Overview of Higgs results from CMS

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In this article we present an overview of Higgs boson results from the CMS Collaboration as presented at the ISMD13 conference.

1. Introduction

With the discovery of the Higgs boson by the CMS and ATLAS collaborations [1] new questions have arisen that need to be addressed. In particular, we need to measure if the new boson couples to the standard model (SM) particles at appropriate levels. Are the signal strengths, where observed, at the correct SM levels? Is the new boson a scalar, and not a pseudo-scalar or a tensor? We need to understand if this is the only new boson, and not one of several, and we need to measure if it couples to itself. Luckily, its mass of about 125 GeV allows us to answer many of these questions experimentally. In this article we present the current status of the ongoing analyses that contribute to these answers. We will show results for the dominant gluon-gluon fusion production process, as well as for vector boson fusion and associated production. The measurements are pursued in various decay channels, both in Higgs decays to vector bosons as well as fermions. Unless otherwise stated, the results are based on the full dataset from Run1 of the LHC, about 25 fb^{-1}.

2. Couplings to vector bosons

2.1. $\text{H} \rightarrow \text{ZZ} \rightarrow 4\ell$

The cleanest channel with the best Higgs mass resolution is the decay of the Higgs to a pair of Z bosons, which in turn decay to two electrons or muons each [2]. Figure 1 shows the four lepton invariant mass spectrum. The data from the full dataset are overlaid with background expectations from $\text{Z}\gamma^*$ and ZZ as well as inclusive Z production. Contributions from single Z decay to four leptons can be around the Z mass, while the SM process of on-shell ZZ production is found around 200 GeV and above. A

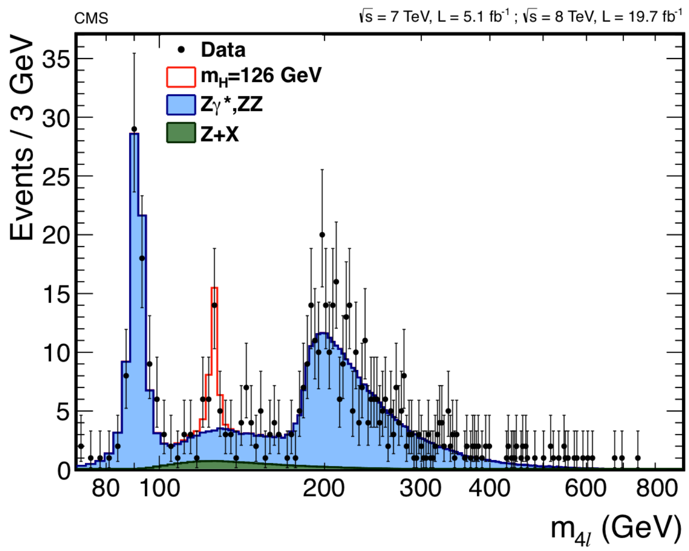

Fig. 1. Data from the H $\rightarrow$ ZZ $\rightarrow 4\ell$ search channel are shown overlaid with SM background expectations. A simulated SM Higgs signal at 126 GeV is indicated as well.

clear excess of events above background expectations can be seen around 126 GeV, consistent with a SM Higgs signal.

The Higgs boson is observed as a narrow resonance with a local significance of 6.7 standard deviations, at a measured mass of $m_{\mathrm{H}} = 125.8 \pm 0.5(\mathrm{stat.}) \pm 0.2(\mathrm{syst.})$ GeV. The production cross section of the new boson times the branching fraction to four leptons is measured to be $0.91^{+0.30}_{-0.24}$ times that predicted by the SM (signal strength). Its spin-parity properties are found to be consistent with the expectations for the SM Higgs boson. The hypothesis of a pseudo-scalar and all the tested spin-one boson hypotheses are excluded at a 99% confidence level or higher. All the tested spin-two boson hypotheses are excluded at a 95% confidence level or higher.

2.2. H $\rightarrow$ WW $\rightarrow \ell\nu\ell\nu$

In the channel where the Higgs decays to a pair of W bosons, which subsequently each decay into a lepton and a neutrino [3], CMS sees a broad enhancement in data compared to the background only hypothesis, which is consistent with the SM Higgs boson of mass around 125 GeV and has a statistical significance of 4 standard deviations for this mass, see Figure 2. This result provides evidence for a Higgs-like particle decaying to $\mathrm{W}^+\mathrm{W}^-$. Additional SM Higgs-like bosons are excluded in the mass range $128 - 600$

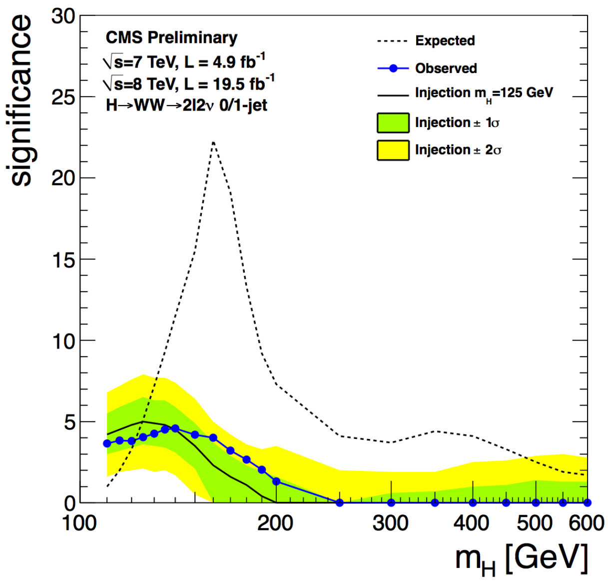

Fig. 2. Expected and observed significances are shown in the Higgs mass range of $110 - 600$ GeV for the $\mathrm{H} \to \mathrm{WW} \to \ell\nu\ell\nu$ search channel. A simulated SM Higgs signal with a Higgs mass of 125 GeV is indicated for comparison as well.

GeV at 95% confidence level.

The best fit value of the signal strength for $m_{\mathrm{H}} = 125$ GeV is found to be 0.76 ± 0.21. The hypothesis of the SM Higgs boson for quantum numbers and couplings is tested against the spin-2 hypothesis of a narrow resonance produced through gluon-gluon fusion and with minimal couplings to the $\mathrm{W}^+\mathrm{W}^-$ pair. Assuming the best fit value of the signal strength obtained for the individual hypotheses, the observed separation is 0.5 and 1.3 standard deviations away from the expected values for the SM Higgs hypothesis and the spin-2 hypothesis, respectively.

2.3. $\mathrm{H} \to \gamma\gamma$

One of the discovery channels is where the Higgs boson decays to a pair of photons [4]. Despite a large cross section times branching ratio this channel is very challenging because of a large SM background. Figure 3 shows the measured 95% exclusion on the signal strength compared to the SM expectation and to the background-only hypothesis.

The signal strength at $m_{\mathrm{H}} = 125$ GeV is measured to be $0.78^{+0.28}_{-0.26}$. The significance of the signal in this channel alone is exceeding 3σ. A fit to the

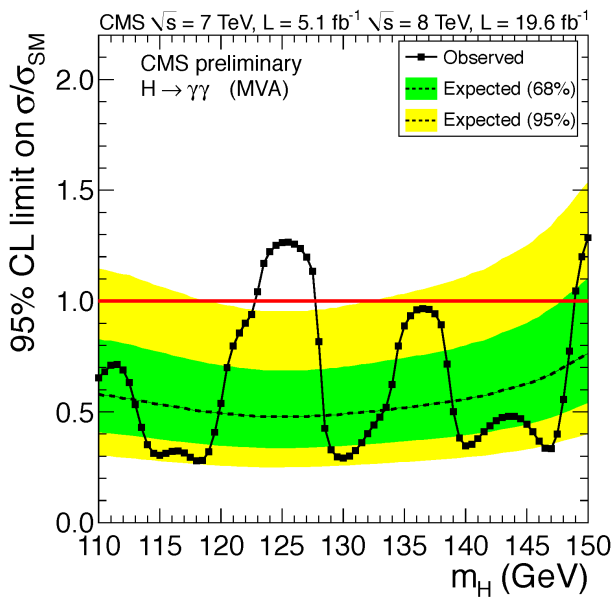

Fig. 3. The 95% upper limit on the signal strength of a Higgs boson decaying to two photons. The symbol $\sigma/\sigma_{\rm SM}$ denotes the production cross section times the relevant branching fractions, relative to the SM expectation. The background-only expectations are represented by their median (dashed line) and by the 68% and 95% CL bands.

di-photon invariant mass distribution in data results in a measured mass of $m_{\rm H} = 125.4 \pm 0.5({\rm stat.}) \pm 0.6({\rm syst.})$ GeV.

3. Couplings to fermions

3.1. $\rm H \to b\bar{b}$

Due to the very large SM background in the gluon fusion production of this channel, we are presenting measurements only in the associated production and vector boson fusion. In the associated production, where the Higgs boson is created in addition to a vector boson, a W or a Z, which then decays subsequently into leptons, while the Higgs decays into a pair of b-quarks [6], the following channels have been taken into account: $\rm W(\to \mu\nu)H(\to b\bar{b})$, $\rm W(\to e\nu)H(\to b\bar{b})$, $\rm W(\to \tau\nu)H(\to b\bar{b})$, $\rm Z(\to \mu\mu)H(\to b\bar{b})$, $\rm Z(\to ee)H(\to b\bar{b})$ and $\rm Z(\to \nu\nu)H(\to b\bar{b})$. We observe a broad excess of events compared to background expectations consistent with the production of the SM Higgs boson. Figure 4 shows the simulated background-subtracted invariant mass distribution, $m_{\rm b\bar{b}}$, for the combination of these production and decay

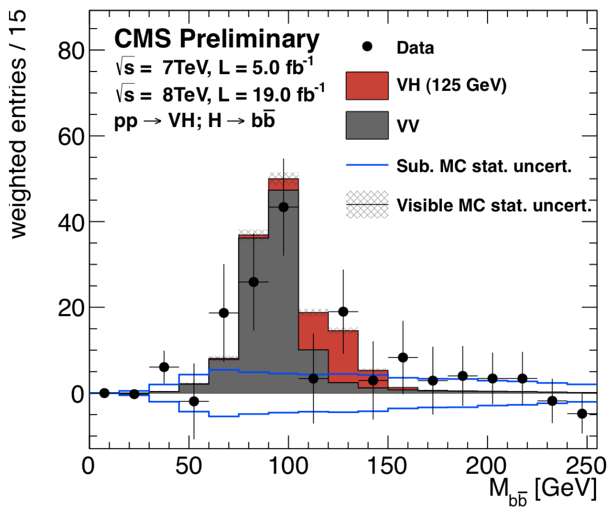

Fig. 4. Weighted $b\bar{b}$ invariant mass distribution, combined for all channels. All backgrounds, except di-boson processes, are subtracted.

channels. A combined significance for $m_{\mathrm{H}} = 125$ GeV is derived to be 2.1 standard deviations, while the signal strength is measured to be 1.0 ± 0.5 times the SM expectation.

In the vector boson fusion production we present a first measurement by using two forward jets to tag the events [7]. No excess is yet being observed in this channel alone.

3.2. $\mathrm{H} \rightarrow \tau\tau$

We are presenting results using the full Run1 dataset and by combining gluon fusion and vector boson fusion production modes using the following final states: $e\mu$, $\mu\mu$, $e\tau_h$, $\mu\tau_h$ and $\tau_h\tau_h$, as well as associated production modes, WH and ZH, with the following final states: $\ell\nu\ell\tau_h$, $\ell\nu\tau_h\tau_h$ and $\ell\ell\tau_h\tau_h$ [8]. An emerging signal can be seen in Figure 5, which shows the invariant mass of the τ-pairs for a subset of the above mentioned channels.

The observed signal above background for $m_{\mathrm{H}} = 125$ GeV is 2.9 standard deviations for all $\mathrm{H} \rightarrow \tau\tau$ decays under study. When combining this result with the $\mathrm{H} \rightarrow \mathrm{bb}$ measurements, we obtain an evidence for the Higgs boson coupling to fermions of 3.4 standard deviations.

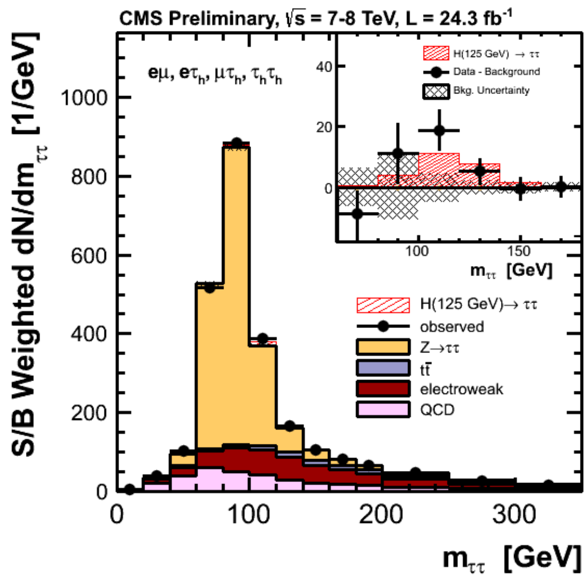

Fig. 5. Combined observed and expected $m_{\tau\tau}$ distribution for the $\mu\tau_h$, eτ_h, eμ and $\tau_h\tau_h$ channels. The distributions obtained in each category of each channel are weighted by the ratio between the expected signal and background yields in the category. The insert shows the corresponding difference between the observed data and expected background distributions, together with the expected signal distribution for a SM Higgs signal at $m_{\mathrm{H}} = 125$ GeV, with a focus on the signal region.

4. Standard model combination

We have combined the SM Higgs measurements in the various channels with each other [10]. The signal strength is measured and found compatible in a multitude of production and decay channels as summarized in Figure 6. All channels are found compatible with the SM Higgs hypothesis. The sensitivity of the measurements will be vastly improved in Run2 of the LHC.

The mass of the observed state has been measured to be $m_{\mathrm{H}} = 125.7 \pm 0.3(\mathrm{stat.}) \pm 0.3(\mathrm{syst.}) = 125.7 \pm 0.4$ GeV. We derive the coupling strength to fermions and vector bosons and find that the combined results are compatible within 1.5 standard deviations with the SM Higgs boson.

In order to determine the spin and tensor structure of the newly observed boson, several alternative models have been tested against the SM Higgs hypothesis of 0^+, such as 0^-, 1^+, 1^- and 2^+, and the preferred solution has been found to be the SM one.

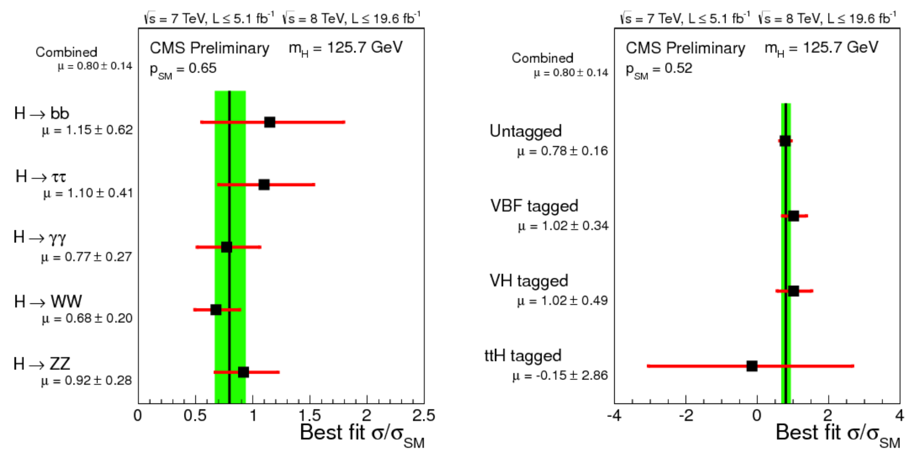

Fig. 6. Values of $\mu = \sigma/\sigma_{\rm SM}$ for the combination (solid vertical line) and for sub-combinations (points). The vertical band shows the overall μ value 0.80 ± 0.14. The horizontal bars indicate the $\pm 1\sigma$ uncertainties on the μ values for individual channels; they include both statistical and systematic uncertainties. Left: grouped by decay mode. Right: grouped by signature enhancing specific production mechanisms.

5. Beyond the standard model

There are many possibilities that change the precise predictions of the minimal Higgs sector of the SM. There could be a fourth, heavy, generation of fermions (SM4), which would modify the Higgs couplings and enhance the SM4 Higgs cross section over the SM one. This has already been ruled out over the entire parameter space with the 7 TeV data alone. The Higgs boson could be fermiophobic, which means that the mass of the fermions has a different origin than the Higgs. This would change the low mass Higgs production and decays dramatically and has also been ruled out for the newly observed boson at 125 GeV [11]. One conceivable expansion of the SM Higgs could be the two Higgs doublet model (2HDM), in which multiple Higgs bosons exist: three neutral and two charged ones, as required for example by the minimal supersymmetric models (MSSM). There are other models with even more Higgs bosons. Within the Run1 dataset collected by the CMS experiment we are looking for additional Higgs bosons, preliminary results have been presented [12, 13]. An additional SM-like Higgs boson is excluded for masses up to 1 TeV.

6. Summary

We have seen an impressive performance of the LHC and the CMS detector during the Run1 data taking period. The CMS collaboration successfully covered a large Higgs program over the past years [14]. The observation of the new boson was confirmed by the latest data. Everything points to a standard model-like Higgs boson. We are currently preparing for the new data to come in Run2, which will be the starting point of a new era: precision measurements of Higgs properties and new channels, searches beyond the standard model, and many more.

References

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