Combined results of SM Higgs searches at CMS

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1 Introduction

The Higgs boson being the last missing piece of the Standard Model is searched in many experiments for at least last three decades. The direct lower limit on the Higgs boson mass comes from electron-positron collision data at LEP, and is $m_H > 114.4$ GeV/c^2 at 95% CL [1]. Recent results from Tevatron with up to 8.6 fb^{-1} of $p\bar{p}$ data exclude also a mass window of $156 < m_H < 177$ GeV/c^2 [2]. The Higgs boson search, within both Standard Model and its extensions, is also in the centre of the CMS experiment physics program [3]. In this contribution we present results combining searches for SM Higgs boson in most sub-channels explored by the CMS. The results are based on 5 fb^{-1} of data collected in 2010 and 2011. We present significance of observed excesses, and in absence of statistically significant excess we show exclusion limits as a function of m_H [4].

2 Search channels

The SM Higgs boson, with direct coupling to all massive particles of SM, has large number of decay modes with the decay pattern heavily dependent on its mass. The CMS Collaboration pursued Higgs boson search in all the most sensitive decay channels: $H \to \gamma\gamma$, $H \to \tau\tau$, $H \to b\bar{b}$, $H \to WW^* \to 2l2\nu$, $H \to ZZ^* \to 4l$, $H \to ZZ \to 2l2\nu$, $H \to ZZ^{(*)} \to 2l2q$, $H \to ZZ \to 2l2\,\tau$, Each of those modes is usually further split in sub-channels to profit from better S/B ratio in different production modes, e.g. vector boson fussion (VBF) vs. gluon-gluon fussion, leading to around 50 sub-channels in total.

3 Statistical analysis

The statistical analysis of the data in the Higgs boson searches is done using the CL_s method with profiled likelihood ratio used as a test statistics. In the combination all statistical and systematic uncertainties and their correlations are accounted for by introducing nuisance parameters (θ) in the likelihood function [5]. Depending on the mass range the number of sources of systematic uncertainties ranges from 156 to 222, including those fully correlated between different search channels. The statistical analysis is done using a signal strength modier μ which multiplies the expected SM Higgs boson cross section: $\sigma = \mu \cdot \sigma_{\mathrm{SM}}$.

In the case of exclusion of possible signal the test statistics for each assumed value of parameter μ is defined as:

$$q_\mu = -2 \ln \frac{\mathcal{L}(data|\mu, \hat{\theta}_\mu)}{\mathcal{L}(data|\hat{\mu}, \hat{\theta})}, \qquad 0 < \mu < \hat{\mu} \tag{1}$$

where $\mathcal{L}(data|\mu, \hat{\theta}_\mu)$ is the likelihood function maximised with respect to nuisance parameters under the hypothesis of a signal strength μ, while $\mathcal{L}(data|\hat{\mu}, \hat{\theta})$ is the likelihood function maximised with respect to both nuisance parameters, and signal strength parameter.

The analysis of observed excesses over the expected background uses similar test statistics function, but assuming $\mu = 0$:

$$q_0 = -2 \ln \frac{\mathcal{L}(data|0, \hat{\theta}_0)}{\mathcal{L}(data|\hat{\mu}, \hat{\theta})}, \qquad \mu \geq 0 \tag{2}$$

An excess is usually quantified in terms of the probability to obtain a value of q_0 greater or equal to the one observed in data ($\mathrm{q}^{\mathrm{obs}}$) assuming background-only hypothesis: $\mathrm{p}_0 = \mathrm{P}(\mathrm{q}_0 \geq \mathrm{q}^{\mathrm{obs}}|\mathrm{b})$. The probability value is then translated into one-sided p-value of the Gaussian distribution, usually denoted a significance Z. According to classical hypothesis testing procedure the threshold on Z marking the discovery limit, has has to be defined before looking at the data. A common value used in High Energy Physics is Z=5, which corresponds to $\mathrm{p}_0 = 2.8 \cdot 10^{-7}$. Since the search is made over a wide mass region the p_0 calculated for given mass hypothesis has to be corrected for the so called look elsewhere effect (LEE) [6]. This correstion always reduces the Z value, and also depends on the search range.

4 Results

Exclusion limits for the CMS combination of SM Higgs boson searches is presented on Fig. 1. The mass range of 114.5 – 543 GeV/c^2 was expected to be excluded basing on detailed Monte Carlo simulations assuming no Higgs boson signal contribution, but the observed exclusion range is 127.5 – 600 GeV/c^2 with some excess around mass of 125 GeV/c^2. The local p-value of observed excesses is presented on Fig. 2 with the largest excesses, comming mainly from $\mathrm{H} \rightarrow \gamma\gamma$ channel, observed around

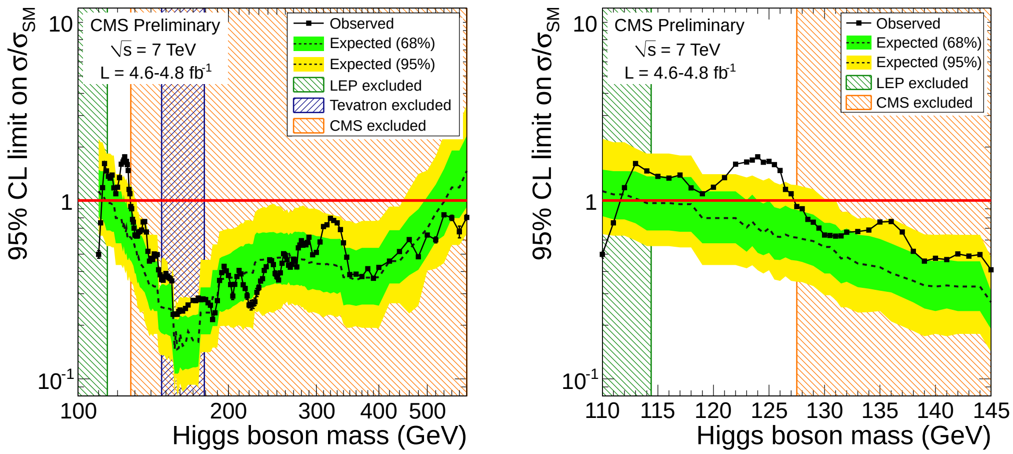

Figure 1: The 95% CL upper limits on the signal strength parameter μ for the SM Higgs boson hypothesis as function of the Higgs boson mass in full search range (left), and for low mass range (right). The observed values are shown by the solid line. The dashed line indicates the expected median of results for the background only hypothesis, while the green (dark) and yellow (light) bands indicate the ranges that are expected to contain 68% and 95% of all observed excursions from the median, respectively. The mass ranges first excluded by LEP, Tevatron and this measurement are shown as hatched areas.

mass of 125 GeV/c^2. The p-value of this excess corresponds to Z=2.8 before applying the LEE correction. After applying the LEE correction the significance is reduced to 2.1, assuming search range 110 – 145 GeV/c^2, or 0.8 for the full range of 110 – 600 GeV/c^2.

5 Conclusion

The CMS Collaboration analysed almost 5 fb^{-1} of data collected at $\sqrt{s}$=7 TeV in 2010 – 2011 searching for SM Higgs boson using number of decay and production modes. After combination of all modes no statistically significant excess was observed, yielding 95% CL exclusion in range 127.5 – 600 GeV/c^2. The largest excess, observed at m$_H$=125 GeV/c^2 has significance of Z=2.1 for search range 110 – 145 GeV/c^2.

6 Acknowledgements

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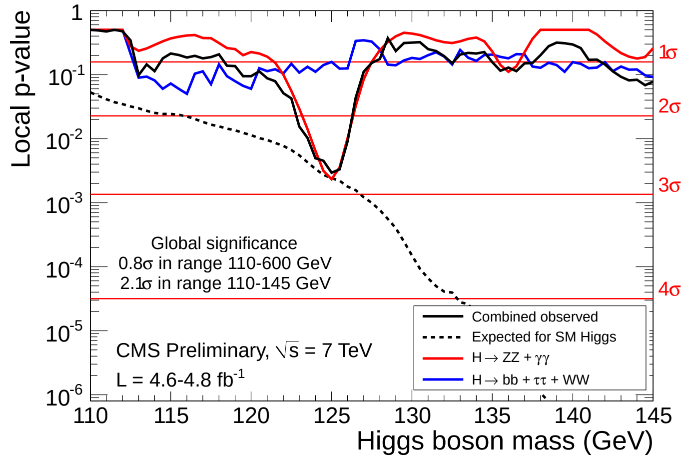

Figure 2: The observed local p-value p_0 as a function of the SM Higgs boson mass in the range 110 – 145 GeV/c^2, for the full combination and the two sub-combinations. The global significance of the observed maximum excess (minimum local p-value) for the full combination in this mass range is 2.1σ. The dashed line shows the expected local p-values $p_0(m_H)$ for the combination, should a Higgs boson with a mass m_H exist.

References

[1] ALEPH Collaboration, DELPHI Collaboration, L3 Collaboration, OPAL Collaboration4 and The LEP Working Group for Higgs Boson Searches, Phys. Lett. B **565**, (2003)

[2] CDF and D0 Collaborations, Phys. Rev. Lett. **104** (2010) 061802. A more recent, unpublished, limit is given in preprint arXiv:1103.3233

[3] CMS Collaboration, JINST **3** S08004 (2008)

[4] CMS Collaboration, Phycis Letters B **710** (2012). A more recent, unpublished, limit is given in CMS-PAS-HIG-12-008

[5] ATLAS and CMS Collaborations, LHC Higgs Combination Group, CMS-NOTE-2011-005, ATL-PHYS-PUB 2011-11 (2011)

[6] Gross E.,Vitells O., Eur. Phys. J. C **70** (2010)