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CMS CR -2012/215

The Compact Muon Solenoid Experiment

Conference Report

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

30 August 2012

Searches for a Light Higgs with CMS

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Abstract

Given that a light Higgs Boson is favored by electroweak precision measurements and LHC's data are becoming sensitive to the SM Higgs' cross section at low mass, the search for SM Higgs in this phase space is very exciting. We report on the search for a low mass Higgs Boson with the CMS detector using the full 2011 dataset extracted from proton-proton collisions provided by LHC at 7 TeV center-of-mass energy. Thanks to the excellent performance of LHC and CMS, this dataset corresponds to approximately 5/fb of data. The di-photon, WW, ZZ, bb and tau tau Higgs' decay channels are sensitive to low mass Higgs (roughly ¡ 150 GeV), and they will be highlighted along with the combined CMS low mass Higgs result.

Presented at *CIPANP 2012: Conference on the Intersections of Particle and Nuclear Physics (2012)*

Searches for a light Higgs with CMS

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Given that a light Higgs Boson is favored by electroweak precision measurements and LHC's data are becoming sensitive to the SM Higgs' cross section at low mass, the search for SM Higgs in this phase space is very exciting. The search for a low mass SM Higgs Boson with the CMS detector using the full 2011 dataset extracted from proton-proton collisions provided by the LHC at 7 TeV center-of-mass energy has yielded 95% CL exclusion limits of 127.5 to 600 GeV while an excess near 125 GeV has been observed. Thanks to the excellent performance of LHC and CMS, this dataset corresponds to approximately 5/fb of data. The di-photon, WW, ZZ, bb and $\tau\tau$ Higgs decay channels are sensitive to low mass Higgs (roughly less than 150 GeV), and they will be highlighted along with the combined CMS low mass Higgs result. In addition, limits derived for a Fermiophobic higgs boson are reported (110-173 GeV at 95% CL).

1 Introduction

The electroweak sector of the Standard Model (SM) predicts a scalar (Higgs) boson which has not conclusively been discovered [1,2,3,4]. A free parameter of electroweak theory is the mass of the Higgs. LHC has been constructed to ascertain the existence of this fundamental particle (or exclude it with great confidence). CMS has been designed to optimize the sensitivity of the search for the Higgs in the most siginificant decay modes over a wide range of possible masses.

Electroweak precision measurements favor Higgs with a mass less than 143 GeV [7]. Previous direct searches have set exclusion limits at the 95% confidence level (CL). LEP excluded SM higgs below 114.4 GeV at 95% CL [5]. The Tevetron combined results have produced exclusion limits at the 95% CL in a range of 147 to 179 GeV [6].

The results of 2011 proton-proton collisions at a center-of-mass energy of 7 TeV were published in early 2012. The results presented here are from the Moriond conference with the same data as the publication with a more sensitive analysis in the $\gamma\gamma$ channel and the addition of a few more sub-channels which add to the overall senitivity.

The most frequent production mode of a SM Higgs Boson at the LHC would be gluon fusion. The next two production modes are vector boson fusion (VBF) and higgstralung via a vector boson (VH). For a SM Higgs boson these production modes would occur at rates approximately 10% of the gluon fusion rate. For a fermiophobic (FP) Higgs Boson there would be no gluon fusion (because the fermion coupling is required), and thus, VBF and VH are the dominant production modes in the FP Higgs scenario. The decay branching ratios of the Higgs boson vary with its mass and for the SM Higgs are dominated by bb and $\tau\tau$ at low mass and by WW and ZZ above 135 GeV. The $\gamma\gamma$ decay channel is most important in the mass range below 130 GeV and its branching ratio is of the order of 10^{-3}. For a FP Higgs the only allowed decays are to the gauge bosons, and so the branching ratios to WW, ZZ and $\gamma\gamma$ are much larger. Indeed, the

$\gamma\gamma$ branching ratio is the dominant decay at low mass for a FP Higgs Boson.

The values of cross section and branching ratios used in the following are taken from the LHC cross section working group [8,9].

In 2011 we had an excellent performance of both LHC and CMS and this allowed us to collect approximately 5 fb^{-1} of data that are good for all analyses. The CMS detector is a multipurpose detector and is extensively described in [10]. The average pileup was about 10 events per bunch crossing, and special care was taken to mitigate its effects on the analysis.

2 Analysis strategy

The SM higgs boson search is performed in the mass range from 110 and 600 GeV. This document will describe the highlights of the analyses performed in the mass range of 110 to 150 GeV. Since the decay branching ratios of a higgs boson significantly vary as a function of its mass, analyses are performed for mass ranges where that decay channel contributes to overall sensitivity. Likewise, since the decay kinematics vary as a function of higgs' mass, some analyses are optimatized as a function of mass.

The most sensitive channel below approximately 130 GeV is the $\gamma\gamma$ channel. Near 130 the WW channel becomes more sensitive. This is true for SM and FP Higgs Boson scenarios. Table 1 summarizes the channels used for the SM Higgs Boson search.

Table 1: These are the channels used to search for a low mass SM Higgs Boson in CMS.

Channel	m_H range (GeV)	Luminosity (fb^{-1})	Sub-channels	m_{H} resolution
$\text{H} \to \gamma\gamma$	110–150	4.8	2	1–2%
$\text{H} \to \tau\tau \to e\tau_{\text{h}}/\mu\tau_{\text{h}}/e\mu + X$	110–145	4.6	9	20%
$\text{H} \to \tau\tau \to \mu\mu + X$	110–140	4.5	3	20%
$W\text{H} \to e\mu\tau_h/\mu\mu\tau_h + \nu$'s	100–140	4.7	2	20%
$(\text{W/Z})\text{H} \to (\ell\nu/\ell\ell/\nu\nu)(\text{bb})$	110–135	4.7	5	10%
$\text{H} \to \text{WW}^* \to 2\ell2\nu$	110–600	4.6	5	20%
$W\text{H} \to \text{W}(\text{WW}^*) \to 3\ell3\nu$	110–200	4.6	1	20%
$\text{H} \to \text{ZZ}^{(*)} \to 4\ell$	110–600	4.7	3	1–2%

3 Channels

3.1 $H \to \gamma\gamma$ 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, between 1 and 2% and the signature in this channel is two high E_{T} isolated photons. In case of the VBF there are two additional high p_{T} jets that provide a further handle to discriminate the signal from the background. A signal in this channel would appear like a small, narrow peak above a large and smooth background. Figure 1 shows a VBF candidate and the mass spectrum of the data and the Monte Carlo background with a superimposed Higgs signal at 120 GeV. The signal is multiplied by 5 to increase its visibility. As can be seen from the figure, after the final selection, the background is dominated by the irreducible two photon QCD production. However there is also a relevant contribution from events in which at least one of the two identified photons is a jet faking a photon. The MC background estimation has large uncertainties, but it enters the analysis only to help the optimization process. It is not used for the derivation of the results for which only the data and the signal MC are employed.

VBF events are selected by using the same photon identification as for the inclusive analysis, but slightly increasing the asymmetry on the photon E_{T} cuts and finally applying additional requirements on jet variables. The signal to background ratio in the di-jet tag class is relatively

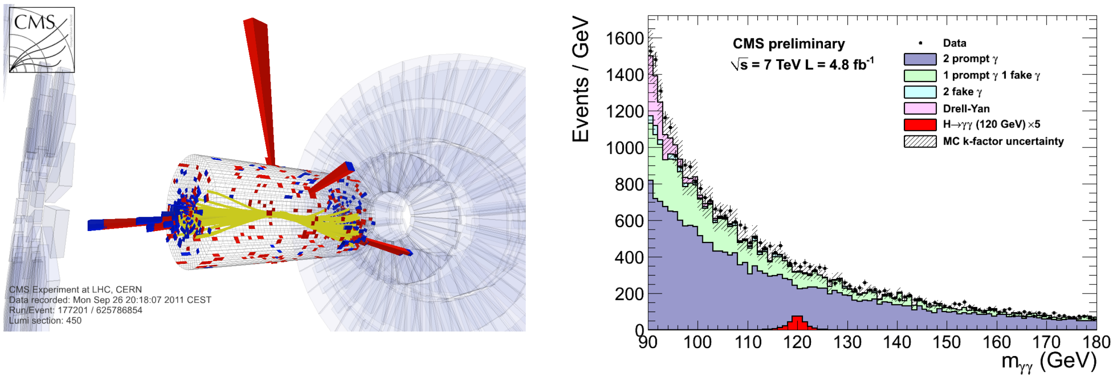

Figure 1: Left: VBF $\gamma\gamma$ candidate event display, Right: di-photon mass spectrum for all events passing the final selection. Data are shown together with the background MC prediction. The hatched area indicates the systematic error on the background normalization from the K-factors. The expected Higgs signal at 120 GeV is also shown superimposed and scaled by a factor 5.

large, and we obtain an improvement on the exclusion sensitivity of approximately 10% in cross section. For the remaining events, in the analysis reported in [12,13] the sensitivity was increased by splitting the dataset into four non overlapping event classes based on the photon pseudorapidity and shower shape. In the analysis presented here, categories are defined in a more optimal way using a MVA based approach that results in a higher sensitivity. Event by event mass resolution, photon Id discriminant, di-photon kinematic variables and vertex probability are combined using a boosted decision tree (BDT). The overall sensitivity improvement of the MVA based analysis is about 20% in exclusion cross section that corresponds to an integrated luminosity increase of more than 50%.

For the limit and significance calculation, the background is estimated by fitting to a polynomial in the full mass range (3^{rd} to 5^{th} order, depending on the class). We found that the possible bias in the background estimation is always less than 20% of the statistical error.

Figure 2 shows the results in terms of 95% CL exclusion on the cross section normalized to the SM cross section and the local p-value where the p-value is the probability that a background only fluctuation is more signal-like than the observation. The expected 95% CL exclusion varies between 1.2 and 2 times the SM while data exclude at 95% CL the 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. Its global significance is 1.6σ when taking into account the look elsewhere effect (LEE) estimated in the full mass range 110–150 GeV.

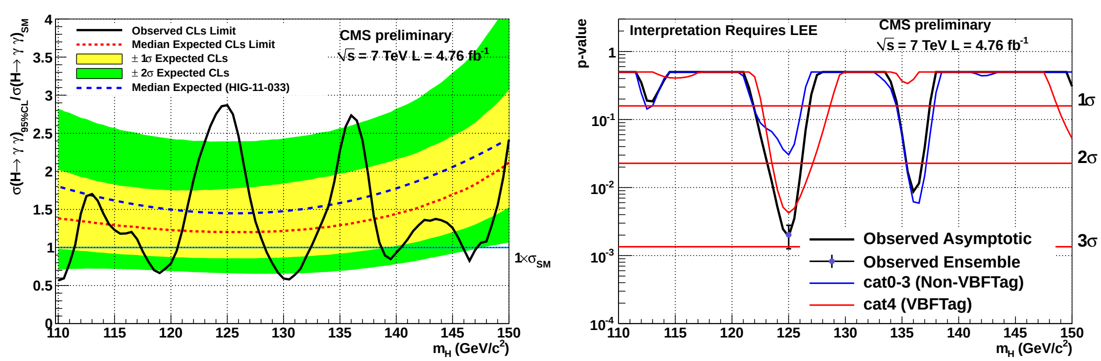

Figure 2: Left: 95% exclusion on the relative signal strength to the SM in the $\gamma\gamma$ channel for the MVA based analysis. The dashed line indicates the expected limit for the cut based analysis. The yellow and green bands indicate the 1 and 2σ expectations around the median expected result. Right: local p-value as function of the Higgs mass. The combined p-value is shown and the VBF tag and other inclusive classes individual contributions are also shown.

3.2 $H \to \tau\tau$ and $H \to bb$ channels

These two channels are the only Higgs boson decays into fermions detectable at LHC. They are less sensitive than the $H \to \gamma\gamma$ channel, but they would be important to measure the couplings to leptons and quarks if and when the Higgs boson is discovered. In both channels the background for the inclusive searches is huge and sensitivity is improved by requesting additional tags such as jets or charged leptons from VBF or VH production.

3.3 $H \to WW \to 2\ell 2\nu$ channel

This is the only viable channel for the Higgs boson search around the mass region of $2 \times m_{\mathrm{W}}$ and the most sensitive in the mass range of approximately 125–200 GeV. The Higgs boson mass cannot be precisely measured because of the undetected neutrinos and the resolution is of the order of 20%. The signature is two isolated high p_{T} leptons and the presence of missing transverse energy (MET). The leptons are aligned (small azimuthal angle $\Delta\phi$) because the Higgs boson is a scalar and because of the V-A structure of the W decay.

The main backgrounds to this channel are WW production that is irreducible, Z plus jets, WZ, ZZ and W plus jets. The background estimation is the most important aspect of the analysis and the main background normalizationss are estimated from the data. The analysis [18] is performed in exclusive jet multiplicities (0, 1 and 2-jet bins) and flavour (ee, $\mu\mu$, eμ) because of the different sensitivities and background contributions. Two types of analyses are carried out: the first is a cut-and-count for all subchannels and the second is a multivariate analysis that is applied to the 0 and 1-jet bins that are the most sensitive ones.

Different cuts are applied in the different flavour and same flavour channels. Cuts are tighter and a Z mass veto is applied in the same flavour channels because they are more affected by the Drell Yan background. The cut based selection has mass dependent cuts while the MVA based analysis uses a BDT trained at different masses with a few extra kinematic inputs.. The overall uncertainties after the final selection are approximately 20% for the signal efficiency and 15% for the expected background.

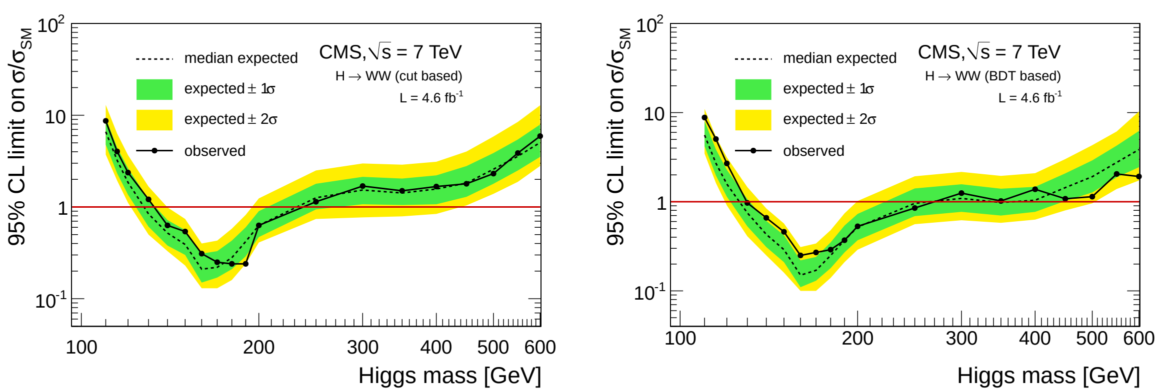

Figure 3: 95% exclusion limit on the relative signal strength to the SM for the cut based analysis(left) and for the MVA analysis (right) in the $H \to WW \to 2\ell 2\nu$ channel.

We recently added the WH→WWW→ $3\ell 3\nu$ channel [19]. This analysis is very similar to the WW channel with the main backgrounds estimated from data. It is a mass independent cut-and-count analysis and it is sensitive to about 4 times the SM in the most sensitive region around $2 \times m_{\mathrm{W}}$.

3.4 $H \to ZZ \to 4\ell$ channel

The $H \to ZZ \to 4\ell$ channel is the cleanest channel and it is often referred as the "golden channel". The signal consists of four isolated leptons. For the low mass Higgs search one of the pairs has the mass of the Z boson while the other is off-shell. Despite having a low branching ratio, this channel is an excellent for searching for a Higgs Boson because the background is very small (mainly from irreducible continuum ZZ production), and because the mass resolution is very good (1-2%). The p_T of the lower p_T leptons is rather small and one of the most important features of the analysis is the achievement of a very high lepton efficiency down to very low p_T.

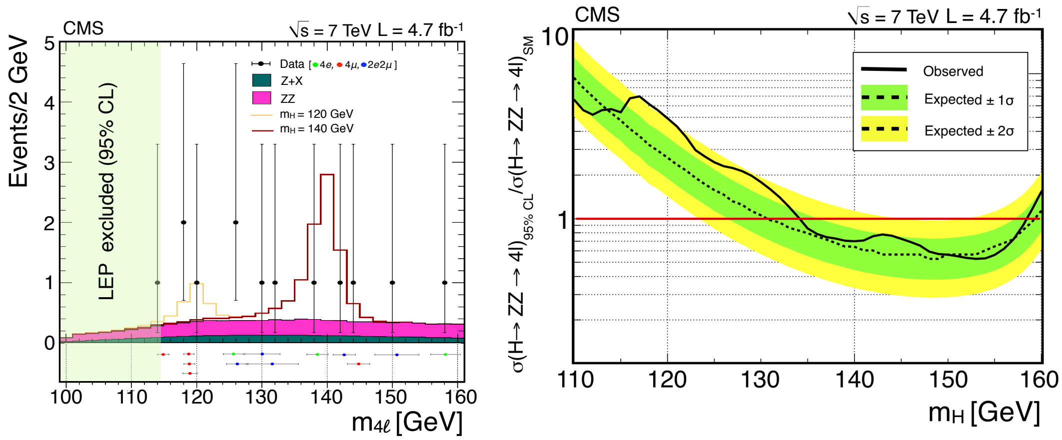

Figure 4: Mass spectrum of the ZZ→ 4ℓ candidates in the full mass range in the low mass range (left). 95% exclusion limit on the relative signal strength to the SM (right).

Figure 4 shows the invariant mass spectrum of the selected data compared to the background expectations. We do not observe any significant excess of the data and we exclude at 95% CL the SM Higgs boson with M_H in 134–158 GeV. 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 1.6σ in the mass range 100–160 GeV.

4 Standard Model Combination

All searched channels are combined to obtain the final exclusion and discovery confidence levels. The combination is carried out using the so-called CLs method described in [11]. The combination of the published results is reported in reference[21]. Here we present the combination that includes results presented at the Moriond conference [22]. SM cross sections and branching ratios are assumed for the combination with their theoretical uncertainties [8,9]. An overall signal strength multiplier $\mu = \sigma/\sigma_{SM}$ is introduced and limits on its value are derived.

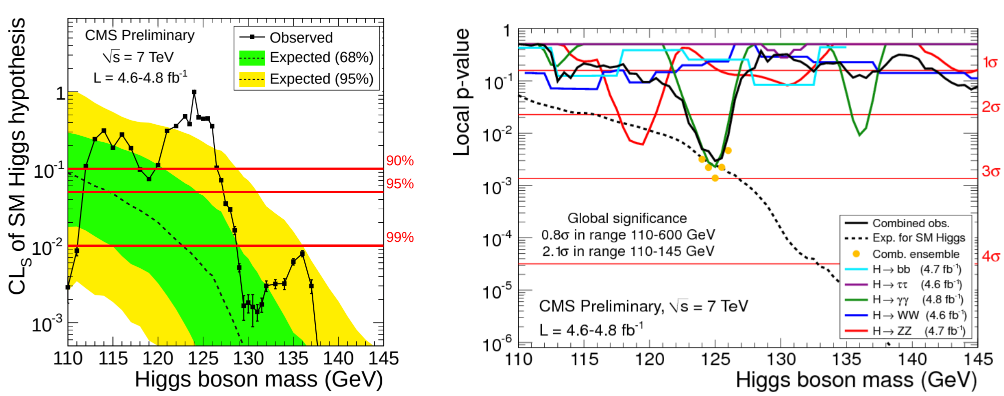

Figure 5: On the left, there are exclusion confidence level for the combined SM Higgs search in the low mass zoom. The solid lines indicate the observed exclusion and the dashed lines the expected. The right shows the probability of excess being caused by a background only fluctuation.

The left figure of 5 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

Figure 6: 95% exclusion confidence level on the signal strength multiplier for the SM Higgs search in the 5 Higgs decay channels. The solid lines indicate the observed exclusion and the dashed lines the expected.

GeV to high mass (600 GeV, not shown) and at 99% confidence level in the range 129 GeV to high mass (525 GeV, not shown). The expected 95% exclusion is 114.5–543 GeV. The observed CMS 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.

The right figure of 5 shows the local p-value as function of the Higgs boson mass in the low mass region. The minimum combined p-value is observed at a mass of 125 GeV with a local significance of 2.8σ with a global significance of 2.1σ for the mass range 110–145 GeV. A similar significance is expected in presence of a 125 GeV Higgs boson signal. More data are needed to investigate this excess.

5 Fermiophobic Combination

In addition to the search for the SM Higgs Boson, a search has been conducted and a combination made in the relevant decay channels for a low mass fermiophobic higgs boson [22]. Again at low mass the decay to two photons is dominant. Since gluon fusion is not allowed in the FP scenario, the VBF tag (also used for the SM) is tags the dominant production mode and thus is most sensitive sub-channel. Also, a lepton tag developed for VH tagged and a two dimensional analysis (mass and $\gamma\gamma$ p_{T}/mass) are applied to the non-VBF tagged $\gamma\gamma$ events.

Figure 7 shows the 95% CL upper limits for a FP with the three relevant gauge boson decay channels. The entire region shown is excluded and indeed mass up to 173 GeV (from 110 GeV) is excluded.

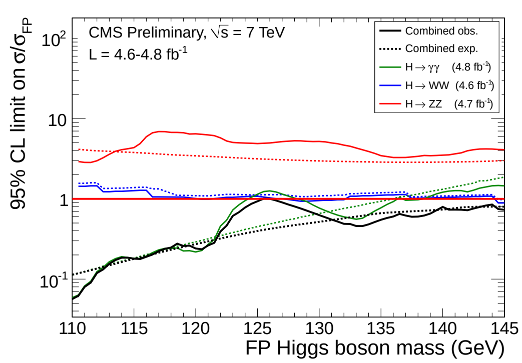

Figure 7: 95% exclusion confidence level on the signal strength multiplier for the FP Higgs search in the 3 Higgs decay channels. The solid lines indicate the observed exclusion and the dashed lines the expected.

6 Summary

The search for a light SM Higgs boson using approximately 5 fb^{-1} of 7 TeV pp collision data collected with the CMS detector at LHC excludes at 95% confidence level a SM Higgs boson with mass between 127.5 and 600 GeV (expected 95% CL 114.5-543 GeV).. The observed exclusion is weaker than expected at low mass because of an observed excessed near 125 GeV. The excess at 125 GeV as a local significance of 2.8σ and a global significance of 2.1σ when evaluated in the range 110–145 GeV. The excess is consistent both with background fluctuation and a SM Higgs boson with mass of about 125 GeV and more data are needed to investigate its origin. The data that will be collected in 2012 at 8 TeV CM energy will provide further insight into this excess.

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