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CMS Higgs boson results

Michał Bluj on behalf of the CMS Collaboration

Abstract

In this report we review recent Higgs boson results obtained with pp collisions at $\sqrt{s}\ = 13$ TeV recorded by the CMS detector in 2016 for an integrated luminosity of 35.9fb^{-1}. The 2016 data allowed the observation of the $H \rightarrow \tau\tau$ and $H \rightarrow WW$ decays with high significance. We also present a combined measurement based on a full set of CMS analyses performed with 2016 data. These results are compatible with the standard model predictions with precision of several measurements exceeding results from combination of ATLAS and CMS data collected in 2011 and 2012.

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CMS Higgs boson results [a]

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In this report we review recent Higgs boson results obtained with pp collisions at $\sqrt{s} = 13\,\mathrm{TeV}$ recorded by the CMS detector in 2016 for an integrated luminosity of $35.9\,\mathrm{fb}^{-1}$. The 2016 data allowed the observation of the $\mathrm{H} \to \tau\tau$ and $\mathrm{H} \to \mathrm{WW}$ decays with high significance. We also present a combined measurement based on a full set of CMS analyses performed with 2016 data. These results are compatible with the standard model predictions with precision of several measurements exceeding results from combination of ATLAS and CMS data collected in 2011 and 2012.

1 Introduction

After the discovery of a new standard-model-like Higgs boson announced by the ATLAS and CMS collaborations in July 2012 [1,2,3] it became essential to establish the nature of this new boson, i.e. observe its production and decay modes with high significance, measure its couplings to standard model (SM) particles, etc. This objective is achieved by a set exclusive analyses sensitive to different production processes and decays of the Higgs boson which are then combined to extract its properties in the most precise way. In this report we focus on recent results acquired using pp collisions at $\sqrt{s} = 13\,\mathrm{TeV}$ with an integrated luminosity of $35.9\,\mathrm{fb}^{-1}$ recorded by the CMS detector [4] in 2016. We present results obtained with the $\mathrm{H} \to \tau\tau$ and $\mathrm{H} \to \mathrm{WW} \to \ell\nu\ell\nu$ ($\ell = \mathrm{e}, \mu$) channels, and through a combination of all CMS Higgs boson measurements with data collected in 2016, while recent results on final states with hadronic signatures, the $\mathrm{H} \to \mathrm{bb}$ decay and ttH production, are discussed elsewhere [5].

2 Observation of the $\mathrm{H} \to \tau\tau$ decay

The $\mathrm{H} \to \tau\tau$ channel, with a relatively high branching fraction of 6.3%, is the fermionic decay mode to which LHC experiments are most sensitive. The CMS search for the $\mathrm{H} \to \tau\tau$ channel is based on an event classification to enhance the impact of events produced in the VBF process, but also in the gluon fusion process with additional jets, which increases the signal-to-background ratio. The $\mathrm{H} \to \tau\tau$ analysis employs an estimate of a full $\tau\tau$ invariant mass, $\mathrm{m}_{\tau\tau}$ with resolution of 15–20%. It is calculated using a likelihood based method taking as input the kinematics of the visible decay products and $p_{\mathrm{T}}^{\mathrm{miss}}$. The signal is extracted from two-dimensional distributions where one dimension is defined by $\mathrm{m}_{\tau\tau}$ and other by a category dependent variable as mass of the tagging jets system, m_{jj}, in the VBF category [6] as shown in Fig. 1 (left). An observed excess of events above background only hypothesis provides an observation of the $\mathrm{H} \to \tau\tau$ decay with a significance of 4.9 standard deviations, σ, with 2016 data, and 5.9σ when combined with

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previous results with 2011 and 2012 data [7]. The ratio of the measured signal yield to the SM expectation, a signal strength, μ, amounts to $1.09^{+0.27}_{-0.26}$ and agrees across categories as shown in Fig. 1 (right).

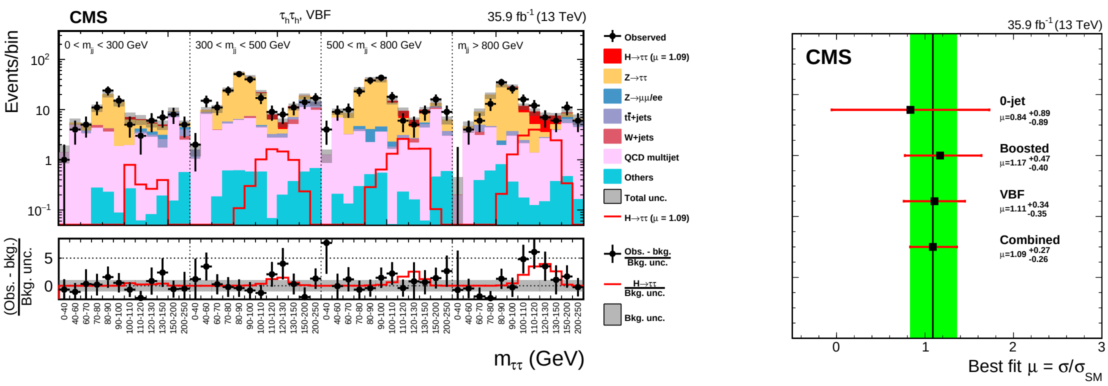

Figure 1 – Left: Distribution of the $\tau\tau$ mass, $m_{\tau\tau}$, in bins of the tagging jets mass, m_{jj}, for the VBF category of the $\tau_h\tau_h$ decay channel. The background histograms are stacked, while the signal is shown both as a stacked filled histogram and an open overlaid histogram. The gray band stands for the systematic uncertainties. Right: The H $\to \tau\tau$ signal strength per an analysis category and combined. Plots from ref. [6].

3 Measurements with the H $\to$ WW $\to \ell\nu\ell\nu$ process

The H $\to$ WW $\to \ell\nu\ell\nu$ process is an important tool in probing the Higgs boson couplings as, thanks to large branching fraction ($\mathcal{B}$(H $\to$ WW) $\approx$ 22%) and relatively low background rates, it is sensitive to almost all Higgs boson production mechanisms. The CMS analysis with 2016 collision data [8] categorises events basing on the number of leptons and number of associated jets. The events are further devised based on the lepton flavour and charge composition to create categories with different signal-to-background ratios. It gives in a total of about 30 signal categories sensitive to the ggH, VBF, WH, and ZH production modes. The signal is extracted using distributions of signal sensitive variables depending on the category, e.g. the mass of the lepton pair, $m_{\ell\ell}$, and the transverse mass of the leptons and p_T^{miss} system, m_T. The signal strength per an analysis category and a production mode is shown in Fig. 2 left and right, respectively. The measured combined signal strength equals to $\mu = 1.28^{+0.18}_{-0.17}$.

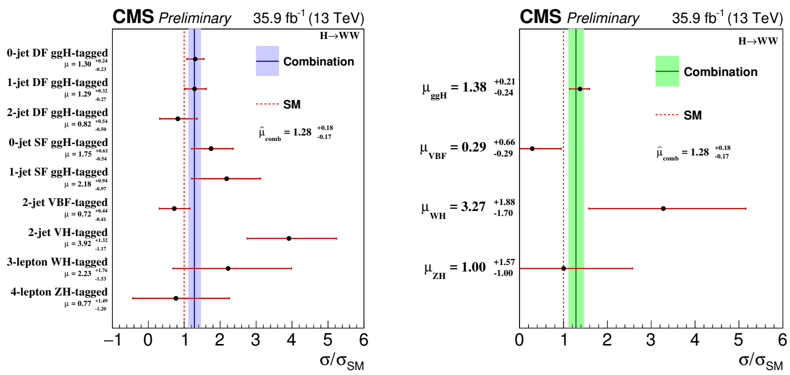

Figure 2 – Signal strength corresponding to the analysis categories (left) and the main Higgs boson production mechanisms (right) measured with the H $\to$ WW $\to \ell\nu\ell\nu$ decay channel. The vertical continuous line represents the combined signal strength of $\mu = 1.28^{+0.18}_{-0.17}$, while the filled area shows the 68% confidence intervals. Plots from ref. [8].

4 Combined measurements

The individual Higgs boson analyses at LHC measure directly only signal yields [b] for a given combination of production and decay modes. However, the production and decay rates, and then individual couplings can be determined separately with a combination of individual analyses to exploit different correlations between production and decay modes to which the analyses (event categories within them) are sensitive. It requires a set of basic theory assumptions which are discussed elsewhere [9].

The CMS Collaboration performed common combined measurements exploiting all analyses based on 13 TeV data collected in 2016 [10]. Production and decay signal strengths obtained with the combined analysis are shown in Fig. 3 (left and middle), all in agreement with the SM expectations. Results of the combined coupling measurement are summarised in Fig. 3 (right) and are in all cases consistent with expectations for the SM Higgs boson. Sensitivity of $\mu_{\rm ggH}$ and $\mu_{\rm ttH}$ measurements with 2016 data exceeds sensitivity of their counterparts from combination of 2011 and 2012 data collected by both ATLAS and CMS detectors [11] by approximately 30% and 50%, respectively. The combined CMS measurement is also used to constrain a set of benchmark

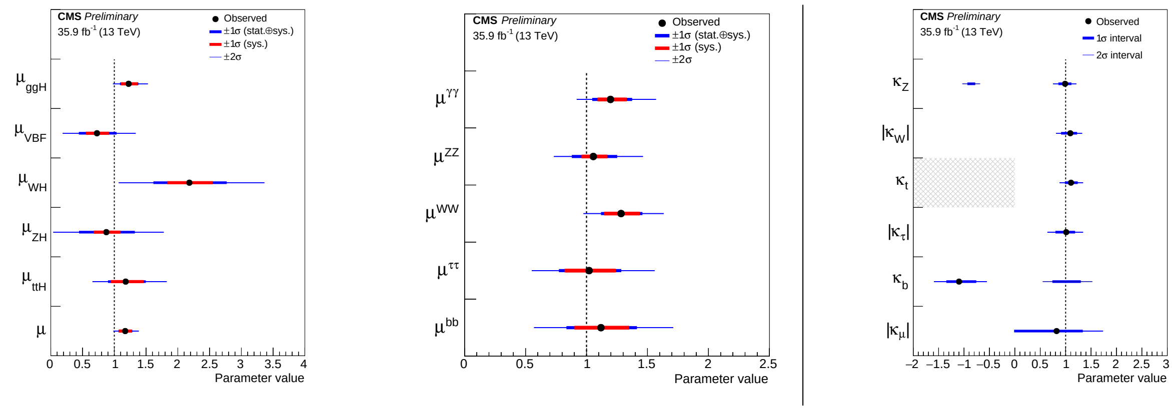

Figure 3 – Signal strength per production mode (left) and per decay mode (middle) from the combined fit. The last point in the per production mode plot indicates the result of the combined signal strength $\mu = 1.17^{+0.10}_{-0.10}$. Right: Measured values of coupling strength scaling factors κ with $\mathcal{B}_{\rm BSM} = 0$, and the gg $\rightarrow$ H and H $\rightarrow \gamma\gamma$ loops resolved in terms of remaining coupling strength scaling factors. Plots from ref. [10].

models extending the Higgs sector: two-Higgs-doublet models (2HDM) [12] and the constrained supersymmetric model hMSSM [13]. Figure 4 shows the constraints in the two-dimensional parameter space describing studied models: $\cos(\beta - \alpha) - \tan\beta$ for different benchmark 2HDM: Type I (left) and Type II (middle), and $\rm m_A - \tan\beta$ for the hMSSM (right). Non-excluded regions of the parameter space correspond to presence of a SM-like Higgs boson. These indirect constraints are complementary to ones from direct searches, e.g. using the H $\rightarrow \tau\tau$ decay channel [14].

5 Summary

The CMS Collaboration performed a number of studies on the Higgs boson properties using $35.9\,\rm fb^{-1}$ of pp collision data recorded in 2016. The studies provide observation of the H $\rightarrow \tau\tau$ decay, per production mode measurements with the H $\rightarrow$ WW $\rightarrow \ell\nu\ell\nu$ process, and combined measurements of multiple production and decay rates and couplings of the Higgs boson. The precision of the combined measurements surpass those from ATLAS and CMS combination of 2011 and 2012 data for ggH and ttH production rates. These measurements are also used to constrain models of the extended Higgs sector complementing direct searches.

[b] More precisely the ratios of signal yields to the SM expectations, i.e. signal strengths are measured.

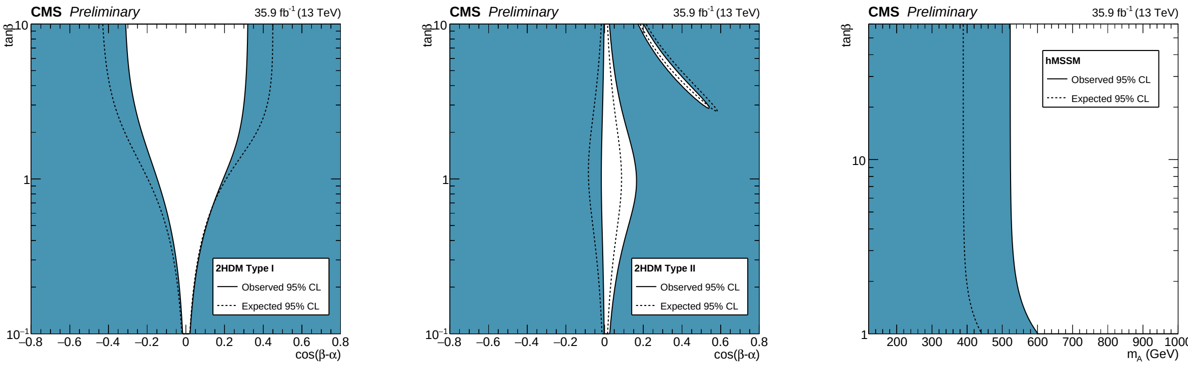

Figure 4 – Constraints in the $\cos(\beta-\alpha) - \tan\beta$ plane for the Type I 2HDM (left) and Type II 2HDM (middle), and in the $m_A - \tan\beta$ plane for the hMSSM (right). The white regions, bounded by the solid lines, represent the regions of the parameter space which are allowed at the 95% confidence level, given the data observed, while the dashed lines indicate the boundaries of the allowed regions expected for the SM Higgs boson. Plots from ref. [10].

Acknowledgments

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