PROCEEDINGS OF SCIENCE

Status and prospects of simplified template cross sections measurements in ATLAS and CMS

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The Higgs boson production cross sections in exclusive kinematic bins are measured as simplified template cross sections (STXS), which are designed to reduce model dependence and maximize sensitivity to new physics beyond the Standard Model. This review summarizes the STXS results in the combined measurements in ATLAS and CMS experiments. Constraints on the self-coupling and future prospects at the High-Luminosity LHC are also discussed. The LHC proton-proton collision data at $\sqrt{s}$ = 13 TeV, collected up to 79.8 fb^{-1} are used.

7th Annual Conference on Large Hadron Collider Physics - LHCP2019
20-25 May, 2019
Puebla, Mexico

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PoS(LHCP2019)133

ATL-PHYS-PROC-2019-080
29 August 2019

1. Introduction

Kinematic distributions of the Higgs boson can be sensitively modified by new physics beyond the Standard Model (SM). Therefore, measurement of the cross sections in specific regions of the phase space is desired in addition to the coupling measurement. The Higgs boson production cross sections in exclusive kinematic bins are measured as simplified template cross sections (STXS) [1, 2], which are designed to reduce model dependence and maximize sensitivity to new physics beyond the Standard Model (BSM).

An overview of the STXS framework is shown in Figure 1. At first, the experimental analyses are used to measure the main production cross sections (ggF, VBF, VH, ttH) in the Higgs boson rapidity range of $|y_H| < 2.5$ (Stage 0). Then, the cross sections in finer bins are measured depending on the analysis sensitivity (Stage 1). The Stage 1 binning is defined for the ggF, VBF, VH using number of jets, transverse momentum (p_T) and so on. Finally the results are used to constrain the coupling modifiers, EFT coefficients and specific BSM scenarios.

Currently reduced Stage 1 STXS binning is used, and revised Stage 1.1 binning is newly defined. The Stage 1.1 binning is designed to capture more of the VBF kinematics and low p_T ggF. This review summarizes the STXS results in the combined measurements in ATLAS and CMS experiments [3, 4, 5, 6]. Constraints on the self-coupling and future prospects at the High-Luminosity LHC are also discussed [7, 8]. The LHC proton-proton collision data at $\sqrt{s}$ = 13 TeV, collected up to 79.8 fb^{-1} are used.

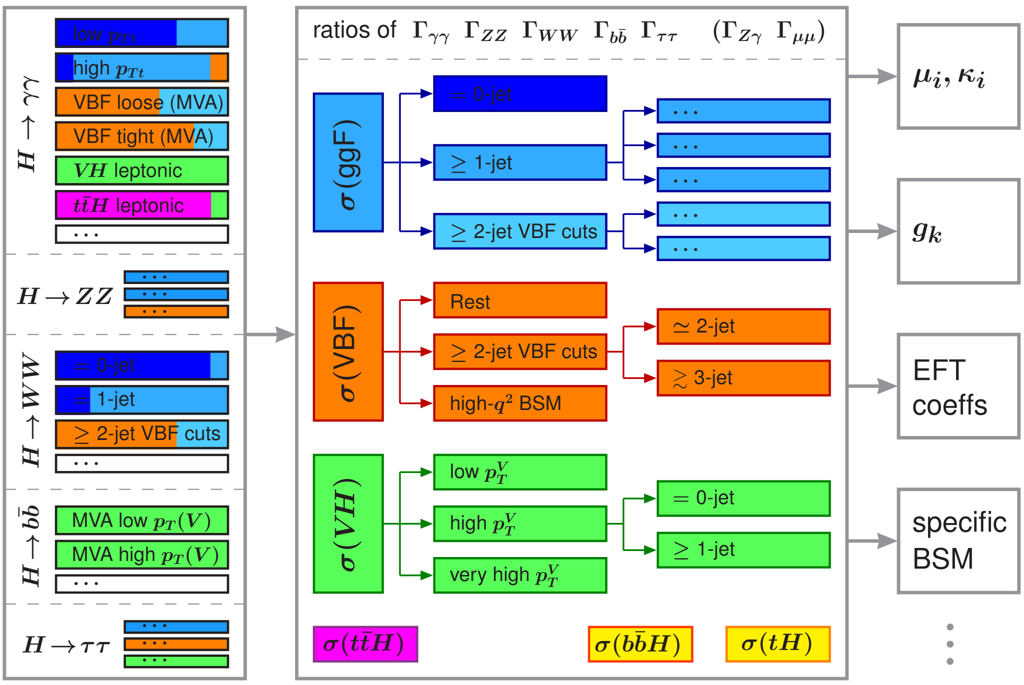

Figure 1: Overview of the STXS framework [1]. Experimental analyses shown on the left are used to measure cross sections shown in the middle. Main production modes are the ggF (blue), VBF (red), VH (green) and ttH (purple). The results are used to constrain coupling modifiers, EFT coefficients and specific BSM scenarios as shown on the right.

2. Combined measurements in ATLAS

Combined measurements of the Higgs boson production and decay rates in ATLAS are reported in [5]. The LHC proton-proton collision data at $\sqrt{s}$ = 13 TeV, collected up to 79.8 fb^{-1} are used. Reduced Stage 1 binning is used in most of the analyses. Stage 0 binning is used for the VBF, $H \to bb$ analysis. The $H \to \mu\mu$ analysis is not used in the STXS results due to the lack of sensitivity. The global signal strength is measured to be

$$\mu = 1.11^{+0.09}_{-0.08} = 1.11 \pm 0.05 \text{ (stat.) } {}^{+0.05}_{-0.04} \text{ (exp.) } {}^{+0.05}_{-0.04} \text{ (sig.th.) } \pm 0.03 \text{ (bkg.th.)}.$$

Dominant uncertainties are from the signal theory (4.2%), background theory (2.6%), photon (2.2%) and luminosity (2%). However dominant uncertainties are different in each analysis, therefore it is important to improve uncertainties in each analysis. Main production cross sections relative to the SM prediction are shown in Figure 2. All major production modes are now observed with significance greater than 5σ. Reduced Stage 1 STXS results are shown in Figure 3. Branching ratios with respect to the branching ratio to ZZ (B_{ZZ}) are measured to be lower than the SM since the B_{ZZ} is measured to be higher than the SM. The results are consistent with the SM, however the sensitivity is still limited in high p_T bins.

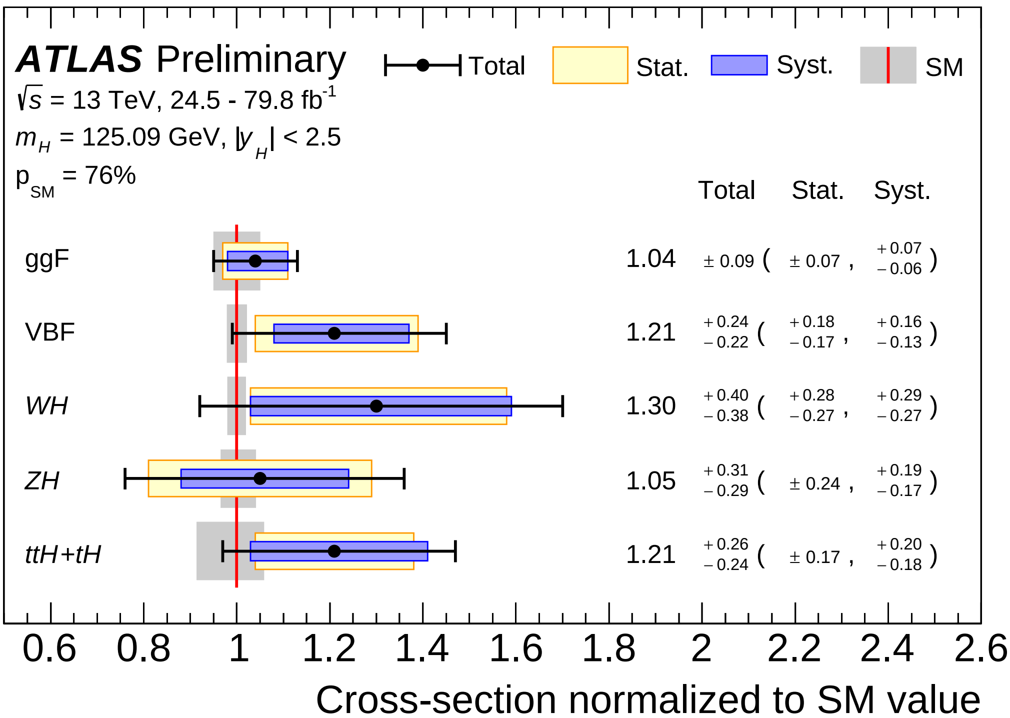

Figure 2: Main production cross sections relative to the SM prediction [5]. The *bbH* is included in the *ggH* bins since the contribution is small and the acceptance is similar.

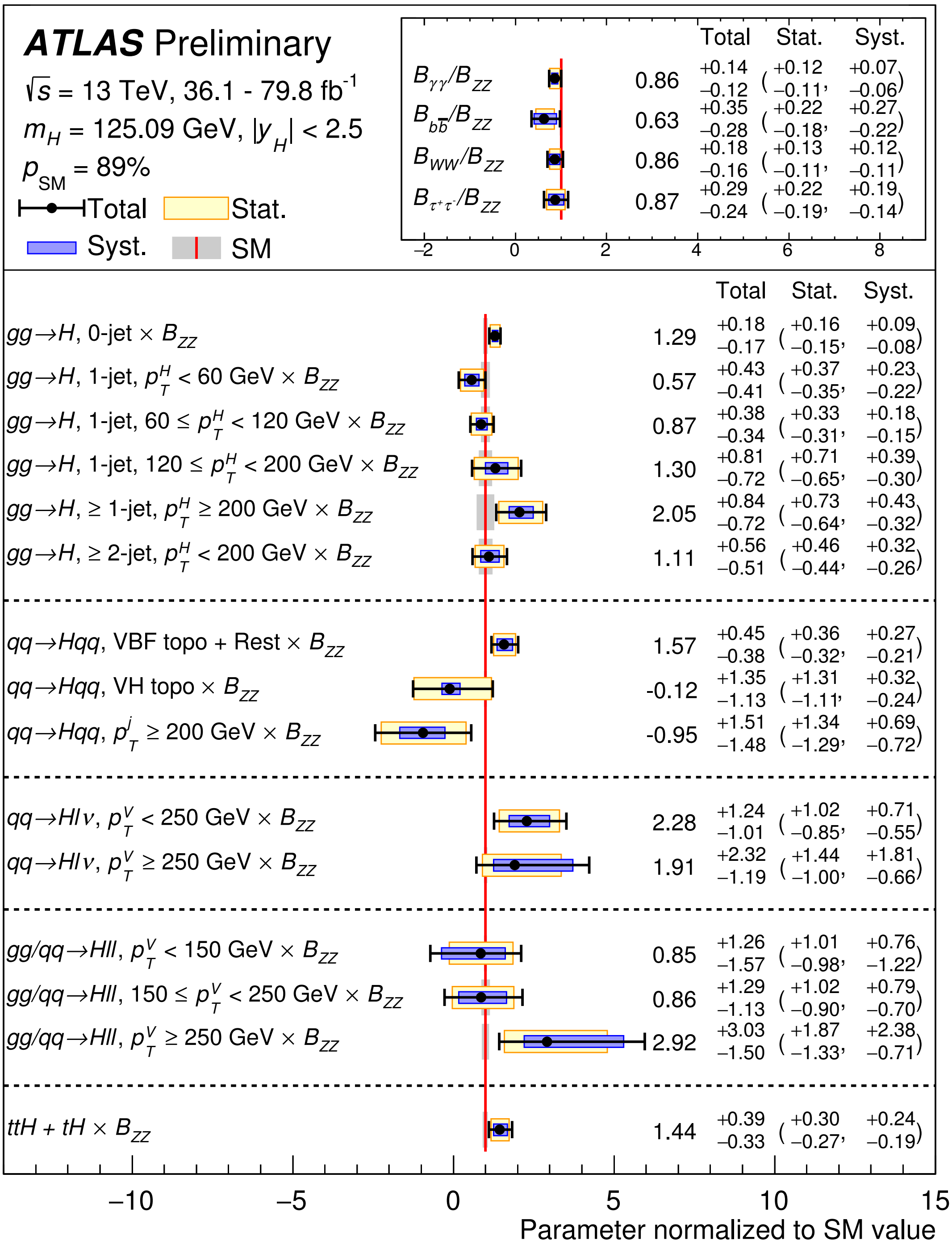

Figure 3: Reduced Stage 1 STXS results [5]. The ggF bins are defined by number of jets and p_T^H. A bin with one or more jets and $p_T^H > 200$ GeV is defined to probe BSM effect in high p_T. The one jet bin with $p_T^H < 200$ GeV is split into bins with p_T^H = 0–60, 60–120 and 120–200 GeV. The VBF bin is split into three bins with $p_T^j > 200$ GeV, m_{jj} = 60–120 GeV (VH topo) and $m_{jj} > 400$ GeV including the rest of the events (VBF topo + Rest). The VH bin is split into WH and ZH bins. The WH bin is split at p_T^W = 250 GeV. The ZH bin is split at p_T^Z = 150 GeV and 250 GeV.

3. Combined measurements in CMS

Combined measurements of the Higgs boson production and decay rates in CMS are reported in [6]. The LHC proton-proton collision data at $\sqrt{s}$ = 13 TeV, collected up to 35.9 fb^{-1} are used. Stage 0 binning is used for all channels. The global signal strength is measured to be

$$\mu = 1.17 \pm 0.10 = 1.11 \pm 0.06 \text{ (stat) } {}^{+0.06}_{-0.05} \text{ (sig theo) } \pm 0.06 \text{ (other syst)}.$$

Dominant uncertainties are from the signal theory (5%), luminosity (2%) and so on. There are up to 50% level improvements compared to Run 1 due to increased cross section, improved theory uncertainty, additional event categories. Signal strength of the main production modes and the Stage 0 STXS results are shown in Figure 4. The branching ratios with respect to B_{ZZ} are also included as parameters of interest in the Stage 0 STXS results. For example, the WH production cross section is measured to be higher than the SM, however the sensitivity is still limited with relatively large uncertainty.

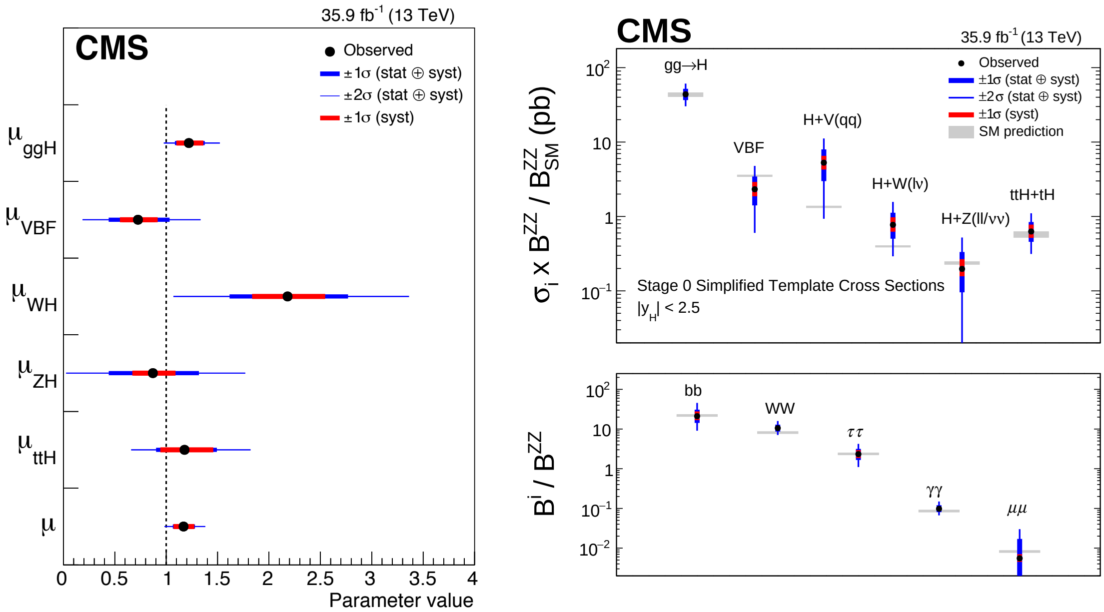

Figure 4: Signal strength of the main production modes (left) and the Stage 0 STXS results (right) [6]. The bbH is merged to ggH due to the lack of sensitivity.

4. Constraints on the self-coupling

Constraints on the Higgs boson self-coupling (λ_{HHH}) using single Higgs boson production are reported in [7]. The Higgs self energy loops and additional diagrams with the self-coupling are included in the NLO EW corrections. Therefore, constraints on the self-coupling can be obtained using single Higgs boson measurements. Assuming that new physics only affects the self-coupling, the ratio compared to the SM is determined to be

$$\lambda_{HHH}/\lambda_{HHH}^{SM} = 4.0^{+4.3}_{-4.1},$$

and values outside

$$-3.2 < \lambda_{HHH}/\lambda_{HHH}^{\mathrm{SM}} < 11.9$$

are excluded at 95% confidence level. The results are comparable to the HH searches. However the constraints become significantly weaker when the other coupling modifiers are included in the fit. Currently STXS Stage 1 parametrization is only used for the VBF and VH, and it does not improve the sensitivity significantly. Dedicated binning including the most sensitive ggF and ttH can potentially improve the sensitivity in future.

5. Future prospects at the High-Luminosity LHC

Future prospects of the Higgs physics at the High-Luminosity LHC, 14 TeV, 3000 fb^{-1} are reported in [8, 9]. In a scenario with improved experimental uncertainties which is expected at the end of High-Luminosity LHC, with negligible statistical uncertainty on simulated samples and background modeling functions, and also half theory uncertainty on signal and background prediction, a few % level precision measurement is expected for the main production cross sections. For example, total uncertainty on the ggF cross section is expected to be 1.6% compared to 9% in the current ATLAS measurement in Figure 2.

6. Conclusion

The STXS results in the combined measurements in ATLAS and CMS experiments are summarized. Using the LHC proton-proton collision data at $\sqrt{s}$ = 13 TeV, collected up to 79.8 fb^{-1}, reduced Stage 1 STXS results are reported. The results are consistent with the SM, however the sensitivity is still limited in high p_{T} bins. Constraints on the Higgs boson self-coupling using single Higgs boson production are comparable to the HH searches. Dedicated binning including the most sensitive ggF and ttH can potentially improve the sensitivity in future. A few % level precision measurement is expected for the main production cross sections at the High-Luminosity LHC.

References

[1] D. de Florian et al., arXiv:1610.07922

[2] https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHXSWGFiducialAndSTXS

[3] ATLAS Collaboration, 2008 JINST 3 S08003

[4] CMS Collaboration, 2008 JINST 3 S08004

[5] ATLAS Collaboration, ATLAS-CONF-2019-005, http://cdsweb.cern.ch/record/2668375

[6] CMS Collaboration, Eur. Phys. J. C (2019) 79: 421.

[7] ATLAS Collaboration, ATL-PHYS-PUB-2019-009, http://cdsweb.cern.ch/record/2667570

[8] M. Cepeda et al., arXiv:1902.00134

[9] https://twiki.cern.ch/twiki/bin/view/LHCPhysics/HLHELHCCommonSystematics