PROCEEDINGS OF SCIENCE

Studies of Higgs boson production in the four-lepton final state at $\sqrt{s} = 13$ TeV on CMS detector

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Studies of Higgs boson production are presented using the $\mathrm{H} \to \mathrm{ZZ} \to 4\ell$ ($\ell = \mathrm{e}, \mu$) decay channel. These studies are performed using a data sample corresponding to an integrated luminosity of 2.8 fb^{-1} of pp collisions at a center-of-mass energy of 13 TeV collected by the CMS experiment at the LHC during 2015. The observed significance for the standard model Higgs boson with $m_{\mathrm{H}} = 125.09$ GeV is 2.5σ, where the expected significance is 3.4σ. The model independent fiducial cross section is measured to be $\sigma_{\mathrm{fid.}} = 2.48^{+1.48}_{-1.14}(\mathrm{stat.} \oplus \mathrm{sys.})^{+0.01}_{-0.04}(\mathrm{model\ dep.})$ fb. In addition, a search for an additional Higgs boson is performed for a range of masses up to 1 TeV and with various widths, and no significant excess is observed. The results of this search are interpreted in the context of the two Higgs doublet model.

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1. Introduction

The start of the LHC Run 2 in 2015, at an increased center-of-mass energy of $\sqrt{s} = 13TeV$, opens the way for an era of new precision measurements of the Higgs boson. This note presents the first CMS studies of Higgs boson production in the $H \to 4\ell$ decay channel at $\sqrt{s} = 13$ TeV, using 2.8 fb^{-1} of proton-proton collision data collected with the CMS experiment at the LHC in 2015. Detail of the studies can be found in Ref. [1] with references therein.

2. Background estimation

The irreducible background to the Higgs signal in the 4ℓ channel comes from the production of ZZ via $q\bar{q}$ annihilation or gluon fusion. The contribution from these backgrounds are estimated using simulation. Higher order QCD and electroweak corrections are applied by K factors as a function of four-lepton mass.

Reducible backgrounds arise from $Z+$jets and $t\bar{t}$ production where heavy-flavor jets produce secondary leptons, and from $Z+$jets, $Z\gamma+$jets, $WW+$jets and $WZ+$jets events where decays of heavy-flavor hadrons, in-flight decays of light mesons within jets, or (for electrons) the decay of charged hadrons overlapping with π^0 decays are misidentified as leptons. Two independent control regions in data are formed by requiring the presence of two leptons which satisfy the full identification criteria, plus two additional opposite-sign or same-sign leptons satisfying relaxed identification requirements. The event yields in the control regions are weighted by the lepton misidentification probability to obtain the expected yield in the signal region.

3. Signal modeling

The signal lineshape of a narrow resonance around $m_H \sim 125$ GeV and mass resolution for higher-mass resonances are parametrized using a double-sided Crystal Ball function. In addition, a Landau function is also added in the total probability density function for the non-resonant part of the signal for the case of WH, ZH and $t\bar{t}H$ production modes. In the case of a search for an additional high-mass resonance, a general parameterization of the signal and background $gg \to 4\ell$ process is used which includes all contributing amplitudes for $gg \to bkg + H(125)^* + X(m_X) \to 4\ell$, and their interference.

4. Results

4.1 Significance and signal strength

Figure 1 (left) shows the significance of the local fluctuation with respect to the SM background-only expectation as a function of m_H. The minimum of the local p-value is reached at 123.4 GeV and corresponds to a local significance of 3.0σ, while 3.1σ are expected for the SM Higgs boson. Two signal-strength modifiers $\mu_{ggH,t\bar{t}H}$ and $\mu_{VBF,VH}$ are defined as scale factors for the fermion and vector-boson induced contributions to the expected SM cross section. A two-dimensional fit is performed assuming a mass of $m_H = 125.09$GeV and profiling the likelihood for all nuisance parameters, leading to the measurements of $\mu_{ggH,t\bar{t}H} = 0.95^{+0.64}_{-0.49}$ and $\mu_{VBF,VH} = 0.0^{+2.5}_{-0.0}$. The 68% and 95% CL contours in the $(\mu_{ggH,t\bar{t}H}, \mu_{VBF,VH})$ plane are shown in Fig.1 (right).

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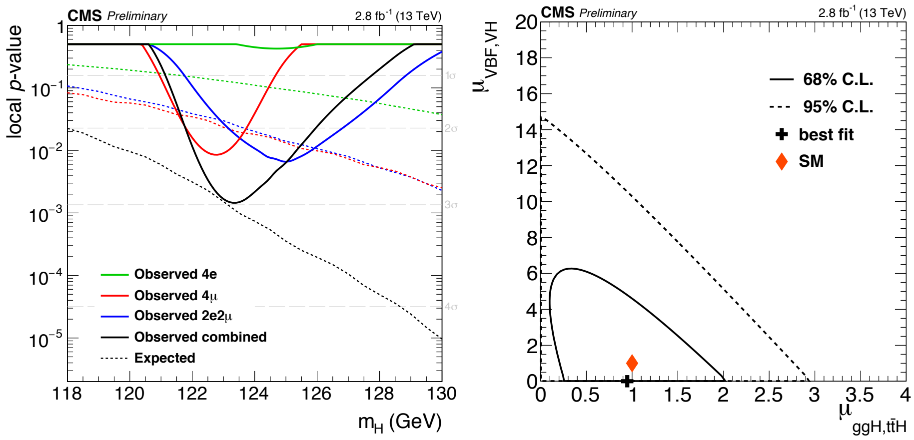

Figure 1: (left) Significance of the local fluctuation with respect to the background-only expectation as a function of the Higgs boson mass. (right) Result of the 2D likelihood scan for the $\mu_{\mathrm{ggH,t\bar{t}H}}$ and $\mu_{\mathrm{VBF,VH}}$ signal-strength modifiers. The solid and dashed contours show the 68% and 95% CL regions, respectively.

4.2 Fiducial cross section

The fiducial volume for the cross section measurement is defined to match closely the reconstruction level selection and is very similar to the definition used in Ref. [2]. The only difference in the fiducial volume definition with respect to the Run 1 analysis is that the leptons are dressed by adding the four-momenta of photons within $\Delta R < 0.4$ to the bare leptons. The integrated fiducial cross section is measured to be $\sigma_{\mathrm{fid.}} = 2.48^{+1.46}_{-1.13}(\mathrm{stat.})^{+0.28}_{-0.18}(\mathrm{sys.})^{+0.01}_{-0.04}(\mathrm{model\ dep.})$ fb. This can be compared to the SM expectation $\sigma^{\mathrm{SM}}_{\mathrm{fid.}} = 2.39 \pm 0.25$ fb. The integrated fiducial cross section as a function of $\sqrt{s}$ is also shown in Fig. 2 (right).

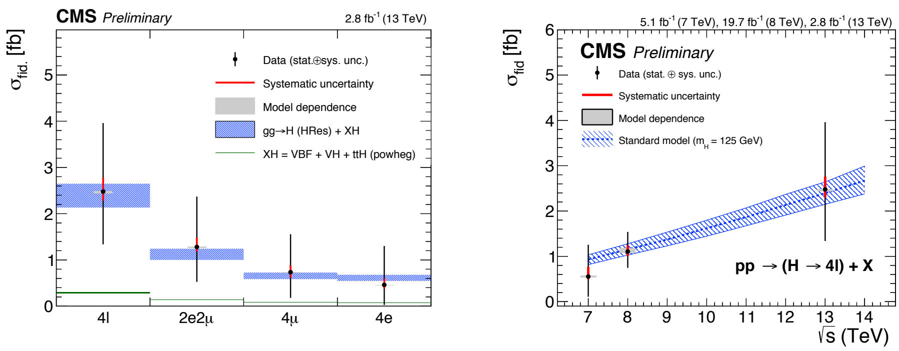

Figure 2: Result of the measured fiducial cross section in each final state (left) and the measured fiducial cross section as a function of $\sqrt{s}$ (right).

4.3 Search for additional resonances

Figure 3 shows observed and expected 95% CL limits on the $\mathrm{gg} \to \mathrm{X} \to \mathrm{ZZ} \to 4\ell$ cross section including the four-lepton branching fraction, as a function of m_X, for several values of Γ_X.

In addition to the generic cross section limit, the results are also interpreted in the context of a two Higgs doublet model (2HDM) benchmark scenario. The parameters m_{H}, the mass of the heaviest CP-even Higgs boson, and $\tan\beta$ are chosen for a two-dimensional scan. The results are shown in Fig. 3.

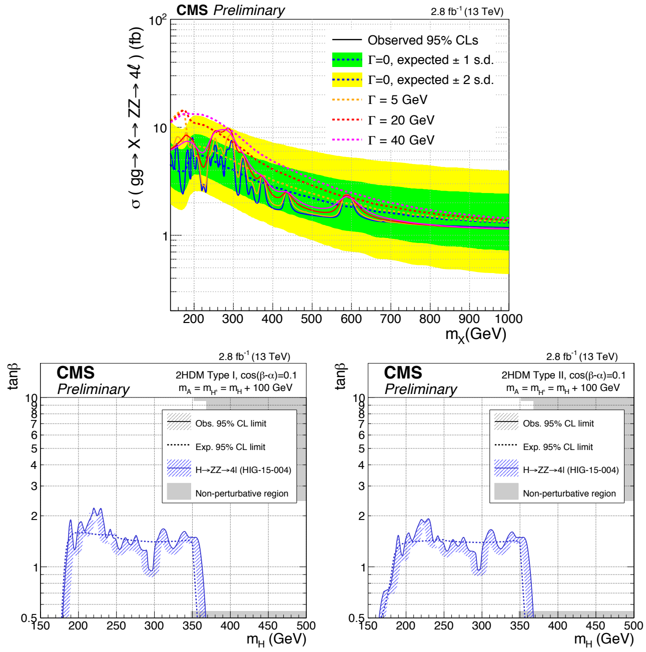

Figure 3: Top: Upper limits at the 95% CL on the gg$\to$ X $\to$ ZZ $\to 4\ell$ cross section σ, including four-lepton branching fraction, as a function of m_{X}, shown for several values of Γ_{X}. Bottom: Exclusion limits at the 95% CL in the $m_{\mathrm{H}} - \tan\beta$ plane for the benchmark 2HDM scenario with Type I (left) and Type II (right) couplings.

5. Summary

Several studies of Higgs boson production in the four-lepton final state at $\sqrt{s} = 13$ TeV have been presented, using data samples corresponding to an integrated luminosity of 2.8 fb^{-1}. The observed significance for the SM Higgs boson at a mass of $m_{\mathrm{H}} = 125.09$ GeV is 2.5σ. The measured signal strength modifiers and the model-independent fiducial cross section for this boson are consistent, within their uncertainties, with the expectations for the SM Higgs boson. In addition, upper limits at a 95% CL are set on the production of an additional Higgs boson for masses up to 1 TeV and for various widths, and these results are interpreted in two 2HDM scenarios.

References

[1] CMS Collaboration, CMS Physics Analysis Summary Report No. CMS-PAS-HIG-15-004, 2015. [http://cdsweb.cern.ch/record/2139978].

[2] CMS Collaboration, "Measurement of differential cross sections for Higgs boson production in the diphoton decay channel in pp collisions at $\sqrt{s}$=8 TeV", Eur. Phys. J. C 76 (2015) 13