PROCEEDINGS OF SCIENCE

Search for the Higgs boson in the final state with two leptons and a photon produced in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

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A search for the Higgs boson decaying into a Z boson and a photon with two electrons or muons and a photon in the final state is presented. A data set of 139 fb^{-1} of pp collisions at a center-of-mass energy of 13 TeV recorded with the ATLAS detector at the LHC is used. Estimates of Higgs boson signal and background contributions are performed based on the three-body invariant mass distribution. Corresponding systematic uncertainties are evaluated. Expected and observed limits on the signal strength, defined as ratio of observed and expected signal event yields, are shown.

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Since the Higgs boson discovery in 2012 [1, 2], efforts are focused on a more precise characterization of its properties, such as its couplings to other particles, including the observation of the Higgs boson in different decay channels. One of these channels is the decay of the Higgs boson into two leptons and a photon. This channel is particularly interesting due to large contributions from one-loop Feynman diagrams, featuring decays through Z/γ^* [3] and a photon. In this report we focus on the Higgs boson decay with a Z boson, $H \rightarrow Z\gamma \rightarrow \ell\ell\gamma$ ($\ell = e, \mu$), which allows efficient triggering and clear distinction from the background. In principle, the three particles in the final state open up a possibility to measure CP violation in the Standard Model (SM) [4]. However, Higgs boson decays in this channel are very rare, the branching ratio $BR(H \rightarrow Z\gamma)$ is $1.541 \cdot 10^{-3}$ [5]. In previously published reports the observed upper limit on the production cross-section times branching ratio for the $pp \rightarrow H \rightarrow Z\gamma$ process was measured at 7.4 [6] (6.6 [7]) times the SM prediction by CMS (ATLAS) collaborations, using the 35.9 (36.1) fb^{-1}data sets. The presented analysis uses a data set of 139 fb^{-1}of pp collisions at $\sqrt{s} = 13$ TeV recorded with the ATLAS detector [8].

To select the events, at least one γ candidate and at least two opposite-charge electrons or muons are required. The leptons must be associated with the primary vertex candidate, reconstructed from charged particles (tracks) in the inner detector (ID) (see Ref. [9] for the ATLAS detector description). The vertex with the largest sum of the squared transverse momenta of the associated tracks is chosen as primary vertex. Muon candidates are obtained by matching high-quality tracks in the muon spectrometer (MS) and ID. Outside the ID acceptance, the MS track itself can be the candidate, provided it points to the beamspot. Electron and γ candidates are reconstructed from topological clusters of energy deposits in the electromagnetic calorimeter. For electrons, a track in the ID is matched to the cluster. For converted γ, a track or conversion vertex is matched to the cluster. The lepton and γ candidates are required to satisfy identification criteria and be well-isolated from additional activity in the tracking detector and in the calorimeters. Jets are reconstructed using the anti-k_t algorithm with a radius parameter of 0.4. Basic kinematic cuts are applied to candidate objects in order to suppress backgrounds, including those from pileup interactions. Finally an overlap removal procedure is performed to avoid double-counting objects. A Z boson is then reconstructed from the selected lepton candidates. In the $Z \rightarrow \mu\mu$ case, an additional final state radiation correction of the μ momenta is performed to improve the Z boson mass resolution. The invariant mass of the Z boson candidates is calculated using a constrained kinematic fit and is required to be within 10 GeV of the true Z boson mass. Higgs boson candidates are formed from Z boson candidates and the highest p_{T} photon in the event, and only the $105 \text{ GeV} < m_{Z\gamma} < 160 \text{ GeV}$ mass range is considered. A cut on the relative photon momenta $p_{\mathrm{T}}^{\gamma}/m_{Z\gamma} > 0.12$ is applied to further reduce background contamination.

The selected events are classified into six mutually exclusive categories with different expected signal-to-background ratios and mass resolutions to improve the sensitivity. Categories are defined according to the lepton flavor and event kinematics. Additionally, a boosted decision tree (BDT) is trained on a subset of kinematic variables to optimize a category with an enhanced contribution of vector boson fusion events, which have a higher signal-to-background ratio.

The background in this search mainly originates from non-resonant production of a Z boson and a γ, with a smaller contribution from the production of Z bosons in association with jets, where one jet is misidentified as a γ. Parametric models of the three-body invariant mass distributions are constructed to estimate signal and background yields. For the signal, the expected acceptance and parameters that describe the shape are obtained from simulated Monte-Carlo events. For the background, the models are chosen using a template constructed from simulated background events with the composition determined from a data-driven fit. The model parameters are determined in the combined signal+background fit to the three-body invariant mass distributions measured in the data.

In this analysis a profile likelihood ratio is maximized to extract the signal strength, defined as ratio of observed and expected signal event yields. Systematic uncertainties mainly arise from the bias associated with the choice of the background model (28%), the theoretical prediction of $BR(H \to Z\gamma \to \ell\ell\gamma\ (\ell = e, \mu))$ (5.7%) and missing higher order corrections in QCD (5.3%). Other theory and experimental uncertainties are also considered, but have a much smaller impact.

The best-fit value for the signal strength is found to be $2.0 \pm 0.9(\text{stat.})^{+0.4}_{-0.3}(\text{syst.}) = 2.0^{+1.0}_{-0.9}(\text{tot.})$ with an expected value of $1.0 \pm 0.8(\text{stat.}) \pm 0.3(\text{syst.})$ assuming the presence of the SM Higgs boson. The result is dominated by statistical uncertainties. The observed 95% CL limit on the signal strength is found to be 3.6 times the SM prediction compared with the expected value of 2.6 assuming the SM Higgs boson.

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