Higgs searches in CMS

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1 Introduction

The search for the scalar boson of the Brout-Englert-Higgs mechanism [1, 2] is one of the most important aspects of the program of the Large Hadron Collider. The boson has been excluded at 95% confidence level (CL) by direct searches at LEP [3] for masses smaller than 114.4 GeV and at Tevatron [4] for masses around 160 GeV.

In the context of the Standard Model (SM) indirect constraints from precision electroweak measurements favour a low mass Higgs boson, with the upper limit $m_H <$ 169 GeV at 95% CL from the standard fit and $m_H <$ 143 GeV at 95% CL including direct searches before LHC. The dominant Higgs production mode at LHC is the gluon-gluon fusion, followed by vector boson fusion (VBF) and associated production with a vector boson (VH) which have smaller cross sections but cleaner final states. The search channels as well as their optimization vary as function of the Higgs mass. The most sensitive decay at low mass, below approximately 130 GeV, is the one into two photons; between $\sim$130 and 200 GeV the WW channel is the most sensitive, and above $\sim$200 GeV the various ZZ channels take over.

A detailed description of the CMS detector can be found in [5]. The analyses described in the following use up to 5 $fb^{-1}$of data collected during 2011 by CMS at a center-of-mass energy of 7 TeV, with an average of 9 pile-up interactions per bunch crossing. Results of searches for the Higgs in the Standard Model and beyond (SUSY and other BSM scenarios) are discussed.

2 Low mass SM channels

2.1 H $\rightarrow \gamma\gamma$ channel

The Higgs boson branching ratio for the decay into two photons is approximately 2×10^{-3} between 110 and 150 GeV. The diphoton mass resolution is very good, around 1-2%, and the signature in this channel is two high E_T isolated photons. A signal would appear as a small, narrow peak above a large background smoothly falling. After the final selection, the dominant background is the irreducible $\gamma\gamma$ QCD production, followed by events in which at least one of the two identified photons is a jet faking a photon. Events produced via VBF are selected requiring two extra jets at large $\Delta\eta$. The signal to background ratio in the di-jet tag class is relatively large, bringing to an improvement on the exclusion sensitivity of approximately 10% in cross section [6, 7]. For the limit and significance calculation, the background is estimated by fitting with a polynomial the full mass range. We found that the possible bias in the background estimation is always less than 20% of the statistical error. The expected 95% CL exclusion limit on the cross-section varies between 1.2 and 2 times the SM prediction, while data exclude at 95% CL the mass ranges 110.0-111.0 GeV, 117.5-120.5 GeV, 128.5-132.0 GeV, 139.0-140.0 GeV and 146.0-147.0 GeV. We observe the largest excess around 125 GeV with a local significance of 2.9σ. The global significance is 1.6σ when taking into account the look elsewhere effect (LEE) estimated in the full mass range 110-150 GeV.

2.2 H $\rightarrow \tau\tau$ and H $\rightarrow bb$ channels

The H $\rightarrow \tau\tau$ and H $\rightarrow bb$ channels are the only Higgs boson decays into fermions detectable at LHC. They are less sensitive than the H $\rightarrow \gamma\gamma$ channel, but would be important to measure the couplings to leptons and quarks. In both channels the background for the inclusive search is huge and the sensitivity is improved by requesting additional tags.

For the $\tau\tau$ channel we exploit the VBF production as well as a boosted topology. The mass reconstruction is not very precise (around 20%) due to the presence of neutrinos in the decay. The search is performed in the mass range between 110 and 150 GeV [8] and the expected exclusion limit at 95% CL is approximately 3 times the SM prediction, without any significant excess in data.

To study the Higgs decays to bb we exploit the VH associated production with W and Z decaying leptonically [9]. We require the bb system to be boosted to improve both the background rejection and the mass resolution, which is about 10%. We perform the search in the mass range between 110 and 135 GeV and the expected sensitivity for exclusion ranges from 3 to 6 times the SM. Also in this channel we see no significant excess in data.

3 SM channels sensitive in the full mass range

3.1 $H \to WW \to 2\ell 2\nu$ channel

The H $\to WW \to 2\ell 2\nu$ channel is the most sensitive one approximately in the mass range 125-200 GeV. The final state consists of two isolated high p_T leptons and large missing transverse energy due to the presence of the two undetected neutrinos, which are also responsible for the poor mass resolution (of the order of 20%). The most important backgrounds are the irreducible WW production and the reducible W plus jets, Z plus jets, ttbar and di-bosons productions. Most of them are estimated from data.

The analysis [10] is performed in the full mass range from 110 to 600 GeV, in exclusive jet multiplicities (0, 1 and 2-jet bins) and flavour (ee, $\mu\mu$, eμ) categories because of the different sensitivities and background contributions. The 2-jet bin corresponds to the VBF topology and the search exploits characteristics such as the presence of jets at large p_T, $\Delta\eta$ and di-jet invariant mass. Two types of searches are carried out: a cut-and-count analysis for all the sub-channels and a multivariate analysis which is applied to the 0 and 1-jet bins only. In both cases a mass dependent selection is used. We observe no significant excess in the full mass range though a small excess is observed at low mass. The 95% C.L. expected exclusionis for m_H between 127 and 270 GeV, while the range 129-270 GeV is excluded at 95% CL in data.

3.2 $H \to ZZ \to 4\ell$ channel

The H $\to ZZ \to 4\ell$ channel has the cleanest final state, which is characterized by the presence of four isolated leptons. For high Higgs mass both pairs of opposite charge and same flavour leptons are consistent with Z decays, while for lower Higgs masses at least one pair has lower mass. The mass resolution is very good and ranges between 1 and 2%. The Higgs branching ratio for this channel is rather small but the background is almost negligible. It mainly consistes of irreducible continuum ZZ production and, to a lesser extent, Z plus jets and Zbb. The p_T of the lower p_T lepton is rather small and one of the most challenging issues of the analysis is the achievement of high lepton selection efficiency down to very low p_T. The analysis is carried out in the full mass range, from 110 to 600 GeV [11]. We do not observe any significant excess in data and we exclude at 95% CL the SM Higgs boson with m_H in the 134-158, 180-305 and 340-465 GeV regions. The most significant excess is given by an accumulation of 3 events at a mass of approximately 119.5 GeV. It has a local significance of 2.5σ and a global significance of 1.0σ in the full mass range and 1.6σ in the mass range 100-160 GeV.

4 High mass SM channels

The SM Higgs boson almost exclusively decays into WW and ZZ for masses above approximately 200 GeV. The search in the previously described H→ $WW \rightarrow 2\ell 2\nu$ and H→ $ZZ \rightarrow 4\ell$ channels have been performed in CMS up to m_H 600 GeV. For the high mass region searches have been performed also in the ZZ channels where one Z decays into ν [12], quark [13] and τ pairs [14]. The first one has high sensitivity for $m_H > 250$ GeV, resulting in a 95% CL exclusion of Higgs masses in the 270-440 GeV region. The second channel a little lower sensitivity, while the last one has a sensitivity of about 4 times the SM. The search in the channel H→ $WW \rightarrow qql\nu$ has been also performed, which has good sensitivity for high masses resulting in a 95% CL exclusion of m_H in the range 327-415 GeV.

5 Combination of all SM channels

Eleven SM decay channels have been studied in CMS using up to 5 $fb^{-1}$of 7 TeV collision data and they are combined to obtain the final exclusion and discovery confidence levels. The combination is carried out using the CLs method. The values of cross sections and branching ratios and their theoretical uncertainties are taken from the LHC cross section working group [15]. More details on the present combination, which includes preliminary results, can be found in [16]. An overall signal strength multiplier $\mu = \sigma/\sigma_{\rm SM}$ is introduced and limits on its value are derived.

Figure 1 on the left shows the SM exclusion confidence level as function of the Higgs boson mass. The SM Higgs boson is excluded by our search at 95% confidence level in the range 127.5–600 GeV and at 99% confidence level in the range 129–525 GeV. The expected 95% exclusion is 114.5–543 GeV. The observed upper limit on the Higgs boson mass is higher than expected in case of no signal because of the excess that is observed in the data in the region between 115 and 128 GeV. Figure 1 on the right shows the local p-value as a function of the Higgs boson mass, which quantifies the probability that a background-only fluctuation is more signal-like than the observation. The minimum combined p-value is observed at a mass of 125 GeV with a local significance of 2.8σ. A similar significance is expected in presence of a 125 GeV Higgs boson signal. When taking into account the look elsewhere effect estimated in the mass range 110-600 GeV (110-145) we obtain a global significance of 0.8σ (2.1σ). The fitted value of the signal strength multiplier $\mu = \sigma/\sigma_{\rm SM}$ of the excess near 125 GeV is consistent with the SM scalar boson expectation and several channels show some excess, though most of it comes from the $H \rightarrow \gamma\gamma$ channel.

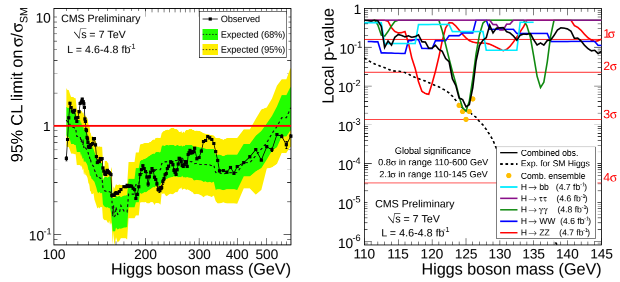

Figure 1: Exclusion confidence level for the combined SM Higgs search in the full mass range 110–600 GeV (left) and combined local p-value for the SM Higgs search (right).

6 Non Standard Model Higgs searches

While the Standard Model describes very precisely the experimental measurements some open points still arise like the dark matter origin and the hierarchy problem. Theories have been proposed to answer some of these questions, such as supersymmetry or other scenarios beyond the standard model (BSM). In the Minimal Superymmetric Standard Model (MSSM), the standard scalar Higgs boson is replaced by three neutral (h, H, A) and two charged ($H^{\pm}$) Higgs particles, and all decays to down-type fermions are enhanced by a factor tanβ. The MSSM neutral Higgs bosons are searched in CMS in the $\tau\tau$ final state and a large fraction of the MSSM Higgs parameters space is constrained [8]. Charged MSSM Higgs bosons are searched in the top decays $t \to bH^{\pm}$ with τ final states $H^{+} \to \tau\nu$ [17]. Higgs studies in the context of the next-to-minimal-supersymmetric extensions of the Standard Model [18] or the see-saw model [19] are also carried out. Finally, searches for the Higgs boson in extensions of the Standard Model including a fourth generation of fermions (SM4) or with a Fermiophobic Higgs are performed [16]. No excess is found in any of these searches with 2011 data, and limits are set.

7 Conclusions

The search for the SM Higgs boson in different final states, using CMS data at $\sqrt{s} =$ 7 TeV, has been presented. The SM Higgs boson is excluded at 95% CL in the mass range 127.5-600 GeV, and an excess of events above the expected SM background is observed at the lower end of the explored mass range. The largest excess, with a local significance of 2.8 standard deviations, is observed for a Higgs boson mass hypothesis of 125 GeV. In addition, a broad program of BSM Higgs searches has been performed, showing no evidence for BSM Higgs bosons.

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