Available on CMS information server

CMS CR -2024/300

The Compact Muon Solenoid Experiment

Conference Report

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

30 October 2024 (v4, 17 November 2024)

Measurement of the ttH production cross-section in multi-leptonic final states in pp collisions at a centre-of-mass energy of 13 TeV with the CMS detector

Mohammad Mobassir Ameen for the CMS Collaboration

Abstract

The Yukawa coupling of the Higgs boson to the top quark is a pivotal parameter in the Standard Model, providing insights into fundamental particle interactions. This coupling is investigated through the production processes of Higgs bosons in association with top quarks, including tH and ttH. Utilizing proton-proton collision data at a centre-of-mass energy of 13 TeV, this study encompasses an integrated luminosity of up to 137 fb^{-1} from the data period 2016 to 2018. Advanced machine learning methods enhance the sensitivity of distinguishing signals from the background and separating tH and ttH signals. The observed production rates for these processes are analyzed, with tH showing a significance of 1.38σ and ttH demonstrating a significance of 4.73σ. The coupling y_t is constrained at a 95$\%$ confidence level within specific intervals. The sensitivity results will be presented, focusing on final states involving multi-lepton configurations.

Presented at *PPC2024 International Conference on Interconnections between Particle Physics and Cosmology*

Measurement of the ttH production cross-section in multi-leptonic final states in pp collisions at a centre-of-mass energy of 13 TeV with the CMS detector

Mohammad Mobassir Ameen on behalf of the CMS collaboration[1]

IIT Madras, Chennai, Tamil Nadu, 600036, India
mohammad.mobassir.ameen@cern.ch

Abstract. The Yukawa coupling of the Higgs boson to the top quark is a pivotal parameter in the Standard Model, providing insights into fundamental particle interactions. This coupling is investigated through the production processes of Higgs bosons in association with top quarks, including tH and ttH. Utilizing proton-proton collision data at a centre-of-mass energy of 13 TeV, this study encompasses an integrated luminosity of up to 137 fb^{-1} from the data period 2016 to 2018. Advanced machine learning methods enhance the sensitivity of distinguishing signals from the background and separating tH and ttH signals. The observed production rates for these processes are analyzed, with tH showing a significance of 1.38σ and ttH demonstrating a significance of 4.73σ. The coupling y_t is constrained at a 95% confidence level within specific intervals. The sensitivity results will be presented, focusing on final states involving multi-lepton configurations.

Keywords: CMS, Yukawa coupling, Higgs Boson, Multileptons.

1 Introduction

The discovery of the Higgs boson at CERN [1, 2] marked a significant milestone in particle physics, prompting intense scrutiny of its properties, particularly its interactions with other particles. Among these, the top quark, being the heaviest known particle, plays a pivotal role due to its strong coupling to the Higgs boson. This coupling is crucial for understanding fundamental processes such as electroweak symmetry breaking (EWSB). Measurement of the top quark's coupling to the Higgs boson can be achieved through various production modes, notably through associated production with top and antitop quark pairs (ttH process). This process allows for a direct, tree-level measurement of the top-Higgs Yukawa coupling, offering insights into fundamental interactions at the highest energy scales accessible at the Large Hadron Collider (LHC).
In addition to direct measurements via associated production, indirect measurements are possible through gluon-gluon fusion (ggF), the dominant Higgs

production mechanism. Such measurements assume Standard Model (SM) contributions only, providing a complementary view that can reveal discrepancies indicative of new physics, such as contributions from dimension-six operators affecting ggH loop vertices [3].

This proceeding focus on the measurement of the ttH and tH production rate at $\sqrt{s} = 13$ TeV at the CMS experiments [4], where the Higgs decays to WW, ZZ, and $\tau\tau$ pairs [5]. These measurements are presented in terms of signal strengths relative to SM predictions and constraints on Yukawa coupling modifiers within the $\kappa-$ framework, at a confidence level of 95%. These efforts aim to not only confirm SM predictions but also to probe potential deviations that could hint at new physics beyond the Standard Model.

2 Event selection

Based on the number of leptons and τ_h candidates, the analysis considers ten exclusive channels: $2\ell ss + 0\tau_h$, $3\ell + 0\tau_h$, $2\ell ss + 1\tau_h$, $1\ell + 1\tau_h$, $0\ell + 2\tau_h$, $2\ell os + 1\tau_h$, $1\ell + 2\tau_h$, $4\ell + 0\tau_h$, $3\ell + 1\tau_h$, and $2\ell + 2\tau_h$. Each channel targets specific combinations of Higgs and top decays. For instance, the $1\ell + 1\tau_h$ and $0\ell + 2\tau_h$ channels focus on $H \to \tau\tau$ with hadronic top decays, while the others target a combination of $H \to WW$, $H \to \tau\tau$, and $H \to ZZ$ with semi-leptonic or leptonic top decays.

Event selection begins at the trigger level, using a combination of single-, double-, and triple-lepton triggers, as well as lepton+tau and double-tau triggers. The selected events are required to have offline-reconstructed electrons, muons, and taus that match the trigger objects. The offline selection criteria for p_T are chosen to be above the corresponding trigger thresholds, and the charge of the leptons and τ_h must match the expected signature for ttH and tH signals. In $2\ell ss + 0\tau_h$ and $2\ell ss + 1\tau_h$, the requirement of same-sign (ss) lepton pairs suppresses backgrounds, particularly from $t\bar{t}$+jets with dileptonic top decays. In contrast, the $2\ell os + 1\tau_h$ channel targets opposite-sign (os) lepton pairs. The number of jets and b-tagged jets is used to enhance signal sensitivity, with a minimum requirement of at least one tight or two loose b-tagged jets.

The jet multiplicity N_j is required to be consistent with the expected jet counts for ttH or tH production, considering $N_j = 10 - 2N_\ell - 2N_\tau$ for ttH and $N_j = 7 - 2N_\ell - 2N_\tau$ for tH, where N_ℓ and N_τ are the numbers of leptons and hadronic tau decays. Additional selection criteria are applied based on missing transverse energy (p_T^{miss}) and dilepton mass, including a ZZ-boson veto to suppress backgrounds from $t\bar{t}Z$, WZ, and Drell–Yan production. Also, background contributions from Drell–Yan and low-mass resonances are reduced by applying a threshold on a linear discriminant, which combines p_T^{miss} and jet-related observables. Events with low dilepton mass are vetoed to minimize contamination from quarkonium and other non-Higgs-like processes. The details of the event selections are described in Reference [5].

3 Background study

After passing the event selection criteria, background processes generally dominate over the expected ttH and tH signal rates, especially in channels with lower lepton and tau multiplicities. To differentiate signal from background, a maximum-likelihood (ML) fit is applied to the distribution of specific observables, chosen to maximize sensitivity based on studies performed with simulated samples of signal and background events. More explicitly, ANN and BDT are used to sepearte signal from background across various channels. Instead of imposing tighter events selection criteria, use of these ML technique retains events with low signal-to-background ratios, which can still contribute valuable information when fitted, enhancing overall sensitivity by increasing the signal yield and constraining background estimates. The background estimation for this analysis can be classified into three major categories based on their source or origin: reducible backgrounds, charge flip backgrounds, and irreducible backgrounds.

1. Reducible/Fake Backgrounds: Reducible backgrounds predominantly arise from jets that fake the final state particles, such as photons, leptons, hadronic τ, or b-jets used in the searches. These backgrounds are typically estimated from data or simulation, with their yield and shape corrected using background-rich sidebands in the data. In the ttH multilepton search, the probability of a jet passing tight selections is measured in a multi-jet enriched sideband (referred to as the measurement region). This probability is then applied to reweight another data sideband that shares the same selections as the signal region but has relaxed lepton identification requirements (referred to as the application region). The reweighted sideband is utilized to estimate the fake background across all channels.

2. Charge Flip Background: Charge flip backgrounds arise from the misidentification of lepton charge within the detector, which can occur due to inelastic scattering or missing hits in the tracking system. This background is measured from data using the "Tag and Probe" method [6] in $Z \to \ell\ell$ events, analyzed in bins of lepton transverse momentum and absolute pseudorapidity. For electrons, the charge flip probability is approximately 10^{-3}, while it is generally found to be negligible for muons.

3. Irreducible Backgrounds: Irreducible backgrounds are caused by genuine physical processes that yield the same final state particles as those in the signal process. These backgrounds are usually estimated via simulation, and their modeling is validated using control regions in the data. Key examples of irreducible backgrounds include ttV (V = W or Z boson)and WW/WZ/ZZ production processes, which can mimic the signature of the ttH signal.

4 Results and Summary

The results presented at this conference, based on the full Run-2 datasets collected by the CMS detector at a center-of-mass energy of $\sqrt{s} = 13$ TeV, are

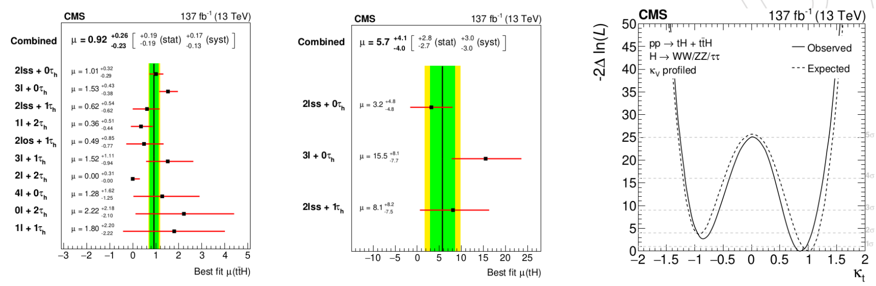

Fig. 1. Extracted signal strengths μ in units of SM expectation, Left: for ttH signal process, Middle: for tH signal process and Right: for Higgs-top coupling modifier (κ_t) for ttH+tH [5].

shown in Figure 1. The measured ttH production cross section, expressed in terms of the signal strength, is consistent with the Standard Model (SM) prediction, while the tH results exhibit a larger uncertainty. The observed significance of the ttH signal is 4.7σ, with an expected significance of 5.2σ under the SM assumption. The observed significance of the tH signal is 1.4σ. Additionally, the measurement of the Yukawa coupling y_t, expressed as the ratio $\kappa_t = y_t/y_t^{SM}$, is consistent with the ranges $-0.9 < \kappa_t < 0.7$ or $0.7 < \kappa_t < 1.1$, showing no significant deviations from the SM expectation.

References

[1] Serguei Chatrchyan et al. "Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC". In: *Physics Letters B* 716.1 (2012), pp. 30–61.

[2] Georges Aad et al. "Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC". In: *Physics Letters B* 716.1 (2012), pp. 1–29.

[3] Raquel Gomez-Ambrosio. "Studies of dimension-six EFT effects in vector boson scattering". In: *The European Physical Journal C* 79 (2019), pp. 1–18.

[4] S. Chatrchyan et al. "The CMS Experiment at the CERN LHC". In: *JINST* 3 (2008), S08004. DOI: 10.1088/1748-0221/3/08/S08004.

[5] Albert M Sirunyan et al. "Measurement of the Higgs boson production rate in association with top quarks in final states with electrons, muons, and hadronically decaying tau leptons at $\sqrt{s} = 13$ TeV". In: *Eur. Phys. J. C* 81.4 (2021), p. 378. DOI: 10.1140/epjc/s10052-021-09014-x. arXiv: 2011.03652 [hep-ex].

[6] Georges Aad et al. "Measurement of the inclusive $W^{\pm}$ and Z/gamma cross sections in the electron and muon decay channels in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector". In: *Phys. Rev. D* 85 (2012), p. 072004. DOI: 10.1103/PhysRevD.85.072004. arXiv: 1109.5141 [hep-ex].