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Higgs differential and fiducial measurements (including boosted) at ATLAS and CMS experiments

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It has been ten years since the Higgs boson discovery by ATLAS and CMS collaborations at CERN. Since then, many measurements have been carried out to understand its nature and so far good agreement with respect to the predictions of the SM was found. Such measurements as the fiducial and differential cross sections play an important role as they test the SM predictions and probe for beyond SM contributions using a wide spectra of physical observables. In the following, the latest differential and fiducial cross-section measurements in the WW, ZZ, $\gamma\gamma$, $\tau\tau$ and $b\bar{b}$ decay channels using the LHC full Run2 dataset at 137-139 fb^{-1} from CMS and ATLAS experiments as well as the latest combination measurement between the ZZ and $\gamma\gamma$ input analysis channels using ATLAS 139 fb^{-1} dataset are presented.

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1. Introduction

The Higgs boson has been discovered [1, 2] ten years ago by the ATLAS [3] and CMS [4] collaborations. Since then, many measurements of its properties have been performed and showed good agreement with the SM predictions. Measurements such as the fiducial and differential cross-section which are performed within a specific phase space (fiducial region) and provide a model independent measurement due to the minimal number of physical assumptions considered. In the following, an overview of the main results for measurements of the fiducial and differential cross sections performed by both ATLAS and CMS experiments using LHC full Run2 dataset at 137-139 fb^{-1} are shown for Higgs decays in bosonic final states as WW [5], ZZ [6, 7], $\gamma\gamma$ [8, 9] and fermionic states as $\tau\tau$ [10] and $b\bar{b}$ [11, 12]. In addition, a combination measurement [13] between ZZ and $\gamma\gamma$ channels is performed in ATLAS by extrapolating the cross sections to the full phase space by applying inclusive and differential acceptance factors computed from SM predictions.

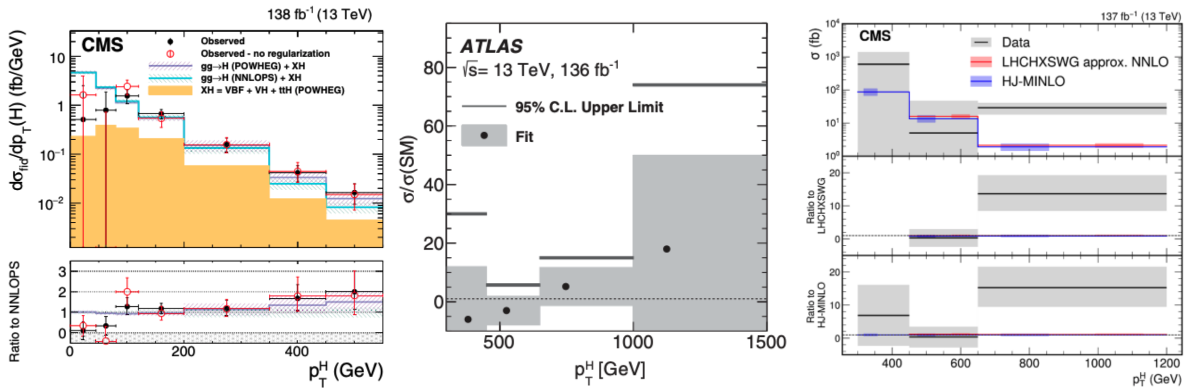
2. Fiducial and differential cross-section measurements in Higgs decays to bosons

The fiducial and differential cross section measurements in events where the Higgs boson decays to a pair of γ, Z or W bosons benefit from relatively low background contributions and well reconstructed final states. In the di-photon channel, ATLAS provides the total cross section measurements in five fiducial regions (inclusive, VBF-enhanced, $N_{\text{lepton}} > 1$, high $E_{\text{T}}^{\text{miss}}$ and ttH-enhanced) while the inclusive fiducial region is available in CMS. As for the differential measurements, a wide variety of physical observables are probed as p_{T}^{H} which is sensitive to perturbartive QCD calculations, $|y_H|$ sensitive to the PDF of the gluons in the protons, N_{jets} and $p_{\text{T}}^{\text{lead. jet}}$ to the Higgs boson production mechanisms and theoretical modelling in high-p_T respectively. Two dimensional variables are also measured in ATLAS as for example p_{T}^{H} versus $|y_H|$. ATLAS measurements are compared to different SM predictions where the default used is the POWHEG NNLOPS N^{3}LO (QCD)+NLO(EW) while CMS use a MADGRAPH5_aMC@NLO reweighted to match the NNLOPS prediction. Overall, good agreement is seen with respect to the SM predictions from the results reported by ATLAS and CMS. Statistical uncertainty dominates the measurement for both ATLAS and CMS, followed by background modelling and photon energy scale and resolution systematic uncertainties at ATLAS. In the ZZ channel, CMS measure the differential cross section for p_{T}^{H}, $|y_H|$, N_{jets} and $p_{\text{T}}^{\text{lead. jet}}$ observables while in ATLAS the list of variables is extended to di-lepton mass pair, angles between the Z boson and leptons in Higgs boson rest frame and double-differential variables as p_{T}^{H} versus $|y_H|$ as examples. In ATLAS, the measurements are compared to NNLOPS and MADGRAPH5_aMC@NLO-FxFx while in CMS, the NNLOPS scaled to N^{3}LO and POWHEG (NLO) are used as the predictions. Measurements show good agreement with respect to SM predictions. In both results, statistical uncertainty is the dominant source, followed by luminosity, lepton reconstruction and identification and $ZZ^\star$ theoretical uncertainties (ATLAS). In the WW channel, the signature is at least two isolated leptons ($e^\pm\mu^\pm$) and missing energy from neutrinos where 2D fits are performed to the di-lepton mass and transverse mass of the Higgs boson to extract the signal yields. The total fiducial cross section is measured to 86.5 ± 9.5 fb and compatible to the SM prediction of 82.5 ± 4.2 fb. In addition, differential measurements in bins of p_{T}^{H} and $|y_H|$ show good compatibility with SM. Dominant systematics uncertainties are the lepton reconstruction and identification, lepton momentum, jet scale and missing energy. Overall, statistical uncertainty size is comparable to the systematic ones.

3. Fiducial and differential cross-section measurements in Higgs decays to fermions

The first fiducial and differential cross section measurements in $H \to \tau\tau$ performed at LHC is reported by the CMS experiment. Its signature includes 4 final states: $e\mu$, $e\tau_{had}$, $\mu\tau_{had}$ and $\tau_{had}\tau_{had}$ which are further categorized in different p_{T}^{had} regions. The main background sources are the di-τ background from $Z \to \tau\tau$ estimated from an "embedded sample" using data and jets misidentified as τ_{had} candidates also estimated from data. The total fiducial cross section measured is 426 ± 102 fb being consistent with the SM predicion of 408 ± 27 fb. The differential cross sections are also measured in bins of p_{T}^{H} and N_{jets} as seen in Figure 1a and are consistent with SM predictions. The measurements discussed are dominated by statistical uncertainty. These measurements are competitive with $H \to ZZ$ from ATLAS and CMS results in the p_{T}^{H} region between 120 GeV and 200 GeV and more sensitive than the $H \to WW$ cross sections measurements from CMS results.

In order to explore the high transverse momentum region, $p_{\mathrm{T}}^{H} > 1$ TeV, which is sensitive to new physics contributions, fiducial cross section measurements in the $H \to b\bar{b}$ final states are performed. The signature is based on reconstructed Higgs bosons with large Lorentz boost from single large radius jet: at least two jets (p_{T} > 450 GeV and 250 GeV) in ATLAS and jet candidates with p_{T} > 450 GeV in CMS. The main background source is due to the QCD multi-jet events which is modelled in the signal region using data. The results are found to be consistent with the SM predictions for the ATLAS measurement as showed in Figure 1b while CMS results show an excess with 2.6σ local significance with respect to the SM prediction as displayed in Figure 1c, which is further reduced to 1.9σ considering the 3 bins of the measurement simultaneously. Measurement is dominated by the statistical uncertainty component followed by the jet systematic uncertainty.

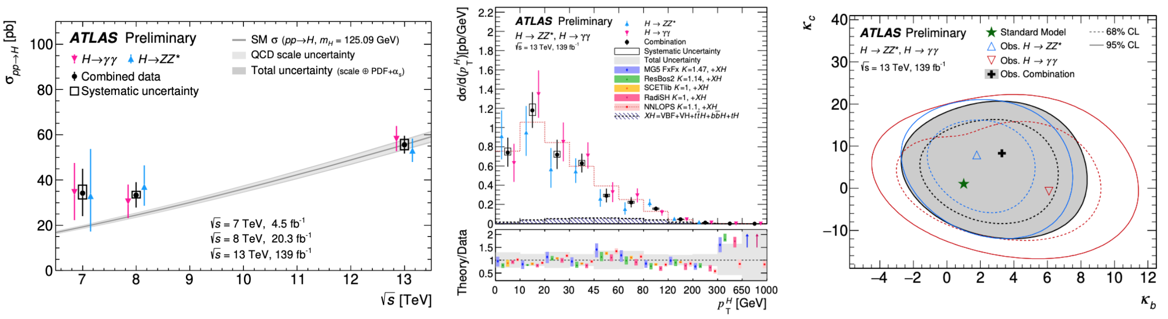


(a) **(b)** **(c)**

Figure 1: Differential p_{T}^{H} measurement compared to SM predictions in (a) $H \to \tau\tau$ (CMS) [10] (b) inclusive $H \to b\bar{b}$ (ATLAS) [11] and (c) inclusive $H \to b\bar{b}$ (CMS) [12].

4. Combined measuremet for total and differencial cross-sections from $\gamma\gamma$ and ZZ input channels

Combination measurements for the total and differential cross sections are performed using the $H \to ZZ$ and $H \to \gamma\gamma$ channels event yields which takes into account the correction for detector effects, luminosity, acceptances and branching fractions. The acceptance factors are estimated using SM predictions and extrapolate the individual event yields from the fiducial to the full phase space. A likelihood statistical procedure is further used for obtaining the final combined measured total cross section as well as the differential cross section for a given observable. Besides the total production cross section, differencial measurements are also performed for p_{T}^{H}, $|y_H|$, N_{jets} and $p_{\mathrm{T}}^{\mathrm{lead.\ jet}}$ observables. The total production cross section measurement is $55.5^{+4.0}_{-3.8}$ pb and consistent with the SM prediction 55.6 ± 2.5 pb as shown in Figure 2a. Differential p_{T}^{H} measurement is found to be 78% compatible with the SM prediction (NNLOPS) as shown in Figure 2b. All measurements are consistent with the SM predictions. In addition, the p_{T}^{H} shape distribution is used to indirect constrain the charm- and bottom-quark Yukawa couplings, κ_c and κ_b, respectively, as shown in Figure 2c.



(a) **(b)** **(c)**

Figure 2: (a) Total production cross section in different center-of-mass energies for the $H \to ZZ$ and $H \to \gamma\gamma$ individual channels as well as for its combination [13]. (b) Differential cross-section measurement in bins of p_{T}^{H} compared to different SM predictions [13]. (c) Observed limits on κ_c and κ_b at 95%CL using p_{T}^{H} shape information only for the individual and combined decay channels [13].

5. Summary

A significant amount of knowledge has been acquired since the Higgs boson discovery through the many measurements performed to understand its properties. The measurements of the fiducial and differential cross sections using the LHC full Run2 dataset in several Higgs boson decays modes from ATLAS and CMS provide a very good agreement with respect to the SM predictions. The statistical uncertainty is still the dominant uncertainty source on these measurements. Exciting new results are expected with the just started Run3 of LHC.

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