Search for the lepton-flavor violating decay of the Higgs boson and additional Higgs bosons in the $e\mu$ final state at $\sqrt{s} = 13$ TeV within CMS

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The search for lepton-flavor violating decays of the Higgs boson to an electron-muon pair using data from proton-proton collisions at $\sqrt{s} = 13$ TeV collected by the CMS experiment at the LHC is presented. The dataset corresponds to an integrated luminosity of $138 fb^{-1}$. No significant excess of events is observed for the 125 GeV Higgs. This analysis leads to the most stringent upper limits at 95% confidence level so far on the branching fraction of the 125 GeV Higgs boson decaying into an electron and a muon, with an observed (expected) limit of 4.4 (4.7)$\times 10^{-5}$. A search for additional scalar resonances, X, in the same decay channel, leads to upper limits on the cross-section of pp$\rightarrow$X$\rightarrow$eμ in the mass-range of 110-160 GeV. Here, an excess of events is observed at an electron-muon invariant mass of approximately 146 GeV with a local (global) significance of 3.8 (2.8) standard deviations. These results provide valuable insights into lepton-flavor-violating Higgs decays and contribute to our understanding of the Higgs boson sector and potential physics beyond the Standard Model.

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1. Introduction

The Standard Model (SM) of particle physics stands as a remarkably successful framework for understanding the electroweak and strong interactions. Central to this framework is the Higgs boson, which allows particles to gain their mass via the electroweak symmetry-breaking mechanism and the Yukawa interaction. Within the SM, lepton flavor conservation is an inherent principle. However, in a variety of Beyond the Standard Model (BSM) theories that are introduced to solve phenomena unexplained by the SM, lepton flavor violating (LFV) processes may be allowed. These include certain scenarios in models with more than two Higgs doublets [1] or composite Higgs boson [2, 3]. In the present summary, a search for the LFV H→eμ, where H refers to the 125 GeV boson discovered at CERN by the CMS and ATLAS experiments in 2012 [4, 5], is shown [6]. A search for additional scalar resonances in the same decay channel, spanning from 110 GeV and 160 GeV, was also conducted. The latter is motivated by the type-III Two-Higgs Doublet Model, where a direct search could constrain the model's parameter space in the aforementioned mass range [7].

2. Event selection and categorization

The invariant mass of an oppositely charged e-μ pairs $m_{e\mu}$, is the main observable of this study. The analysis triggers consist of single-electron and single-muon triggers with year-dependent p_T requirements [6]. To ensure a triggering efficiency of approximately 100%, an offline p_T cut is applied to the e (μ), which is set slightly above the trigger value. Additionally, the e-μ pair must have an angular separation $\Delta R > 0.3$. The search is conducted in the mass range of 110 GeV $< m_{e\mu} <$ 170 GeV, to fully enclose all probed mass points. Furthermore, targeting masses higher than 110 GeV allows for an extended background suppression from the $t\bar{t}$, $H \rightarrow \tau\tau$ and $H \rightarrow WW$, which peak below the selected mass-window. Events including additional electrons, muons, hadronically decaying tau candidates, b-jets, and missing transverse energy are vetoed.

Events are first split into two broad categories according to the production mode targeted, i.e. gluon-gluon fusion (ggH) and vector-boson fusion (VBF). A further separation to enhance the sensitivity of this analysis is imposed, relying on the output of a boosted decision tree (BDT), and according to the signal purity. For this, two different BDTs are trained separately for each production mode, using simulated signal and background events. The ggH and VBF BDTs input variables are carefully selected to avoid usage or correlation with the main observable to avoid distortions on the shape of the di-lepton mass distribution. These include kinematic variables of the selected electron and muon, and variables related to the missing transverse energy in the event, out of which the p_T^{miss} has the strongest discriminating power in both VBF and ggH categories. The resulting BDT discriminant distributions of data and simulated signal and backgrounds, as well as the boundaries of the sub-categories, are shown in Fig. 1 left (right) for the ggH (VBF) category.

3. Signal and background modeling and systematic uncertainties

The electron-muon invariant mass distributions of simulated signal events are fit with a sum of three (two) Gaussian distributions in the ggH (VBF) categories. Various systematic effects can affect either the total yield or the shape of the simulated signal samples. The systematic uncertainties affect

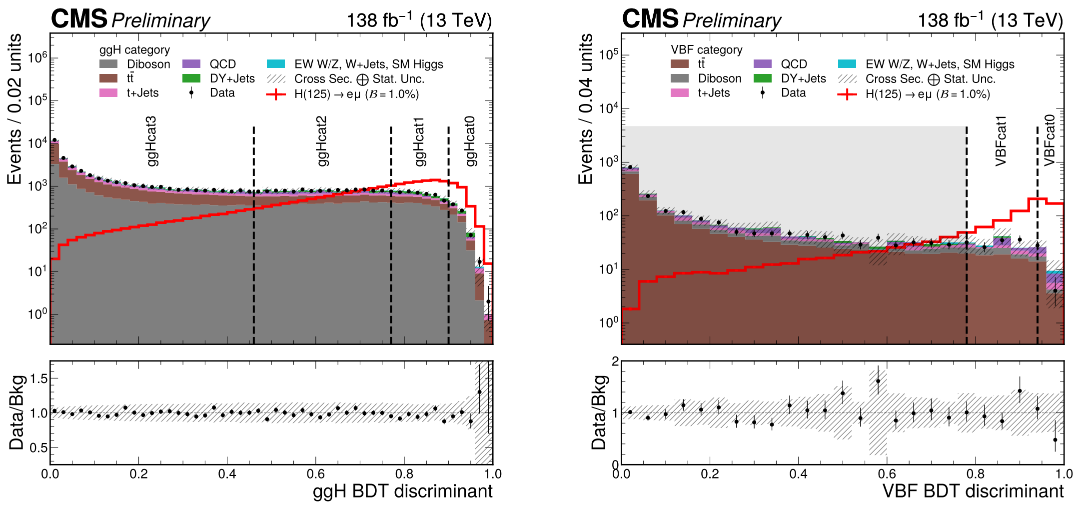

Figure 1: BDT discriminant distributions of data, simulated backgrounds and H→ e μ signal for the ggH (left) and VBF (right) categories [6].

the expected signal yield in up to 20%. The electron and muon momentum scale and resolution systematics have an effect on the model parameters of 0.1 and 10% respectively. The background is estimated in a data-driven approach, and modeled using Bernstein polynomials. The optimal order of the polynomial, as well as the systematic uncertainty associated to the choice of the functional form are addressed with a bias study. The contribution of this to the total uncertainty ranges from 6.9 to 14.4%.

4. Results

No significant excess of data beyond the background prediction was detected for the decay of the H→ eμ. Fig. 2 (left) shows the corresponding upper limit set 95% confidence level for each analysis category and for their combination. The latter results in an observed (expected) limit of 4.4 (4.7)$\times 10^{-5}$, the most stringent upper limits so far on the branching fraction of the 125 GeV Higgs boson in this decay channel. These limits can be translated into constraints on the LFV non-diagonal Yukawa couplings, shown in Fig. 2 (right).

The search for additional LFV scalar resonances displays a local (global) excess of 3.8 (2.8) standard deviations at 146 GeV, where a cross-section of $3.89^{+1.11}_{-1.08}$(stat.)$^{+0.57}_{-0.34}$(syst.) σ(pp → X(146)→eμ) was obtained after all categories were combined. The 95% CL upper limits as a function of the hypothesized m_X are shown in Fig. 3.

5. Summary

The present search reported an excess on the production cross section of X times branching fraction in the hypothesized mass of m_X =146 GeV, corresponding to a local (global) excess of 3.8 (2.8) standard deviations. These results are limited by the statistical precision. The LFV search of

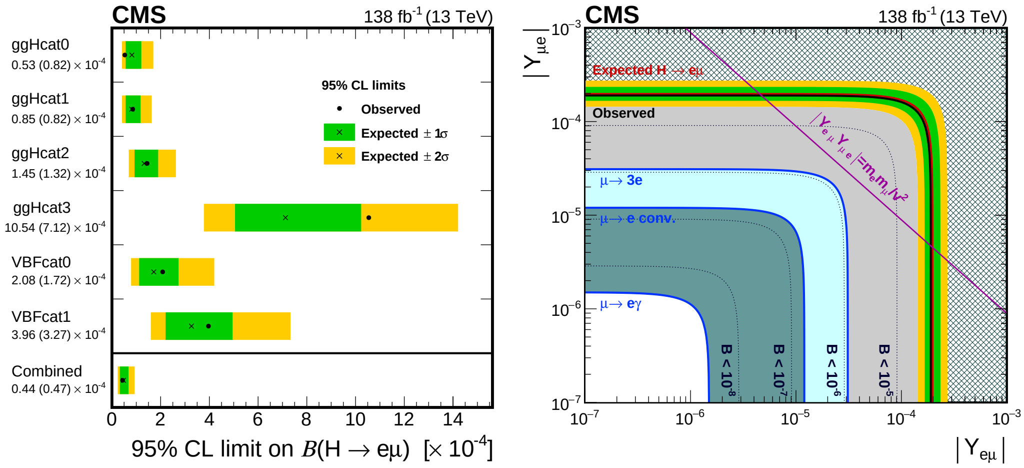

Figure 2: 95% CL expected and observed upper limits on the branching ratio of H→eμ for the analysis categories and their combination (left) and constraints in the non-diagonal LFV Yukawa couplings (right) [6].

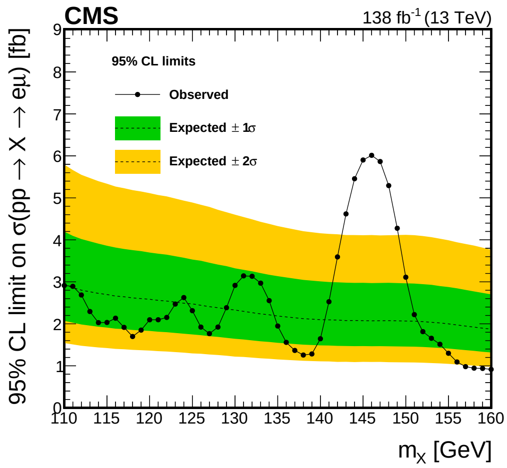

Figure 3: 95% CL expected and observed upper limits on theσ(pp $\longrightarrow$ X(146) $\longrightarrow$ eμ). A SM-like production cross-section of the studied production modes were assumed [6].

H resulted in a good agreement with the expected background only prediction. Upper limits were set in the branching ratio of H $\rightarrow$eμ and the corresponding non-diagonal Yukawa coupling. These are the most stringent limits to date obtained from direct searches.

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