Search for the SM Higgs in the two photon and tho Z to four lepton decay channels at CMS

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Results are presented on the search for the Standard Model Higgs decaying into two photons or into two Z bosons, with each Z boson decaying into a pair of charged leptons. The full data sample of 4.7/fb of pp collisions collected in 2011 with the CMS experiment at the LHC have been analysed. The search results are translated into 95% exclusion limits for the Higgs boson, as function of the Higgs mass.

1 Introduction

The Standard Model (SM) of particle physics is an extremely accurate description of the fundamental particles and their interactions. Although the predictions of the SM have been experimentally verified to extreme precision, the mechanism by which the W and Z bosons acquire mass while the photon remains massless is unknown. One proposed mechanism by which this is achieved in nature is through spontaneous electroweak symmetry breaking through the introduction of a complex scalar field. In addition to supplying a mechanism by which the W and Z gain mass, the theory predicts the existence of a fundamental scalar boson, the SM Higgs boson. The mass of this particle, m_H, is not predicted by the theory although direct searches [1] and precision electroweak measurements [2] suggest a range $114 < m_H < 152$ GeV. The two decay channels $H \rightarrow \gamma\gamma$ and $H \rightarrow ZZ \rightarrow 4l$ provide very clean final states with a fully reconstructible mass peak making them very sensitive at low m_H. This document describes the search performed using data recorded at CMS corresponding to $4.7fb^{-1}$ of pp collisions at $\sqrt{s} = 7$TeV.

2 $H \rightarrow \gamma\gamma$ decay channel

The search for the Higgs boson decaying to two photons is described in detail in [3]. Although this decay channel has a relatively low branching ratio of around 10^{-3}, such events can be selected online readily by the presence of two high p_T photons. The main SM backgrounds are prompt photons from hard QCD interactions (around 70%) and fakes from narrow jets and π^0's. Since these backgrounds are non-resonant, the main strategy is to search for a narrow mass peak on a smoothly falling background in the invariant mass, $m_{\gamma\gamma}$, spectrum.

2.1 Event Selection and Classification

Cuts of $p_T/m_{\gamma\gamma} > \frac{1}{3}, \frac{1}{4}$ are applied to the photons. The cuts are designed to reduce inefficiencies in triggering and to avoid shaping the background spectrum.

A boosted decision tree (BDT) is trained at the per photon level to discriminate against fake photons. In addition to variables describing the shower shape and isolation of the two photons, the number of vertices in the event is included in order to maintain the efficiency in high pileup conditions. A second event-level BDT is trained to rank the vertices of the event using information from tracks and the diphoton system and select the vertex that most likely produced the Higgs. The efficiency for selecting the correct vertex is measured using $Z \to \mu\mu$ events in data and found to be around 80%.

For low m_H the width of the signal peak is dominated by the resolution of the electromagnetic calorimeter (ECAL). A regression BDT is used to correct the energy of the photons using information from the ECAL to improve the resolution of the signal mass peak. The resolution in data is measured using $Z \to ee$ events. The uncertainty in this measurement is the dominant source of systematic.

A final BDT is used to categorize the events based on their resolution and kinematic properties of the diphoton system. The number of categories and the range in BDT output covered is optimized to produce the lowest expected limit.

One additional category is formed from events in which at least two jets with $E_T > 30/20$ GeV are identified. This category exploits vector-boson fusion production of the Higgs which accounts for around 10% of the signal. The requirement of two jets greatly improves the signal to background ratio for these events and increases the overall sensitivity of the search by 10%.

2.2 Results

A shape analysis in $m_{\gamma\gamma}$ is used in order to statistically interpret the data. The background in each category is modelled using a polynomial whose number of degrees of freedom is chosen to provide negligible bias in the result while the signal is modelled using MonteCarlo simulation which is tuned to data. The largest excess in the data is found around 125 GeV and corresponds to a local significance of 2.9σ. The results are translated into exclusion limits on SM Higgs production in the range $110 < m_H < 150$ at the 95% confidence level. The expected exclusion is less than $2\times$ SM across this range.

3 $H \to ZZ \to 4l$ decay channel

The search for the SM Higgs boson in the four lepton decay channel is described in detail in [4]. The four lepton decay mode provides a very clean, fully reconstructible final state. The channel is particularly sensitive as the ratio of signal to background exceeds 1. The largest of the backgrounds is from the ZZ continuum from QCD while the remaining backgrounds are largely from Zbb and $t\bar{t}$ production.

The search is performed in three categories, $\mu^+\mu^-\mu^+\mu^-$, $\mu^+\mu^-e^+e^-$ and $e^+e^-e^+e^-$ in order to exploit the varying levels of signal to background from the different final states.

3.1 Object Identification

Since there is very little contamination from background, the four lepton search is designed to maximise the efficiency of the signal selection. Electrons and muons can be reconstructed with transverse momenta as low as 7 and 5 GeV within the detector acceptance respectively with both the electron and muon identification remaining $> 85\%$ efficient for $p_T > 10$ GeV. Selection of the signal requires two opposite signed, same flavour combinations of the identified leptons with invariant masses $50 < m_{Z_1} < 120$ and $12 < m_{Z_2} < 120$ with the leptons satisfying $p_T > 20/10$ GeV.

The contribution from background processes is measured using data-driven techniques. The ZZ production rate is estimated from single Z production in a control region and propagated to the signal region using theoretical calculations for the ratio of single to two Z production cross-sections and efficiencies for lepton identification measured in data. The $Z + X$ background is determined by measuring the lepton mis-identification rate in a $Z+l$ sample in data. A 30% systematic is included on this background to account for uncertainty in the p_T dependence of the mis-identification rate.

3.2 Results

A total of 13 events were observed in the range $110 < m_{4l} < 160$ GeV while 9.5 ± 1.3 were expected from SM backgrounds. A shape analysis in m_{4l} were performed to statistically interpret the data. The backgrounds are modelled using polynomials whereas the signal is modelled using a parametric fit to signal MonteCarlo. The largest local excess in the range of Higgs masses tested corresponds to a significance of 2.5σ near 119 GeV. Exclusions on the production of a SM Higgs bosons are placed in the range 134 to 158 GeV at the 95% confidence level.

4 Combined Results

The two searches in the decay channels $H \to \gamma\gamma$ and $H \to ZZ \to 4l$ were combined statistically to calculate exclusion limits and local significances of the data as shown in figure 1. The data exclude the production of the SM Higgs with a mass in the

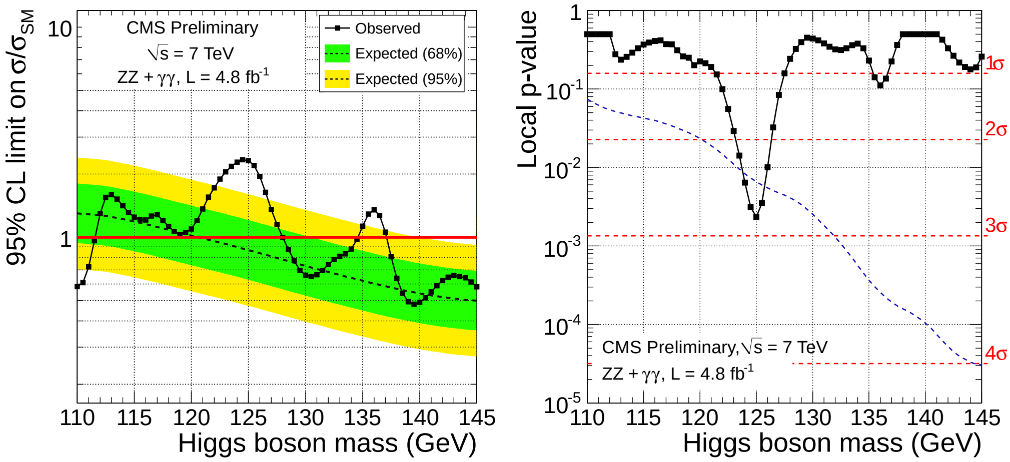

Figure 1: Combined results from the $H \to \gamma\gamma$ and $H \to ZZ \to 4l$ searches in the low mass region, $110 < m_H < 145$ GeV. Upper panel: Exclusion limits are on the production of the SM Higgs given the data observed. Lower panel: Local significances of excesses in data. The dashed blue line in the lower panel shows the expected local p-value should a Higgs boson with mass m_H exist while the solid shows the observed p-values.

ranges $128 < m_H < 134$ GeV and $137 < m_H < 145$ GeV at the 95% confidence level. The largest excess observed is at 125 GeV corresponding to a local significance of 2.8σ. This is reduced to 1.6σ when accounting for the look-elsewhere effect.

References

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