PROCEEDINGS OF SCIENCE

STXS and differential Higgs boson cross section measurements at CMS

Benedetta Camaiani[ab,*] **on behalf of the CMS Collaboration**

[a] *Department of Physics and Astronomy,*
Via G. Sansone 1, 50019 Sesto Fiorentino (Firenze), Italy
[b] *Istituto Nazionale di Fisica Nucleare,*
Via G. Sansone 1, 50019 Sesto Fiorentino (Firenze), Italy

E-mail: benedetta.camaiani@cern.ch

STXS and differential measurements of the Higgs boson production cross section are a valuable tool for testing standard model predictions and searching for physics beyond the standard model. This report presents the latest differential and STXS results for Higgs boson production, based on data from proton-proton collisions recorded by the CMS experiment during the Run 2 of the CERN LHC. First results with Run 3 data are also presented.

42nd International Conference on High Energy Physics (ICHEP2024)
18-24 July 2024
Prague, Czech Republic

*Speaker

PoS(ICHEP2024)047

1. Introduction

The discovery of the Higgs boson [1–3] by the ATLAS [4] and CMS [5] experiments marked the beginning of precision measurements of the properties of the newly observed particle. Fiducial and differential measurements play a key role to understand deeper the standard model (SM), offering a model independent way to measure production cross sections and to increase sensitivity to beyond the standard model (BSM) effects. Fiducial measurements limit the extrapolation of results to a restricted phase space that is defined as closely as possible to the experimental selection. This approach minimizes the model assumptions for extrapolation to the full phase space, easing the comparison with different theoretical predictions. In differential measurements, on the other hand, the cross section is measured in bins of some kinematic observables, providing more detailed information than inclusive measurements. A complementary approach to differential measurements is provided by the simplified template cross sections (STXS) framework [6]. In this case, the cross section is measured in predefined bins per production mode, aiming to maximize experimental sensitivity to BSM effects and reduce the model dependence of the measurement.
This report provides a summary of the recent differential and STXS cross section measurements of the Higgs boson production, performed by the CMS Collaboration using data collected during the LHC Run 2 at $\sqrt{s} = 13$ TeV and corresponding to an integrated luminosity of $\mathcal{L} = 138$ fb^{-1}. First differential results using Run 3 data at the higher energy of $\sqrt{s} = 13.6$ TeV and corresponding to $\mathcal{L} = 34.7$ fb^{-1} are also presented.

2. Differential cross section measurement in boosted $H \to \tau\bar{\tau}$

In the low transverse momentum (p_T) region, the analysis sensitivity is primarily driven by the Higgs boson decay channels into a Z boson or photon pair. In contrast, at higher values of p_T, the measurement precision improves by the $H \to \tau\tau$ and $H \to b\bar{b}$ modes due to their large branching ratios and a reasonable background level. Consequently, these decay channels are often selected for measurements in the boosted regime. The measurement in the $H \to \tau\tau$ decay channel [7] is the first ever performed in a boosted regime using this decay mode. The analysis employs the full Run 2 data set, and targets the production of a Higgs boson with a transverse momentum greater than 250 GeV. This specific focus allows to test BSM effects that inclusive measurements might overlook, particularly concerning the Higgs boson couplings with massive fermions. Because of the high transverse momentum of the Higgs boson, the τ leptons are produced spatially closed, with an angular separation less than 0.8 and with their decay products overlapping. To handle this challenge, a dedicated algorithm has been developed to accurately reconstruct the τ leptons across four different final states. Finally, to enhance the analysis sensitivity, a multiclass neural network is trained in each final state to discriminate signal from major backgrounds. The Higgs boson production cross section is measured as a function of the transverse momentum of both the Higgs boson and the p_T-leading jet in the final state. The results are presented in Fig. 1. The leading source of systematic uncertainty arises from the identification of the τ candidates, though the differential results are predominantly limited by statistical uncertainty, particularly in the highest-p_T bins. No significant deviation from the SM expectation are found.

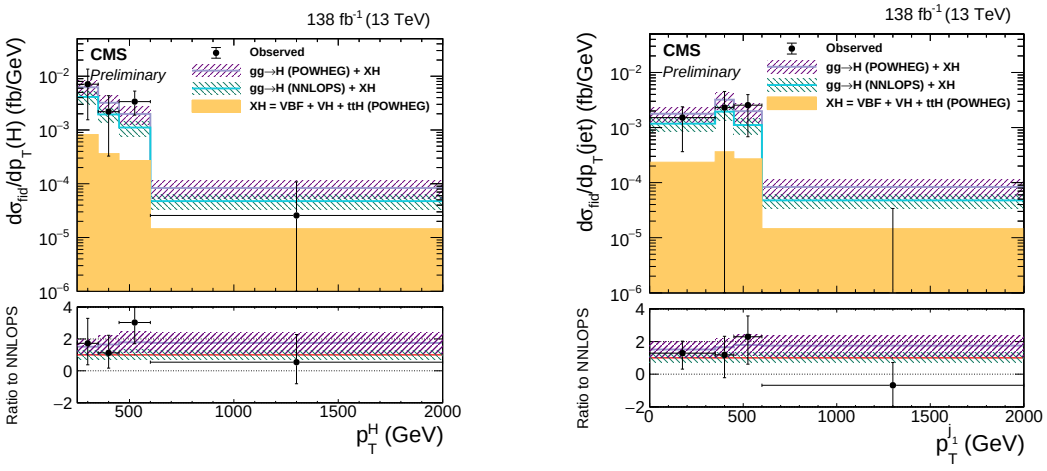

Figure 1: Higgs boson production cross section as a function of the transverse momentum of the Higgs boson (left) and p_{T}-leading jet (right), measured in the $\mathrm{H} \to \tau\tau$ decay channel [7].

3. Differential cross section measurement in boosted $\mathrm{H} \to \mathrm{b\bar{b}}$

The first full Run 2 measurement presented in the $\mathrm{H} \to \mathrm{b\bar{b}}$ decay channel [8] targets the production of a Higgs boson with a transverse momentum greater than 450 GeV through the vector boson fusion (VBF) and gluon fusion (ggH) mechanism. In this boosted regime, gluon fusion becomes less dominant compared to the low-energy spectrum, thus providing the possibility to directly probe Higgs boson couplings to vector bosons. The decay products of the Higgs boson, due to the high momentum, are reconstructed as a single jet with large radius, identified by using a multivariate jet tagger. The signal extraction is then performed using the soft-drop mass of the jet as discriminating variable between the signal process and the main background contributions, such as QCD multijet events or W/Z+jets production.
The VBF and ggH cross sections are measured in bins of the invariant mass of the two VBF-jets and the Higgs boson transverse momentum, respectively. The measured VBF and ggH signal strengths in each bin are reported in Fig. 2 (left). These results are unfolded in five STXS stage 1.2 bins and are presented in Fig. 2 (right). Overall, results are compatible with the SM expectation within two standard deviations.

4. STXS cross section measurement in $\mathrm{H} \to \mathrm{b\bar{b}}$

An additional measurement in the $\mathrm{H} \to \mathrm{b\bar{b}}$ decay channel [9] is carried out within the STXS framework using the full Run 2 data set and focuses on the Higgs boson production via vector boson associated production (VH). The primary distinction from the previous publication is the introduction of dedicated categories for boosted jet topologies. Three different analysis channels (0, 1, and 2 leptons) are considered, based on the decay of the associated vector boson for both resolved and boosted topology. Reconstructed-level categories are defined by applying selections on the transverse momentum of the vector boson and the number of additional jets in the event. The main background contributions come from top quark pair production and V+jets processes. The results are obtained through a simultaneous maximum-likelihood fit of the signal-plus-background

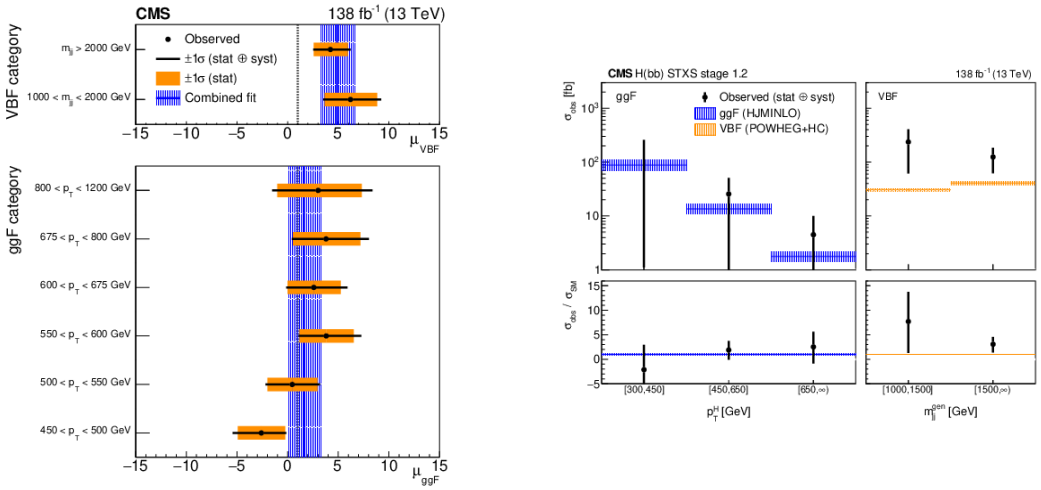

Figure 2: VBF and ggH signal strengths (left) and unfolded cross section in five STXS stage 1.2 bins, measured in the H → b$\bar{\text{b}}$ decay channel [8].

model, using different fit variables tailored to each analysis category. For instance, a classifier based on a deep neural network is employed in the resolved signal regions, while a boosted decision tree is used for the boosted regions.

The measured signal strengths in the STXS bins that have been considered in this analysis are shown in Fig. 3 (left). These results are interpreted in Fig. 3 (right) as the product of the production cross sections (σ) and the branching fractions ($\mathcal{B}$) for V to leptons and H → b$\bar{\text{b}}$.

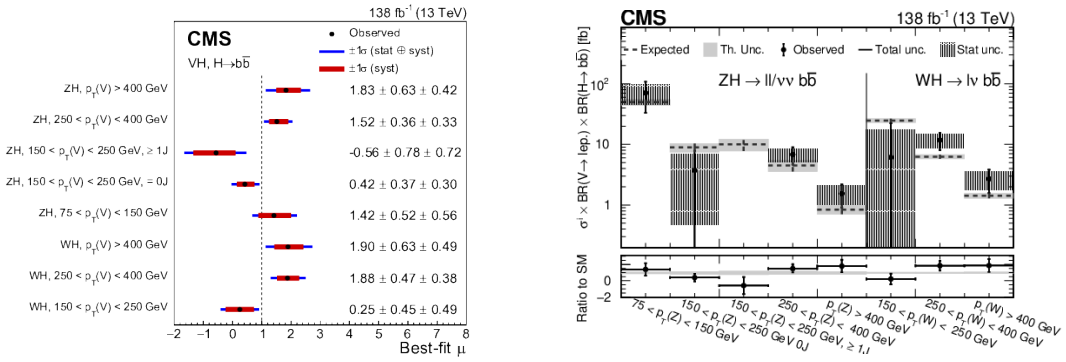

Figure 3: STXS signal strength modifiers (left) and values of $\sigma\mathcal{B}$ (right) for the VH production, measured in the H → b$\bar{\text{b}}$ decay channel [9].

5. First differential cross section measurements at $\sqrt{s}$ = 13.6 TeV

The first differential measurements using Run 3 data at the center-of-mass energy of $\sqrt{s}$ = 13.6 TeV [10] have been performed in the H → ZZ and H → $\gamma\gamma$ decay channels. Despite their low branching ratios, these channels benefits from a clean final state topology, that allows to perform precision measurement of the Higgs boson properties.

The measurement in H → ZZ [11], with the Z bosons decaying to leptons (electrons or muons), includes both the inclusive Higgs boson production cross section and the differential fiducial cross

section as a function of the Higgs boson transverse momentum and rapidity. The signal extraction employs the invariant mass of the four leptons in the final state, as it is highly discriminating between the signal and the main background contribution coming from non-resonant production of Z boson pair. Differential distributions are shown in Fig. 4 and are found to be in agreement with the SM predictions, although dominated by statistical uncertainty.

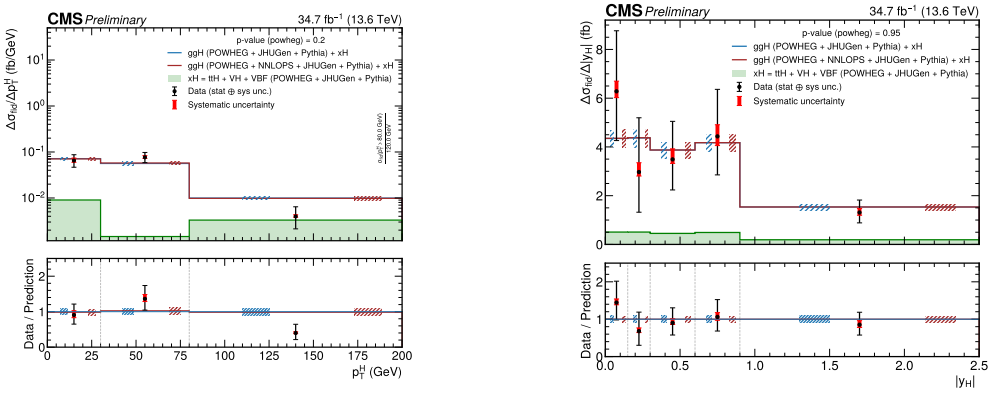

Figure 4: Differential cross section as a function of the Higgs boson transverse momentum (left) and rapidity (right), measured in the H → ZZ → 4ℓ decay channel [11].

Similarly to the H → ZZ channel, the measurement performed in the H → $\gamma\gamma$ decay channel [12] quotes both inclusive and differential cross sections. The main background contributions in this analysis are due to the non-resonant diphoton production and the γ+jets events. To reduce the model dependence of the measurement, a fiducial phase space is defined as close as possible to the experimental selection, by means of cuts on the single photons and the diphoton system. The signal is then extracted using the diphoton invariant mass as fit variable.
Differential cross sections are measured as a function of the Higgs boson transverse momentum, rapidity and the number of hadronic jets in the final state. The differential distribution, shown in Fig. 5, are limited by statistical uncertainty but agree within the uncertainties with the SM predictions.

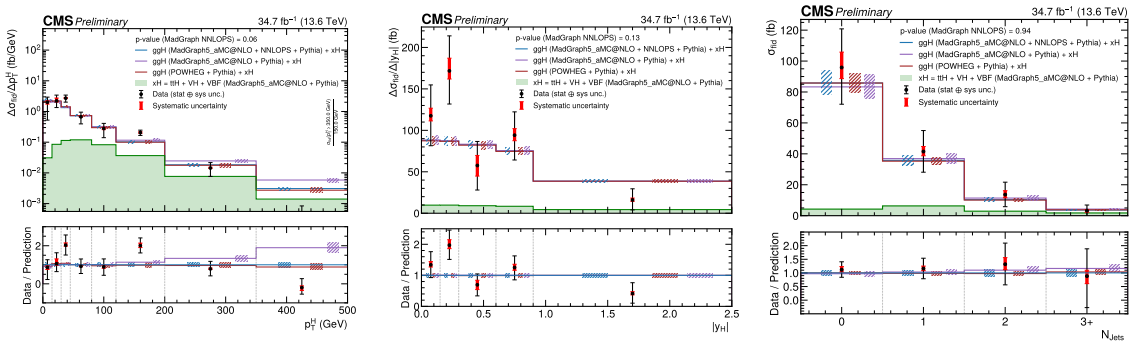

Figure 5: Differential cross section as a function of the Higgs boson transverse momentum (left), Higgs boson rapidity (center) and the number of hadronic jets in the final state (right), measured in the H → $\gamma\gamma$ decay channel [12].

Summary

In this brief review, some of the most recent STXS and differential measurements of the Higgs boson production cross section have been presented, including the first results from Run 3 data collected by the CMS experiment. Several decay channels have been analyzed, each carrying complementary information. To date, no significant deviations from Standard Model predictions have been observed.

References

[1] ATLAS Collaboration, *Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC* *Phys. Let. B* **716** 1 2012 [hep-ex/1207.7214].

[2] CMS Collaboration, *Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC* *Phys. Let. B* **716** 30 2012 [hep-ex/1207.7235].

[3] CMS Collaboration, *Observation of a new boson with mass near 125 GeV in pp collisions at* $\sqrt{s}$ = 7 *TeV and 8 TeV* *J. High Energ. Phys.* **2013** 81 2013 [hep-ex/1303.4571].

[4] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider**JINST* **3** S08004.

[5] CMS Collaboration, *The CMS experiment at the CERN LHC*, *JINST* **3** S08004 [hep-ex/1303.4038].

[6] Berger N, et al, *Simplified Template Cross Sections - Stage 1.1*, arXiv:1906.02754[hep-ph/1906.02754]

[7] CMS Collaboration, *Measurement of the highly Lorentz-boosted Higgs boson cross section in the decay mode of a pair of* τ *leptons in proton-proton collisions at* $\sqrt{s}$ = 13 TeV, *CMS-PAS-HIG-21-007*.

[8] CMS Collaboration, *Measurement of boosted Higgs bosons produced via vector boson fusion or gluon fusion in the* $H \to b\bar{b}$ *decay mode using LHC proton-proton collision data at* $\sqrt{s}$ = 13 TeV, *Submitted to J. High Energ. Phys.* [hep-ex/2407.08012].

[9] CMS Collaboration, *Measurement of simplified template cross sections of the Higgs boson produced in association with W or Z bosons in the* $H \to b\bar{b}$ *decay channel in proton-proton collisions at* $\sqrt{s}$ = 13 TeV, *Phys. Rev. D* **109** 092011 [hep-ex/2312.07562v2].

[10] CMS Collaboration, *Development of the CMS detector for the CERN LHC Run 3*, *JINST* **19** (2024) P05064 [hep-ex/2309.05466]

[11] CMS Collaboration, *Measurements of Higgs boson production cross sections in the four-lepton final state at 13.6 TeV*, CMS-PAS-HIG-24-013.

[12] CMS Collaboration, *Measurements of inclusive and differential Higgs boson production cross sections at 13.6 TeV in the* $H \to \gamma\gamma$ *decay channel*, CMS-PAS-HIG-23-014.