Search for the Standard Model Higgs boson decaying to b quark with CMS experiment

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A search for the standard model (SM) Higgs boson decaying to bottom quarks pairs is presented. Two production channels have been analyzed: vector-boson fusion and associated production with a vector boson decaying to leptons. The search is performed on data collected with the CMS detector at LHC during 2011 and 2012, at center-of-mass energies of 7 and 8 TeV, corresponding to integrated luminosities of about 5. fb^{-1} and 19.0 fb^{-1}, respectively. A 95% confidence level upper limit of 1.79 (0.89) times SM Higgs boson cross section has been observed (expected) at a Higgs boson mass of 125 GeV. An excess of events is observed above the expected background with a local significance of 2.2 standard deviations, which is consistent with the expectation from the production of the SM Higgs boson. The signal strength corresponding to this excess, relative to that of the SM Higgs boson, is 0.97 ± 0.48.

1 Introduction

In 2012, CMS [1] and ATLAS collaborations have observed a Higgs boson in the $\gamma\gamma$, ZZ, WW decay channels and its mass is about $m_H \approx 125\,\mathrm{GeV}$ [2, 3]. More recently, an evidence of the decay of the Higgs boson to a τ pair has been presented [4, 5]. This paper presents the search performed by CMS for the standard model (SM) Higgs boson decaying to bottom quarks, one of the most important decay channels not yet seen [6, 7].

Although the Higgs boson decay to b quark has a high branching ratio, the channel has a low sensitivity due to the large QCD background. Indeed the b-quark QCD production cross section is some 10^8 times larger than the Higgs boson cross section. In order to cope with such a large background, the topologies of two distinctive production modes have been exploited: the vector-boson associated production (VH) and the vector-boson fusion (VBF). These production modes have about one tenth of the cross-section of the gluon-gluon fusion dominant mode, but their topologies are useful to reduce the background.

2 Signal topologies

In the VH production, only the leptonic decays of the vector bosons are considered. Here, the topology is defined by the presence of two b jets from the Higgs boson decay, and at least one isolated charged lepton or large missing transverse energy (MET). These requirements make the QCD background negligible.

The VBF signal, is characterized by the presence of two b jets from the Higgs boson decay and two energetic quark-jets with a large η separation. No gluons participate in the interaction, so a low additional hadronic activity is expected. Nevertheless, in this channel the QCD background remains the main background.

3 Signal and background regions

The main processes that can simulate the VH signal topology are: W/Z + jets and $t\bar{t}$ production. Their shapes are taken from simulation whereas their normalizations are data-driven. The analysis is divided in six sub-channels, according to the vector-boson decay mode: $W \rightarrow e\nu\,,\mu\nu\,,\tau\,(1-\text{prong})\nu$ and $Z \rightarrow ee\,,\mu\mu\,,\nu\nu$. In addition, the channels are binned in two or three vector-boson p_T bins. In each bin a signal region is defined cutting on: jet kinematic variables, b-tagging discriminants, lepton momentum and/or MET, number of additional leptons and jets. Inverting some cuts, up to five control regions are defined for $t\bar{t}$ and W/Z + heavy/light quark jets backgrounds. They are used to evaluate up to seven scale factors to apply to $t\bar{t}$ and W/Z + 0/1/2b-jets background normalizations.

The main background in the VBF analysis is the multi-jet QCD production. This background is estimated directly from data. Minor backgrounds are W/Z + jets and $t\bar{t}$ productions and they are taken from simulation. The signal regions are defined using an Artificial Neural Network (ANN). It is trained to separate the signal from the backgrounds, using simulations. With the exception of the b-jets kinematic it exploits the most discriminants variables: $\Delta\eta$ between the most forward/backward jets, b-tagging discriminants and additional hadronic activity in the event. Five signal regions are defined using the ANN output, as shown in Figure 1. In each region the background and the signal yield are obtained with a fit to the $b\bar{b}$ jet mass distribution. The QCD background is extrapolated from the sidebands using a fifth-degree Bernstein polynomial, while the signal and the minor backgrounds shapes and are taken from simulations.

4 Multi BDT (VH)

In order to reduce the background in VH analysis, three specialized BDT are trained to reject the $t\bar{t}$, W/Z + jets and WW/WZ/ZZ backgrounds. The BDT variables are: Higgs boson candidate mass and p_T, b-tag discriminants, lepton momentum and MET, number of additional leptons and jets, other kinematic variables.

The final multi-BDT score distribution is realized as following. An event rejected by the $t\bar{t}$ BDT gets a score between -1 and -0.5. The other events that fail the W/Z + jets BDT have a score between -0.5 and 0. Again, the other events that fail the WW/WZ/ZZ BDT have a score between 0 and 0.5. A final BDT is applied to reject all backgrounds and it assigns a score between 0.5 and 1. In this way the combined multi-BDT is more powerful than the classic one-step BDT.

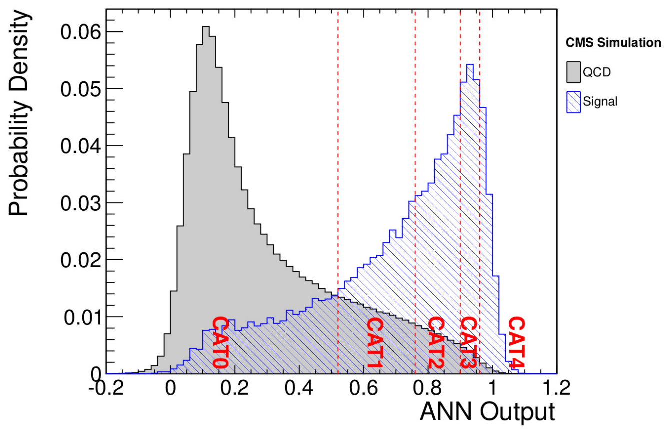

Figure 1: Probability distribution of the ANN output for signal and background, for VBF analysis. The vertical dashed lines define the signal regions used in the analysis.

The last step is the extraction of the signal. In the VH analysis this is obtained with a fit of the multi-BDT score distribution using the shapes from simulation and the data-driven scale factors.

5 Results

In the VH analysis an upper limits of 1.89 (0.95) times the SM Higgs boson cross section at 125 GeV with 95% C.L. has been observed (expected), as shown in Figure 2(a). Corresponding to an excess of events of 2.1 standard deviations and to a signal strength of $\mu = 1.0 \pm 0.5$. The Figure 2(b) shows the distribution of the bb dijet invariant mass for the VH analysis, combining all sub-channels.

In the VBF channel an upper limit of 3.6 (3.0) times the SM Higgs boson cross section at 125 GeV with 95% C.L. has been observed (expected), as shown in Figure 3(a). It corresponds to a signal strength of $\mu = 0.7 \pm 1.4$. The Figure 3(b) shows the bb dijet invariant mass distribution in the most sensitive signal region.

A combination of the two analysis gives a signal strength of $\mu = 0.97 \pm 0.48$. It corresponds to an excess of events of 2.2 standard deviations from the expected background.

6 Conclusions

A search for the SM Higgs boson decaying to bottom quarks has been presented. Two production channels have been studied: the associated production with vector boson decaying to leptons (VH) and the vector-boson fusion (VBF). An excess of events of 2.2 standard deviations at a mass of 125 GeV has been reported that corresponds to a signal strength of $\mu = 0.97 \pm 0.48$.

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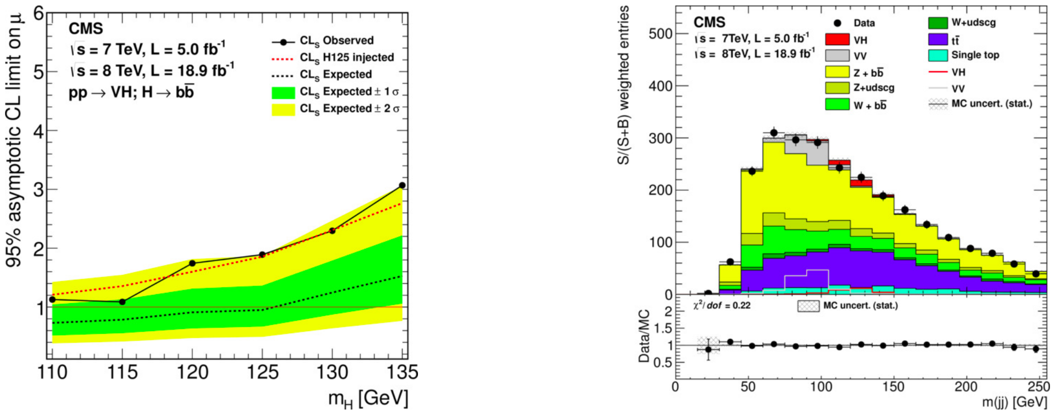
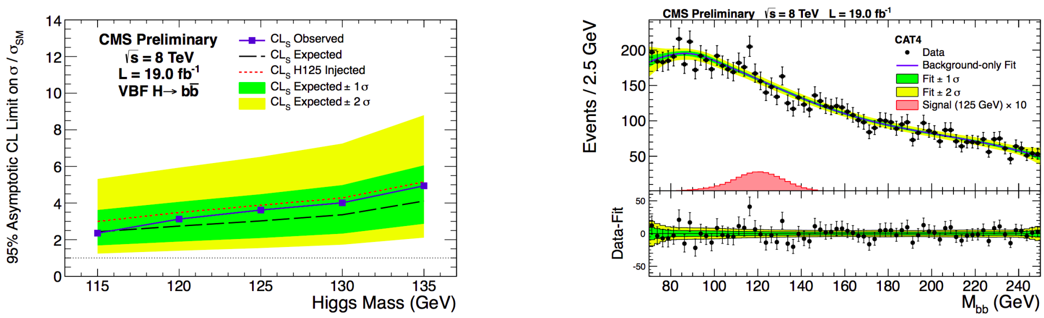


(a) (b)

Figure 2: On the left, the 95% CL upper limits on the signal strength for the SM Higgs boson hypothesis as a function of the Higgs boson mass, for the VH analysis. On the right, the b-jet pair invariant mass distribution in the VH analysis.



(a) (b)

Figure 3: On the right, the b-jet pair invariant mass distribution in the VBF analysis.

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