Chinese Academy of Science, Beijing, China*
*Centre de Physique des Particules de Marseille, CNRS/IN2P3, Marseille, France*

**Abstract.** The sensitivity of the ATLAS detector at LHC to a Standard Model Higgs boson produced in association with $t\bar{t}$ or $W$ bosons, and decaying into $WW^{(*)}$ and $b\bar{b}$ final states is reported. In the associated production with a top pair, events with Higgs boson decays to $b\bar{b}$ and $WW^{(*)}$ are analyzed, characterized by the presence of $b$ jets and two or three leptons; in the associated production with $W$ bosons, events with three leptons in the final state are analyzed. These studies are based on the analysis of Monte Carlo signal and background, simulated in detail through the experimental apparatus.

**Keywords:** ATLAS, Higgs, Coupling, Associated
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## INTRODUCTION

The Large Hadron Collider (LHC) at CERN, is scheduled to start operations at a center-of-mass energy $\sqrt{s} =$ 10 TeV in 2009 for proton-proton collisions. It is expected that it will reach the designed energy of $\sqrt{s} = 14$ TeV and an instantaneous luminosity of $10^{33}\text{cm}^{-2}\text{s}^{-1}$ in 2009. One of its general purpose detectors, ATLAS, will accumulate 30 $\text{fb}^{-1}$ data during the first few years.

The discovery and subsequent study of the Higgs boson is one of LHC primary goals. The possible mass range of the Standard Model Higgs boson is bounded by the lower limit set at LEP of 114 GeV and could reach up to 1000 GeV. The ATLAS experiment will use all possible channels, to discover and extract information on the Higgs boson couplings.

At LHC, the Higgs boson will be mainly produced by gluon fusion, vector-boson fusion and associated production with top quark pairs or $W/Z$ gauge bosons. The discovery potential is dominated by the first two production mechanisms [1]. However, despite a cross-section two orders of magnitude lower than for gluon fusion, associated productions have more distinct final state signatures to be separated from physics backgrounds. They could contribute to the Higgs boson discovery and give unique coupling information by comparing the rates in the different channels [2]. Especially, the $t\bar{t}H$ channel is expected to give information on top quark Yukawa coupling at LHC and $WH, H \to WW$ channel could give information on Higgs boson to $W$ partial width.

The Standard Model Higgs boson decay is dominated by $b\bar{b}$ if its mass is less than about 135 GeV (e.g. 68% at $m_H = 120$ GeV) and $WW^{(*)}$ (91% around $m_H = 160$ GeV) for higher mass regions. In this report, the searches for associated production of $t\bar{t}H, H \to b\bar{b}, WW^{(*)}$ and $WH, H \to WW$ for an intermediate Higgs boson mass at ATLAS are presented, based on a realistic detector geometry with the full simulation based on the *GEANT* 4 package.

## $t\bar{t}H, H \to b\bar{b}$ SEARCHES

This channel is of special interest for the top quark Yukawa coupling measurement and possible Higgs boson discovery at Higgs boson mass around 120 GeV.

Since the top quark almost exclusively decays to $Wb$, the signature of $t\bar{t}H, H \to b\bar{b}$ can be classified according to the decays of the two $W$ bosons. Hadronic final state is difficult to trigger due to QCD multijet contamination and dileptonic (in this report, lepton refers to electron or $\mu$, not include $\tau$) final state is difficult as well since the two neutrinos prevent top pair system reconstruction. Therefore, only the semileptonic final state channel is considered with the signature of four $b$ jets, two light jets, one lepton and missing energy. The main physics background of this channel comes from $t\bar{t}$ events, especially the irreducible $t\bar{t}b\bar{b}$ background. These two backgrounds are considered in this analysis. Due to big production cross-sections, the $W$+jets, $tW$ production and QCD multi-jets production could also have a non-negligible impact on the analysis. However, their contribution can be reduced to a negligible level by requiring four $b$ jets. Contamination from $b\bar{b}b\bar{b}$ is still possible. However, the reconstruction of the $t\bar{t}$ system allows a certain degree of safety against non-top backgrounds. None of these samples are presented in what follows. The generation specifications of each sample are presented in Table 1.

**TABLE 1.** Summary of the different samples used in $t\bar{t}H, H \to b\bar{b}$ searches

| Process | $\sigma$ [fb] | Generator |
|---|---|---|
| $t\bar{t}H, m_H$=120GeV | 537 (LO) | PYTHIA |
| $t\bar{t}b\bar{b}$ QCD | 8700 (LO) | ACERMC |
| $t\bar{t}b\bar{b}$ EW | 940 (LO) | ACERMC |
| $t\bar{t}$ | 833000(NLO+NLL) | MC@NLO |

After a high $p_T$ lepton trigger requirement of 82% efficiency for the semileptonic signal, the events are required to have only one electron(muon) reconstructed within the acceptance region of transverse momentum $p_T > 25(20)$ GeV and pseudorapidity $|\eta| < 2.5$. Tracker isolation is performed by setting the upper limit on the sum $p_T$ of extra tracks reconstructed in the Inner Detector around the electron(muon) track in a cone size of $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.2$ over the electron(muon) track to be 0.15(0.30). At least 6 jets with $p_T > 20$ GeV and $|\eta| < 5$, of which at least 4 jets are tagged as $b$ jets by a multi-variable tagger which uses track information, such as the track impact parameter, and properties of the secondary vertices.

The reconstruction of $t\bar{t}H, H \to b\bar{b}$ system requires a full reconstruction of the $t\bar{t}$ system to recognize the two $b$ jets associated to the top decay chain. The remaining two $b$ jets define the Higgs boson system. There are three approaches used to solve the jet combinatorics:

- The cut based analysis uses the two top quark mass constraints. The combination with minimum

$$\chi^2 = \left(\frac{m_{jjb} - m_{top}}{\sigma_{m_{jjb}}}\right)^2 + \left(\frac{m_{l\nu b} - m_{top}}{\sigma_{m_{l\nu b}}}\right)^2, \quad (1)$$

  which falls in the top and $W$ mass windows is kept.
- The pairing likelihood analysis explores six kinematic variables of the $t\bar{t}$ system. The combination that maximizes the resulting likelihood output is kept. A final selection on the likelihood value is used to increase the purity.
- The constrained fit analysis uses the jet resolution information, kinematic $b$-tagging and jet charge variables, $W$ and top quark mass constraints. A likelihood is build to chose the best combinations and a cut on this likelihood value is used to increase the separation of signal and physics backgrounds.

After the preselection and reconstruction, using respectively cut based, pairing likelihood and constrained analysis, the experimental uncertainties on signal are 18%, 20%, 19%, and 22%, 25%, 28% on the total background. The biggest uncertainties are from jet energy scale and $b$-tagging efficiency. Table 2 summarises the results, with systematics, of the three analysis.

**TABLE 2.** Summary results of the three analysis in $t\bar{t}H, H \to b\bar{b}$ searches

| @ 30 fb$^{-1}$ | S [fb] | B [fb] | $S/\sqrt{B + \Delta B^2}$ |
|---|---|---|---|
| Cut based | 1.0 | 9.0 | 0.49 |
| Likelihood | 1.2 | 11.8 | 0.40 |
| Constrained fit | 1.3 | 10.5 | 0.43 |

The combinatorial background dilutes the Higgs boson mass peak. $b$-tagging is crucial in background suppression and reduces the combinatorial background by improving the hadronically decaying $W$ reconstruction. Subsequent studies should be performed in the background normalization (and shape information) with real data to accurately estimate total background.

## $t\bar{t}H, H \to WW^{(*)}$ SEARCHES

This channel is of special interest for top quark Yukawa coupling measurement at Higgs boson mass around 160 GeV.

The overwhelming $t\bar{t}$+x background restricts the analysis to well defined final states. Therefore only two same-charge lepton(2L) and three lepton (3L) final states are considered. The four lepton final states have too small branching ratio to be considered. The 2L final state provides two same sign leptons, six jets of which two are $b$ jets, and missing energy from the two neutrinos. The 3L final state provides three leptons, four jets of which two are $b$ jets, and missing energy from the three neutrinos. The possible backgrounds are mainly from $t\bar{t} + x$, e.g. $t\bar{t}$, $t\bar{t}Z$, $t\bar{t}W + n\,jets$, $t\bar{t}t\bar{t}$, $t\bar{t}b\bar{b}$. These backgrounds, together with $Wb\bar{b}$, are studied in the analysis. Besides these, single top events, QCD multi-jets, $WZ$, $W$+jets, $b\bar{b}$ could contaminate the signal due to their big production cross-section despite the small probability of prompt leptons (non isolated lepton) from jets. However, the high multiplicity of jets and isolated leptons are expected to reduce them to a safe level and thus they are not presented in this report. The samples generated are presented in Table 3 ($t\bar{t}$ and $t\bar{t}b\bar{b}$ sample are listed in Table 1).

**TABLE 3.** Summary of the different samples used in $t\bar{t}H, H \to WW^{(*)}$ searches. ($t\bar{t}$ and $t\bar{t}b\bar{b}$ are listed in Table 1)

| Process | $\sigma$ [fb] | | Generator |
|---|---|---|---|
| $t\bar{t}H, m_H = 160$ GeV | 291 | (NLO) | PYTHIA |
| $t\bar{t}W + n\,jets$ | 582 | (LO) | ALPGEN |
| $t\bar{t}Z$ | 1090 | (NLO) | ACERMC |
| $t\bar{t}t\bar{t}$ | 2.7 | (LO) | ACERMC |
| $Wb\bar{b}$ | 210000 | (NLO) | ALPGEN |

The respective 2L(3L) selection starts from an isolated high $p_T$ lepton trigger, with an efficiency of about

80%(90%). At least 6(4) jets and exactly 2(3) well isolated leptons are required to be within the acceptance of $p_T > 15$ GeV and $|\eta| < 2.5$ (muon $p_T$>20 GeV). These leptons are required to pass the calorimeter isolation (a 10 GeV upper limit on total energy deposited in the calorimeter around the lepton in a cone size of $\Delta R = 0.2$) the tracker isolation and the lepton-jet angular separation isolation. Then, the same sign requirement for the two leptons is added to suppress $t\bar{t}$ dileptonic events for the 2L analysis. In order to separate $t\bar{t}Z$ and signal, a $Z$ veto is performed, by excluding the $Z$ mass window ([75,100] GeV) from the mass distribution based on lepton pairs fulfilling the loose isolated and lower $p_T$ threshold, same flavor, zero sum charge criteria. This selection results respectively for 2L (3L) in an signal of 1.85 (0.82) fb and total background of 10.3 (3.4) fb. The biggest contribution of the background is from $t\bar{t}$. An alternative analysis using electron likelihood isolation method, which combined several isolation variables, can slightly improve the $t\bar{t}$ background rejection while keeping all other samples at same acceptance.

The theoretical plus experimental uncertainties, are estimated to be 10% (10%) for the signal and 15% (18%) for the total background in 2L (3L) analysis. The biggest uncertainties come from normalization and jet energy scale. However, the uncertainties should be larger for the background due to the lack of knowledge of $t\bar{t} + jets$ modeling at present.

At least two neutrinos from both top and Higgs boson systems make it very difficult to reconstruct Higgs boson or top pair system. Lepton isolation methods are crucial on the dominant reducible background. Subsequent studies should focus on the background normalization, either from real data or other advanced Monte Carlo tools. Possible improvements are expected from $t\bar{t}H$ system recovering with the help of two $b$ jets tagged.

## $WH, H \rightarrow WW$ SEARCHES

This channel is of special interest for the Higgs boson to $W$ boson coupling measurement.

The $WH, H \rightarrow WW$ analysis starts from the tri-lepton final states. The two or less lepton final states are very hard to be visible from the overwhelming $W$+jets samples and thus are not reported here. The signature of the signal is three isolated leptons and missing energy. The main physics backgrounds are $t\bar{t}$, $WZ/ZZ$, $t\bar{t}W$, $Wb\bar{b}$, $W$+jets. All the samples that are not in Table 1 nor in Table 3 are presented in Table 4.

The signal selection starts with an isolated high $p_T$ lepton trigger, with a 70% efficiency, then requires three isolated leptons within the acceptance of $|\eta| < 2.5$, a leading lepton $p_T > 35$ GeV, two others leptons of $p_T > 15$ GeV. These leptons fulfill the calorimeter, tracker,

**TABLE 4.** Summary of the different samples used in $WH, H \rightarrow WW$ searches

| Process | $\sigma$ [fb] | | Generator |
|---|---|---|---|
| $WH, m_H = 170$ GeV | 511 | (NLO) | MC@NLO |
| $WZ$ | 47760 | (NLO) | MC@NLO |
| $ZZ$ | 14750 | (NLO) | MC@NLO |
| $W + jets$ | $1.91{*}10^8$ | (NLO) | HERWIG |

closest jet-lepton separation and lepton three dimensional impact parameter significance isolation. A $Z$ veto excludes the invariant mass of [65,105] GeV for $Z$ candidate lepton pairs. The lower limit of missing transverse energy is set to 30 GeV. And the summed $p_T$ of jets in the acceptance of $p_T > 20$ GeV and $|\eta| < 2.5$ is required to be less than 120 GeV. In order to further suppress backgrounds with top($b$ jets) signature, none of these jets are tagged as $b$ jet. Further rejection of physics backgrounds is achieved by using Higgs boson spin information, cutting on the minimum angular $\Delta R$ between lepton pairs. This selection results in a 0.3 fb signal and 0.4 fb background. The theoretical plus experimental uncertainties are expected to be 10% for the signal and 20% for the total background. The biggest uncertainties come from normalization and jet energy scale.

The lepton isolation is crucial in this analysis, and the background normalization is vital. Therefore it is required to develop a data driven background estimation.

## SUMMARY

The signal and background conditions for current analysis of associated production of $H \rightarrow bb, WW^{(*)}$ for the intermediate Higgs boson mass at ATLAS are reported. They could contribute to top quark Yukawa coupling and $W$ coupling measurement and might contribute to the discovery of the Higgs boson at 30 fb$^{-1}$ of integrated luminosity, providing the background normalization and the systematics are well controlled. There is still room for improvement of the associated production analysis, especially using data driven background accurate estimations. More details are in Ref. [3]

## REFERENCES


1. Abdelhak Djouadi. The anatomy of electro-weak symmetry breaking. I: The Higgs boson in the standard model. *Phys. Rept.*, 457:1–216, 2008.
2. D. Zeppenfeld, R. Kinnunen, A. Nikitenko, and E. Richter-Was. Measuring Higgs boson couplings at the LHC. *Phys. Rev.*, D62:013009, 2000.
3. ATLAS Collaboration. Expected performance of the atlas experiment, detector, trigger and physics. CERN-OPEN-2008-020, Geneva, Sep 2008.