

Search for the Higgs boson decaying to b quark pairs in the W/Z associated production channels with ATLAS

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1 Introduction

In 2012, the ATLAS [1] and CMS experiments at CERN discovered the Higgs boson with an approximate mass of 125 GeV in LHC pp collisions at $\sqrt{s} = 7$ and 8 TeV center of mass energy [2][3].

Given the very large branching ratio to b-quark pairs (58%), the $H \rightarrow bb$ decay measurement is fundamental to determine the boson decay width and couplings and to confirm the Standard Model hypothesis. However, the bb production cross-section in $\sqrt{s} = 8$ TeV pp collisions is seven orders of magnitude greater than the Higgs production cross section, making the $H \rightarrow bb$ decay one of the most challenging searches at the LHC. In fact, this decay was not yet observed and the Higgs couplings to down-type quarks are still to be measured. In the associated production in which the Higgs is produced with a W/Z boson, the leptonic decay of the W/Z is used to trigger the event and substantially reduce the backgrounds.

The ATLAS Run 1 search for the $H \rightarrow bb$ in the W/Z associated production is presented here [4]. The data set used corresponds to integrated luminosities of 4.7 fb^{-1} at $\sqrt{s} = 7$ TeV and 20.3 fb^{-1} at $\sqrt{s} = 8$ TeV.

2 Analysis Overview

The $H \rightarrow bb$ analysis is conducted in three different channels depending on the number of charged leptons in the final state. The 0-lepton channel corresponds to the signal process $ZH \rightarrow \nu\nu bb$, the 1-lepton channel represents the search for $WH \rightarrow \ell\nu bb$ and finally, the 2-lepton channel represents the $ZH \rightarrow \ell\ell bb$ process. In all the cases, $\ell = (e, \mu)$. These three channels are combined in a global fit.

The signal final state is characterized by 0, 1 or 2 charged leptons, two jets originated by b-quarks and large missing transverse energy - $E_{\text{T}}^{\text{miss}}$ - in the case of neutrino presence. The main backgrounds to the analysis are top pair production ($t\bar{t}$), W and Z +jets production, dibosons (WW, WZ and ZZ), single top and multijets. All the backgrounds with the



Variable	Selection	
Common selection		
p_T^V - Vector Boson Transverse Momentum [GeV]	0-120	> 120
$\Delta R(jet_1, jet_2)$ - Radial Distance between the two Jets	>0.7	($p_T^V > 200$ GeV)
0-lepton selection		
p_T^{miss} - Missing Transverse Momentum [GeV]		> 30
$\Delta\phi(E_T^{\text{miss}}, p_T^{\text{miss}})$ - ϕ between E_T^{miss} and p_T^{miss}	NU	< $\pi/2$
$\min[\Delta\phi(E_T^{\text{miss}}, jet)]$ - ϕ between E_T^{miss} and closest jet		> 1.5
$\sum_{i=1}^{N_{jet=2(3)}} p_T^{jet_i}$ - Jets Transverse Momentum sum [GeV]		> 120 (150)
1-lepton selection		
m_T^W - W Transverse Mass [GeV]	> 180	-
E_T^{miss} [GeV] Missing Transverse Energy	-	> 20
2-lepton selection		
$m_{\ell\ell}$ - Invariant Mass of the Leptons system [GeV]	71-121	

Table 1: Event selection criteria used in the 0- 1- and 2-lepton channel of the W/ZH ($H \rightarrow bb$) analysis. NU stands for not used. This corresponds in fact to the $p_T^{\text{miss}} > 120$ GeV condition for the 0-lepton channel [4].

exception of multijets are obtained through Monte-Carlo (MC) simulation corresponding to the ATLAS Run 1 conditions at $\sqrt{s} = 7$ and 8 TeV and normalized using control regions in the global fit. Here, the principal background normalizations are allowed to vary during the fit to let the data constrain their yields. The single top background is generated separately in the 3 production modes: t-channel, s-channel and Wt-channel. Details about the MC generators used for each process can be found at [4]. The MC does not reproduce accurately enough the multijet process and so a data-driven method is used instead. The signal is generated with different Higgs mass hypothesis ranging from 100 to 150 GeV.

Each analysis channel has an independent event selection in order to maximize the sensitivity as summarized in Table 1. These criteria were designed to maximize the signal to background ratio. The p_T^V -dependent variable cuts provide finer selection and sensitivity optimization. Common to all selections is the requirement of 2 or 3 high transverse momentum jets. The two highest p_T jets have to be identified as originated by b-quarks. For this, the MV1c algorithm is used. MV1c is a Multivariate Analysis (MVA) based algorithm designed to improve b- and c-jets separation. The b-tagging uses 3 levels of tagging cuts of varied tagging efficiency - 50, 70 and 80 % - corresponding to the tight (TT), medium (MM) and loose (LL) b-tagging categories. The analysis is further categorized into two regions of the p_T^V spectra: smaller or larger than 120 GeV.

No charged leptons are required in the 0-lepton channel, one isolated high p_T electron or muon is required in the 1-lepton channel and two oppositely charged electrons or muons are required in the 2-lepton channel. In the case of the 1- and 2-lepton channel, the selected lepton is required to have fired the trigger. In the 0-lepton channel the E_T^{miss} trigger is used.

Jets, electrons and muons are calibrated for MC samples to match the energy or p_T scale and resolution measured from reference data samples. Following this calibration the E_T^{miss} is reevaluated.

MC samples are corrected for b-tagging, and electron and muon reconstruction, identification and trigger efficiency differences with respect to experimental data. A pile-up correction is also applied to MC to correct for data/MC differences in the mean number of interactions per proton bunch crossing. Other corrections are also applied to MC to account for generator level mis-modeling of variables relevant to the analysis as detailed in [4].

The analysis sensitivity is further enhanced by the use of the MVA method Boosted Decision Tree (BDT). After event selection, a BDT is trained to separate signal from background exploring fine correlations between variables. Several BDTs are constructed depending on the analysis categories: 0-, 1- or 2-lepton channels, 2 or 3 jets and p_T^V interval. The BDTs are trained also for each Higgs mass hypothesis. The variable set used as input to the method includes kinematic variables, as the vector boson and jets p_T and the invariant mass of the jets system, and angular variables, as the radial distance between the two jets and the ϕ angle between the vector boson and the jets system. The BDT outputs are exhibited in Figure 1. It can be seen that the signal to background ratio is globally very low but the BDT method produces a powerful discriminant of signal-like events to be given as input to the analysis fit. Data is statistically compatible with expectation within uncertainties.

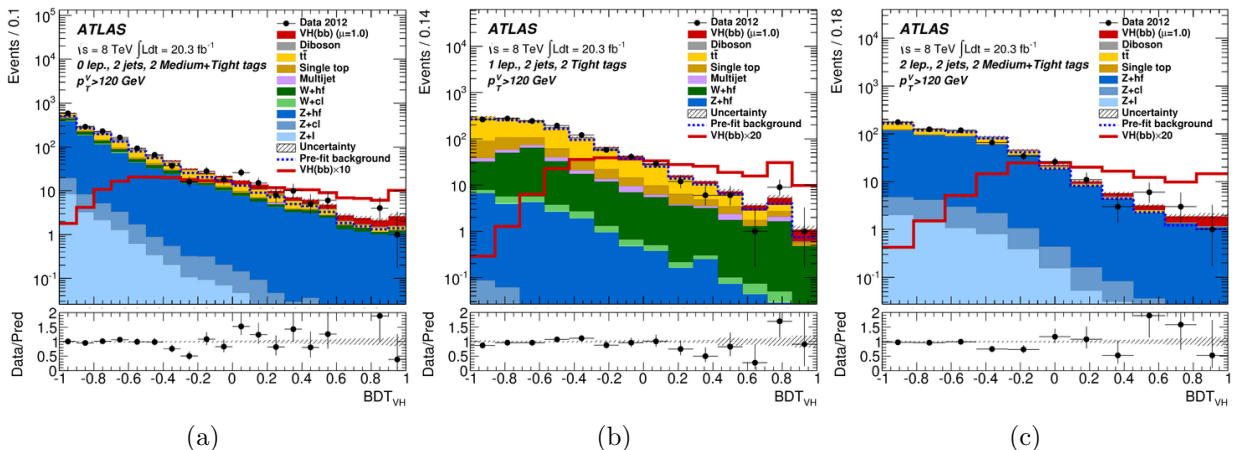


Figure 1: (a) BDT discriminant for the 2 jet 2 b-tag region of the (a) 0-lepton, (b) 1-lepton and (c) 2-lepton channel, observed in data (points with error bars) and expected (histograms). Taken from Ref. [4]

Slightly different selections are designed to construct specific background enriched regions allowing their control and normalization constraint in the final fit. These include the 3 jets regions for $t\bar{t}$ and the 1 b-tag region for $W/Z + \text{jets}$ as exhibited in Figure 2. The BDT distribution is shown in Figure 2(a) from which can be seen the high purity of $t\bar{t}$

events achieved with this control region. The same holds for the W and Z + jets samples as seen in the b-tagging weight (MV1c) distribution in Figures 2(b) and 2(c), respectively. Data and expectation agree within uncertainties.

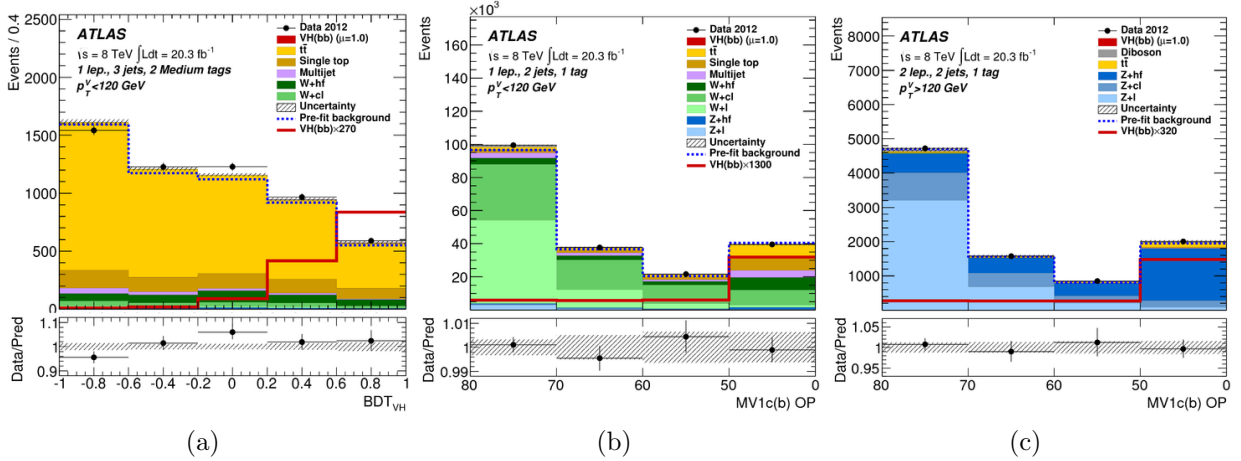


Figure 2: (a) BDT output distribution for the 3 jet 2 medium tag region of the 1-lepton channel and the leading jet b-tag weight (MV1c) distribution for the 2 jet 1 tag region of the (b) 1-lepton channel and (c) 2-lepton channel, observed in data (points with error bars) and expected (histograms). Taken from Ref. [4].

3 Fit Method

A maximum likelihood binned fit is performed simultaneously on the 3 channels using 38 regions. The input distributions are the BDT discriminant for the 2 b-tag signal region as shown in Figure 1 and the leading jet b-tag weight distribution for the 1 b-tag control region. The experimental and systematic uncertainties are included as a set of nuisance parameters and the impact of each contribution on the signal strength uncertainty $\Delta\mu$ is evaluated independently. The largest backgrounds normalizations are allowed to vary during the fit and their scale is constrained by the experimental data.

The analysis procedure and the fit method is validated by the VZ ($Z \rightarrow bb$, $V=W/Z$) yield measurement. The measured VZ signal strength was $\mu_{VZ} = 0.74 \pm 0.09(stat) \pm 0.14(syst)$.

4 Results

The observed (expected) deviation from the background-only hypothesis corresponds to a significance of 1.4 (2.6) σ . The 3 channel combined signal strength is found to be $\mu = 0.52 \pm 0.32(stat) \pm 0.24(syst)$ for a Higgs boson mass of 125.36 GeV. This result and the 0-, 1- and 2-lepton channels individual signal strength is shown in Figure 3(a). The

observed and expected 95 % confidence level on the $\sigma_{W/ZH} \times BR_{H \rightarrow bb}$ upper limits is shown as a function of the Higgs mass in Figure 3(b).

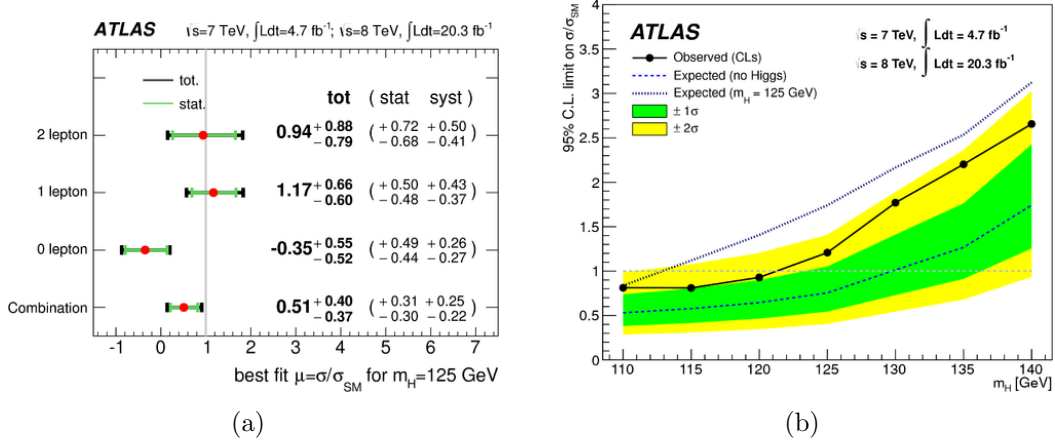


Figure 3: (a) Signal strength μ for 0-, 1- and 2-lepton channels and combined channels result. (b) Observed and expected 95 % confidence level on the $\sigma_{W/ZH} \times BR_{H \rightarrow bb}$ upper limits. Taken from Ref. [4]

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References

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