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Higgs boson couplings at ATLAS

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The discovery of a Higgs boson with a mass of about 125 GeV by the ATLAS and CMS collaborations at the LHC has given access to a new fundamental sector of the Standard Model. The existence of this new particle provides the opportunity to measure its properties, such as the coupling of the Higgs boson to gauge bosons and to fermions. Run 2 of the LHC was completed in 2018 and provided about 140 fb^{-1} of data of 13 TeV p–p collisions. Run 3 of the LHC started in 2022 at an increased p–p centre of mass energy of $\sqrt{s}$ = 13.6 TeV. These proceedings discuss the state of the art of the 125 GeV Higgs boson coupling measurements and their implications for the understanding of the Higgs sector.

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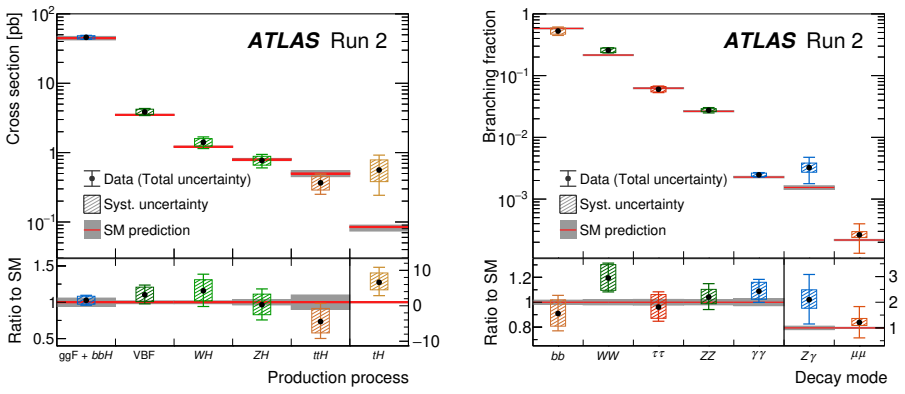
1. Introduction

A Higgs boson with a mass of about 125 GeV was discovered by the ATLAS [1] and CMS [2] collaborations in 2012 [3, 4]. Several properties of this particle, such as its coupling strengths to bosons and fermions, have been accurately studied in p–p collisions at an energy in the centre of mass $\sqrt{s}$ = 13 TeV, delivered by the Large Hadron Collider (LHC) in 2015–2018, and referred to as 'Run 2'. The Run 2 data allowed the ATLAS experiment to measure the Higgs boson production cross-section of five production modes (ggF, VBF, WH, ZH, ttH). Using the first 31 fb^{-1} of Run 3 p–p collisions, collected in 2022, the ATLAS Collaboration measured as well the Higgs boson cross-section at $\sqrt{s}$ = 13.6 TeV in the $H \to \gamma\gamma$ and $H \to ZZ^*(\to 4\ell)$ final states.

2. Run 2 cross-section measurements

The ATLAS collaboration has performed precise measurements of the total cross-section of the Higgs boson production modes using about 140 fb^{-1} of Run 2 data at $\sqrt{s}$ = 13 TeV [5]. Total cross-section measurements have been performed for the main production modes in six decay channels ($b\bar{b}$, $\tau^+\tau^-$, $\mu^+\mu^-$, WW^*, ZZ^*, $\gamma\gamma$). Results have a high compatibility between the measurements and the SM predictions, as shown in Figure 1. For the ggF and VBF production processes, the cross-sections are measured with a precision of 7% and 12%, respectively. The following production processes are now also observed: WH with an observed (expected) signal significance of 5.8 (5.1) standard deviations (σ), ZH with 5.0σ (5.5σ) and the combined ttH and tH production processes with 6.4σ (6.6σ), where the expected signal significances are obtained under the SM hypothesis. The separate ttH and tH measurements lead to an observed (expected) upper limit on tH production of 15 (7) times the SM prediction at the 95% confidence level.

In the Simplified Template Cross-Section framework (STXS) [6–8], cross-sections are measured within exclusive fiducial phase spaces mimicking the experimental selection to avoid large extrapolation uncertainties to the full phase space. Results from the experiments are generally unfolded to be independent from resolution and efficiency effects. Migration effects are considered and corrected for. A summary of STXS measurements performed by the ATLAS experiment are given in Figure 2, following the so-called Stage-1.2 scheme.



(a) (b)

Figure 1: ATLAS cross-section measurements for the main Higgs boson production modes. (a) Cross-sections for different Higgs boson production processes are measured assuming SM values for the decay branching fractions. The p-value for compatibility of the measurement and the SM prediction is 65%. (b) Ratio of observed rate to predicted SM event rate for different combinations of Higgs boson production and decay processes. The horizontal bar on each point denotes the 68% confidence interval. The narrow grey bands indicate the theory uncertainties in the SM cross-section times the branching fraction predictions. The p-value for compatibility of the measurement and the SM prediction is 72% [5].

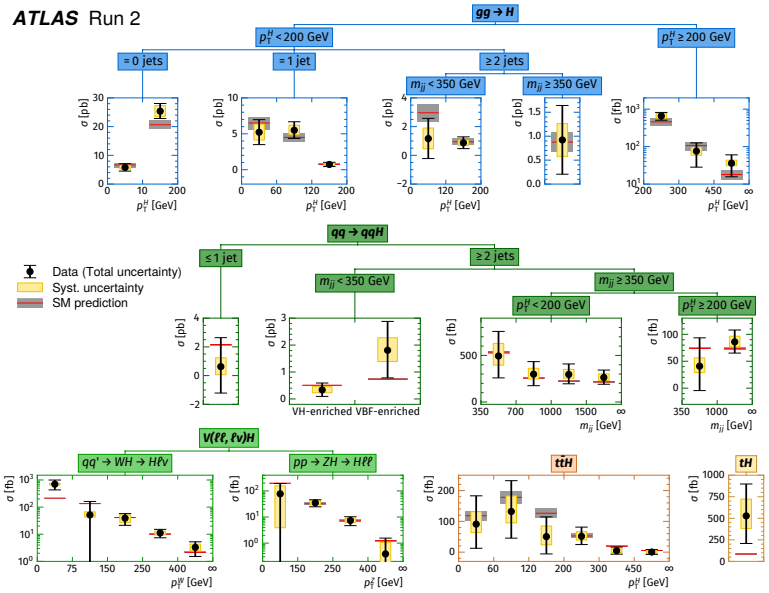
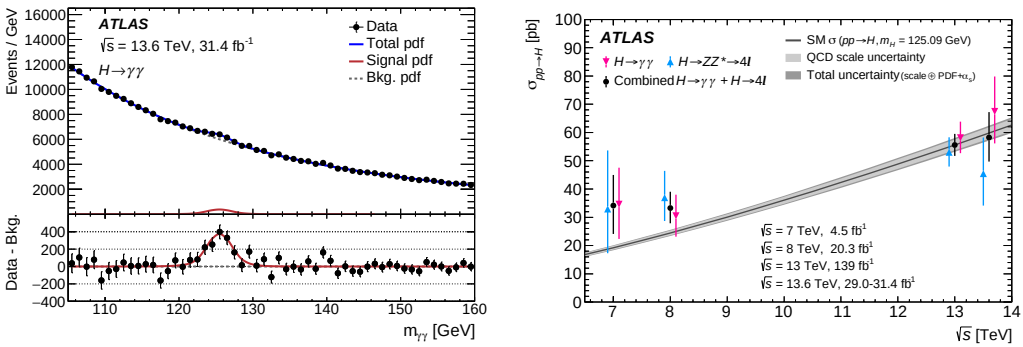


Figure 2: ATLAS observed and predicted Higgs boson production cross-sections in different kinematic regions. The vertical bar on each point denotes the 68% confidence interval. The p-value for compatibility of the combined measurement and the SM prediction is 94%. Kinematic regions are defined separately for each production process, based on the jet multiplicity, the transverse momentum of the Higgs (p_{T}^{H}) and vector bosons (p_{T}^{W} and p_{T}^{Z}) and the two-jet invariant mass (m_{jj}). The 'VH-enriched' and 'VBF-enriched' regions with the respective requirements of $m_{jj} \in [60, 120)$ GeV and $m_{jj} \notin$ [60,120) GeV are enhanced in signal events from VH and VBF productions, respectively [5].



(a) (b)

Figure 3: (a) Di-photon invariant mass spectrum within the $H \to \gamma\gamma$ selection. The signal, background and total probability density functions (pdf) derived from the fit to data in the window $105 \leq m_{\gamma\gamma} \leq 160$ GeV are also shown. (b) Values of the $\sigma(pp \to H)$ obtained from the ATLAS measurements as a function of the p-p centre-of-mass energy. The SM predicted values and their uncertainties are shown by the shaded band. The individual channel results are offset along the x-axis for display purposes [9].

3. Run 3 cross-section measurements

ATLAS performed the first measurements of the Higgs boson cross-section at $\sqrt{s} = 13.6$ TeV, using about 31 fb^{-1} of Run 3 data. The measurements are performed in the $H \to \gamma\gamma$ and $H \to ZZ^*(\to 4\ell)$ final states [9]. Results of the measurements and the corresponding SM predictions are shown in Figure 3. From the combination of the two measurements, the total cross-section at $\sqrt{s} = 13.6$ TeV is found to be $\sigma = 58.2 \pm 8.7$ pb, compatible with the SM prediction of 59.9 ± 2.6 pb. The systematic uncertainties of the measurements have been conservatively extrapolated from Run 2 prescriptions.

4. Conclusions

Outstanding performance of the LHC collider allowed to perform measurements of the Higgs boson couplings with a precision better than 10% in most of the cases. Precise cross-section measurements with Run 2 data are compared as well to SM predictions with STXS methodology. Yukawa interaction for third and second generation fermions have been probed by the ATLAS experiment. The first Higgs boson cross-section measurements at $\sqrt{s} = 13.6$ TeV have been performed in the $H \to \gamma\gamma$ and $H \to ZZ^*(\to 4\ell)$ channels. So far no significant deviation from the SM has been observed.

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