Higgs searches by CMS at LHC

M. Kirsanov[a]*,
[a] *INR RAS*
Moscow

Abstract

A search for the Standard Model Higgs boson in a wide range of masses and several decay channels is described. The analysis is performed using a dataset recorded by the CMS experiment at the LHC from pp collisions at a centre-of-mass energy of 7 TeV, and corresponds to an integrated luminosity of 4.8 fb^{-1}. Limits are set on the cross sections of a Standard Model Higgs boson. The expected excluded mass range in the absence of the standard model Higgs boson is 114.5 - 543 GeV at 95% CL. The observed results exclude the standard model Higgs boson in the mass range 127.5 - 600 GeV at 95% CL. An excess of events above the expected standard model background is observed at the low end of the explored mass range making the observed limits weaker than expected in the absence of a signal. The largest excess, with a local significance of 2.8 σ, is observed for a Higgs boson mass hypothesis of 125 GeV. A search for a Higgs boson corresponding to several extensions of the Standard Model is also described.

1 Introduction

The Standard Model (SM) [1], [2] of particle physics has been very successful in explaining experimental data. The origin of the masses of the W and Z bosons that arise from electroweak symmetry breaking remains to be identified. In the SM the Higgs mechanism is postulated, which leads to an additional scalar field whose quantum, the Higgs boson, should be experimentally observable [3], [4].

The mass of the Higgs boson is not fixed in the Standard Model. The constraints on it are derived from the following considerations [5]:

- "Unitarity": Higgs boson exchange allows to avoid unphysical W - W scattering probability at high energies if $M_H < 800$ GeV
- "Triviality": Higgs boson self-coupling becomes too strong (so that perturbative methods are not applicable) if its mass is higher than some value depending on the cut-off scale Λ. This value has significant uncertainties, approximately it is given by $M_H^2 < 4\pi^2\nu^2/(3ln(\Lambda/\nu))$.
- "Stability" of the vacuum: potential $V(\phi)$ has only one absolute minimum. Requires $M_H^2 > m_t^4 ln(\Lambda/\nu)/\pi^2\nu^2$

Here ν is the vacuum-expectation value of the Higgs field and Λ is the cut-off scale.

The estimation of M_H from the presision measurements (electroweak fits) is based on the following relations [6]:

$$m_W^2 = \frac{\pi\alpha}{\sqrt{2}G_F sin^2\Theta_W(1-\Delta r)}, \quad (1)$$

* **e-mail**: Mikhail.Kirsanov@cern.ch

where the first order contribution from the Higgs to the higher order corrections Δr can be written approximately as

$$(\Delta r)_{Higgs} = \frac{11 G_F m_Z^2 cos^2\Theta_W}{24\sqrt{2}\pi^2} ln(\frac{M_H^2}{m_Z^2}) \tag{2}$$

Electroweak fits give $M_H = 96(^{+31}_{-24})$ GeV or $M_H < 158$ GeV at 95% CL. The big errors here are determined mainly by the accuracy of the m_t measurements. The problem is that the higher order contribution to Δr from the top quark depends quadratically on m_t.

Direct searches at LEP give a lower limit: $M_H > 114$ GeV at 95% CL [7].

The LHC and its major experiments were conceived and built to explore in depth the multi-TeV region and solve in a way or in another this major puzzle of particle physics. Excellent performance of the LHC in 2011 allowed to the experiments to collect enough data to reach sensitivity exceeding or close to the SM Higgs boson cross sections. The teams of physicists of the ATLAS and CMS experiments managed to quickly perform the analysis of data in complicated conditions of pile-up (multiple proton-proton interactions in one bunch crossing, 10 - 15 on the average) and high backgrounds (cross sections up to 10^{11} of the Higgs boson cross sections). The results of the searches in the CMS experiment are presented in this paper.

2 The CMS detector

A detailed description of the CMS detector can be found elsewhere [8]. The main features and those most pertinent to this analysis are described below. The central feature is a superconducting solenoid, 13 m in length and 6 m in diameter, which provides an axial magnetic field of 3.8 T. The bore of the solenoid is instrumented with particle detection systems. The steel return yoke outside the solenoid is instrumented with gas detectors used to identify muons. Charged particle trajectories are measured by the silicon pixel and strip tracker, with full azimuthal coverage within $|\eta|$ <2.5, where the pseudorapidity η is defined as $\eta = -ln[tan(\Theta/2)]$, with Θ being the polar angle of the trajectory of the particle with respect to the counterclockwise beam direction. A lead-tungstate crystal electromagnetic calorimeter (ECAL) and a brass/scintillator hadron calorimeter (HCAL) surround the tracking volume and cover the region $|\eta|$ <3. The ECAL barrel extends to $|\eta|$ =1.48. A lead/silicon-strip preshower detector is located in front of the ECAL endcap. A steel/quartz-fibre Cherenkov forward calorimeter extends the calorimetric coverage to $|\eta|$ <5.0. In the region $|\eta|$ <1.74, the HCAL cells have widths of 0.087 in both pseudorapidity and azimuth (ϕ). In the (η, ϕ) plane, and for $|\eta|$ <1.48, the HCAL cells map on to 5x5 ECAL crystal arrays to form calorimeter towers projecting radially outwards from points slightly offset from the nominal interaction point. In the endcap, the ECAL arrays matching the HCAL cells contain fewer crystals. Calibration of the ECAL uses π^0s, $W \to e\nu$, and $Z \to ee$. Deterioration of transparency of the ECAL crystals due to irradiation during the LHC running periods and their subsequent recovery is monitored continuously and corrected for using light injected from a laser and LED system.

3 SM Higgs boson production and decays

There are four main mechanisms for Higgs boson production in pp collisions. The gluon-gluon fusion mechanism has the largest cross section, followed in turn by vector boson fusion (VBF), associated WH and ZH production, and production in association with top quarks, $t\bar{t}H$. The Higgs boson decay modes are determined by its nature, in particular by the fact that its coupling to elementary particles (except gauge bosons, for which the dependency is more complicated) is proportional to their masses. This means that it prefers to decay to heavy particles. For the same reason the brancing ratios depend strongly on the Higgs boson mass m_H, as shown in

Figure 1. These peculiarities of the Higgs boson decays and comparably small production cross sections render its searches rather complicated, in particular for some ranges of m_H, for example below 120 GeV. The strategy of the searches for the Higgs boson are in turn determined by the peculiarities mentioned above. The decays modes most relevant to the searches at the LHC are listed in Figure 2.

There are three types of independent theoretical uncertainties on Higgs boson production: uncertainties associated with (i) parton density functions (PDFs), (ii) incomplete perturbative calculations (also known as QCD scale uncertainties), and (iii) the treatment of the finite width of the Higgs boson. All these uncertainties are taken from Ref. [9].

4 Higgs boson searches in the CMS detector

The $WW^{(*)} \rightarrow 2l2\nu$ analysis [10] searches for an excess of events with two leptons of opposite charge, large E_T^{miss}, and up to two jets. Events are divided into five categories, with different background compositions and signal-to-background ratios. For events with no jets, the main background stems from non-resonant WW production; for events with one jet, the dominant backgrounds are from WW and top-quark production. The events with no jets and one jet are split into same-flavour and different-flavour dilepton sub-channels, since the background from Drell-Yan production is much larger for the same-flavour dilepton events. The two-jet category is optimized to take advantage of the VBF production signature. The main background in this channel is from top-quark production. To improve the separation of signal from backgrounds, MVA classifiers are trained for a number of Higgs boson masses, and a search is made for an excess of events in the output distributions of the classifiers. All background rates, except for very small contributions from WZ, ZZ, and Wg, are evaluated from data.

In the $H \rightarrow ZZ \rightarrow 2l2\nu$ search [11], we select events with a lepton pair (ee or $\mu\mu$), with invariant mass consistent with that of an on-shell Z boson, and a large E_T^{miss}. We then define a transverse invariant mass m_T from the dilepton momenta and E_T^{miss}, assuming that the latter arises from a $Z \rightarrow \nu\nu$ decay. We search for a broad excess of events in the m_T distribution. The non-resonant ZZ and WZ backgrounds are taken from simulation, while all other backgrounds are evaluated from control samples in data. This analysis alone excludes the SM Higgs boson in the range $270 < m_H < 440$ GeV at 95% CL.

In the $H \rightarrow ZZ^{(*)} \rightarrow 2\ell 2q$ search [12], we select events with two leptons (ee or $\mu\mu$) and two jets with zero, one, or two b-tags, thus defining a total of six exclusive final states. Requiring b-tagging improves the signal-to-background ratio. The two jets are required to form an invariant mass consistent with that of an on-shell Z boson. The aim is to search for a peak in the invariant mass distribution of the dilepton-dijet system, with the background rate and shape estimated using control regions in data.

In the $H \rightarrow ZZ \rightarrow 2\ell 2\tau$ search [13], one Z boson is required to be on-shell and to decay to a lepton pair (ee or $\mu\mu$). The other Z boson is required to decay through a $\tau\tau$ pair to one of the four final-state signatures $e\mu$, $e\tau_{\rm h}$, $\mu\tau_{\rm h}$, $\tau_{\rm h}\tau_{\rm h}$. Thus, eight exclusive sub-channels are defined. We search for a broad excess in the distribution of the dilepton-ditau mass, constructed from the visible products of the tau decays, neglecting the effect of the accompanying neutrinos. The dominant background is non-resonant ZZ production whose rate is estimated from simulation. The main sub-leading backgrounds with jets misidentified as τ leptons stem from Z + jets (including ZW) and top-quark events. These backgrounds are estimated from data.

In the $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$ channel [14], we search for a four-lepton mass peak over a small continuum background. This is extremely clean, high resolution channel, often called "Golden", but with a very low rate. The $4e$, 4μ, $2e2\mu$ sub-channels are analyzed separately since there are differences in the four-lepton mass resolutions and the background rates arising from jets misidentified as leptons. The dominant irreducible background in this channel is from non-resonant ZZ production (with both Z bosons decaying to either $2e$, or 2μ, or 2τ with the taus decaying leptonically) and is estimated from simulation. The smaller reducible backgrounds with jets misidentified as leptons, e.g. $Z+\text{jets}$, are estimated from data. This analysis alone excludes the SM Higgs boson at 95% CL. in the ranges $134 < m_H < 158$ GeV, $180 < m_H < 305$ GeV, $340 < m_H < 460$ GeV. The range below 134 GeV is not excluded due to the observed excess of events. The maximal excess is at 119.5 GeV with the local significance of 2.5 σ.

The $H \to \gamma\gamma$ analysis [15] is focused on a search for a narrow peak in the diphoton mass distribution. This is the most important channel in the low mass range. Events are classified according to a multivariate analysis (MVA) discriminator incorporating the kinematics of the di-photon system (excluding $m_{\gamma\gamma}$), a per-event estimate of the expected di-photon mass resolution, and a per-object photon-jet discriminator. This classification is motivated by the fact that the signal-to-background-ratio and relative contribution of fakes from jets varies as a function of the photon kinematics, and the di-photon mass resolution depends on the location of the photons in the calorimeter, whether or not one or both photons convert in the detector volume traversed before the calorimeter, and the probability that the correct primary vertex has been used to compute the di-photon mass. After a loose cut on this multivariate discriminant, the event sample is split into two mutually exclusive sets: (i) diphoton events with one forward and one backward jet, consistent with the VBF topology, and (ii) all remaining events. This division is motivated by the consideration that there is a better signal-to-background-ratio in the first set compared to the second. The second set, containing over 99% of data, is further subdivided into four classes based on the multivariate discriminant, in order of decreasing S/B. The background in the signal region is estimated from a fit to the observed diphoton mass distribution in data. This analysis excludes the SM Higgs boson in a number of low mass bands, but the most interesting feature observed in it is the excess of events at 125 GeV with the local significance of 2.9 σ.

The $H \to \tau\tau$ search [16] is performed using the final-state signatures $e\mu$, $\mu\mu$, $e\tau_\text{h}$, and $\mu\tau_\text{h}$, where electrons and muons arise from leptonic τ-decays $\tau \to \ell\nu_\ell\nu_\tau$ and τ_h denotes hadronic τ-decays $\tau \to \text{hadrons} + \nu_\tau$. Each of these four categories is further divided into three exclusive sub-categories according to the nature of the associated jets: (i) events with the VBF signature, (ii) events with just one jet with large transverse energy E_T, and (iii) events with either no jets or with one with a small E_T. In each of these twelve categories we search for a broad excess in the reconstructed $\tau\tau$ mass distribution. The main irreducible background is from $Z \to \tau\tau$ production, whose $\tau\tau$ mass distribution is derived from data by using $Z \to \mu\mu$ events, in which the reconstructed muons are replaced with reconstructed particles from the decay of simulated τ leptons of the same momenta. The reducible backgrounds ($W+\text{jets}$, multijet production, $Z \to ee$) are also evaluated from control samples in data. In addition, a search for $H \to \tau\tau$ is performed for a Higgs boson produced in association with a W boson. Two final states, $e^\pm\mu^\pm\tau_\text{h}^\mp$ and $\mu^\pm\mu^\pm\tau_\text{h}^\mp$, are considered.

The $H \to bb$ search [17] concentrates on Higgs boson production in association with W or Z bosons, in which the focus is on the following decay modes: $W \to e\nu/\mu\nu$ and $Z \to ee/\mu\mu/\nu\nu$. The $Z \to \nu\nu$ decay is identified by requiring a large missing transverse energy E_T^{miss}. The dijet system, with both jets tagged as b-quark jets [18], is also required to have a large transverse momentum, which helps to reduce backgrounds and improves the dijet mass resolution. We use a multivariate analysis technique, in which a classifier is trained on simulated signal and background events for a number of Higgs boson masses, and the events above an MVA output threshold are counted as signal-like. The rates of the main backgrounds, consisting of W/Z+jets and top-quark events, are derived from control samples in data. The WZ and ZZ backgrounds with a Z boson decaying to a pair of b-quarks, as well as the single-top background, are estimated from simulation.

5 Combination methodology

The combination of the SM Higgs boson searches requires simultaneous analysis of the data from all individual search channels, accounting for all statistical and systematic uncertainties and their correlations. The results presented here are based on a combination of Higgs boson searches in a total of 50 exclusive sub-channels described in Section 4. Depending on the sub-channel, the input to the combination may be a total number of selected events or an event distribution for the final discriminating variable. Either binned or unbinned distributions are used, depending upon the particular search sub-channel.

The number of sources of systematic uncertainties considered in the combination ranges from 156 to 222, depending on the Higgs boson mass. A large fraction of these uncertainties are correlated across different channels and between signal and backgrounds within a given channel. Uncertainties considered include: theoretical uncertainties on the expected cross sections and acceptances for signal and background processes, experimental uncertainties arising from modelling of the detector response (event reconstruction and selection efficiencies, energy scale and resolution), and statistical uncertainties associated with either ancillary measurements of backgrounds in control regions or selection efficiencies obtained using simulated events. Systematic uncertainties can affect either the shape of distributions, or event yields, or both.

The combination is repeated for 183 Higgs boson mass hypotheses in the range 110–600 GeV. The step size in this scan varies across the mass range and is determined by the Higgs boson mass resolution. The minimum step size is 0.5 GeV at lower masses, where it is commensurate with the mass resolution of the $\gamma\gamma$ and $4l$ channels. The maximum step size is 20 GeV at large masses, where the intrinsic Higgs boson width is the limiting factor.

The overall statistical methodology used in this combination was developed by the CMS and ATLAS collaborations in the context of the LHC Higgs Combination Group. The detailed description of the methodology can be found in Ref. [19].

The combination procedure introduces a signal strength modifier μ that multiplies the expected SM Higgs boson cross section such that $\sigma = \mu \cdot \sigma_{\rm SM}$. Each independent source of systematic uncertainty is assigned a nuisance parameter θ_i. The expected Higgs boson and background yields are functions of these nuisance parameters, and are written as $\mu \cdot s(\theta)$ and $b(\theta)$, respectively. Most nuisance parameters are constrained by other measurements. They are encoded in the probability density functions $p_i(\tilde{\theta}_i|\theta_i)$ describing the probability to measure a value $\tilde{\theta}_i$ of the i-th nuisance parameter, given its true value θ_i.

For the calculation of the exclusion limit, we adopt the modified frequentist construction CL_s [21].

$$CL_s = \frac{\rm CL_{s+b}}{\rm CL_b}. \tag{3}$$

If $CL_s \leq \alpha$ for $\mu = 1$, we determine that the SM Higgs boson is excluded at the $1 - \alpha$ confidence level. To quote the upper limit on μ at the 95% confidence level, we adjust μ until we reach $CL_s = 0.05$.

6 Results

Combined results of searches for SM Higgs bosons are presented in this section. Unless stated otherwise, the following conventions are used. The observed values are shown by a solid line. A dashed line indicates the median of the expected results for the background-only hypothesis. The green (dark) and yellow (light) bands indicate the ranges in which the measured values are expected to reside in at least 68% and 95% of all experiments under the background-only hypothesis. The probabilities for an observation to lie above or below the 68% (95%) band are at most 16% (2.5%) each. The observed and median expected values of CL_s as well as the 68% and 95% bands are obtained by generating ensembles of pseudo-datasets.

The mass regions where the observed CL_s values are smaller than 0.05 are excluded at 95% CL, the regions where they are smaller than 0.01 are excluded at 99% CL. We exclude a SM Higgs boson at 95% CL in the mass range 127.5 – 600 GeV. At 99% CL, we exclude it in the mass range 129 – 525 GeV.

Figure 3 shows the 95% CL upper limits on the signal strength modifier, $\mu = \sigma/\sigma_{\rm SM}$, obtained by generating ensembles of pseudo-datasets, as a function of m_H. The ordinate thus shows the Higgs boson cross section that is excluded at 95% CL, expressed as a multiple of the SM Higgs boson cross section.

The median expected exclusion range of m_H at 95% CL in the absence of a signal is 114.5–543 GeV. The differences between the observed and expected limits are consistent with statistical fluctuations since the observed limits are generally within the green (68%) or yellow (95%) bands of the expected limit values. For the largest values of m_H, we observe fewer events than the median expected number for the background-only hypothesis, which makes the observed limits in that range stronger than expected. However, at small m_H we observe an excess of events. This makes the observed limits weaker than expected in the absence of a SM Higgs boson.

For masses beyond 200 GeV, the limits are driven mostly by the $H \to ZZ$ decay channels, while in the range 125–200 GeV, the limits are largely defined by the $H \to WW$ decay mode. For the mass range below 120 GeV, the dominant contributor to the sensitivity is the $H \to \gamma\gamma$ channel. The results shown are calculated using the asymptotic formula for the CL_s method.

To quantify the consistency of the observed excesses with the background-only hypothesis, we show in Fig. 4 (left) a scan of the combined local p-value p_0 in the low-mass region. The local p-values shown in Fig. 4 are obtained with the asymptotic formula (lines) and validated by generating ensembles of background-only pseudo-datasets (points).

A broad offset of about one standard deviation, caused by excesses in the channels with poor mass resolution (bb, $\tau\tau$, WW), is complemented by localized excesses observed in the $ZZ \to 4l$ and $\gamma\gamma$ channels. The largest excess in the combination is at 125 GeV and arises mostly from the observed excess in the $\gamma\gamma$ channel. The narrow feature in the $H \to ZZ^{(*)} \to 4l$ channel at 119.5 GeV, associated with three $ZZ \to 4l$ events, is considerably reduced in the combination, mostly by the $H \to \gamma\gamma$ channel that has a better sensitivity and actually shows a deficit of events for that mass.

The minimum local p-value $p_{min} = 0.003$ at $m_H \simeq 125 GeV$ corresponds to a local significance Z_{max} of 2.8σ. The global significance of the observed excess for the entire search range of 110–600 GeV is estimated directly from the data following the method described in Ref. [19] and corresponds to about 0.8 σ. For a restricted range of interest, the global p-value is evaluated using pseudo-datasets. For the mass range 110–145 GeV, it yields a significance of 2.1 σ.

The p-value characterises the probability of background producing an observed excess of events, but it does not give information about the compatibility of an excess with an expected signal. The latter is provided by the best fit $\hat{\mu}$ value, shown in Fig. 4 (right). In this fit the constraint $\hat{\mu} \geq 0$ is not applied, so that a negative value of $\hat{\mu}$ indicates an observation below the expectation from the background-only hypothesis. The band corresponds to the $\pm 1\sigma$ uncertainty (statistical+systematic) on the value of $\hat{\mu}$. The observed $\hat{\mu}$ values are within 1σ of unity in the mass range from 121–126 GeV.

6.1 SM4 Higgs boson

In an extension of the standard model including a fourth generation of fermions (the SM4 model), the additional heavy quarks in the quark loop associated with the $gg \to H$ process greatly enhance its production cross-section. Other production mechanisms are not affected. The Higgs boson decay branching fractions are also strongly affected by the presence of the virtual heavy quarks.

We assume the SM4 benchmark parameters recommended by the LHC Higgs cross section group in Ref. [22]: $m_{D4} = m_{L4} = 600$ GeV and $m_{U4} - m_{D4} = (50 + 10 \cdot \ln(m_H/115))$ GeV. Here m_{U4} and m_{D4} are the masses of the "up" and "down" quarks of the 4th generation, and m_{L4} is the mass of the 4th generation charged lepton. In this case the $gg \to H$ cross section is enhanced by a factor from about 10 (low m_H) to 4 (high m_H).

Following the LHC Higgs cross section group prescription, the theoretical uncertainties on the production and decay of the SM4 Higgs boson are kept the same as for the SM Higgs boson.

For the SM4 Higgs boson search, for each of the production-decay modes, a signal acceptance as used in the SM interpretation is assumed.

We exclude the SM4 Higgs boson at 95% CL in the mass range 120–600 GeV.

In contrast with the SM Higgs boson search, in the SM4 scenario the $H \to \tau\tau$ search becomes the most sensitive channel in the low Higgs boson mass range. This is not unexpected, given the changed values of the Higgs boson cross sections and branching fractions (SM4 $H \to \tau\tau$ branching is 1.5 - 2. times higher than the SM value for the Higgs masses 150 - 160 GeV).

The excess observed in the combination of all channels is too weak to be consistent with the SM4 Higgs boson signal. At 99% CL, we exclude the SM4 Higgs boson in the range 125–600 GeV.

6.2 Fermiophobic Higgs boson

If the Higgs boson responsible for the electroweak symmetry breaking does not couple to fermions, then the $gg \to H$ and $t\bar{t}H$ production modes disappear, while the VBF and VH production cross sections remain unchanged. Direct decays $H \to \tau\tau$ and $H \to bb$ become impossible, while branching fractions for $H \to \gamma\gamma$, $H \to WW$, and $H \to ZZ$ become significantly enhanced for the low mass Higgs boson (factor of about 7 for $H \to \gamma\gamma$ at m_H=125 GeV). Such a Higgs boson is referred to as fermiophobic and appears in a variety of extensions to the SM (e.g. [23] and references therein). In this analysis, loop-induced decays to fermions are ignored.

Following the LHC Higgs cross section group prescription, the QCD scale uncertainties on the FP Higgs boson production are increased by 5% with respect to those of the SM Higgs boson. This 5% uncertainty, added linearly to the SM Higgs QCD scale uncertainties, is introduced to cover the effects of electroweak corrections, which have not yet been calculated. For the fermiophobic Higgs boson search, for each of the production-decay modes, a signal acceptance as used in the SM interpretation is assumed.

The fermiophobic Higgs boson is excluded at 95% CL in the mass range 110–192 GeV. At 99% CL, we exclude the fermiophobic Higgs boson in the range 110–188 GeV, with the exception of two gaps: 124.5–128 and 148–154 GeV.

The local p-value calculated for the fermiophobic Higgs boson shows an excess at $m_H \sim 125$ GeV, almost as pronounced as in the SM Higgs combination. However, this excess is too weak to be consistent with the fermiophobic Higgs boson signal.

6.3 Searches for other BSM (Beyond Standard Model) Higgs bosons

The Higgs sector in the supersymmetric models is more complicated. Namely, in the MSSM (Minimal Supersymmetric Model) there are two Higgs doublets resulting in the SM-like Higgs boson h^0 plus two other neutral bosons A^0, H^0 and a charged boson $H^{\pm}$. The production rate and coupling to τ-leptons and b-quarks can be enhanced and depend on the supersymmetric parameter $tan\beta$.

The search for corresponding particles is also performed by the CMS collaboration. The results are often presented as limits on the supersymmetric parameters m_A - $tan\beta$ plane [24].

In the NMSSM models (Next to MSSM) the existence of light boson decaying to a lepton pair is possible. Some extensions of the SM, such as models with type II seesaw mechanism [25], introduce doubly charged Higgs. The analysis of the 2011 data alowes to obtain limits on these particles. The limit on the former is expressed in the limits on supersymmetric parameters [26], while the limits on the mass of the doubly charged Higgs boson are in the range 350–450 GeV [27].

7 Conclusions

Results are reported from searches for a Higgs boson in proton-proton collisions at $\sqrt{s}$=7 TeV. Five decay modes of the Higgs boson are used in the combination: WW, ZZ, $\gamma\gamma$, $\tau\tau$ and bb. The explored Higgs boson mass range is 110 - 600 GeV. The analysed data correspond to an integrated luminosity of 4.6–4.8 fb^{-1}. The expected excluded mass range in the absence of the standard model Higgs boson is 114.5–543 GeV at 95% CL. The observed results exclude the standard model Higgs boson in the mass range 127.5–600 GeV at 95% CL, and in the mass range 129–525 GeV at 99% CL. An excess of events above the expected standard model background is observed at the low end of the explored mass range making the observed limits weaker than expected in the absence of a signal. The largest excess, with a local significance of 2.8σ, is observed for a Higgs boson mass hypothesis of 125 GeV. The global significance of observing an excess with a local significance $> 2.8\sigma$ anywhere in the search range 110–600 (110–145) GeV is estimated to be 0.8σ (2.1σ). More data are required to ascertain the origin of the observed excess. For an extension of the standard model including a fourth generation of fermions (SM4), the SM4 Higgs boson is excluded in the mass range 120–600 GeV at 95% CL. In the fermiophobic (FP) Higgs boson scenario, the FP Higgs boson is excluded in the mass range 110–192 GeV at 95% CL.

The 2012 LHC run is now ongoing at $\sqrt{s}$=8 TeV. At this collision energy the low mass Higgs production cross section is larger by 25 - 30%. The priority in this run is given to the Higgs boson search. The data taking and analysis of the 2012 run will be even more challenging because of increased instantaneous luminosity (factor of two). The statistics collected by June 2012 should give a possibility to make conclusive statements (confirmation at the observation level or exclusion at least at 95% CL) about the hints of the possible presence of the SM Higgs boson at around 125 GeV.

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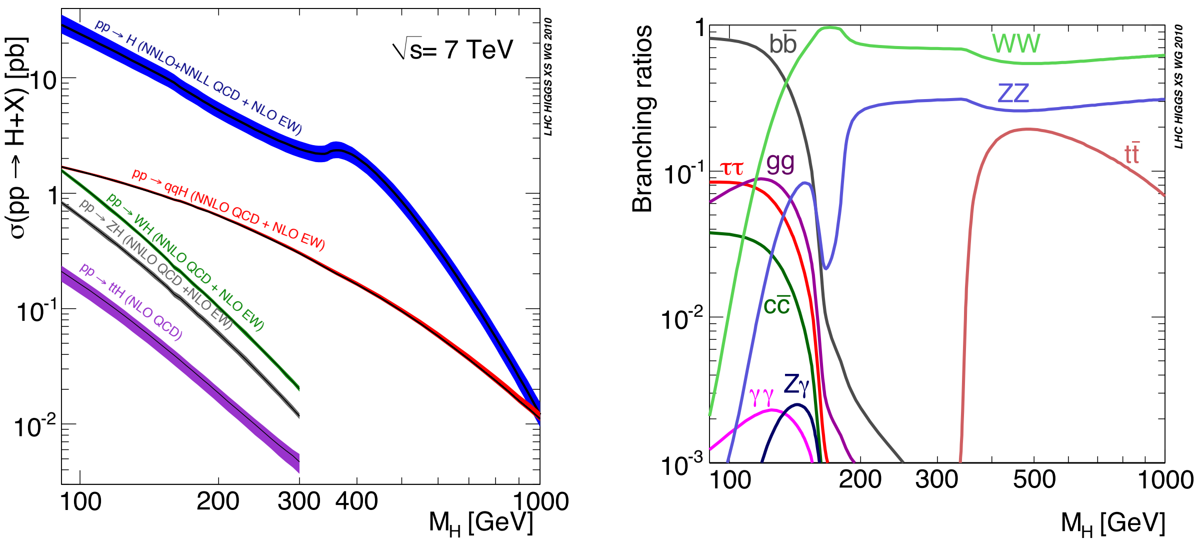

Figure 1: The standard model Higgs boson production cross sections (left) and decay branching fractions (right). The plots are taken from Ref. [9].

Channel	Mass range [GeV]	Branching	Production modes	Sensitivity range	Other comments
H->γγ	110-150	$2\cdot10^{-3}$	inclusive, VBF	Most sensitive at low mass	Good mass resolution
H->bb	110-135	~0.7	VH		
H->ττ	110-150	~0.08	Inclusive, VBF, VH		
H->WW->lνlν	110-600	~0.03	gg-fusion, VBF, VH	Most sensitive at intermediate mass	
H->ZZ->4l	110-600	$(3-8)\cdot10^{-4}$	Inclusive		Good mass resolution
H->ZZ->other decays	~200-600	~0.2	inclusive	Most sensitive at high mass	
H->WW->lνqq	170-600	~0.15	inclusive		

Figure 2: SM Higgs boson decay channels and production modes relevant for the searches at the LHC.

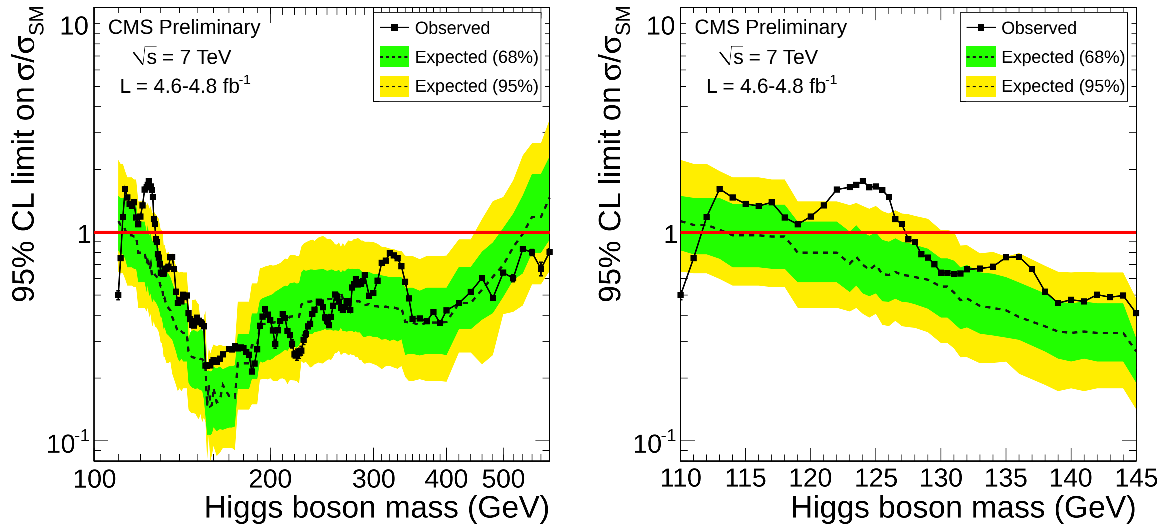

Figure 3: The observed and expected 95% CL upper limits on the signal strength parameter $\mu = \sigma/\sigma_{\rm SM}$ for the SM Higgs boson hypothesis as a function of the Higgs boson mass in the range 110–600 GeV (left) and 110–145 GeV (right).

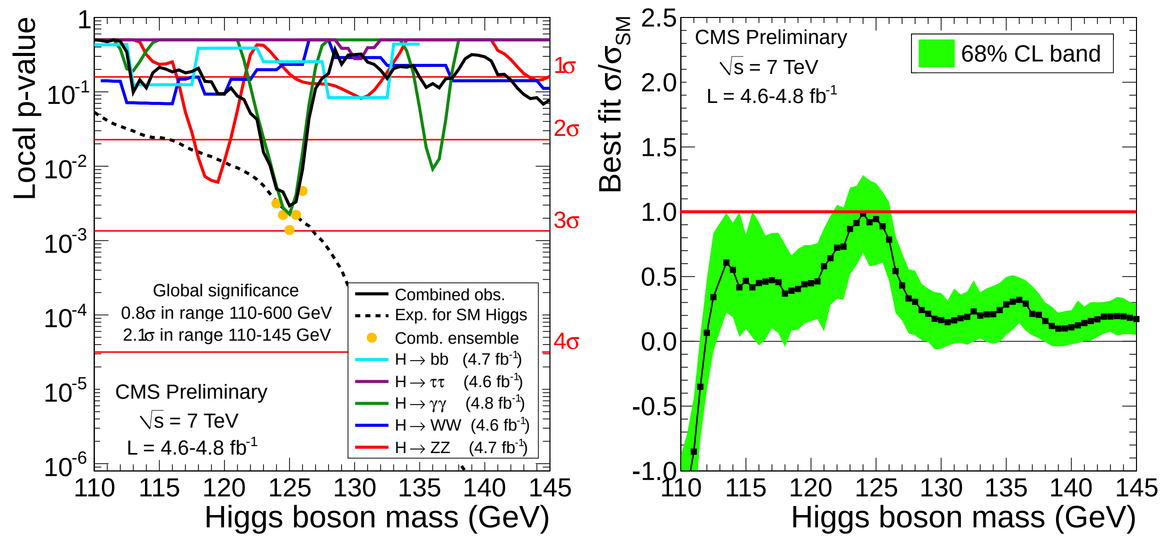

Figure 4: The observed local p-value p_0 (left) and best-fit $\hat{\mu} = \sigma/\sigma_{\rm SM}$ (right) as a function of the SM Higgs boson mass in the range 110–145 GeV. The local p-values for individual channels and their combination are obtained with the asymptotic formula (lines); the combined local p-value is validated by generating ensembles of background-only pseudo-datasets (points). The dashed line shows the expected local p-values $p_0(m_H)$, should a Higgs boson with a mass mH exist. The band in the right plot corresponds to the $\pm 1\sigma$ uncertainties on the $\hat{\mu}$ values.