Physics Letters B 744 (2015) 184–207

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Search for a standard model-like Higgs boson in the $\mu^+\mu^-$ and e^+e^- decay channels at the LHC

CMS Collaboration [⋆]

CERN, Switzerland

ARTICLE INFO

Article history:
Received 24 October 2014
Received in revised form 20 February 2015
Accepted 23 March 2015
Available online 26 March 2015
Editor: M. Doser

Keywords:
CMS
Physics
Higgs
Lepton
Muon
Electron
Dilepton
Dimuon
Dielectron
Higgs boson

ABSTRACT

A search is presented for a standard model-like Higgs boson decaying to the $\mu^+\mu^-$ or e^+e^- final states based on proton–proton collisions recorded by the CMS experiment at the CERN LHC. The data correspond to integrated luminosities of 5.0 fb^{-1} at a centre-of-mass energy of 7 TeV and 19.7 fb^{-1} at 8 TeV for the $\mu^+\mu^-$ search, and of 19.7 fb^{-1} at 8 TeV for the e^+e^- search. Upper limits on the production cross section times branching fraction at the 95% confidence level are reported for Higgs boson masses in the range from 120 to 150 GeV. For a Higgs boson with a mass of 125 GeV decaying to $\mu^+\mu^-$, the observed (expected) upper limit on the production rate is found to be 7.4 $(6.5^{+2.8}_{-1.9})$ times the standard model value. This corresponds to an upper limit on the branching fraction of 0.0016. Similarly, for e^+e^-, an upper limit of 0.0019 is placed on the branching fraction, which is $\approx 3.7 \times 10^5$ times the standard model value. These results, together with recent evidence of the 125 GeV boson coupling to τ-leptons with a larger branching fraction consistent with the standard model, confirm that the leptonic couplings of the new boson are not flavour-universal.

1. Introduction

After the discovery of a particle with a mass near 125 GeV [1–3] and properties in agreement, within current experimental uncertainties, with those expected of the standard model (SM) Higgs boson, the next critical question is to understand in greater detail the nature of the newly discovered particle. Answering this question with a reasonable confidence requires measurements of its properties and production rates into final states both allowed and disallowed by the SM. Beyond the standard model (BSM) scenarios may contain additional Higgs bosons, so searches for these additional states constitute another test of the SM [4]. For a Higgs boson mass, m_H, of 125 GeV, the SM prediction for the Higgs to $\mu^+\mu^-$ branching fraction, $\mathcal{B}(H \to \mu^+\mu^-)$, is among the smallest accessible at the CERN LHC, 2.2×10^{-4} [5], while the SM prediction for $\mathcal{B}(H \to e^+e^-)$ of approximately 5×10^{-9} is inaccessible at the LHC. Experimentally, however, $H \to \mu^+\mu^-$ and $H \to e^+e^-$ are the cleanest of the fermionic decays. The clean final states allow a better sensitivity, in terms of cross section, σ, times branching fraction, $\mathcal{B}$, than $H \to \tau^+\tau^-$. This means that searches for $H \to \mu^+\mu^-$ and $H \to e^+e^-$, combined with recent strong evidence for decays of the new boson to $\tau^+\tau^-$ [6,7], may be used to test if the coupling of the new boson to leptons is flavour-universal or proportional to the lepton mass, as predicted by the SM [8]. In addition, a measurement of the $H \to \mu^+\mu^-$ decay probes the Yukawa coupling of the Higgs boson to second-generation fermions, an important input in understanding the mechanism of electroweak symmetry breaking in the SM [9,10]. Deviations from the SM expectation could also be a sign of BSM physics [11,12]. A previous LHC search for SM $H \to \mu^+\mu^-$ has been performed by the ATLAS Collaboration and placed a 95% confidence level (CL) upper limit of 7.0 times the rate expected from the SM at 125.5 GeV [13]. The ATLAS Collaboration has also performed a search for BSM $H \to \mu^+\mu^-$ decays within the context of the minimal supersymmetric standard model [14].

This paper reports a search for an SM-like Higgs boson decaying to either a pair of muons or electrons ($H \to \ell^+\ell^-$) in proton–proton collisions recorded by the CMS experiment at the LHC. The $H \to \mu^+\mu^-$ search is performed on data corresponding to integrated luminosities of 5.0 ± 0.1 fb^{-1} at a centre-of-mass energy of 7 TeV and 19.7 ± 0.5 fb^{-1} at 8 TeV, while the $H \to e^+e^-$ search is only performed on the 8 TeV data. Results are presented for Higgs boson masses between 120 and 150 GeV. For $m_H = 125$ GeV,

---

[⋆] *E-mail address:* cms-publication-committee-chair@cern.ch.

http://dx.doi.org/10.1016/j.physletb.2015.03.048

the SM predicts 19(95) $H \to \mu^+\mu^-$ events at 7 TeV (8 TeV), and $\approx 2 \times 10^{-3}$ $H \to e^+e^-$ events at 8 TeV [15–18].

The $H \to \ell^+\ell^-$ resonance is sought as a peak in the dilepton mass spectrum, $m_{\ell\ell}$, on top of a smoothly falling background dominated by contributions from Drell–Yan production, $t\bar{t}$ production, and vector boson pair-production processes. Signal acceptance and selection efficiency are estimated using Monte Carlo (MC) simulations, while the background is estimated by fitting the observed $m_{\ell\ell}$ spectrum in data, assuming a smooth functional form.

Near $m_H = 125$ GeV, the SM predicts a Higgs boson decay width much narrower than the dilepton invariant mass resolution of the CMS experiment. For $m_H = 125$ GeV, the SM predicts the Higgs boson decay width to be 4.2 MeV [16], and experimental results indirectly constrain the width to be <22 MeV at the 95% CL, subject to various assumptions [19,20]. The experimental resolution depends on the angle of each reconstructed lepton relative to the beam axis. For dimuons, the full width at half maximum (FWHM) of the signal peak ranges from 3.9 to 6.2 GeV (for muons with $|\eta| < 2.1$), while for electrons it ranges from 4.0 to 7.2 GeV (for electrons with $|\eta| < 1.44$ or $1.57 < |\eta| < 2.5$).

The sensitivity of this analysis is increased through an extensive categorization of the events, using kinematic variables to isolate regions with a large signal over background (S/B) ratio from regions with smaller S/B ratios. Separate categories are optimized for the dominant Higgs boson production mode, gluon-fusion (GF), and the sub-dominant production mode, vector boson fusion (VBF). Higgs boson production in association with a vector boson (VH), while not optimized for, is taken into account in the $H \to \mu^+\mu^-$ analysis. The SM predicts Higgs boson production to be 87.2% GF, 7.1% VBF, and 5.1% VH for $m_H = 125$ GeV at 8 TeV [18]. In addition to $m_{\ell\ell}$, the most powerful variables for discriminating between the Higgs boson signal and the Drell–Yan and $t\bar{t}$ backgrounds are the jet multiplicity, the dilepton transverse-momentum ($p_T^{\ell\ell}$), and the invariant mass of the two largest transverse-momentum jets (m_{jj}). The gluon–gluon initial state of GF production tends to lead to more jet radiation than the quark–antiquark initial state of Drell–Yan production, leading to larger $p_T^{\ell\ell}$ and jet multiplicity. Similarly, VBF production involves a pair of forward–backward jets with a large m_{jj} compared to Drell–Yan plus two-jet or $t\bar{t}$ production. Events are further categorized by their $m_{\ell\ell}$ resolution and the kinematics of the jets and leptons.

This paper is organized as follows. Section 2 introduces the CMS detector and event reconstruction, Section 3 describes the $H \to \mu^+\mu^-$ event selection, Section 4 the $H \to \mu^+\mu^-$ selection efficiency, Section 5 details the systematic uncertainties included in the $H \to \mu^+\mu^-$ analysis, Section 6 presents the results of the $H \to \mu^+\mu^-$ search, Section 7 describes the $H \to e^+e^-$ search, and Section 8 provides a summary.

2. CMS detector and event reconstruction

The central feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter, providing a magnetic field of 3.8 T. Within the superconducting solenoid volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter (ECAL), and a brass/scintillator hadron calorimeter (HCAL), each composed of a barrel and two endcap sections. Muons are measured in gas-ionization detectors embedded in the steel flux-return yoke outside the solenoid. Extensive forward calorimetry complements the coverage provided by the barrel and endcap detectors.

The first level of the CMS trigger system, composed of custom hardware processors, uses information from the calorimeters and muon detectors to select the most interesting events in a fixed time interval of less than 4 μs. The high level trigger processor farm further decreases the event rate from at most 100 kHz to less than 1 kHz, before data storage. A more detailed description of the detector as well as the definition of the coordinate system and relevant kinematic variables can be found in Ref. [21].

The CMS offline event reconstruction creates a global event description by combining information from all subdetectors. This combined information then leads to a list of particle-flow (PF) objects [22,23]: candidate muons, electrons, photons, and hadrons. By combining information from all subdetectors, particle identification and energy estimation performance are improved. In addition, double counting subdetector energy deposits when reconstructing different particle types is eliminated.

Due to the high instantaneous luminosity of the LHC, many proton–proton interactions occur in each bunch crossing. An average of 9 and 21 interactions occur in each bunch crossing for the 7 and 8 TeV data samples, respectively. Most interactions produce particles with relatively low transverse-momentum (p_T), compared to the particles produced in an $H \to \ell^+\ell^-$ signal event. These interactions are termed "pileup", and can interfere with the reconstruction of the high-p_T interaction, whose vertex is identified as the vertex with the largest scalar sum of the squared transverse momenta of the tracks associated with it. All charged PF objects with tracks coming from another vertex are then removed.

Hadronic jets are clustered from reconstructed PF objects with the infrared- and collinear-safe anti-k_T algorithm [24,25], operated with a size parameter of 0.5. The jet momentum is determined as the vectorial sum of the momenta of all PF objects in the jet, and is found in the simulation to be within 5% to 10% of the true momentum over the whole p_T spectrum of interest and detector acceptance. An offset correction is applied to take into account the extra neutral energy clustered in jets due to pileup. Jet energy corrections are derived from the simulation, and are confirmed by in-situ measurements of the energy balance in dijet, photon plus jet, and Z plus jet (where the Z-boson decays to $\mu^+\mu^-$ or e^+e^-) events [26]. The jet energy resolution is 15% at 10 GeV, 8% at 100 GeV, and 4% at 1 TeV [27]. Additional selection criteria are applied to each event to remove spurious jet-like objects originating from isolated noise patterns in certain HCAL regions.

Matching muons to tracks measured in the silicon tracker results in a relative p_T resolution for muons with $20 < p_T < 100$ GeV of 1.3–2.0% in the barrel and better than 6% in the endcaps. The p_T resolution in the barrel is better than 10% for muons with p_T up to 1 TeV [28]. The mass resolution for $Z \to \mu\mu$ decays is between 1.1% and 1.9% depending on the pseudorapidity of each muon, for $|\eta| < 2.1$. The mass resolution for $Z \to ee$ decays when both electrons are in the ECAL barrel (endcaps) is 1.6% (2.6%) [29].

3. $H \to \mu^+\mu^-$ event selection

Online collection of events is performed with a trigger that requires at least one isolated muon candidate with p_T above 24 GeV in the pseudorapidity range $|\eta| \le 2.1$. In the offline selection, muon candidates are required to pass the "Tight muon selection" [28] and each muon trajectory is required to have an impact parameter with respect to the primary vertex smaller than 5 mm and 2 mm in the longitudinal and transverse directions, respectively. They must also have $p_T > 15$ GeV and $|\eta| \le 2.1$.

For each muon candidate, an isolation variable is constructed using the scalar sum of the transverse-momentum of particles, reconstructed as PF objects, within a cone centered on the muon. The boundary of the cone is $\Delta R = \sqrt{[b](\Delta\eta)^2 + (\Delta\phi)^2} = 0.4$ away from the muon, and the p_T of the muon is not included in the sum. While only charged particles associated with the primary vertex