EPJ Web of Conferences **71**, 00088 (2014)
DOI: 10.1051/epjconf/20147100088

Search for the Higgs boson produced in association with top quarks

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Abstract. Associate production of the Higgs boson with other particles is crucial to evaluate the consistency of the properties of the new discovered particle with the Standard Model (SM) expectations. In particular, associate production of the Higgs boson with a pair of top quarks (ttH) allows to directly access the Higgs-top coupling, which is important to understand if the top quark, given its large mass, plays a special role in the electroweak symmetry breaking mechanism. The most recent CMS results on the search for a Higgs boson produced in association with top quarks, using the full dataset recorded at the LHC from pp collisions at centre of mass energies of 7 and 8 TeV, are presented. The Higgs decays studied cover all major decay channels, such as $b\bar{b}$, $\gamma\gamma$, $\tau\tau$.

1 Introduction

During the three years of data taking, the CMS experiment [1] has performed extremely well, collecting an integrated luminosity of ~ 6 fb^{-1}, at a center of mass energy of 7 TeV and more than $20 fb^{-1}$ at an energy of 8 TeV. With this amount of data, CMS has discovered a new boson, compatible with the Standard Model Higgs boson, with ~125 GeV mass [2][3].

The detailed study of the properties of this new particle is now a fundamental topic in high energy physics. The challenge of LHC in the next year is to understand if this particle is exactly the Standard Model Higgs or if there are additional effects beyond the SM theory to be considered.

In the SM the Higgs boson is responsible through the spontaneous gauge symmetry breaking for the boson masses and contemporary thanks to the Yukawa coupling to fermions also for the fermion masses. To understand the nature of the Higgs boson, it is necessary to measure if its properties. In order to achieve this goal, the exact determination of the Higgs couplings to bosons and fermions is crucial; indeed the value of the couplings can be predicted by the theory and their measurements at collider experiments could prove or deny these predictions.

A disagreement between theory and experiments could be a hint of physics beyond the SM theory, signalling the presence of new particles, new gauge symmetries or simply a different mechanism to give masses to bosons or fermions.

The couplings can be measured by simultaneously probing different Higgs decay final states and production mechanism, whose predicted signal strengths are defined in terms of fermionic and bosonic Higgs couplings.

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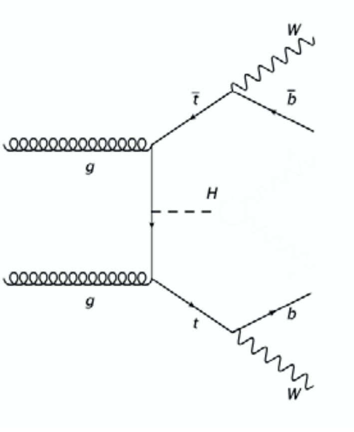

Figure 1. Feynman diagram for ttH production mode.

In these framework the measurement of associate production of the Higgs boson with a pair of top quarks (ttH) is of paramount importance since it is the only way to directly access the Yukawa Higgs-top coupling. The SM prediction for this quantity is $\mathrm{Y_t} = \frac{\sqrt{2}\mathrm{M_{top}}}{\mathrm{vev}} = 1$, and this very natural value could be an hint for a special role of the top quark in the electroweak symmetry breaking mechanism and could also explain why the top is so heavy compared to other particles.

Moreover final states with top and Higgs are also interesting since predicted by many new physics scenarios, such as little Higgs, composite Higgs and extra dimensions.[6][7]

2 ttH searches at the Compact Muon Solenoid experiment

As can be seen from the the Feynman diagram in Fig. 1 the ttH process has a very complex final state from the experimental point of view. The presence of other tagging objects (either b-jets, jets or leptons) in addition to the Higgs boson allows us to effectively reduce the background, reaching a good sensitivity despite the low cross section of this process.

CMS has investigated different combinations of the Higgs and $\mathrm{t\bar{t}}$ decays to exploit the advantages of each channel and obtain the best possible precision. The decay modes analyzed here are:

- H decaying to $\mathrm{b\bar{b}}$, with the $\mathrm{t\bar{t}}$ pair decaying to a lepton and jets or two leptons and jets
- H decaying to $\tau\tau$, with the $\mathrm{t\bar{t}}$ pair decaying to a lepton and jets
- H decaying to $\gamma\gamma$, with the $\mathrm{t\bar{t}}$ pair decaying in both the hadronic and the leptonic channel

As can be seen from this great variety of final states for ttH we need to reconstruct photons, leptons, jets and missing energy, using all the different sub-detectors of the CMS experiment.

2.1 ttH in the $\mathrm{H \rightarrow b\bar{b}}$ channel

In this decay channel we categorize events according to the presence of one or two leptons in the final state, targeting semileptonic or fully leptonic $\mathrm{t\bar{t}}$ decays. Further categorization is performed using number of jets or b-jets in the final state. A complete description of the categories used in this analysis can be found in [4].

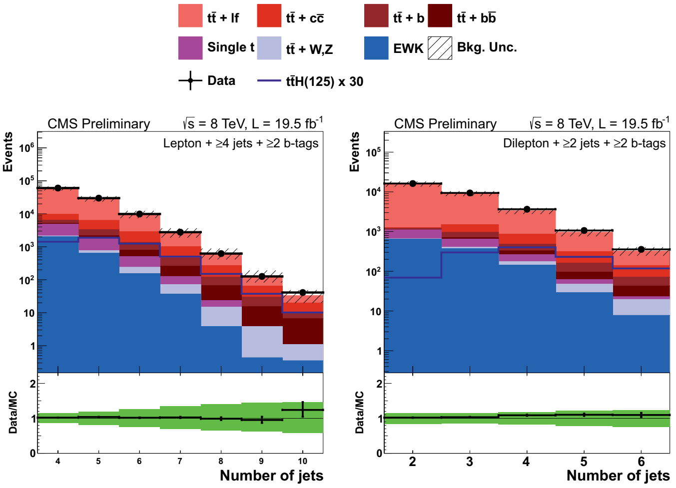

Figure 2. Distribution of number of jets for leptonic (left) and dileptonic channel (right) in the $H \rightarrow b\bar{b}$ channel. Different contributions for Monte Carlo background and signal are shown, data points are superimposed.

As can be seen in Fig. 2, where the distributions for number of jets in semileptonic and dileptonic events are shown, the signal over background ratio increases requiring a higher number of jets (and also b-jets), according to the ttH topology, where two b-jets are always present and additional jets come from W decays.

The main background in this channel is prompt $\mathrm{t\bar{t}}$ production and a multivariate approach is used to discriminate signal from background. Variables related to objects kinematics and b-tag discriminator value are used as input variables to a boosted decision tree (BDT).The BDT output distribution for the two most sensitive categories is shown in Fig. 3.

A fit to the BDT output distribution is performed to extract the number of signal and background events. No significant excess is observed in this decay channel so upper limits are set for both leptonic and dileptonic category. The 95% CL observed (expected) limit on $\mu = \frac{\sigma}{\sigma_{\mathrm{SM}}}$ is 4.9 (4.7) in the leptonic channel and 9.1 (8.2) in the dileptonic one.

2.2 ttH in the $\mathrm{H} \rightarrow \tau\tau$ channel

In the $\tau\tau$ channel we select events with one lepton and at least four jets, two of which tagged as τ-jets. Events are categorized according to the number of jets or b-jets to increase sensitivity; a full description of the categories used can be found in [4].

Hadronic decays of the τ are reconstructed using the Particle Flow algorithm. An MVA discriminant for isolation based on $\sum p_{\mathrm{T}}$ of particles in rings around the τ direction is used.

As in $\mathrm{b\bar{b}}$ channel, tt+jets is the main background and a BDT discriminant is built using input variables related to τ isolation and kinematics. The distribution of this discriminant is shown in Fig. 4. A fit to the BDT output distribution is performed to extract the number of signal and background events. No significant excess is observed in this decay channel so upper limits are set. The 95 % CL observed (expected) upper limit on μ is 13.2 (14.2).

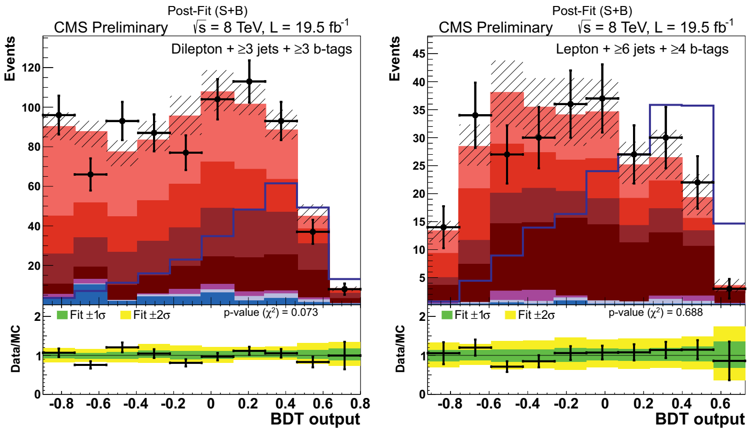

Figure 3. BDT output distribution for one dileptonic category (left) and for one of the leptonic ones (right) in the $H \to b\bar{b}$ channel. Different contributions for Monte Carlo background and signal are shown, data points are superimposed.

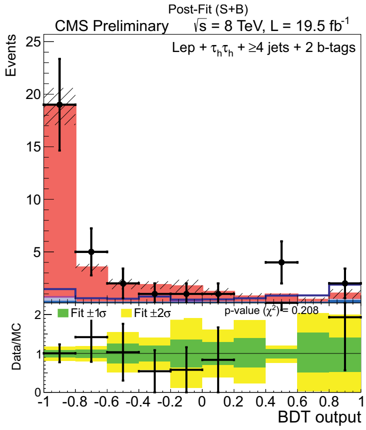

Figure 4. BDT output distribution for one category of the $H \to \tau\tau$ channel. Different contributions for Monte Carlo background and signal are shown, data points are superimposed.

2.3 ttH in the $\mathrm{H} \to \gamma\gamma$ channel

The $\gamma\gamma$ decay channel, even if limited by statistics (the branching ratio of the Higgs boson in two photons is only $\sim 2‰$), has a very distinctive signature compared to other decay channels: two energetic photons, that can be reconstructed with high precision in the electromagnetic calorimeter of CMS. The main advantage of searches in this channel is that we search for a narrow Higgs peak over a falling background in the $\mathrm{M}_{\gamma\gamma}$ distribution. This allows to easily estimate the background in a data-driven way, instead of relying on Monte Carlo simulation.

The analysis is performed splitting the events into two categories (leptonic and hadronic) to match all hadronic and semi-leptonic decays.

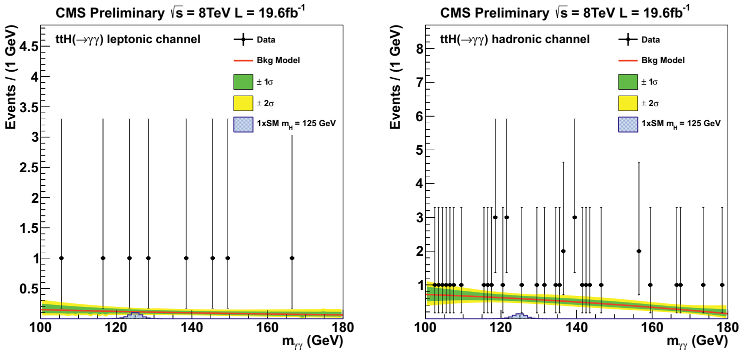

Figure 5. Diphoton invariant mass distribution for candidate ttH events passing the leptonic selection (left plot) and the hadronic selection (right plot) in the $H \to \gamma\gamma$ channel.

Table 1. Summary of observed and expected 95% CL upper limits to the production cross section of a standard model Higgs boson with mass $m_H = 125$ GeV: the observed, expected and expected limit neglecting systematic uncertainties are given for the hadronic channel, the leptonic channel and their combination.

	Observed	Expected	Expected (No Syst.)
Hadronic Channel	6.8	9.2	8.8
Leptonic Channel	10.7	8.0	7.7
Combined	5.4	5.3	5.1

With respect to inclusive searches of H $\to \gamma\gamma$ we can exploit the photon kinematics, since photons coming from ttH are boosted with respect to those produced with the gluon fusion mechanism and background processes. As in other decay channels we require jets and b-jets in the final state to reduce the background, including that coming from other production mechanism. A full description of the event selection can be found in [5].

The diphoton mass distribution for the leptonic and hadronic category is shown in Fig. 5. Monte Carlo signal contributions, data points and fit to the diphoton mass distribution are shown.

No significant excess is observed over background expectations in the $\gamma\gamma$ channel so we can set upper limits combining the two categories. In Table 1 observed and expected upper limit at 95% of confidence level are shown. As can be seen the leptonic category is the most sensitive, and systematics have a low impact since the analysis is statistically dominated.

3 Conclusions

We can combine all different decay channels to achieve the best sensitivity on ttH measurements. As can be seen in Fig. 6 the observed (expected) 95% CL upper limit on μ is 3.4 (2.7) while the best fit value combining all channels is $\mu = 0.74^{+1.34}_{-1.30}$.

This is the most sensitive analysis to ttH production as of today. More can be said with the current amount of data since more final states can be added (i.e. H → WW) and actual analysis can be further improved in the future.

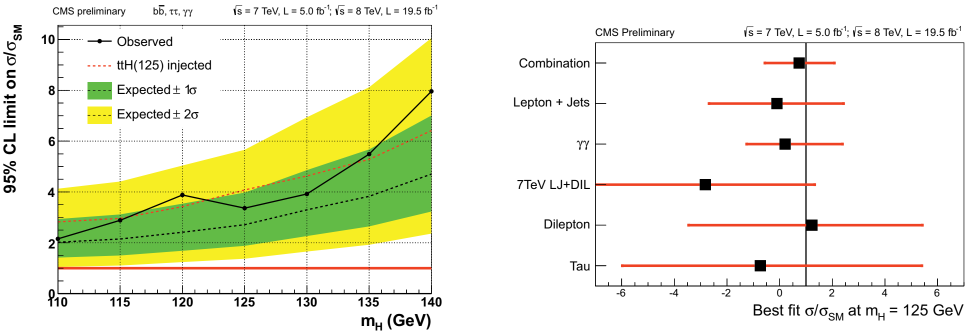

Figure 6. Expected and observed 95 % CL upper limit versus the Higgs boson mass (left) and best fit value on $\frac{\sigma}{\sigma_{SM}}$ for the different decay channels and for their combination.

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