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The Compact Muon Solenoid Experiment

Conference Report

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

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Recent measurements of Higgs boson properties in the diphoton decay channel with the CMS detector

Prafulla Saha for the CMS Collaboration

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Recent measurements of Higgs boson properties in the diphoton decay channel with the CMS detector

Prafulla Saha[1] (for CMS Collaboration)

National Institute of Science Education and Research, HBNI, Bhubaneswar, India
`prafulla.saha@niser.ac.in`

Abstract. A comprehensive analysis on the $H \rightarrow \gamma\gamma$ signature, including all possible SM Higgs boson production modes using the full Run 2 dataset of $137 fb^{-1}$ recorded by the CMS experiment has been presented here. The present analysis improves the sensitivity by categorizing the signal events based on different Higgs production mechanisms: Gluon-Gluon fusion (GGH), Vector Boson Fusion (VBF), Vector Boson associated production (VH) and top quark associated production (ttH, tH). Combining all channels, the Higgs boson signal strength is measured to be $1.02^{+0.11}_{-0.09}$ with respect to the corresponding SM predictions.

Keywords: Compact Muon Solenoid, Standard Model

1 Introduction

The Higgs boson has been discovered by the ATLAS and CMS experiments in 2012 during Run1 of LHC operation. However analyzing a larger volume of LHC dataset collected by the CMS detector from 2016 to 2018 at a higher center of mass energy ($\sqrt{s}$ = 13 TeV) is expected to shed more light on the Higgs boson properties and would improve the corresponding measurement sensitivity. The SM Higgs boson can be produced at the LHC through different production mechanisms such as Gluon-Gluon fusion (GGH), Vector Boson Fusion (VBF), Vector Boson associated production (VH) and top quark associated production (ttH, tH). The analysis presented here targets different production modes of the SM Higgs boson in separate categories which are further splitted into various kinematic regions. Such a strategy enables to perform the fine-grained measurements for individual Higgs production modes in various kinematic regions to enable measurements within the simplified template cross section(STXS) framework[2]. Moreover this kind of measurement reduces the theoretical uncertainties that are directly folded into the measurements and provide a common framework for the measurement combining with different decay channels.

In SM, Higgs boson decaying within two photon has a very small branching ratio of 0.023%, However, in the CMS detector $H \rightarrow \gamma\gamma$ signature can easily be triggered and provides relatively clean signal having the diphoton invariant mass resolution of ∼1-2%.

2 Analysis Strategy

The analysis is based on the $35.9fb^{-1}$, $41.5fb^{-1}$, and $59.4fb^{1}$ of proton-proton collision data(at$\sqrt{s} = 13TeV$) recoreded with the CMS detector during the 2016, 2017 and 2018, respectively. Simulated signal samples, corresponding to the different Higgs boson production mechanisms, are generated using MADGRAPH5_aMC@NLO (version 2.4.2). The analysis categories are constructed where the narrow signal peak is distinguishable on top of the falling background in diphoton invariant mass distribution. Since the main probe is the photon in the events, the photons are reconstructed with the energy deposits in the electromagnetic calorimeter(ECAL) not associated with the charge particle tracks. Because of imperfect containment of electromagnetic shower and the energy loss due to the converted photons, a multivariate regression technique is trained on the simulated photon to correct the photon energy. Further the additional disagreement between the data and MC is corrected simultaneously in bins of $|\eta|$, showershape variable(R_9) and LHC fill. The selection of two photons from the same vertex has a significant impact on the diphoton mass resolution. Event vertex identification algorithm uses a multivariate analysis approach with boosted decision trees(BDT) considering observables related to tracks recoiling against the diphoton system. Finally, the selected vertex is chosen to be within the 1cm in position along beam axis(z) and is found to have negligible impact on the diphoton mass resolution. The vertex identification algorithm is validated with the simulated $Z \to \mu\mu$ events. Photons in events passing the preselection criteria are further required to satisfy a photon identification criterion based on a BDT trained to separate genuine ("prompt") photons from jets mimicking a photon signature. This photon identification BDT is trained with simulated sample of γ+jet events, where prompt photons are used as the signal while jets are used as the background.

3 Event Categorisation

The analysis is designed to separate different Higgs production modes such as tH, ttH, VH, VBF, ggH. All the analysis categories require two preselected leading photons which satisfy $p_T^{\gamma_1} > m_{\gamma_1\gamma_2}/3$ and $p_T^{\gamma_2} > m_{\gamma_1\gamma_2}/3$ respectively while the diphoton invariant mass falls in range of 100GeV to 180GeV. Depending upon the associated particles and their decay modes, additional selections are applied in leptons, jets, missing transverse energy etc. In the ggH categorisation the events are assigned to an STXS region using a multiclass BDT, which predicts the probability that a diphoton events belongs to a given STXS bin. Furthermore, another BDT training is performed to reject non-Higgs background events entering ggH categorisation. Similarly VBF, VH Hadronic, VH MET, ZH Leptonic, WH Leptonic categorisation also use BDT based on the respective signal characteristics. The Higgs production associated with single top quark(tHq) and a pair of top quark(ttH) have very similar final state topologies. Therefore a dedicated deep neural network(DNN) has been designed to separate tHq and ttH events along with separate BDTs to reject Non-Higgs background events in tHq and ttH categories.

4 Signal and Background Model

Signal processes are modelled with the MC signal samples passing the dedicated category and the $m_{\gamma\gamma}$ distributions are fitted using a sum of most five Gaussian functions. The background processes are modelled using $m_{\gamma\gamma}$ distribution from data between $m_{\gamma\gamma} < 115$ and $m_{\gamma\gamma} > 135$. A set of functions: exponential functions, Bern-stein polynomials, Laurent series and power law functions are used to fit the $m_{\gamma\gamma}$ distribution for the background processes. The discrete profiling method[5] has been used to estimates the systematic uncertainty associated with choosing a particular function for fit. A F-test[3] is performed in the signal model to find the best order of the Gaussian fit to simulated signal events and in the background model for each family of functions to find the order of the polynomial to be used. The signal and the background model are shown in Fig. 1

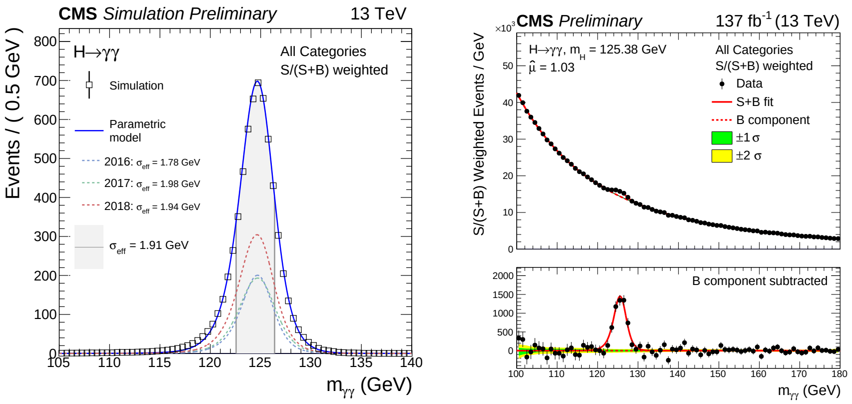

Fig. 1. The left side plot is the signal model of all year together plotted with blue line. The grey shaded area shows the σ eff. value (half the width of the narrowest interval containing 68.3% of the invariant mass distribution). Right side plot is the background model, Data points (black) and signal-plus-background model fit for the sum of all categories. The bottom panel shows the residuals after subtraction of this background component.

5 Result

The signal strength, μ, is defined as the ratio of the observed product of the Higgs boson cross section and diphoton branching fraction to it's SM expectation. To extract the results, simultaneous binned maximum likelihood fits are performed to the $m_{\gamma\gamma}$ distributions for all analysis categories, in the mass range $100 < m_{\gamma\gamma} < 180$ GeV. A likelihood function is defined for each analysis category using analytic models to describe the $m_{\gamma\gamma}$ distributions of signal and background events, with nuisance parameters to account for the experimental and theoretical systematic uncertainties. The signal strength of different Higgs boson production mode and the cross section times branching ratio for different STXS bins are shown in Fig. 2. Combining all Higgs boson production modes, the Higgs boson signal strength is measured to be $1.02^{+0.11}_{-0.09}$ with respect to the corresponding SM predictions.

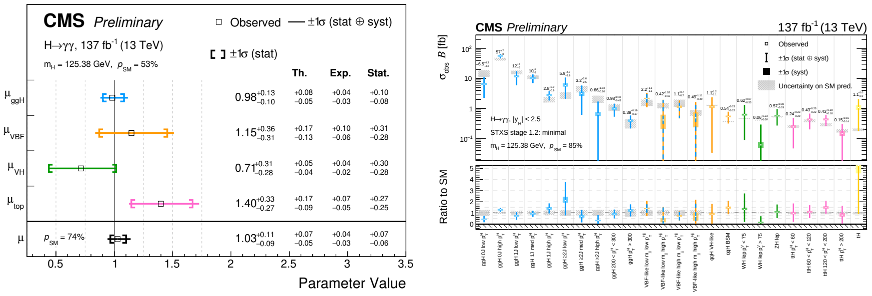

Fig. 2. The left plot is the observed results of best fit signal strength with respective 1σ uncertainty for four Higgs production modes. In the right side plot the observed best fit cross sections are plotted along with the respective 68% confidence level intervals in different STXS bins .

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