PROCEEDINGS OF SCIENCE

Higgs boson measurements in the WW and ZZ final states with the CMS Detector

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This contribution outlines the most recent measurements of the Higgs boson properties in the $H \to WW$ and $H \to ZZ$ decay channels performed with the CMS experiment at the CERN LHC.

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1. Introduction

The Compact Muon Solenoid (CMS) experiment [1] is one of the two multi-purpose experiments installed at the CERN LHC to hunt for the Higgs boson and to explore a large variety of physics scenarios at the TeV energy scale. After the dicovery of a new particle compatible with the Standard Model (SM) Higgs (H) boson by the ATLAS and CMS experiments in 2012, subsequent analyses in various decay channels and production mechanisms showed that the properties of this new particle are so far consistent with the predictions for the SM Higgs boson. These predictions can now be further tested exploiting the entire dataset of 137 fb^{-1}, collected during the so called Run-II phase of the LHC operations, thus entering the realm of the *Higgs physics precision era*.

In this regard, the Higgs boson decays into vector boson pairs (either WW or ZZ) play a key role, because of their large sensitivity to all the prouction modes, but also to the fermionic and vector-boson induced couplings of the SM Higgs boson. This contribution presents the most recent results from the CMS Collaboration in the HWW and HZZ decay channels. The former is characterised by a high sensitivity from its large cross section and branching ratio, but with a relatively poor mass resolution due to missing energy in the final state; the latter, also known as *the golden channel*, features a large signal-to-background ratio, an excellent mass resolution and a completely resolved final state, although suffering from limited event number due to its small branching fraction.

The CMS Collaboration reported an extensive characterisation of the SM Higgs boson properties from the analysis of these two decay channels: measurements of the Higgs boson mass and width, two of the fundamental pillars of the SM; a study of the production mechanisms, both inclusively and in dedicated phase space regions, defined according to the Simplified Template Cross Section (STXS) framework; and measurements of fiducial differential cross sections, of particular interest because of their model independence and sensitivity to possible deviations from SM couplings of the Higgs boson.

2. The Higgs boson mass

A precise measurement of the Higgs boson mass (m_H) is crucial to nail down the H couplings and to test the SM predictions. The HZZ decay channel, with the many virtues aforementioned, is one of the best candidates to perform such a measurement. Using only this decay mode, the CMS Collaboration reported a value of $m_H = 125.26 \pm 0.21$ GeV [2], measured using statistics collected during the 2016 data taking period. This result, combined with the H$\gamma\gamma$ decay channel and the full Run-I measurement, lead to the current best value of $m_H = 125.38 \pm 0.14$ GeV reported by the CMS collaboration [3]. The likelihood scans of the Higgs boson mass using the HZZ channel and its combination with H$\gamma\gamma$ are shown in Fig. 1.

3. The Higgs boson width

The SM prediction for the Higgs boson width (Γ_H) is around 4 MeV. Along with the H mass, a precision measurement of Γ_H is to be considered as fundamental tool when it comes to the assessment of the SM itself. With an analysis on 2016 data in the HZZ decay channel, the CMS

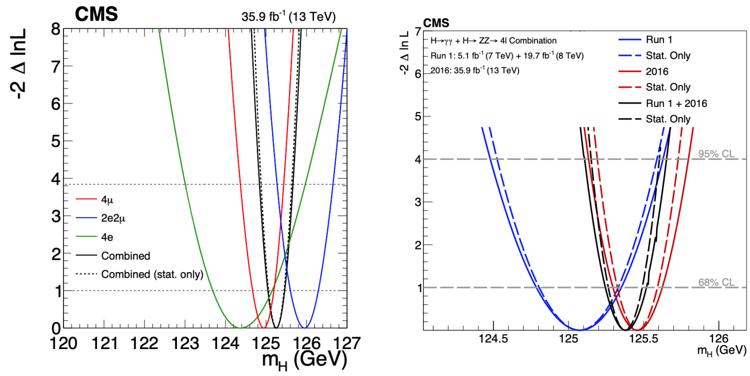

Figure 1: Likelihood scan of the Higgs boson mass (m_H) in the HZZ channel with the 2016 dataset [2] (left) and its combination with H$\gamma\gamma$ and Run-I measurements [3] (right).

Collaboration constrained the Higgs boson width to be $\Gamma_H \leq 1$ GeV [2]. However this measurement relied only on the on-shell production region. A more stringent constraint can be set analysing this data together with the full Run-I statistics and the 2017 data set, alongside with the combination of the on-shell and off-shell production methods, leading to an observed [0.08, 9.16] MeV interval on Γ_H at 95% confidence level. The log likelihood scans of Γ_H are shown in Fig. 2. The right plot clearly shows how the increasing statistics available and the combination of the on-shell and off-shell regions can lead to more and more stringent constraints on Γ_H, competitive with the SM expected precision of 4 MeV.

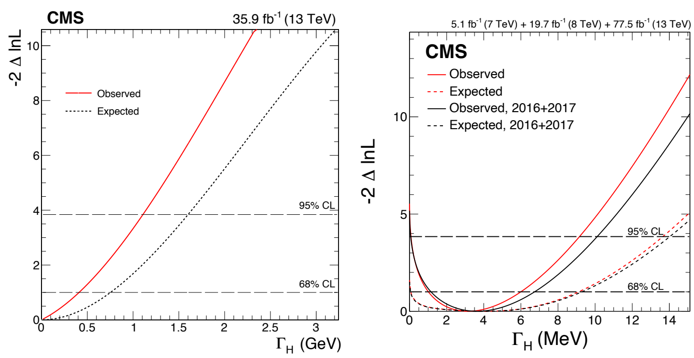

Figure 2: Likelihood scan of the Higgs boson width (Γ_H) in the HZZ channel with the 2016 dataset, using only the on-shell production region [2] (left) and its combinationwith Run-I and 2017 measurements, using the off-shell production region as well [4] (right).

4. The Higgs boson production mechanisms and couplings

As outlined above, one of the main goals of the Run-II physics programme was the discovery of all the Higgs boson production mechanisms, in order to assess the compatibility of this long-sought particle with the one predicted by the SM. Both HWW and HZZ decay channels have good sensitivity to almost all the five main production modes. The common way of presenting these measurements is in the form of *signal strengths*, i.e. modifiers of the SM expected cross section.

More recently all the analyses are moving towards an alternative approach, measuring the cross sections in pre-defined kinematic bins. This scheme goes by the name of Simplified Template Cross Section (STXS) framework and it was designed with the aim of minimising the measurement dependence on theory predictions, without losing sensitivity. To cope with the reduced datasets of the early data-taking periods of Run-II, the STXS Stage 0 bins were targetting only the 5 main production modes of the Higgs boson. The CMS Collaboration performed measurements of STXS Stage 0 both in the HWW [5] and HZZ [6] decay channels. The results of these two analyses are reported in Fig. 3.

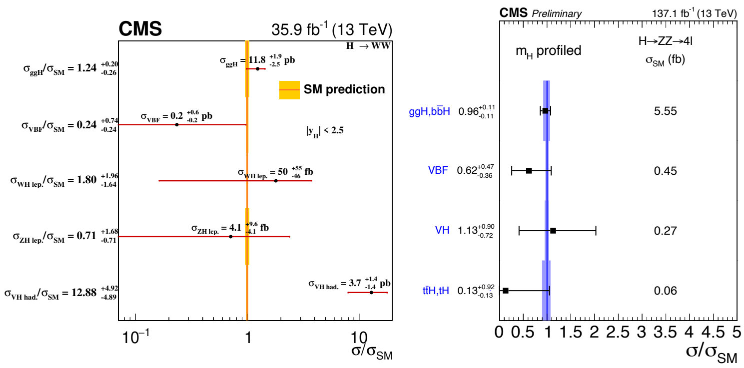

Figure 3: Simplified Template Cross Section (STXS) Stage 0 measurement in the HWW [5] (left) and HZZ [6] (right) decay channels.

With the full Run-II statistics a more granular description of the Higgs boson production modes becomes accessible: STXS Stage 1.2. Besides minimising the theory dependence in the measurements, thus empovering multiple interpretation scenarios, the STXS provide a common framwork for all the analyses, allowing easier comparisons and combinations. An analysis exploiting the full Run-II statistics was performed in the HZZ decay channel [6]. The measurements of the cross sections in the different STXS bins are presented in Fig. 4.

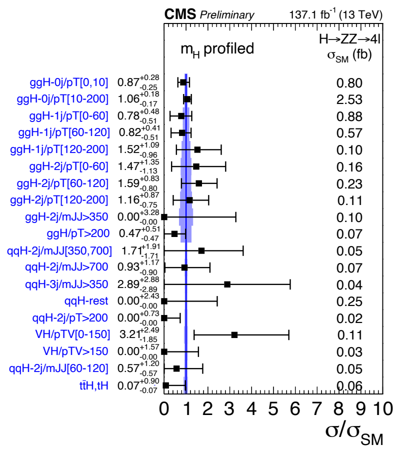

Figure 4: Simplified Template Cross Section (STXS) Stage 1.1 measurement in the HZZ [6] (right) decay channel.

The HWW and HZZ decay channels also allow to test the fermions and vector-bosons induced

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contributions to the expected SM cross section. These can be quantified by measuring the signal strength modifiers μ_V and μ_F, where the former identifies a scaling of the inclusive VBF and VH cross section, while the latter represents a possible modification of the inclusive ggH, $b\bar{b}$H, $t\bar{t}$H, and tH cross section. A two-dimensional likelihood scan has been performed both in the HWW , using the 2016 dataset, and in the HZZ, using the full Run-II statistics, decay channels. The results are presented in Fig. 5. Besides the different sensitivity of the analyses to the various production mechanisms, it is interesting to observe the more stringent limits derived in the HZZ analysis, mainly due to the use of the 137 fb^{-1} recorded by the CMS experiment during the Run-II phase of data taking.

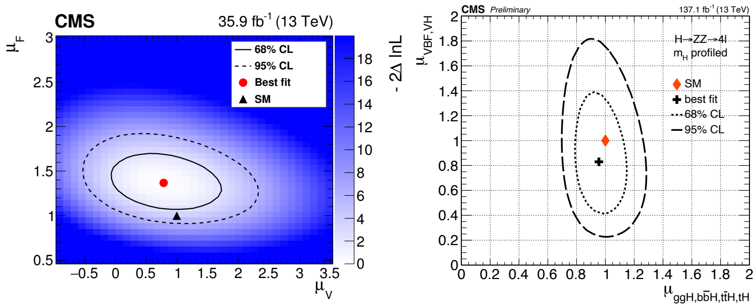

Figure 5: Fermion and vector-boson induced couplings to the SM cross section in the HWW [5] (left) and HZZ [6] (right) decay channels.

5. Fiducial cross sections

Fiducial measurements represent the ideal tool when it comes to extract model-independent results. The CMS Collaboration presented fiducial differential cross section measurements both in the HZZ [6] and, for the first time, in the HWW [7] decay channels exploiting the 137 fb^{-1} statistics collected during Run-II. Of particular interest is the differential cross section as a function of the Higgs boson's transverse momentum ($p_T(H)$), as it is sensitive to possible deviations from the SM in the Yukawa couplings of light quarks and to effective operators of dimension 6. The measurements, along with comparisons to different Monte Carlo (MC) generators, are shown in Fig. 6.

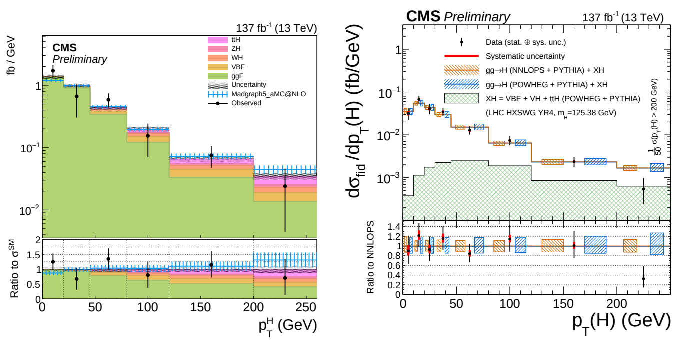

Figure 6: Fiducial cross section measurement as a function of the transverse momentum of the Higgs boson ($p_T(H)$) in the HWW [7] (left) and HZZ [6] (right) decay channels.

6. Conclusions

After the discovery of the Higgs boson in 2012, the main focus of the analyses during the Run-II phase of the LHC has been the characterisation of all the main production modes, as well as the precision measurements of its properties. Exploiting the 137 fb^{-1} collected by the CMS experiment during this data taking period, all the measurements are starting to become dominated by systematic uncertainties. The latest results of the CMS analyses in the HZZ and HWW decay channels are presented in this contribution. The former consist of an extensive set of measurments of the Higgs boson properties using full Run-II data, while the latter includes the first measurement of differential fiducial cross sections in the HWW channel. All the results were found to be consistent with the SM prediction at 95% confidence level.

References

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