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Measurement of Higgs boson properties in the four-lepton final state at $\sqrt{s} = 13$ TeV at CMS

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Summary. — This paper reports the measurement of Higgs boson properties performed in the four-lepton final state using proton-proton collision data collected by the CMS experiment at CERN in 2016 at a centre-of-mass energy of 13 TeV. In particular, the measurement of the signal strength modifier (defined as the ratio of the observed Higgs boson rate in the four-lepton decay channel to the Standard Model expectation) is presented both inclusively and separately for the individual Higgs boson production modes. The measurements of the Higgs boson mass and width are also reported.

1. – Introduction

In 2012 the ATLAS and CMS COLLABORATIONS at the CERN LHC reported the observation of a particle with properties consistent with those of the predicted Standard Model (SM) of the particle physics Higgs boson [1-3]. Since then, further studies by the two experiments have been performed in order to understand in detail the nature of this particle and to test possible discrepancies from the SM predictions. Among the Higgs boson decay modes, the $H \to ZZ \to 4\ell$ channel ($\ell = e, \mu$) is one of the most important to measure the properties of the Higgs boson. It has been widely exploited since it has a large signal-to-background ratio and the precise reconstruction of the final state decay products allows the complete determination of the kinematics of the Higgs boson. This paper presents the measurement of the Higgs boson properties performed in the four-lepton final state using a data sample of proton-proton collisions at 13 TeV collected with the CMS detector at LHC corresponding to an integrated luminosity of 35.9 fb^{-1} [4].

2. – Event selection

Event reconstruction is based on the particle-flow algorithm which exploits the information from all the CMS subdetectors to identify and reconstruct individual particles in the

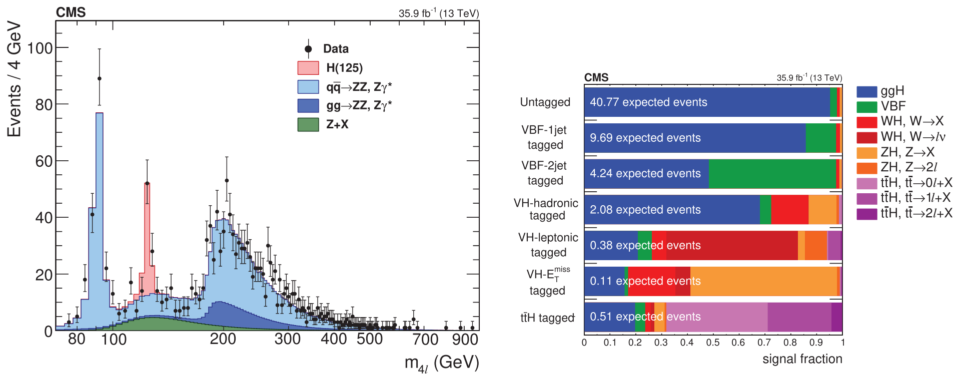

Fig. 1. – Distribution of the reconstructed four-lepton invariant mass $m_{4\ell}$ in the full mass range (left). Relative signal purity in the seven event categories in terms of the main production mechanisms of the Higgs boson in the $118 < m_{4\ell} < 130$ GeV mass window (right) [4]

event. Electrons with $p_T^e > 7$ GeV and muons with $p_T^\mu > 5$ GeV are reconstructed and selected with criteria on identification, isolation and impact parameter. Then Z candidates are formed with pairs of leptons of the same flavour and opposite charge $(e^+e^-, \mu^+\mu^-)$ and required to have $12 < m_{\ell^+\ell^-} < 120$ GeV. They are then combined into ZZ candidates, wherein the Z candidate with invariant mass closest to the nominal Z boson mass is denoted as Z_1, and the other one as Z_2. The flavours of the leptons involved define three mutually exclusive sub-channels: $4e$, 4μ, $2e2\mu$. To be considered for the analysis, ZZ candidates have to pass a set of kinematic requirements that improve the sensitivity to Higgs boson decays, in particular they are required to have $m_{Z_1} > 40$ GeV and $m_{ZZ} > 70$ GeV. The result of the event selection is shown in fig. 1 (left).

3. – Event categorization

Selected events are then divided into 7 mutually exclusive categories in order to improve the sensitivity to the Higgs boson different production mechanisms, especially to subleading production modes like vector boson fusion (VBF), and associated production with a vector boson (ZH, WH) or top quark pair (ttH). The category definitions exploit the multiplicity of additional leptons and jets in the final state and requirements on the kinematic information in each event, which is extracted performing a matrix element calculation. The definitions of the categories are chosen to achieve high signal purity while maintaining high efficiency for each of the main Higgs boson production mechanisms. Figure 1 (right) shows the performance of the event categorization in terms of relative signal purity of the seven categories for the various Higgs boson production processes.

4. – Results

4·1. *Signal strength modifier.* – The signal strength modifier μ, defined as the ratio of the observed Higgs boson rate in the four-lepton decay channel to the Standard Model expectation, is extracted performing a multi-dimensional fit which relies on two variables: the four-lepton invariant mass $m_{4\ell}$ and a kinematic discriminant $\mathcal{D}_{\rm bkg}^{\rm kin}$. $\mathcal{D}_{\rm bkg}^{\rm kin}$ is

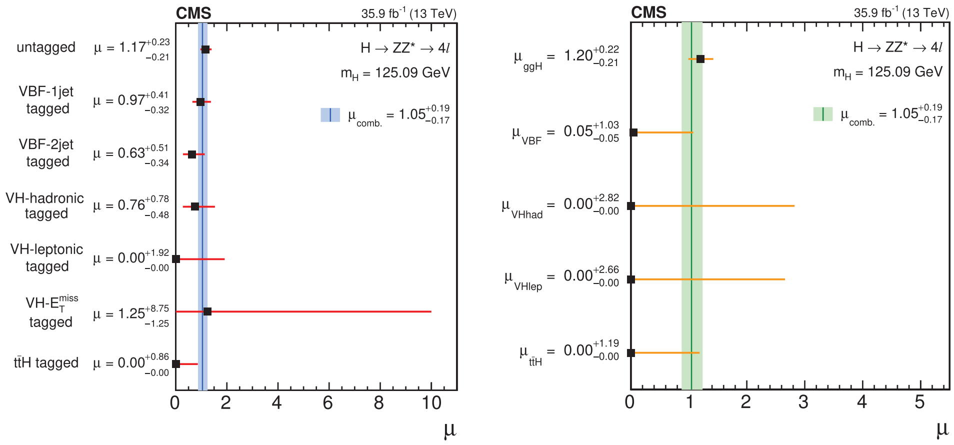

Fig. 2. – Left: observed values of the signal strength modifier for the seven categories, compared to the combined μ shown as a vertical line. Right: result obtained for the signal strength modifiers corresponding to the main SM Higgs boson production modes, compared to the combined μ shown as a vertical line [4].

defined using the variables that characterize the Higgs boson decay kinematics in order to discriminate between signal and background. A simultaneous fit to all categories is performed to extract the signal strength modifier. At the ATLAS and CMS Run 1 combined mass value of $m_{\mathrm{H}} = 125.09$ GeV, the signal strength modifier is measured to be $\mu = 1.05^{+0.19}_{-0.17}$. The observed value is consistent with the SM prediction of $\mu = 1$ within the uncertainties. It is then compared to the measurement for each of the seven event categories and the result is shown in fig. 2 (left). The result is extracted also for five signal strength modifiers that control the contributions of the main SM Higgs boson production modes and it is shown in fig. 2 (right).

4·2. *Mass and width.* – The measurement of the mass of the Higgs boson exploits additional information from per-event relative mass uncertainties $\mathcal{D}_{\mathrm{mass}}$, which are defined by propagating per-lepton momentum errors to the 4ℓ candidate. The result obtained for the Higgs boson mass from the three-dimensional likelihood fit is $m_{\mathrm{H}} = 125.26 \pm 0.21$ GeV. The measurement of the Higgs boson width is performed for the on-shell Higgs boson production. It is extracted performing an unbinned maximum-likelihood fit to the 4ℓ distribution. The width is constrained to be $\Gamma_{\mathrm{H}} < 1.10$ GeV, at 95% confidence level.

5. – Conclusions

All the presented results are consistent, within their uncertainties, with the expectations for the SM Higgs boson. The detailed analysis is presented in the paper [4].

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