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Observation of $t\bar{t}H$ production at CMS

Carmen Diez Pardos* **on behalf of the CMS Collaboration**
DESY Hamburg
E-mail: carmen.diez@desy.de

Recent searches for the production of a Higgs boson (H) in association with a top quark pair ($t\bar{t}H$) by the CMS Collaboration are presented. They are performed using 36 fb^{-1} of LHC pp collision data at $\sqrt{s}$=13 TeV collected in 2016. The analyses exploit several Higgs boson decay channels, together with different top quark decay modes. The results combined with previous searches yield the first observation of the $t\bar{t}H$ production process. An excess of events is observed with a significance of 5.2 standard deviations over the expectation from the background-only hypothesis. The combined best fit signal strength normalized to the standard model prediction is $1.26^{+0.31}_{-0.26}$.

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*Speaker.

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The associated production of a Higgs boson with a top quark pair ($t\bar{t}H$) is the best direct probe of the top quark - Higgs boson Yukawa coupling with minimal model dependence, which was a missing vital element to verify the SM nature of the discovered Higgs boson. A measurement of the $t\bar{t}H$ production cross section also has the potential to distinguish the SM Higgs boson mechanism from alternative mechanisms to generate fermion mass. The observation of $t\bar{t}H$ and the measurement of the coupling is amongst the major goals of the physics programme for the LHC Run 2. Here, the most recent results by the CMS experiment [1] and their combination with the Run 1 results are presented.

Several topologies depending on the Higgs boson and $t\bar{t}$ decays are exploited. The Higgs boson decays considered in the searches involved final states with photons, bottom quark-antiquark pairs or leptons via WW, ZZ, and $\tau\tau$. Top quarks decay almost exclusively via the $t \rightarrow bW$. Thus, $t\bar{t}$ signatures can be classified according to the combinatorics of the decay of the W bosons, either to a quark and an antiquark or to a charged lepton and its associated neutrino.

The $H \rightarrow b\bar{b}$ decay channel has the largest branching fraction (for a 125 GeV Higgs boson) and precisely defined couplings in both production (top quarks) and decay (b quarks). However, it is affected by overwhelming background from $t\bar{t}$+jets, and especially, irreducible background from $t\bar{t}b\bar{b}$. CMS performed the search considering all decay channels of the $t\bar{t}$ system [2, 3]. Events are identified by the presence of exactly zero, one or two isolated leptons and categorised depending on the number of jets and/or b-tagged jets. In the single-lepton channel, artificial neural networks (NN) are employed to perform a multiclassification of an event as either signal or any of five different $t\bar{t}$+jets background processes. Events are consequently subcategorised by the most-probable process, and the corresponding NN classifier output is used as final discriminant. An example in shown in Fig. 1 (left). In the dilepton channel, classification boosted decision trees (BDT) and the output of a matrix-element-method (MEM) are used as final discriminant depending on the category based on the number of b-jets. In the fully hadronic analysis, the MEM discriminant is used to extract the signal in the three analysis categories, based on the number of jets. In this case, the main background source arises from multijet events. The best fit values μ (the ratio of the measured $t\bar{t}H$ signal cross section to the SM expectation) are summarised in Fig. 1 (middle and right).

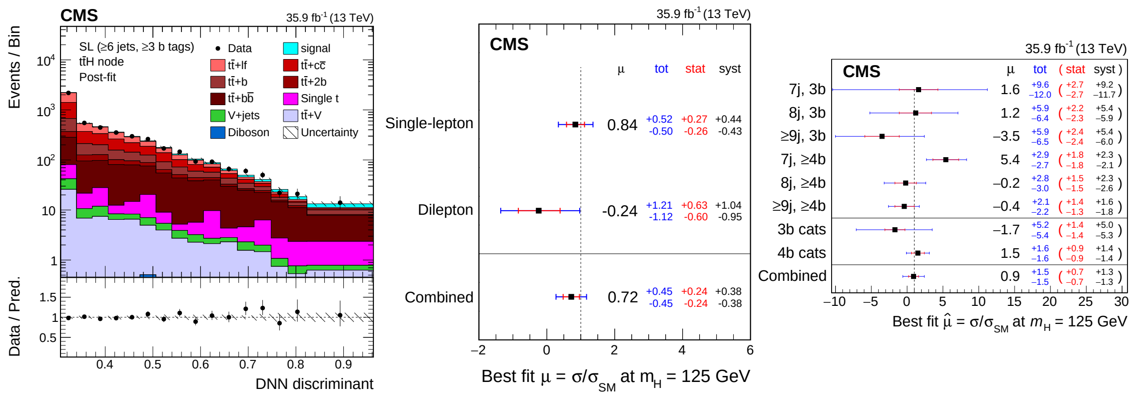

Figure 1: Left: Example of a final DNN discriminant in the single-lepton channel after the fit to data in a jet-process category [2]. Middle and Right: Best fit value of the signal strength modifier, $\mu_{t\bar{t}H}$, with its 1 and 2 standard deviation confidence intervals, for the individual decay channels in the leptonic [2] and fully hadronic searches [3], respectively.

The tt̄H multilepton analysis selects events with jets and leptons compatible with top quark decays and three decay channels of the Higgs boson: ZZ, WW, and $\tau\tau$ [4]. Events are categorised based on the number of leptons and hadronic τ candidates and further divided depending on the lepton flavour and number of b-tagged jets. The major irreducible background processes are tt̄ produced in associated with a W or Z boson, and diboson events. The largest source of reducible background arises from non-prompt leptons (or fake τ) in tt̄+jets events. Depending on the category, the total number of events, BDT and/or MEM discriminants are used as the final distributions to separate signal from background events. An example is shown in Fig. 2 (left) for the category with 2 same-sign leptons and a hadronic τ. The best fit values of the signal strength are summarised in Fig. 2 (right). The significance of the tt̄H signal over the background-only hypothesis is 3.2 standard deviations.

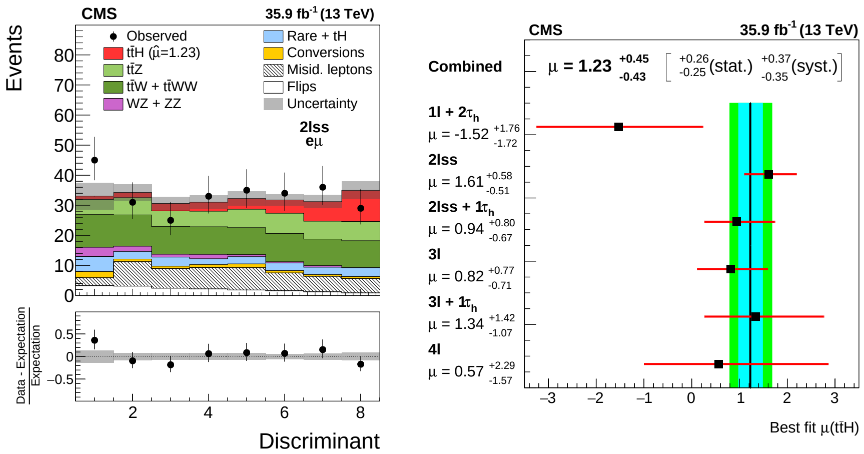

Figure 2: Left: Example of a final discriminant after the fit to data in a category with 2 same-signed leptons (eμ). Right: Signal strength measurements in the individual multilepton channels and their combination [4].

The search for tt̄H in the H$\to$ZZ$\to 4\ell$ decay channel with 2016 data is performed in a dedicated category of Ref. [5]. The selection requires two pairs of opposite-charge electrons or muons and at least 4 jets and at least 1 b-tagged jet, or at least 1 additional lepton. The signal strength for the excess of events observed in the Higgs boson peak region is extracted from a multidimensional fit that relies on the four-lepton invariant mass and a kinematic discriminant. This channel is also exploited in an analysis performed using the 2017 data [6].

The search in the tt̄H(H $\to \gamma\gamma$) channel is performed in a dedicated category of the broader $H \to \gamma\gamma$ measurement [7]. Events are selected if they contain two isolated photons compatible with the Higgs boson mass and at least one lepton, at least two jets and at least 1 b-tagged jet, or at least 3 jets and 1 or more b-tagged jets. The signal is extracted from a fit to the diphoton invariant mass spectrum and results in $\mu = 2.2 \pm 0.9$, corresponding to a 3.3 standard deviation significance over the background-only hypothesis.

A combination of all the tt̄H analyses with 2016 data and the analogous searches carried out with the 7 and 8 TeV data is performed [8]. The inclusive signal theory and some background theory uncertainties are treated as correlated sources of uncertainty among the Run 1 and Run 2 data sets, while experimental uncertainties are largely uncorrelated. The results of the tt̄H combination are summarised in Fig. 3. The sensitivity of the combination is slightly dominated by systematic uncertainties, in particular the uncertainty in the inclusive $t\bar{t}$H cross section, the $t\bar{t}$H+heavy-flavour background prediction, the lepton efficiencies and misidentification, b tagging efficiencies, and the limited size of the simulated samples.

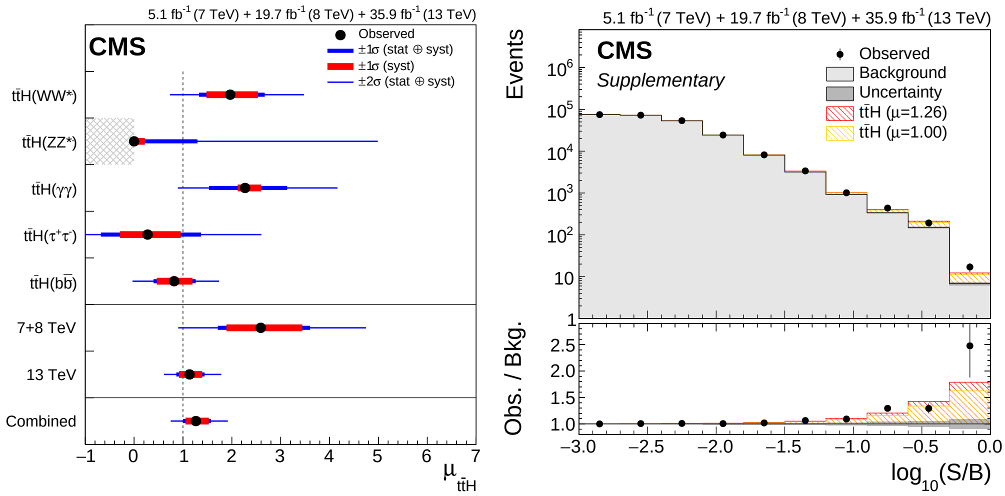

Figure 3: Left: Best fit value of the signal strength modifier, $\mu_{t\bar{t}H}$, with its 1 and 2 standard deviation confidence intervals, for the individual decay channels considered (upper section), the combined result for 7+8 TeV and for 13 TeV alone (middle section), and the overall combined result (lower section). Right: Distribution of all events as a function of log10 S/B, where S and B are the expected signal (with $\mu_{t\bar{t}H}$= 1.0) and background yields respectively, evaluated for each bin in the combined analysis. The yields are determined using the values of the nuisance parameters after the fit to data [8].

This result represents the first observation of the $t\bar{t}$H production with a significance of 5.2 standard deviations above the background-only hypothesis, at a Higgs boson mass of 125.09 GeV. The measured production rate is consistent with the SM prediction within one standard deviation. This measurement establishes the tree-level coupling of the Higgs boson to an up-type quark.

References

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