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Measurements of properties of the Higgs boson in the four-lepton final state at $\sqrt{s}$ = 13 TeV

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The H $\rightarrow$ ZZ $\rightarrow 4\ell$ decay channel ($\ell = e, \mu$) is one of the most important channels for studies of properties of the Higgs boson since it has a large signal-to-background ratio due to the complete reconstruction of the final state decay objects and excellent lepton momentum resolution. Measurements performed using this decay channel and Run 1 data include, among others, the determination of the mass, spin-parity, and width of the new boson as well as tests for anomalous HVV couplings. This analysis presents measurements of properties of the Higgs boson in the H $\rightarrow$ ZZ $\rightarrow 4\ell$ decay channel at the $\sqrt{s} = 13$ TeV using 41.8 fb^{-1} of pp collision data collected with the CMS experiment at the LHC in 2017. In the previous iteration, categories have been introduced targeting sub-leading production modes of the Higgs boson such as vector boson fusion (VBF) and associated production with a vector boson (WH, ZH) or top quark pair ($\mathrm{t\bar{t}H}$). Apart from a larger dataset used, the main improvements in this analysis are newly optimised lepton selection, featuring in particular the usage of a new multivariate discriminant for electrons, and improved categorisation, especially optimised towards the associated production with a top quark.

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1. Analysis

This analysis makes use of pp collision data recorded in 2017 by the CMS detector corresponding to an integrated luminosity of 41.5 fb^{-1}. Collision events are selected by high-level trigger algorithms that require the presence of leptons passing loose identification and isolation requirements. The main triggers of this analysis select either a pair of electrons or muons, or an electron and a muon. The minimal transverse momentum of the leading electron (muon) is 23(17) GeV, while that of the subleading lepton is 12(8) GeV. The particle-flow algorithm [1] aims to reconstruct and identify each individual particle in an event, with an optimized combination of information from the various elements of the CMS detector. The energy of photons is directly obtained from the ECAL measurement. The energy of electrons is determined from a combination of the electron momentum at the primary interaction vertex as determined by the tracker, the energy of the corresponding ECAL cluster, and the energy sum of all bremsstrahlung photons spatially compatible with originating from the electron track. The energy of muons is obtained from the curvature of the corresponding track.

The electrons are reconstructed within the geometrical acceptance defined by pseudorapidity $|\eta_e| < 2.5$ and for transverse momentum $p_{\mathrm{T}}^{e} > 7$ GeV with an algorithm that combines information from the ECAL and the tracker [2]. The electrons are identified using a multivariate discriminant which includes observables sensitive to the presence of bremsstrahlung along the electron trajectory, the geometrical and momentum-energy matching between the electron trajectory and the associated cluster in the ECAL, the shape of the electromagnetic shower in the ECAL, variables that discriminate against electrons originating from photon conversions, and the isolation sums computed around the electron direction.

The muons are selected among the reconstructed muon track candidates by applying minimal requirements on the track in both the muon system and inner tracker system, and taking into account compatibility with small energy deposits in the calorimeters. To discriminate prompt muons from Z boson decay from those arising from electroweak decays of hadrons within jets, an isolation requirement of $I_\mu < 0.35$ is imposed.

For each event, hadronic jets are clustered from the reconstructed particles using the infrared and collinear safe anti-k_{T} algorithm [3, 4] with a distance parameter of 0.4. The jet momentum is determined as the vectorial sum of all particle momenta in the jet, and is found from simulation to be within 5 to 10% of the true momentum over the whole p_{T} spectrum and detector acceptance.

The event selection is designed to extract signal candidates from events containing at least four well-identified and isolated leptons, each originating from the primary vertex and possibly accompanied by an FSR photon candidate. First, Z candidates are formed with pairs of leptons of the same flavor and opposite charge and required to pass $12 < m_{\ell\ell} < 120$ GeV cut. They are then combined into ZZ candidates, wherein we denote as Z_1 the Z candidate with an invariant mass closest to the nominal Z boson mass [5], and as Z_2 the other one. The flavors of involved leptons define three mutually exclusive subchannels: $4e$, 4μ and $2e2\mu$.

The full kinematic information from each event using either the Higgs boson decay products or associated particles in its production is extracted using matrix element calculations and used to form several kinematic discriminants. These computations rely on the MELA package [6, 7, 8, 9] and use JHUGEN matrix elements for the signal and MCFM matrix elements for the background.

In order to improve the sensitivity to the Higgs boson production mechanisms, the selected events are classified into mutually exclusive categories. Category definitions exploit the multiplicity of jets, b-tagged jets and additional leptons (defined as leptons that are not involved in the ZZ candidate selection and that pass identification, vertex compatibility, and isolation requirements), and requirements on the kinematic discriminants.

The irreducible background to the Higgs boson signal in the 4ℓ channel, which come from the production of ZZ via qq annihilation or gluon fusion, is estimated using simulation. Additional backgrounds to the Higgs boson signal in the 4ℓ channel arise from processes in which heavy-flavor jets produce secondary leptons, and also from processes in which 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. The contribution from this, reducible, background is estimated using control regions in data.

2. Results

The reconstructed four-lepton invariant mass distribution is shown in the Fig. 1. The observed distribution agrees with the expectation within the statistical uncertainties over the whole spectrum.

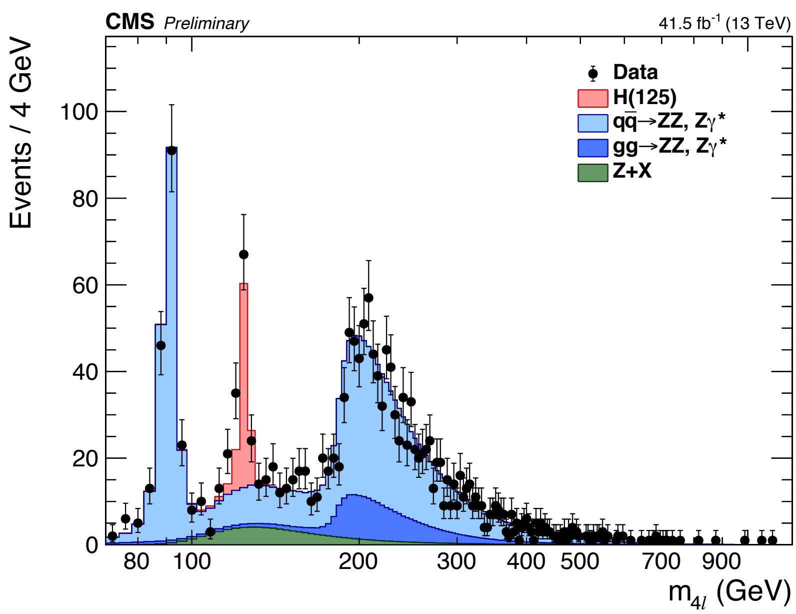

Figure 1: Distribution of the four-lepton reconstructed invariant mass in the full mass range. Points with error bars represent the data and stacked histograms represent expected distributions of the signal and background processes.

To extract the signal strength for the excess of events observed in the Higgs boson peak region, we perform a multi-dimensional fit that relies on two variables: the four-lepton invariant mass $m_{4\ell}$ and the kinematic discriminant. The results are shown in the Fig. 2. Results based on data collected in 2016 and 2017 are combined and the measured signal strength modifier is $\mu = 1.06^{+0.15}_{-0.13}$. All results are consistent, within their uncertainties, with the expectations for the SM Higgs boson.

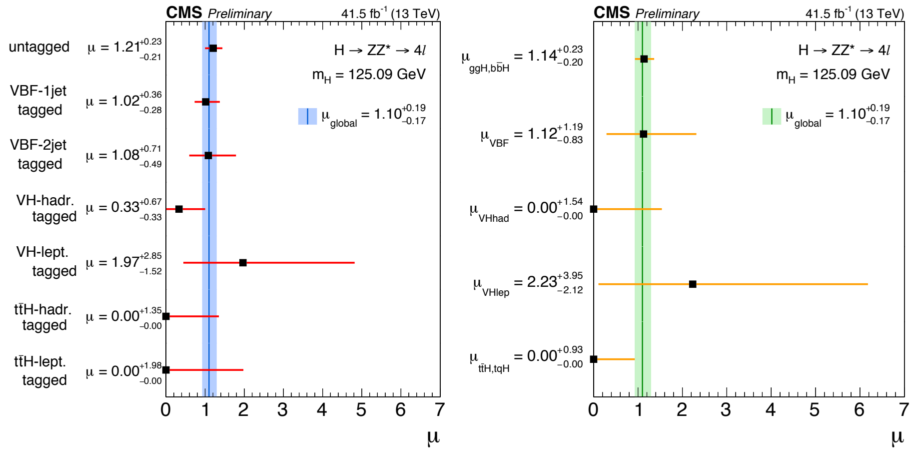

Figure 2: (Left) Observed values of the signal strength $\mu = \sigma/\sigma_{\rm SM}$ for the seven event categories, compared to the combined μ shown as a vertical line with a filled band representing the uncertainty. The horizontal bars indicate the one standard deviation uncertainties. (Right) Results of likelihood scans for the signal-strength modifiers corresponding to the main SM Higgs boson production modes, compared to the combined μ shown as a vertical line.

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