PROCEEDINGS OF SCIENCE

Higgs boson properties (mass/width) at CMS

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The Higgs boson mass and its decay width are fundamental properties of this particle. Here we summarise the latest measurements of these properties performed analysing Run 2 data at a centre of mass energy of 13 TeV, with the CMS experiment, in the four-lepton and di-photon final states. The most precise Higgs boson mass measurement is $m_H = 125.38 \pm 0.14$ GeV, while for the width is $\Gamma_H = 3.2^{+2.4}_{-1.7}$ MeV, excluding the scenario with $\Gamma_H = 0$ with 3.6 standard deviation.

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1. Introduction

The Higgs boson (H) discovery was announced by the ATLAS [1] and CMS [2] Collaborations, on the 4th of July 2012 [3–5] and since then, much effort has been put into determining its properties. The mass of the H (m_H) is a free parameter of the Standard Model (SM) and it must be measured with high precision since it determines all the other H properties. Currently, all theoretical information (such as production cross-section and branching ratios) is predicted by the SM for a Higgs boson mass of 125 GeV. For example, the couplings with other massive particles depend on m_H and are precisely predicted by the SM, thus its precise measurement, together with the measurement of the production cross sections and decays to SM particles are a suitable test for the SM. The Higgs boson width (Γ_H) is predicted instead precisely within the SM, for a given m_H. However, modifications of the H boson couplings to the SM particles, or possible decays to yet undiscovered particles would alter these predicted values, and therefore it also needs to be experimentally measured.

2. The Higgs boson mass

The m_H measurement is performed using the $H \to ZZ^* \to 4\ell$ [6] and $H \to \gamma\gamma$ [7] channels thanks to their very good mass resolution (1-2%) and complete reconstruction of the final state. Data collected during 2016 proton-proton collisions at 13 TeV, corresponding to an integrated luminosity of 36 fb^{-1} have been analysed (see Figure 1). In the $H \to ZZ^* \to 4\ell$ channel, final results have

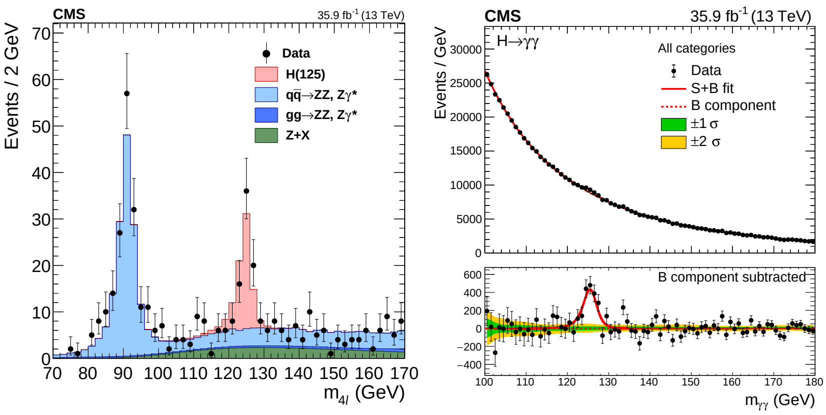

Figure 1: Invariant mass distribution for the four-lepton [6] (left) and di-photon [7] (right) final state.

been extracted building a three-dimensional statistical model, with the four-lepton invariant mass, a kinematic discriminant (D^{kin}_{bkg}) and the event-by-event mass uncertainty ($\delta m_{4\ell}$). The D^{kin}_{bkg} helps in discriminating signal from the main background due to $gg/qq \to 4\ell$ events. The $\delta m_{4\ell}$ instead helps in proper accounting for the signal mass resolutions for individual events.

The mass value measured using $H \to ZZ^* \to 4\ell$ channel is m_H = 125.26 ± 0.21 [0.19(stat) ± 0.08(syst)] GeV [6]. The inclusion of D^{kin}_{bkg} and $\delta m_{4\ell}$ in the model improves the mass measurement of about 4% and 10% respectively. The impact of including these variables in the model is visible in the scan of the profile likelihood projection on m_H in Figure 2.

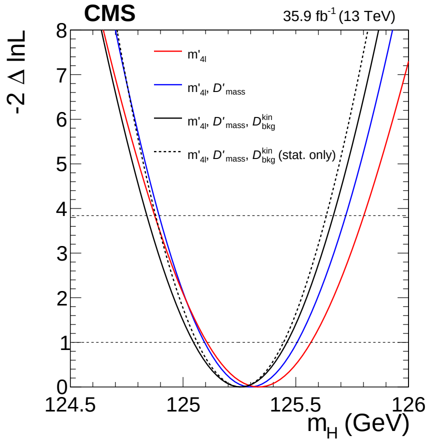

Figure 2: Profile likelihood projection on m_H for different statistical models [6].

The measurement precision is limited by the statistical uncertainty with a small contribution from systematic uncertainties, mainly due to lepton momentum scale. In the $H \to \gamma\gamma$ channel instead the relative contribution of the two uncertainties is different since the calibration of the energy response of the detector to photons plays a crucial role. Cluster containment corrections are derived on simulation using a multivariate regression. The residual differences in energy scale and resolution between simulation and data is dealt with a multistep approach, using Z $\to$ ee events in bins of electron η and p_T. In order to enhance the sensitivity, selected events are classified according to their production mode, the mass resolution and their predicted signal-to-background ratio. The mass value measured using $H \to \gamma\gamma$ channel is m_H = 125.78 ± 0.26 [0.18(stat) ± 0.19(syst)] GeV [7]. Figure 3 shows the breakdown of the systematic uncertainty: the main contributions come from photon calibrations and the non-uniformity of the light collected by the detector. This last effect is a direct consequence of the different shower shape of electrons (used to extract calibration) and photons.
This result has been then combined with the one from $H \to ZZ^* \to 4\ell$ and the one obtained analysing data collected during 2011-2012 at 7 and 8 TeV corresponding to 5.1 and 19.7 fb^{-1}, respectively (see Figure 4), resulting in m_H = 125.38 ± 0.14 [0.11(stat) ± 0.08(syst)] GeV [7].

Source	Contribution (GeV)
Electron energy scale and resolution corrections	0.10
Residual p_T dependence of the photon energy scale	0.11
Modelling of the material budget	0.03
Nonuniformity of the light collection	0.11
Total systematic uncertainty	0.18
Statistical uncertainty	0.18
Total uncertainty	0.26

Figure 3: Breakdown of the systematic uncertainties [7].

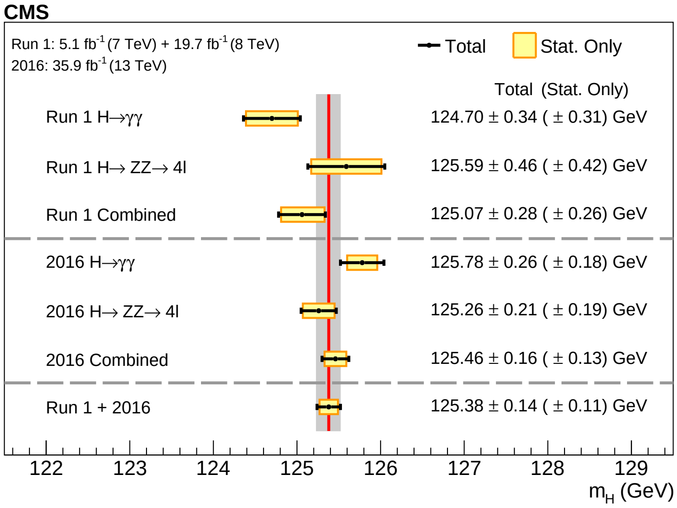

Figure 4: Summary of the m_H measurement in the $H \to ZZ^* \to 4\ell$ and $H \to \gamma\gamma$ channels, using data collected during 2011, 2012 and 2016 at 7, 8 and 13 TeV respectively [7].

3. The Higgs boson width

The direct measurement of the Γ_H is mainly affected by the detector resolution compared to the predicted value (4.07 MeV [8]). A proposed solution, adopted in the H → ZZ channel, is the measurement of the Higgs boson width comparing the on-shell and off-shell production rates:

$$\frac{\sigma^{on-shell}_{gg\to H\to ZZ^*}}{\sigma^{off-shell}_{gg\to H^*\to ZZ}} \sim \frac{1}{\Gamma_H}$$

The analysis is performed using data collected during 2016-2018 at $\sqrt{s}$ = 13 TeV, corresponding to an integrated luminosity of 138 fb^{-1}in the $H \to ZZ^* \to 4\ell$ and $H \to ZZ^* \to 2\ell 2\nu$ final states [9]. Figure 5 shows the off-shell invariant mass distributions in the four-lepton and the transverse mass in the $2\ell 2\nu$ final state. The measured value of the width is $\Gamma_H = 3.2^{+2.4}_{-1.7}\ MeV$. Figure 6 shows the profile likelihood projection on Γ_H, with the splitting of the contributions from the different final states. The scenario in which there is no off-shell contribution (Γ_H= 0) is excluded at a p-value of 0.0003 (3.6 standard deviations).

4. Conclusion

The Higgs boson properties (mass and width) as measured by the CMS Collaboration have been summarised. The Higgs boson mass, free parameter of the SM, is measured with a precision of the order to 0.1%. The best width measurement is extracted comparing on-shell with off-shell decay rates resulting in $\Gamma_H = 3.2^{+2.4}_{-1.7}\ MeV$, and excluding the scenario with Γ_H= 0 with 3.6 standard deviation.

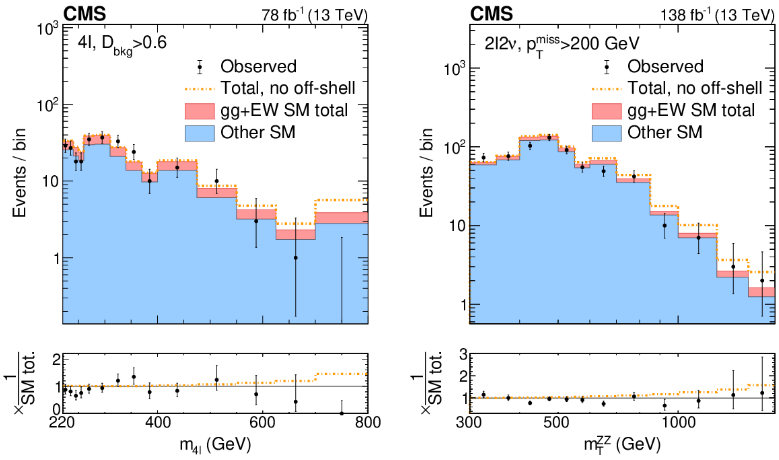

Figure 5: Distributions of the (transverse) ZZ invariant mass from the 4ℓ ($2\ell 2\nu$) off-shell signal region [9].

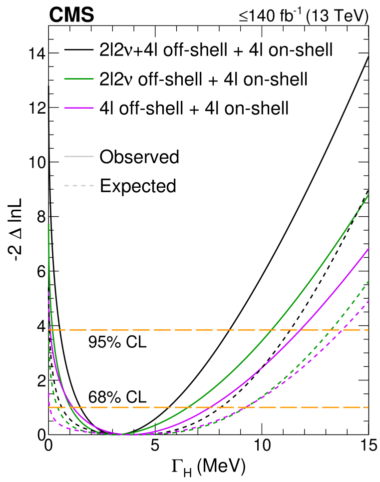

Figure 6: 1D profile likelihood projection on m_H for the combination of on-shell data with 4ℓ and/or $2\ell 2\nu$ off-shell data [9].

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